# New York City
# Department of Environmental Protection

# 2006 Watershed Water Quality Annual Report

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Cover photo taken by Steven Adamec

# Table of Contents

# List of Tables

# List of Figures

# Acknowledgments

The production of this report required the scientific expertise, creativity, and cooperation of the many staff members of the Division of Drinking Water Quality Control (DWQC). All deserve special recognition and thanks for their willing participation in the many facets of the Division's work, ranging from sample collection and analysis to data interpretation and report production. This report would not exist without the extensive field work, laboratory analysis, and administrative work needed to keep the Division operating. Therefore, thanks are due to all the field and laboratory staff who collected and analyzed the thousands of samples emanating from the watershed monitoring programs and the administrative, health and safety, and quality assurance staff who support them. It is only through the collective dedication of these many individuals that the mission of the Division can be accomplished; the scope and content of the information contained herein attests to the special efforts and perseverance of the staff.

General guidance in the activities of the Division in 2006 was provided by Mr. David Warne, Acting Deputy Commissioner of the Bureau of Water Supply, and Mr. Steven Schindler, Director of DWQC. Dr. Lorraine Janus, Deputy Chief of Watershed Operations, provided program guidance throughout 2006, as well as editorial guidance for this report. Mr. Andrew Bader and Ms. Lori Emery were the Section Chiefs responsible for management of the Division's Upstate Field and Laboratory Operations, respectively.

In March of 2007, the Bureau of Water Supply underwent significant re-organization. At that time, the Division of Watershed Water Quality Science and Research (WWQSR) was formed. This is the first report produced by the new Division. In that context, Dr. Lorraine Janus, Chief, WWQSR, provided oversight on development of the content of this report as well as editing of final submissions. A leading role was taken by Mr. Jim Mayfield in working with contributors to shape the chapters, and as a lead author for hydrology in Chapter 2 and water quality in Chapter 3. Mr. Gerry Marzec and Mr. Rich Van Dreason were primary authors for the extensive work of the Division on water quality and reservoir limnology in Chapter 3. Ms. Kerri Alderisio was program director and lead author for all pathogen research in Chapter 4, aided by Mr. Gerald Pratt and Mr. Steve DiLonardo. Mr. Bryce McCann 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 the forward-looking modeling development and applications in Chapter 6. Mr. Martin Rosenfeld was the primary author of future research objectives for several disciplines described in Chapter 7. Special mention of sub-section authors and contributors goes to Mr. Andrew Bader, Mr. Thomas Baudanza, Mr. Larry Beckhardt, Mr. Ed Blouin, Ms. Lori Emery, Ms. Salome Freud, Mr. Jeff Graf, Mr. Tracy Lawrence, Ms. Deborah Layton, Ms. Laurie Machung, Mr. Michael Meyer, Ms. Sharon Neuman, Ms. Carla Paltridge, Dr. James Porter, Mr. Tom Stalter, Ms. Marilyn Shanahan, Mr. David Tobias, and Mr. Michael Usai. Mr. Martin Rosenfeld is acknowledged for his professionalism in the painstaking work of editing and proof-reading the entire document in its final stages. Ms. Patricia Girard is commended for her diligent work in skillfully consolidating hundreds of files into a cohesive document, and in ensuring that style conventions and formats are consistent throughout. This document could not be produced in polished form without Ms. Girard’s knowledge and facility with desktop publishing.

Thanks to Mr. Paul Rush, Mr. Steven Schindler, Mr. David Warne and Dr. Kimberlee Kane for their final review and comments.

It is only through the combined talent of the many contributors and their staff members that we are able to produce a document that is accurate in the description of the scientific work done to manage water quality for NYC and that is engaging for a wide audience, from staff of regulatory agencies to the general public. Thanks to all for the contributions to document the watershed water quality events of 2006.

# 1. Introduction

## 1.1 What is the purpose and scope of this report?

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 with a general overview of the City's water resources, their condition during 2006, and compliance with regulatory standards or guidelines during this period. It is complementary to another report entitled "NYC Drinking Water Supply and Quality Report" that is distributed to consumers annually to provide information about the quality of the City's tap water. However, the focus of this report is different in that it addresses how the City protects its drinking water sources upstream of the distribution system. 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. More detailed reports on some of the topics described herein can be found in other DEP publications accessible through our website at http://www.nyc.gov/dep/ (Figure 1.1).

Figure 1.1 DEP website.

## 1.2 What role does each Division in the Bureau of Water Supply play in the operation of the NYC water supply?

The Bureau of Water Supply (BWS) is responsible for operating, maintaining, and protecting New York City's upstate water supply system to ensure delivery of high quality drinking water. In 2006, BWS was comprised of 12 separate Divisions which perform various functions to meet the Bureau's mission. In March 2007, after the close of this report period, the Bureau underwent a reorganization which will be discussed in the 2007 Watershed Water Quality Annual Report.

## 1.3 How does the City monitor the condition of its reservoirs and watersheds?

The condition of the water supply is monitored by the Division of Drinking Water Quality Control (DWQC). DWQC has a staff of approximately 255 who are responsible for monitoring and maintaining high water quality for the entire (upstate watershed and downstate distribution system) water supply, with over half within the upstate operations.

DWQC's Watershed Operations are now divided into five sections: Watershed Field Operations, Watershed Laboratory Operations, Information Management and Modeling, Pathogen Monitoring and Research, and Health and Safety.

The Watershed Field Operations Section consists of five units: Limnology, Hydrology, Wildlife Studies, Watershed Management Studies (including Natural Resources), and Water Quality Impacts Assessment. These staff are responsible for: i) designing scientific studies, ii) collecting environmental samples for routine and special investigations, iii) submitting these samples to the Laboratory Operations (or contracted lab) for analysis, iv) organizing and interpreting data, v) documenting findings, and vi) making recommendations for effective watershed management. Field Operation staff members are located in all three water supply Systems (Catskill, Delaware, and Croton). Extensive monitoring of a large geographic network of sites to support reservoir operations and watershed management decisions are the top priority of the Field Operations Section.

DWQC's Watershed Laboratory Operations Section also consists of five units: East-of-Hudson Laboratory & Compliance Operations (including the Brewster and Kensico Laboratories), West-of-Hudson Laboratory and Compliance Operations (including the Ben Nesin and Grahamsville Laboratories), Quality Assurance, Technical Operations, and the Watershed Administrative Unit. The units are comprised of laboratory managers, chemists, microbiologists, laboratory support and sample collection personnel, scientists, technical specialists, and administrative staff. The four water quality laboratories are certified by the New York State Department of Health Environmental Laboratory Approval Program (ELAP) for approximately 60 analytes in the non-potable water and potable water categories. These analytes include physical parameters (e.g., pH, turbidity, color, conductivity), chemical parameters (e.g., nitrates, phosphates, chloride, chlorine residual, alkalinity), microbiological parameters (e.g., total and fecal coliform bacteria, algae), trace metals (e.g., lead, copper, arsenic, mercury, nickel), and organic parameters (e.g., organic carbon). Daily monitoring of water quality at critical "keypoint" monitoring sites for rapid detection and tracking of any changes in water quality is one of the top priorities of the Watershed Laboratory Operations Section. For the 2006 reporting period covered in this report, DWQC staff performed 201,346 analyses on 21,838 samples from 634 different sampling locations.

The Information Management and Modeling Section is responsible for Watershed and Reservoir Modeling, the administration of the Upstate Water Quality database, some data analysis and production of many of the reports for the Division and Bureau. The Pathogen Monitoring and Research Section deals with field sampling and laboratory analysis of samples, and laboratory methodological research. The Health and Safety Section deals with all aspects of staff health and safety in the numerous DWQC workplaces.

# 2. Water Quantity

## 2.1 What is NYC's source of drinking water?

New York City's water supply is provided by a system consisting of 19 reservoirs and three controlled lakes with a total storage capacity of approximately 2 billion cubic meters (550 billion gallons). The total watershed area for the system drains approximately 5,100 square kilometers (1,972 square miles) (see Figure 2.1).

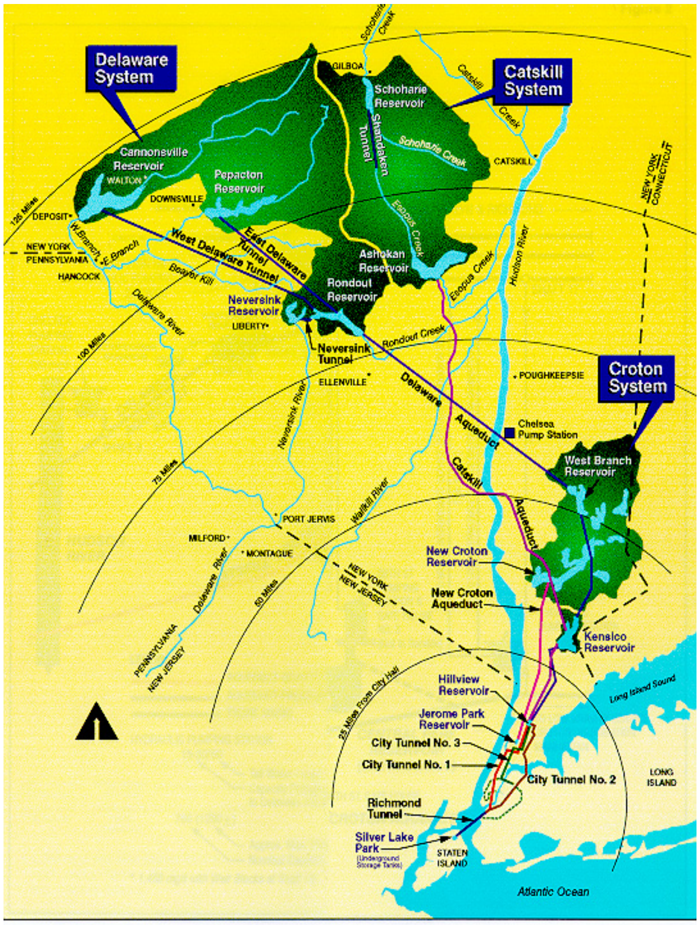
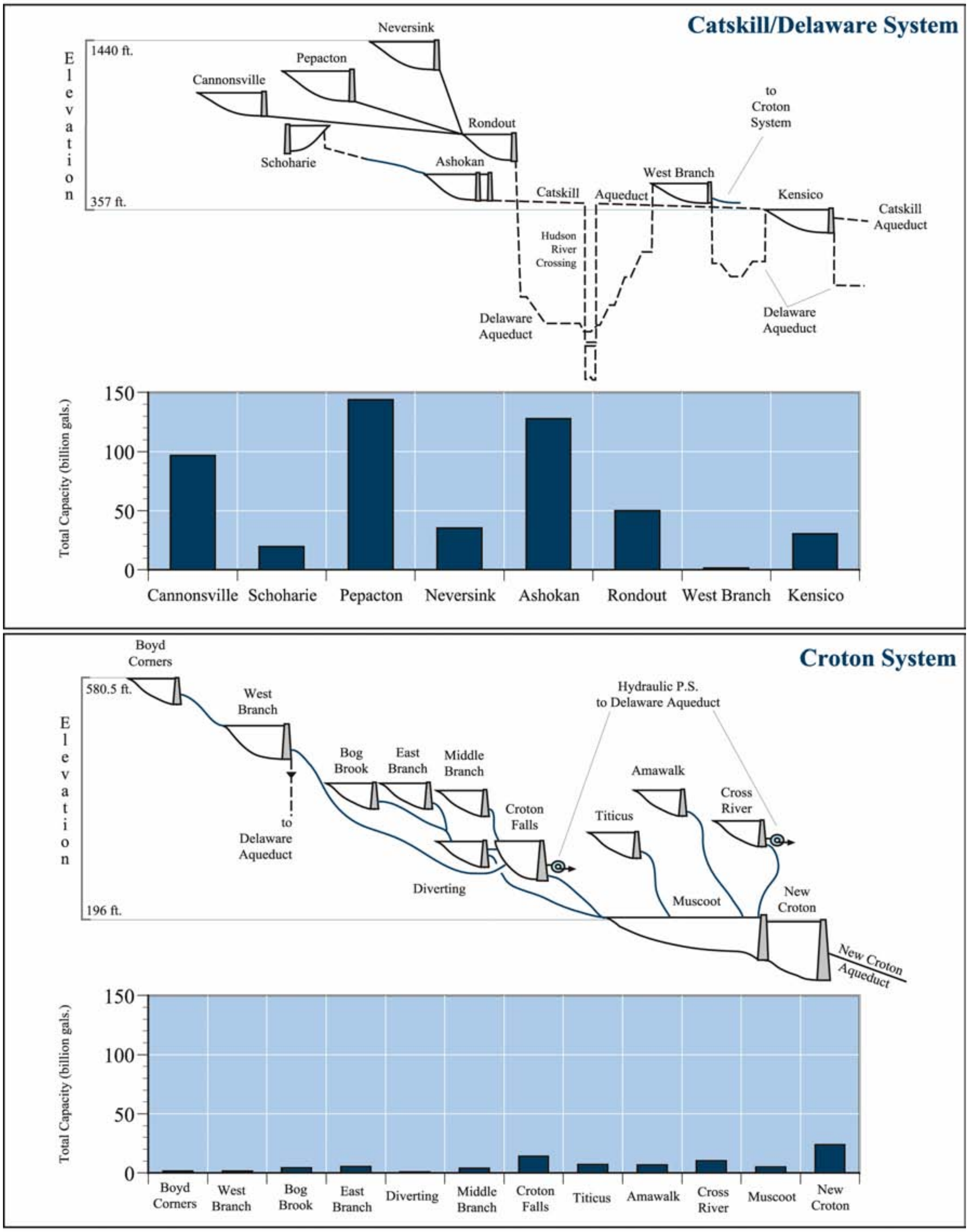


Figure 2.1 New York City water supply watershed.

The system is dependent on precipitation (rainfall and snow melt) and subsequent runoff to supply the reservoirs in each of three watershed systems, the Catskill, Delaware, and Croton Systems. The first two are located West-of-Hudson (WOH) and the Croton System is located East-of-Hudson (EOH) (see Figure 2.2) 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 pollutant loads and hydraulic residence time, which in turn directly influence the reservoirs' water quality and productivity.

## 2.2 How much precipitation fell in the watershed in 2006?

The average precipitation for each basin was determined from a network of precipitation gauges located in or near the watershed that collect readings daily. The total monthly precipitation for each watershed is based on the average readings of the gauges located in the watershed. The 2006 monthly precipitation total for each watershed is plotted along with the historical monthly average (see Figure 2.3).



Elevations of reservoirs are at
masonry crest of spillway (MSI Sandy Hook)

Total Available Capacity
(Above Sill or Outlet)

Figure 2.2 NYC water supply reservoirs and their available storage capacities.

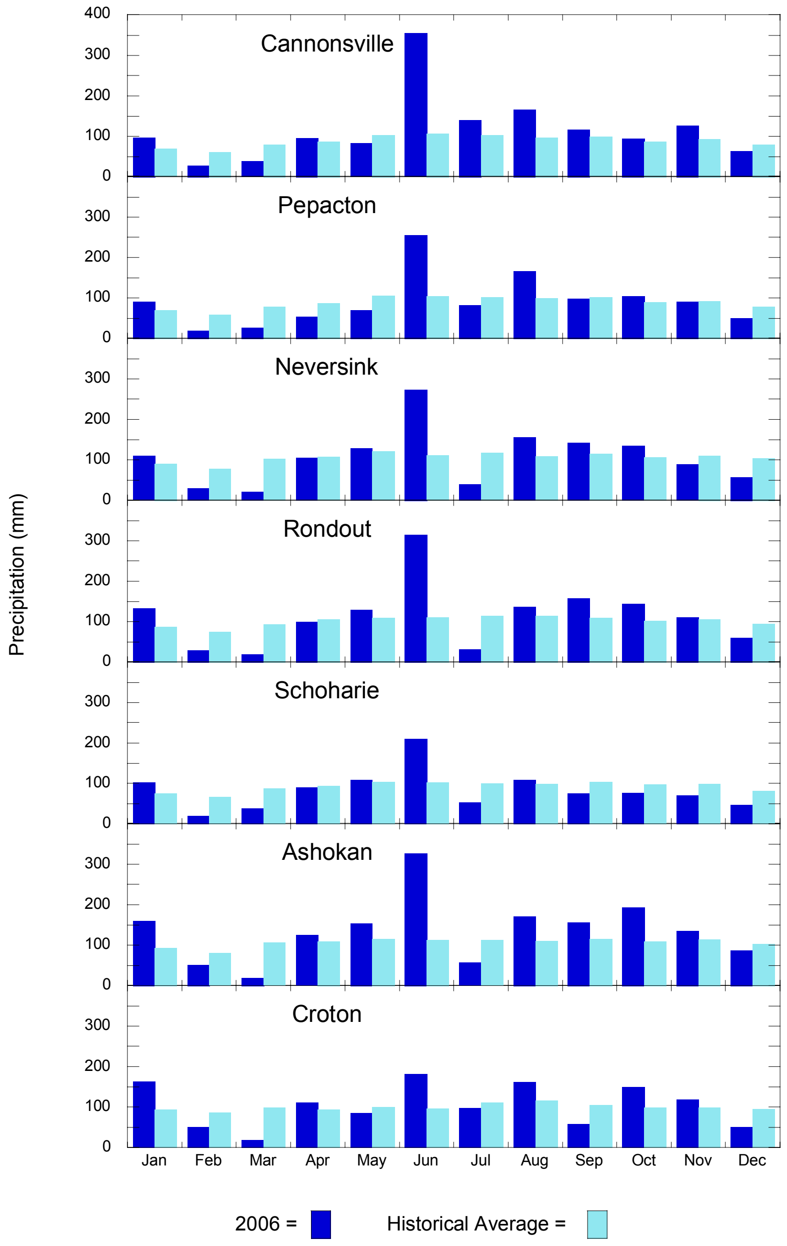


Figure 2.3 Monthly rainfall totals for NYC watersheds, 2006 and historical values.

The total monthly precipitation figures show that in general precipitation was slightly above normal for January, but less than normal for the remainder of the winter (February and March). April and May were about normal, but there was a significant event in May (see below). June brought precipitation totals well above the historical totals, and will be discussed in more detail below. July's precipitation was somewhat below normal with August having greater than normal precipitation. Overall, the 2006 summer period (June-August) was the wettest on record for New York State, based on data from the National Climatic Data Center (http://www.ncdc.noaa.gov/oa/climate/research/2006/ann/us-summary.html). The fall period (September-November) generally had above average precipitation, while December's precipitation was somewhat less than normal in all basins. Overall the total precipitation in the watershed for 2006 was 1,278 mm (50.3 in), which is 140 mm (5.5 in) above normal. According to the National Climatic Data Center's *2006 Annual Climate Review U.S. Summary* (http://www.ncdc.noaa.gov/oa/climate/research/2006/ann/us-summary.html), 2006 was New York State's fifth wettest year on record (1895-2006). Also, several significant precipitation events occurred which led to water quality issues.

On May 11-12, 2006 the Ashokan watershed received 2.57 inches of rain. Typically an event of this magnitude would be assimilated and not require treatment; however, the system had not fully recovered from the previous turbidity event, which required alum treatment from October 13, 2005 until April 10, 2006, and runoff from this event quickly impacted the water quality of Ashokan Reservoir. DEP re-started treatment of the Catskill Supply with alum on May 15, 2006, which lasted for only 10 days as turbidity levels entering the Catskill Aqueduct quickly receded to less than 5 NTU. (See section 3.2 for more information on alum treatment.)

Beginning on June 25, the West-of-Hudson watersheds received a 3-day rain event which produced over 7 inches of rain in some areas. This event caused extensive flooding throughout the region, leading Governor Pataki to formally request that President Bush issue a major federal disaster declaration to provide federal disaster assistance to individuals and communities in 13 counties. The Catskill and Delaware System reservoirs are located within four of the counties identified for disaster relief. Flood waters overwhelmed many of DEP's Water Supply Reservoirs. Water spilled over the Cannonsville and Pepacton Reservoir dams at levels never before recorded. Such substantial runoff scoured soils and stream beds in the watershed, creating high turbidity in streams and creeks, which in turn led to high turbidity levels in DEP's Water Supply Reservoirs. The Catskill Watershed received over 4.5 inches of rainfall, causing significant runoff. The Esopus Creek peaked at 15 feet, four feet above flood stage (11.0 feet) on June 26, 2006. This high runoff raised the elevation in the West Basin of Ashokan Reservoir causing it to spill over the dividing weir into the East Basin. On June 28, the level of turbidity entering the Catskill Aqueduct at the Ashokan Reservoir exceeded 100 NTU and DEP began alum treatment of the Catskill Supply. Alum treatment lasted for 36 days and was terminated on August 2, 2006. (See section 3.2.)

## 2.3 What improvements were made to DEP's meteorological data network in 2006, 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 the 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 understanding, and ultimately reducing, the amounts of sediment, turbidity, nutrients, and other pollutants entering the reservoirs, as well as making operational decisions.

Recognizing that, in addition to the precipitation data that have been historically collected, meteorological ("met") data were valuable in meeting the DEP's mission of providing high-quality drinking water through environmental monitoring and research, DEP installed a network of 26 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). Most of the stations utilize radio telemetry to transmit data in near real-time. 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. These data are also important as input for DEP's water quality models (Chapter 6).

In 2006, DEP began the process of upgrading its rain gauges and telemetry system. The RAWS network currently uses tipping bucket rain gauges, which only measure liquid precipitation. These will be upgraded to a weighing bucket gauge (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. The telemetry upgrade is intended to improve the flow of data and will utilize multiple base stations at DEP facilities (wastewater treatment plants, valve chambers, etc.) spread throughout both the East- and West-of-Hudson watersheds. Each RAWS will transmit data to the nearest base station, where it will be put onto the DEP computer network and routed to the master dataset at Grahamsville as well as to a separate backup location. This upgrade should improve the reliability of data reception, increase data security, and incorporate EOH stations into the near-real-time data program.

DEP also began the process in 2006 of purchasing electronic, load-cell-based snow water sensors. These are a new device, developed by Dr. Jerry Johnson of the U.S. Army Corps of Engineers in Ft. Wainwright, AK. They are not yet commercially available but Dr. Johnson will fabricate two for DEP. The funding for these is a grant from the National Oceanic and Atmospheric Administration (NOAA), obtained on DEP's behalf by the Delaware River Basin Commission. These sensors will continuously monitor snowpack water content and transmit the data back via the meteorological telemetry system. Continuous snowpack data are being required by the downbasin states as part of the Spill Mitigation program (Pepacton and Neversink watersheds). Pillows will be installed for a pilot program at two sites: New Kingston (Pepacton watershed) and Blue Hill (Neversink watershed). The near-real-time data will be monitored daily, and significant changes will trigger field staff to perform a manual snow survey to get a more accurate estimate of water equivalent in the basin.

## 2.4 How much runoff occurred in 2006?

Runoff is defined as the part of the precipitation and snow melt that appears in uncontrolled surface streams and rivers, i.e. “natural” flow. The runoff from the watershed can be affected by meteorological factors such as: type of precipitation (rain, snow, sleet, etc.), rainfall intensity, rainfall amount, rainfall duration, distribution of rainfall over the drainage basin, direction of storm movement, antecedent precipitation and resulting soil moisture. 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, etc. in the basin which prevent or alter runoff from continuing downstream. The annual runoff statistic 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 United States Geological Survey (USGS) stations were used to characterize annual runoff in the different NYC watersheds (Figure 2.4). The total annual runoff from both the WOH and EOH watersheds was well above historic medians, as it was a rather wet year, especially the latter half.

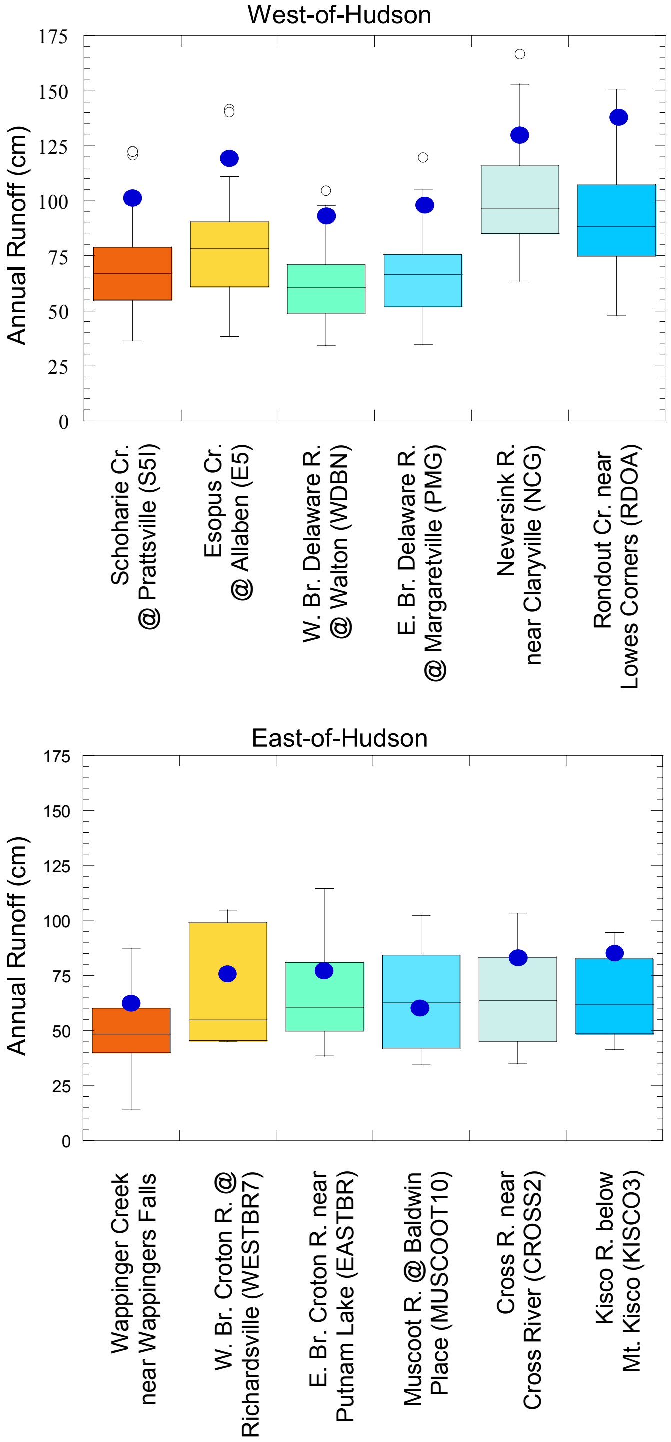


Figure 2.4 Historic annual runoff (cm) as boxplots for the WOH and EOH watersheds with the values for 2006 displayed as a dot. The USGS data collected after Sept. 30, 2005 are provisional.

## 2.5 What was the storage history of the reservoir system in 2006?

The total available percent capacity (Actual) in 2005-2006 is compared to the monthly long-term average (Normal) in Figure 2.5. The long-term average was determined by calculating the monthly percent capacity during 1995-2004. Historically, seasonal patterns are readily discernible. Capacity normally ranges from a high of 96 percent in the spring to about 76 percent in the fall. At the start of 2005, capacity was unusually high, actually exceeding 104 percent by early April. Snow melt and high rainfall caused flooding in early April. Normal patterns resumed thereafter as capacity decreased throughout the spring and summer to a low of 63 percent during the first week of October. Drought was avoided, however, as exceptionally high rainfall during the remainder of October and above average rainfall in November brought total capacity to about 94 percent by year's end.

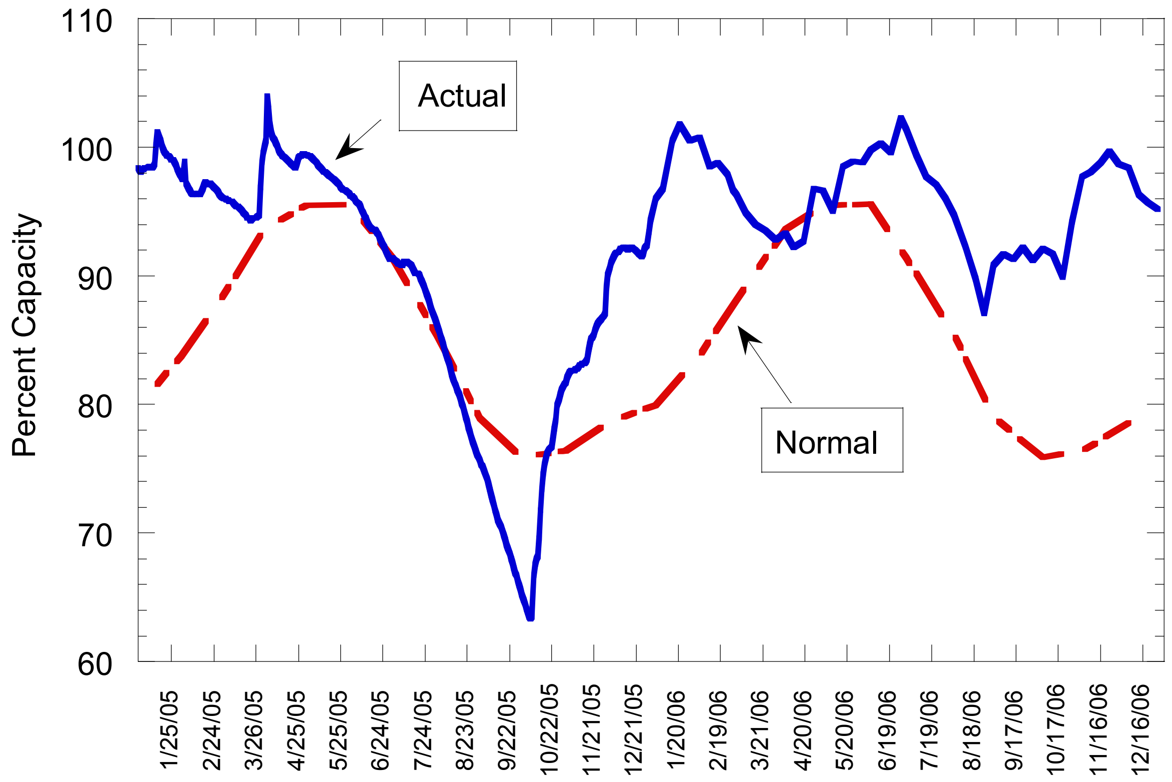


Figure 2.5 Percent usable storage in 2005-2006 (Actual) compared to long-term (1995-2004) average (Normal) storage.

In 2006, capacity soon exceeded 100 percent, dropping to 92 percent by April. Rain events in April, May, and especially June again returned capacity to above 100 percent by July. Thereafter, capacity followed the typical historic pattern of decline in the summer and fall, but remained well above normal through the end of the year.

# 3. Water Quality

## 3.1 How did DWQC Watershed Operations help to ensure the delivery of the highest quality water from upstate reservoirs in 2006?

DWQC Watershed Operations continued extensive water quality monitoring at multiple sampling sites from aqueducts, reservoir intakes and tunnel outlets within the Catskill, Delaware and Croton Systems. In 2006, over 46,600 physical, chemical and microbiological analyses were performed on nearly 7,000 samples that were collected from 57 different key aqueduct locations. DWQC also continued to operate and maintain continuous monitoring instrumentation at critical locations to provide real-time water quality data to support operational decision-making (Figure 3.1).


Figure 3.1 Continuous monitoring turbidity instrumentation at the Catskill Lower Effluent Chamber.

Scientists from DWQC work cooperatively with the Bureau's Operations Division 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 2006 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. For example, when an 8" rain event in June caused water quality to deteriorate in the Cannonsville Reservoir, DEP responded by isolating the reservoir from the Delaware System (Figure 3.2). By shutting down the West Delaware Tunnel, DEP prevented poor quality water from being diverted from the Cannonsville Reservoir into the Rondout Reservoir.

Figure 3.2 Aerial view of the Cannonsville Reservoir following the June 2006 rain event.

- Selective Withdrawal

  DEP continued to monitor water quality at different intake sites within the reservoirs and used that information to determine the optimal location of withdrawal. For example, DEP conducted water quality monitoring at various intake locations within the New Croton Reservoir prior to delivering water to the outside communities during the summer months. Based on the water quality results, DEP withdrew water from the bottom of the reservoir near the New Croton Dam to optimize the quality of the water being delivered to consumers north of NYC.

- Treatment Operations

  DEP implemented treatment options to manage events that could not be adequately addressed by selective diversion, selective withdrawal and blending operations. As a result of 3 major storm events in the Catskill watershed, DEP added aluminum sulfate (alum) to the Catskill Aqueduct at the Pleasantville Alum Plant for a total of 146 days. The addition of alum caused the particles in the water to coagulate and settle out with minimal impacts to water quality in the Kensico Reservoir (see Section 3.2 for more details).

## 3.2 What is alum treatment: how and why was it used during 2006?

As described above, through a large portion of 2006 the normally relatively clear waters of the Catskills remained turbid due to the entrainment of the fine, glacially-deposited clay material which is ubiquitous in the stream channels of the Catskills. The clay particles that entered these Catskill streams are highly efficient at scattering light and therefore readily caused these streams to appear highly turbid. The suspended particles are very fine, and can remain in suspension for weeks or months. They can limit the use of water as a drinking water supply by affecting the water's color and taste, interfering with chemical disinfection, and by providing a basis for the growth of potentially harmful bacteria and other microorganisms.

Due to these concerns, state and federal agencies have set a limit on the level of turbidity allowed in public drinking water. Turbidity is a measure of the light-scattering property of water, and is analyzed in the laboratory by an instrument called a nephelometer. This instrument assesses side-scattered light in arbitrary units known as nephelometric turbidity units (NTU). The limit for an unfiltered surface water source is set forth in the federal Surface Water Treatment Rule (SWTR) (40 CFR 141.71) and in the New York State Sanitary Code (10 NYCRR Section 5-1.1). Both the SWTR and the State Sanitary Code specify that raw water turbidity immediately prior to the first or only point of disinfection cannot exceed 5 NTU.

In order to comply with the NYS Drinking Water turbidity standards, in 2005 and 2006 DEP treated the Catskill water supply with alum (aluminum sulfate) to control turbidity. Alum is a coagulant. When added to water, it reacts with suspended particles causing them to clump together forming larger, heavier particles called floc, which then settles out of the water column. This process of coagulation, flocculation and sedimentation is a commonly accepted water treatment industry practice for the removal of impurities.

Treatment of the Catskill supply with alum is a relatively rare occurrence and in fact, prior to 2005, treatment has only been necessary four times over the past 20 years for a total of 232 days or 3.5% of the time. DEP normally implements operational controls to manage turbidity within the water supply system. These actions are intended to ensure that the suspended particles which cause turbidity settle out. However, 2005 and 2006 have been extremely wet years with record flooding (the 4th and 5th wettest years on record, respectively), which has led to the need for alum treatment. When treatment does become necessary, DEP applies alum by injecting it as a slurry into the Catskill Aqueduct just upstream of where it enters Kensico Reservoir. The alum mixes with the water in the aqueduct and forms a floc containing the suspended particles which then settle out as the water enters Kensico Reservoir (Figure 3.3).

Figure 3.3 Photograph of the Catskill Influent Chamber Cove on Kensico Reservoir during alum treatment.

The incoming turbid water can be seen to the north of the chamber (mid photograph) with the suspended material flocculating out very quickly as water moves to the south (to the left of the photograph). Some turbid water that entered the Reservoir prior to the treatment can be seen hugging the shoreline to the south of the chamber.

The addition of alum is generally considered to be harmless to both the ecology of lakes and reservoirs, and to drinking water consumers. In fact, the use of alum by lake managers to control eutrophication is considered a safe and effective practice (NALMS, 2004). Aluminum is the most abundant metal on Earth, and is found in soil, water and air. In the Catskills, it is naturally occurring as aluminosilicates in the ubiquitous glacial clay deposits. Aluminum is pervasive in the environment to the point of being unavoidable. Its chemical and physical properties make it ideal for a wide variety of uses such as in food additives, in drugs (e.g., antacids) and in consumer products such as cooking utensils and aluminum foil. Aluminum also occurs naturally in many foods such as dairy products and grains. About 95% of the normal daily intake of aluminum for an adult comes from food. Thus, the intake of aluminum in drinking water generally amounts to less than 5% of the total daily intake (Health Canada, 2003). Since nearly all of the alum added to water during the treatment process settles out prior to consumption, the aluminum content of treated water is only slightly higher than untreated water.

DEP intensively monitors the drinking water supply for many analytes, including aluminum. Aluminum is generally considered to be non-toxic so there are no State or Federal regulations limiting its concentration in drinking water. However, the USEPA has published a secondary standard for aluminum of 50-200 mg $L^{-1}$ to be used as a guidance value. Since 2000 approximately 78% of DEP's measurements of aluminum in water leaving Kensico Reservoir were below this range. In addition, only two values exceeded the 200 mg $L^{-1}$ upper limit.

## 3.3 How did the 2006 water quality of NYC's source waters compare with standards set by Federal regulations for fecal coliforms and turbidity?

The Surface Water Treatment Rule (SWTR) (40 CFR 141.71(a)(1)) requires that water at a point just prior to disinfection not exceed thresholds for fecal coliform bacteria and turbidity. To ensure compliance with this requirement, DEP monitors water quality for each of the supplies at "keypoints" just prior to disinfection (the Croton System at CROGH, the Catskill System at CATLEFF and the Delaware System at DEL18). Figures 3.4 and 3.5 depict fecal coliform and turbidity data for 1992-2006. Both figures include a horizontal line marking the SWTR limit.

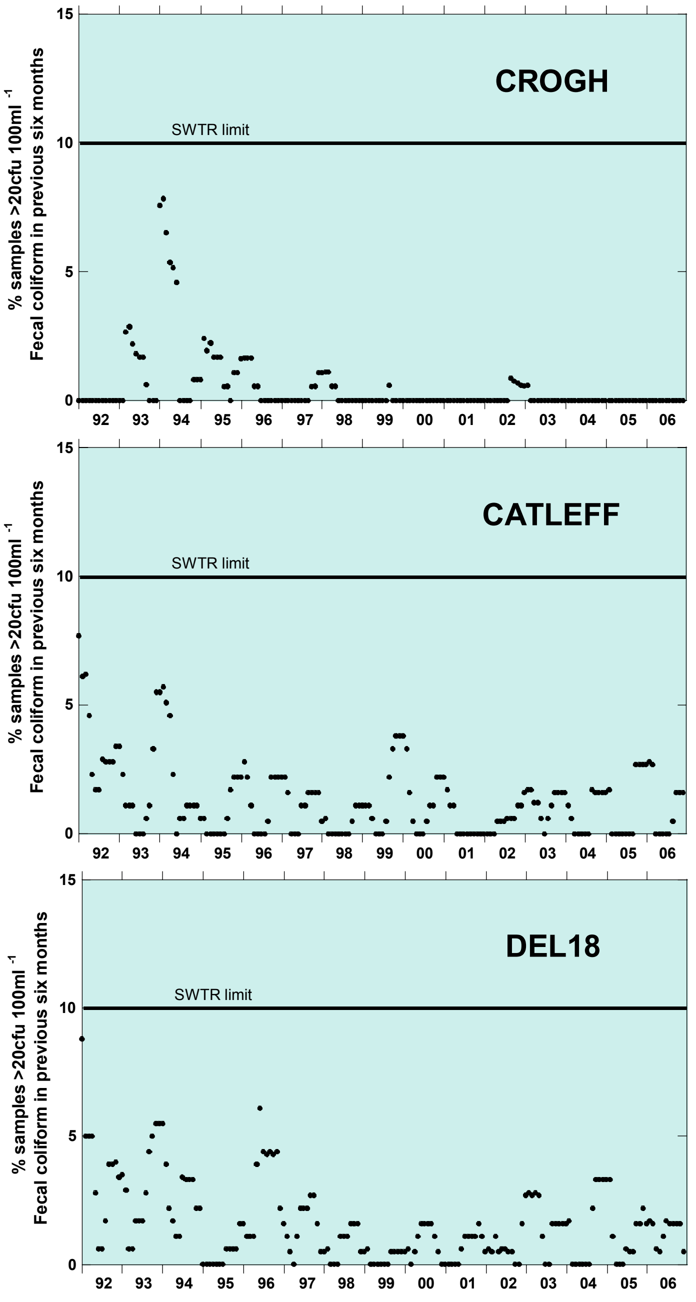


Figure 3.4 Temporal plots of fecal coliform (% of daily samples > 20 CFU 100ml$^{-1}$ in the previous six months) compared with Surface Water Treatment Rule limit.

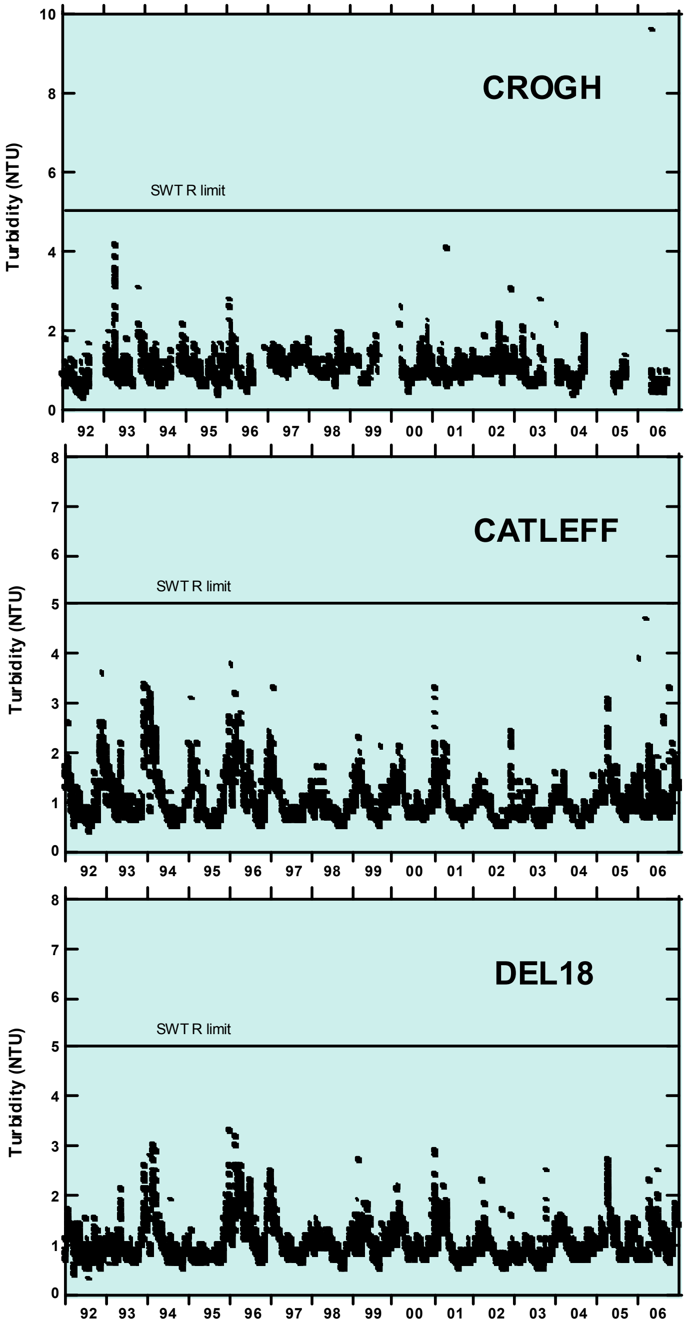


Figure 3.5 Temporal plots of turbidity compared with Surface Water Treatment Rule limit.

As indicated in Figure 3.4, the fecal coliform concentrations at all three keypoints consistently met the SWTR standard; for 2006, the calculated percentages for effluent waters at CROGH, CATLEFF, and DEL18 are far below the 10% limit set by the SWTR standard. For 2006, for raw water samples taken at the three keypoints CROGH, CATLEFF, and DEL18, the mean and median fecal coliform concentrations (CFU 100 $mL^{-1}$) were 0.4 and 0, 1.9 and 1, and 2.6 and 1, respectively.

For turbidity, the SWTR limit is 5 NTU. As indicated in Figure 3.5, all three effluent waters were consistently well below this limit in 2006. One anomaly occurred when, due to startup operations on May 16, CROGH turbidity measured 9.6 NTU, but quickly returned to normal. For the three keypoints CROGH, CATLEFF, and DEL18, the mean and median turbidity values (NTU) were 0.7 and 0.6, 1.0 and 0.9, and 1.1 and 1.0, respectively.

## 3.4 What was the water quality in 2006 in the streams that represent the major flow into NYC's reservoirs?

The stream sites used in this report are presented in Table 3.1 and shown pictorially in Figure 3.6. 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.

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

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

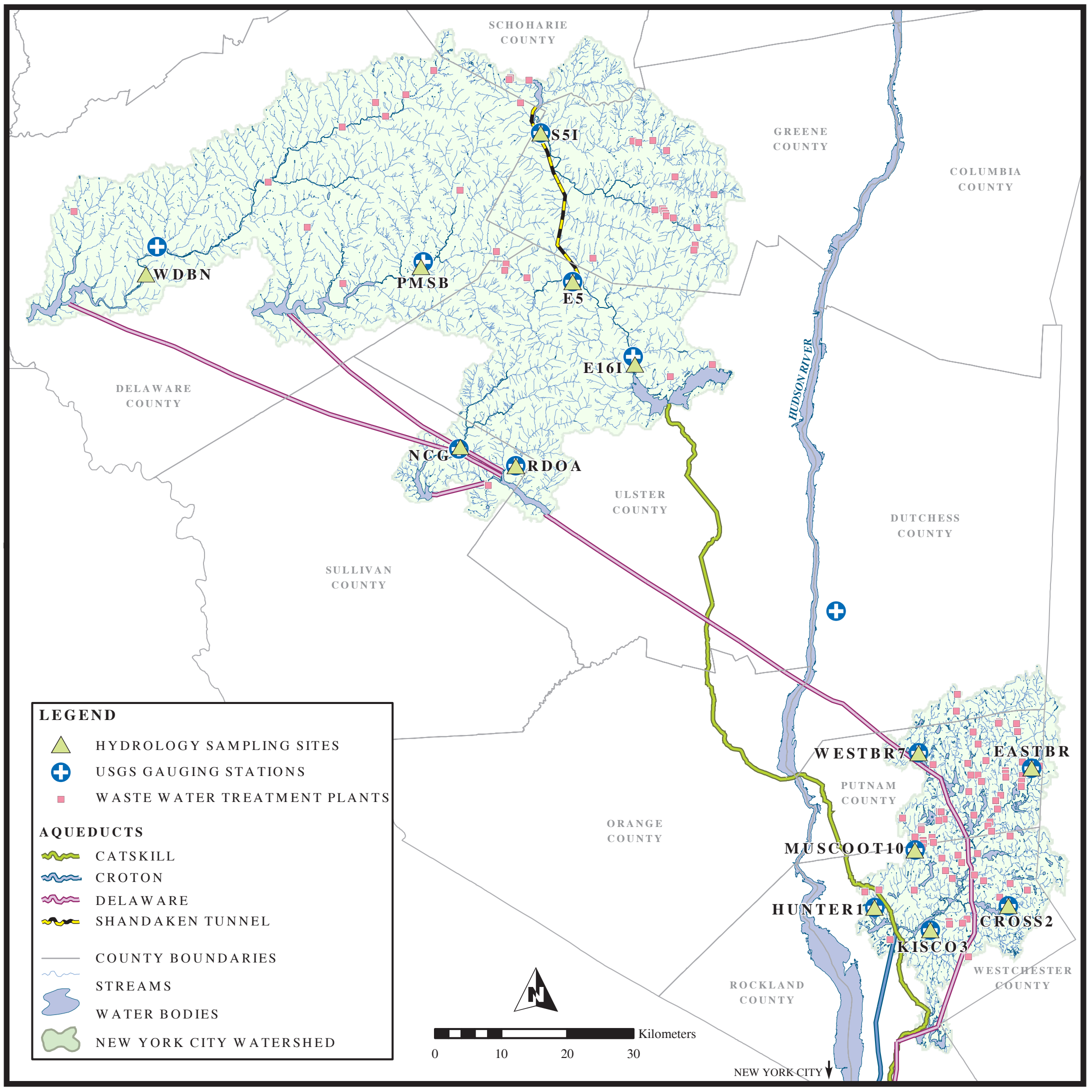


Figure 3.6 Locations of sampling sites discussed in Section 3.4 and USGS stations used to calculate the runoff values presented in Section 2.4. .

The analytes chosen are considered to be the most important for the City water supply. For streams, they are turbidity (Surface Water Treatment Rule limit), total phosphorus (nutrient/ eutrophication issues), and fecal coliform bacteria (Surface Water Treatment Rule limits).

The results presented in Figure 3.7 are based on grab samples generally collected twice a month (generally once a month for turbidity and total phosphorus for the EOH sites although fecal coliform samples are generally collected twice a month). The figures compare the 2006 median values against historic median annual values for the previous 10 years (1996–2005). However, two of the EOH sites have shorter sampling histories. These are: KISCO3 (1999–present), and HUNTER1 (1998–present). It should also be noted that the 2006 data from the Delaware and East-of-Hudson Systems are still considered provisional in nature.

## Turbidity

The turbidity levels for 2006 were generally near "normal" values (Figure 3.7a) except for the inflow to Ashokan (E16I), which showed an exceptionally elevated median turbidity value for 2006. This was due in part to events that affected Ashokan (see Section 2.2), which in turn led to the use of alum. In addition, the Shandaken Tunnel operated under emergency conditions while the Gilboa Dam (impounding the Schoharie Reservoir) underwent emergency repairs during the period November, 2005 through December, 2006. This resulted in a year of sustained high flows from the tunnel to the Esopus Creek along with somewhat increased turbidity.

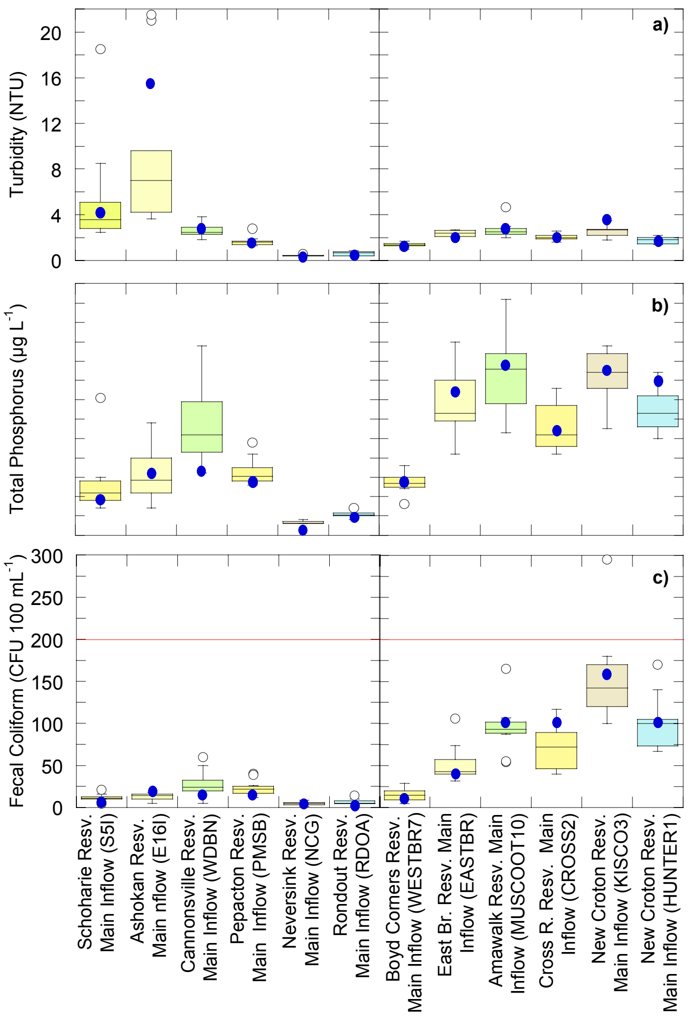


Figure 3.7 Boxplot of annual medians (1996–2005) for a) turbidity, b) total phosphorus, and c) fecal coliforms for selected stream (reservoir inflow) sites, with the value for 2006 displayed as a dot.

## Total Phosphorus

In the Catskill/Delaware System, the 2006 total phosphorus levels (Figure 3.7b) were for the most part near typical historical values. The total phosphorus value in Cannonsville in 2006 remained well below the historical median, perhaps reflecting the influence of improvements in agricultural practices and wastewater treatment plant upgrades. The 2006 total phosphorus values in the Croton System (Figure 3.7b) were generally within the range of typical values, except for Hunter Brook, a tributary to New Croton Reservoir, which was slightly higher than historical values.

## Fecal Coliform Bacteria

The 2006 fecal coliform bacteria levels (Figure 3.7c) in the Catskill/Delaware and Croton Systems were generally near the typical historical levels. Only CROSS2, the inflow to the Cross River Reservoir, showed a slightly elevated median value of fecal coliforms in 2006. A fecal coliform benchmark of 200 CFU 100 $mL^{-1}$ is shown as a solid line on Figure 3.7c. This benchmark relates to the NYSDEC water standard (expressed as a monthly geometric mean of five samples, the standard being $\leq$200 CFU 100 $mL^{-1}$) for fecal coliforms (6 NYCRR §703.4b). The 2006 median values for all streams shown here lie below this value.

## 3.5 Were the total phosphorus concentrations in the reservoirs affected by the precipitation and runoff in 2006?

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

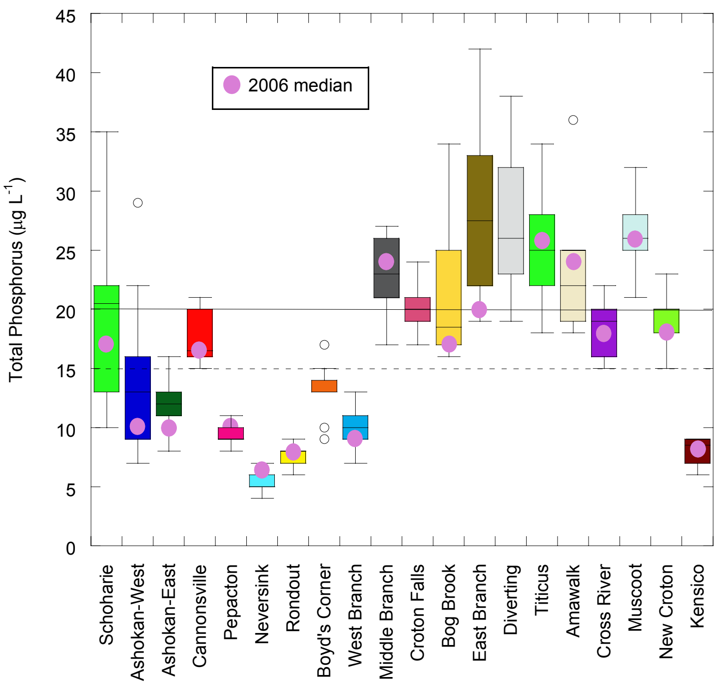


Figure 3.8 Annual median total phosphorus in NYC water supply reservoirs (2006 vs. 1996-2005). The horizontal dashed line at 15 µg $L^{-1}$ refers to the NYC TMDL guidance value for source waters. The horizontal solid line at 20µg $L^{-1}$ refers to the NYSDEC ambient water quality guidance value appropriate for reservoirs other than source waters (the remaining reservoirs).

Note: These plots are based on epilimnetic samples collected biweekly from June-September. In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. Due to limited data in 2006, representative annual medians could not be calculated for Boyd Corners, Croton Falls and Diverting. Although Kensico and New Croton are usually operated as source waters, these reservoirs can be bypassed so that any or all of the following can be operated as source waters: Rondout, Ashokan East, Ashokan West and West Branch.

In 2006, median phosphorus results in all Catskill System reservoirs were lower compared to past years (Figure 3.8). Although the late June rain event did increase July phosphorus concentrations appreciably, high diversion rates (to drain Schoharie for dam repair) quickly “flushed” the phosphorus from these reservoirs. In contrast, most Delaware reservoirs were slightly higher compared to historical phosphorus concentrations. To compensate for the increased diversion from the Catskill System, Delaware diversions were reduced, apparently causing constituents (e.g., phosphorus, turbidity) to become more concentrated due to increased residence time. Although phosphorus increases, starting in July, were also apparent at Cannonsville Reservoir, the annual median phosphorus at this reservoir was equivalent to past levels. Below average spring concentrations, perhaps the result of ongoing watershed phosphorus reduction programs, offset the high summer concentrations.

Normally, West Branch, a balancing reservoir for the Delaware System, receives about 90% of its water from Rondout and, not surprisingly, one generally observes similar water quality patterns in these reservoirs. However, after the June rain event, West Branch was placed in “float” mode for much of the rest of the year. In float mode, Rondout water is not allowed to enter West Branch at DEL9 while DEL10 is kept open, allowing water from West Branch to enter the Delaware Aqueduct at a variable, but relatively low rate. By avoiding the post-June high phosphorus inputs from Rondout, West Branch’s 2006 median phosphorus concentration was slightly lower than normal. Kensico Reservoir, which receives water from both Rondout (via West Branch) and the East Basin of Ashokan, showed no change in phosphorus compared to historical levels. Although the phosphorus concentrations of the Delaware System water entering Kensico were somewhat higher than historical values, the phosphorus concentrations in the alum treated Catskill System water were lower.

As shown in Figure 3.8 total phosphorus concentrations in the Croton System Reservoirs are normally much higher than in the Catskill and Delaware Systems. The Croton watershed is more urbanized; there are 60 waste water treatment plants, numerous septic systems and abundant paved surfaces scattered throughout the Croton watershed. The 2006 phosphorus concentrations appear to be consistent with past concentrations for most Croton reservoirs. East Branch and Bog Brook were uncharacteristically low due to relatively low phosphorus concentrations in August through October. New Croton was also relatively low in phosphorus in 2006.

The 2006 data were relatively scarce for Croton Falls and Diverting due to dam rehabilitation work on Middle Branch that necessitated the drawdown of these two impoundments. Although accurate representative medians could not be calculated for 2006, the distribution of past annual medians is provided in Figure 3.8. Phosphorus concentrations at Gilead, Gleneida and Kirk lakes were 20, 18 and 29 µg $L^{-1}$, respectively, consistent with historical levels (not shown in Figure 3.8).

## 3.6 Which basins were phosphorus-restricted in 2006?

The phosphorus-restricted basin status is provided in Table 3.2 and was derived from two consecutive assessments (2001–2005; 2002–2006) using the methodology stated in Appendix C. The table in this appendix lists the annual growing season geometric mean phosphorus concentration for each of the City reservoirs. Only reservoir basins that exceed the guidance value for both assessments are restricted. Figure 3.9 graphically depicts the phosphorus-restriction status of the NYC reservoirs and the 2006 geometric mean for the phosphorus concentration.

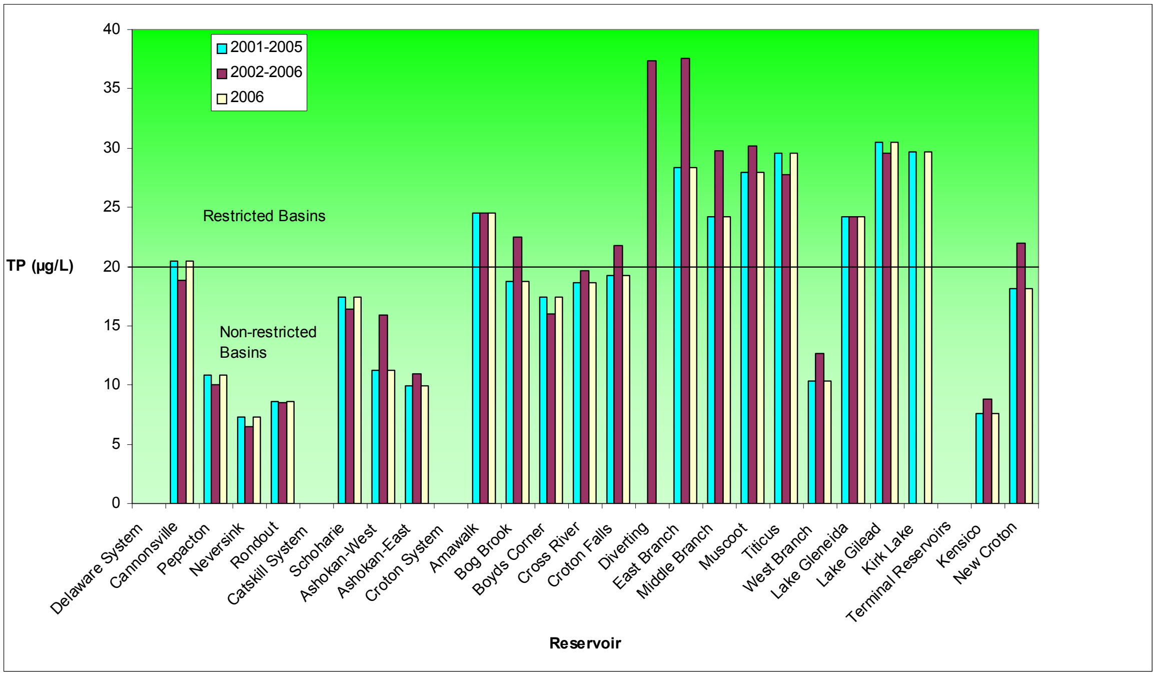


Figure 3.9 Phosphorus-restricted basin assessments with the current year (2006) geometric mean phosphorus concentration displayed for comparison.

There are a few notes and highlights in the phosphorus-restricted basin status this year.

- Cannonsville Reservoir continued to demonstrate the effect of runoff events as the basin was hit particularly hard with storms in the middle of the year. Decreased diversions may have exacerbated TP concentrations later in the year. The annual geometric mean TP in Cannonsville continued to be elevated in 2006 as it was in 2005 (Appendix C), yet the five-year assessment remained below 20 µg $L^{-1}$ . All other Delaware reservoir assessments were well below this value.
- Schoharie Reservoir was operated quite differently in 2006. Keeping the reservoir at a relatively low elevation for dam repair may have decreased the residence time and helped to flush out some of the incoming TP load. Similarly, increased diversion from Ashokan in 2006 may also have helped decrease incoming phosphorus loads by decreasing the West Basin residence time. However, even though the medians for 2006 were lower than in 2005, they were relatively high enough to increase the current five-year assessment in Schoharie and, to a lesser degree, in Ashokan's West and East Basins.
- Croton System reservoir assessments remained unchanged in their phosphorus-restricted status. Sufficient samples were collected for Lake Gleneida, Lake Gilead and Kirk Lake which will allow for assessments next year. Boyd Corners Reservoir had the minimum number of three surveys required for the analysis, while Diverting fell short with only two surveys during the growing season for the year. Diverting and East Branch Reservoirs had the highest 5-year assessment geometric mean TP levels of all the reservoirs. It should also be noted that Cross River Reservoir continues to approach 20 µg $L^{-1}$ for this and the last assessment period.

- Kensico Reservoir had similar analyses for each of the last two five-year assessments, and remains unrestricted. New Croton Reservoir's assessments remained above 20 µg $L^{-1}$, continuing to maintain its restricted status.

Table 3.2: Phosphorus-restricted reservoir basin status for 2006.

| Reservoir Basin | 01–05 Assessment (mean + S.E.) (µg $L^{-1}$) | 02–06 Assessment (mean + S.E.) (µg $L^{-1}$) | Phosphorus-Restricted Status |
|---|---|---|---|
| **Delaware District** | | | |
| Cannonsville Reservoir | 18.4 | 18.8 | Non-Restricted |
| Pepacton Reservoir | 9.5 | 10.1 | Non-Restricted |
| Neversink Reservoir | 6.1 | 6.5 | Non-Restricted |
| Rondout Reservoir | 8.3 | 8.5 | Non-Restricted |
| **Catskill District** | | | |
| Schoharie Reservoir | 15.8 | 16.4 | Non-Restricted |
| Ashokan-West Reservoir | 15.6 | 15.9 | Non-Restricted |
| Ashokan-East Reservoir | 10.7 | 11.0 | Non-Restricted |
| **Croton District** | | | |
| Amawalk Reservoir | 23.7 | 24.5 | Restricted |
| Bog Brook Reservoir | 23.1 | 22.5 | Restricted |
| Boyd Corners Reservoir | 14.7 | 16.0 | Non-Restricted |
| Cross River Reservoir | 19.4 | 19.6 | Non-Restricted |
| Croton Falls Reservoir | 22.5 | 21.8 | Restricted |
| Diverting Reservoir | 35.8 | 37.3 | Restricted |
| East Branch Reservoir | 38.3 | 37.6 | Restricted |
| Middle Branch Reservoir | 30.4 | 29.8 | Restricted |
| Muscoot Reservoir | 30.6 | 30.2 | Restricted |
| Titicus Reservoir | 27.4 | 27.7 | Restricted |
| West Branch Reservoir | 12.7 | 12.6 | Non-Restricted |
| Lake Gleneida | Insufficient Data | 24.2 | Restricted |
| Lake Gilead | 34.4 | 30.0 | Restricted |
| **Source Water** | | | |
| Kensico Reservoir | 8.9 | 8.8 | Non-Restricted |
| New Croton Reservoir | 22.6 | 22.0 | Restricted |

Note that the 01–05 assessment now uses "verified" data, whereas the 02–06 assessment uses "provisional" data for 2006.

## 3.7 What were the total and fecal coliform concentrations in NYC's reservoirs?

Coliform bacteria include total coliform and fecal coliform counts, which are regulated *in source waters* by the Safe Drinking Water Act (SDWA) at levels of 100 CFU 100 $mL^{-1}$ and 20 CFU 100 $mL^{-1}$, respectively. Both are used as indicators of potential pathogen contamination. Fecal coliform bacteria are more specific in that their source is the gut of warm-blooded animals while the other coliforms comprising the total originate in water, soil and sediments.

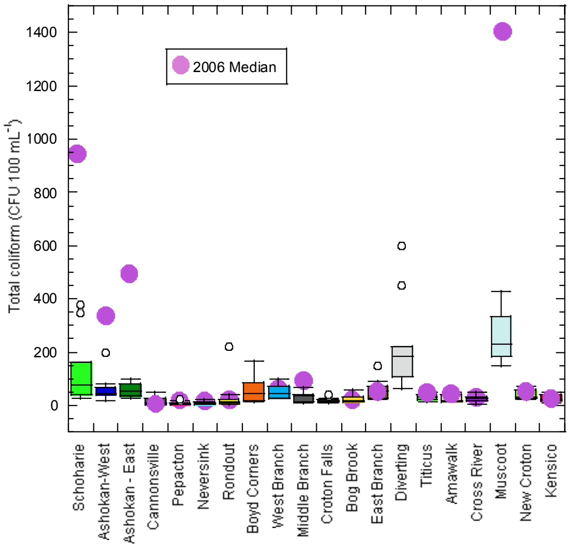


Figure 3.10 Annual median total coliform in NYC water supply reservoirs (2006 vs. 1996–2005).

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 medians were not calculated in 2006 for Boyd Corners,

Figure 3.10 shows that the long-term (1996–2005) annual median levels of total coliform have exceeded 100 CFU 100 $mL^{-1}$, primarily in Diverting and Muscoot Reservoirs. In 2006, insufficient data exist from Diverting, as well as from Croton Falls and Boyd Corners, to accurately estimate annual medians. Of the remaining Croton reservoirs, most were very close to their historical annual medians. Exceptions occurred at Muscoot and Middle Branch where coliform levels were at their highest levels in the past 11 years. Reasons for this are not clear. Muscoot receives water from five reservoirs, three of which were not elevated in total coliforms. As noted above, the other two, Diverting and Croton Falls, were not sampled all that often in 2006. Muscoot is normally relatively high in total coliforms since it is a shallow reservoir constructed over a wetland. Research indicates that surficial sediments from the littoral zone contain the highest density of coliform bacteria in the water body (Wetzel, 2001). Shallow reservoirs and lakes are susceptible to wind derived re-suspension events which distribute bacteria and detritus into the water column. Dam repairs were undertaken at Muscoot in 2005–2006, which necessitated keeping its elevation low throughout these years. The low elevation combined with an increased bottom release (to drain the reservoir) most likely caused entrainment of total coliforms from the sediments and explains the elevated counts observed in 2006. Middle Branch was also lowered in 2005–2006 to repair its release works. Like Muscoot, re-suspension is a possible cause for the increase in total coliforms noted here.

Results for the controlled lakes—Gilead, Gleneida and Kirk—were similar to historical levels and are provided in Table 3.3 below. The relatively high counts observed at Kirk are probably due to sediment re-suspension events common in shallow water bodies such as Kirk (mean depth = 2 meters).

Table 3.3: Coliform summary statistics for NYC controlled lakes.

| Lake | Median Total coliform (10 yr.) | Median Total coliform (2006) | Median Fecal coliform (10 yr.) | Median Fecal coliform (2006) |
|---|---|---|---|---|
| Gilead | 13 | 23 | 0.5 | 1.0 |
| Gleneida | 7 | 10 | 0.5 | 0.5 |
| Kirk | 87 | 88 | 2 | 2 |

The Catskill reservoirs were all well above their long-term medians in 2006. Extremely heavy rainfall starting in October 2005 coupled with storms in May and June 2006 contributed to this increase. Moreover, to facilitate dam repair, water was diverted from Schoharie at the maximum rate to keep the elevation low. Under these conditions, re-suspension of coliforms from exposed sediments was very likely. In contrast, all the Delaware reservoirs were equivalent to their historical levels despite precipitation patterns similar to those of the Catskills. Research has shown that total coliforms commonly adhere to soil particles. Because soils are much less susceptible to erosion in the Delaware watersheds, an equal volume of runoff there tends to produce much lower total coliform counts than in the Catskill System. In addition, diversion rates in Delaware were much less than normal. With the reservoirs at or near capacity, inputs from re-suspension were lessened considerably.

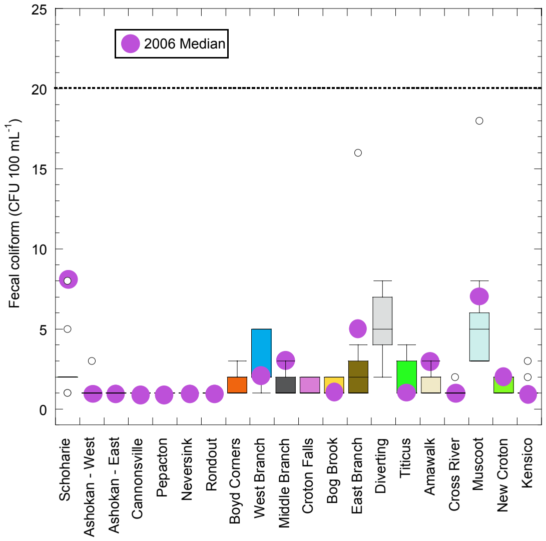


Figure 3.11 Annual median fecal coliform in NYC water supply reservoirs (2006 vs. 1996-2005). The dashed line represents the SDWA standard for source waters as a reference.

Note: In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. However, the medians were not calculated in 2006 for Boyd Corners, Croton Falls and Diverting because of a very limited number of samples that may not be an accurate representation of the year.

Figure 3.11 compares the long-term (1996-2005) annual fecal coliform medians with the current (2006) annual median. Not enough data were collected in 2006 to estimate accurate medians for Diverting, Croton Falls or Boyd Corners Reservoirs. Of the remaining Croton reservoirs, East Branch, Muscoot, Middle Branch and Amawalk all showed a substantial increase in 2006 while fecal levels at New Croton, Cross River and Titicus were within their normal ranges. Fecal levels at the controlled lakes were low and also within their normal ranges (Table 3.3). Reasons for the increases in some of the reservoirs are unclear and probably vary from reservoir to reservoir. Muscoot's increase coincided with significant rain events in July and November but drawdown for dam repair may also have been a factor. Rain events account for most of the high counts in Amawalk but drawdown in September-October along with increased bird activity during this time is the most likely explanation for high counts in October. Fecal counts in East Branch were also elevated especially in the bottom sample near the dam. Normally bottom waters are released through the dam, which, in addition to providing cool water to the stream below, helps to keep the lower depths in the reservoir from stagnating. In 2006, the release valve was seized closed and fecal coliform were apparently concentrated in the stagnant water. This situation should be resolved in 2007 with the repair of the valve and the resumption of normal operations. Elevated fecal coliform in Middle Branch coincided with rain events in June and November but drawdown for dam repair began in June, and may also have been a factor.

Most West-of-Hudson reservoirs (including West Branch and Kensico) continued to have uniformly low levels of fecal coliform in 2006, as demonstrated by the medians in Figure 3.11. Only Schoharie experienced higher than normal fecal levels in 2006, most likely from the combined effects of excessive precipitation in June coupled with the often low elevation of the reservoir, maintained to facilitate dam repair.

## 3.8 Which basins were coliform-restricted in 2006?

New York City DEP’s Watershed Rules and Regulations state that an annual review of the City reservoirs will be performed to determine which, if any, should receive a coliform-restricted designation in regards to coliform bacteria. There are two parts to be considered in the determination of which basins are coliform restricted: Section 18-48 (a)(1) considers the water in all reservoirs and in Lakes Gilead and Gleneida; Section 18-48 (b)(1) considers the waters within 500 feet of the aqueduct effluent chamber located at a terminal reservoir (Kensico, West Branch, New Croton, Ashokan, and Rondout). Terminal basins are those that serve, or potentially serve, as source-water reservoirs.

With respect to NYC’s five terminal basins, a coliform-restricted assessment has been made for 2006 under Section 18-48 (b)(1) using *fecal* coliform data at the effluent keypoints (Table 3.4). Currently, these assessments 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 had values $\geq$ 20 CFU $100mL^{-1}$, and the cause was determined to be from anthropogenic (man-made) sources, the associated basin would be deemed a “coliform-restricted” reservoir. If < 10 % of the effluent keypoint samples measured $\geq$ 20 CFU $100mL^{-1}$, then the associated reservoir would be “non-restricted” with regard to coliform bacteria.

With respect to non-terminal basins, the water quality standard is for *total* coliform only and this poses several problems for reservoir basin designation. Total coliform come from a variety of natural and anthropogenic sources, so using total coliform alone will not meet the spirit of the regulation. The draft methodology developed by DEP for determining coliform-restricted basins for these non-terminal reservoirs will use the total coliform standard as an initial assessment, but will also go further to consider other microbial data to determine whether the source is anthropogenic. This method is pending approval and is not in use at this time; therefore, coliform-restricted basins have not been determined for the non-terminal reservoirs for 2006.

Table 3.4: Coliform-restricted basin status as per Section 18-48 (b) (1) for 2006.

| **Reservoir Basin** | **Effluent Keypoint** | **2006 Assessment** |
|---|---|---|
| Kensico | CATLEFF and DEL18 | Non-restricted |
| New Croton | CROGH | Not determined* |
| Ashokan | EARCM | Non-restricted |
| Rondout | RDRRCM | Non-restricted |
| West Branch | DEL10/CWB1.5 | Not determined** |

* The site CROGH was only represented from May through September due to shut-down of the Croton Aqueduct; therefore, a complete assessment could not be made.

** The WRR relies on five representative samples analyzed per week over each six-month period to be used for the coliform restriction assessment of terminal basins. Since the keypoint at West Branch (DEL10) was only sampled once per week for the first half of the year, there were not enough samples analyzed to meet this criterion. Beginning in October, a new site was established where samples were collected five days per week. This site should permit calculation of the coli-restricted status in the future.

## 3.9 How did source water quality compare with standards in 2006?

Table 3.5 represents reservoir-wide median values for a variety of physical, biological and chemical analytes for the four source water reservoirs: Kensico, New Croton, Ashokan (East Basin) and Rondout. Appendix A gives additional statistical information on these and other reservoirs in the system. New Croton Reservoir water quality was noticeably different from the other three source water reservoirs. The pH in New Croton tends to be higher because of the underlying geology and because of primary production, which at times can exceed the 8.5 pH water quality standard. The pH readings in WOH reservoirs tend to be lower than the standard of 6.5 pH units at times as a result of low alkalinity which provides little buffering of acidic precipitation. Cation data in EOH tended to be 4 to 10 times higher on average than WOH reservoirs. Of important note is that sodium typically exceeds calcium in EOH reservoirs, which reflects the increased anthropogenic sources of sodium in the watershed. Chloride levels were much higher in New Croton than in other reservoirs and the levels continue to increase as compared to previous years. The chloride levels, however, remain well below the 250 mg $L^{-1}$ NYS ambient water quality standard. Appendix A shows the chloride levels for all other EOH reservoirs, which continue to increase.

Table 3.5: Reservoir-wide median values for a variety of physical, biological and chemical analytes for the four source water reservoirs in 2006.

| **ANALYTE** | Water Quality Standard | Kensico | New Croton | East Ashokan Basin | Rondout |
|---|---|---|---|---|---|
| **PHYSICAL** | | | | | |
| Temperature (C) | | 11.5 | 11.5 | 11.0 | 10.2 |
| pH (units) | 6.5-8.5[1] | 7.0 | 7.5 | 7.2 | 6.9 |
| Alkalinity (mg/l) | | 9.5 | 59.6 | 10.1 | 7.6 |

Table 3.5: Reservoir-wide median values for a variety of physical, biological and chemical analytes for the four source water reservoirs in 2006.

| **ANALYTE** | Water Quality Standard | Kensico | New Croton | East Ashokan Basin | Rondout |
|---|---|---|---|---|---|
| Conductivity (µS/cm) | | 65 | 333 | 57 | 47 |
| Hardness (mg/l)[2] | | 19 | 88 | 17 | 15 |
| Color (Pt-Co units) | (15) | 10 | 25 | 12 | 12 |
| Turbidity (NTU) | (5) [3] | 1.3 | 2.3 | 3.4 | 1 |
| Secchi Disk Depth (m) | | 4.5 | 2.5 | 2.9 | 4.4 |
| **BIOLOGICAL** | | | | | |
| Chlorophyll *a* (µg/l) | 7 [4] | 4.2 | 11.2 | 3.56 | 7.4 |
| Total Phytoplankton (SAU) | 2000 [4] | 300 | 1100 | 215 | 280 |
| **CHEMICAL** | | | | | |
| Dissolved Organic Carbon (mg/l) | | 1.7 | 3.1 | 1.7 | 1.6 |
| Total Phosphorus (µg/l) | 15 [4] | 9 | 19 | 10 | 7.8 |
| Total Nitrogen (mg/l) | | 0.3 | 0.47 | 0.35 | 0.3 |
| Nitrate+Nitrite-N (mg/l) | 10 [1] | 0.18 | 0.20 | 0.26 | 0.19 |
| Total Ammonia-N (mg/l) | 2 [1] | 0.01 | 0.02 | 0.02 | 0.01 |
| Iron (mg/l) | 0.3 [1] | 0.02 | 0.05 | 0.13 | 0.02 |
| Manganese (mg/l) | (0.05) | 0.02 | 0.03 | 0.02 | 0.03 |
| Lead (µg/l) | 50 [1] | 0.5 | 0.5 | 0.5 | 0.5 |
| Copper (µg/l) | 200 [1] | 1.5 | 1.5 | 1.5 | 1.5 |
| Calcium (mg/l) | | 5.4 | 22.6 | 5.2 | 4.4 |
| Sodium (mg/l) | | 4.7 | 30 | 3.5 | 3.4 |
| Chloride (mg/l) | 250 [1] | 7.2 | 59.8 | 6.1 | 5.4 |

Note: See Appendix A for water Quality Standards footnotes.

Typically, higher nutrient inputs can cause higher chlorophyll *a* and phytoplankton levels in New Croton, and in 2006 there were several samples above the DWQC internal limit of 2000 standard areal units (SAU). Chlorophyll *a* data were elevated as high as 41 µg $L^{-1}$. The total phosphorus (TP) data summary demonstrates that the median TP in New Croton exceeded the NYSDEC guidance value of 15 µg $L^{-1}$, which applies to source waters. Other reservoirs in the Croton System also exceeded the 20 µg $L^{-1}$ guideline for non-source waters in 2006 (Appendix A). New Croton’s turbidity levels, though elevated at times, were typically lower than those found in Ashokan Reservoir, where turbidity is associated with ubiquitous terrestrial sources of clay. It should also be noted that during the period of November, 2005 through December, 2006 the Shandaken Tunnel operated under emergency conditions while the Gilboa Dam (impounding the Schoharie Reservoir) underwent emergency repairs. This resulted in a year of sustained high flows from the tunnel to the Esopus Creek along with increased turbidity. The deeper Secchi disc transparencies were found in Rondout and Kensico, which are less productive and less turbid than the other source water reservoirs, although the 2006 median chlorophyll *a* of 7.4 µg $L^{-1}$ for Rondout was this reservoir's highest in the past 11 years. Higher levels of discoloration, iron, manganese and organic carbon occurred in New Croton. In contrast to New Croton, Kensico's water quality is reflective of the fact that most of its water is derived from Rondout and Ashokan Reservoirs. Kensico was impacted by heavy rains that affected the WOH reservoirs in mid-2006. Once again, alum was used to attenuate the turbidity from Ashokan in 2006 and minimize any chance of exceeding the SWTR standard of 5 NTU at the intakes. The alum treated waters may also have helped to keep the Kensico trophic state index (TSI) level similar to previous years by reducing the overall phosphorus levels in the incoming Catskill waters.

## 3.10 What were the trophic states of the City's 19 reservoirs in 2006 and why is this important?

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

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

where CHLA is the concentration of chlorophyll *a.*

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

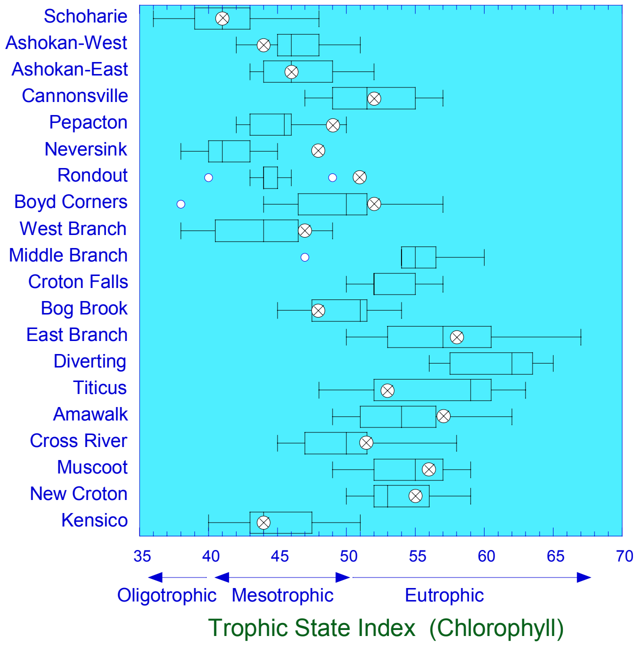


Figure 3.12 Annual median Trophic State Index (TSI) in NYC water supply reservoirs (2006 vs. 1996–2005).

See text for differences between districts. 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.

Historical annual median TSI based on chlorophyll *a* concentration is presented in box plots for all reservoirs in Figure 3.12. The EOH data included 1998–2004, while Catskill and Delaware Reservoirs included 1996–2005 data. The 2006 annual median TSI appears in the figure as a circle containing an “x”. This analysis usually 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.

In 2006, the median TSI for all Catskill reservoirs decreased or remained the same compared to past data, indicating normal algal production. Most Delaware reservoirs, however, showed a marked increase in 2006, approaching or exceeding the highest trophic status observed in these reservoirs in the past 11 years. A potential cause may be that decreased diversions due to operational changes increased the residence times in these basins, leading to greater productivity. Based on TSI results, Rondout and Cannonsville would be considered eutrophic in 2006, with Neversink and Pepacton approaching this trophic status as well. Algal production was predictably high. In most months algal counts were approximately 2 to 5 times higher than historical levels at Rondout and 3 to 10 times higher at Neversink and Pepacton. A variety of diatoms, all considered taste and odor producers, were the most prevalent organisms found. *Asterionella* was usually dominant in the spring at Rondout and Pepacton while *Fragillaria* blooms occurred in the summer. At Neversink, *Asterionella* and *Rhizosolenia* dominated in spring and early summer while *Tabellaria* was elevated throughout the summer and fall. The taste and odor producing flagellate, *Dinobryon,* was also present in relatively high numbers during June and July. Interestingly, Cannonsville, the most eutrophic reservoir in the Delaware system, did not vary appreciably from its past trophic status. Light transparency, an essential requirement for algal growth, was markedly reduced by prolonged turbid conditions from storms starting in late June, which probably helped to prevent the large increases observed in the other Delaware reservoirs. TSI was also high at West Branch, which is not surprising given that it normally receives the bulk of its water from Rondout. Even though less water was derived from Rondout in 2006 than in the past, TSI at West Branch's other main source, Boyd Corners Reservoir, was fairly elevated as well. TSI at Kensico, which receives more than 95% of its water from a combination of the Delaware system, usually via West Branch, and the Catskill system via the East Basin of Ashokan, was equivalent to its historical median TSI. Apparently the effect of increasing the relative percentage of Catskill water that was treated with alum was enough to prevent an increase in trophic status at this reservoir.

TSI results for the Croton System reservoirs indicated increases for most in 2006 although usually within the 75th percentile of the historical data. In 2006, data were insufficient to calculate annual TSI for three Croton System reservoirs, Middle Branch, Croton Falls, and Diverting, and for lakes Kirk and Gilead. In most of the Croton reservoirs, blue-green algae dominated the assemblage of phytoplankton during the summer.

The exceptions that didn't exhibit an increase in TSI included Bog Brook and Titicus Reservoirs. Bog Brook experienced relatively low TP during the year, which may explain the low chlorophyll *a* and the consequent TSI. Titicus Reservoir's low TSI could be explained by comparison to historical data. The box plot represents seven years of data, five of which occurred during low elevations due to dam rehabilitation and subsequently slow recharge during relatively dry years. The chlorophyll *a* data from those years were relatively high, causing a higher median and 75th percentile for the TSI plot. A return to more typical, full elevations may be responsible for the comparatively low TSI in Titicus.

## 3.11 How did the reservoir water conductivity in 2006 compare to previous years?

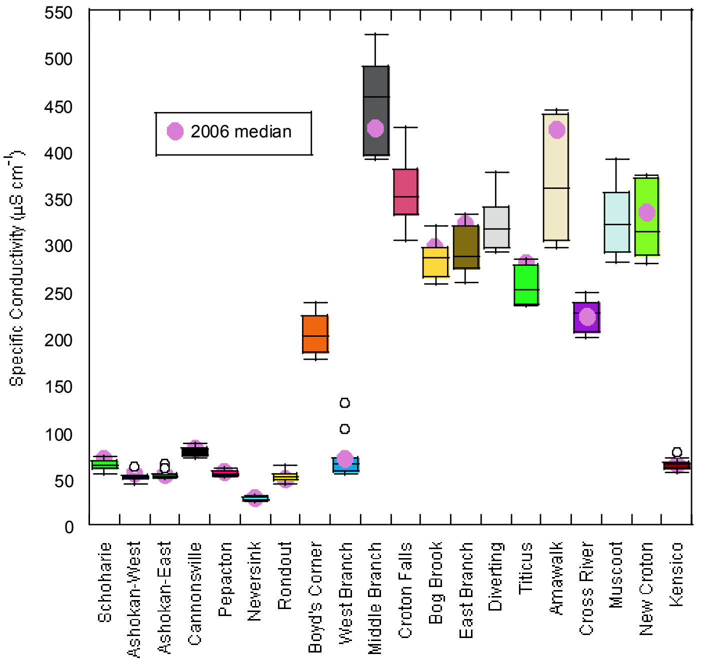


Figure 3.13 Annual median specific conductivity in NYC water supply reservoirs (2006 vs. 1996–2005).

Note: In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies (1 or 2x per month) from April through December. Note that insufficient data were available to calculate representative annual medians for Boyd Corners, Croton Falls, Diverting and Muscoot Reservoirs.

Specific conductance (conductivity) is a measure of the ability of water to conduct an electrical current. It varies as a function of the amount and type of ions that the water contains. The ions which typically contribute most to reservoir conductivity include: 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 (i.e., 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. This type of terrain will also produce waters of low conductivity. Such is the case with NYC's water supply reservoirs. Catskill and Delaware System reservoirs have displayed uniformly low median conductivities in the past and continued to do so in 2006 (Figure 3.13). These reservoirs are situated in mountainous terrain underlain by relatively insoluble deposits, which produce relatively low conductivities in the 25 to 100 $\mu S\ cm^{-1}$ 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 usually in the 50 to 100 $\mu S\ cm^{-1}$ range. In 2006, conductivity in Schoharie, Ashokan's West Basin and Cannonsville were slightly elevated above the historic median, possibly due to different operational patterns in these impoundments. The remaining Catskill and Delaware System reservoirs, including West Branch and Kensico, were all very close to historical medians.

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 (i.e., marble and/or limestone) within the watershed. However, most of the reservoirs have displayed steady increases in conductivity since the early 1990s most likely associated with development pressure in the watershed (e.g., increased use of road salt). In 2006, conductivity in the Croton System reservoirs continued to rise above the long-term median in most reservoirs, including Bog Brook, East Branch, Titicus, Amawalk and New Croton reservoirs. Two interesting points to make about the data presented in Figure 3.13 are that Amawalk had an increase of approximately 70 $\mu S\ cm^{-1}$ in 2006, and Middle Branch, which typically has the highest conductivity in the system, was approximately 30 $\mu S\ cm^{-1}$ lower in 2006 than the long-term median. Reasons for these changes are unclear at this time. Note that insufficient data were available to calculate representative annual medians for Boyd Corners, Croton Falls, Diverting, and Muscoot Reservoirs. The controlled lakes are not represented on this plot, but summary statistics can be found for lakes Kirk, Gilead and Gleneida in Appendix A.

## 3.12 What Special Investigations were conducted in 2006?

The term "Special Investigations" (SIs) refers to limited non-routine collection of environmental data, including photographs and/or analysis of samples, in response to a specific concern or event. In 2006, 17 SIs were conducted and reported on (cf. 16 in 2005). More investigations were conducted EOH (13) than WOH (4). Actual or possible oil spills were the commonest incidents investigated (8), followed by sewage spills (4). None of the investigations conducted in 2006 identified a pollution problem that was considered an immediate threat to consumers of the water supply. Below is a list of reservoir watersheds in which investigations occurred in 2006, with dates and a brief description of each investigation.

### Kensico Reservoir

- May 22, a fuel oil leak from a private residence.
- October 16, an SUV drove off Rte. 22 and rolled to the shore of the reservoir. No oil or gasoline was detected in the reservoir.

### New Croton

- March 9, a pressurized sewer line ruptured in Yorktown.
- June 14, investigated report of discolored water in a construction trench draining to a tributary to the reservoir. No water quality concern was identified.
- September 15, responded to a complaint that a septage hauler discharged a load of septage into a tributary to the Kisco River. There was no indication that the stream was impacted by the discharge.
- September 18, a heating oil spill from an underground storage tank in Yorktown.

Figure 3.14 Vacuum truck removing spilled sludge at Yorktown Heights WWTP, Muscoot Reservoir watershed.

## Muscoot Reservoir

- July 25, an anaerobic digester spill at the Yorktown Heights WWTP.
- November 8, an aboveground storage tank in Golden's Bridge leaked fuel oil into a storm drain leading to the reservoir.

## Croton Falls Reservoir

- March 31, a tanker truck spilled diesel fuel to a tributary to Michael Brook in Kent.
- October 14, a sewer manhole overflowed into a wetland in Carmel.

## Diverting Reservoir

- June 28, a diesel fuel spill into a storm drain leading to the East Branch Croton River.

## East Branch Reservoir

- August 31, a rotten egg odor downstream of the reservoir.

## West Branch Reservoir

- November 7, an automobile leaked fuel after crashing into the reservoir.

## Schoharie Reservoir

- December 12, a sewage overflow resulting from a mechanical malfunction at a pumping station.

## Cannonsville Reservoir

- October 28, a tractor trailer truck spilled home heating oil into the reservoir.

## Pepacton Reservoir

- March 17, an investigation to determine if polluted runoff from a landfill was entering the reservoir.
- June 5, a fish kill in the reservoir, thought to be caused by rapid temperature change and elevated pH.

Figure 3.15 Damaged fuel oil truck being removed from the shore of Cannonsville Reservoir.

## 3.13 Has DEP monitoring of aquatic biota in streams feeding the reservoirs revealed any changes to the macroinvertebrate community?

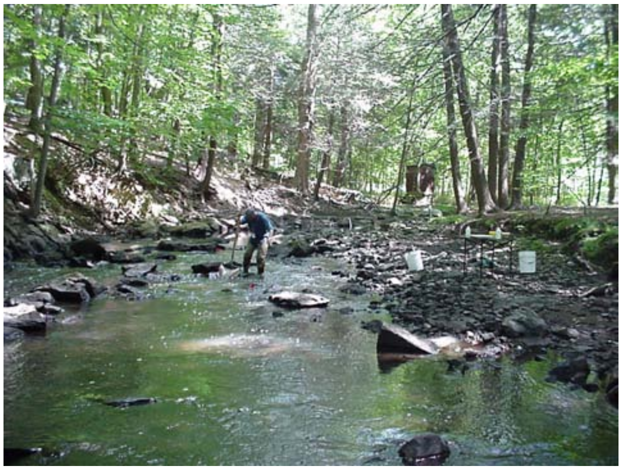


Figure 3.16 Collecting a kick sample from the Kisco River in the New Croton Reservoir watershed.

DEP has been performing water quality assessments of watershed streams based on resident benthic macroinvertebrate assemblages since 1994, using protocols developed by the NYSDEC's Stream Biomonitoring Unit. Streams are sampled in areas of riffle habitat, using the traveling kick method (Figure 3.16); collected organisms are preserved in the field and later identified, and a series of metrics 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 water quality assessment 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, for that matter, a lack of change) to the macroinvertebrate community as reflected in the water quality assessment score can provide important information to DEP managers, 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 2006 sampling season, DEP had established 154 sampling sites in streams throughout the water supply watershed, with roughly equal numbers in each of the system's three Districts. 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 those sites with a 5-year or better record were examined, to reduce the chances that short-term variation, or aberrant samples, might cloud the analysis. Thirty-four (34) sites met the 5-year criterion, 12 in the East-of-Hudson District, 11 in Catskill, and 11 in Delaware (Figure 3.17). Of these, 20 are routine sites (generally, major tributaries to receiving reservoirs); the rest were sampled to monitor the impacts of existing pollution sources or proposed development, or to evaluate the effectiveness of streambank stabilization projects.

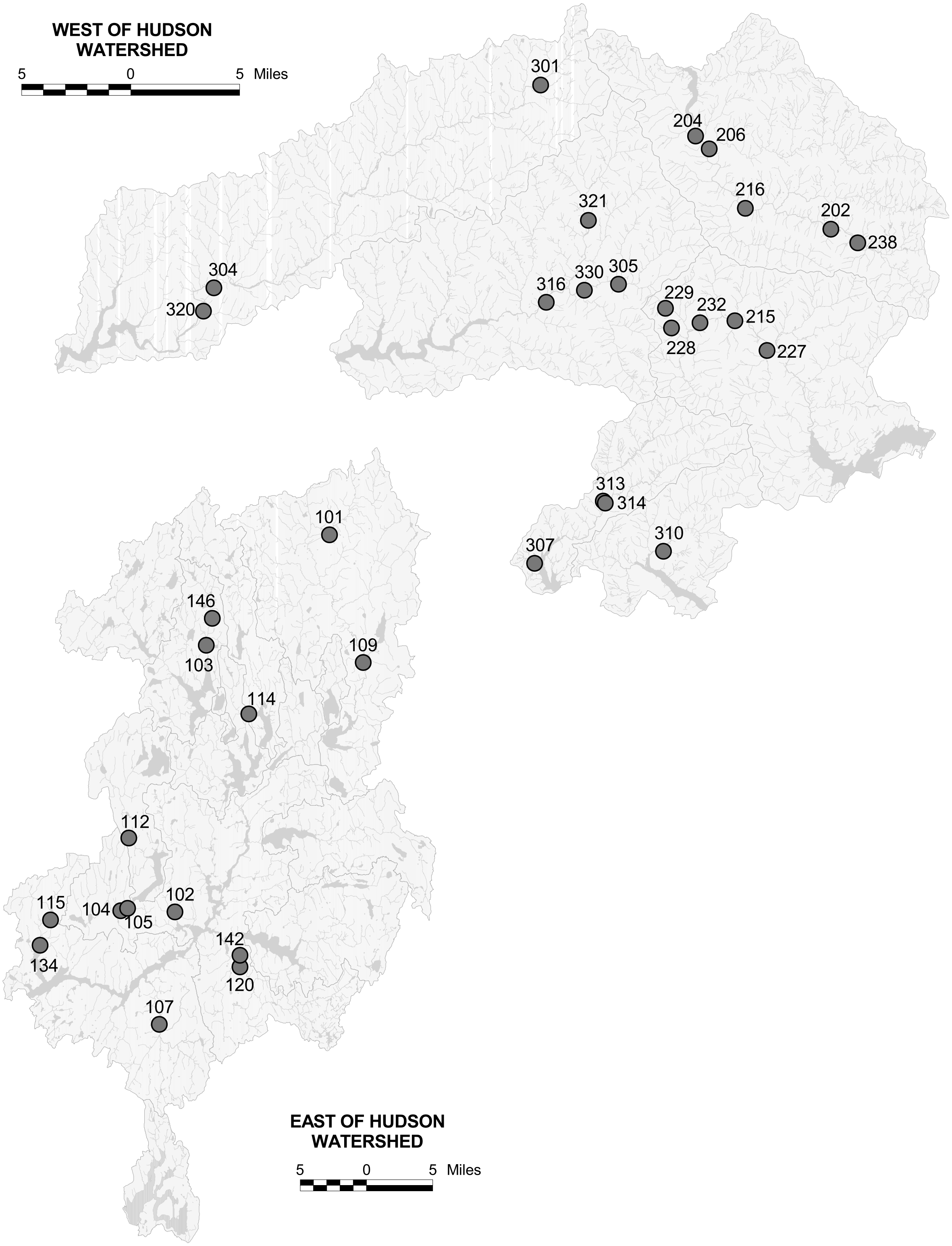


Figure 3.17 Stream biomonitoring sites with a 5-year or better record.

The data are plotted in Figures 3.19 through 3.21 for the East-of-Hudson, Catskill, and Delaware Districts, respectively. In most cases, long-term changes to the macroinvertebrate community were not observed. At several sites, however, the data suggest otherwise. In 2005, for example, following several years of generally upward-trending scores, the East Branch Croton River (Site 109) assessed as non-impaired for the first time since sampling began in 1995. The most important factor in the improved assessment was the decline in numbers of the caddisfly *Cheumatopsyche* sp., which greatly improved the percent model affinity metric, a measure of the community's similarity to a model New York State stream community.

At two other sites—Hallocks Mill Brook above the Yorktown Heights wastewater treatment plant (Site 104) and Stone Hill River (Sites 120 and 142)—assessment scores dipped to new lows after hovering for several years around the threshold dividing adjoining assessment categories. In each case, the change was due largely to the increase in abundance of a single beetle taxon, *Stenelmis* sp. at Hallocks Mill Brook, and *Oulimnius* sp. at Stone Hill River, which resulted in depressed percent model affinity scores. Because *Stenelmi*s and *Oulimnius* are generally considered relatively tolerant taxa, a significant increase in their numbers might suggest a decline in the already impaired conditions at these streams, but at present no stressor has been identified at either Hallocks Mill Brook or Stone Hill River which would explain the rapid increase of these organisms at these sites. Additional data will be needed to determine whether the changes in scores represent an actual change to the macroinvertebrate community or merely reflect natural variability in these stream systems.

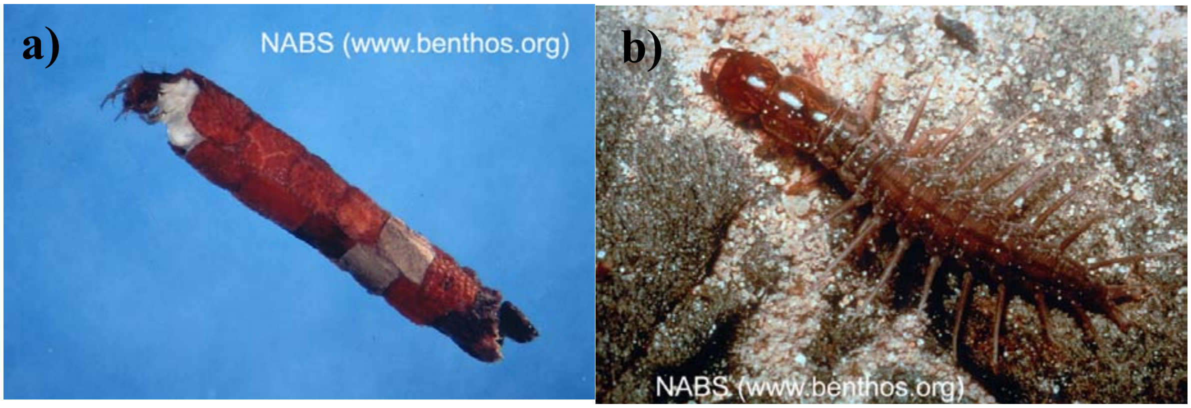


Figure 3.18 Some characteristic macroinvertebrates from New York City water supply watershed streams. a) *Lepidostoma*, a sensitive caddisfly, in its case of 4-sided leaf pieces.b) *Corydalus*, the common hellgrammite, is a predator in Catskill streams.

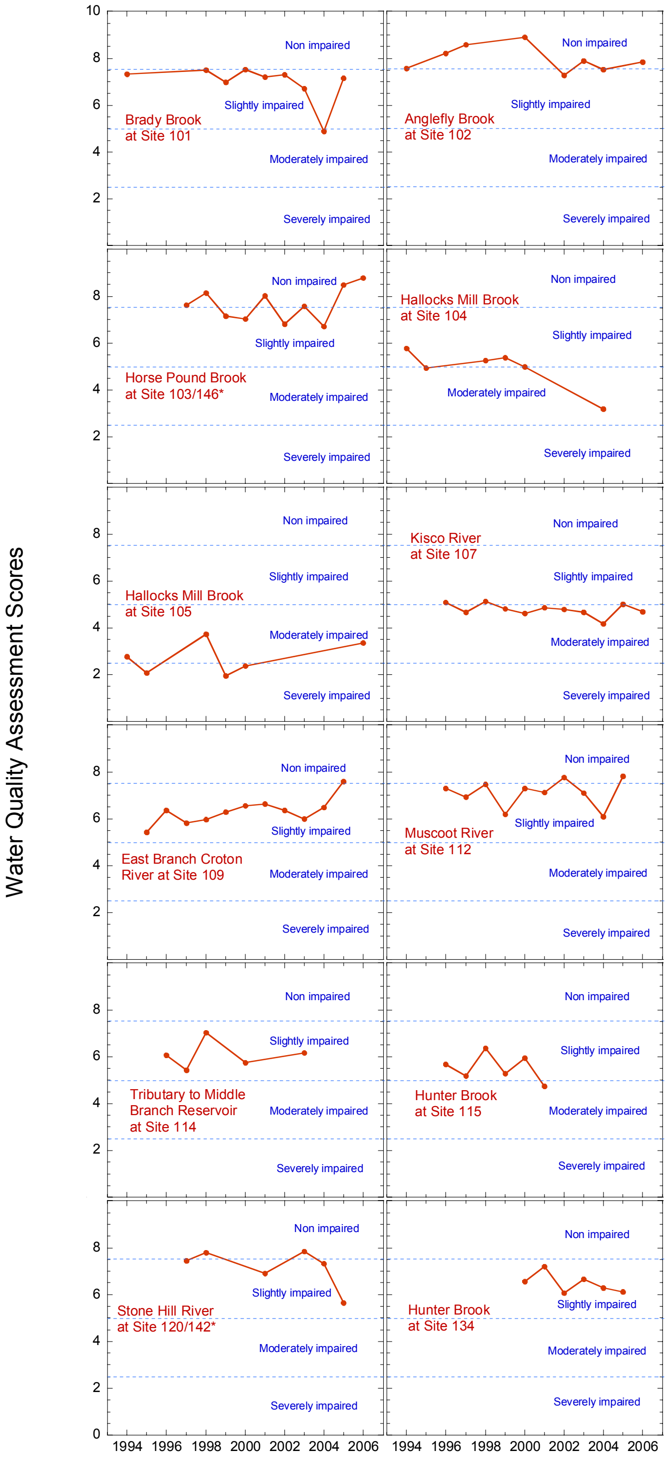


Figure 3.19 Water Quality Assessment Scores based on stream biomonitoring data for East-of-Hudson streams with a 5-year or better record.

*The Horse Pound Brook site was moved from Site 103 to Site 146 in 2004. The Stone Hill River site was moved from Site 120 to Site 142 in 2003. In both cases, data for the combined sites are plotted as a single graph.

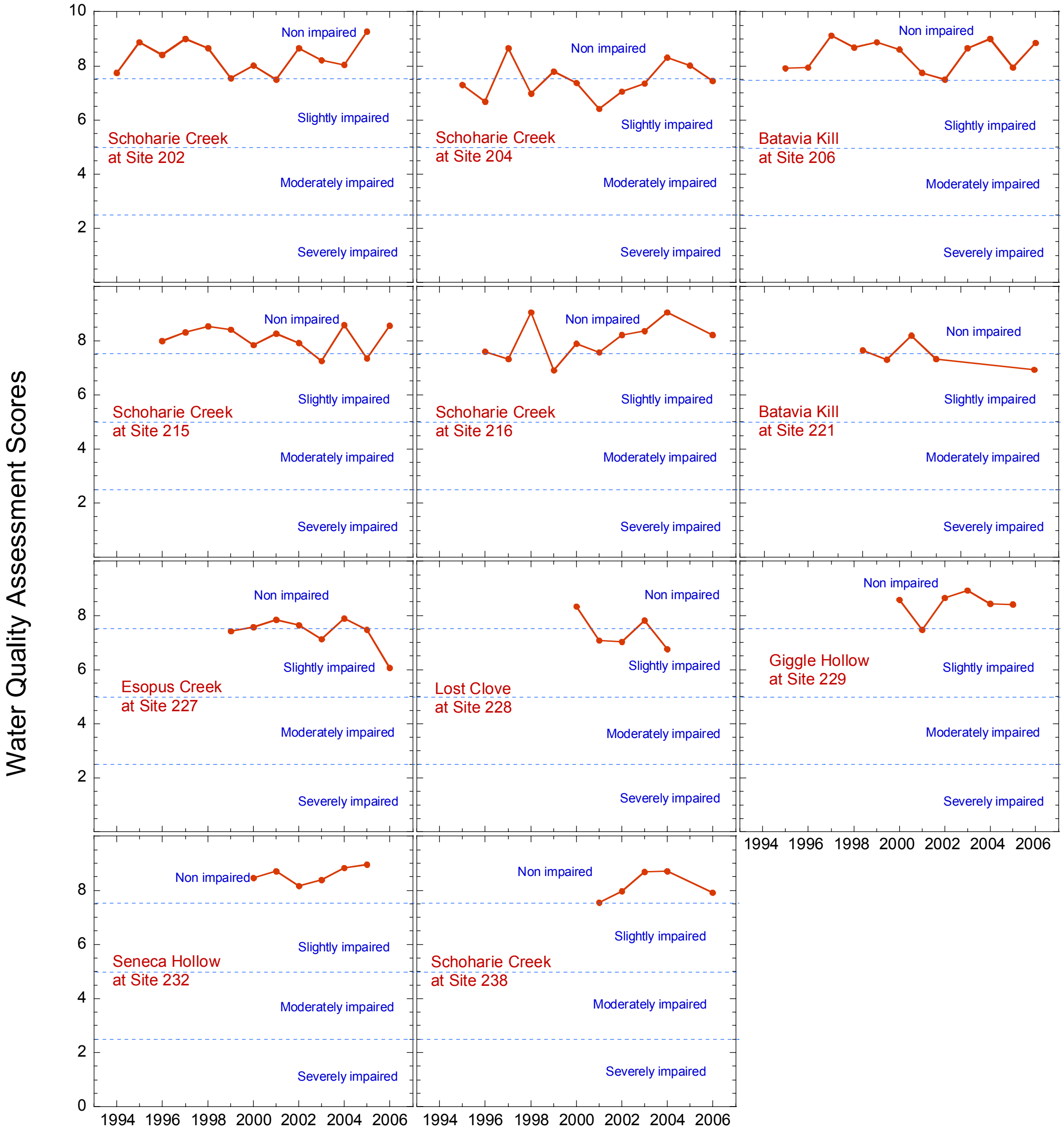


Figure 3.20 Water Quality Assessment Scores based on stream biomonitoring data for Catskill streams with a 5-year or better record.

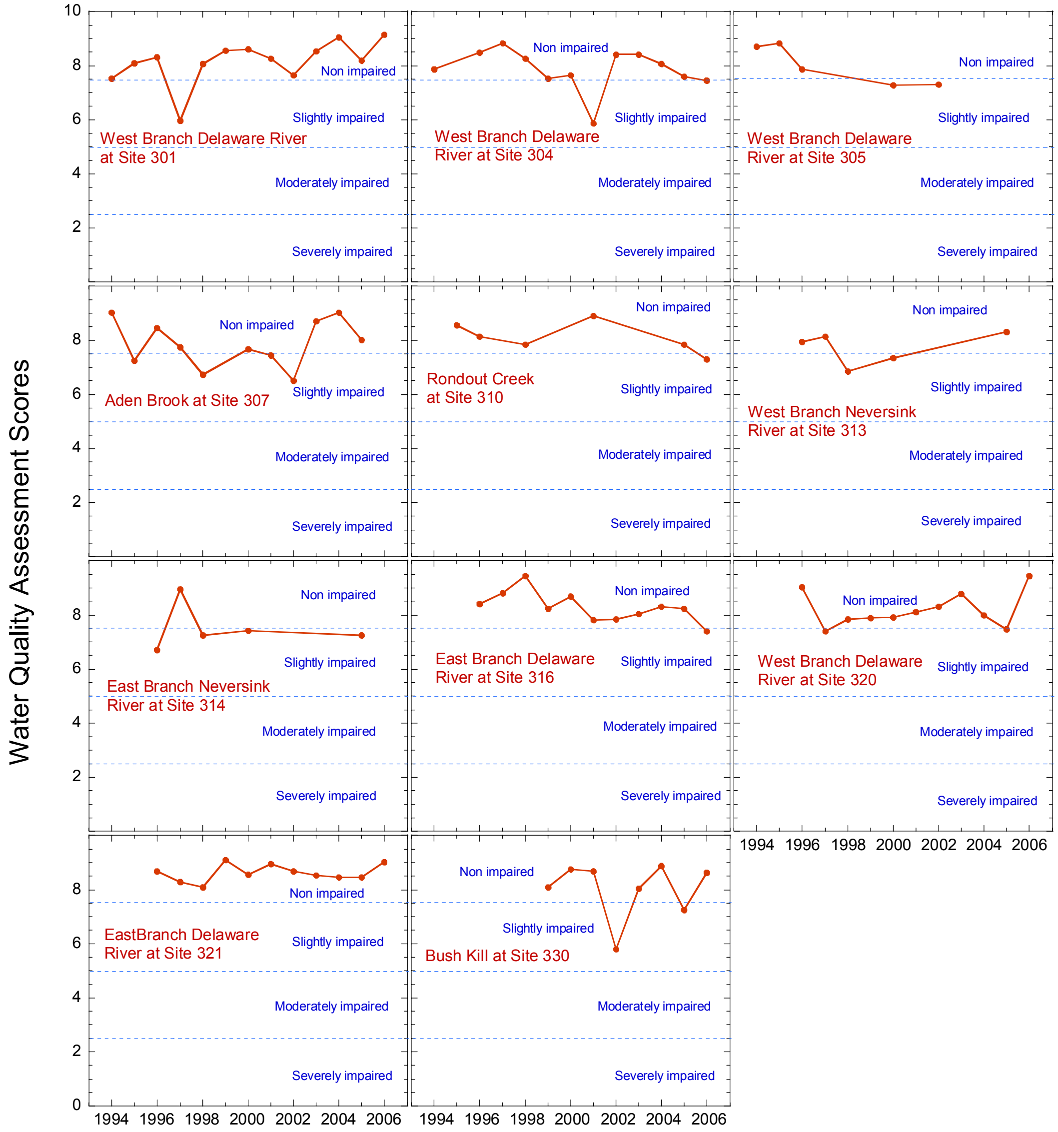


Figure 3.21 Water Quality Assessment Scores based on stream biomonitoring data for Delaware streams with a 5-year or better record.

At two further sites—Schoharie Creek at Lexington Bridge (Site 216) and Aden Brook (Site 307)—the macroinvertebrate community appears to have returned to its non-impaired condition after several years of less than optimal scores. Both sites underwent extensive channel alteration in the mid-1990s, the former as part of a stream stabilization project, the latter in the wake of heavy flooding, and in both cases construction activities had a measurable impact on the benthic communities, reflected in a decline in water quality assessment scores. (For a fuller description of events at these sites, see DEP, 2006f.)

## 3.14 What are disinfection by-products, and what were their concentrations in the distribution system in 2006?

Disinfection by-products (DBPs) are formed in drinking water during treatment with chlorine, which reacts with certain acids that are in naturally-occurring organic material (e.g., decomposing vegetation such as tree leaves, algae, or other aquatic plants) in surface water such as rivers and lakes. The quantity of DBPs in drinking water can change 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. Drinking water is disinfected by public water suppliers to kill bacteria and viruses that could cause serious illnesses. Chlorine is the most commonly used disinfectant in New York State. For this reason, disinfection of drinking water by chlorination is beneficial to public health.

DEP monitors two important groups of DBPs: trihalomethanes and haloacetic acids. Trihalomethanes (TTHM) are a group of chemicals that includes chloroform, bromoform, bromodichloromethane, and chlorodibromomethane, of which chloroform is the main constituent. Haloacetic acids (HAA) are a group of chemicals that includes 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 five haloacetic acids (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 2006 annual running quarterly averages are presented in Table 3.6 and show system compliance for TTHM and HAA5 in both the Catskill/Delaware and Croton Distribution Areas of New York City. It should be noted that the Croton System remained off-line for 2006. However, the monitoring sites are still designated as the Croton Distribution Area for consistency.

Table 3.6: Results for the Stage 1 annual running quarterly average calculation of distribution system DBP concentrations ($\mu g\ L^{-1}$) for 2006.

| | Catskill/Delaware | | Croton | |
|---|---|---|---|---|
| 2006 Quarter | TTHM | HAA5 | TTHM | HAA5 |
| 1st | 35 | 43 | 41 | 45 |
| 2nd | 34 | 41 | 41 | 44 |
| 3rd | 38 | 42 | 44 | 46 |
| 4th | 38 | 42 | 46 | 47 |
| MCL | 80 | 60 | 80 | 60 |

## 3.15 What can DEP do to prevent turbidity spikes in the aqueducts at the Kensico effluent points when the reservoir gates are opened or closed?

DEP is in the process of conducting surveys to investigate the accumulation of sediments in the Kensico Reservoir in the immediate vicinity of the effluent chambers. When the bathymetric surveys have been completed, decisions on potential dredging to clear the intake channels will be made. The objective of such dredging is to prevent turbidity spikes in the aqueducts when reservoir gates are opened or closed.

CR Environmental, Inc. (CR) performed hydrographic and sub-bottom surveys at the Kensico Reservoir on October 11, and November 27 and 28, 2006 in support of DEP's investigation of sediment accumulation in the channel leading to the Catskill Aqueduct Upper Effluent Chamber (CATUEC) and the channel leading to the Delaware Aqueduct South Effluent Chamber (Shaft 18). The goals of the surveys were to determine the current bottom elevations (bathymetry) and thickness of sediment in each channel using modern sonar technologies, including a precision echosounder and an acoustic sub-bottom profiling system. This survey effort is the first of a two-year monitoring program established by DEP.

It was suggested by CR that the methods specified for the 2007 survey effort be modified to maximize productivity and data quality by inclusion of data acquisition using the deep deployment of the 200 kHz 3-degree transducer, data verification using lead line soundings, and acquisition of sub-bottom sonar data at the Shaft 18 channel. The quality of the survey data would also benefit from use of the 26-ft vessel as a stable work platform.

According to a report prepared by CR, the survey data documented between 2.0 and 6.3 ft of sediment in the CATUEC channel. Exploration of the channel using a video probing system and a gravity coring system suggest that this sediment is composed primarily of sandy silts and coarse organic detritus (i.e., leaves and small sticks). Survey data document less than 1 ft of sediment accumulation in the portion of the Shaft 18 channel within 100 meters of the chamber. Exploration with the video probe system and gravity coring system suggest that sediment in the channel is composed of silty clay covered with a thin layer of organic detritus. Sub-bottom sonar data collected in the Shaft 18 channel suggests minimal accumulation of sediment within 100 meters of the gate, and as much as 2 ft of sediment accumulation in outer portions of the channel.

# 4. Pathogens

## 4.1 How many samples did DEP collect for *Cryptosporidium, Giardia* and human enteric viruses in 2006, and what were the occurrences and concentrations in the "source waters"?

DEP conducts compliance and surveillance monitoring for protozoan pathogens and human enteric viruses (HEV) throughout the 1,972 square mile NYC watershed. DEP staff collected over 1,000 samples for protozoan analysis during 2006, with the exception of special projects. To provide some perspective, streams comprised the greatest number of samples with 35%, the next largest proportion was source water samples which comprised 24%, while upstate reservoir releases and effluents, wastewater treatment plants, and storm events made up the remaining 41% (Figure 4.1). Under routine operations, "source waters" are the waters in the two influent and effluent chambers of Kensico Reservoir (four chambers altogether) and the one effluent chamber of New Croton Reservoir. Filtration Avoidance compliance requires weekly sampling for *Cryptosporidium*, *Giardia* and human enteric viruses at all five of these sites. The effluent results are posted every week on DEP's website (DEP, 2006h), and tabulated in monthly reports as well as in two semiannual pathogen reports for 2006 (DEP, 2006c,d).

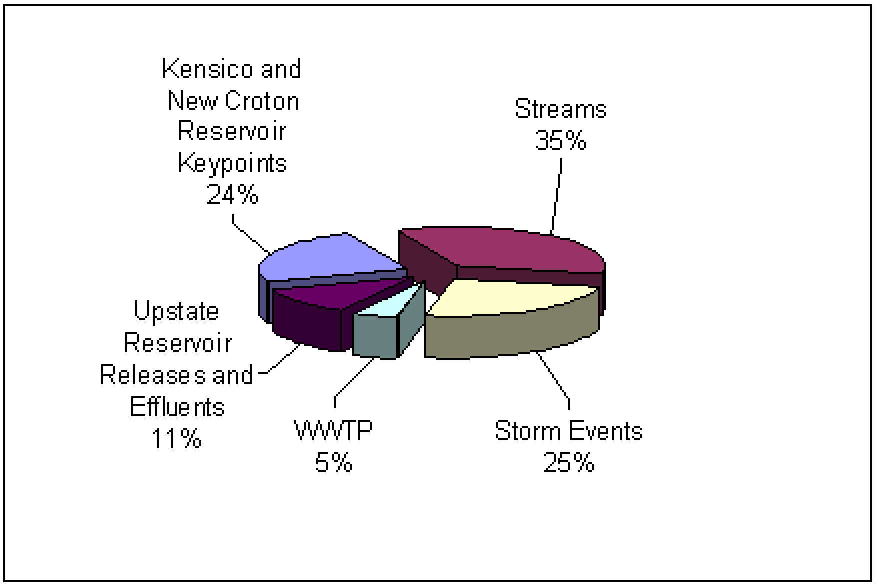


Figure 4.1 Breakdown of samples collected by DEP in 2006.

The occurrence of *Cryptosporidium* at the influents to Kensico Reservoir was very low (Table 4.1). The Catskill influent had only 6% positive samples and Delaware only 8%. This compares to their respective effluents at 13% each. The mean *Cryptosporidium* concentration at the Catskill influent to Kensico Reservoir was 0.06 oocysts 50 $L^{-1}$, and the Delaware influent was 0.08 oocysts 50 $L^{-1}$ .

Table 4.1: Summary of *Giardia, Cryptosporidium* and enteric virus compliance monitoring data at the five DEP keypoints for 2006.

| **Keypoint Location** | **Samples** | **Pathogen** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *Cryptosporidium* oocysts 50$L^{-1}$ | | | *Giardia* cysts 50$L^{-1}$ | | | Human Enteric Viruses mpn 100$L^{-1}$ | | |
| | Total Number | Positive Samples | Mean *** | Max | Positive Samples | Mean *** | Max | Positive Samples | Mean *** | Max |
| Catskill Influent Keypoint | 52 | 3 | 0.06 | 1.00 | 27 | 1.35 | 6.00 | 24 | 2.17 | 8.54 |
| Catskill Effluent Keypoint | 52 | 7 | 0.13 | 1.00 | 34 | 1.48 | 7.00 | 6 | 0.16 | 2.09 |
| Delaware Influent Keypoint** | 52 | 4 | 0.08 | 1.00 | 32 | 1.54 | 6.00 | 12 | 0.42 | 5.75 |
| Delaware Effluent Keypoint | 52 | 7 | 0.15 | 2.00 | 28 | 1.21 | 6.00 | 3 | 0.08 | 2.11 |
| New Croton Effluent Keypoint* | 52 | 7 | 0.13 | 1.00 | 28 | 1.06 | 6.00 | 10 | 0.82 | 8.62 |

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

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

*** Zero value is substituted for non-detect values when calculating mean scores.

The New Croton Reservoir effluent *Cryptosporidium* and *Giardia* occurrence were both very similar to the Delaware effluent of Kensico Reservoir for 2006. For *Cryptosporidium,* the occurrence at New Croton was 13%, the same as Delaware’s, while Croton’s effluent mean concentration of 0.13 oocysts 50 $L^{-1}$ was only slightly less than Delaware’s 0.15 oocysts 50 $L^{-1}$ . *Giardia* occurrence at both effluents was also the same, 54%, while effluent mean concentrations differed only slightly—1.21 cysts 50 $L^{-1}$ at New Croton compared to 1.06 cysts 50 $L^{-1}$ at Delaware.

Human enteric viruses (HEV) were found in low concentrations at all influent and effluent locations sampled (Table 4.1). The Catskill influent location had 24 of 52 positive samples collected and the Delaware influent 12 of 52. These results are higher than their respective effluents. The Catskill effluent location had 6 of 52 positive samples and the Delaware effluent 3 of 52. The Catskill influent average concentration was 2.17 MPN per $100L^{-1}$ and the Delaware influent average concentration was 0.42 MPN per $100L^{-1}$. These results are also higher than their respective effluent locations. The Catskill effluent location average concentration was 0.16 MPN per $100L^{-1}$ and the Delaware effluent was 0.08 MPN per $100L^{-1}$. The differences in HEV values between influents and effluents suggest there is a reduction of HEV occurring within the reservoir.

The weekly occurrence of *Cryptosporidium* during this period was relatively infrequent compared to *Giardia*, and *Cryptosporidium* was also present in lower concentrations by approximately an order of magnitude. The concentrations of *Giardia* varied throughout 2006. *Giardia* differences were more notable than *Cryptosporidium,* as higher numbers occurred in the winter and spring compared to the summer months (Figure 4.2). This pattern is consistent with what we have seen historically at many source water and watershed locations.

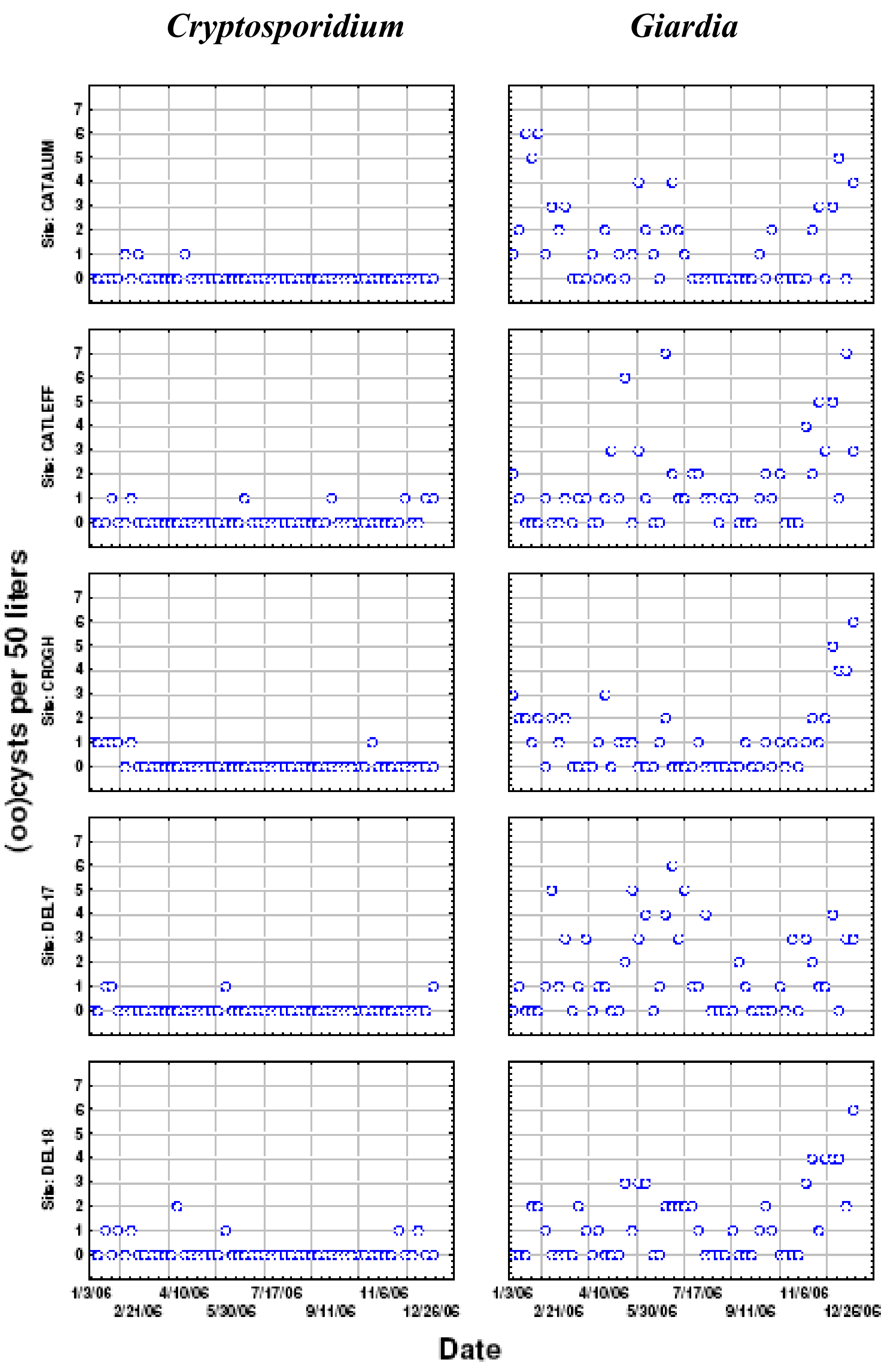


Figure 4.2 Routine weekly source water keypoint monitoring results for 2006.

## 4.2 How do NYC water protozoan concentrations compare with proposed regulatory levels for the country?

The Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) (USEPA, 2006) requires that utilities conduct source water monitoring for *Cryptosporidium* at least monthly for a two year period, though a more frequent sampling schedule may be used. The LT2 monitoring results are used to classify utilities into one of four categories (bins). This classification system determines if the utility is required to provide any additional treatment for *Cryptosporidium*. For perspective, results have been calculated here using data from the most recent two year period (January 1, 2005 to December 31, 2006) and were based on all routine and supplemental samples.

The average of *Cryptosporidium* oocysts at each of the three source waters remained below the LT2ESWTR threshold level of 0.01 oocysts per liter, achieving the 99% (2-log reduction) bin classification set under the LT2ESWTR. The current results, as shown in Figure 4.3, are: 0.0019 oocysts per liter at the Croton effluent, 0.0036 oocysts at the Catskill effluent and 0.0037 oocysts at the Delaware effluent.

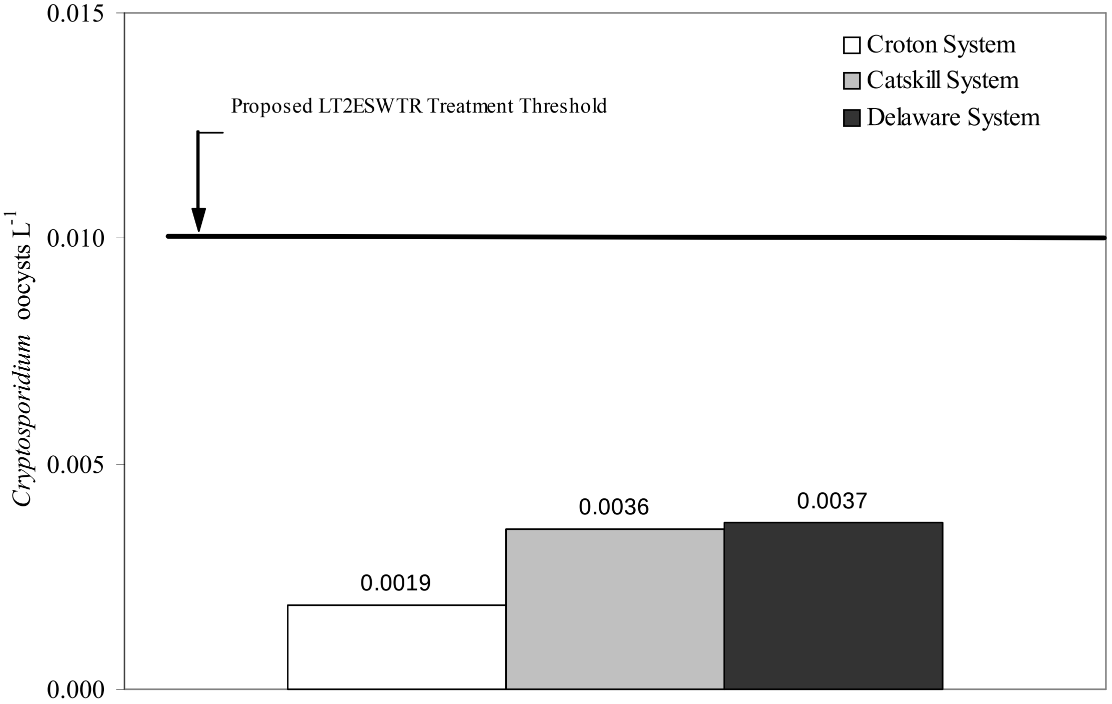


Figure 4.3 Comparison between the proposed LT2ESWTR treatment threshold and averages of all samples at DEP's three source waters—January 1, 2005 to December 31, 2006.

## 4.3 How do 2006 "source water" concentrations compare to historical data?

The "source water" sampling locations are the two influents and effluents representing the Catskill and Delaware systems in Kensico Reservoir, and the effluent of the New Croton Reservoir. These locations represent their respective watersheds and reservoirs, which are dependent on precipitation (rainfall and snow melt) and subsequent runoff to supply the reservoirs in each of the three watershed systems. Thus as water quality conditions change upstate, the "source water" keypoints can reflect those changes as well. As such, the protozoan concentrations often differ from year to year. A review of several years of source water data shows that 2006 *Giardia* concentrations were generally lower at the Kensico effluent locations (DEL18 and CATLEFF) and New Croton effluent (CROGH) compared to past data (Figure 4.4). The same is also true for the influent locations DEL17 and CATALUM. As in the past, the multiple year plots also show higher amounts of *Giardia* cysts during the late fall, winter, and early spring months when the temperatures are lower and periods of high runoff into the reservoir occur. Conversely there are fewer cysts during the summer months when the temperature is higher and runoff into the reservoir is low. The magnitude of this seasonal cycle varies from year to year (Figure 4.5); time series plots of 2001 through 2006 data show the annual variation in *Giardia* cysts. To better illustrate trends a locally weighted scatterplot smooth (LOWESS) line is plotted through the data points. The line is intended to show the natural trend of the center-of-mass of the data. Curves in the LOWESS line indicate short-term fluctuations within the distribution. For these analyses, lines were smoothed using 25% of the data on either side of the point being weighted.

*Cryptosporidium* data at keypoint locations were very low, which is comparable to historical data. *Cryptosporidium* detection of oocysts remains infrequent at all keypoints, and when detected, concentrations remain low. For this reason there is insufficient data to discuss any cyclic elevation of this organism.

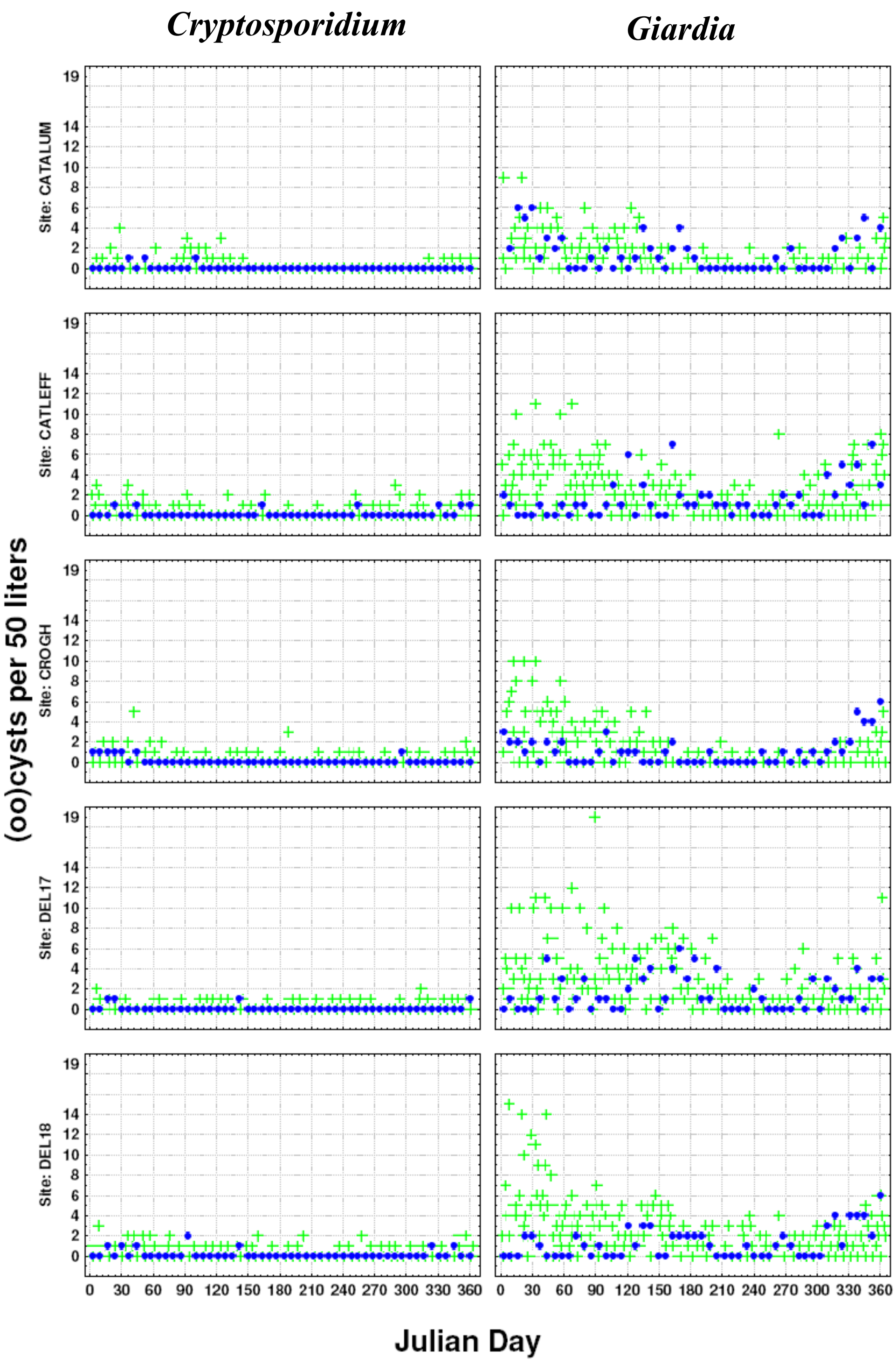


Figure 4.4 Source water keypoint weekly sampling results from October 2001 through December 2006. The blue dots are 2006 data; green crosses represent 2001–2005 data. Julian days are the days of a calendar year, numbered sequentially.

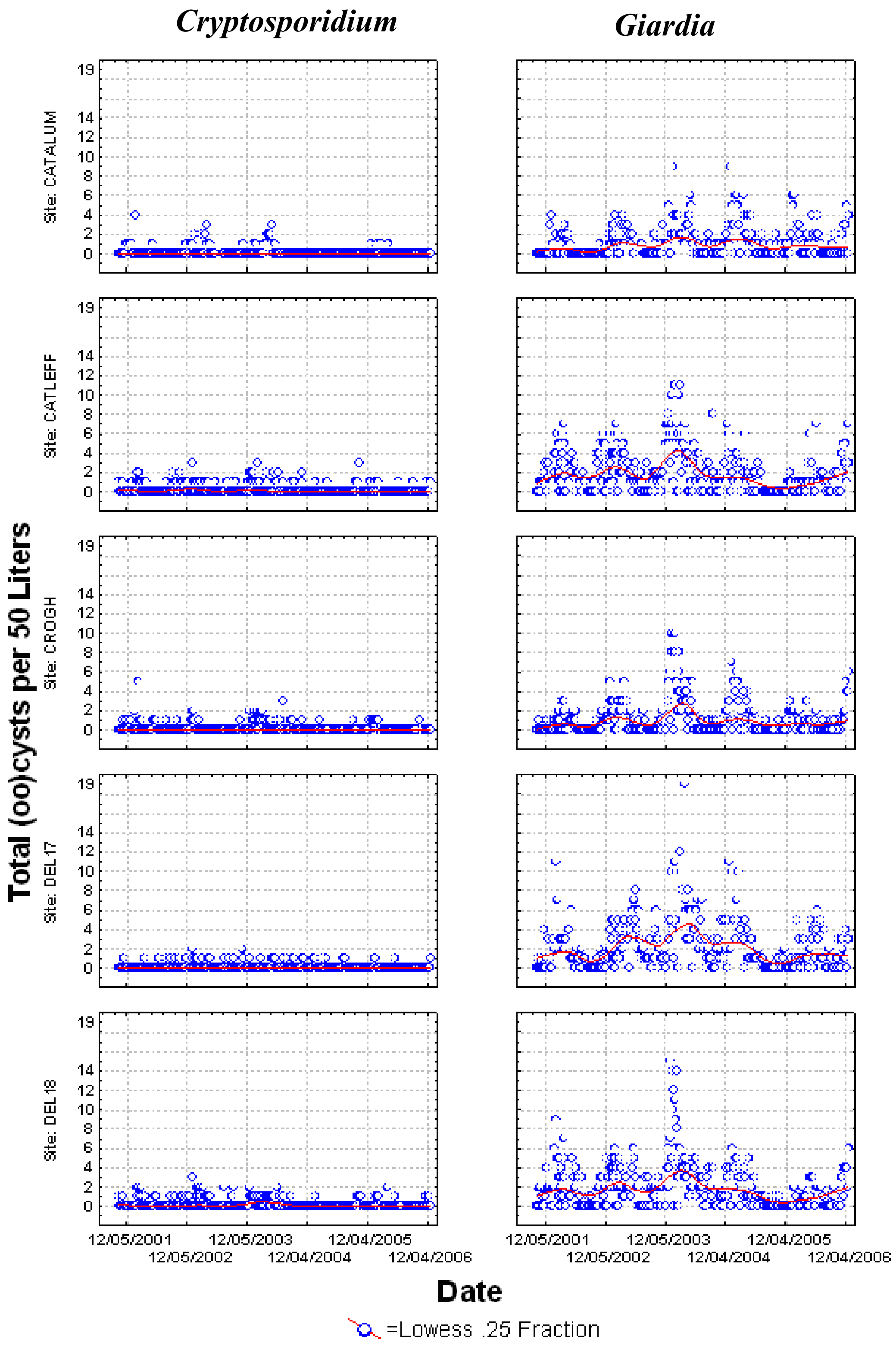


Figure 4.5 October 15, 2001 to December 31, 2006 weekly routine source water key-point results, LOWESS smooth added to visualize seasonal variation.

## 4.4 What concentrations of *Cryptosporidium* and *Giardia* were found in the various NYC watersheds in 2006?

Watershed sample sites for *Cryptosporidium* and *Giardia* are located in streams, the upstate reservoir releases and the upstate reservoir effluents. Figures 4.6 through 4.11 symbolically depict the *Cryptosporidium* and *Giardia* concentrations spatially for each of these systems and watersheds.

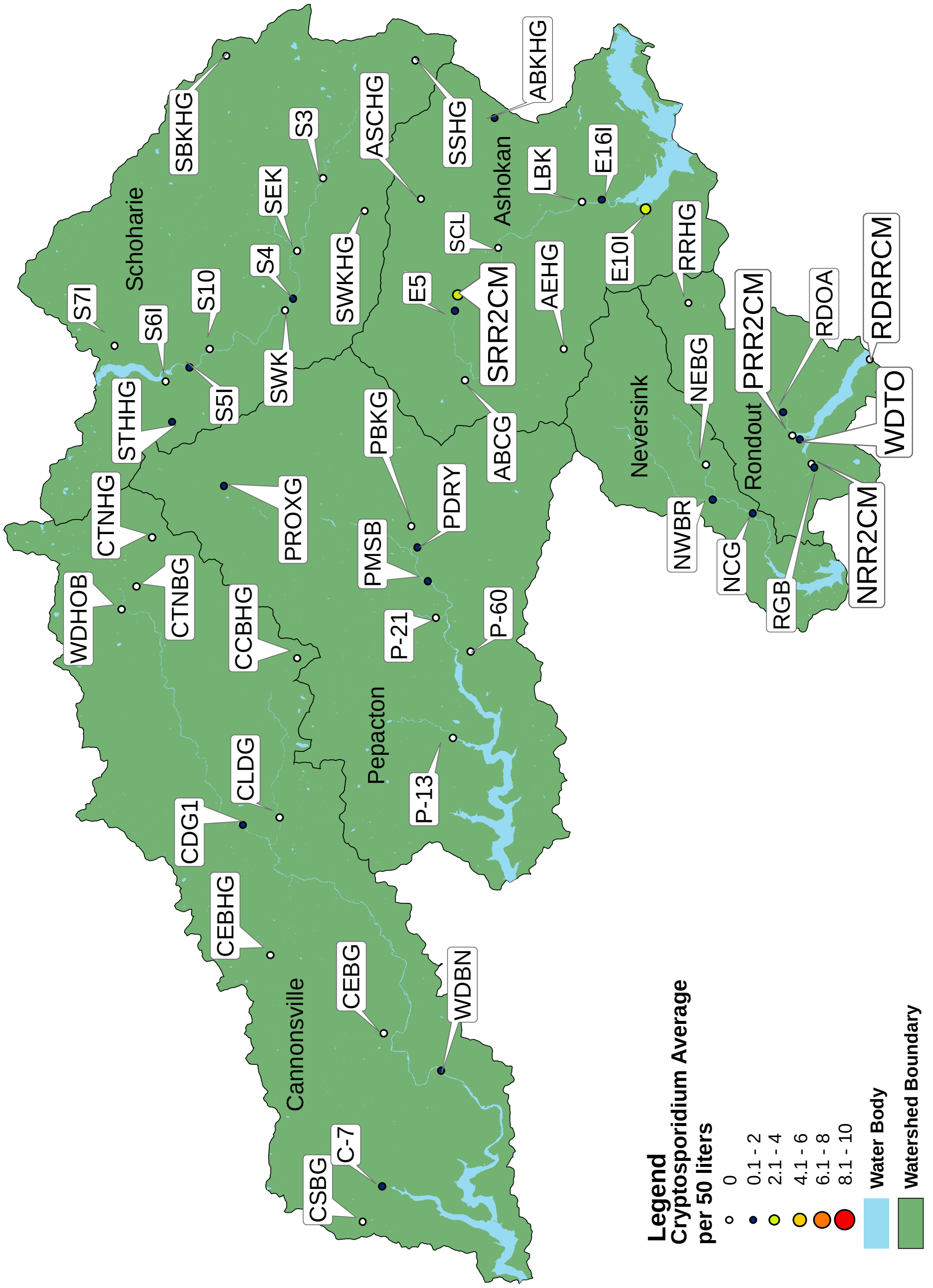


Figure 4.6 2006 Total *Cryptosporidium* average concentrations for the Delaware and Catskill System sampling locations.

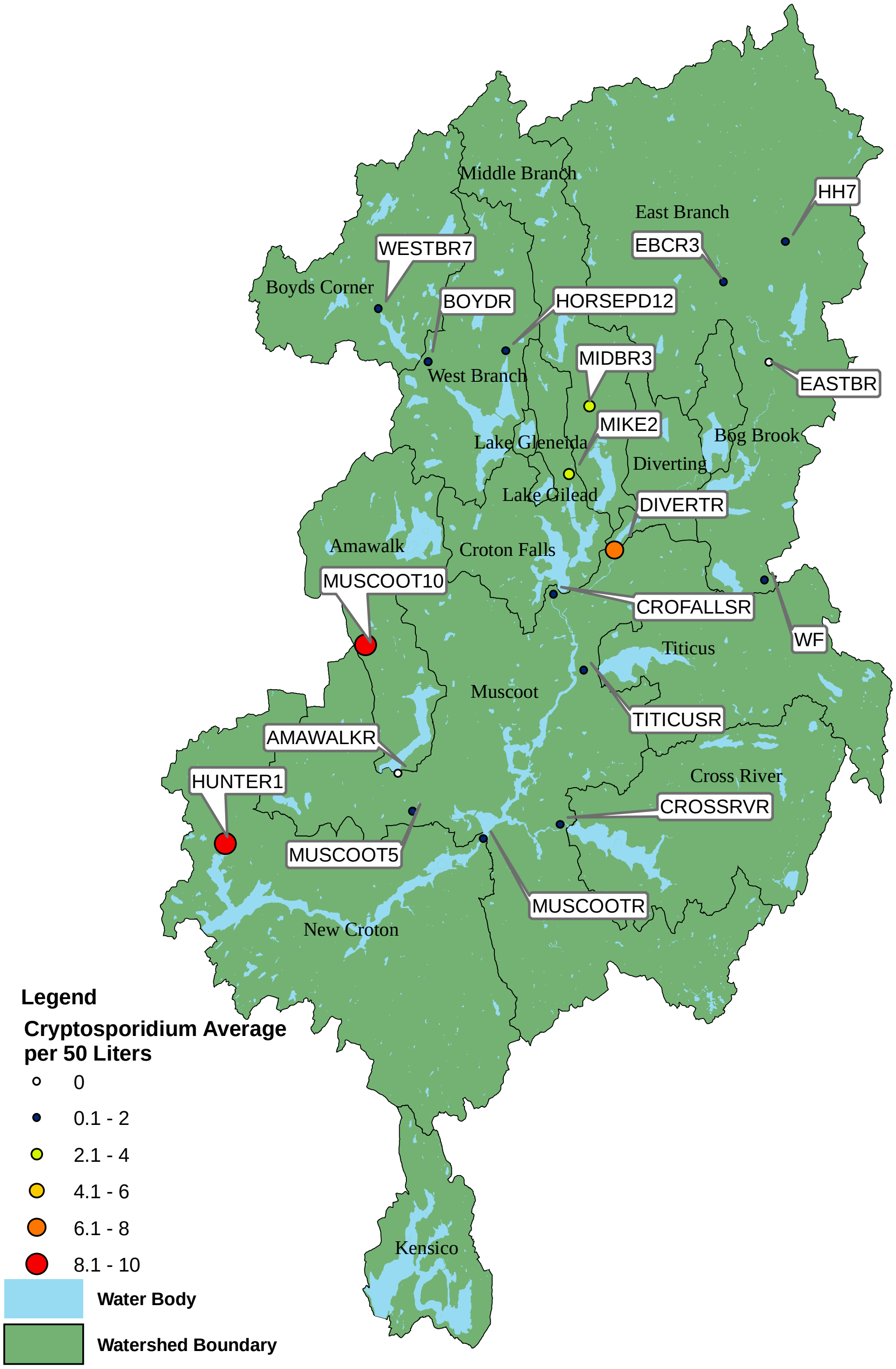


Figure 4.7 2006 Total *Cryptosporidium* average concentrations for the Kensico watershed sampling locations.

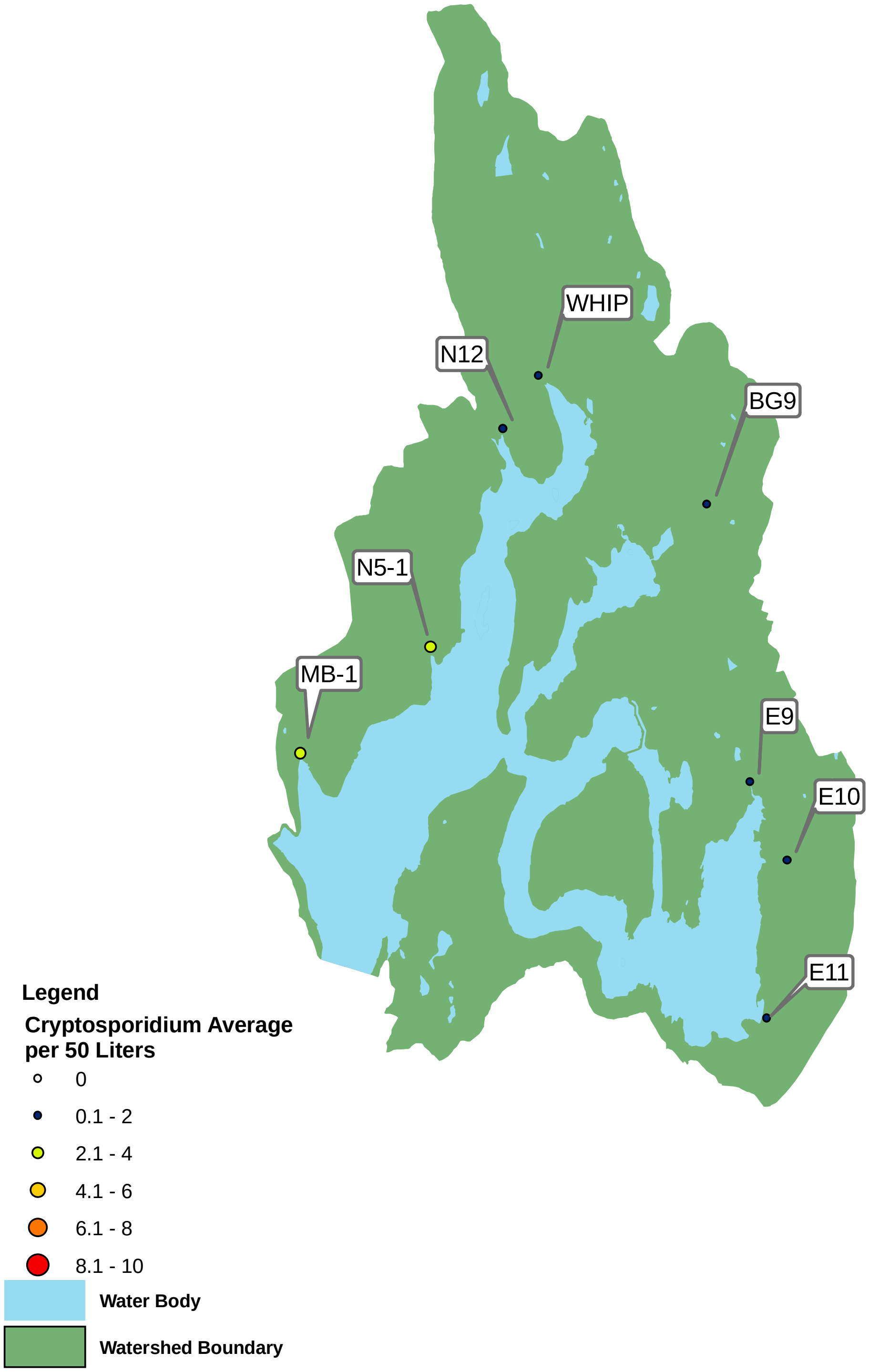


Figure 4.8 2006 total *Cryptosporidium* average concentrations for the Kensico watershed sampling locations.

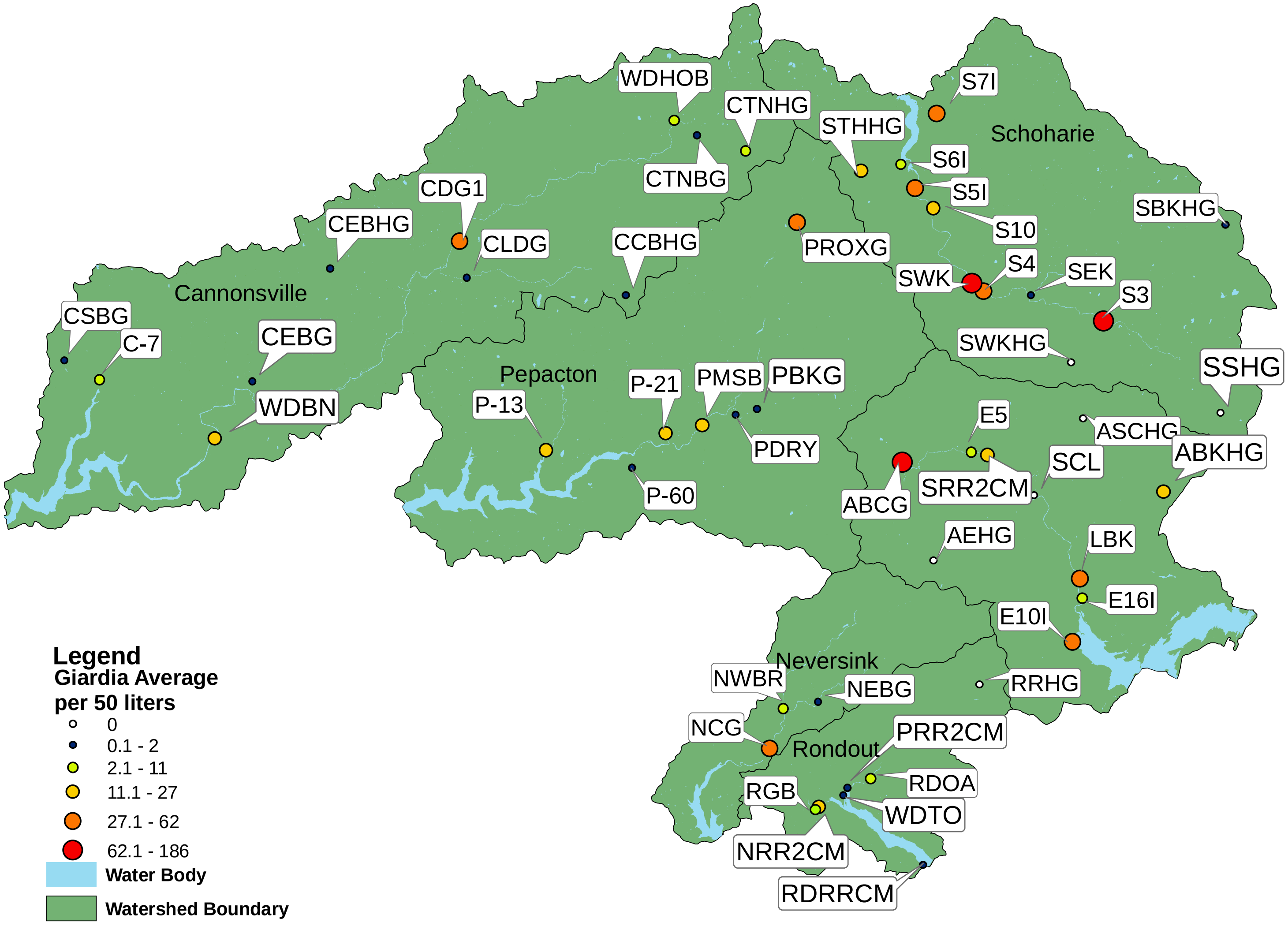


Figure 4.9 2006 total *Giardia* average concentrations for the Delaware and Catskill sampling locations.

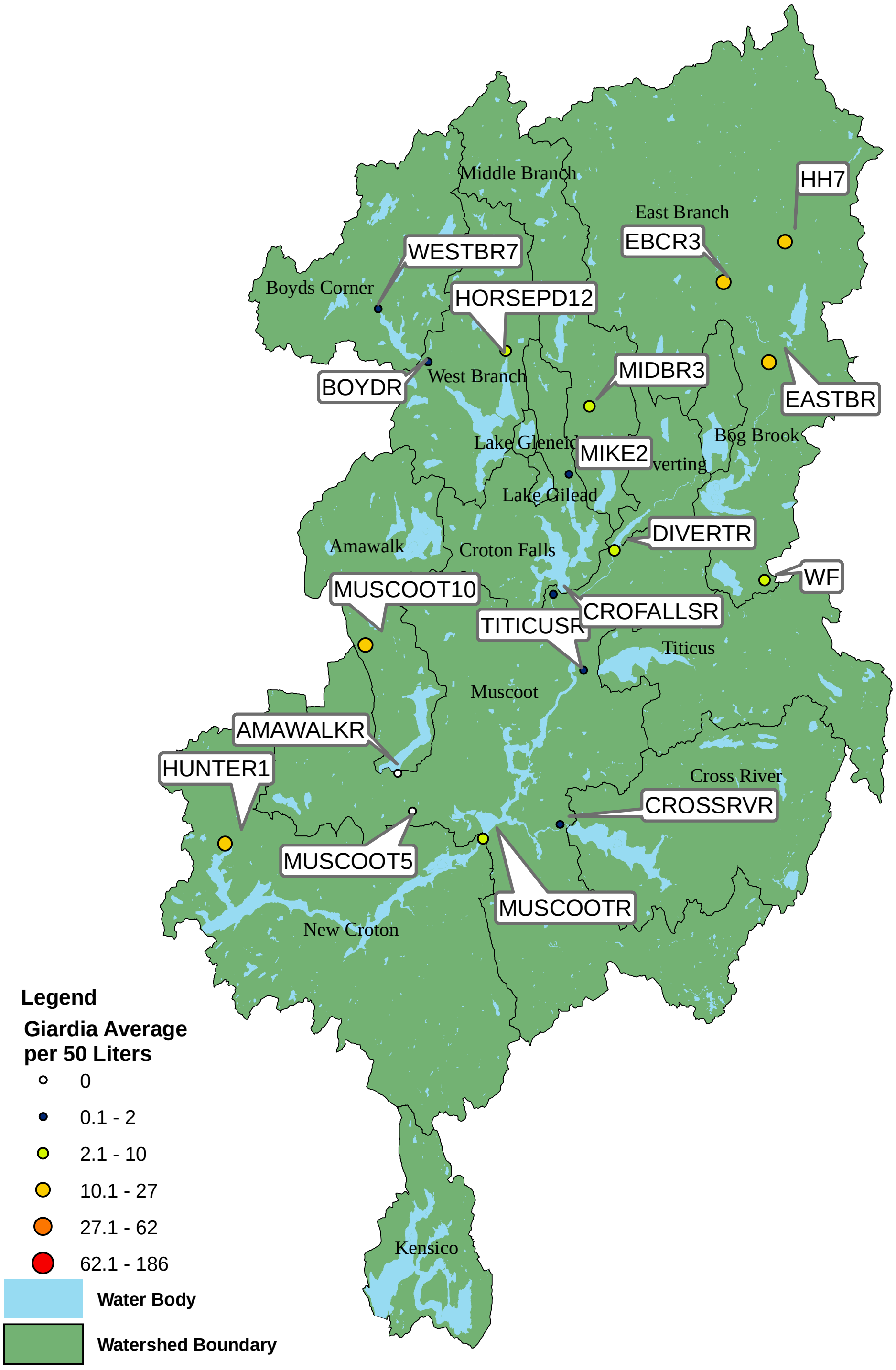


Figure 4.10 2006 total *Giardia* average concentrations for the New Croton sampling locations.

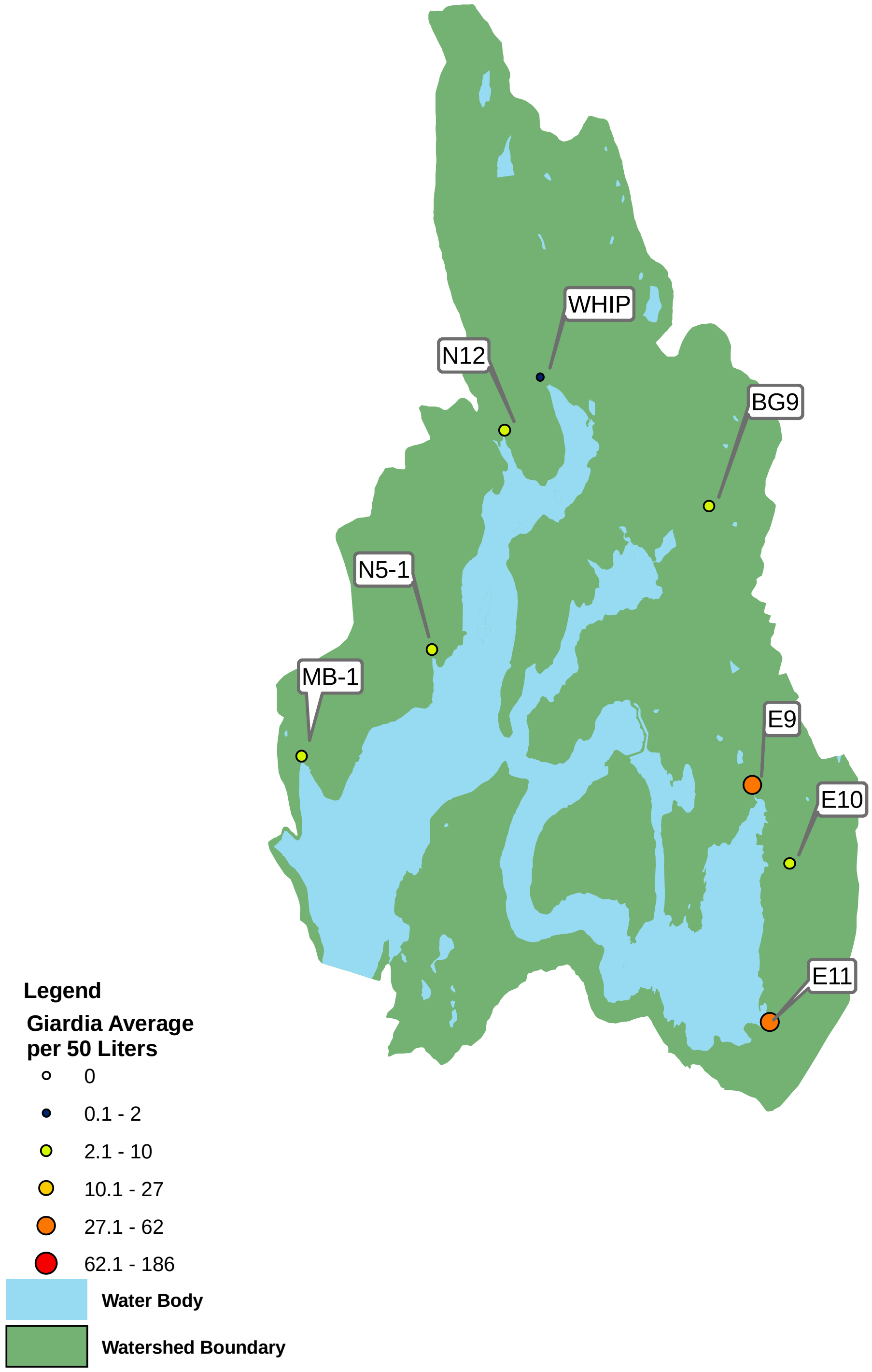


Figure 4.11 2006 total *Giardia* average concentrations for the Kensico watershed sampling locations.

The 2006 results show that a majority of sample locations were negative for *Cryptosporidium.*

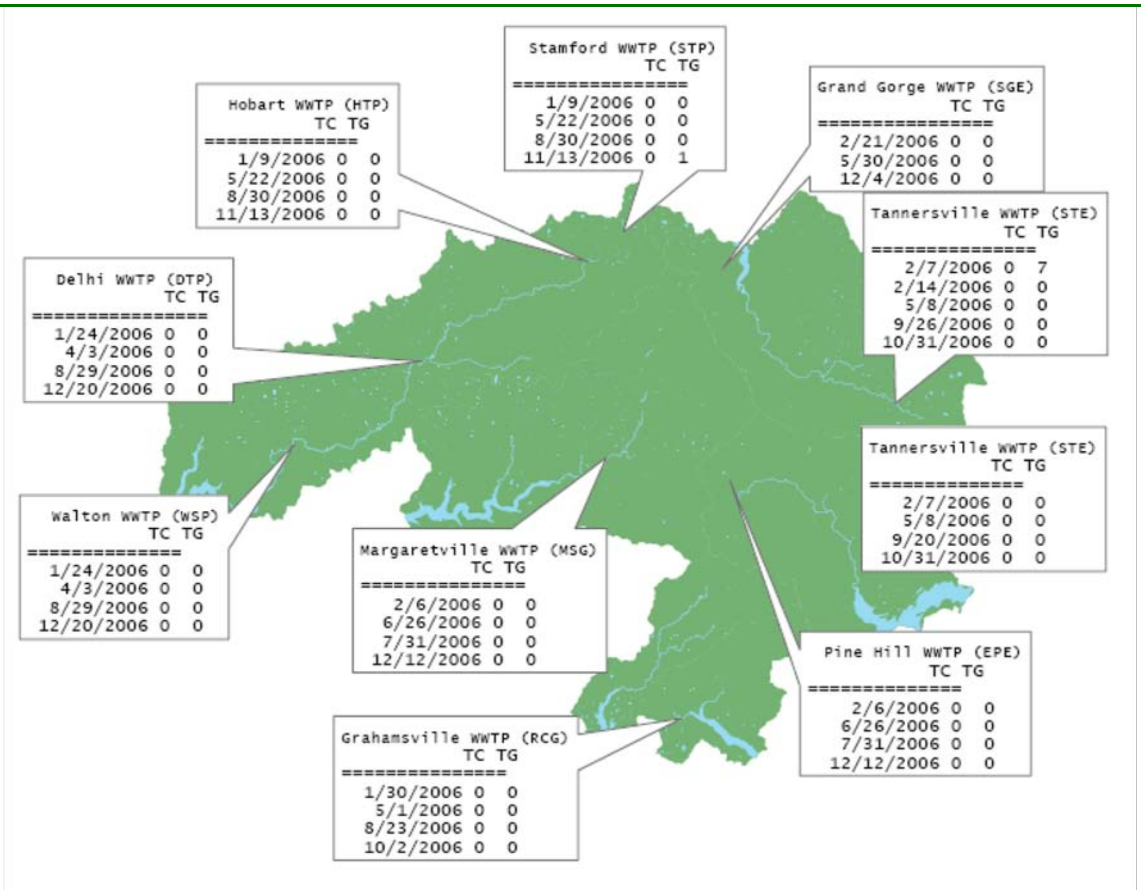
In the Delaware and Catskill Systems, 29 of 45 locations were negative, and in New Croton 2 of 18 locations were negative for *Cryptosporidium*. At the 16 Catskill and Delaware System locations where *Cryptosporidium* was detected, average concentrations were low. Averages ranged from 0.1 to 4 oocysts $50L^{-1}$ with most results less than 1 oocyst $50L^{-1}$. The New Croton System average concentrations were somewhat higher than the Catskill and Delaware locations. Of the 16 sample sites that were positive for *Cryptosporidium,* values ranged from 0.1 to 10 oocysts $50L^{-1}$. Eleven of these sites averaged 2 oocysts $50L^{-1}$or less. Kensico watershed average *Cryptosporidium* results ranged from 0.3 to 3.6 oocysts $50L^{-1}$, and 5 sites had averages of 1 oocyst $50L^{-1}$ or less.

As has occurred in the past, *Giardia* averages for 2006 were significantly higher than *Cryptosporidium*. Nearly all sample locations were positive for *Giardia* and at higher concentrations. Average concentrations of Delaware and Catskill System samples ranged from 0 to 186 cysts $50L^{-1}$, though most were less than 62 cysts $50L^{-1}$. The New Croton System average concentrations of *Giardia* ranged from 0 to 23 cysts $50L^{-1}$, and most were less than 11 cysts $50L^{-1}$. Kensico watershed average concentrations ranged from 0 to 58 cysts $50L^{-1}$, with most less than 9 cysts $50L^{-1}$**.**

*Cryptosporidium* and *Giardia* occurrence and concentration show variations among basins, which are evident in nearly all of the figures. For example, the Schoharie basin exhibited higher *Giardia* concentrations throughout the watershed sampling locations in 2006 compared to the remainder of the WOH basins (Figure 4.9) and the East Branch basin had more sites with higher concentrations of *Giardia* than the remainder of the EOH basins (Figure 4.10). These differences occur for many reasons, such as dissimilar animal populations or densities, watershed physiographic characteristics, landuse, and climate, to name a few.

## 4.5 What levels of protozoa and human enteric viruses were found in waste water treatment plant effluents, and do they act as sources of protozoa and human enteric viruses?

DEP began monitoring pathogens at 10 waste water treatment plants (WWTP) in July 2002. Sampling of each plant's final effluent is conducted four times a year. The WWTPs monitored are: Hunter Highlands, Delhi, Pine Hill, Hobart, Margaretville, Grahamsville, Grand Gorge, Tannersville, Stamford and Walton (Figure 4.12). All plants were monitored four times in 2006 with the exception of Grand Gorge, which was sampled only three times due to a scheduling conflict, and Hunter Highlands, which was sampled one additional time. Of the 40 WWTP samples collected, none were positive for *Cryptosporidium* and two were positive for *Giardia*. One positive *Giardia* sample was collected on 02/07/06 at the Hunter Highlands waste water treatment plant with a result of 7 cysts 50L$^{-1}$. As a follow up, an additional sample was collected at this site the following week, and there was no detection of *Giardia* cysts. The other sample positive for *Giardia* occurred at the Stamford WWTP on 11/13/06, which contained 1 cyst 50L$^{-1}$. Subsequent sampling at this location yielded no further detection of *Giardia*. Regarding viruses, only one of the 40 samples tested positive for HEV. This sample was collected on 8/30/06 at the Stamford WWTP and contained 1.02 MPN 100L$^{-1}$. These results indicate that these waste water treatment facilities provide an effective barrier to pathogens and viruses.



Stamford WWTP (STP)

| | TC | TG |
|---|---|---|
| 1/9/2006 | 0 | 0 |
| 5/22/2006 | 0 | 0 |
| 8/30/2006 | 0 | 0 |
| 11/13/2006 | 0 | 1 |

Hobart WWTP (HTP)

| | TC | TG |
|---|---|---|
| 1/9/2006 | 0 | 0 |
| 5/22/2006 | 0 | 0 |
| 8/30/2006 | 0 | 0 |
| 11/13/2006 | 0 | 0 |

Grand Gorge WWTP (SGE)

| | TC | TG |
|---|---|---|
| 2/21/2006 | 0 | 0 |
| 5/30/2006 | 0 | 0 |
| 12/4/2006 | 0 | 0 |

Tannersville WWTP (STE)

| | TC | TG |
|---|---|---|
| 2/7/2006 | 0 | 7 |
| 2/14/2006 | 0 | 0 |
| 5/8/2006 | 0 | 0 |
| 9/26/2006 | 0 | 0 |
| 10/31/2006 | 0 | 0 |

Delhi WWTP (DTP)

| | TC | TG |
|---|---|---|
| 1/24/2006 | 0 | 0 |
| 4/3/2006 | 0 | 0 |
| 8/29/2006 | 0 | 0 |
| 12/20/2006 | 0 | 0 |

Tannersville WWTP (STE)

| | TC | TG |
|---|---|---|
| 2/7/2006 | 0 | 0 |
| 5/8/2006 | 0 | 0 |
| 9/20/2006 | 0 | 0 |
| 10/31/2006 | 0 | 0 |

Walton WWTP (WSP)

| | TC | TG |
|---|---|---|
| 1/24/2006 | 0 | 0 |
| 4/3/2006 | 0 | 0 |
| 8/29/2006 | 0 | 0 |
| 12/20/2006 | 0 | 0 |

Margaretville WWTP (MSG)

| | TC | TG |
|---|---|---|
| 2/6/2006 | 0 | 0 |
| 6/26/2006 | 0 | 0 |
| 7/31/2006 | 0 | 0 |
| 12/12/2006 | 0 | 0 |

Pine Hill WWTP (EPE)

| | TC | TG |
|---|---|---|
| 2/6/2006 | 0 | 0 |
| 6/26/2006 | 0 | 0 |
| 7/31/2006 | 0 | 0 |
| 12/12/2006 | 0 | 0 |

Grahamsville WWTP (RCG)

| | TC | TG |
|---|---|---|
| 1/30/2006 | 0 | 0 |
| 5/1/2006 | 0 | 0 |
| 8/23/2006 | 0 | 0 |
| 10/2/2006 | 0 | 0 |

Figure 4.12 2006 *Cryptosporidium* and *Giardia* sample results for Catskill and Delaware System waste water treatment plants.

## 4.6 What is the distribution of *Giardia* and *Cryptosporidium* in reservoirs East and West of the Hudson River, and what watershed processes can affect sources and transport of these protozoa?

The data from watershed streams and upstate keypoints allow for a broad evaluation of the spatial variations in *Cryptosporidium* and *Giardia* (oo)cyst occurrence within the NYC watersheds. It has also helped to identify locations of unusually high or low concentrations of these protozoa (wetlands, sewer mains, farms, etc.). Variations in land uses and animal populations will affect the occurrence of (oo)cysts within the basins of the watersheds. On a basin scale, *Cryptosporidium* concentrations vary little, and averages range from <1 to 1 WOH (n =195) and <1 to 2.5 EOH (n = 48). This is a result of not detecting oocysts often, and when detected they are found at low concentrations. Conversely, *Giardia* concentrations vary greatly, with averages ranging from 5 to 66 WOH (n = 195) and 4 to 30 EOH (n = 48). Clearly, as has been seen historically, *Giardia* are found at much higher concentrations than *Cryptosporidium* within each basin and within watershed systems. Figures 4.13 and 4.14 illustrate the differences of (oo)cyst occurrence within WOH and EOH basins.

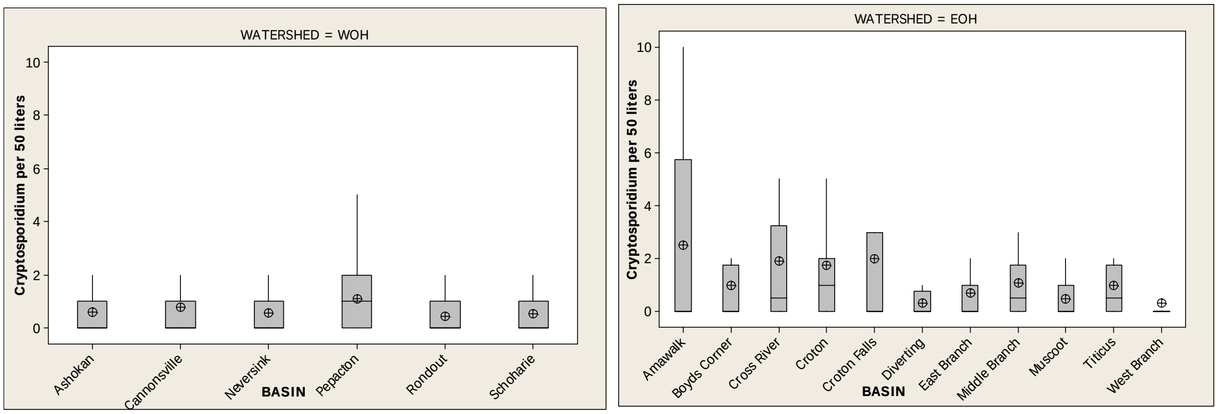


Figure 4.13 Summary of *Cryptosporidium* distribution among WOH and EOH basins
(⌖= mean, -- = median).

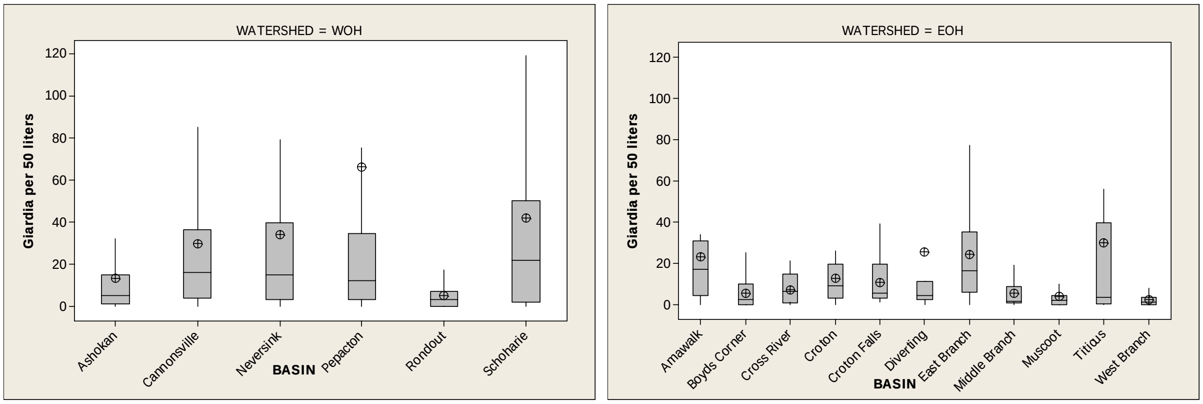


Figure 4.14 2006 Summary of *Giardia* distribution among WOH and EOH Basins
(⌖= mean, -- = median).

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In addition to these factors, there are reservoir processes that contribute to varying (oo)cyst occurrence. A reduction of (oo)cysts occurs from stream influents to their potential exit from the reservoir at aqueduct effluent locations (Figure 4.15). This may be due, in part, to the potential process of (oo)cyst attachment to larger or denser particles and subsequent sedimentation out of the water column, or to the formation of larger aggregates of (oo)cysts, which also causes settling. Residence time within reservoirs, often longer in the larger reservoirs, has also been shown to be a factor in the decline in occurrence of (oo)cysts leaving the reservoir (Pratt, 2006). This decline is probably due simply to increased time for settling, although greater residence time also allows for increased exposure to ultraviolet light and predation by other organisms. Temperature is also likely to be a factor in the fluctuation of (oo)cyst concentrations in surface waters, which is also associated with seasonal variations. Cyst concentrations tend to be lower in the warmer months of the year and higher in the colder months. Annual *Giardia* distribution shows a steady decrease from May through October when counts increase into the winter months. This observation can be seen at the keypoint sampling locations, as well as throughout the watershed.

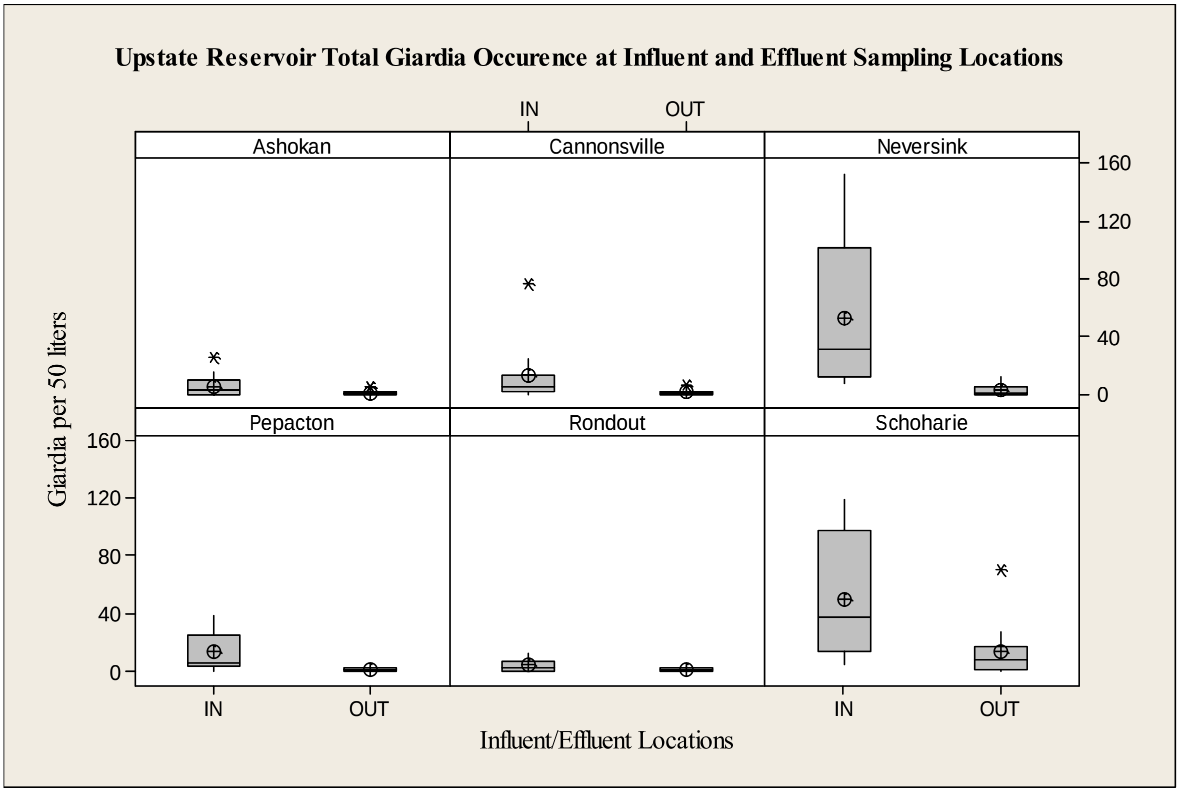


Figure 4.15 Comparison of influent and effluent total *Giardia* concentrations
(⌖= mean, -- = median).

## 4.7 Do protozoans adhere to particles in the water and does this tend to improve their sedimentation and removal from the drinking water?

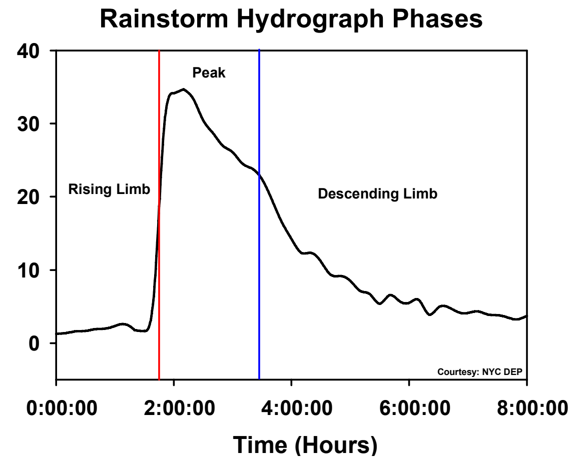


Figure 4.16 Depiction of the typical hydrologic phases of a storm event.

DEP's goal for the SDWA Grant 5 Project 5.5 is to characterize the pathogen-particle associations in the water column to assess the partitioning behavior of protozoa with suspended particulate matter. This is being studied on multiple streams within the watershed during storm events to clarify if the protozoa entering the reservoir associate with denser suspended particles and settle to the reservoir bottom, or with less dense particles (or even no particles) allowing for the increased potential to float across the reservoir and into the aqueducts which supply water to New York City residents. Further, DEP aims to analyze storms by hydrologic phase (Figure 4.16) to assess the possible differences in the parameters during the different times of the storm.

Assessing the partitioning behavior under several precipitation events may allow for the development of predictive relationships describing the fraction of attached organisms as a function of pathogen concentration, particle concentration, turbidity, temperature, and/or pH, among other parameters. The information on the loading profile and attachment behavior will also be critical to the development of models which may be used to evaluate strategies for managing source water quality.

This project involves the evaluation of the partitioning behavior of *Giardia* and *Cryptosporidium* (where present) over the course of the hydrologic phases of storm events, with attention to other indicator organisms (e.g., *E. coli*, *Cl. perfringens* spores, somatic coliphages and F+ coliphages), on five perennial tributaries to Kensico Reservoir (MB-1, N5-1, E9, E11, and WHIP). These tributaries were selected based on spatial location and stream type (i.e., preceded by a BMP) (Figure 17). In addition, DEP is assessing historical data for the study streams and the aqueducts entering and leaving Kensico Reservoir, which will be used as reference data in the explanation of the study results. Microbial particle attachment in the Kensico tributaries can have a direct influence on the impact those microbes may have on the receiving water. A comprehensive database documenting the behavior of targeted microbes entering Kensico Reservoir would be greatly beneficial to DEP in order to best estimate when, or if, microbes entering the reservoir truly have the potential to exit the reservoir and enter the effluent aqueducts.

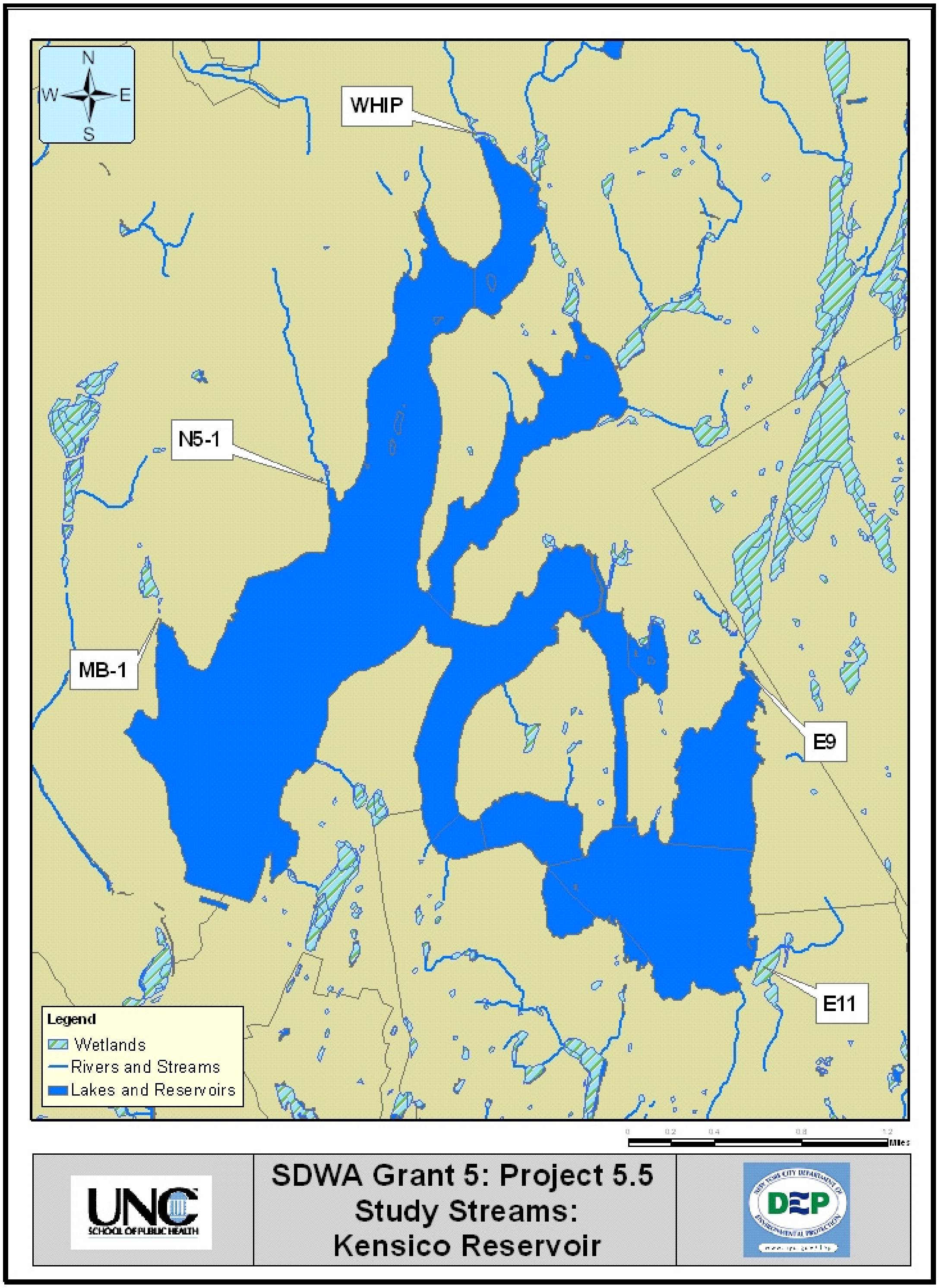


Figure 4.17 SDWA 5 study streams.

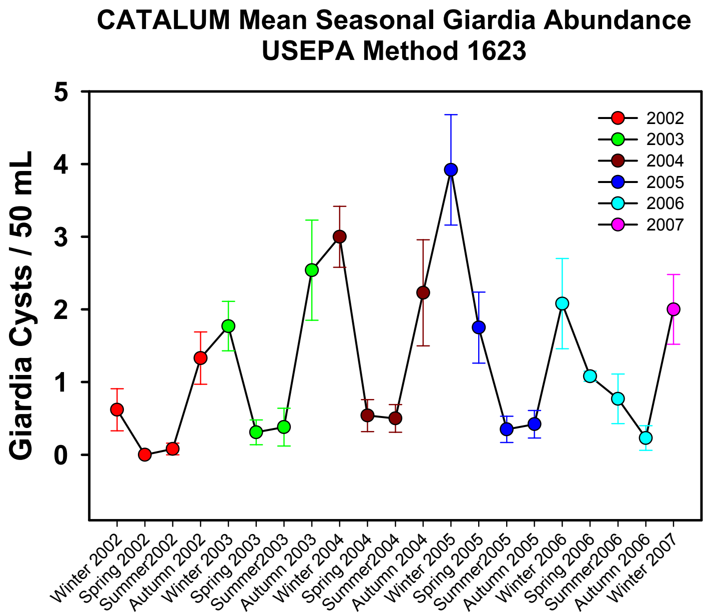


Figure 4.18 Seasonal pattern of the historical *Giardia* data for the Catskill influent keypoint at Kensico.

In addition to the microbial partitioning, the contract laboratory (University of North Carolina at Chapel Hill) is performing test case alum coagulation experiments with a few NYC aqueduct water samples to examine the suspended particle settling at different alum concentrations. DEP adds alum during high turbidity events to reduce the turbidity in the water supply. These few experiments will provide preliminary data to determine if additional work should be done in the area of alum addition as it relates to particle settling and effective alum dosing. Lastly, DEP is continuing to perform genotyping on *Cryptosporidium* from wildlife in the NYC watershed, to improve the library begun with the SDWA Grant 4 dataset. DEP has completed the historical database analysis for the study streams and the four keypoint facilities associated with the aqueducts entering and leaving the reservoir as well as the first phase of the study which included four storm events and three background samples. The historical data revealed a clear seasonal pattern in pathogen abundance, with higher pathogen numbers in the colder months (Figure 4.18).

A review of the historical stream data revealed generally low protozoan concentrations at background conditions and significantly higher protozoan concentrations during storm events. Similarly, during this study, the background samples from the first phase had low protozoan concentrations, while storm samples had significantly higher concentrations.

The particle partitioning data from the first phase of the study revealed possible differences in the degree of particle attachment, both for the different species analyzed and for the different environmental conditions (storm or background conditions). *Cryptosporidium* and *Giardia* seem to have a greater degree of association during storm conditions (Figure 4.19).

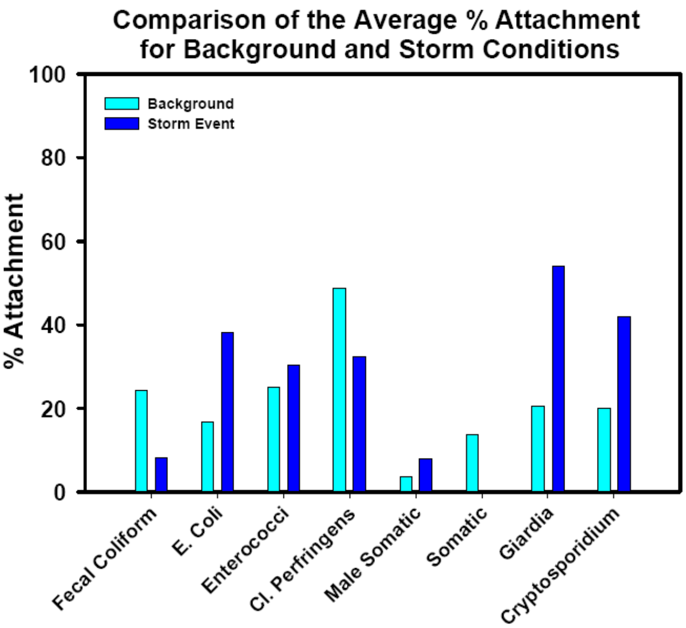
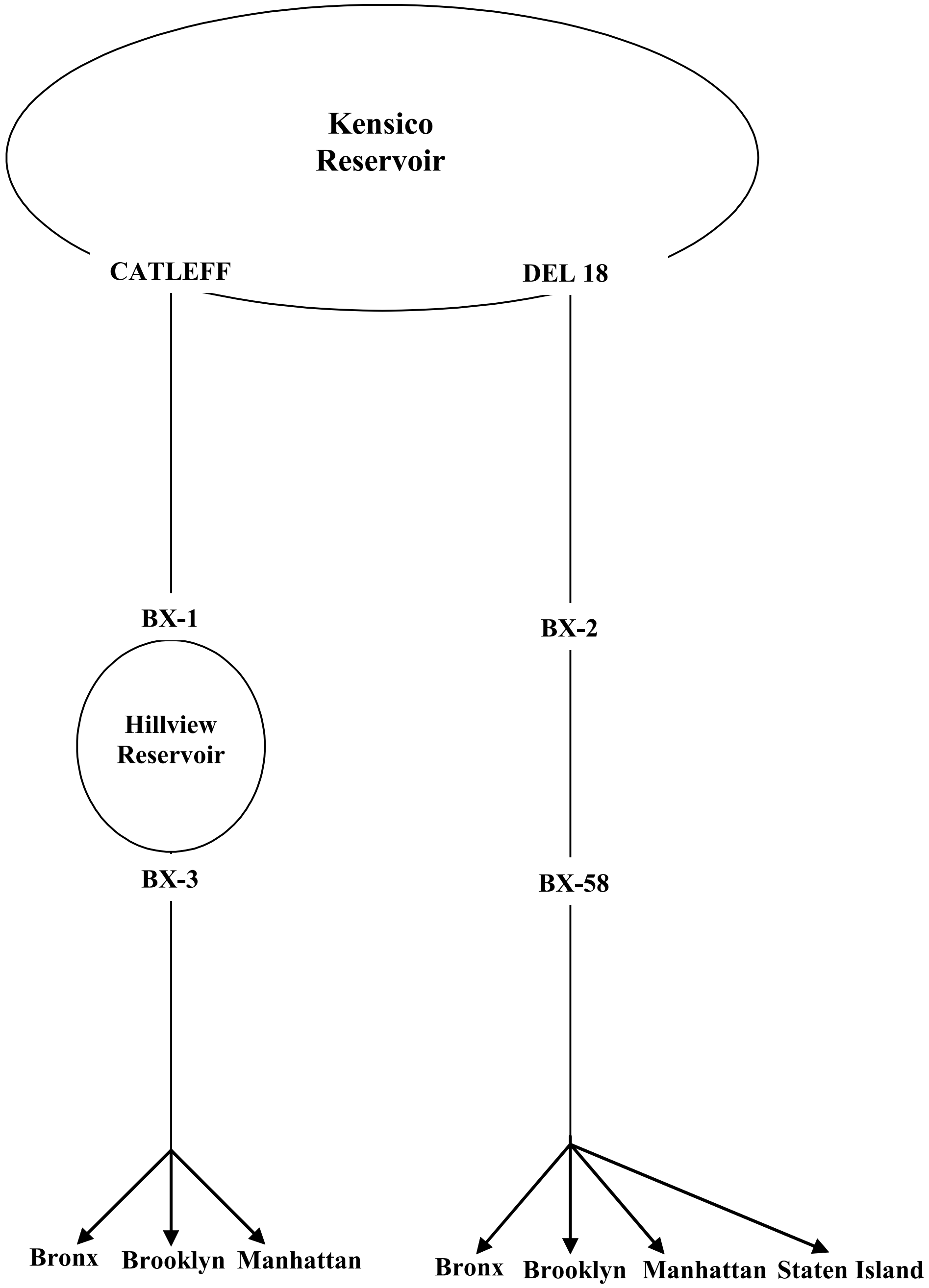


Figure 4.19 Average percent attachment for the different species analyzed during background and storm conditions.

DEP has completed half of the second phase of this project and the data is currently under review. The streams selected for the second phase of the study, which involved sampling the different phases of a storm (Figure 4.16), included E9, N5-1, and WHIP. These streams were selected based on pathogen concentration and relative stream flow. A final report will be available in September 2007, and the results will also be included in the 2007 Watershed Water Quality Annual Report.

## 4.8 What has DEP learned from its Hillview Reservoir protozoan monitoring project?

The objectives of this study are to monitor the uptakes and downtakes of Hillview Reservoir keypoint facilities for *Giardia* and *Cryptosporidium* (oo)cyst concentrations over the course of a year to determine if a difference exists between the concentrations of these protozoa at the uptake and downtake flowing through Hillview Reservoir from Kensico Reservoir via the Catskill Aqueduct. Specifically, the study intends to address whether Hillview Reservoir, which is open to environmental elements, acts as a sink for *Giardia* and *Cryptosporidium* (oo)cysts. As a control, we also compared concentrations of the uptake and downtake keypoint facilities along the Delaware Aqueduct, which runs parallel to the Catskill Aqueduct from Kensico Reservoir but bypasses Hillview Reservoir. Lastly, we used the results of *Giardia* and *Cryptosporidium* (oo)cyst monitoring at the upstream keypoint facilities (CATLEFF and DEL 18) during the same sampling period, which are indicative of Kensico Reservoir inputs to Hillview Reservoir via the Catskill and Delaware Aqueducts (Figure 4.20).



Courtesy: NYC DEP

Figure 4.20  The Hillview Reservoir system showing inputs, outputs, and control sites.

Hillview keypoints have been sampled 38 times and no significant change from inflow to outflow in *Cryptosporidium* oocysts was observed as a result of being open to the environment at Hillview Reservoir (Figure 4.21a and 4.21b). For *Giardia*, a significant decrease in cyst concentration was observed when comparing the influent to the effluent of the reservoir (Figure 4.21a). Similar to the Catskill System, no significant change was observed in the Delaware aqueduct (Figure 4.21b). Hence, Hillview Reservoir appears no different than the control. Furthermore, a comparison with the Kensico keypoint sampling revealed a significant decrease for both *Cryptosporidium* and *Giardia* (oo)cysts. Antecedent conditions (i.e., storm events) were also examined as possible factors affecting *Cryptosporidium* and *Giardia* (oo)cyst numbers in an open reservoir. Three large storm events (> 3 inches) occurred a few days before sampling at Hillview (March 1-2, April 15-16, and June 3-4 of 2007), which did not result in significant increases in *Cryptosporidium* or *Giardia*. In summary, data thus far suggest that Hillview Reservoir does not have significant sources of *Cryptosporidium* or *Giardia*. As a result, these preliminary data indicate that covering Hillview Reservoir would not necessarily improve the protozoan quality of the water. A full analysis will be presented in the final report and will be summarized in the 2007 Watershed Water Quality Annual Report.

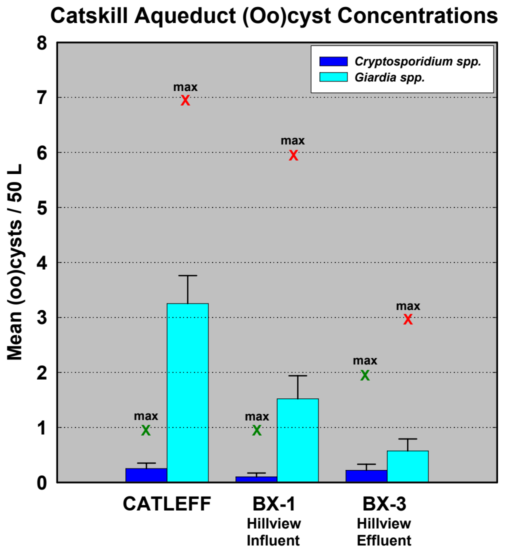


Figure 4.21a Basic statistics for sample sites along the Catskill Aqueduct. **(The Catskill aqueduct flows through the Hillview Reservoir)**

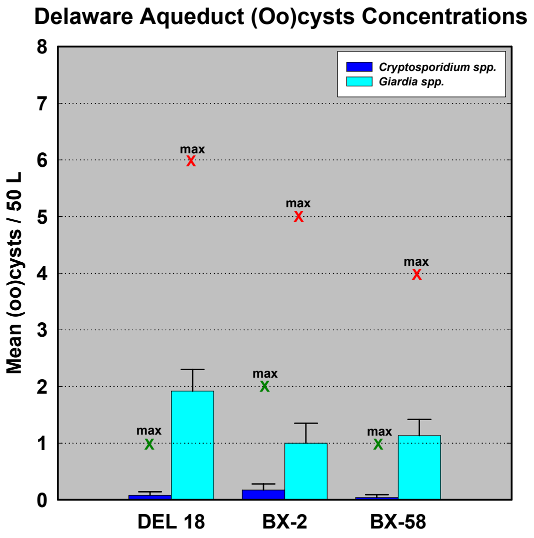


Figure 4.21b Basic statistics for sample sites along the Delaware Aqueduct.

## 4.9 How does protozoan occurrence and transport vary during dry and wet weather conditions?

As part of a Water Resources Development Act (WRDA) grant awarded to the DEP, storm event pathogen monitoring was performed at six West-of-Hudson (WOH) and 15 East-of-Hudson (EOH) sites (Figures 4.22 and 4.23). The study was conducted in two phases. The first phase, conducted over a one year period, involved the development and monitoring of two EOH sites to establish the methodology for the optimal sampling regimen (sampling duration and interval) to best assess protozoan occurrence, concentration and loading during storm events.

Year 1 of the second phase of the project (2006) involved expanding the number of sample stations to sample all the perennial streams according to the sample regimens. This involved the development and deployment of storm sampling equipment at 13 EOH stream sites (distributed along nine tributaries: E9, E10, E11, WHIP, BG-9, N-12, N-1, MB-1, N5-1), two keypoints entering Kensico Reservoir, and 3 WOH sites along the Esopus Creek entering Ashokan Reservoir. Pathogen occurrence, concentration and loading during storm events was determined. An added objective was to determine the efficacy of BMPs at reducing the protozoan load into the reservoir. As part of evaluating BMP efficacy at reducing protozoan loading, three EOH streams had pre-existing, constructed BMPs and two of them were sampled above and below the BMP.

The second year of the second phase of the project (2007) involves storm monitoring of the EOH district streams with higher resolution sampling in order to determine the loading from streams during the different phases of a storm. This will allow DEP to determine if a particular phase of a storm is more important in terms of protozoan contribution to the water supply, and to continue to evaluate BMP removal efficacy. WOH monitoring along the Esopus Creek concluded in 2006 and monitoring during the second year shifted to three locations along the Schoharie Creek (Figure 4.23).

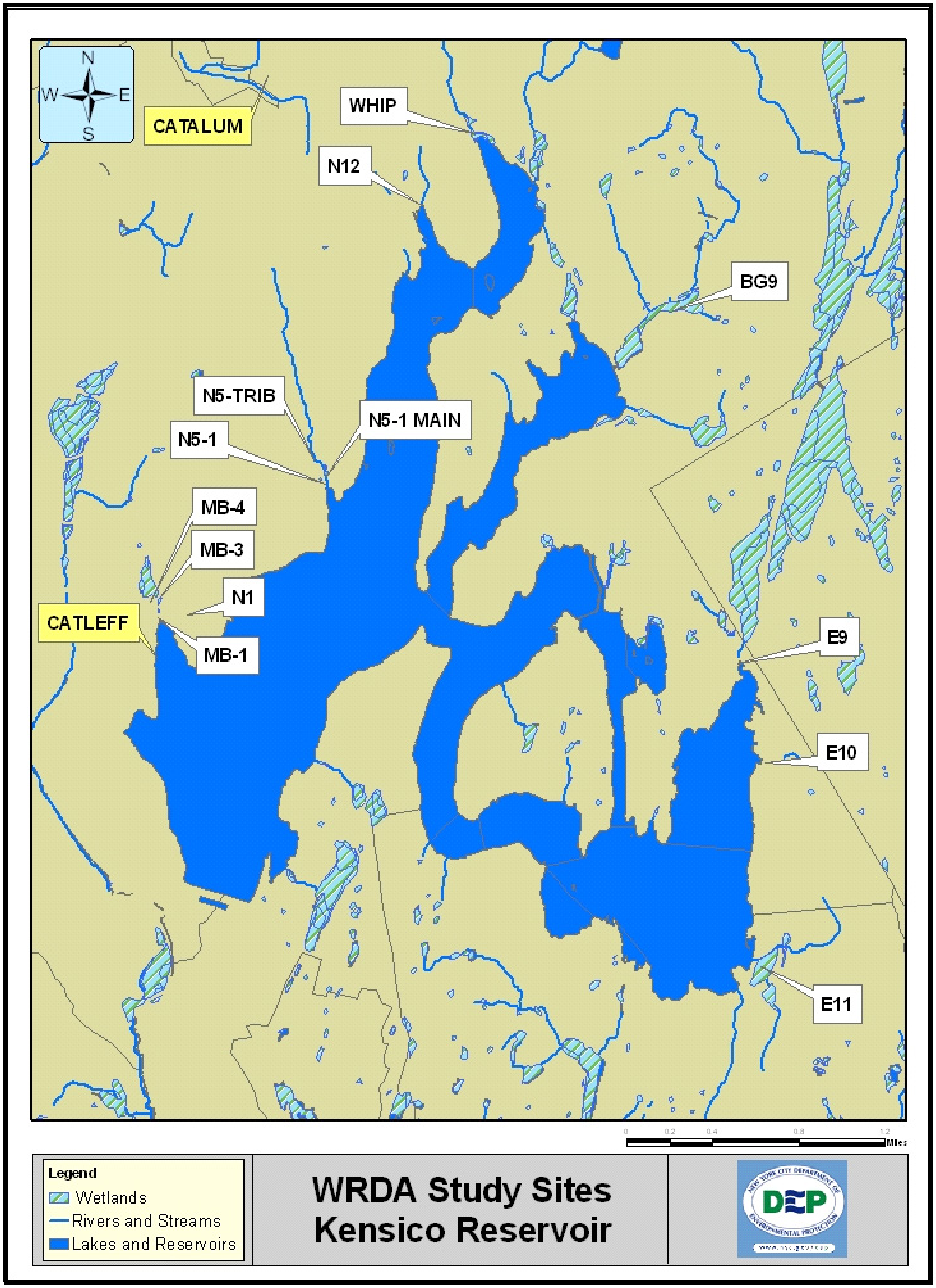


Figure 4.22  EOH WRDA study sites.

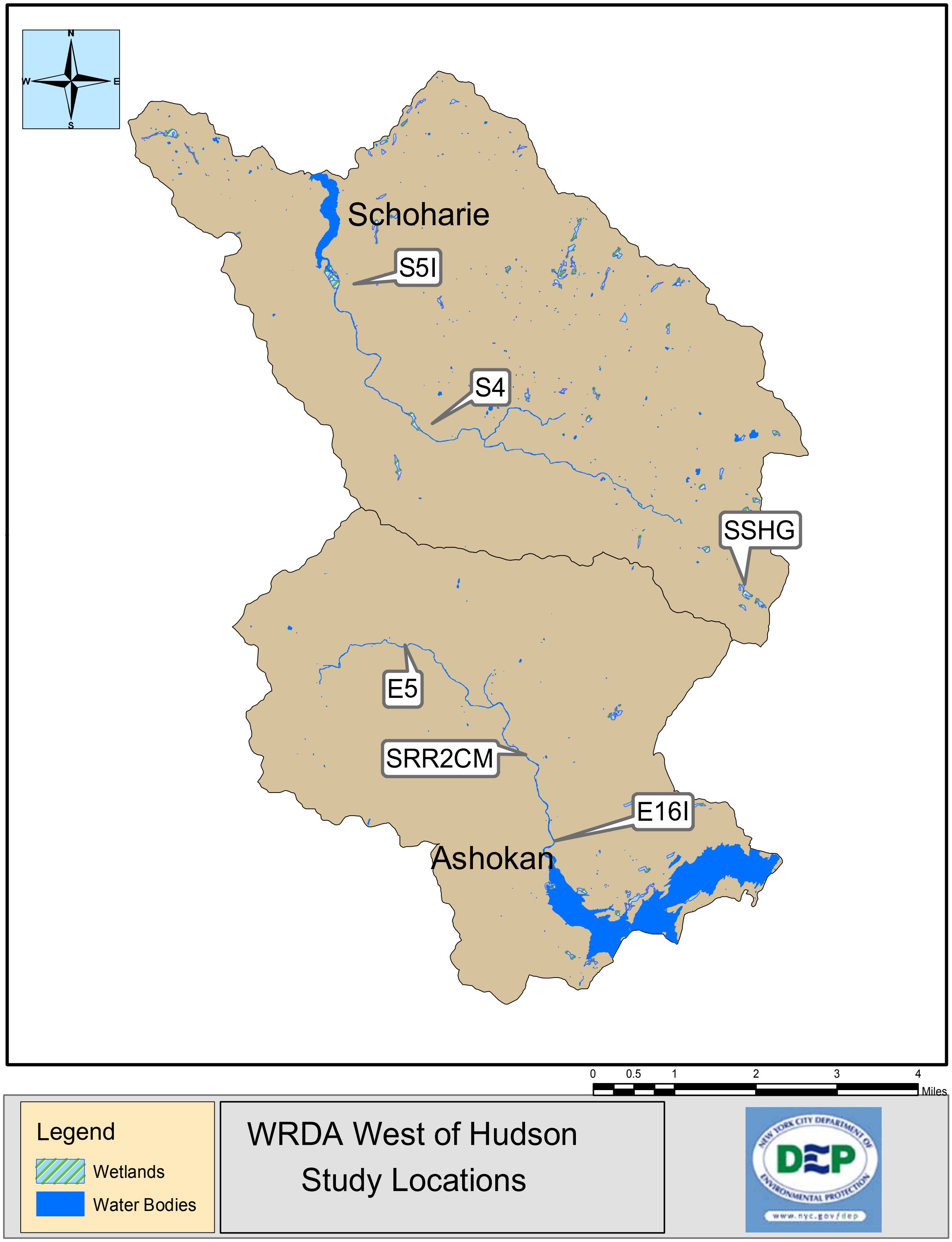


Figure 4.23 WOH WRDA Study Sites.

In 2005, DEP developed sample stations with autosamplers and flow gauges, linked to Campbell Dataloggers, which enabled flow-based sample triggers for each storm event. A pilot study was conducted at selected sites (E9, N5-1, N5-1 main, and N-12) to determine the ideal sample size, flow trigger, interval, and duration for storm events at the selected sites. As a result of the first phase of this study, a 30-min sample interval over 24 h, composited in 24 L Cubitainers, with a 1.5 X flow trigger was identified as the most appropriate sample regimen for the first year of the second phase of the project (Alderisio, et al., 2006). In 2006, DEP completed the development of the sample stations at all the perennial streams, and successfully sampled 10 storm events for the EOH and WOH sites. DEP analyzed data during the winter of 2007 in order to select sites for sampling at increased resolution based on relative stream flow, protozoan concentration, and at sites with BMPs.

## EOH Results 2006

Based on the stream flow and sample concentration, DEP summarized the protozoan loading for a storm (Table 4.2).

Table 4.2: *Cryptosporidium* and *Giardia* loading (as the total number of cysts for 10 storms) in the nine perennial Kensico tributaries.

| Site Name | *Cryptosporidium* Loading | *Giardia* Loading | Loading Rank *Cryptosporidium* | Loading Rank *Giardia* |
|---|---|---|---|---|
| **E9** | 1121915 | 22325933 | 3 | **1** |
| **E11** | 294124 | 9381287 | 8 | 4 |
| **E10** | 1059909 | 6633903 | 4 | 6 |
| **N1** | 324238 | 690798 | 7 | 9 |
| **BG-9** | 615185 | 12182434 | 6 | 3 |
| **N12** | 85338 | 759521 | 9 | 8 |
| **WHIP** | 2562014 | 7355691 | 2 | 5 |
| **MB-1** | 1004933 | 4770785 | 5 | 7 |
| **N5-1** | 3987262 | 14892354 | **1** | 2 |

The load ranking of these streams in some cases (e.g., WHIP) was heavily weighted by stream flow volume, which is why the protozoan concentration in the stream was also considered in the selection of stream sites. DEP also analyzed the relationship between stream flow and protozoan concentration and found that protozoan concentration varied with stream flow with the exception of sample stations below BMPs.

## WOH Results 2006

WOH monthly routine monitoring and event based monitoring were significantly different with regard to mean (arithmetic) concentrations per sample (Table 4.3). Event means at all three sites were 1.5 to 3 times larger than the routine means.

Table 4.3: Summary of monitoring results at Esopus Creek sites.

| MONITORING SITES | 2006 EVENT MEAN | 2006 BASELINE MEAN | 2003-2006 HISTORICAL MEAN | NUMBER OF OBSERVATIONS |
|---|---|---|---|---|
| E5 *Giardia* | 7.7 | 5 | 6.5 | 18 |
| E5 *Crypto* | 0.2 | 0.1 | 0.2 | 18 |
| | | | | |
| SRR2CM *Giardia* | 13.1 | 6.4 | 4.7 | 11 |
| SRR2CM *Crypto* | 2.5 | 0.1 | 0.1 | 11 |
| | | | | |
| E16I *Giardia* | 9.3 | 2.9 | 4.8 | 21 |
| E16I *Crypto* | 0.4 | 0.1 | 0.1 | 21 |

Events were sampled over a 24-hour period and therefore a comparison to a daily loading of routine data is possible. Mean daily loads calculated from 2006 sample concentrations and mean daily flows from USGS gage stations for the three sites ranged from 1.1 to 8.5 million *Giardia* cysts and 0.02 to 0.15 million *Cryptosporidium* oocysts (Figure 4.24). Mean event loads calculated from 2006 event monitoring from the same sources ranged from 344 to 2759 million *Giardia* cysts and 4.7 to 192 million *Cryptosporidium* oocysts (Figure 4.25). These differences between routine and event monitoring are on the order of 3 to 4 orders of magnitude. This demonstrates the importance of monitoring storm events for assessment of protozoan risks.

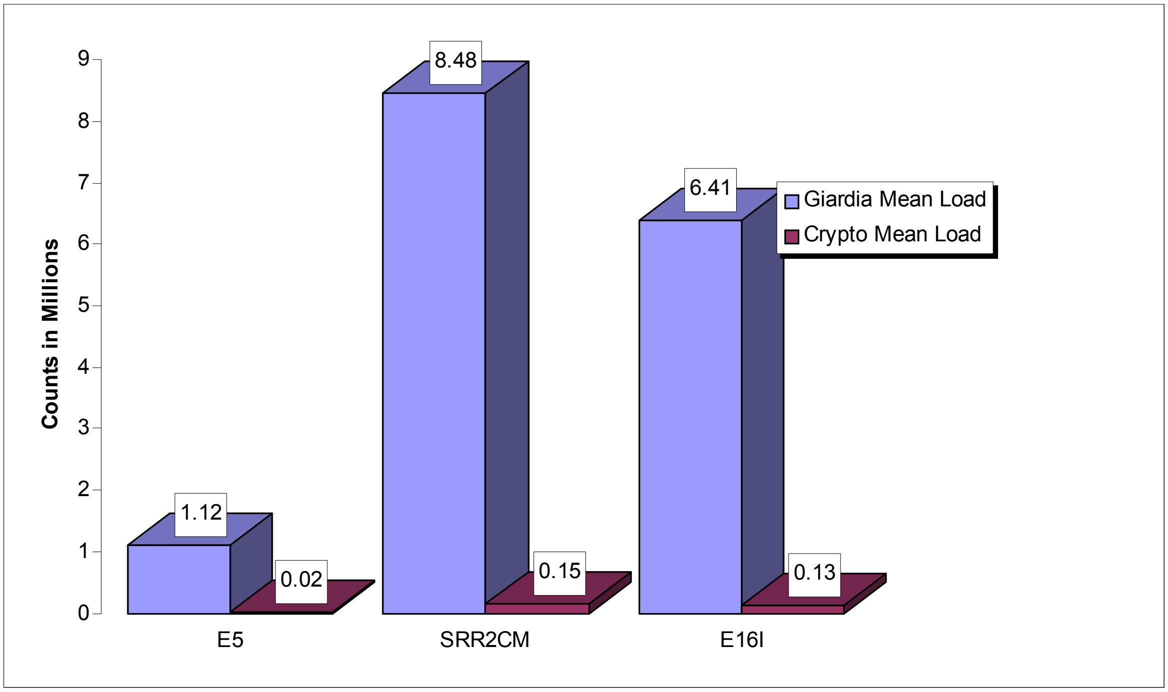


Figure 4.24 2006 daily mean (arithmetic) protozoan load for routine monitoring.

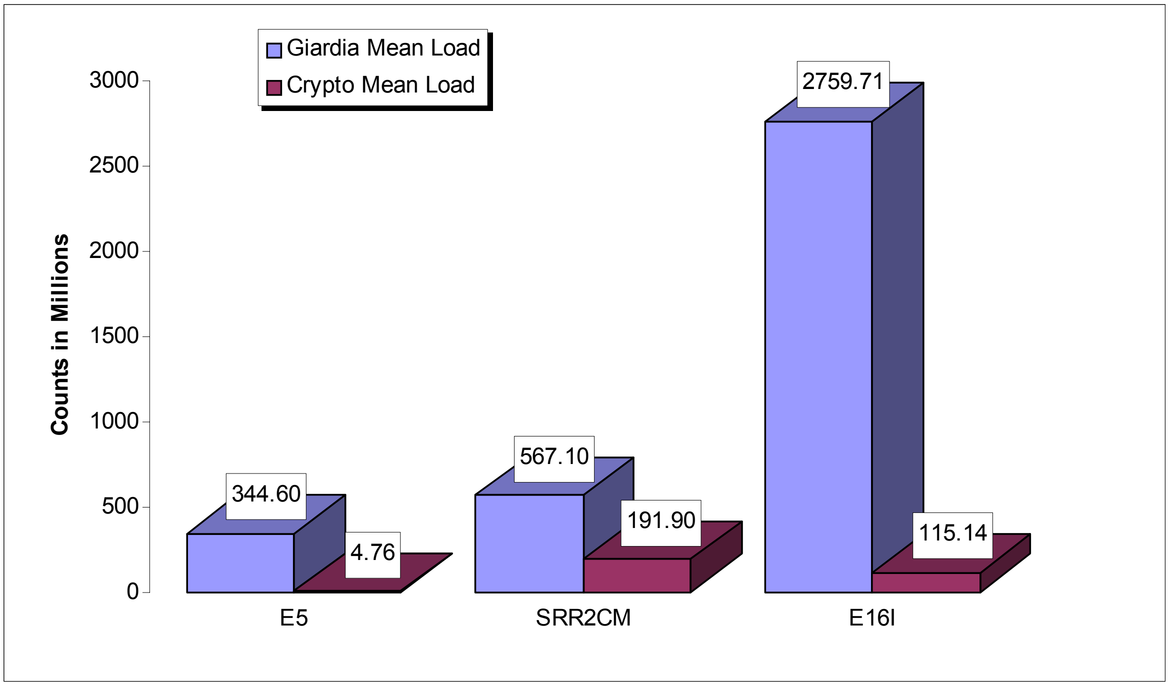


Figure 4.25 2006 mean (arithmetic) protozoan load for event monitoring.

## 2007 Sampling

In 2007, our goal is to dissect storms based on hydrologic phases (i.e., ascending limb, descending limb) to determine whether protozoan loading is weighted based on the different phases of a storm. This will provide a more accurate picture of protozoan loading dynamics and ultimately guide programs or structures to attenuate protozoan loading. Sites for the storm phase analysis include E9, E10, MB-1, N5-1, N5-1 Trib, and N5-1 Main for the EOH sites (Figure 4.22), based on loading rank, relative concentration, and stream features (e.g., BMP); WOH sites include SSHG, S4, and S5I (Figure 4.23). In the spring of 2007 the storm monitoring equipment at EOH and WOH sites was redeployed with new programming to reflect the new sampling regimen and we are currently sampling storm events.

## 4.10 How is DEP improving its methods of detecting protozoa and human enteric viruses?

DEP is currently involved in two studies related to improving methods for recovering viruses from water samples. Both studies focus on molecular detection assays using polymerase chain reaction (PCR) for the recovery and identification of specific viruses. Molecular methods offer several advantages over current methods in that they reduce the time needed to obtain a result, and they can provide results with higher sensitivity and specificity. Selection and development of the appropriate method will expand the tools DEP currently has available to detect human enteric viruses in the water supply.

## 4.11 What pathogen research was published by DEP in 2006?

Alderisio, K. A., J. Alair, and C. Pace. 2006. Automated storm sampling of *Giardia* cysts and *Cryptosporidium* oocysts to optimize recovery. *In*: Proceedings of the 2006 New York City Watershed Science and Technical Conference, September 21-22. Fishkill, New York.

Pratt, G. 2006. Evaluating the transport of *Giardia* spp. from field monitoring data within the West of Hudson District New York City upstate reservoirs. *In*: Proceedings of the 2006 New York City Watershed Science and Technical Conference, September 21-22. Fishkill, New York.

Xiao, L., K. A. Alderisio, and J. Jiang. 2006. Detection of *Cryptosporidium* oocysts in water: effect of the number of samples and analytic replicates on test results. *In*: Proceedings of the International Symposium on Waterborne Pathogens. AWWA, Atlanta, GA.

Xiao, L., K. A. Alderisio, and J. Jiang. 2006. Detection of *Cryptosporidium* oocysts in water: effect of the number of samples and analytic replicates on test results. *Appl. Environ. Microbiol*. 72: 5942-5947.

# 5. Watershed Management

## 5.1 How can watershed management improve water quality?

There is a close relationship between activities within a drainage basin and the quality of its water resources. This is the underlying premise of all watershed management programs. DEP has a comprehensive watershed protection program that focuses on implementing both protective (antidegradation) and remedial (specific actions taken to reduce pollution generation from identified sources) initiatives. Protective programs, such as the Land Acquisition Program, protect against potential future degradation of water quality from land use changes (Figure 5.1). Remedial programs are directed at existing sources of impairment. DEP recently completed a comprehensive analysis of the watershed protection program and a brief summary is provided below. More information on the management programs and water quality analysis can be found in the 2006 Watershed Protection Program: Summary and Assessment Report (DEP, 2006g). Information on research programs in the watershed can be found in the 2006 Research Objectives Report (DEP, 2007e).

Figure 5.1 Watershed Protection Program's attempt to displace or control excessive runoff that can result from activities or land uses that disrupt vegetation or create impervious surfaces which prevent the natural infiltration of rainfall.

## 5.2 How has DEP assessed the water quality improvements of watershed management efforts in the Catskill/Delaware Systems?

The 2006 Watershed Protection Program: Summary and Assessment Report (DEP, 2006g) not only provides a status report of the City's watershed protection program but also presents an analysis of water quality covering 12 years of data collection and program implementation. Five critical analytes were chosen for analysis: fecal coliform, turbidity, phosphorus, conductivity and trophic status. Case studies were done for selected monitoring sites that had sufficient proximity and sampling intensity to demonstrate program effects. Modeling was conducted to attribute program effects to programs on a watershed-wide basis.

While DEP is responsible for the collection, monitoring, treatment and delivery of high quality water to the City, DEP relies heavily on the work of partner organizations to carry out watershed protection efforts. Numerous towns, counties, State and federal agencies, not-for-profit organizations, and private businesses have participated in and helped make the watershed protection programs a success (Figure 5.2). Highlights of some key watershed programs are:

- Watershed Agricultural Program: To date, more than 93.5% of large farms in the Catskill/Delaware watershed have Whole Farm Plans. Of these, 96.5% have commenced implementation and 78.4% have substantially completed implementation. The Conservation Reserve Enhancement Program has protected more than 165 miles of farm stream buffers.
- Land Acquisition: To date the City has acquired, or has under contract, more than 75,000 acres, which triples the land area held for watershed protection before the program began.
- Wastewater Treatment Plant (WWTP) Upgrades: The five City-owned WWTPs were upgraded in the late 1990s; 96% of the flow from the remaining non-City-owned WWTPs have been upgraded leading to measurable improvements in water quality.
- New Infrastructure Program: Five new WWTPs and one collection system/force main project have been substantially completed in communities with failing or likely to fail septic systems. A seventh community has completed the WWTP project design phase. However, voters recently rejected a referendum to form the sewer district necessary to allow the project to move forward to construction. The community has been given until June 30, 2008 to establish the required sewer district or project funds will be reallocated to the Community Wastewater Management Program for use in other communities.
- Partnership Programs: DEP, in conjunction with its partners, has remediated more than 2,300 failing septic systems, upgraded 30 facilities that store winter road de-icing materials and constructed stormwater BMPs in communities throughout the City’s West-of-Hudson watershed.

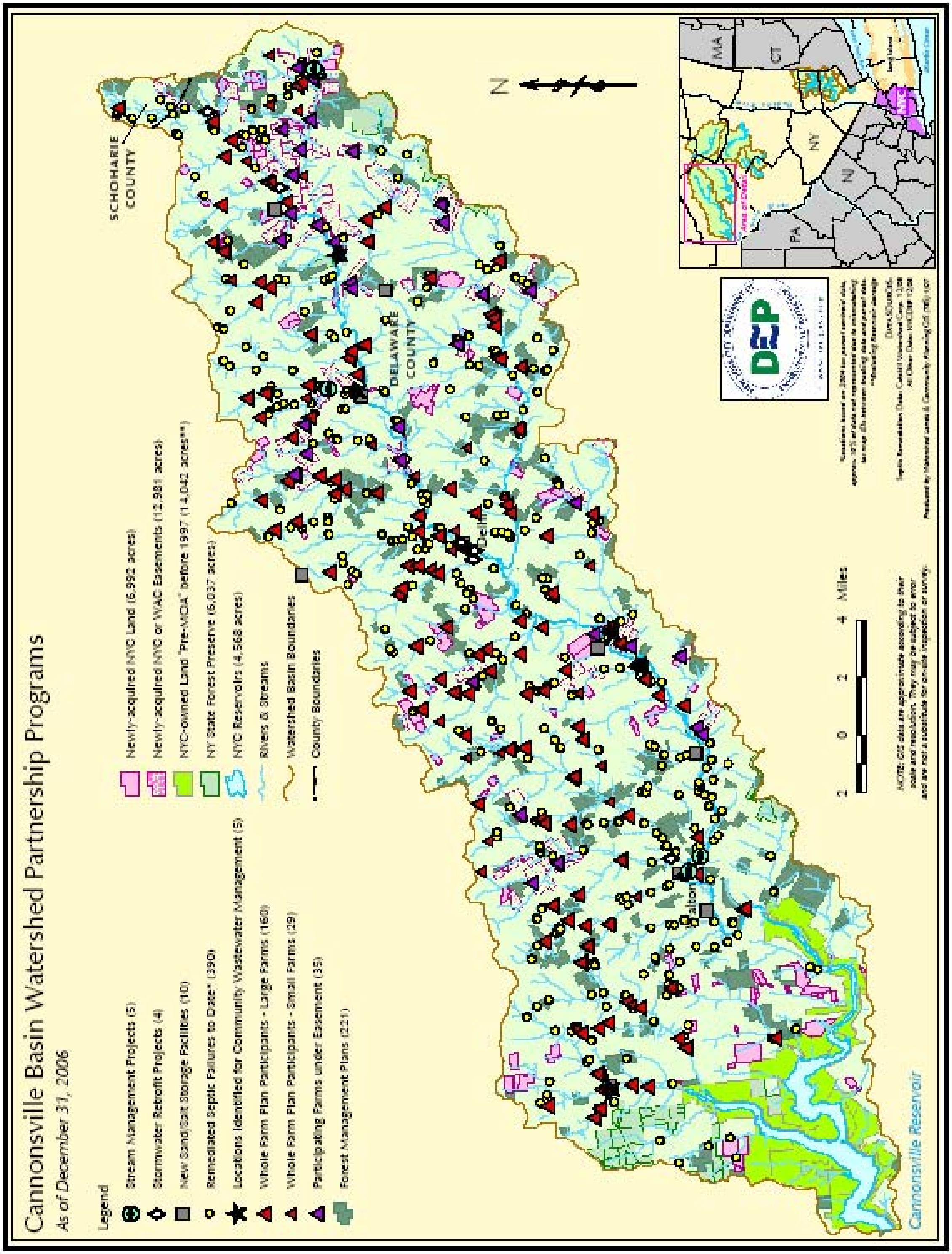


Figure 5.2 Cannonsville basin Watershed Partnership Programs as of December 31, 2006.

Water quality has been and continues to be excellent in the Catskill and Delaware systems. Even though watershed hydrology is the dominant factor in controlling water quality, as demonstrated by recent flood events and the resulting turbidity in the Catskill System, many positive changes in water quality were observed over the time period (1993–2006) studied. The most dramatic change has been the reduction in phosphorus in the Catskill/Delaware basins due to the upgrade of the wastewater treatment plants. As an example, Figure 5.3 shows phosphorus loads and flows from WWTPs in the Cannonsville basin. The reduction in total phosphorus loads from 1994 to 1999 was due to the intervention and assistance of DEP at Walton 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 diversion of another. As a result, Cannonsville was taken off the phosphorus-restricted basin list in 2002.

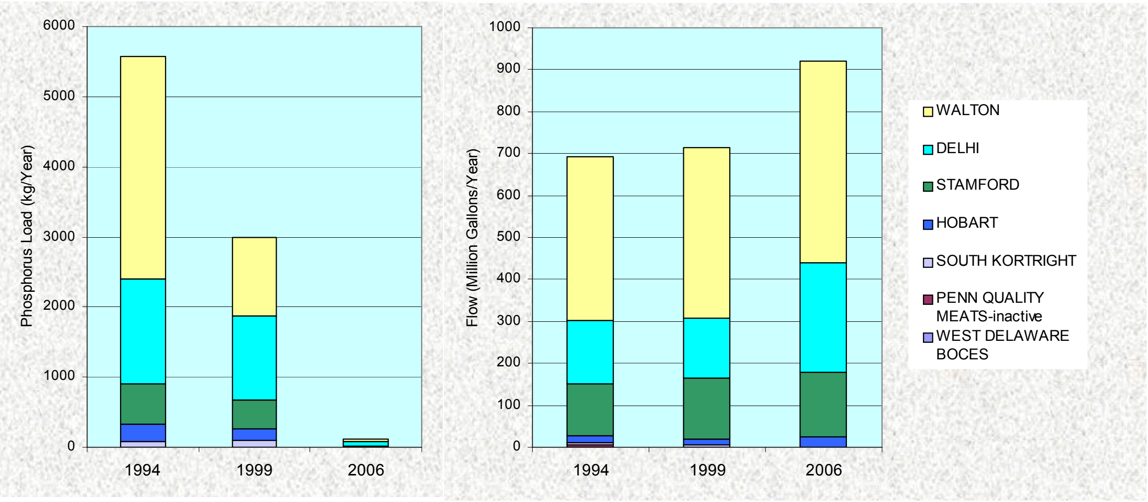


Figure 5.3 Wastewater Treatment Plant TP loads and flow in the Cannonsville watershed, 1999-2006.

## 5.3 What are the watershed management efforts in the Croton System to improve water quality?

The watershed management programs are designed differently in the Croton District from those in the Catskill and Delaware Districts. Instead of explicitly funding certain management programs (e.g., Stormwater Retrofit Program), DEP provided funds to Putnam and Westchester Counties to develop a watershed plan ("Croton Plan") and to support water quality investment projects in the Croton watershed. Other management programs (e.g., Wastewater Treatment Plant Upgrade Program, Watershed Agricultural Program) operate similarly in all districts.

## Croton Plan and Water Quality Investment Program

In the Croton System, DEP provided funds to Putnam and Westchester Counties to develop a watershed plan to protect water quality and guide the decision-making process for the Water Quality Investment Program (WQIP) funds. In 2006, both counties worked to finish remaining workplan tasks as well as incorporate comments from DEP and municipalities for the Final Draft Croton Plans. Public review of the plans is anticipated in 2007. The counties have continued the distribution of the WQIP funds and a few notable projects for 2006 are given below.

- *Putnam County Septic Repair Program (SRP)* – Putnam County continued the implementation of the Septic Repair Program in the high priority areas of the 60-day travel time. The county added an additional $200,000 to the original $3.3 million allocation to rehabilitate some additional communities in close proximity to waterbodies.
- *Putnam County Stormwater* – Putnam County authorized approximately $400,000 for stormwater improvements in Kent and Carmel, NY.
- *Westchester County Local Grant Program* – The 12 Westchester County municipalities continued the use of $312,500 in 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 license septic contractors.

## Wastewater Treatment Plant Upgrade Program

The Croton Watershed has a large number of wastewater treatment plants with the bulk of them serving schools, developments or commercial properties. Of the total of 70 non-City-owned WWTPs East-of-Hudson, 60 of them are in the Croton System (totaling 4.76 million gallons per day) and 10 are in either West Branch, Croton Falls or Cross River basins (totaling 1.34 million gallons per day). Sixty four percent of the WWTPs have flows of less than 100,000 gallons per day. Upgrade plans for five (5) WWTPs located East-of-Hudson are on hold pending decisions on diversion to existing plants or out of the Croton Watershed. 15 facilities within the Croton System, comprising 26% of the permitted flow in the System, have completed their upgrades (are Functionally Complete) as of December 2006 and are either ready to start-up or already have. Of the 33 WWTPs located within the 60 day travel time, which comprises 47% of the total number of non-City-owned WWTPs located East-of-Hudson, seven (7) (comprising 11% of the permitted flow) have completed their upgrades and this equates to 20% of the permitted flow within the 60 day travel time; an additional 22 WWTPs (79% of the flow) either have commenced construction of the upgrades or are in the design phase.

## Watershed Agricultural Program

The farms in the EOH district tend to be smaller and more focused on equestrian-related activities than the WOH farms and the EOH Watershed Agricultural Program has been specially tailored to address these issues. At the end of 2006, 33 farms in the Croton System have approved Whole Farm Plans. Twenty-six of these farms have commenced implementation of Best Management Practices (BMPs) and a total of 156 BMPs have been installed.

## The Nonpoint Sources Management Program

The Nonpoint Source Management Plan was designed to identify and eliminate sources and incidents of nonpoint source pollution in the East-of-Hudson Catskill/Delaware reservoirs. The nonpoint sources targeted for remediation programs include wastewater, stormwater, turf management chemicals and hazardous materials. Some recent highlights include:

- A contract to complete the mapping and inspection in the West Branch and Boyds Corners basins was registered in December 2006. This continues the video inspection and digital mapping of the stormwater infrastructure that was initiated in 2005. The program identified the locations, conditions and potential pollution threats associated with stormwater infrastructure.
- Stormwater remediation projects continue to be identified and implemented. Ten small remediation projects are repaired each year. The designs necessary for the larger retrofit projects are currently underway (Figure 5.4).
- Implemented a Spill Containment Plan modeled after DEP's successful spill containment plan in the Kensico Basin.
- In conjunction with Cornell Cooperative Extension, DEP completed a residential survey of lawn care practices to obtain data on fertilizer applications and assess the potential for adverse water quality impacts.

Figure 5.4 Site WB-1, West Branch: Joseph Court. Stormwater remediation will include repair of severely eroded channel on steep slope and installation of catch basin(s), stormwater drainage pipe, outlet protection and vegetation. The project is currently in the design phase.

## 5.4 How do environmental project reviews help protect water quality?

DEP staff review 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 2006, DEP staff reviewed a total of 165 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 staff review other projects upon request. Review of these projects helps ensure that they are designed and executed in such a manner as to minimize impacts to water quality. DEP provides its expertise in reviewing and identifying on-site impacts to wetlands, vegetation, fisheries and wildlife and makes recommendations on avoiding or mitigating proposed impacts. These reviews also provide guidance on interpreting regulations as they apply to wetlands as well as threatened and endangered species. DEP also coordinates review of Federal, State and local wetland permit applications in the watershed for the Bureau of Water Supply.

Approximately 60 of these projects were reviewed and commented on by DEP in 2006. Many of those projects were large, multiyear projects with ongoing review and many others were smaller scale projects scattered throughout the NYC watershed. Also in 2006, approximately 38 wetland permit applications were reviewed and commented on.

## 5.5 What is the status of WWTP TP loads in the watershed in 2006?

Figure 5.5 displays the sum of the annual total phosphorus (TP) loads from all surface-discharging wastewater treatment plants (WWTPs) by district for the period 1999-2006. 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 remain far below the WLA. The fact that loads in the Delaware and Catskill Systems remain so far below their respective WLAs reflects the effect of the WWTP upgrade program, which is largely complete WOH.

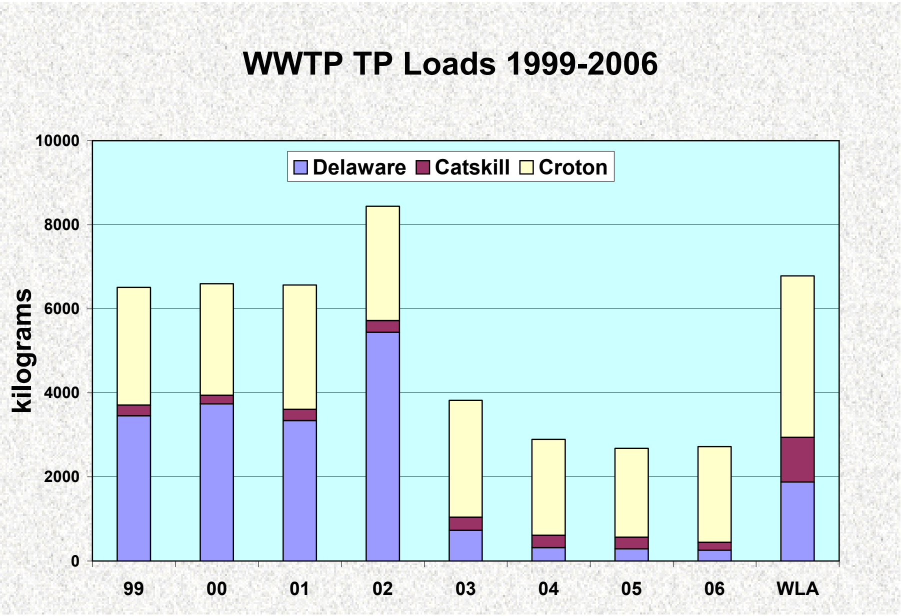


Figure 5.5 Wastewater Treatment Plant TP loads, 1999-2006. The wasteload allocation for the entire watershed is shown in the right-hand bar for comparison.

Upgrades to WWTPs include phosphorus removal and microfiltration to make the plants comply with the Watershed Rules and Regulations. All NYC-owned WWTPs in the watershed have been upgraded with the exception of the Brewster WWTP, which will be transferred to the Village of Brewster when its upgrade is complete. Several non-NYC-owned WWTPs have already been upgraded, while a number of others are being connected to plants in the New Infrastructure Program.

The New Infrastructure Program (NIP) is another major wastewater management program funded by New York City. The NIP builds new WWTPs in communities previously relying on individual septic systems. Since many of the older septic systems in village centers such as Andes, Roxbury, Windham, Hunter, and Fleischmanns could not be rehabilitated to comply with current codes, this program seeks to reduce potential nonpoint source pollution by collecting and treating wastewater with compliant systems. The Village of Andes NIP began operation in 2004, and the villages of Hunter and Windham NIPs began in 2005.

Although WWTP TP loads in 2006 continue to trend downward, TP loads are expected to eventually approach the WLAs for the respective Systems as new NIPs are completed and sewer districts expand to their full capacities.

## 5.6 How are DEP's wetland and forest scientists changing the face of engineering projects and site restoration in the watershed?

DEP's wetland and forest scientists within the Natural Resources Section have a breadth of experience and education in wetland and upland ecosystems, site restoration, plant taxonomy, and understanding of engineering project design features that allows review of projects with respect to their impacts on natural resources. They assess impacts to the landscape based on information provided in the New York State Environmental Quality Review Act (SEQRA) process, as well as by using available reference materials such as GIS databases, and site visits to determine whether all impacts have been properly represented and appropriate mitigation measures chosen to protect or replace resources that may be disturbed during construction operations. They assist landowners and contractors in developing site-appropriate plant lists for landscaping and site restoration projects as well as offer advice on many aspects of carrying out these plans. On NYC-owned lands, they take this a step further by providing direct oversight of landscaping contractors to assure that the finished product is successful.

To retain healthy ecosystems throughout the watershed, DEP is discouraging the use of exotic, invasive plants and encouraging their replacement with native plants. By taking into account the goals of each landowner—whether they be aesthetic, erosion prevention, low maintenance, safety, etc.—DEP's experts offer suggestions for a palette of plants that would be successful for each site. Because native plants often require less watering and fertilization, but still protect soil from erosion and can be quite beautiful, they can be a better choice long-term. Although there are not yet regulations to restrict the use of exotic invasives in New York State, DEP primarily uses natives in its own construction projects to minimize maintenance, and has been pleasantly surprised by the willingness of private landowners to use native plants once they realize that their aesthetic landscaping objectives can be met with lower-maintenance natives. In years to come, DEP believes this shift toward appropriate native species in landscaping and site restoration plans will reduce not only invasive species infestations in our green spaces but also nutrient flows from lawn chemicals and overuse of our precious water resource for watering of lawns.

In 2006, Natural Resources staff provided guidance on over 50 construction projects ranging from single-family homes to large dam rehabilitation and highway construction projects, and provided continuing oversight of on-the-ground site restoration for 5 DEP capital projects.

Figure 5.6 A successful wetland mitigation project at Amawalk Reservoir contains native trees, shrubs, sedges, grasses, and wildflowers.

Figure 5.7 A native meadow planting at West Branch Reservoir provides habitat for songbirds while deterring Canada geese from feeding and defecating at the dam.

## 5.7 How does DEP determine the cause of fish kills and how are they indicative of water quality changes?

Fish are indicators of the health and condition of the aquatic environment in which they live. Since a die-off can be an early indication of a serious degradation of water quality, investigating fish kills in the New York City Water Supply and determining their cause is essential for maintaining high water quality and for ensuring public health for over half the population of New York State. Fish kills can be attributed to a variety of causes ranging from simple changes in environmental conditions with no implications for water quality, such as elevated temperature, to more serious causes such as pathogenic or chemical exposures.

The first step in a fish kill investigation is assessing the scene to determine numbers and species of fish involved, unusual fish behavior (gulping at the surface, flaring gills, flashing, lethargy, swimming in circles, rapid swim bursts, or rubbing on the bottom), exact location and extent of the kill, environmental conditions and obvious potential causes. Dying or freshly dead fish are then collected and examined for clinical signs of disease or impairment (external lesions, parasites, bulging eyes, fins (clamped down, frayed or bloody), gills (bloody, discolored, frayed), excessive mucous formation, missing scales, unusual coloration and visible injury). Fish are then sent to a fish disease diagnostic laboratory for necropsy, bacteriological, virological and toxicological analysis to determine cause of death. Concurrently with the collection of biological samples and information on the fish, water quality samples are taken to determine the environmental conditions at the time of the kill.

In 2006, there were three reported fish kills investigated by DEP:

- On June 5, 2006, DEP Limnology staff observed dead and dying alewives (*Alosa pseudoharengus*) at Pepacton Reservoir during a routine water quality survey. A fish kill investigation was conducted by DEP Fisheries, DEP Limnology and DEP Police. A total of nine alewives were collected with six being submitted to the diagnostics lab for necropsy. All six alewives submitted were collected live, individually bagged and shipped in water from the area of collection. Three exhibited various external anomalies (scale loss, hemorrhaging, fungus/parasite/bacterial infection). Although a definitive cause of death could not be determined, the kill is thought to have resulted from the combined effect of rapid temperature change and elevated pH, causing immunosuppression which in turn allowed for secondary bacterial and fungal infection.
- On July 19, 2006, DEP Land Management reported approximately 45 dead trout in a pooled area below the Ashokan Reservoir spillway. DEP Police notified DEP Fisheries that carp were also involved in the kill. Water temperatures were measured at 10 AM on July 20 and ranged from 78-80°F. No live fish were collected or submitted to the Fish Health Diagnostic Laboratory. Mortality was attributed to high water temperatures.
- On August 20, 2006, DEP Fisheries received a report of a fish kill from a local angler at East Branch Reservoir of an estimated 100 dead yellow perch. The smell of hydrogen sulfide gas

was evident during the subsequent field investigation, indicative of low dissolved oxygen. No live fish were collected or submitted to the Fish Health Diagnostic Laboratory.

## 5.8 How did trout spawning affect stream reclassification in the Cannonsville Reservoir drainage basin?

Streams in New York State are classified and regulated by NYSDEC based on existing or anticipated best use standards. The purpose of the stream reclassification program is to enhance the protection of water supply source tributaries by determining best use standards for trout and trout spawning. These standards strengthen compliance criteria for dissolved oxygen, ammonia, ammonium, temperature and volume permitted under any currently regulated action, and further increases the number of protected streams in the watershed.

Reclassification surveys concentrate on sections of streams with likely trout habitat including riffles, pools and undercut banks. Streams are electrofished and all stunned fish are collected and held for processing (identification, length and weight) (Figure 5.8). The fish are then released when all data are collected. The presence of trout shorter than 100mm (young-of-the-year) in length is used to indicate the occurrence of trout spawning. Physical and chemical stream data (temperature, depth, width, dissolved oxygen, pH, conductivity, stream gradient and estimated discharge) are then collected to assess stream conditions suitable for trout spawning. Bottom substrate and land characteristics are also described. Collection reports and reclassification petitions are compiled and submitted to DEC on an annual basis. DEC will then update the stream classification based on these petitions.

Figure 5.8 DEP and DEC staff electrofishing the Esopus Creek.

DEP is systematically surveying each reservoir drainage basin in the West-of-Hudson watershed. In 2006, surveys of the Cannonsville Reservoir basin streams were begun. Of the approximately 25 streams surveyed in the Cannonsville drainage to date, 20 will be petitioned for upgrade to trout or trout spawning.

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

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 Oklahoma, 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 they can reproduce quickly and are capable of clogging pipes. 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, they create taste and odor problems in the water.

To protect the system from zebra mussels, DEP does the following:

- *Monitoring*. As suppliers of water to over nine million people, it is DEP's responsibility to monitor New York City's water supply for zebra mussels, since early identification of a zebra mussel problem will allow us to gain control of the situation quickly, preserve the excellent water quality of this system, and save us money in the long run. DEP has been monitoring NYC's reservoirs for zebra mussels since the early 1990s, via contract with a series of laboratories that have professional experience in identifying zebra mussels. The objective of our contract is to monitor all 19 of New York City's reservoirs for the presence of zebra mussel larvae (veligers) 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 as well as "bridal veil" (a potential mesh-like settling substrate) sampling 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. To date, zebra mussels have not been found within the NYC reservoir system.

Figure 5.9 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 5.9). 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. This requirement for all boats being steam cleaned applies to all boats that will be used on the reservoirs, whether they be rowboats used by the general public, or motor boats 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 arrival for DEP inspection.
- *Public Education*. DEP provides educational pamphlets to fishermen on NYC's reservoirs and to bait and tackle shops in NYC's watersheds on preventing 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 that may have zebra mussels in them (depending upon where the bait was obtained), or by failing to clean equipment that's been used in bodies of water infested with zebra mussels before using it in bodies of water not infested with zebra mussels. The brochures help educate fishermen as to how they can prevent the spread of zebra mussels. In addition, signs are put up throughout the watershed providing information as to how to prevent the spread of zebra mussels.

# 6. Model Development and Application

## 6.1 Why are models important?

DEP utilizes simulation models to understand and quantify the effects of climate, watershed management and reservoir operations on the quality and reliability of the NYC water supply system. The models encapsulate the key processes and interactions that control generation and transport of water, sediment and nutrients from the land surface, through the watersheds and within the reservoirs. This allows the estimation of watershed loads and reservoir eutrophication under varying scenarios of watershed and reservoir management. By providing information on flow pathways and nutrient sources, watershed management and planning can be focused on the critical land uses and transport pathways that influence loads to reservoirs. Coupling simulated watershed loading estimates to reservoir eutrophication models allows the timing of nutrient delivery and the source of nutrient loads to be examined in relation to simulated changes in reservoir nutrient and phytoplankton concentrations.

## 6.2 What can models tell us about the effects of 2006's weather on nutrient loads and flow pathways to reservoirs?

Applying watershed models to include the current year allows a better understanding of how 2006 nutrient loads to the reservoirs compare to long term flow and loading patterns.

Using the model results, annual results for 2006 can be placed in an appropriate historical context that accounts for the effects of natural meteorological variability on water quality. This variability is the background within which watershed management operates, and provides an important context for judging the effects of watershed management.

Watershed modeling of streamflow and nutrient loads provides insight into the flow paths that water and nutrients take in the watershed. Total streamflow is comprised of direct runoff and baseflow. Direct runoff is water that moves rapidly on or near the land surface, as opposed to much slower-moving baseflow. Direct runoff has a high potential for transporting phosphorus (P) as it interacts with P sources on the land surface. Figure 6.1 depicts the annual streamflow, direct runoff, and dissolved nutrient loads simulated by the model for 2006 in relation to long-term simulated annual statistics. These box plots show that 2006 was a much wetter year than normal with both higher than normal streamflow and direct runoff. Consistent with these high flows, 2006 dissolved nutrient loads were also higher than normal. The relationship between 2006 and long-term annual total dissolved nitrogen (TDN) loads follows a similar pattern as annual streamflow, while the relationship between the 2006 and long-term annual total dissolved phosphorus (TDP) loads closely follows direct runoff. These results have important consequences for watershed management, suggesting that management of non-point sources of dissolved phosphorus in direct runoff can be particularly effective in controlling TDP loads, to which algal growth in the reservoirs is particularly sensitive.

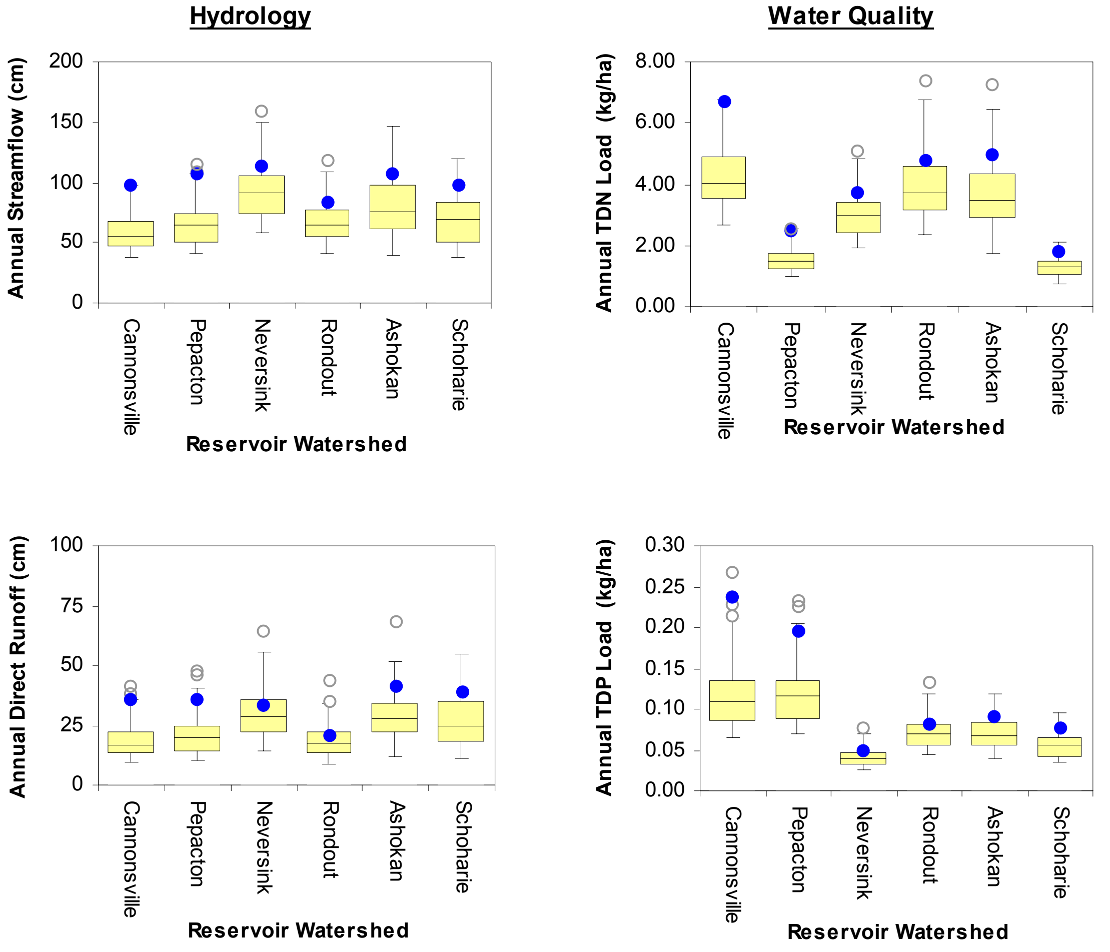


Figure 6.1 Annual streamflow, overland flow and dissolved nutrient loads simulated by the GWLF model for 2006 in relation to long-term simulated annual statistics. Box plots show long term statistics. Blue dots show 2006 results.

## 6.3 What was accomplished in 2006 in the development of modeling capabilities?

Modeling capabilities continued to be improved for both DEP's watershed and reservoir models (DEP, 2006e, 2007b).

DEP has continued to update and perform further testing of the latest version of the Variable Source Loading Functions (VSLF) watershed model (Schneiderman et al., 2007). The VSLF model improves upon the GWLF watershed model by addressing a growing body of evidence that the predominant mechanism for runoff generation in the NYC watersheds is saturation-excess on

Variable Source Areas (VSAs), as opposed to an infiltration-excess runoff generating mechanism upon which the standard GWLF is based. Model testing conducted by researchers from Cornell University demonstrated that VSLF predictions of the spatial pattern of runoff and soil moisture align well with both observed soil moisture patterns along transects in the Cannonsville watershed and with runoff predictions from the more detailed process-based model, SMDR, developed at Cornell. In addition, the USDA Curve Number (CN) method for estimating direct runoff in VSLF was refined to better account for seasonal variability in watershed-scale runoff response to rain and snow melt events (NYCDEP 2007b). The refinement allows the minimum and maximum values on the CN corresponding to wet and dry condition to be calibrated rather than be set to pre-defined values.

Data to support model testing and applications were updated. Time series data used for watershed modeling include daily precipitation and air temperature (Pre-1960–2005); daily streamflow data from USGS (Pre-1960–water year 2005); stream chemistry data from DEP (routine and storm events, 1987–2005); stream chemistry data from NYSDEC (W. Br. Delaware River, water years 1992–2005); and Waste Water Treatment Plant data from DEP (monthly phosphorus loads, 1990–2005). Updated data for reservoir modeling include hourly meteorological data (1994–2004); daily water flow measurements of reservoir input (streams) and outputs (aqueduct discharge, dam releases, and spills) (1987–2005); daily stream and aqueduct temperature data (1987–2005); and reservoir water quality and temperature profiles (1992–2005). Improvements to GIS data to support modeling include updated Soil Survey Geographic data (SSURGO), land cover/land use for East-of-Hudson watersheds, and wetness index maps based on soils and topography. In addition, GIS tools for developing VSLF model inputs were improved to support new model versions.

DEP completed its EPA FAD requirement (Section 5.2 of the 2002 FAD) to complete calibration and validation of VSLF (formerly GWLF) models for Catskill and Delaware System watersheds. The model was successfully calibrated and tested for the major tributaries in these basins for hydrology (streamflow and runoff), dissolved nutrients, sediment and particulate phosphorus (DEP, 2006b, 2007c).

DEP continued to develop, refine and apply its methodology for predicting turbidity transport in the Catskill System and Kensico Reservoir, using the 2D reservoir models. In Kensico, simulations helped to minimize the use of alum while maintaining acceptable turbidity levels at the Kensico effluent withdrawal locations, or to determine the need for alum treatment in the first place. These simulations (DEP, 2007b) were used to both determine the levels of Catskill turbidity that can be reasonably sustained under a given set of flow and mixing conditions, and as an aid in planning operational measures, such as limiting aqueduct flow or treatment of turbid water with alum, in response to extreme turbidity. Turbidity transport simulations were also used to support decisions regarding the operations of Rondout Reservoir (DEP, 2007b).

## 6.4 How did DEP use model simulations to support decision making regarding the need for alum treatment during 2006?

During 2006 a number of storm events affected the Catskill portion of the NYC water supply (Table 6.1, Figure 6.2). These caused elevated turbidity levels in the Schoharie and Ashokan Reservoirs to occur over a longer period of time than normally experienced, especially considering the fact that turbidity was already elevated at the end of 2005 as a result of earlier storm events. High and sustained levels of Catskill system turbidity impaired DEP's ability to use this water, and required treatment with alum on several occasions in order to reduce the turbidity of the water transferred to Kensico Reservoir from Ashokan Reservoir. DEP strives to minimize the use of alum, and simulations of the transport and attenuation of turbidity in Kensico Reservoir have provided an important source of guidance in determining the need for alum treatment. For cases when alum treatment can not be avoided, model simulations are also valuable to help determine the optimal length of treatment, and therefore minimize the use of alum. Here we provide two examples of: 1) How simulations were used to show that alum treatment could be ended, and 2) How simulations were used to evaluate the potential need for alum treatment.

Table 6.1: Reservoir model simulations used to determine the need for alum treatment during 2006.

| Date | Event Description | Simulation Support |
|---|---|---|
| 6-Apr<br>Event 1 | Due to events in October-November of 2005, and January of 2006, Ashokan Reservoir effluent turbidity levels ranged between 40-10 NTU during the first three months of 2006. Consequently alum treatment was required. | Estimate the time at which alum treatment could be safely discontinued, as Ashokan effluent turbidity levels dropped to levels at or below 10 NTU. Predictions of Kensico effluent turbidity in the absence of alum treatment were made to support the decision to end treatment on 10 April 2006. |
| 18-May<br>Event 2 | A large storm event caused the fourth highest Esopus Creek discharge recorded during 2006, and this in turn led to Ashokan Effluent turbidity again increasing to levels greater than 10 NTU. | Make predictions of Kensico effluent turbidity in response to elevated Catskill aqueduct turbidity levels. Based on these simulations alum treatment was again used between 15-24 May. |

Table 6.1: Reservoir model simulations used to determine the need for alum treatment during 2006.

| Date | Event Description | Simulation Support |
|---|---|---|
| 21-Jul<br>Event 3 | On June 26 an unusual storm event led to the highest Esopus Creek discharges measured during 2006. As a result of this storm Ashokan effluent turbidity levels briefly exceeded 100 NTU, and remained above 20 NTU for an extended period. | Given the high turbidity levels generated by this storm, simulations were not required to show the need for alum treatment. Simulations were used to define the time at which alum treatment could be safely discontinued. |
| 28-Oct<br>Event 4 | A series of storms beginning in early September led to a progressive increase in Esopus Creek discharge. A storm on 28 October caused the discharge to reach the third highest level of the year and a moderate increase in Ashokan effluent turbidity to levels approaching 10 NTU. | The consequences of increased Catskill aqueduct turbidity inputs associated with this event on the Kensico effluent turbidity levels was examined, in order to judge the need for alum treatment. These simulations suggested that alum treatment was not needed. |

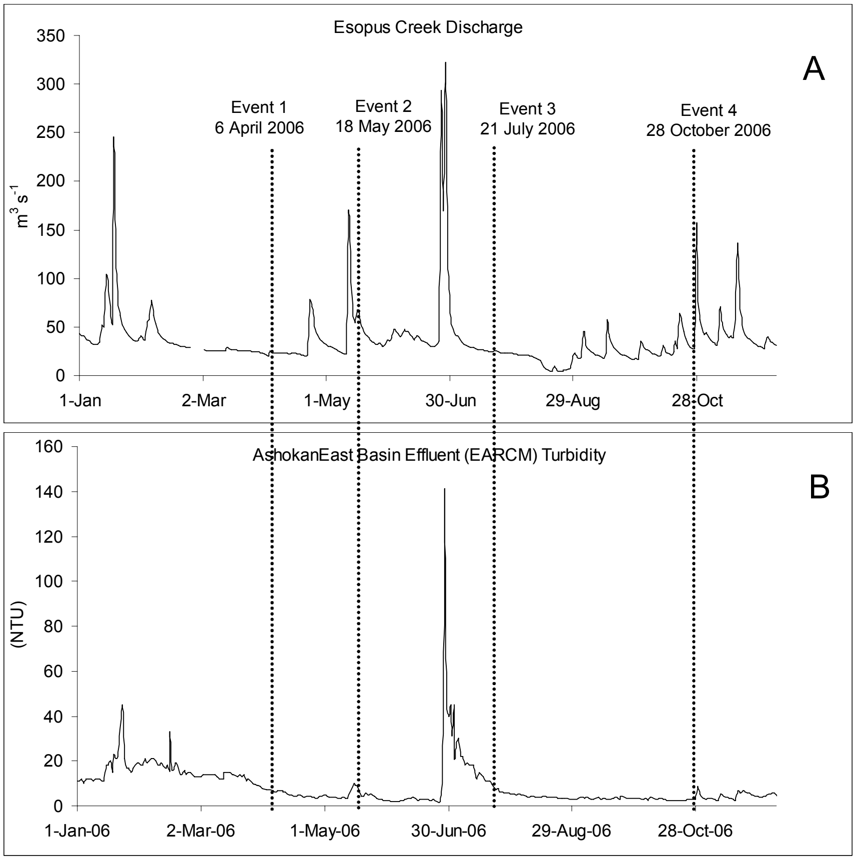


Figure 6.2 A) The discharge of the Esopus Creek, which is the major input to Ashokan Reservoir. B) Turbidity measurements made at the effluent chamber (EARCM) in the East Basin of Ashokan Reservoir. The times corresponding to the 4 sets of simulations described in Table 6.1 are shown as dotted vertical lines.

## Example 1 – defining the end of alum treatment

During 2005, and continuing through the winter of 2005–2006, a series of turbidity events led to a sustained period of elevated Catskill system turbidity and the unavoidable need for alum treatment of this source of water entering Kensico Reservoir (DEP, 2006a, 2007a). Simulations of Kensico effluent turbidity levels in the absence of alum treatment were made, in order to define a time that alum treatment could be discontinued while maintaining acceptable Kensico effluent turbidity.

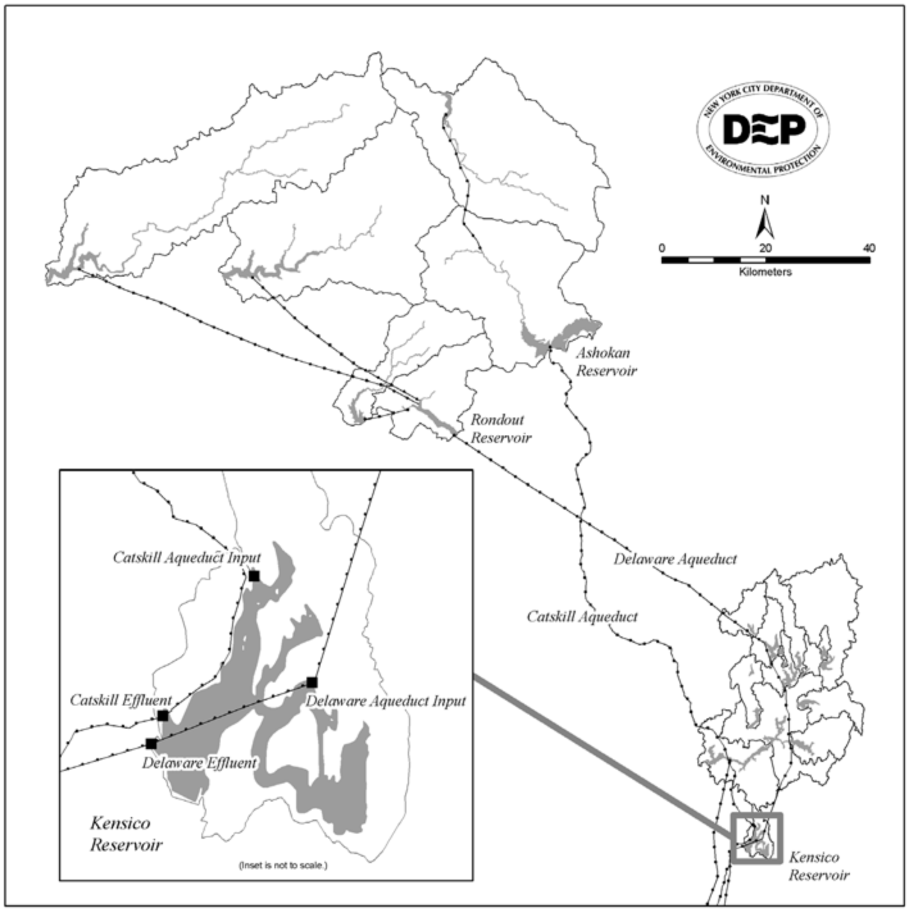


Figure 6.3 Connections between Kensico Reservoir and the upstate reservoirs via the Catskill and Delaware aqueducts. Model simulations presented here examined the consequences of turbidity inputs on the turbidity levels at the Kensico effluent locations (see insert).

Predictions of the turbidity at the Kensico aqueduct effluent chambers (Figure 6.3) began on January 1, 2006 and were driven using measured aqueduct flow, turbidity (adjusted when appropriate for the effects of alum treatment) and water temperature up until July 21. From July 22, forecasts of turbidity levels into the future were made by using assumed aqueduct flow rates, and 3 possible fixed turbidity levels (6 NTU, 8 NTU and 10 NTU) for the Catskill system. The Delaware aqueduct turbidity was set to 1 NTU which is representative of the turbidity normally encountered there. Fixing the turbidity to the measured level at the start of the forecast (approximately 10 NTU) provided a conservative "worse case" forecast of future conditions in the absence of alum treatment, while the lower fixed turbidity levels provided more realistic simulations, since Ashokan turbidity levels were clearly on the decline (Figure 6.2). The sensitivity of predicted Kensico effluent turbidity levels to reasonable variations in particle settling rates (0.25 $m\ d^{-1}$ – 0.75 $m\ d^{-1}$) was also tested.

The results of this set of simulations (Figure 6.4) show that the model did an excellent job of predicting the Kensico effluent turbidity levels, up until the time when forecasting began (July 22 ). Comparison of the simulated and measured turbidity values at the two effluent locations shows that prior to the forecast period, the simulated and measured data closely correspond to each other particularly when a particle sinking rate of 0.5 m $d^{-1}$ was used.

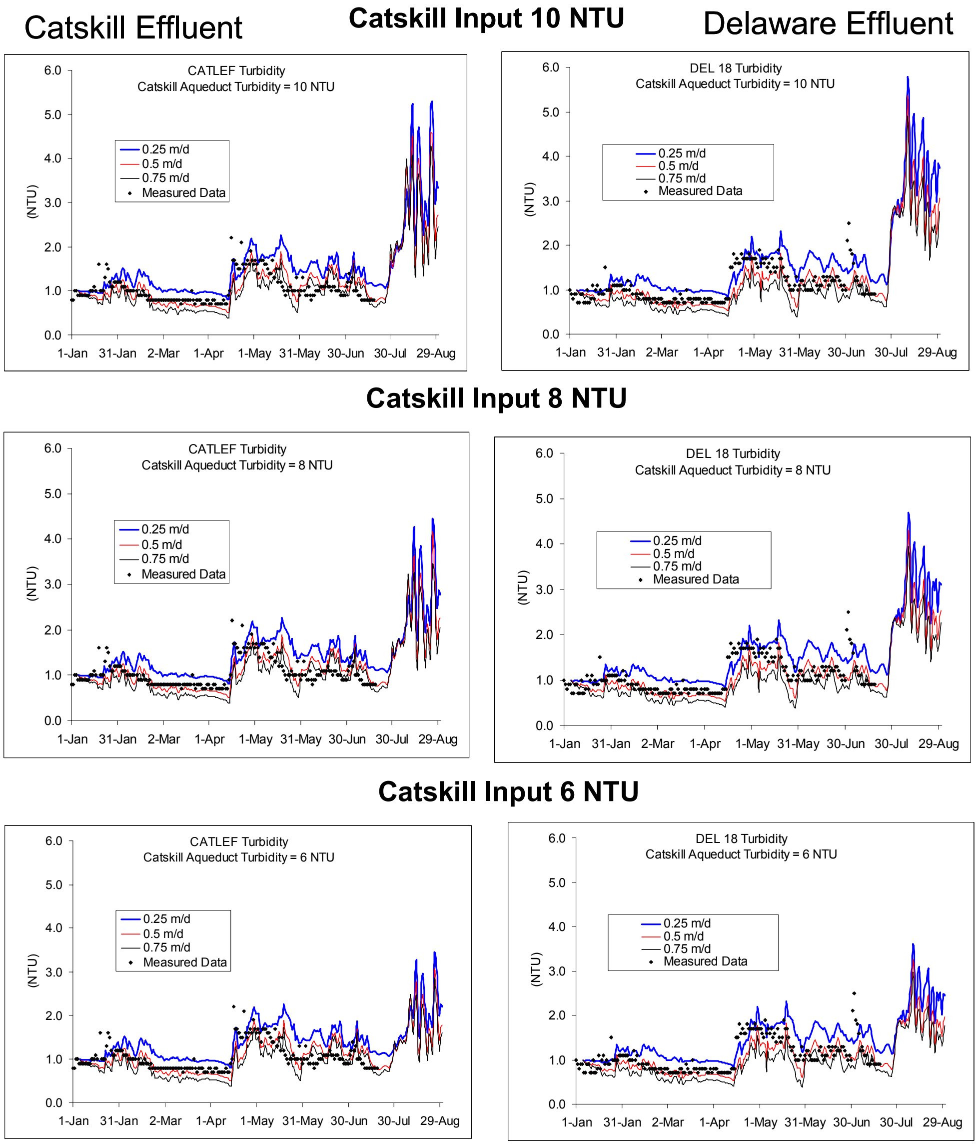


Figure 6.4 Simulations of the turbidity levels at the Kensico effluent locations. Catskill effluent turbidity is shown in the left column of graphs while Delaware effluent turbidity is shown in the right column of graphs. Up until July 21 the simulations are driven by measured variations in aqueduct flow and turbidity. Turbidity forecasts begin on July 22 and are based on the assumption of a fixed Catskill aqueduct turbidity input to Kensico of 10 NTU (top), 8 NTU (middle), or 6 NTU (bottom).

The forecasts (Figure 6.4) suggested that if Catskill aqueduct turbidity levels remained between 8 NTU–10 NTU for a sustained period of time, the Kensico effluent turbidity levels could exceed 5 NTU in the absence of alum treatment. If the Ashokan effluent turbidity fell below 8 NTU it was deemed safe to discontinue alum treatment. Based on these results alum treatment continued following these simulations, but was ended on August 2, once the turbidity of the water entering the Catskill Aqueduct had declined to approximately 5 NTU.

## Example 2 – assessing the need for alum treatment

The final series of turbidity causing storms in 2006 occurred between September and October, and culminated in an event on October 28 (Table 6.1, Figure 6.2). While this event led to significant increases in Esopus Creek turbidity (10 NTU–300 NTU), the effects on Ashokan East Basin effluent turbidity were moderate. Also at this time, following the completion of repairs to the Schoharie dam, DEP regained the flexibility to cut back Catskill aqueduct flows in order to limit the effect of Catskill turbidity on Kensico Reservoir. DEP felt that by reducing Catskill aqueduct flow it would be possible to maintain Kensico effluent turbidity below 5 NTU, without resorting to alum treatment. These simulations were done to confirm that alum treatment was not needed. Forecasts began on October 30 and continued until December 25. At the start of the simulation Kensico Reservoir's temperature and turbidity levels were initialized to values consistent with recent field surveys (vertical profiles) of these parameters. The same range of turbidity and sinking rates as used in the simulations described above were also used for these simulations, given the starting Ashokan effluent turbidity level of 8.7 NTU. Two sets of input flows to Kensico Reservoir were used. The first represented "normal" operating procedure with equal input flows from the Catskill and Delaware aqueducts of 600 MGD. The second forecast evaluated the impact of changes in reservoir operations: cutting back the Catskill aqueduct flow to 300 MGD, while increasing the Delaware aqueduct flow to 900 MGD.

The results of two simulation series using a fixed Catskill aqueduct input turbidity of 8 NTU at two different flow rates (300 or 600 MGD, Figure 6.5) show that even at the 600 MGD flow there would be a low chance of the Kensico effluent turbidity approaching the 5 NTU regulatory limit. However, given inherent levels of uncertainty in the simulations, and the possibility of future storms further increasing the Ashokan turbidity, the margin of safety in these predictions was judged to be small. Reducing the Catskill aqueduct flow to 300 MGD clearly eliminated the risk of unacceptable high turbidity levels at the Kensico effluent locations. This was due to dilution by the less turbid Delaware system water, and to the fact that settling and dilution were more effective at reducing turbidity during isothermal conditions found in Kensico Reservoir at this time of the year. These simulations provide an example of how DEP's modeling capabilities can aid in defining operational strategies that minimize the use of alum.

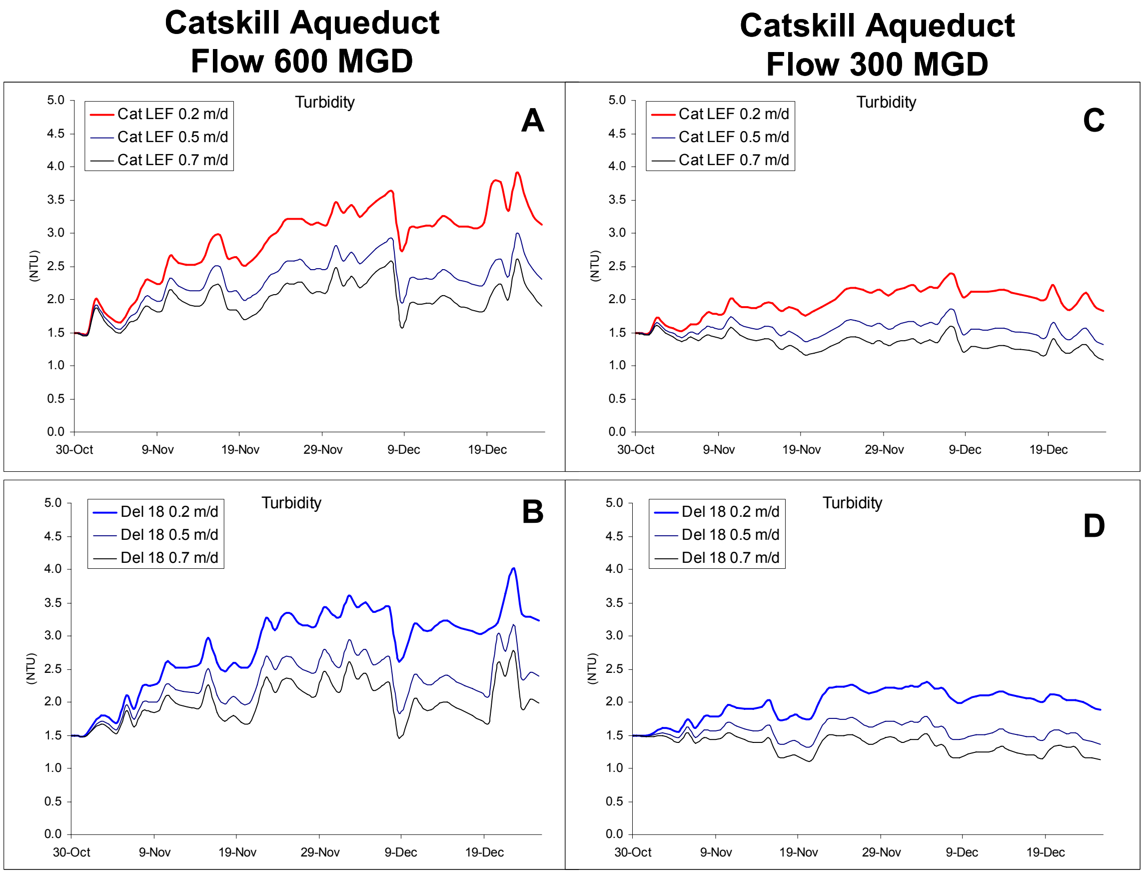


Figure 6.5 Forecast turbidity levels at the two Kensico Reservoir effluent locations. A fixed input turbidity of 8 NTU was used with two different Catskill aqueduct flow rates. Turbidity predictions using a 600 MGD flow are shown for the Catskill effluent (A) and Delaware effluent (B). For the 300 MGD flows, predicted turbidity levels are shown in C and D for the Catskill and Delaware aqueducts, respectively.

# 7. Further Research

## 7.1 How does DEP extend its capabilities for water quality monitoring and research?

DEP extends its capabilities through grants and contracts. To date, Safe Drinking Water Act (SDWA) grants (contracted to DEP through the New York State Department of Environmental Conservation (DEC)) have supported a number of DEP projects devoted to guiding watershed management. Up to the end of 2006 these grants have totaled approximately $2.9 million, and work to be paid for by two more SDWA grants will be completed in 2007. It should be noted that this amount is less than the amount stipulated in last year's report because not all the funds allocated could be used within the timeframe of the grant. These projects have typically allowed DEP to establish better data on existing watershed conditions and to estimate the effects of watershed programs or policies. In addition, contracts are needed to support the work of DEP.

## 7.2 What is the status of DEP projects supported through SDWA grants?

DEP secured funding in 2006 under SDWA Grants 5 and 6 to further several water quality research investigations. These research projects include:

### Kensico Stormwater BMP Efficiency Assessment

The primary goal of this one-year project is to assess the performance of stormwater BMP projects installed in the Kensico Reservoir watershed. This assessment will be performed by an independent consultant who will evaluate stormwater monitoring performed by DEP from 2000 to 2006. In addition to this data analysis task, a complete review of DEP's current Kensico stormwater BMP sampling program will be performed in order to standardize/improve sampling protocols and to improve sample collection and analysis methods.

### Modeling of Pathogen Fate and Transport in NYCDEP Reservoirs

This project will develop a fate and transport model for pathogens in the NYC water supply reservoirs, particularly pathogens that are present in low concentrations. This work will address conceptual and practical problems associated with the application of traditional water quality modeling techniques for these pathogens.

### Characterization of Pathogen-Particle Associations in the Water Column and Their Impact on the Management of New York City Source Water Quality

This project involves an evaluation of the partitioning behavior of *Giardia* and *Cryptosporidium* (where available), with attention to other indicator organisms (e.g., *E. coli*, *Cl. perfringens* spores, somatic coliphages, and F+ coliphages) as time and funds allow, in five perennial tributaries to Kensico Reservoir. Analyses will be conducted on samples collected under dry weather (base flow) conditions and throughout the duration of individual storm events. Coagulant work on a pilot scale will also be performed during this project.

An additional task has been added to this project as a follow up to results from the SDWA Grant 4 study, Genotyping of *Cryptosporidium* from Wildlife and Sediment Samples in the NYC Watershed. During the Grant 4 project, the targeted number of samples was not collected from certain species due to the seasonal absence of those species during the sampling period. As a result, part of the contract has been set aside to complete *Cryptosporidium* genotyping for approximately 60-70 additional samples. The study will be conducted in exactly the same fashion as the Grant 4 work, from methodology to sample cost.

### Advancements of Croton System Reservoir Models: 1D Water Quality Models

The purpose of this project is to develop fully calibrated and verified 1D water quality models for Muscoot, Titicus, Diverting, Croton Falls, Amawalk, and Cross River Reservoirs. Water quality sub-models will be added to the 1D hydrothermal models available for these reservoirs, and these will subsequently be calibrated and verified. For Muscoot and Croton Falls, where sediment-water nutrient exchange can lead to significant internal phosphorus loading, particular effort will be placed on calibrating and verifying the sediment-water sub-model developed under SDWA Grant 4.

### Advancements of Croton System Reservoir Models: 2D Water Quality Models

The purpose of this project is to develop a fully calibrated and verified 2D water quality model for the New Croton Reservoir. This model will include both the pelagic and sediment-water exchange water quality algorithms. When calibrating and verifying the model both vertical and longitudinal variations in water quality will be examined.

Table 7.1 displays the contract term for all these projects.

Also in 2006, final reports were submitted for a number of projects funded under SDWA Grant 4. Summaries of these projects can be found in the 2005 Research Objectives Report (DEP, 2005) (Ambient Surface Water Quality Monitoring of High Runoff, Wetland Water Quality Functional Assessment, Survey of Residential Fertilization Practices in the Croton Watersheds, Croton System Reservoir Model Development, New Croton Sediment-Nutrient Sub-Model), and the 2005 Annual Report (DEP, 2006f) (Genotyping of *Cryptosporidium* Oocysts and Ribotyping of *Escherichia coli* Isolates from Wildlife Fecal Samples within the New York City Watershed).

## 7.3 What work is supported through contracts?

DEP accomplishes several things through contracts, as listed in Table 7.1. The primary types of contracts are: i) Operation and Maintenance, ii) Monitoring, and iii) 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 (including SDWA grants) 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) | 10/1/06–9/30/09 |
| Operation and Maintenance of DEP's Hydrological Monitoring Network (Water Quality) | 10/1/06–9/30/10 |
| Waterfowl Management at Kensico Reservoir | 10/1/06–9/30/07 |
| SAS Software Contract | 6/24/03–6/30/08 |
| **Monitoring** | |
| Monitoring of NYC Reservoirs for Viruses | 1/29/07–1/28/08 |
| Monitoring of NYC Reservoirs for Zebra Mussels | 8/1/05–7/31/07 |
| Monitoring of NYC Residences for Lead and Copper | 1/1/07–12/31/09 |
| Organic Analysis Laboratory Contract | 3/1/07–2/28/08 |
| Bulk Chemical Analysis | 8/1/05–7/31/08 |
| Analysis of Stormwater at Beerston Cannonsville Watershed | 11/1/05–10/31/07 |
| **Research and Development** | |
| Design of Controls for Zebra Mussels in NYC's Water Supply System | 1/5/94–6/30/08 |
| Development of Turbidity Models for Schoharie Reservoir and Esopus Creek | 8/26/03–12/31/07 |
| Pathogen Monitoring Stations Project in the Counties of Delaware, Ulster, Greene, Sullivan and Westchester New York | 7/7/04–8/15/07 |
| Croton System Model Development and Protech (partially funded by SDWA grant and partially funded by DEP) | 11/15/05–11/14/08 |
| *Cryptosporidium* Oocysts in Wildlife and Stream Sediments (partially funded by SDWA Grant 5) | 3/1/06–8/31/07 |
| Occurrence and Partitioning of *Giardia* & *Cryptosporidium* within the Kensico Drainage Basin of the NYC Watershed (includes Modeling of Pathogen Fate and Transport in NYCDEP Reservoirs) (funded by SDWA Grant 5) | 9/1/06–8/31/07 |
| Advancements of Croton System Reservoir Models (funded by SDWA Grants 5 and 6) | 11/26/06-11/26/07 |
| Best Management Practices Efficiency Assessment Project | 2/5/07–2/5/08 |

## 7.4 How can DEP's modeling system be used to investigate the potential effects of climate change on the water supply?

In the Northeastern United States the effects to climate change are expected to lead to near certain increases in air temperature, and also some increases in precipitation, although these are less certain. (Figure. 7.1).

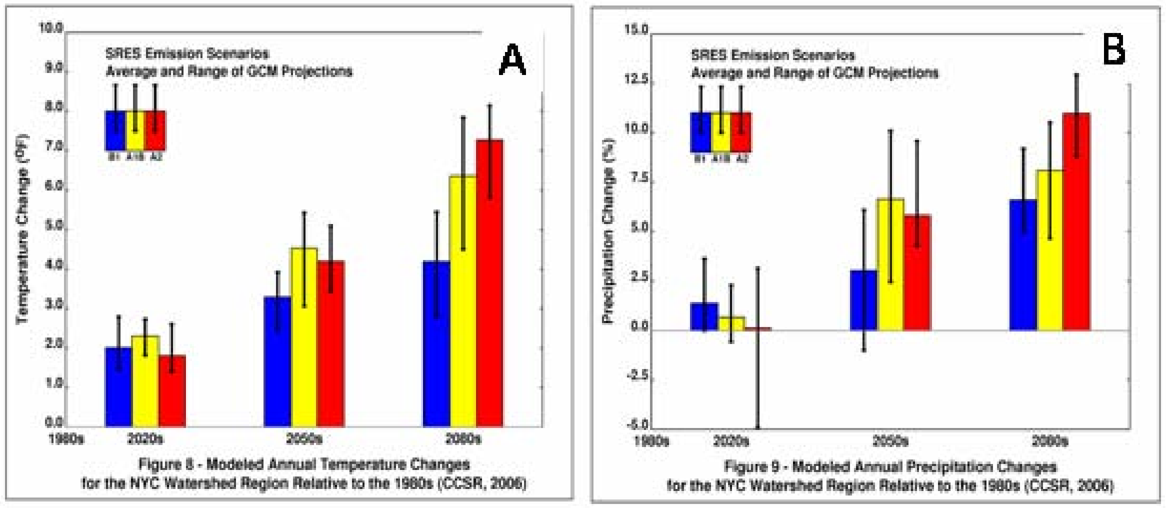


Figure 7.1 Predicted changes in air temperature (A) and precipitation (B) in the area encompassing the NYC water supply watersheds in the 2020, 2050, and 2080 decades.

Note: The different color bars show variations due to differing emission scenarios. The range associated with each bar is the variation obtained from using different GCM models. These data are from DEP, 2007d.

Climate change can potentially alter both the quantity and quality of water in the NYC drinking water supply. While it is easy to speculate on possible climate change effects, it is much more demanding to examine the potential effects of climate change in a quantitative framework that is consistent with DEP's present water quality modeling framework (Figure 7.2).

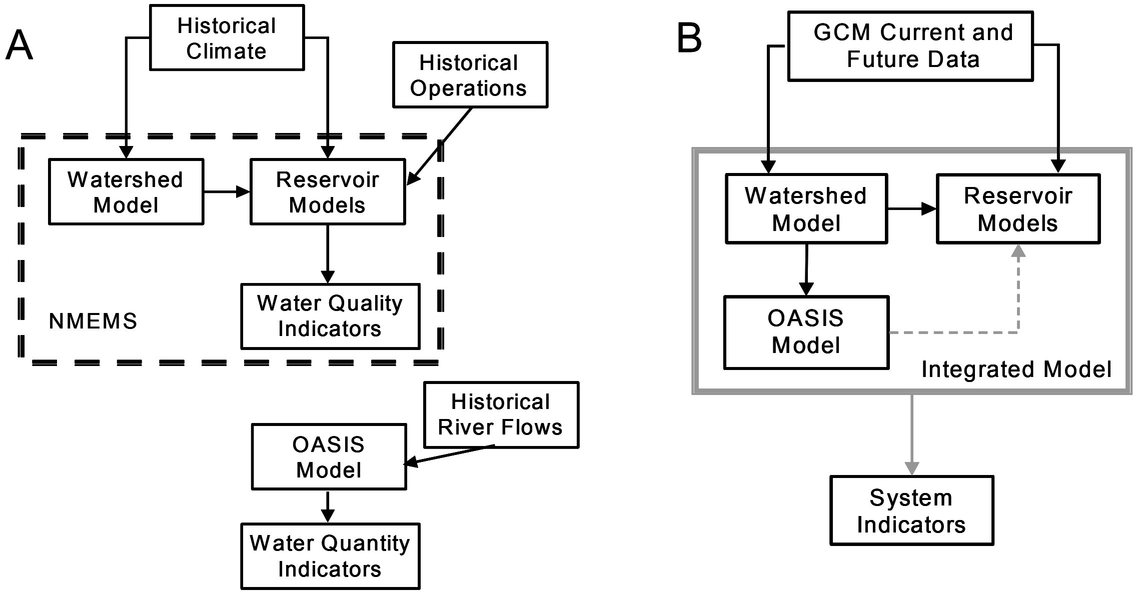


Figure 7.2 DEP's present configuration of models (A) and the configuration proposed for evaluating the effects of climate change. Note that in case B reservoir operations are derived from the OASIS model.

DEP's Nutrient Management Eutrophication Modeling System (NMEMS) is a tool that will allow quantitative estimates of the effects of climate change to be made given time series of present day and future climate data needed to drive the modeling system. A project is presently in the planning stages, which will attempt to use DEP's present system of models to simulate climate change effects on water quality in two "top of the system" reservoirs, i.e., reservoirs that do not receive inputs from other reservoirs. The planned simulations will look at changes in turbidity in the Schoharie Reservoir, and changes in eutrophication (chlorophyll concentration) in the Cannonsville reservoir. In order to examine the effects of climate change on the water supply, the modeling system will be modified in two ways:

1. Climate data will be derived from a variety of Global Climate Models (GCM) which would themselves be driven by a variety of emission scenarios. Making separate simulations driven by the output of different GCM/emission scenarios will allow the uncertainty in water quality predictions due to variations in climate model input to be assessed. Over the last year DEP has worked with Columbia University Center for Climate Systems Research (CU-CCSR) to obtain the GCM data needed to drive NMEMS. Presently DEP has data from three GCM models run under three different emission scenarios.

2. Water quality changes to a water body vary in part due to variations in climate influencing the thermal structure and mixing of the water body, and in part due to climate influencing watershed hydrology, biogeochemistry and the resultant loading of water and nutrients to the water body. In the case of reservoirs (as opposed to lakes) an additional factor influencing water

quality is the operations of the reservoir, which defines the amount and timing of the withdrawal of water from it. The NYC water supply is an interconnected system of 19 reservoirs, and a decision to withdraw water from any one reservoir is dependent on the status of the system as a whole, not only on the conditions in the reservoir under question. Simulations using the present version of NMEMS are run under historical time periods when known records of climate inputs and reservoir operations are available. To run future simulations, future climate inputs can be predicted from GCM models, but future operations will not be known. To solve this problem we plan to make a use of the OASIS system supply model that DEP presently uses to evaluate reservoir operations on a system wide basis. This model, which only concerns water quantity, has embedded rule sets that allow it to predict system flows at key points in the system such as reservoir effluents, as a function of hydrologic inputs to the reservoirs. Our plan is to drive OASIS with future river flows derived from GWLF in order to obtain future records of reservoir operations.

This work will provide simulations, under present and future climate conditions, which will provide preliminary predictions of the effects of climate change on reservoir water quality. Over a longer term, we hope this work will improve our ability to simulate the effects of climate change on the water supply. Anticipated modeling advances include: better downscaling of the GCM data, complete coupling of OASIS with NMEMS, and modifications to NMEMS to make it more suitable for simulating future climate conditions.

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# Glossary

**Alkalinity** – The acid-neutralizing (or buffering) capacity of water.

**Anthropogenic** – Man-made.

**Best management practice** (BMP) – Physical, structural, and/or managerial practices that, when used singly or in combination, prevent or reduce pollution of water (i.e., extended detention basin).

**Clarity (Visual )** – The distance an underwater target can be seen. Measured horizontally with a black disk (cf. Secchi disk).

**Coliforms** – A group of bacteria used as an indicator of microbial contamination in water.

**Conductivity –** A measure of the ability of a solution to carry an electrical current.

***Cryptosporidium* –** A protozoan causing the disease cryptosporidiosis.

**Cyst** – the infectious stage of *Giardia*, and some other protozoan parasites, that has a protective wall which provides resistance to environmental stress.

**Dissolved oxygen (DO)** – The amount of oxygen dissolved in water expressed in parts per million (ppm) or milligrams per liter (mg $L^{-1}$) or percent saturation.

***E. coli*** – A bacterial species inhabiting the intestinal tract of humans and other warm-blooded animals. Some *E. coli* can cause serious diseases.

**Eutrophic** – Water with elevated nutrient concentrations, elevated algal production, and often low in water clarity.

**Eutrophication** – Refers to the process where nutrient enrichment of water leads to excessive growth of aquatic plants, especially algae.

**Fecal coliforms –** A group of bacteria found in the intestinal tracts of people and warm-blooded animals. Their presence in water usually indicates pollution that may pose a health risk.

***Giardia*** – A protozoan that causes the disease giardiasis.

**Hydrology** – The science of the behavior of water in the atmosphere, on the surface of the earth, and underground.

**Keypoint** – A sampling location where water enters or leaves an aqueduct.

**Limnology** – The study of the physical, chemical, hydrological, and biological aspects of fresh waterbodies.

**Macroinvertebrate** – Organism that lacks a backbone and is large enough to be seen with the naked eye.

**Mesotrophic** – A waterbody intermediate in biological productivity between oligotrophic (low productivity) and eutrophic (high productivity) conditions.

**Nitrate** – A nutrient that is essential to plants and animals. Can cause algal blooms in water if all other nutrients are present in sufficient quantities.

**Nitrogen** – An element that is essential for plant and animal growth.

**Nutrients** – Substances necessary for the growth of all living things, such as nitrogen, carbon, potassium, and phosphorus. High concentrations of nutrients in waterbodies can contribute to algal blooms.

**Oligotrophic** – Water with low nutrient concentrations, low in algal production, and tending to have high water clarity.

**Oocyst** – A phase of the normal life cycle of an organism. It is characterized by a thick and environmentally resistant cell wall. *Cryptosporidium* are shed as oocysts.

**Pathogen –** A disease-producing agent, often a microorganism .

**pH** – A symbol for expressing the degree to which a solution is acidic or basic. It is based on a scale from roughly 0 (very acid) to roughly 14 (very basic). Pure water has a pH of 7 at 25°C.

**Phosphates** – Certain chemical compounds containing phosphorus. A plant nutrient.

**Phosphorus** – An essential chemical food element that can contribute to the eutrophication of lakes and other waterbodies. Increased phosphorus levels result from discharge of phosphorus-containing materials into surface waters.

**Photic zone** – Uppermost part in a body of water into which daylight penetrates in sufficient amounts to permit primary production.

**Phytoplankton** – Portion of the plankton community comprised of tiny plants, e.g., algae.

**Protozoa** – Mostly motile, single-celled organisms. Pathogenic intestinal protozoa can cause diarrhea or gastroenteritis of varying severity.

**Runoff** – Water from rain, snowmelt, or irrigation that flows over the ground and returns to streams. It can collect pollutants from air or land and carry them to streams and other waterbodies.

**Secchi disk** – A black-and-white disk used to measure the visual clarity of water. The disk is lowered into the water until it just disappears and then raised until it just reappears. The average of these two distances is the Secchi disk transparency (or depth).

**SPDES** – State Pollution Discharge Elimination System. The permitting program which regulates all discharges to surface water.

**Source Waters** – Kensico and New Croton are usually operated as source waters, but these reservoirs can be by-passed so that any or all of the following can be operated as source waters: Rondout, Ashokan East, Ashokan, and West Branch.

**Trophic State** – Refers to a level of biological productivity in a waterbody (i.e., eutrophic, mesotrophic, oligotrophic).

**Turbidity** – An arbitrary assessment of a water's cloudiness (actually, light side-scatter). For cloudy water, turbidity would be high; for clear water, turbidity would be low. It is inversely related to visual clarity.

**Watershed** – The area of land that drains into a specific waterbody.

**Wetland** – An area where water covers the soil or is present either at or near the surface of the soil all year (or at least for periods of time during the year).

# Appendix A  Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2006.

| | | Kensico | | | New Croton | | | East Ashokan Basin | | | Rondout | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analyte | WQS | N | Range | Median | N | Range | Median | N | Range | Median | N | Range | Median |
| PHYSICAL | | | | | | | | | | | | | |
| Temperature (°C) | | 282 | 4.6 - 20.9 | 11.5 | 282 | 4.7 - 24.5 | 11.45 | 123 | 4.1 - 22.8 | 11.0 | 200 | 3.5 - 21.6 | 10.2 |
| pH (units) | 6.5-8.5[1] | 269 | 5.8 - 7.5 | 7.0 | 239 | 6.8 - 8.5 | 7.5 | 93 | 6.2 - 8.1 | 7.2 | 200 | 6.3 - 8.3 | 6.9 |
| Alkalinity (mg/L) | | 11 | 8.6 - 11.7 | 10.2 | 28 | 52.4 - 70.2 | 59.6 | 9 | 9.3 - 12.1 | 10.1 | 9 | 5.1 - 7.9 | 7.6 |
| Conductivity (µS/cm) | | 282 | 54 - 74 | 65 | 282 | 275 - 357 | 333 | 104 | 48 - 59 | 57 | 200 | 34 - 53 | 47 |
| Hardness (mg/L)[2] | | 10 | 17.7 - 19.21 | 18.52 | 29 | 80.17 - 100.21 | 87.61 | 9 | 15.43 - 17.84 | 16.79 | 9 | 11.35 - 15.89 | 14.94 |
| Color (Pt-Co units) | (15) | 278 | 5 - 15 | 10 | 280 | 12 - 40 | 25 | 122 | 9 - 21 | 12 | 200 | 6 - 17 | 12 |
| Turbidity (NTU) | (5)[3] | 284 | 0.5 - 2.5 | 1.3 | 280 | 0.5 - 7.3 | 2.3 | 124 | 1.1 - 13 | 3.4 | 200 | 0.4 - 2.1 | 1.0 |
| Secchi Disk Depth (m) | | 79 | 1.7 - 6.0 | 4.5 | 91 | 1.3 - 3.8 | 2.5 | 31 | 0.9 - 4.7 | 2.9 | 48 | 1.3 - 5.6 | 4.4 |
| BIOLOGICAL | | | | | | | | | | | | | |
| Chlorophyll *a* (µg/L) | 7[4] | 45 | 1.3 - 7.2 | 4.2 | 65 | 1.3 - 41.1 | 11.2 | 26 | 0.5 - 8.3 | 3.6 | 22 | 2.7 - 9.7 | 7.4 |
| Total Phytoplankton (SAU) | 2000[4] | 143 | 5 - 960 | 300 | 106 | 70 - 3300 | 1100 | 82 | 5 - 800 | 215 | 119 | 5 - 1700 | 280 |
| CHEMICAL | | | | | | | | | | | | | |
| Dissolved Organic Carbon (mg/L) | | 139 | 0.6 - 2.2 | 1.7 | 183 | 2.2 - 4.2 | 3.1 | 70 | 1.2 - 2.3 | 1.7 | 80 | 1.3 - 2.4 | 1.6 |
| Total Phosphorus (µg/L) | 15[4] | 146 | 2 - 13 | 9 | 146 | 2 - 42 | 19 | 90 | 3 - 19 | 10 | 150 | 4 - 17 | 8 |
| Total Nitrogen (mg/L) | | 139 | 0.17 - 0.38 | 0.29 | 181 | 0.23 - 0.73 | 0.47 | 49 | 0.14 - 0.41 | 0.35 | 80 | 0.15 - 0.37 | 0.30 |
| Nitrate+Nitrite-N (mg/L) | 10[1] | 162 | 0.06 - 0.31 | 0.18 | 168 | 0.01 - 0.56 | 0.20 | 70 | 0.05 - 0.34 | 0.26 | 80 | 0.01 - 0.28 | 0.19 |
| Total Ammonia-N (mg/L) | 2[1] | 160 | 0.01 - 0.04 | 0.01 | 167 | 0.01 - 0.18 | 0.02 | 70 | 0.01 - 0.05 | 0.02 | 80 | 0 - 0.04 | 0.01 |
| Iron (mg/L) | 0.3[1] | 4 | 0.02 - 0.03 | 0.02 | 29 | 0.02 - 0.16 | 0.05 | 2 | 0.13 - 0.13 | 0.13 | 8 | 0.02 - 0.17 | 0.02 |
| Manganese (mg/L) | (0.05) | 4 | 0.01 - 0.07 | 0.02 | 29 | 0 - 0.24 | 0.03 | 2 | 0.02 - 0.02 | 0.02 | 8 | 0.02 - 0.19 | 0.03 |
| Lead (µg/L) | 50[1] | 4 | 0.5 - 0.5 | 0.5 | 29 | 0.5 - 2.2 | 0.5 | 2 | 0.5 - 0.5 | 0.5 | 8 | 0.5 - 0.5 | 0.5 |
| Copper (µg/L) | 200[1] | 4 | 1.5 - 1.5 | 1.5 | 29 | 1.5 - 1.5 | 1.5 | 2 | 1.5 - 1.5 | 1.5 | 8 | 1.5 - 1.5 | 1.5 |
| Calcium (mg/L) | | 10 | 5.07 - 5.65 | 5.44 | 29 | 20 - 26 | 22.6 | 9 | 4.71 - 5.46 | 5.18 | 9 | 3.31 - 4.6 | 4.35 |
| Sodium (mg/L) | | 10 | 4.31 - 5.33 | 4.73 | 29 | 25 - 31.8 | 30 | 9 | 3.23 - 3.89 | 3.51 | 9 | 2.92 - 4.16 | 3.35 |
| Chloride (mg/L) | 250[1] | 5 | 5.9 - 8 | 7.2 | 25 | 51 - 64.4 | 59.8 | 64 | 3.8 - 6.8 | 6.05 | 9 | 4.2 - 7.0 | 5.4 |

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2006.

| | | Amawalk | | | Bog Brook | | | Boyd Corners | | | Croton Falls | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analyte | WQS | N | Range | Median | N | Range | Median | N | Range | Median | N | Range | Median |
| PHYSICAL | | | | | | | | | | | | | |
| Temperature (°C) | | 29 | 6.5 - 27.5 | 14.1 | 33 | 7.6 - 25.82 | 11.3 | 12 | 14.6 - 25.7 | 24.8 | 39 | 7.9 - 24.4 | 16.0 |
| pH (units) | 6.5-8.5 [1] | 25 | 6.96 - 9.1 | 7.6 | 33 | 6.99 - 9.41 | 7.7 | 12 | 6.7 - 8.4 | 7.5 | 36 | 7 - 9.2 | 7.4 |
| Alkalinity (mg/L) | | 9 | 65.1 - 82.4 | 69.4 | 8 | 61.9 - 68.6 | 63.3 | 2 | 36.2 - 37.4 | 36.8 | 3 | 51.5 - 77.8 | 51.7 |
| Conductivity (µS/cm) | | 29 | 407 - 477 | 422 | 33 | 286 - 301 | 292 | 12 | 185 - 223 | 189.5 | 39 | 238 - 458 | 338 |
| Hardness (mg/L) [2] | | 9 | 97.87 - 105.94 | 103.63 | 9 | 85.35 - 91.82 | 87.17 | 2 | 45.18 - 46.51 | 45.85 | 3 | 72.97 - 84.87 | 73.14 |
| Color (Pt-Co units) | (15) | 29 | 15 - 80 | 22 | 33 | 12 - 60 | 20 | 22 | 30 - 45 | 35 | 39 | 10 - 40 | 22 |
| Turbidity (NTU) | (5) [3] | 29 | 1.6 - 6.4 | 3 | 33 | 1.2 - 8 | 2.1 | 22 | 1.3 - 4.5 | 2.15 | 39 | 1 - 20 | 2.2 |
| Secchi Disk Depth (m) | | 12 | 1.5 - 3.9 | 2.3 | 12 | 2.5 - 5.4 | 3.55 | 8 | 1.9 - 3.7 | 2.2 | 14 | 0.8 - 4.3 | 2.65 |
| BIOLOGICAL | | | | | | | | | | | | | |
| Chlorophyll *a* (µg/L) | 7 [4] | 10 | 4.9 - 20.1 | 14.6 | 13 | 2.0 - 20.7 | 7.5 | 10 | 2.4 - 24.8 | 9.2 | 12 | 2.5 - 153.9 | 12.7 |
| Total Phytoplankton (SAU) | 2000 [4] | 6 | 320 - 1900 | 1100 | 9 | 70 - 2400 | 1400 | 2 | 660 - 4500 | 2580 | 8 | 680 - 12000 | 1750 |
| CHEMICAL | | | | | | | | | | | | | |
| Dissolved Organic Carbon (mg/L) | | 24 | 2.9 - 4.1 | 3.3 | 28 | 3.2 - 4.0 | 3.45 | 21 | 3.1 - 4.3 | 3.7 | 31 | 2.2 - 4.1 | 2.9 |
| Total Phosphorus (µg/L) | 15 [4] | 24 | 13 - 153 | 24 | 23 | 12 - 41 | 17 | 14 | 13 - 20 | 18 | 37 | 2 - 117 | 19 |
| Total Nitrogen (mg/L) | | 23 | 0.22 - 0.74 | 0.36 | 28 | 0.18 - 0.48 | 0.24 | 16 | 0.11 - 0.25 | 0.21 | 31 | 0.18 - 1.03 | 0.30 |
| Nitrate+Nitrite-N (mg/L) | 10 [1] | 29 | 0.01 - 0.35 | 0.03 | 33 | 0.01 - 0.07 | 0.01 | 20 | 0.01 - 0.02 | 0.01 | 37 | 0.01 - 0.50 | 0.05 |
| Total Ammonia-N (mg/L) | 2 [1] | 29 | 0.01 - 0.89 | 0.03 | 33 | 0.01 - 0.29 | 0.02 | 20 | 0.01 - 0.02 | 0.01 | 37 | 0.01 - 0.91 | 0.02 |
| Iron (mg/L) | 0.3 [1] | 1 | 0.07 - 0.07 | 0.07 | 3 | 0.02 - 1.2 | 0.08 | 2 | 0.09 - 0.1 | 0.10 | 2 | 0.03 - 0.03 | 0.03 |
| Manganese (mg/L) | (0.05) | 1 | 0.04 - 0.04 | 0.04 | 3 | 0.01 - 0.39 | 0.02 | 2 | 0.02 - 0.03 | 0.02 | 2 | 0.02 - 0.51 | 0.26 |
| Lead (µg/L) | 50 [1] | 1 | 0.5 - 0.5 | 0.5 | 3 | 0.5 - 0.5 | 0.5 | 2 | 0.5 - 0.5 | 0.5 | 2 | 0.5 - 0.5 | 0.5 |
| Copper (µg/L) | 200 [1] | 1 | 1.5 - 1.5 | 1.5 | 3 | 1.5 - 1.5 | 1.5 | 2 | 1.5 - 1.5 | 1.5 | 2 | 1.5 - 1.5 | 1.5 |
| Calcium (mg/L) | | 9 | 23 - 26.4 | 26.0 | 9 | 21.4 - 23 | 22.0 | 2 | 11.4 - 11.7 | 11.55 | 3 | 18.9 - 22.0 | 19.0 |
| Sodium (mg/L) | | 9 | 38.9 - 42.2 | 40.4 | 9 | 21.7 - 23.9 | 22.9 | 2 | 18.7 - 18.8 | 18.75 | 3 | 27.2 - 30.4 | 27.8 |
| Chloride (mg/L) | 250 [1] | 9 | 77.1 - 83.9 | 82.0 | 9 | 44.6 - 47.6 | 46.7 | 2 | 6.3 - 32.3 | 19.3 | 2 | 52.6 - 61.8 | 57.2 |

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2006.

| | | Cross River | | | Diverting | | | East Branch | | | Lake Gilead | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analyte | WQS | N | Range | Median | N | Range | Median | N | Range | Median | N | Range | Median |
| PHYSICAL | | | | | | | | | | | | | |
| Temperature (°C) | | 47 | 5.0 - 26.0 | 10.1 | 10 | 18.9 - 23.2 | 20.6 | 35 | 6.3 - 25.4 | 9 | 25 | 4.3 - 24.1 | 4.6 |
| pH (units) | 6.5-8.5 [1] | 41 | 6.6 - 9.0 | 7.4 | 10 | 7.2 - 8.8 | 7.6 | 35 | 7.0 - 8.8 | 7.4 | 15 | 6.9 - 9.1 | 7.0 |
| Alkalinity (mg/L) | | 9 | 39.6 - 48.4 | 43 | 2 | 80.9 - 83.1 | 82.0 | 8 | 70.5 - 93.6 | 76.1 | 3 | 39.2 - 45.8 | 40.8 |
| Conductivity (µS/cm) | | 47 | 206 - 233 | 222 | 10 | 322 - 365 | 336 | 35 | 253 - 334 | 320 | 15 | 186 - 207 | 189 |
| Hardness (mg/L) [2] | | 9 | 61.17 - 63.83 | 62.63 | 2 | 98.33 - 103.1 | 100.72 | 9 | 84.15 - 112.39 | 100.74 | 3 | 53.09 - 57.33 | 55.5 |
| Color (Pt-Co units) | (15) | 48 | 15 - 60 | 22 | 6 | 30 - 45 | 38 | 35 | 18 - 60 | 32 | 9 | 8 - 22 | 12 |
| Turbidity (NTU) | (5) [3] | 48 | 1.3 - 5.4 | 2.2 | 6 | 3.0 - 5.6 | 3.6 | 35 | 1.3 - 9.9 | 2.4 | 9 | 0.9 - 9.2 | 1.7 |
| Secchi Disk Depth (m) | | 16 | 2.3 - 3.2 | 2.8 | 6 | 0.9 - 1.9 | 1.4 | 14 | 1.6 - 4.1 | 2.4 | 5 | 3.4 - 5.5 | 4.6 |
| BIOLOGICAL | | | | | | | | | | | | | |
| Chlorophyll *a* (µg/L) | 7 [4] | 16 | 4.3 - 13.5 | 9.1 | 4 | 14.5 - 25.2 | 23.8 | 13 | 1.5 - 32.4 | 15.5 | 2 | 4 - 5.5 | 4.8 |
| Total Phytoplankton (SAU) | 2000 [4] | 8 | 590 - 2300 | 1080 | 2 | 4200 - 4600 | 4400 | 9 | 260 - 5200 | 1400 | 2 | 150 - 850 | 500 |
| CHEMICAL | | | | | | | | | | | | | |
| Dissolved Organic Carbon (mg/L) | | 42 | 2.6 - 4.0 | 3.2 | 6 | 4.4 - 5.2 | 4.8 | 30 | 2.7 - 5.7 | 3.7 | 6 | 3 - 3.7 | 3.2 |
| Total Phosphorus (µg/L) | 15 [4] | 35 | 12 - 29 | 18 | 6 | 27 - 37 | 35 | 25 | 13 - 100 | 20 | 14 | 10 - 405 | 20 |
| Total Nitrogen (mg/L) | | 42 | 0.04 - 0.6 | 0.28 | 5 | 0.32 - 0.57 | 0.37 | 30 | 0.21 - 1.01 | 0.34 | 6 | 0.21 - 0.6 | 0.25 |
| Nitrate+Nitrite-N (mg/L) | 10 [1] | 42 | 0.01 - 0.23 | 0.03 | 6 | 0.01 - 0.15 | 0.05 | 35 | 0.01 - 0.22 | 0.01 | 6 | 0.01 - 0.11 | 0.02 |
| Total Ammonia-N (mg/L) | 2 [1] | 42 | 0.01 - 0.25 | 0.01 | 6 | 0.01 - 0.11 | 0.01 | 35 | 0.01 - 0.36 | 0.05 | 6 | 0.01 - 0.28 | 0.01 |
| Iron (mg/L) | 0.3 [1] | 3 | 0.03 - 0.41 | 0.06 | 0 | - | - | 3 | 0.03 - 1.01 | 0.09 | 2 | 0.09 - 0.16 | 0.13 |
| Manganese (mg/L) | (0.05) | 3 | 0.01 - 0.73 | 0.01 | 0 | - | - | 3 | 0.02 - 0.71 | 0.02 | 2 | 0.02 - 0.51 | 0.26 |
| Lead (µg/L) | 50 [1] | 3 | 0.5 - 0.5 | 0.5 | 0 | - | - | 3 | 0.5 - 0.5 | 0.5 | 2 | 0.5 - 0.5 | 0.5 |
| Copper (µg/L) | 200 [1] | 3 | 1.5 - 1.5 | 1.5 | 0 | - | - | 3 | 1.5 - 1.5 | 1.5 | 2 | 1.5 - 1.5 | 1.5 |
| Calcium (mg/L) | | 9 | 16.4 - 17.5 | 16.9 | 2 | 25 - 26.3 | 25.7 | 9 | 21.2 - 28.7 | 25.6 | 3 | 13.1 - 14.5 | 13.9 |
| Sodium (mg/L) | | 9 | 15.7 - 18.2 | 17.4 | 2 | 23.8 - 24 | 23.9 | 9 | 15.9 - 23.9 | 20.9 | 3 | 13.8 - 13.9 | 13.9 |
| Chloride (mg/L) | 250 [1] | 9 | 8.9 - 37.1 | 36 | 2 | 48.2 - 48.5 | 48.4 | 8 | 34.1 - 48.5 | 44.3 | 3 | 27.6 - 27.7 | 27.6 |

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2006.

| | | | Lake Gleneida | | | Kirk Lake | | | Muscoot | | | Middle Branch | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analyte | WQS | N | Range | Median | N | Range | Median | N | Range | Median | N | Range | Median |
| PHYSICAL | | | | | | | | | | | | | |
| Temperature (°C) | | 29 | 4.7 - 23.8 | 6.2 | 25 | 7.7 - 28.3 | 19.1 | 39 | 7.8 - 24.9 | 16.4 | 25 | 8.9 - 22.2 | 12.4 |
| pH (units) | 6.5-8.5 [1] | 19 | 7.1 - 8.9 | 7.4 | 15 | 6.9 - 8.9 | 7.4 | 32 | 7 - 8.4 | 7.7 | 20 | 6.8 - 8.4 | 7.6 |
| Alkalinity (mg/L) | | 5 | 62 - 70.4 | 65.3 | 3 | 54 - 55.3 | 54.5 | 5 | 56.5 - 71.1 | 59.5 | 6 | 49.2 - 58.7 | 54.1 |
| Conductivity (µS/cm) | | 19 | 366 - 413 | 374 | 15 | 283 - 340 | 301 | 39 | 233 - 401 | 320 | 25 | 383 - 442 | 422 |
| Hardness (mg/L) [2] | | 6 | 87.41 - 95.74 | 93.65 | 3 | 80.49 - 82.85 | 81.98 | 5 | 75.58 - 96.22 | 90.78 | 6 | 77.28 - 86.83 | 81.87 |
| Color (Pt-Co units) | (15) | 12 | 8 - 25 | 10 | 9 | 22 - 40 | 30 | 37 | 20 - 50 | 30 | 25 | 18 - 40 | 25 |
| Turbidity (NTU) | (5) [3] | 13 | 0.9 - 4.0 | 1.8 | 9 | 2.6 - 6 | 3.7 | 37 | 1.8 - 6.4 | 3.3 | 25 | 1.8 - 4.2 | 3.1 |
| Secchi Disk Depth (m) | | 6 | 4.3 - 5.6 | 5.2 | 16 | 1.3 - 3.2 | 1.9 | 19 | 1.5 - 3.9 | 2.3 | 10 | 2.1 - 3.6 | 2.7 |
| BIOLOGICAL | | | | | | | | | | | | | |
| Chlorophyll *a* (µg/L) | 7 [4] | 3 | 1.7 - 2.7 | 2.6 | 2 | 8.1 - 9.8 | 9.0 | 22 | 0.6 - 25.5 | 10.0 | 9 | 3.1 - 14.6 | 8.8 |
| Total Phytoplankton (SAU) | 2000 [4] | 3 | 130 - 820 | 190 | 2 | 480 - 1200 | 840 | 18 | 230 - 3700 | 1150 | 4 | 680 - 1200 | 965 |
| CHEMICAL | | | | | | | | | | | | | |
| Dissolved Organic Carbon (mg/L) | | 9 | 2.8 - 3.5 | 3.1 | 6 | 4.4 - 4.7 | 4.6 | 33 | 2.7 - 4.4 | 3.6 | 20 | 2.2 - 3.8 | 2.8 |
| Total Phosphorus (µg/L) | 15 [4] | 17 | 7 - 188 | 18 | 14 | 22 - 44 | 29 | 37 | 18 - 41 | 26 | 25 | 15 - 38 | 24 |
| Total Nitrogen (mg/L) | | 9 | 0.23 - 0.6 | 0.25 | 5 | 0.26 - 0.32 | 0.28 | 33 | 0.24 - 0.9 | 0.4 | 20 | 0.26 - 0.55 | 0.39 |
| Nitrate+Nitrite-N (mg/L) | 10 [1] | 9 | 0.01 - 0.02 | 0.01 | 6 | 0.01 - 0.01 | 0.01 | 37 | 0.01 - 0.6 | 0.18 | 25 | 0.01 - 0.31 | 0.14 |
| Total Ammonia-N (mg/L) | 2 [1] | 9 | 0.01 - 0.36 | 0.01 | 6 | 0.01 - 0.02 | 0.01 | 35 | 0.01 - 0.16 | 0.02 | 25 | 0.01 - 0.21 | 0.02 |
| Iron (mg/L) | 0.3 [1] | 3 | 0.02 - 0.53 | 0.07 | 2 | 0.03 - 0.04 | 0.04 | 3 | 0.13 - 0.3 | 0.13 | 0 | - | - |
| Manganese (mg/L) | (0.05) | 3 | 0.01 - 1.45 | 0.02 | 2 | 0.02 - 0.04 | 0.03 | 3 | 0.03 - 0.22 | 0.05 | 0 | - | - |
| Lead (µg/L) | 50 [1] | 3 | 0.5 - 0.5 | 0.5 | 2 | 0.5 - 0.5 | 0.5 | 3 | 0.5 - 0.5 | 0.5 | 0 | - | - |
| Copper (µg/L) | 200 [1] | 3 | 1.5 - 1.5 | 1.5 | 2 | 1.5 - 1.5 | 1.5 | 3 | 1.5 - 1.5 | 1.5 | 0 | - | - |
| Calcium (mg/L) | | 6 | 21.4 - 25 | 23.9 | 3 | 19.8 - 20.4 | 20.1 | 5 | 19.6 - 24.5 | 24.4 | 6 | 19.7 - 22.8 | 21.15 |
| Sodium (mg/L) | | 6 | 36.1 - 39.5 | 37.5 | 3 | 24.1 - 25.6 | 24.6 | 5 | 23.4 - 30.8 | 27.8 | 6 | 42.1 - 55.3 | 49.25 |
| Chloride (mg/L) | 250 [1] | 6 | 72.2 - 72.8 | 72.6 | 3 | 52.3 - 53 | 53 | 4 | 53.7 - 65.7 | 55.45 | 6 | 77.1 - 95.3 | 87.2 |

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2006.

| | | Titicus | | | West Branch | | | West Ashokan Basin | | | Pepacton | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Analyte | WQS | N | Range | Median | N | Range | Median | N | Range | Median | N | Range | Median |
| PHYSICAL | | | | | | | | | | | | | |
| Temperature (°C) | | 41 | 5.3 - 26.1 | 11.2 | 131 | 3.8 - 17.5 | 13 | 201 | 4.5 - 20.7 | 11.07 | 290 | 2.5 - 21.8 | 8.7 |
| pH (units) | 6.5-8.5[1] | 35 | 6.9 - 8.9 | 7.6 | 122 | 6.4 - 7.6 | 7.1 | 168 | 6.3 - 7.6 | 7.0 | 257 | 6.4 - 9.1 | 7.2 |
| Alkalinity (mg/L) | | 10 | 62.5 - 71.1 | 66.7 | 13 | 9.4 - 27.1 | 12.5 | 12 | 9.3 - 12.8 | 10.4 | 21 | 9.9 - 13.3 | 10.8 |
| Conductivity (µS/cm) | | 41 | 255 - 281 | 266 | 130 | 51 - 148 | 76 | 172 | 42 - 66 | 57.4 | 274 | 45 - 60 | 55 |
| Hardness (mg/L)[2] | | 8 | 85.32 - 88.15 | 87.26 | 14 | 16.98 - 40.34 | 23.18 | 12 | 16.07 - 18.04 | 17.24 | 21 | 17.42 - 20.27 | 19.29 |
| Color (Pt-Co units) | (15) | 41 | 17 - 40 | 25 | 131 | 10 - 22 | 15 | 181 | 11 - 22 | 15 | 232 | 6 - 21 | 12 |
| Turbidity (NTU) | (5)[3] | 41 | 1.5 - 5.1 | 2.8 | 131 | 0.7 - 2.3 | 1.4 | 206 | 2.0 - 45.0 | 8.0 | 278 | 0.6 - 10 | 1.6 |
| Secchi Disk Depth (m) | | 16 | 2 - 3.1 | 2.7 | 58 | 2.2 - 5 | 4.05 | 45 | 0.3 - 3 | 1.9 | 86 | 1 - 5.1 | 3.6 |
| BIOLOGICAL | | | | | | | | | | | | | |
| Chlorophyll *a* (µg/L) | 7[4] | 15 | 4.3 - 23.5 | 8.8 | 29 | 1.7 - 11.2 | 6.0 | 36 | 0.8 - 8.1 | 2.88 | 43 | 1.7 - 9.0 | 6.0 |
| Total Phytoplankton (SAU) | 2000[4] | 8 | 95 - 6400 | 1300 | 72 | 23 - 950 | 420 | 104 | 2.5 - 600 | 65.5 | 109 | 2.5 - 1600 | 360 |
| CHEMICAL | | | | | | | | | | | | | |
| Dissolved Organic Carbon (mg/L) | | 35 | 2.7 - 4.2 | 3.5 | 57 | 1.5 - 2.6 | 1.9 | 100 | 1.1 - 2.5 | 1.8 | 167 | 1.1 - 2.0 | 1.4 |
| Total Phosphorus (µg/L) | 15[4] | 26 | 15 - 103 | 24.5 | 52 | 6 - 24 | 10 | 146 | 3 - 26 | 11 | 264 | 2 - 26 | 10 |
| Total Nitrogen (mg/L) | | 35 | 0.19 - 0.75 | 0.27 | 64 | 0.11 - 0.33 | 0.23 | 77 | 0.17 - 0.50 | 0.41 | 136 | 0.16 - 0.39 | 0.31 |
| Nitrate+Nitrite-N (mg/L) | 10[1] | 31 | 0.01 - 0.45 | 0.03 | 62 | 0.01 - 0.18 | 0.12 | 100 | 0.08 - 0.4 | 0.35 | 163 | 0.01 - 0.3 | 0.21 |
| Total Ammonia-N (mg/L) | 2[1] | 31 | 0.01 - 0.36 | 0.01 | 62 | 0.01 - 0.03 | 0.01 | 100 | 0.01 - 0.04 | 0.02 | 167 | 0 - 0.04 | 0.00 |
| Iron (mg/L) | 0.3[1] | 4 | 0.03 - 0.25 | 0.08 | 4 | 0.02 - 0.05 | 0.03 | 4 | 0.17 - 0.64 | 0.2 | 8 | 0.02 - 0.47 | 0.02 |
| Manganese (mg/L) | (0.05) | 4 | 0.02 - 0.64 | 0.07 | 4 | 0.01 - 0.02 | 0.02 | 4 | 0.02 - 0.09 | 0.07 | 8 | 0.02 - 0.07 | 0.02 |
| Lead (µg/L) | 50[1] | 4 | 0.5 - 0.5 | 0.5 | 4 | 0.5 - 0.5 | 0.5 | 4 | 0.5 - 0.5 | 0.5 | 8 | 0.5 - 0.5 | 0.5 |
| Copper (µg/L) | 200[1] | 4 | 1.5 - 1.5 | 1.5 | 4 | 1.5 - 1.5 | 1.5 | 4 | 1.5 - 3.5 | 2.4 | 8 | 1.5 - 1.5 | 1.5 |
| Calcium (mg/L) | | 8 | 21.7 - 23.1 | 22.6 | 14 | 4.74 - 10.3 | 6.25 | 12 | 4.9 - 5.56 | 5.34 | 21 | 5.21 - 6.09 | 5.68 |
| Sodium (mg/L) | | 8 | 16.6 - 18.3 | 17.95 | 14 | 4.45 - 14.7 | 8.17 | 12 | 2.76 - 4.76 | 3.65 | 21 | 2.99 - 3.86 | 3.68 |
| Chloride (mg/L) | 250[1] | 6 | 32.4 - 37.3 | 34.8 | 13 | 6.1 - 26.8 | 11.5 | 100 | 2.7 - 8.9 | 6.2 | 21 | 4.2 - 6.7 | 5.9 |

Appendix Table A.1. Reservoir-wide summary statistics for a variety of physical, biological, and chemical analytes, 2006.

| | | Neversink | | | Schoharie | | | Cannonsville | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Analyte | WQS | N | Range | Median | N | Range | Median | N | Range | Median |
| PHYSICAL | | | | | | | | | | |
| Temperature (°C) | | 186 | 4.7 - 22.1 | 8.9 | 124 | 4.1 - 20.9 | 8.9 | 261 | 3.2 - 23.3 | 11.1 |
| pH (units) | 6.5-8.5[1] | 186 | 5.7 - 7.0 | 6.4 | 113 | 6.4 - 7.7 | 7.1 | 228 | 6.4 - 8.9 | 7.2 |
| Alkalinity (mg/L) | | 9 | 2.1 - 2.7 | 2.4 | 8 | 12.4 - 16.8 | 12.9 | 18 | 11.8 - 22.7 | 15.5 |
| Conductivity (µS/cm) | | 182 | 18.9 - 28.7 | 25.6 | 105 | 45 - 83 | 65 | 246 | 59.2 - 94 | 79.1 |
| Hardness (mg/L)[2] | | 9 | 7.39 - 8.32 | 7.98 | 8 | 18.5 - 22.06 | 20.08 | 18 | 21.46 - 34.56 | 24.07 |
| Color (Pt-Co units) | (15) | 171 | 6 - 24 | 13 | 78 | 10 - 29 | 22 | 222 | 6 - 48 | 16 |
| Turbidity (NTU) | (5)[3] | 186 | 0.3 - 4.9 | 1.1 | 124 | 1.7 - 30.0 | 14.0 | 237 | 0.5 - 45.0 | 4.3 |
| Secchi Disk Depth (m) | | 57 | 1.6 - 6.1 | 4.3 | 43 | 0.4 - 2 | 1.1 | 79 | 0.6 - 4.8 | 2.5 |
| BIOLOGICAL | | | | | | | | | | |
| Chlorophyll *a* (µg/L) | 7[4] | 29 | 2.2 - 8.9 | 6.2 | 23 | 0.5 - 26.5 | 2.0 | 61 | 1.8 - 38.5 | 8.7 |
| Total Phytoplankton (SAU) | 2000[4] | 86 | 2.5 - 770 | 245 | 51 | 2.5 - 350 | 21 | 111 | 2.5 - 3800 | 420 |
| CHEMICAL | | | | | | | | | | |
| Dissolved Organic Carbon (mg/L) | | 89 | 1.4 - 3.6 | 1.9 | 51 | 1.1 - 2.9 | 2.4 | 183 | 0.9 - 2.9 | 1.8 |
| Total Phosphorus (µg/L) | 15[4] | 176 | 4 - 14 | 7 | 108 | 6 - 35 | 17 | 249 | 5 - 68 | 17 |
| Total Nitrogen (mg/L) | | 89 | 0.16 - 0.37 | 0.29 | 45 | 0.16 - 0.47 | 0.37 | 120 | 0.25 - 0.66 | 0.53 |
| Nitrate+Nitrite-N (mg/L) | 10[1] | 89 | 0.01 - 0.3 | 0.17 | 51 | 0.06 - 0.36 | 0.26 | 183 | 0.01 - 0.59 | 0.40 |
| Total Ammonia-N (mg/L) | 2[1] | 78 | 0 - 0.04 | 0.01 | 51 | 0.01 - 0.08 | 0.03 | 183 | 0 - 0.07 | 0.01 |
| Iron (mg/L) | 0.3[1] | 7 | 0.04 - 0.13 | 0.07 | 3 | 0.02 - 0.89 | 0.37 | 8 | 0.02 - 0.68 | 0.19 |
| Manganese (mg/L) | (0.05) | 7 | 0.03 - 0.26 | 0.03 | 3 | 0.07 - 0.1 | 0.08 | 8 | 0.01 - 0.04 | 0.02 |
| Lead (µg/L) | 50[1] | 7 | 0.5 - 0.5 | 0.5 | 3 | 0.5 - 0.5 | 0.5 | 8 | 0.5 - 0.5 | 0.5 |
| Copper (µg/L) | 200[1] | 7 | 1.5 - 1.5 | 1.5 | 3 | 1.5 - 1.5 | 1.5 | 8 | 1.5 - 3.3 | 1.5 |
| Calcium (mg/L) | | 9 | 2.15 - 2.39 | 2.29 | 8 | 5.76 - 6.97 | 6.26 | 18 | 6.04 - 9.98 | 6.82 |
| Sodium (mg/L) | | 9 | 1.28 - 1.99 | 1.6 | 8 | 3.52 - 5.72 | 4.33 | 18 | 5.37 - 8.23 | 5.97 |
| Chloride (mg/L) | 250[1] | 6 | 2.14 - 2.93 | 2.45 | 51 | 4.4 - 10.4 | 6.9 | 18 | 7.56 - 12.2 | 8.94 |

## Notes for Appendix A:

### Footnotes:

**1** = Numeric water quality standards, from 6NYCRR, Part 703.

**2** = Hardness calculated as follows:

$$\text{Hardness}=2.497[\text{Ca}^{+2}] + 4.118[\text{Mg}^{+2}]$$

**3** = Narrative water quality standards.

**4** = NYCDEP target values are listed for chlorophyll a, total phosphorus and total phytoplankton. The total phosphorus target value of 15 µg L-1 applies to source water reservoirs only and has been adopted by NYSDEC in the TMDL Program. The turbidity, color and manganese standards in parentheses are only applicable to keypoint and treated water, respectively, but are supplied to provide context for the reservoir data

### Abbreviations:

**N** = number of samples

**Range** = minimum to 95%-ile (to avoid the occasional outlier in the dataset)

**ND** = non detect

**SAU** = standard areal units

### Data Analysis Considerations:

Most reservoirs are sampled at least monthly from April to November. Exceptions include the controlled lakes Gleneida, Kirk and Gilead, which are only sampled 3 times per year. Some reservoirs (e.g., Boyd Corners, Croton Falls, Muscoot, Diverting, and Middle Branch) had fewer samples because of boat malfunctions and because of limited access due to dam rehabilitation work. 2006 EOH water quality data are considered provisional at this time as they have not been fully reviewed in time for this publication.

For most parameters, the data for each reservoir represent a statistical summary of all samples taken at the sites and depths listed in Objective 3.3, Reservoir Status, of the Integrated Monitoring Report (DEP, 2003).

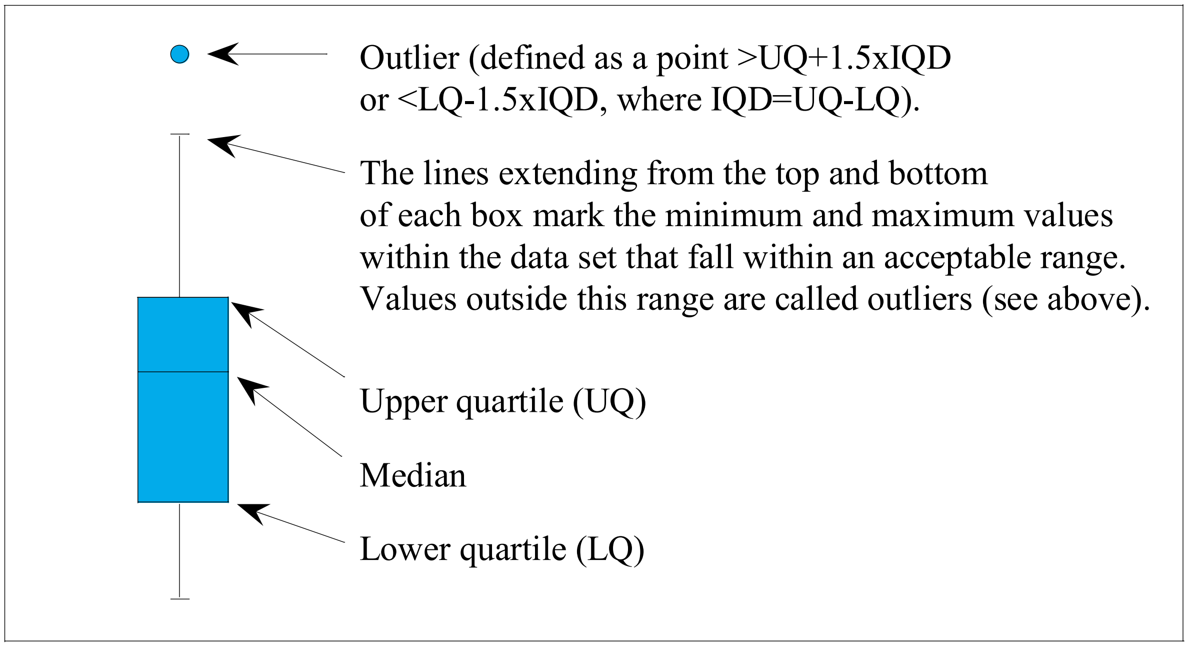
Chlorophyll *a* results are from surface samples collected at a 3-meter depth from April–November. Note that this differs from the trophic status box plots presented in Chapter 3 (Figure 3.12), which only consider photic samples collected from the growing season (May–October).

Values less than the detection limit have been converted to half the detection limit for all calculations. Analytical detection limits vary by analyte and laboratory.

## Analytical Methods:

In general all analytical methods are taken from Standard Methods (APHA, 1998, 2001). Details are available on request.

# Appendix B  Key to Box Plots



Outlier (defined as a point >UQ+1.5xIQD or <LQ-1.5xIQD, where IQD=UQ-LQ).

The lines extending from the top and bottom of each box mark the minimum and maximum values within the data set that fall within an acceptable range. Values outside this range are called outliers (see above).

Upper quartile (UQ)

Median

Lower quartile (LQ)

# Appendix C Phosphorus-Restricted Basin Assessment Methodology

A phosphorus restricted basin is defined in the New York City Watershed Regulations as "the drainage basin of a reservoir or controlled lake in which the phosphorus load to the reservoir or controlled lake results in the phosphorus water quality values established by the New York State Department of Environmental Conservation and set forth in its Technical and Operational Guidance Series (TOGS) 1.1.1, Ambient Water Quality and Guidance Values (October 22, 1993) being exceeded as determined by the Department pursuant to its annual review conducted under Section 18-48c of Subchapter D." The designation of a reservoir basin as phosphorus restricted 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 a 2-year, 24-hour storm. 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 list of phosphorus-restricted basins is updated annually. The data utilized in the analysis is from the routine limnological monitoring of the reservoirs. All reservoir samples taken during the growing season, which is defined as May 1 through October 31, are used. 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 $\mu g\ L^{-1}$. Phosphorus concentration data for the reservoirs approaches a lognormal distribution; therefore, the geometric mean is used to characterize the annual phosphorus concentrations.

The five most recent annual geometric means are averaged arithmetically, and this average constitutes one assessment. The "running average" method weights each year equally thus reducing the effects of unusual hydrology or phosphorus loading for any given year, while maintaining an accurate assessment of the current conditions in the reservoir. If any reservoir has less than three surveys during a growing season, then that 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 $\mu g\ L^{-1}$. A basin is **unrestricted** if the five-year mean plus standard error is below the guidance value of 20 $\mu g\ L^{-1}$, and phosphorus-**restricted** if it is equal to or greater than 20 $\mu g\ L^{-1}$, 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. Any recorded concentrations below the analytical limit of detection are set equal to half the detection limit.

| Reservoir Basin | 2001 μg $L^{-1}$ | 2002 μg $L^{-1}$ | 2003 μg $L^{-1}$ | 2004 μg $L^{-1}$ | 2005 μg $L^{-1}$ | 2006 μg $L^{-1}$ |
|---|---|---|---|---|---|---|
| **Delaware District** | | | | | | |
| Cannonsville Reservoir | 19.3 | 17.9 | 15.4 | 15.1 | 19.6 | 20.5 |
| Neversink Reservoir | 5.8 | 4.7 | 5.2 | 5.0 | 7.3 | 7.3 |
| Rondout Reservoir | 7.4 | 8.8 | 6.8 | 8.6 | 7.8 | 8.6 |
| **Catskill District** | | | | | | |
| Schoharie Reservoir | 15.2 | 11.7 | 7.5 | 13.3 | 20.6 | 17.4 |
| Ashokan-West Reservoir | 9.2 | 9.6 | 6.1 | 9.3 | 26 | 11.2 |
| Ashokan-East Reservoir | 7.9 | 12.4 | 7.0 | 10 | 11.0 | 9.9 |
| **Croton District** | | | | | | |
| Amawalk Reservoir | 19.8 | 22.2 | 19.6 | 26.5 | 24.0 | 24.5 |
| Bog Brook Reservoir | 21.4 | * | 16.9 | 26.8 | 18.6 | 18.7 |
| Boyd Corners Reservoir | 13.6 | 15.9 | 12.4 | 13.8 | * | 17.4 |
| Cross River Reservoir | 14.8 | 20.3 | 17.9 | 20.2 | 18.7 | 18.6 |
| Croton Falls Reservoir | 22.3 | 24.1 | 20.4 | 18.1 | * | 19.2 |
| Diverting Reservoir | 31.8 | 41.7 | 28.8 | 28.3 | * | * |
| East Branch Reservoir | 33.3 | * | 26.5 | 44.2 | 28.3 | 28.4 |
| Middle Branch Reservoir | 27.7 | 31.2 | 23.7 | * | 31.5 | 24.2 |
| Muscoot Reservoir | 29.7 | 33.9 | 29.5 | 26.0 | 26.8 | 27.9 |
| Titicus Reservoir | 28.7 | 27.3 | 27.3 | 25.4 | 24.6 | 29.6 |
| West Branch Reservoir | 11.2 | 12.1 | 10.2 | 11.5 | 14.8 | 10.3 |
| Lake Gleneida | 31.6 | * | 22.8 | * | * | 24.2 |
| Lake Gilead | 38.4 | * | 28.5 | 21.8 | * | 30.5 |
| Kirk Lake | * | * | 30.8 | * | * | 29.7 |
| **Source Water** | | | | | | |
| Kensico Reservoir | 8.5 | 8.4 | 7.8 | 8.8 | 9.7 | 7.6 |
| New Croton Reservoir | 21.9 | 25.0 | 19.5 | 22.4 | 18.2 | 18.1 |

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