New York City Environmental Protection

2014 Watershed Water Quality Annual Report

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Table of Contents

Table of Contents....................i
List of Figures....................v
List of Tables....................ix
List of Acronyms....................xi
Acknowledgements....................xv
Executive Summary....................xvii
1. Introduction to Watershed Monitoring....................1
1.1 Water Quality Monitoring....................2
1.1.1 Samples and Analyses....................2
1.1.2 Robotic Monitoring....................2
1.2 Operations in 2014 to Control Turbidity and Fecal Coliforms....................4
2. Water Quantity....................7
2.1 The Source of New York City's Drinking Water....................7
2.2 2014 Watershed Precipitation....................7
2.3 2014 Watershed Runoff....................9
2.4 Use of Rainfall Data in the Design of Stormwater Pollution Prevention Plans....................12
2.5 Reservoir Usable Storage Capacity in 2014....................15
3. Water Quality....................17
3.1 Reservoir Turbidity Patterns in 2014....................17
3.2 Coliform-Restricted Basin Assessments in 2014....................19
3.2.1 Terminal Basin Assessments....................19
3.2.2 Non-terminal Basin Assessments....................20
3.3 Reservoir Total and Fecal Coliform Patterns in 2014....................21
3.4 Phosphorus-Restricted Basin Assessments in 2014....................24
3.5 Reservoir Total Phosphorus Patterns in 2014....................27
3.6 Terminal Reservoir Comparisons to Benchmarks in 2014....................30
3.7 Reservoir Trophic Status in 2014....................33
3.8 Water Quality in the Major Inflow Streams in 2014....................36
3.9 Stream Comparisons to Benchmarks in 2014....................40

3.10 Stream Biomonitoring....43
3.11 Supplemental Contaminant Monitoring....51
3.12 Metals Monitoring....52
4. Kensico Reservoir....57
4.1 Kensico Reservoir Overview....57
4.2 Reservoir Raw Water Quality Compliance....59
4.3 Reservoir Operations and Waterfowl Management....63
4.4 Kensico Streams and Turbidity Curtain Inspections....65
4.4.1 Kensico Stream Water Quality....65
4.4.2 Turbidity Curtain Monitoring....71
4.5 Kensico Research Projects....72
4.5.1 Bryozoan Research....72
4.5.2 Special Investigation Report: Kensico Reservoir Storm Event, July 14-16, 2014....73
5. Pathogens....85
5.1 Introduction....85
5.2 Source Water Results....86
5.2.1 2014 Source Water Compared to Historical Data....90
5.2.2 2014 Source Water Compared to Regulatory Levels....94
5.3 Upstate Reservoir Effluents....96
5.4 Watershed Streams....98
5.5 Wastewater Treatment Plants....103
5.6 Hillview Monitoring....104
5.6.1 Annual Results - 2014....104
5.6.2 CGAP Activation – March 2014....105
6. Modeling for Watershed Management....107
6.1 Introduction....107
6.2 Overview of Model Development and Applications....108
6.3 CUNY Modeling Support Contract....110
6.4 Climate Change Integrated Modeling Project....111
7. Further Research....115

7.1 Contracts Managed by the Water Quality Directorate in 2014 115
7.1.1 *Cryptosporidium* Infectivity Analysis for Hillview 115
7.1.2 Laboratory Analytical Support 116
7.1.3 Water Quality Operation and Maintenance and Assessment for the Hydrological Monitoring Network 117
7.1.4 CUNY Postdoctoral Support 117
7.1.5 Waterfowl Management 118
7.1.6 Zebra Mussel Monitoring 119
7.1.7 Bathymetric Surveys of the Six West of Hudson Reservoirs 119
7.2 Water Research Foundation Project Participation by WQD in 2014 119
7.3 Water Utility Climate Alliance: Piloting Utility Modeling Applications 120
7.4 Global Lake Ecological Observation Network (GLEON) 120
References 123
Appendix A. Key to Boxplots and Summary of Non-Detect Statistics Used in Data Analysis 127
Appendix B. Monthly Coliform-Restricted Calculations for Total Coliform 129
Appendix C. Phosphorus-Restricted Basin Assessment Methodology 133
Appendix D. Comparison of Reservoir Water Quality Results to Benchmarks 137
Appendix E. Comparison of Stream Water Quality Results to Benchmarks 151
Appendix F. Biomonitoring Sampling Sites 163
Appendix G. Semivolatile and Volatile Organic Compounds 165

List of Figures

Figure 1.1 The New York City Water Supply System. 1

Figure 2.1 Monthly precipitation totals for New York City watersheds, 2014 and historical values 8

Figure 2.2 Historical annual runoff (cm) as boxplots for the WOH and EOH watersheds. 10

Figure 2.3 Daily mean discharge for 2014 at selected USGS stations. 11

Figure 2.4 The 1-year, 24-hour storm for New York State, from the 2015 Stormwater Management Design Manual (http://www.dec.ny.gov/docs/ water_pdf/ swdm2015chptr04.pdf). 13

Figure 2.5 The 10-year, 24-hour storm for New York State, from the 2015 Stormwater Management Design Manual (http://www.dec.ny.gov/docs/ water_pdf/swdm2015chptr04.pdf). 13

Figure 2.6 The 100-year, 24-hour storm for New York State, from the 2015 Stormwater Management Design Manual (http://www.dec.ny.gov/docs/ water_pdf/swdm2015chptr04.pdf). 14

Figure 2.7 Ninety percent rainfall in New York State, from the 2015 Stormwater Management Design Manual (http://www.dec.ny.gov/docs/water_pdf/ swdm2015chptr04.pdf). 14

Figure 2.8 2014 Systemwide usable storage compared to normal storage.. 15

Figure 3.1 Annual median turbidity in NYC water supply reservoirs (2014 vs. 2004-2013).. 18

Figure 3.2 Annual 75th percentile of fecal coliforms in NYC water supply reservoirs (2014 vs. 2004-2013).. 22

Figure 3.3 Annual 75th percentile of total coliforms in NYC water supply reservoirs (2014 vs. 2004-2013). 23

Figure 3.4 Phosphorus-restricted basin assessments, with the current year (2014) geometric mean phosphorus concentration displayed for comparison.. 27

Figure 3.5 Annual median total phosphorus in NYC water supply reservoirs (2014 vs. 2004-2013).. 28

Figure 3.6 Annual median Trophic State Index (TSI) in NYC water supply reservoirs (2014 vs. 2004-2013).. 35

Figure 3.7 Locations of major inflow stream water quality sampling sites and USGS gage stations used to calculate runoff. 37

Figure 3.8 Boxplot of annual medians (2004-2013) for a) turbidity, b) total phosphorus, and c) fecal coliform for selected stream (reservoir inflow) sites. 39

Figure 3.9 Biological Assessment Profile scores for East of Hudson biomonitoring sites 45

Figure 3.10 Biological Assessment Profile scores for Sites 102, 146, 206, 301, 304, and 321.. 46

Figure 3.11 Anglefly Brook biomonitoring sites.. 47

Figure 3.12 Biological Assessment Profile scores for West of Hudson biomonitoring sites...... 49

Figure 3.13 Hydropsychid percent composition at Site 321, 1996-2014. 51

Figure 4.1 Kensico Reservoir, showing limnological and hydrological sampling sites, keypoints, and aqueducts.. 58

Figure 4.2 Five-day-per-week fecal coliform grab sample results at CATALUM, Kensico Reservoir’s Catskill Aqueduct influent keypoint.. 60

Figure 4.3 Five-day-per-week fecal coliform grab sample results at DEL17, Kensico Reservoir’s Delaware Aqueduct influent keypoint.. 60

Figure 4.4 Five-day-per-week turbidity grab sample results at CATALUM, Kensico Reservoir’s Catskill Aqueduct influent keypoint.. 61

Figure 4.5 Five-day-per-week turbidity grab sample results at DEL17, Kensico Reservoir’s Delaware Aqueduct influent keypoint.. 61

Figure 4.6 Seven-day-per-week fecal coliform grab sample results at DEL18DT, Kensico Reservoir’s Delaware Aqueduct effluent keypoint.. 62

Figure 4.7 Four-hour turbidity and daily grab sample daily results at DEL18DT, Kensico Reservoir’s Delaware Aqueduct effluent keypoint... 63

Figure 4.8 Percent of keypoint fecal coliform samples at Kensico Reservoir greater than 20 fecal coliforms 100mL^{-1} for the previous six-month period, 1987-2014...................................... 65

Figure 4.9 Fecal coliform plots for routine Kensico streams monitoring, January-December 2014.. 67

Figure 4.10 Turbidity plots for routine Kensico streams monitoring, January-December 2014.. 68

Figure 4.11 Photographs showing progression of *P. magnifica* colony growth on ladder rungs 12 and 13 at Delaware Shaft 18 in Sluice Gate 3.. 73

Figure 4.12 Fecal coliforms and turbidity at MB-1 over the course of the storm.. 75

Figure 4.13 Fecal coliforms and turbidity at N5-1 over the course of the storm......................... 76

Figure 4.14 Eastern shore limnological sampling sites at 1-meter depth on Kensico Reservoir, with fecal coliform results shown by date (fecal coliforms 100 mL^{-1}). 78

Figure 4.15 Kensico Reservoir Site 2.9 fecal coliform results from limnology surveys conducted July 14-July 17, 2014. 79

Figure 4.16 Kensico Reservoir Site 2 fecal coliform results from limnology surveys conducted July 14-July 16, 2014. 80

Figure 4.17 Turbidity and fecal coliform results for daily grab samples taken at DEL18DT from July 10 to July 24, 2014. 81

Figure 4.18 Seep onto DEP property at 38 Greenwood Lane........ 84

Figure 5.1 DEP protozoan analysis type distribution for 2014........ 85

Figure 5.2 Annual percent detection of *Giardia*, mean concentration and maximum result for the Kensico keypoint sites during each year from 2002 to 2014........ 88

Figure 5.3 Routine weekly source water keypoint monitoring results for 2014........ 90

Figure 5.4 Weekly routine source water keypoint results for *Giardia* (LOWESS smoothed - 0.1) from October 15, 2001 to December 31, 2014......... 94

Figure 5.5 LT2 calculated means for *Cryptosporidium* since initiation of Method 1623 at DEP's three source waters; Croton and Delaware Aqueducts 2002-2014 and Catskill Aqueduct 2002-2012........ 96

Figure 5.6 2014 summary of *Giardia* distribution among WOH basins (---Mean, ━━median, _ outliers)......... 98

Figure 5.7 WOH stream sites sampled for protozoans in 2014. 99

Figure 5.8 The Manorkill sub-basin in the Schoharie watershed, depicting local pathogen monitoring sites sampled in 2014. 101

Figure 6.1 Mean monthly observed turbidity for Ashokan Reservoir from historical operations (black line) and the range of predicted mean monthly turbidity for 2080 to 2100 from five climate change scenarios (maroon bars). 113

List of Tables

Table 1.1: Number of grab samples collected, water quality analyses performed, and sites visited by DEP in 2014. 2

Table 1.2 Summary of ROBOMON Project for 2014. 4

Table 3.1: Site codes and site descriptions for the major inflow streams. 19

Table 3.2: Coliform-restricted basin status as per Section18-48(c)(1) for terminal reservoirs in 2014. 20

Table 3.3: Coliform-restricted calculations for total coliform counts on non-terminal reservoirs in 2014.. 21

Table 3.4: Summary statistics for coliforms in NYC controlled lakes (coliforms 100 mL^{-1}) 23

Table 3.5: Phosphorus-restricted reservoir basins for 2014. 26

Table 3.6: Total phosphorus summary statistics for NYC controlled lakes (µg L^{-1}). 29

Table 3.7: Reservoir and controlled lake benchmarks as listed in the WR&R. 31

Table 3.8: Trophic State Index summary statistics for NYC controlled lakes 34

Table 3.9: Site codes and site descriptions for the major inflow streams. 36

Table 3.10: Stream water quality benchmarks as listed in the WR&R (Appendix 18-B). 40

Table 3.11: Percent hydropsychid abundance at 2014 Anglefly Brook biomonitoring sites. 48

Table 3.12: Total Taxa, Percent Model Affinity (PMA), Nutrient Biotic Index-Phosphorus (NBI-P), and Percent Hydropsychidae for 2014 impaired sites in the Catskill/Delaware watershed.. 50

Table 3.13: Sampling sites for VOC and SVOC monitoring. 52

Table 3.14: Keypoint sampling sites for trace and other metal occurrence monitoring. 53

Table 3.15: USEPA National Primary and Secondary Drinking Water Quality Standards. 54

Table 3.16: Water quality standards for metals from Part 703.5. 54

Table 4.1: Summary of Kensico water quality samples 57

Table 4.2: Annual statistics for physical, nutrient, and other chemical analytes in Kensico's perennial streams, January–December, 2014. 69

Table 4.3: Visual inspections of the Catskill Upper Effluent Chamber turbidity curtains. 71

Table 4.4: Routine monthly sampling fecal coliform results for Kensico stream sites on July 8, 2014, prior to the storm event, and 95th percentile data. 74

Table 4.5: MST results for Kensico stream and reservoir samples, 7/14-7/15/2014. <LOD = below Limit of Detection (10 copy numbers per reaction). 82

Table 4.6: Supplemental testing for sample N5-1 #6 at Kensico Reservoir. <LOD = below Limit of Detection (10 copy numbers per reaction)........ 83

Table 5.1: Summary of *Cryptosporidium*, *Giardia* and HEV compliance monitoring data at the five DEP keypoints for 2014........ 87

Table 5.2: Annual detection and mean oocyst concentration of *Cryptosporidium* at influent keypoints to Kensico Reservoir 2002 - 2014........ 92

Table 5.3: Annual detection and mean oocyst concentration of *Cryptosporidium* at Kensico and New Croton Reservoir effluent keypoints 2002 - 2014........ 93

Table 5.4: Number and type of samples used to calculate the LT2 bin classification set from January 1, 2013 to December 31, 2014........ 95

Table 5.5: Summary of upstate reservoir effluent protozoan results for 2014........ 97

Table 5.6: Watershed stream protozoan results summary for WOH sites in 2014........ 100

Table 5.7: Watershed stream protozoan results summary for EOH sites in 2014........ 102

Table 5.8: Protozoan detections at WWTPs in 2014........ 103

Table 5.9: Hillview Site 3 monitoring results summary for 2014........ 104

Table 5.10: Protozoan sampling results at DEL18DT and Hillview Site 3 from March 17 to March 31, 2014........ 106

Table 7.1 *C. parvum* infectious oocyst recovery data for samples collected at Hillview Reservoir, spiked with 100 oocysts and analyzed using Method 1623 and CC-IFA........ 116

Table 7.2 Recovery of infectious *C. parvum* oocysts in spike doses of 5, 3 and 1 oocyst in control and Hillview matrix samples........ 116

List of Acronyms

AGPM	Animation and Graphics Portfolio Management
ARMA	Auto Regressive Moving Average
ASU	Areal Standard Unit
BAP	Biological Assessment Profile
BWS	Bureau of Water Supply
CCD	Croton Consent Decree
CC-IFA	Cell-culture immunofluorescent assay
CCIMP	Climate Change Integrated Modeling Project
CEC	Constituent of Emerging Concern
CGAP	*Cryptosporidium* and *Giardia* Action Plan
CMIP	Coupled Model Intercomparison Project
CUNY	City University of New York
CUNY-RF	City University of New York-Research Foundation
DBP	Disinfection byproduct
DBPFP	Disinfection byproduct formation potential
DEM	Digital Elevation Model
DEP	New York City Department of Environmental Protection
DOC	Dissolved organic carbon
DRO	Diesel range organics
EOH	East of Hudson
EPT	Ephemeroptera, Plecoptera, Trichoptera taxa
FAD	Filtration Avoidance Determination
GLEON	Global Lake Ecological Observation Network
GPM	Gallons per minute
GUI	Graphical user interface
GWLF	Generalized Watershed Loading Function
HBI	Hilsenhoff Biotic Index
HEV	Human enteric virus
ICR	Information Collection Rule
LOWESS	Locally Weighted Scatterplot Smoothing
LT2	Long Term 2 Enhanced Surface Water Treatment Rule
MPN	Most probable number
MST	Microbial Source Tracking
NBI-P	Nutrient Biotic Index-Phosphorus
NCDC	National Climatic Data Center

NTU	Nephelometric Turbidity Unit
NYCRR	New York Codes, Rules and Regulations
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
OASIS	Operational Analysis and Simulation of Integrated Systems
OST	Operational Support Tool
PMA	Percent Model Affinity
PUMA	Piloting Utility Modeling Applications
RHESSys	Regional Hydro-Ecologic Simulation System
ROBOMON	Robotic Water Quality Monitoring Network
ROS	Regression on Ordered Statistics
SBU	New York State Stream Biomonitoring Unit
SI	Special investigation
SSM	Single sample maximum
SVOC	Semivolatile organic compound
SWAT	Soil Water Assessment Tool
SWPPP	Stormwater pollution prevention plan
SWTR	Surface Water Treatment Rule
TDS	Total dissolved solids
TMDL	Total Maximum Daily Loads
TNTC	Too numerous to count
TOC	Total organic carbon
TP	Total phosphorus
TSI	Trophic State Index
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFWS	Unites States Fish and Wildlife Service
USGS	United States Geological Survey
VOC	Volatile organic compound
WMP	Waterfowl Management Program
WPP	Watershed Protection Programs
WQD	Water Quality Directorate
WQSR	Water Quality Science and Research
WR&R	Watershed Rules and Regulations
WRF	Water Research Foundation
WUCA	Water Utility Climate Alliance

WWQMP	Watershed Water Quality Monitoring Plan
WWQO	Watershed Water Quality Operations
WWTP	Wastewater treatment plant

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Executive Summary

Chapter 1 Introduction to Watershed Monitoring

This report provides summary information about the 19 reservoirs, 3 controlled lakes, streams, and aqueducts that comprise the New York City drinking water system. It is an annual report that provides the public, regulators, and other stakeholders with a general overview of the City's water resources and their condition during 2014. This report is complementary to the "New York City 2014 Drinking Water Supply and Quality Report," which is distributed to consumers annually to provide information about the quality of the City's tap water. Thus the two reports together document water quality from its source to the tap. DEP publications are accessible through the DEP website at http://www.nyc.gov/dep/.

Water quality samples were taken at the reservoirs, streams, and aqueducts throughout the watershed in order to: i) demonstrate regulatory compliance, ii) guide operations to provide the highest quality drinking water to the City, iii) demonstrate the effectiveness of watershed protection measures, and iv) provide data for modeling predictions. In 2014, approximately 14,600 samples (resulting in approximately 183,000 analyses) were taken at 432 sites. In addition to these grab samples, continuous monitoring systems were in place. The robotic monitoring network was expanded to ensure well-informed operation of the system and to provide data necessary for modeling. Over one million measurements were taken at 16 sites. Operational changes to divert high quality water from the Delaware and Catskill Systems to Kensico were made to accommodate typical seasonal changes, and "float" mode was used in nine instances to avoid localized wind-driven turbidity at the Kensico intake.

Chapter 2 Water Quantity

The NYC Water Supply System is dependent on precipitation and subsequent runoff to supply the reservoirs in each of the three watersheds, Catskill, Delaware, and Croton. Overall, the total precipitation in the watershed for 2014 was 1,008 mm (39.7 inches), which was 140 mm (5.5 inches) below normal. Reflecting the below normal precipitation in the watershed for the year, the annual runoff was also below normal for all WOH sites as well as the EOH sites Muscoot River and Cross River, while the annual runoff for the other EOH sites was near normal. The United States Geological Survey (USGS) also reported that New York State had above normal annual runoff for the 2014 water year (October 1, 2013-September 30, 2014). System-wide usable storage levels in the reservoir system were generally higher than historical levels for much of 2014. However, following extremely low rainfall in August and September, capacity was about five percent below normal at the end of the year. Also the 1-year, 10-year, and 100-year/24-hour events, and the 90% rainfall event maps available in Chapter 4 of the New York State Stormwater Management Design Manual were updated in January 2015.

Chapter 3 Water Quality

In 2014, turbidity levels were at or below long-term mean levels in most NYC reservoirs throughout the Catskill, Delaware, and Croton Systems. This is largely attributed to low levels of rainfall, particularly in the period from August to November. An exception was seen in response to spring and early summer rain events that elevated the turbidity in Schoharie Reservoir in the Catskill System.

Reservoir and stream levels of fecal coliform, turbidity, and total phosphorus were generally within historical ranges throughout the NYC Water Supply System in 2014. Reservoir total coliform counts were uniformly very low and trophic state was generally low for most WOH reservoirs. Most reservoirs located EOH, on the other hand, showed relatively high levels of productivity compared to historical levels.

Annual total phosphorus concentrations in 2014 ranged from normal to below normal mean values in all parts of the system. The Croton System generally has higher concentrations, and more sources of phosphorus than the rest of the watershed, but in 2014 levels were generally below their historical ranges, with reductions attributed to continuing efforts to reduce phosphorus through stormwater and wastewater nutrient mitigation strategies. The phosphorus-restricted basin calculations indicated that nine basins associated with the Catskill/Delaware System (including West Branch and Kensico) and one basin in the Croton System (Boyd Corners) were non-restricted in 2014. Restricted basins included 13 of 14 Croton System reservoirs and controlled lakes.

Additional reservoir analytes were evaluated against benchmarks in 2014. As in 2013, all chloride samples in New Croton in 2014 exceeded the Croton System benchmarks of the 40 mg L^{-1} single sample maximum standard and the annual mean standard of 30 mg L^{-1}. Likewise, all chloride samples in West Branch when compared to the Catskill/Delaware System benchmarks exceeded the single sample maximum of 12.0 mg L^{-1} and annual mean standard of 8.0 mg L^{-1}. All chloride levels were well below the health standard of 250 mg L^{-1}.

Water quality assessments of watershed streams based on resident benthic macroinvertebrate assemblages were also used to assess water quality in 2014. Assessments are made following protocols developed by the New York State Stream Biomonitoring Unit. In the Catskill System, 12 sites were non-impaired and 4 were slightly impaired, while in the Delaware System, 6 sites were non-impaired and 5 slightly impaired. High numbers of hydropsychid caddisflies (>30%) were present at two-thirds of the impaired sites and nearly half overall, a phenomenon of recent years that remains unexplained. Taxa counts, while low by historical standards, were higher than last year. In the Croton System, 13 sites were slightly impaired and 2 were moderately impaired. The high percentage of impaired sites is typical of the Croton System.

Supplemental (non-required) monitoring for metals and a large number of semivolatile and volatile organic compounds were conducted at important keypoint locations throughout the water supply system. None of the monitored semivolatile or volatile compounds were detected in 2014. Most metal results were well below state and federal benchmarks. Benchmarks related to aesthetic concerns (e.g., taste, staining) were occasionally exceeded for iron, manganese, and aluminum at locations well upstream of the distribution system.

Chapter 4 Kensico Reservoir

Kensico Reservoir is the terminal reservoir for the City's Catskill/Delaware water supply. Because it is the last impoundment of Catskill/ Delaware water prior to entering the City's distribution system and is a key location prior to disinfection, monitoring is done at its highest frequency here. As an unfiltered surface water supply, New York City's Catskill/Delaware System must meet strict requirements for turbidity and fecal coliform concentrations set forth in the federal Surface Water Treatment Rule (SWTR). In 2014, four-hourly sampling of untreated (raw) water turbidity at site DEL18DT, the effluent keypoint for water leaving Kensico and moving toward the distribution system, had a maximum recorded value of 2.4 NTU. None of the samples from DEL18DT exceeded the 20 fecal coliform 100 m L^{-1} threshold in 2014. The 2014 water quality data also demonstrated that the Waterfowl Management Program continued to be instrumental in keeping coliform bacteria concentrations well below the limits set by the SWTR. Water quality from the influents to Kensico from the Catskill/Delaware System as well as from the stream inputs was generally good in 2014, with only one special investigation occurring due to a storm event. This happened in July 2014, when over three inches of rain fell over a 48-hour period from July 14 to 16. Overall, the storm had little impact on water quality in Kensico Reservoir, with increases in turbidity and fecal coliforms at the stream sites, as is normal for storm response. Microbial Source Tracking (MST) testing indicated low levels of ruminant fecal biomarkers in three of the six stream samples, and one stream sample was positive for two different human fecal biomarkers. Other activities at Kensico included biweekly inspections of the turbidity curtains located near the Catskill Effluent. Also, video monitoring of the development of bryozoan colonies on the sluice gates at Delaware Shaft 18 was conducted in 2014. Overall, water quality at Kensico during 2014 was excellent.

Chapter 5 Pathogen Monitoring and Research

DEP analyzed 484 samples for protozoans and 169 samples for human enteric virus (HEV) in 2014. Most samples were collected at keypoint locations and watershed streams, with additional samples collected at upstate reservoir effluents, Hillview Reservoir, and wastewater treatment plants (WWTPs). *Giardia* cysts continued to be detected at higher frequencies and concentrations in the watershed compared to *Cryptosporidium* oocysts. For the two-year period from January 1, 2013 to December 31, 2014, DEP source water continued to be well below the Long Term 2 Enhanced Surface Water Treatment Rule *Cryptosporidium* threshold for additional treatment at an unfiltered water supply (0.010 oocysts L^{-1}), with a mean of 0.0009 oocysts L^{-1} at the Delaware effluent site and 0.0000 oocysts L^{-1} (all non-detects) at the New Croton Reservoir effluent. Overall, protozoan concentrations leaving the upstate reservoirs and Kensico Reservoir were lower than levels at the stream sites that feed these reservoirs, suggesting a reduction as water passes through the system. There were four detections of *Giardia* cysts at WWTPs this year; however, there were no *Cryptosporidium* oocysts detected. As per the Hillview Administrative Order, DEP continued weekly protozoan monitoring at the Hillview Reservoir outflow (Site 3) through 2014, with 54 samples collected. Of the 54 samples, there were 19 detections of *Giardia* and 2 occasions when there was a single *Cryptosporidium* oocyst detected.

Chapter 6 Water Quality Modeling

DEP uses a number of models to simulate current and future conditions in the watersheds, reservoirs, and reservoir drinking water withdrawals. The GWLF, SWAT, and RHESSys watershed models have been used to simulate runoff and nutrient and carbon loading for both historical and future conditions. One-dimensional (simulating vertical variations) and two-dimensional (simulating vertical and longitudinal variations) reservoir models have been used to simulate water quantity and supply, sediment, turbidity, and nutrients. In particular, the Operational Support Tool (OST), based on the two-dimensional framework and a reservoir operations module, is being used routinely to evaluate the impact of water system operation alternatives on water supply. Use of this tool for additionally projecting the impact of operations on water quality is moving forward.

The second four-year phase of DEP's Climate Change Integrated Modeling Project (CCIMP) began in 2014. At the close of Phase I in 2013, a workshop and evaluation by outside experts led to a number of useful suggestions for future phases of the CCIMP. In particular it was recognized that future changes in the internal and external loading of dissolved organic carbon (DOC) to the reservoirs could result in water quality concerns associated with disinfection by-products (DBPs).

During 2014, a long-term planning exercise was begun to understand the possible impacts of the Rondout-West Branch Tunnel shutdown planned for 2022. Modeling analyses using CEQUAL-W2 for Kensico Reservoir were begun to test various Catskill water quality and flow scenarios to determine conditions that are needed to maintain turbidity at acceptable levels in the Kensico Reservoir effluent.

Chapter 7 Further Research

DEP uses contracts and participates in research projects to extend its monitoring and data analysis capabilities where unique expertise may be required. In 2014, there were seven water quality-related contracts in place. They addressed bathymetry of the six Catskill/Delaware reservoirs, laboratory analysis of unusual compounds, microbial source tracking, and benthic macroinvertebrates. The USGS provided operation and maintenance of stream gauges and monitoring of turbidity in Esopus Creek. A contract with the City University of New York has provided post-doctoral positions that have supported modeling work in climate data analysis, reservoir system modeling, watershed modeling, and forest ecosystem modeling. This contract led to improved modeling tools and future climate scenarios for modeling-based evaluations of climate change impacts. The current Waterfowl Management Program contract (WMP-12 Renewal), with Henningson Durham & Richardson, requires staffing of contractor personnel annually to cover waterfowl management activities at several upstate reservoirs. It is intended to run through July 31, 2015. Other contracts assisted in monitoring for the presence of potentially problematic organisms such as zebra mussels.

DEP also participated in the Water Utility Climate Alliance (WUCA), a consortium of water utilities nationwide. DEP contributed to the Piloting Utility Modeling Applications (PUMA) effort by documenting its modeling work as a case study for a white paper entitled Actionable Science in Practice: Co-Producing Climate Change Information for Water Utility Vulnerability Assessments that will be published in 2015.

Finally, DEP participated in the GLEON16 meeting in Montreal in 2014, in an effort to begin learning the readily available software tools for analyzing the high-frequency data generated by the ROBOMON network. This network has proved invaluable to DEP and the program is in a growth phase. It is therefore necessary to find efficient ways to display and use the data generated by the systems in which DEP has invested.

1. Introduction to Watershed Monitoring

This report provides summary information about the watersheds, streams, and reservoirs that are the sources of New York City's drinking water. It is an annual report that provides the public, regulators, and other stakeholders with a general overview of the City's water resources, their condition during 2014, and compliance with regulatory standards. It also provides information on operations and the use of water quality models for management of the water supply. It is complementary to the New York City 2014 Drinking Water Supply and Quality Report (http://www.nyc.gov/html/dep/pdf/wsstate14.pdf), which is distributed to consumers annually to provide information about the quality of the City's tap water. Thus the two reports together document water quality from its source to the tap. More detailed reports on some of the topics described herein can be found in other DEP publications, accessible through the DEP website at http:// www.nyc.gov/dep/.

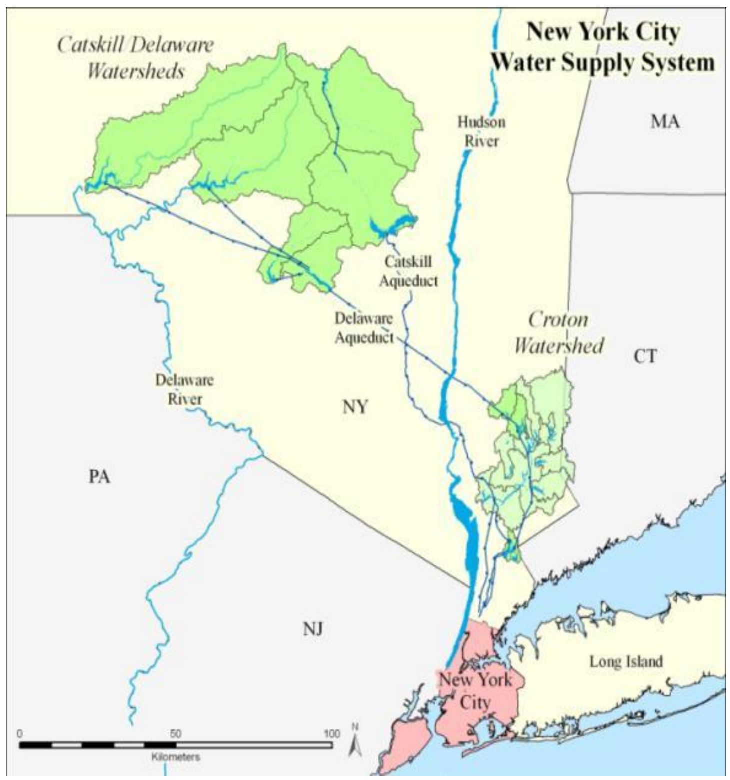

Figure 1.1 The New York City Water Supply System.

The New York City Water Supply System (Figure 1.1) supplies drinking water to almost half the population of the State of New York, which includes over eight million people in New York City and one million people in upstate counties, plus millions of commuters and tourists. New York City's Catskill/Delaware System is one of the largest unfiltered surface water supplies in the world. The City's water is supplied from a network of 19 reservoirs and 3 controlled lakes that contain a total storage capacity of approximately 2 billion cubic meters (580 billion gallons). The total watershed area for the system is approximately 5,100 square kilometers (1,972 square miles), extending over 200 kilometers (125 miles) north and west of New York City. This resource is essential for the health and well-being of millions and must be monitored, managed, and protected for the future. The mission of the Bureau of Water Supply (BWS) is to reliably deliver a sufficient quantity of high quality drinking water to protect public health and the quality of life of the City of New York.

1.1 Water Quality Monitoring

1.1.1 Samples and Analyses

Water quality of the reservoirs, streams, and aqueducts is monitored throughout the watershed in order to demonstrate regulatory compliance, guide operations to provide the highest quality drinking water to the City, demonstrate the effectiveness of watershed protection measures, and provide data for modeling predictions. These data are acquired from the analysis of grab samples or from field instrumentation in accordance with the Watershed Water Quality Monitoring Plan (WWQMP) (DEP 2009a). This document is DEP's comprehensive plan that describes what, when, where, and why water quality samples are taken throughout the watershed.

A summary of the number of the samples collected and analyses performed in 2014 by the four upstate laboratories, and the number of sites that were sampled, is provided below in Table 1.1. The samples were collected from streams, reservoirs, reservoir releases, wastewater treatment plants (WWTPs), and keypoints (i.e., water supply intakes and aqueduct sites), and also includes samples for drinking water in upstate facilities and the analysis of lead and copper in at-the-tap samples from the distribution system. The sampling is described in the 2009 WWQMP and associated addenda. Also, sampling that was conducted by DEP as the result of special investigations is included in the table. Finally, the sampling effort for the distribution system is also listed for completeness; however, the discussion here is based on the results from samples taken throughout the upstate watershed.

Table 1.1: Number of grab samples collected, water quality analyses performed, and sites visited by DEP in 2014.

System/Laboratory	Number of Samples	Number of Analyses	Number of Sites
Catskill/Kingston	2,823	56,148[1]	123
Delaware/Grahamsville	3,453	40,184	121
EOH/Kensico	7,587	82,146	122
EOH/Brewster	1,032	8,279	66
Watershed	**14,895**	**186,757**	**432**
Distribution	30,000	347,000	1,000
Total	**44,895**	**533,757**	**1,432**

[1] Catskill/Kingston totals include samples analyzed by the Pathogen Laboratory.

1.1.2 Robotic Monitoring

In 2012, Watershed Water Quality Operations (WWQO) successfully insourced a previously contracted Robotic Water Quality Monitoring Network (ROBOMON), saving DEP an estimated $567,000 year. Continuous monitoring data obtained under this network are critical for ensuring the effective management of storm events, providing early warning, and forming a basis for management actions that guide the operations of the supply system.

The ROBOMON project has continued successfully since then and has fulfilled two basic requirements: (1) continuous representative measurements of current watershed conditions, and (2) timely communication of data to decision makers and to management tools (e.g., Operational Support Tool (OST) and watershed models).

There were two fixed-depth buoys deployed on Kensico Reservoir in 2014, one near the Delaware Aqueduct intake and the other approximately midway between the Delaware Aqueduct intake and the turbidity curtain which mitigates impacts from Malcolm Brook. Each buoy had three transmissometers which were suspended at 5, 10, and 15 meters in the water column to provide near-real-time estimates of turbidity. Data were recorded in 15-minute intervals and were used to determine trends in turbidity and assist with operational decisions at Delaware Shaft 18.

In 2014, four new reservoir water column profiling buoys were added to the existing buoy network. The existing four buoys were located on the West Basin of Ashokan Reservoir (Sites 1.4 and 3.1), the East Basin of Ashokan Reservoir (Site 4.1), and Kensico Reservoir (Site 4.1). Four new buoys were added at Rondout (Site 1), Neversink (Site 1.5), Schoharie (Site 4), and Kensico (Site 4) Reservoirs. These buoys performed full water column profiles every six hours with sensors measuring temperature, turbidity, and specific conductivity. Additionally, the Ashokan West Basin (Site 1.4) buoy and the Kensico (Site 4.1) buoy were outfitted with meteorological stations.

Watershed Water Quality Operations (WWQO) deployed two under-ice buoys specifically designed to monitor water quality during ice-over conditions at Ashokan Reservoir, threby allowing access to water quality conditions that might otherwise remain invisible. These were fixed depth buoys located at two depths at approximate elevations of 555 feet and 515 feet at the gatehouse locations of each basin.

Six automated stream monitoring stations (RoboHuts) were maintained by WWQO staff throughout the year. RoboHuts, in the Catskill System at Esopus Creek near Coldbrook and in the Delaware System at Rondout Creek near Lowes Corners, continuously monitor water temperature, specific conductivity, and turbidity. Five additional stream monitoring stations—one on the Neversink River adjacent to the USGS gauge station, one on the West Branch Delaware River, and three in the Stony Clove/Warner Creek watershed—are monitored for turbidity and temperature only.

Each robotic monitoring location was powered by a battery which was charged by solar panels and contained data logging and communications equipment. At regular intervals, the most recent data were imported to a database at the Kingston Laboratory and made viewable on the DEP intranet through a custom Web application. In some cases near-real-time data were available within three minutes of the field measurement being taken. Divisional Standard

Operating QUAL5000D describes data management procedures, and the web application includes the ability to display data comments as appropriate. The ROBOMON project yielded over 1,000,000 measurements in 2014 at 16 sites (Table 1.2).

Table 1.2 Summary of ROBOMON Project for 2014.

System/Field Section	Number of Measurements*	Number of Sites
Catskill/Kingston	492,221	7
Delaware/Grahamsville	217,965	5
EOH/Kensico	320,261	4
Total	**1,030,447**	**16**

*includes turbidity, temperature, and specific conductivity.

To meet new demands for water quality data, WWQO is expanding the program to include chlorophyll, phycocyanin, dissolved oxygen and colored dissolved organic matter in an effort to improve DEP's reservoir loading models and ultimately improve DEP's understanding of the factors that influence disinfection by-product formation potential. Some or all of these enhancements are expected to be installed in 2015 at the existing RoboHut on the Neversink River, the existing buoy on Neversink Reservoir and on a newly installed buoy on Cannonsville Reservoir.

1.2 Operations in 2014 to Control Turbidity and Fecal Coliforms

In the Catskill System, the elevation of withdrawal at Ashokan Reservoir was adjusted throughout the year, as necessary, to draw the best quality water (i.e., low turbidity, low coliforms) from the reservoir and to meet operational needs (e.g., lowering the West Basin to accept more runoff during large storm events). From January to May water was diverted from the surface and middle elevations in Ashokan's West Basin in anticipation of spring snowmelt. Following the annual runoff event, a switch was made to the East Basin where turbidity was lowest. By August good water quality was again available in the West Basin and the creation of a void was pursued. In September a decision was made to go with an East/West blend to mix better quality East Basin water with water from the West Basin. In October, Operations blended water from two elevations (surface and middle) in the East Basin. In November, good quality water could again be obtained from the West Basin and a blend of middle and bottom waters was maintained until the end of the year.

In the Delaware System, selective withdrawal was not needed at any of the four system reservoirs in 2014. Water quality was very good throughout the year and no changes were needed to deliver the best quality water to the distribution system.

When weather forecasts predict sustained easterly or northeasterly winds in excess of 15 mph, the mode at Delaware Aqueduct Shaft 18 is often changed from direct reservoir-only withdrawal to "float" mode due to the potential for wave action to stir up adjacent shoreline sediments. Float mode operation brings water from Rondout Reservoir via the Delaware Aqueduct directly to the downtake at Delaware Aqueduct Shaft 18. Since the bypass mode cannot fully meet demand from Rondout Reservoir, water is also drawn from Kensico Reservoir as needed and in much lesser amounts than would occur during reservoir mode operation. Float operation in anticipation of strong winds occurred nine times in 2014.

2. Water Quantity

2.1 The Source of New York City's Drinking Water

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

2.2 2014 Watershed Precipitation

The average precipitation for each watershed was determined from daily readings collected from a network of precipitation gauges located in or near each watershed. The total monthly precipitation is the sum of the daily average precipitation values calculated for each reservoir watershed. The 2014 monthly precipitation total for each watershed is plotted along with the historical monthly average (Figure 2.1).

The total monthly precipitation figures show that precipitation was generally near normal to somewhat below normal for the first five months of 2014. June had above average precipitation in all watersheds except Rondout, which was near normal. July also had above average precipitation in all watersheds except Cannonsville and Schoharie, which were somewhat below normal. All watersheds, except Cannonsville, were well below normal in August and September, while Cannonsville was slightly above normal in August and near normal in September. October and December both had mixed results, but generally with near normal precipitation, while November had below normal precipitation for all watersheds. Overall, the total precipitation across the watershed for 2014 was 1,008 mm (39.7inches), which was 140 mm (5.5 inches) below normal.

The National Climatic Data Center's (NCDC) climatological rankings (http://www.ncdc.noaa.gov/temp-and-precip/climatological-rankings/) were queried to determine the 2014 rankings for New York. In contrast to the precipitation in the NYC watersheds discussed above, overall precipitation for New York State was 74.4 mm (2.93 inches) above normal in 2014 (33rd wettest in the last 120 years). Also, the average temperature for 2014 was normal for New York.

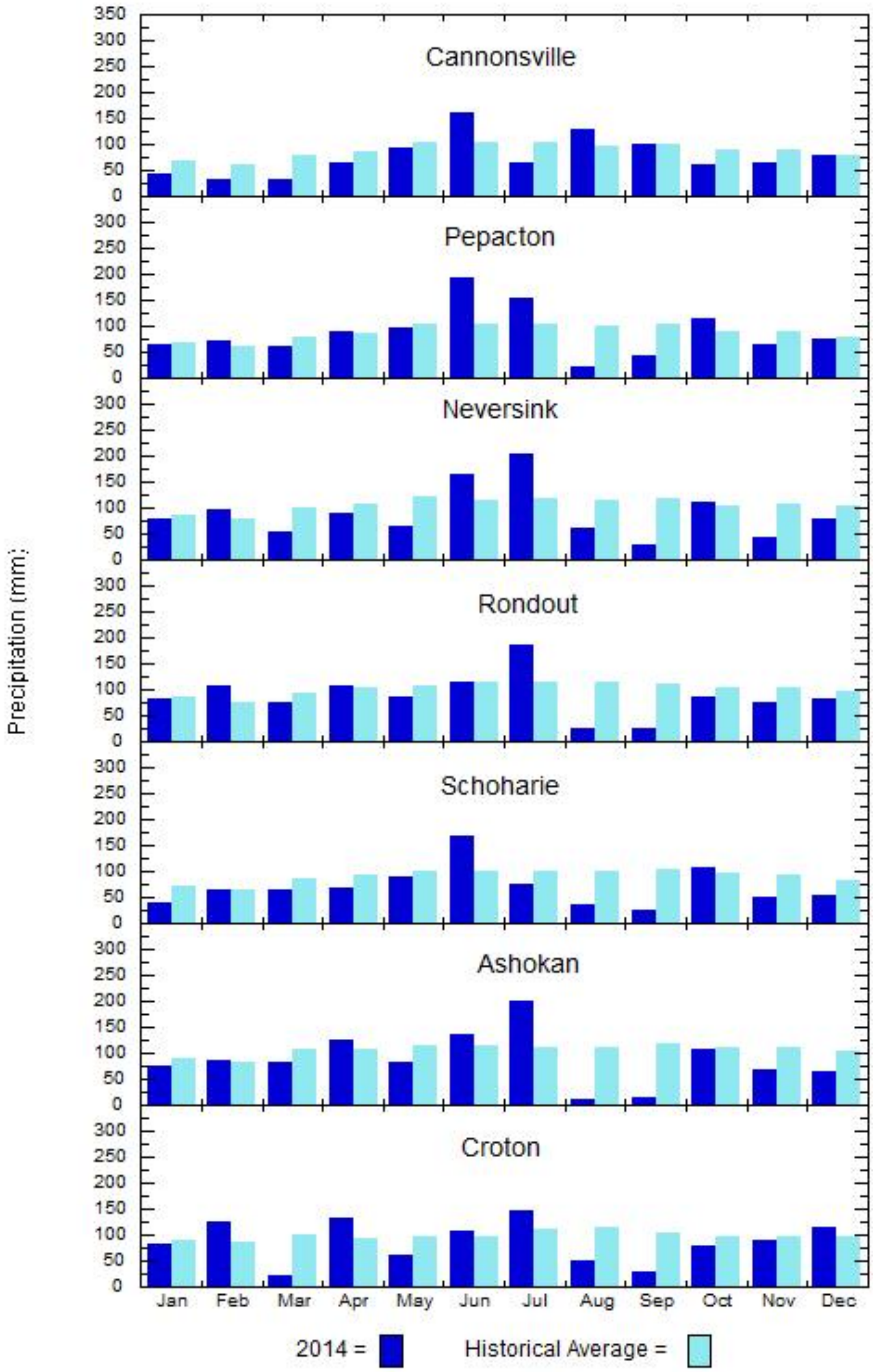

Figure 2.1 Monthly precipitation totals for New York City watersheds, 2014 and historical values

2.3 2014 Watershed Runoff

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

Selected USGS stations (Figure 3.7) were used to characterize annual runoff in the different NYC watersheds (Figure 2.2). The annual runoff in 2014 was below normal for all WOH sites and for the EOH sites Muscoot River and Cross River. The other EOH sites were near normal. The period of record for the WOH stations ranges from 51 years at the Esopus Creek Allaben station to 108 years at the Schoharie Creek Prattsville gauge. The EOH stations have a 19-year period of record, except for the Wappinger Creek site (86-year period of record). (Wappinger Creek is not located in the EOH System, but is included here because it is located in nearby Dutchess County, and its longer period of record is more comparable to those found in the WOH System.) New York State had above normal runoff (15th highest out of the last 114 years) for the 2014 water year (October 1, 2013-September 30, 2014), as determined by the USGS (http://waterwatch.usgs.gov/index.php?r=ny&m=statesum).

Figure 2.3 shows the 2014 mean daily discharge, along with the minimum, maximum, and median daily discharge for the period of record, for the same USGS stations that were used to characterize annual runoff. Overall, discharge was near normal for most of the year. The streams showed a spike in flows in January and several spikes from April through July. Flows were below normal from late August through November although there were some spikes in flows in October, and EOH streams also had a spike in August.

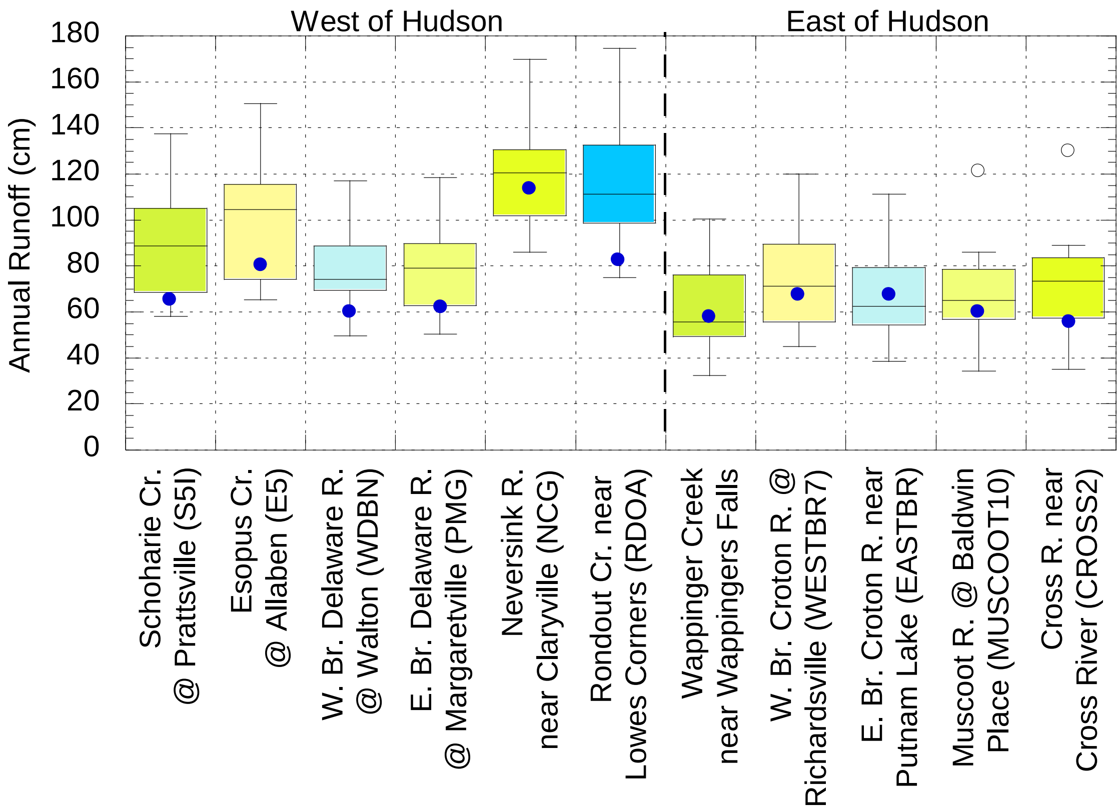

Figure 2.2 Historical annual runoff (cm) as boxplots for the WOH and EOH watersheds, with the values for 2014 displayed as a dot.

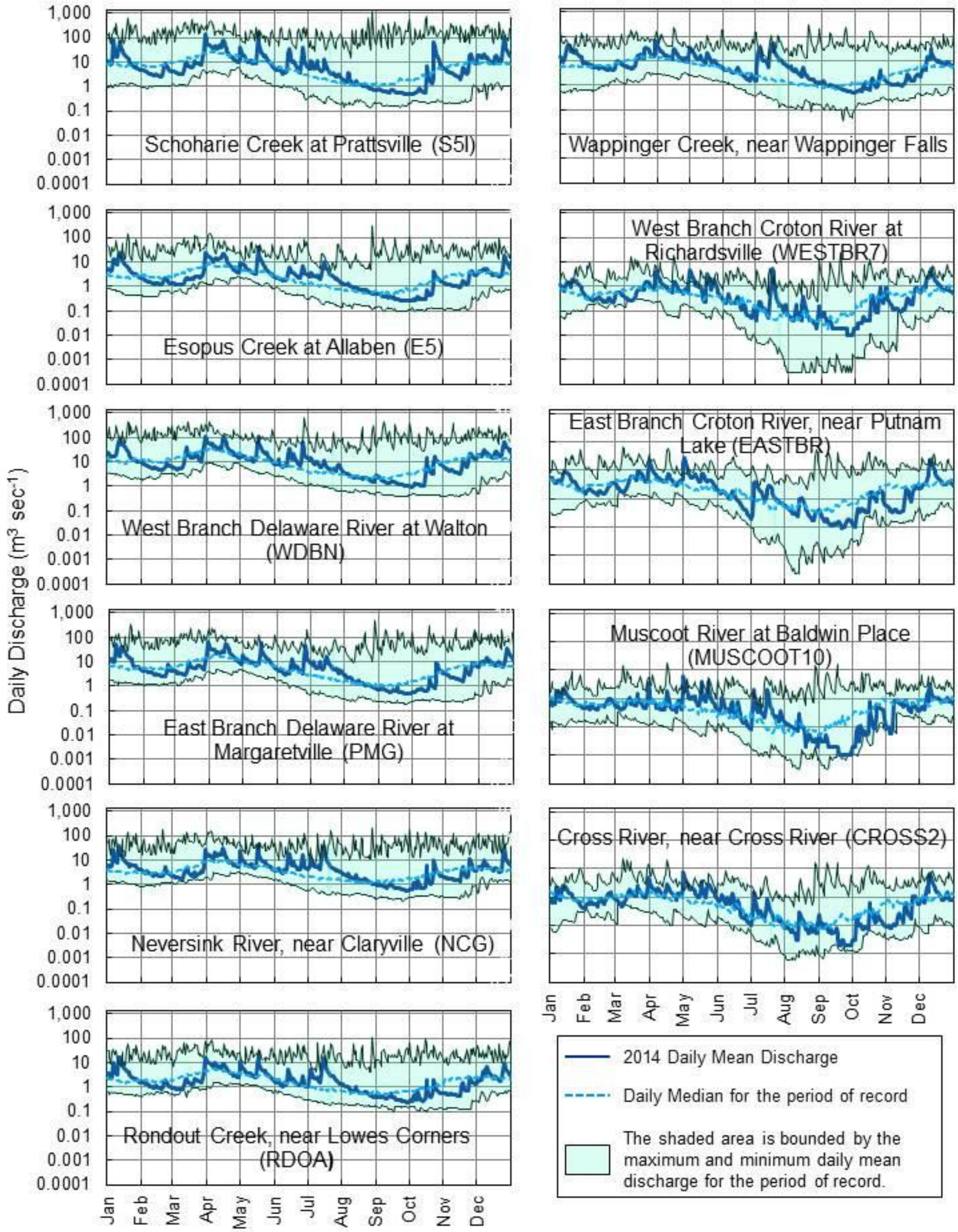

Figure 2.3 Daily mean discharge for 2014 at selected USGS stations.

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

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

SWPPPs require specific hydrologic modeling and analyses of site runoff conditions prior to and after proposed construction and development activities. Stormwater computer models rely on historical records to size stormwater management practices, gauge a variety of runoff conditions and predict downstream impacts. These records include rainfall data to define the magnitude of a number of storm events, namely the 1-year, 10-year, and 100-year/24-hour events, and the 90% rainfall event (see Figures 2.4 through 2.7). The 1-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 100% chance of occurring in any given year, while the 10-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 10% chance of occurring in any given year. The 100-year, 24-hour storm means the storm, with a 24-hour duration, that statistically has a 1% chance of occurring in any given year. Figures 2.4 through 2.7 are isohyetal maps that present estimates of these precipitation return periods for New York State. Where construction activities require DEP review and approval of an SWPPP in accordance with the WR&R, these maps may be used in the design of stormwater management practices. They are available in Chapter 4 of the New York State Stormwater Management Design Manual (updated January 2015) ("Design Manual") or online at http://www.dec.ny.gov/docs/water_pdf/swdm2015chptr04.pdf. Alternatively, as precipitation data are updated, designers may use the most recent rainfall frequency values developed by acceptable sources as noted in the Design Manual.

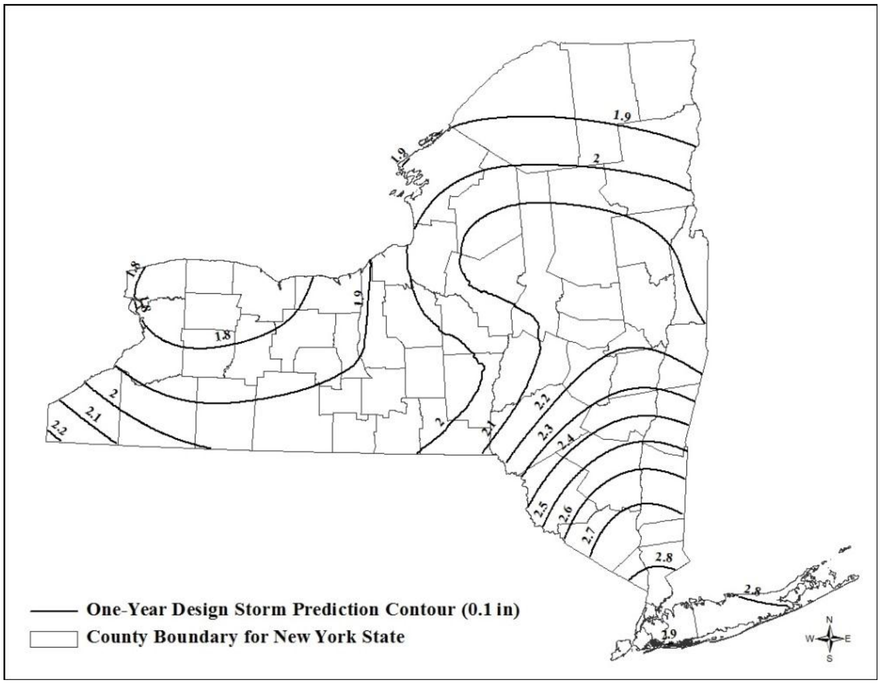

Figure 2.4 The 1-year, 24-hour storm for New York State, from the 2015 Stormwater Management Design Manual (http://www.dec.ny.gov/docs/ water_pdf/ swdm2015chptr04.pdf).

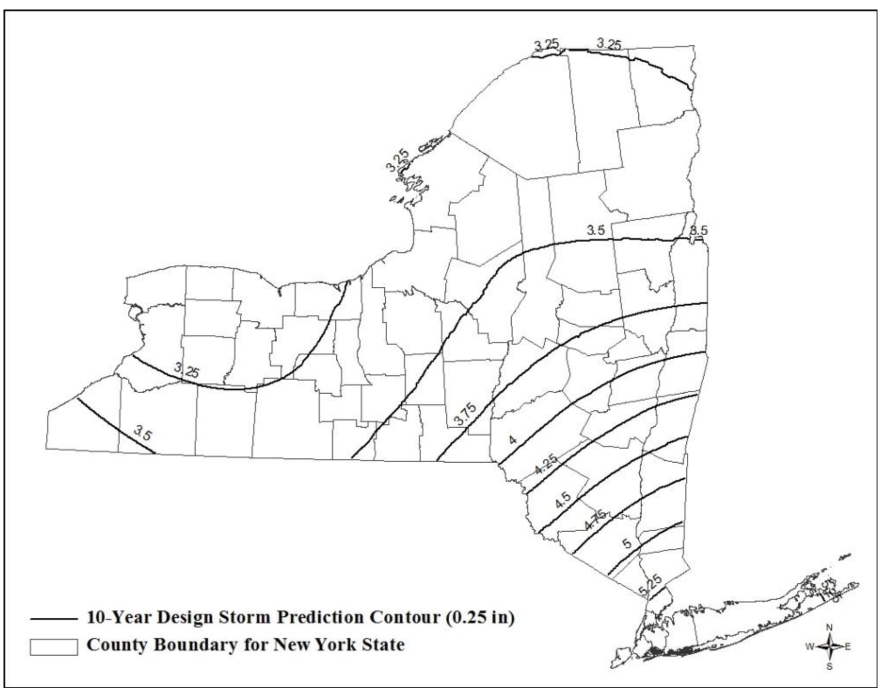

Figure 2.5 The 10-year, 24-hour storm for New York State, from the 2015 Stormwater Management Design Manual (http://www.dec.ny.gov/docs/ water_pdf/swdm2015chptr04.pdf).

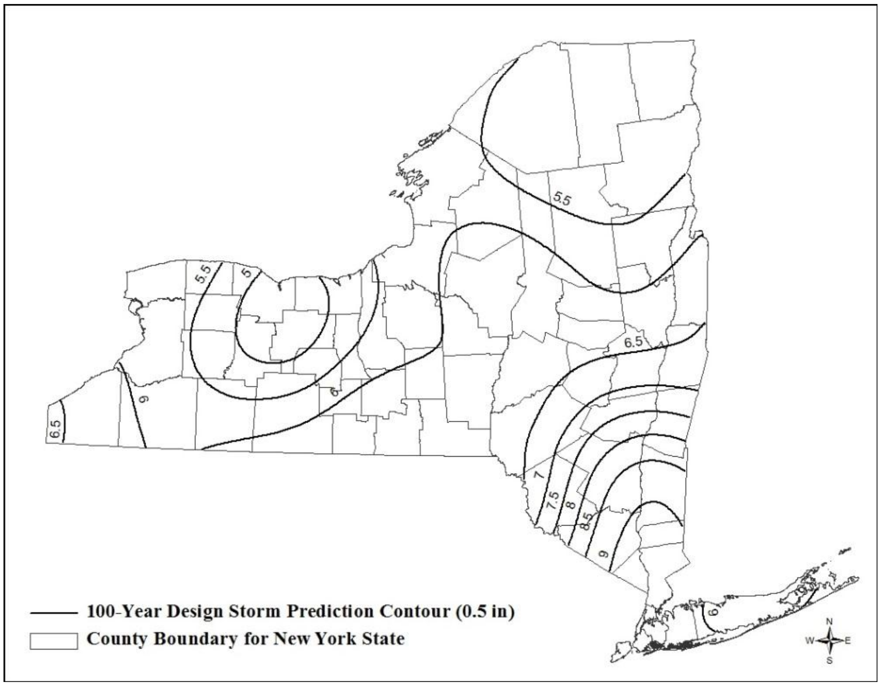

Figure 2.6 The 100-year, 24-hour storm for New York State, from the 2015 Stormwater Management Design Manual (http://www.dec.ny.gov/docs/ water_pdf/swdm2015chptr04.pdf).

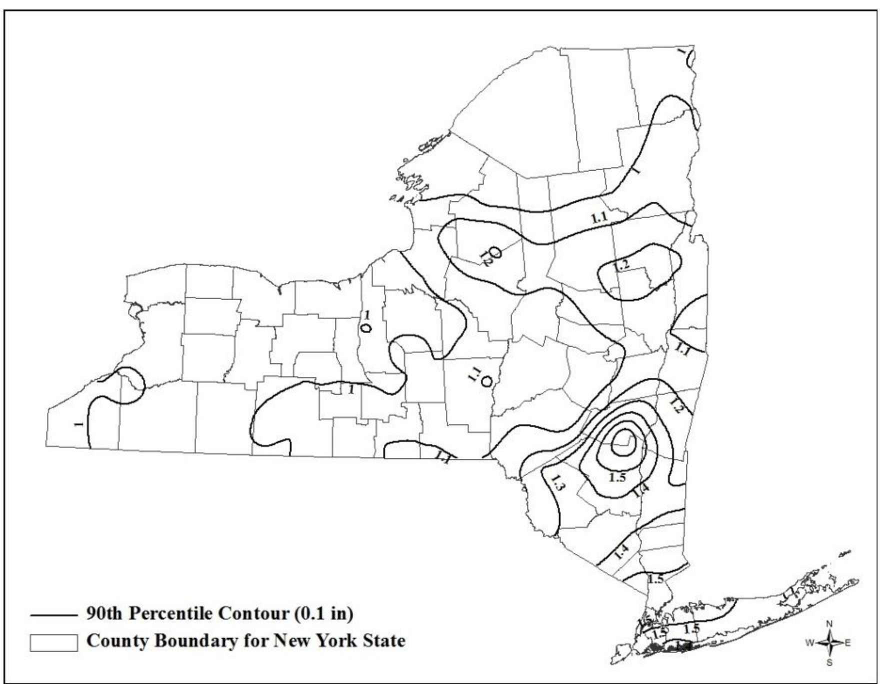

Figure 2.7 Ninety percent rainfall in New York State, from the 2015 Stormwater Management Design Manual (http://www.dec.ny.gov/docs/water_pdf/ swdm2015chptr04.pdf).

2.5 Reservoir Usable Storage Capacity in 2014

Ongoing daily monitoring of reservoir storage allows DEP to compare the present system-wide storage against what is considered "normal" for any given day of the year. "Normal" system-wide usable storage levels were determined by calculating the average daily storage from 1991 to 2013. In 2014, system capacity was generally higher than historic levels for much of the year (Figure 2.8). Due to rain events in late 2013, capacity peaked to nearly 96% in mid-January 2014. The cold winter prevented snow melt from recharging the system and capacity declined throughout the winter months to 84% by mid-March. System-wide rain in late March and in mid- and late April, together with the slow melt of a substantial snowpack, caused capacity to increase to 99% by April 17. A large rain event in the WOH watersheds caused capacity to exceed 101% by mid-May. Above average rainfall in June and July kept capacity near 100% through mid-July. Extremely low rainfall in August and September and somewhat low precipitation in October and November caused capacity to drop to 68% by late November. Subsequent large (>1 inch) rain events in the EOH watersheds and numerous small events in both EOH and WOH caused capacity to increase to 78% by the end of the year, leaving the system about 5% below normal capacity entering 2015.

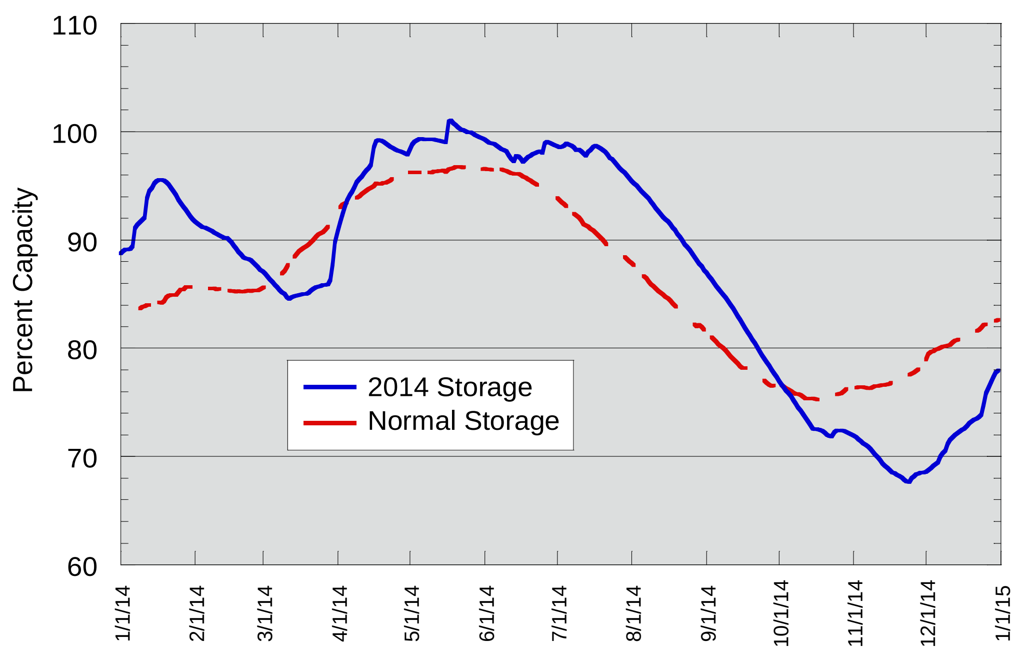

Figure 2.8 2014 Systemwide usable storage compared to normal storage. Storage greater than 100% is possible when the reservoirs are spilling or when the water surface elevation is greater than the spillway elevation.

3. Water Quality

3.1 Reservoir Turbidity Patterns in 2014

Turbidity in reservoirs is comprised of both inorganic (e.g., clay, silt) and organic (e.g., plankton) particulates suspended in the water column. Turbidity may be derived from the watershed by erosional processes (storm runoff in particular) or generated within the reservoir itself (e.g., internal plankton development, sediment resuspension). In general, turbidity levels are highest in the Catskill reservoirs due to the occurrence of easily erodible lacustrine clay deposits found in these watersheds.

Turbidity in the Catskill System's Schoharie Reservoir was about 69% higher than normal in 2014 (Figure 3.1). (An explanation of the boxplots used in this and other figures in this chapter is provided in Appendix A.) Spring turbidity levels were elevated due primarily to a 1.3 inch rain event in mid-April. Turbidity increased again in early summer following a very large rain event (3.0 inches) that occurred on June 25. Although rainfall thereafter was very low, higher turbidity levels persisted for the remainder of the sampling season due to the low settling rate of the lacustrine clay particles that comprise the turbidity in the Schoharie watershed. In contrast, despite more rain events (>1 inch) in the May-June period, and a relatively wet July (7.9 inches), annual turbidity levels were normal to below normal in the east and west basins of Ashokan Reservoir. This is largely explained by below average rainfall from August-November. August and September were especially dry, with rainfall totaling only 1.3 inches versus the historical average of 11.9 inches. Low annual turbidity was also supplemented by reducing the transfer of more turbid Schoharie water to the Ashokan basins via the Shandaken Tunnel. Particle loss by sedimentation in the West Basin further benefits the East Basin and explains the East's generally lower turbidity levels.

In the Delaware System, despite a generally wet June and July, Cannonsville and Rondout turbidity were very close to their historical medians, while Pepacton was about 16% lower than normal in 2014. As was the case in the Catskill System, rainfall was often well below normal from August through November and especially dry in August and September. In contrast, despite similar rainfall patterns, Neversink was about 50% higher than normal in 2014 and slightly higher than 2013 levels (1.8 NTU vs. 1.6 NTU). The high annual turbidity at Neversink is probably explained by the timing of sample collection. Higher than normal turbidity samples collected in April-June and in November were all associated with above average flows.

West Branch Reservoir, which receives inputs from both the Delaware and Croton Systems, had normal turbidity levels in 2014. West Branch was almost exclusively operated in "float" status, minimizing the amount of Delaware water entering the West Branch Reservoir. The higher turbidity of West Branch Reservoir compared to Rondout Reservoir is largely a function of higher turbidity inputs from local streams in the West Branch watershed.

Turbidity at Kensico, the terminal reservoir for the Catskill and Delaware Systems, was expectedly low given the high clarity of water received from both systems in 2014.

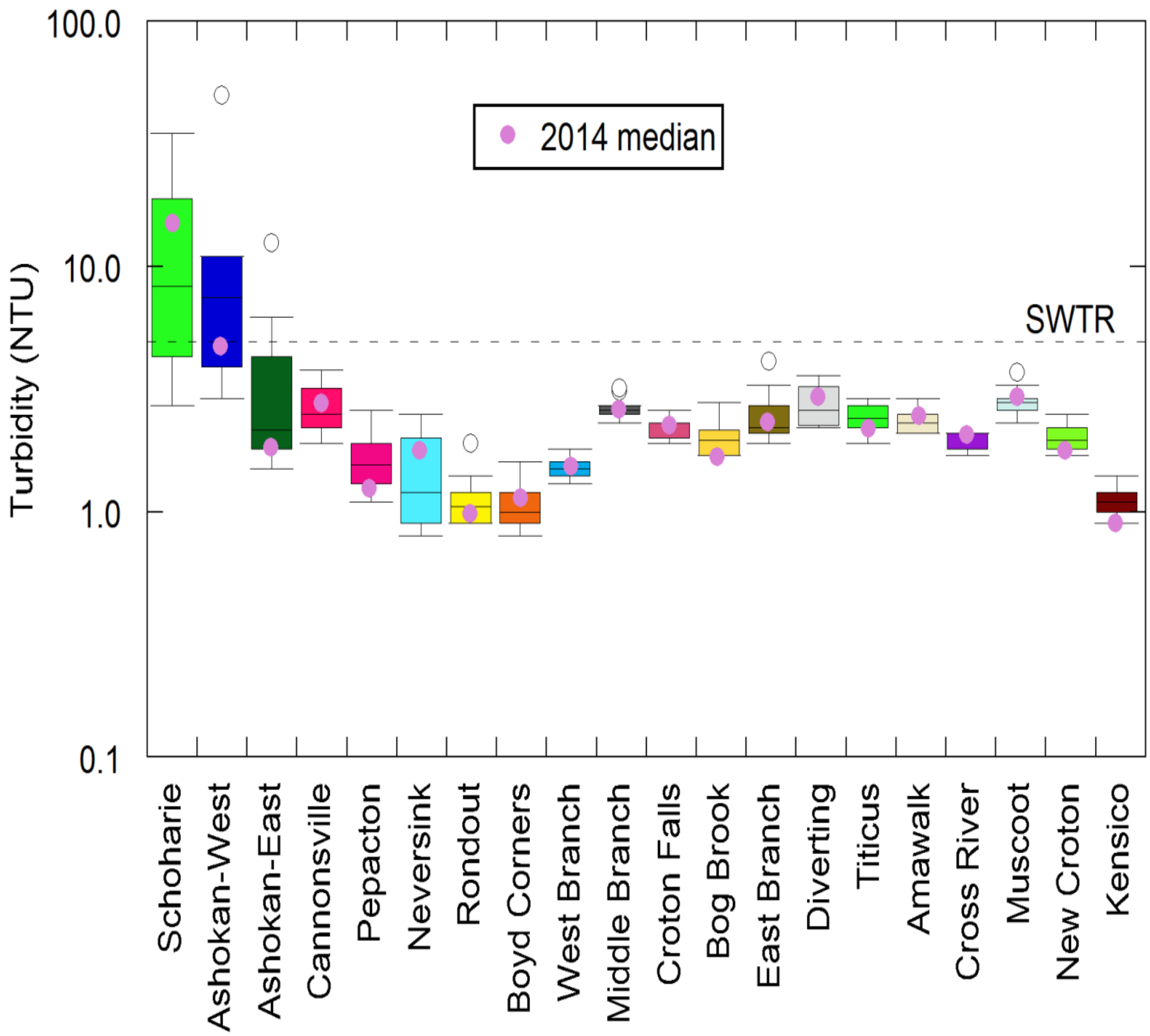

Figure 3.1 Annual median turbidity in NYC water supply reservoirs (2014 vs. 2004-2013). The dashed line at 5 NTU refers to the SWTR criterion that considers 2 consecutive days > 5NTU as a violation in source water reservoirs. In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November.

Turbidity in the Croton System was generally normal to below normal in 2014 (reservoirs shown in Figure 3.1, controlled lakes in Table 3.1). Annual rainfall was below average (41.4 vs. 45.7 inches) and large (<1.0 inches) rain events were infrequent in 2014. Similar to the Catskill and Delaware Systems, August and September were extremely dry in the Croton watersheds. Only Diverting, Muscoot, Cross River, Kirk Lake and Lake Gleneida were slightly above historical turbidity levels, with higher turbidity occurring in months that would usually be associated with algal blooms.

Table 3.1: Site codes and site descriptions for the major inflow streams.

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

3.2 Coliform-Restricted Basin Assessments in 2014

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

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

3.2.1 Terminal Basin Assessments

In 2014, assessments were made for all five NYC terminal reservoir basins. Currently, coliform-restricted assessments for terminal basins are made using data from a minimum of five samples each week over two consecutive six-month periods. If 10% or more of the samples measured have values > 20 fecal coliforms $100mL^{-1}$, and the source of the coliforms is determined to be anthropogenic (Section 18-48(d)(2)), the associated basin is rated as a coliform-restricted basin. All terminal reservoirs had fecal coliform counts that were well below the 10% threshold and met the criteria for non-restricted basins for both six-month assessment periods in 2014 (Table 3.2).

Table 3.2: Coliform-restricted basin status as per Section18-48(c)(1) for terminal reservoirs in 2014.

Reservoir basin	Effluent keypoint	2014 assessment
Kensico	DEL18DT	Non-restricted
New Croton	CROGH[1]	Non-restricted
Ashokan	EARCM[2]	Non-restricted
Rondout	RDRRCM[2]	Non-restricted
West Branch	CWB1.5	Non-restricted

[1] Data from sites CRO1B and CRO1T were also used for this analysis.
[2] Data from the elevation tap that corresponds to the level of withdrawal are included one day per week, and all other samples are collected at the specified effluent keypoint.

3.2.2 Non-terminal Basin Assessments

Section 18-48(a)(1) requires that non-terminal basins be assessed according to 6 NYCRR Part 703 for total coliform. These New York State regulations are specific to the class of the reservoir. A minimum of five samples must be collected per month in each basin. Both the median value and more than 20% of the total coliform counts for a given month must exceed the values ascribed to the reservoir class to exceed the standard. Table 3.3 provides a summary of the coliform-restricted calculation results for the non-terminal reservoirs. In 2014, there were no exceedances of the Part 703 standard for total coliform during the sampling season (Table 3.3). Detailed results of monthly calculations are provided in Appendix B.

Total coliform bacteria originate from a variety of natural and anthropogenic (human-related) sources. However, Section 18-48(d)(1) states that the source of the total coliforms must be proven to be anthropogenic before a reservoir can receive coliform-restricted status. Since other microbial tests for identification of potential sources were not performed on these samples, the results in Table 3.3 represent only an initial assessment of total coliforms for the non-terminal basins in 2014. There were no other data indicating an anthropogenic source.

Table 3.3: Coliform-restricted calculations for total coliform counts on non-terminal reservoirs in 2014. NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20% of the total coliform sample for a given month must exceed the stated values in order to exceed the standard. TNTC = coliform plates too numerous to count.

Reservoir	Class[1]	Standard Monthly Median/ >20% (Total coliforms 100 mL^{-1})	Number of months that exceeded the standard/months of data	Number of months not evaluated due to TNTC data[2]
Amawalk	A	2400/5000	0/8	
Bog Brook	AA	50/240	0/8	
Boyd Corners	AA	50/240	0/7	
Croton Falls	A/AA	50/240	2/8	
Cross River	A/AA	50/240	0/8	
Diverting	AA	50/240	3/8	
East Branch	AA	50/240	0/8	
Lake Gilead	A	2400/5000	0/8	
Lake Gleneida	AA	50/240	0/8	
Kirk Lake	B	2400/5000	0/7	1
Muscoot	A	2400/5000	0/8	
Middle Branch	A	2400/5000	0/8	2
Titicus	AA	50/240	0/8	
Pepacton	A/AA	50/240	0/8	
Neversink	AA	50/240	0/8	
Schoharie	AA	50/240	2/8	1
Cannonsville	A/AA	50/240	0/8	

[1] The reservoir class for each water body is set forth in 6 NYCRR Chapter X, Subchapter B. For those reservoirs that have dual designations, the higher standard was applied.
[2] Determination of the monthly median or individual sample exceedance of the standard was not possible for TNTC (too numerous to count) samples.

3.3 Reservoir Total and Fecal Coliform Patterns in 2014

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

Reservoir fecal coliform results are presented in Figure 3.2 and reservoir total coliform results in Figure 3.3. Coliform results for the controlled lakes of the Croton System are summarized in Table 3.4. Note that data used to construct the boxplots are annual 75th percentiles rather than medians. Using the 75th percentile makes it is easier to discern differences among reservoirs because a large percentage of coliform data are generally below the detection limit.

Fecal and total coliform counts throughout the entire water supply were low (or low-to-normal) in 2014 coinciding with the generally low rainfall. Historically, the highest total coliform counts occur in the Catskill System reservoirs (Figure 3.3). Because coliforms commonly adhere to soil particles, and soils are very susceptible to erosion in these watersheds, an equal volume of runoff tends to produce much higher coliform counts in the Catskill System reservoirs. However, in 2014, Catskill total coliform counts were 35 to 120 times lower than historical counts and consistent with levels typically observed for the rest of the water supply system. Again, low precipitation, particularly in August and September when total coliforms often peak, may explain the exceptionally low counts in 2014.

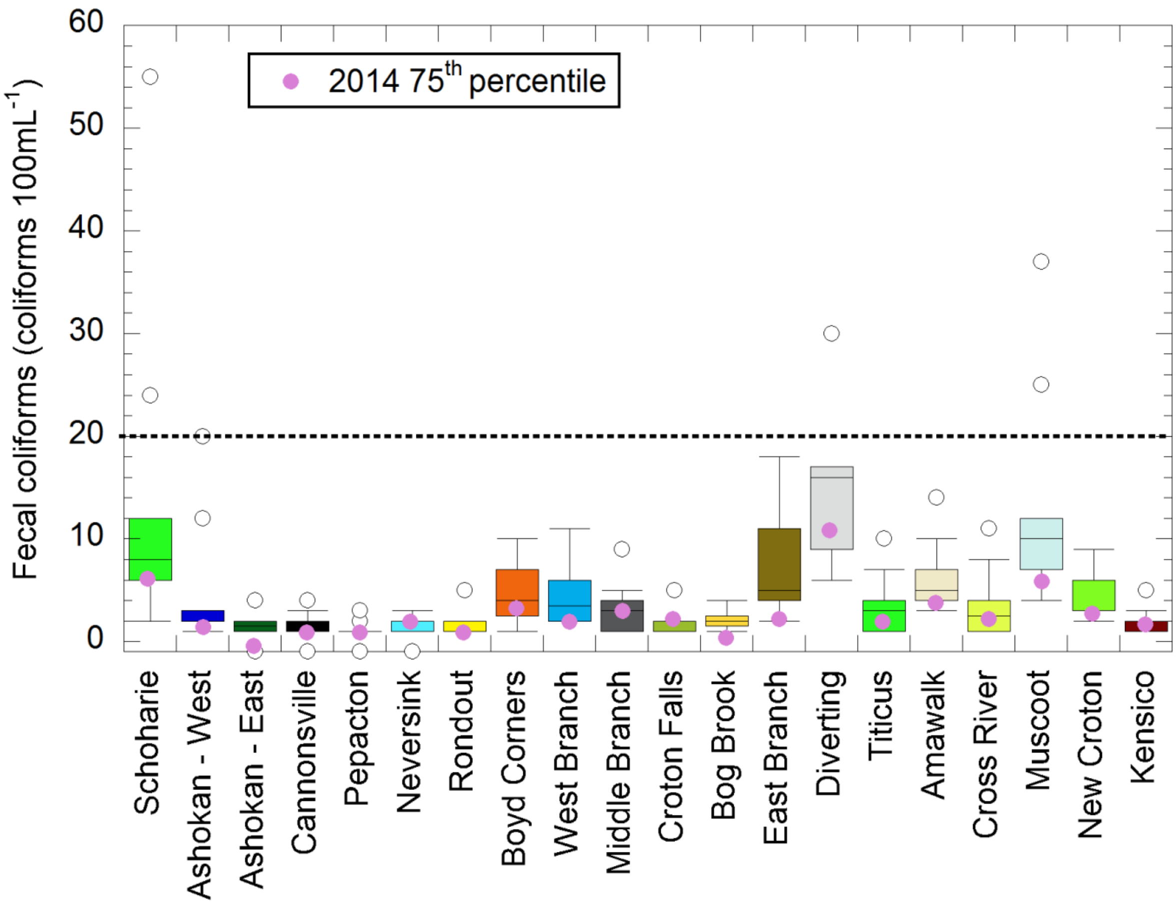

Figure 3.2 Annual 75th percentile of fecal coliforms in NYC water supply reservoirs (2014 vs. 2004-2013). The dashed line represents the SWTR standard for source waters as a reference. In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November.

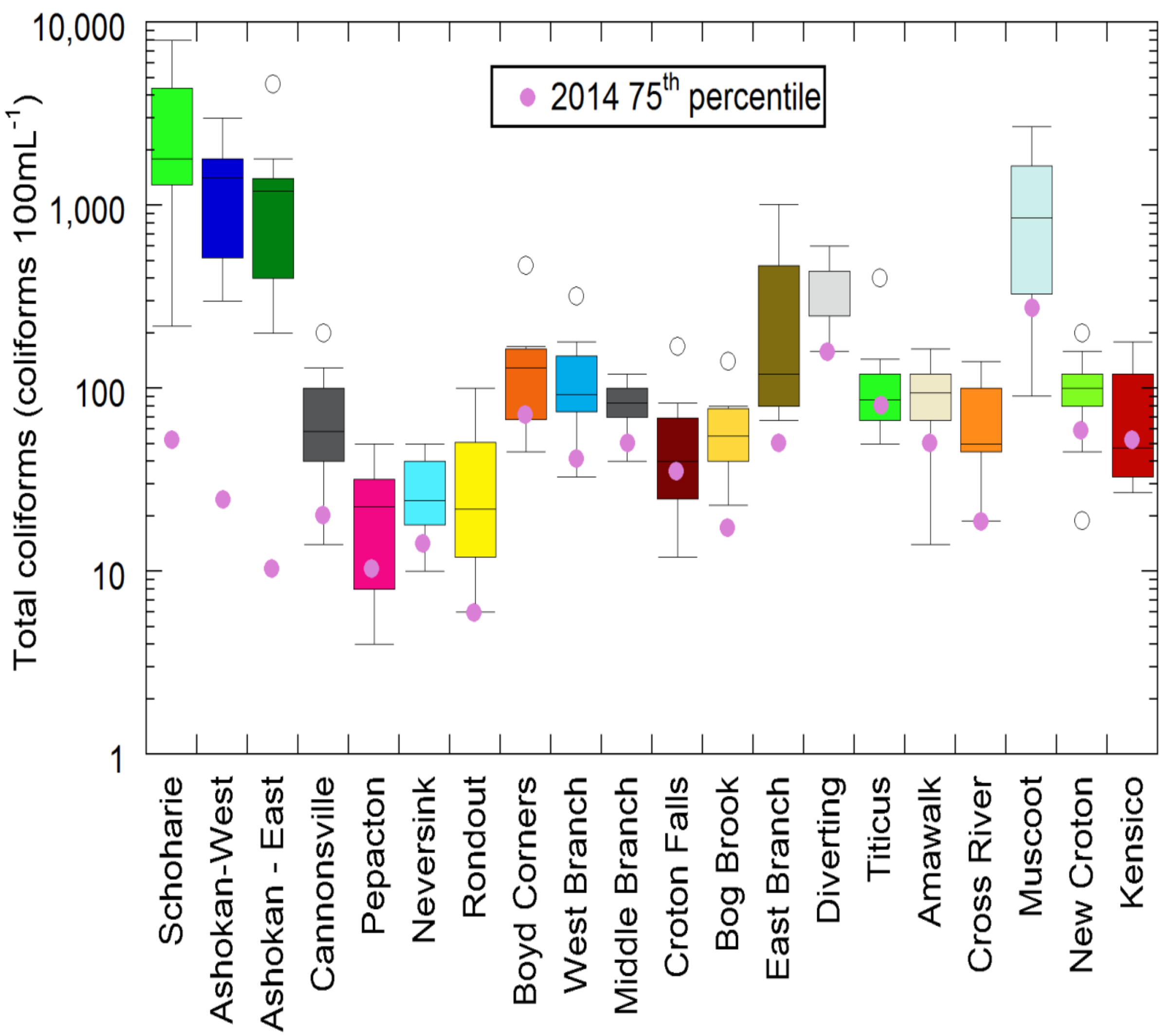

Figure 3.3 Annual 75th percentile of total coliforms in NYC water supply reservoirs (2014 vs. 2004-2013). In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November.

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

Lake	Historical total coliforms (75th percentile 2004-13)	Current total coliforms (75th percentile 2014)	Historical fecal coliforms (75th percentile 2004-13)	Current fecal coliforms (75th percentile 2014)
Gilead	27	4	2	1
Gleneida	20	1	1	0
Kirk	180	40	4	2

3.4 Phosphorus-Restricted Basin Assessments in 2014

The phosphorus-restricted basin status determination for 2014 is presented in Table 3.5 and was derived from two consecutive assessments (2009-2013 and 2010-2014) using the methodology described in Appendix C. Reservoirs and lakes with a geometric mean total phosphorus concentration that exceeds the benchmarks of 20 µg L^{-1} for non-source waters and 15 µg L^{-1} for source waters in the New York City Watershed Rules and Regulations (DEP 2010a) for both assessments are classified as restricted. Figure 3.4 graphically shows the phosphorus restriction status of the City's reservoirs and controlled lakes along with their 2014 geometric mean total phosphorus concentrations.

Some notable features of the phosphorus-restricted basin status determinations in 2014 are:

• The Delaware System reservoirs remained non-restricted with respect to total phosphorus (TP). There was little change between the two evaluation periods (2009-2013 and 2010-2014), as shown in Table 3.5.

• In the Catskill System, the five-year average used for the phosphorus-restricted basin status determination remained high due to the effects of Tropical Storms Irene and Lee, with a geometric mean concentration of 31 µg L^{-1} in 2011. The assessment for any five-year period that includes this high value for 2011 also includes the addition of the standard error of the mean to take interannual variability into consideration. The geometric mean TP concentration for Schoharie Reservoir was similar to its 2013 value (15.0 µg L^{-1}) in 2014 (15.3 µg L^{-1}). Both of the five-year assessments (2009-2013 and 2010-2014) reflect the impacts of tropical storms in 2011. The reservoir remained non-restricted based upon best professional judgment, since the five-year average is still influenced by the extreme storm events in 2011.

• The Croton System reservoirs remained unchanged in terms of their phosphorus-restricted status for 2014. All reservoirs in the Croton System are listed as "restricted" with the exception of Boyd Corners, which remained non-restricted, with a low value of 9.8 µg L^{-1} for both the latest assessment period and the previous assessment period (Table 3.5).

• Source water reservoirs have a limit of 15 µg L^{-1} and, as in the preceding assessment period, Cross River, Croton Falls, and New Croton remained in the "restricted" category, although there was a notable decrease in 2014 for Croton Falls, where the annual geometric mean declined from 23.0 µg L^{-1} in 2013 to 19.9 µg L^{-1} in 2014 (Appendix C). Kensico, Ashokan-East, Rondout, and West Branch Reservoirs were non-restricted for the current assessment period (Table 3.5). For Ashokan-West Basin, the current assessment was above the limit, due to the high value related to 2011 storms, but because it did not result in eutrophication in the reservoir in 2011 or in subsequent years, DEP exercised its best professional judgment and did not designate Ashokan Reservoir's West Basin as phosphorus restricted for the current assessment. The annual geometric mean phosphorus value for Ashokan-West Basin was slightly higher in 2014 (8.2 µg L^{-1}) than in 2013 (7.3 µg L^{-1}), as was the value for Ashokan-East Basin, with a value of 7.5 µg L^{-1} in 2014 as compared to 6.4 µg L^{-1} in 2013 (Appendix C).

Table 3.5: Phosphorus-restricted reservoir basins for 2014.

Reservoir basin	2009-2013 Assessment (mean + S.E.)[1] (µg L^{-1})	2010-2014 Assessment (mean + S.E.)[1] (µg L^{-1})	Phosphorus restricted status[2]
Non-Source Waters (Delaware System)			
Cannonsville	15.6	15.5	Non-restricted
Pepacton	9.9	10.0	Non-restricted
Neversink	8.5	8.5	Non-restricted
Non-Source Waters (Catskill System)			
Schoharie	21.9	22.4	Non-restricted
Non-Source Waters (Croton System)			
Amawalk	21.4	21.4	Restricted
Bog Brook	27.0	26.3	Restricted
Boyd Corners	9.8	9.8	Non-restricted
Diverting	30.0	29.8	Restricted
East Branch	31.1	31.0	Restricted
Middle Branch	32.2	34.3	Restricted
Muscoot	29.8	30.1	Restricted
Titicus	25.6	25.8	Restricted
Lake Gleneida	27.3	27.0	Restricted
Lake Gilead	30.8	29.8	Restricted
Kirk Lake	32.1	32.8	Restricted
Source Waters (all systems)			
Ashokan-East	10.7	10.3	Non-restricted
Ashokan-West	18.2	18.2	Non-restricted
Cross River	16.9	17.5	Restricted
Croton Falls	19.6	20.7	Restricted
Kensico	6.8	6.8	Non-restricted
New Croton	17.6	17.7	Restricted
Rondout	8.2	8.0	Non-restricted
West Branch	11.5	11.7	Non-restricted

[1] Arithmetic mean of annual geometric mean total phosphorus concentration for 5-year period with S.E. (standard error of the mean) added to account for interannual variability.
[2] The WR&R standard for non-source waters is 20 µg L^{-1} and for source waters is 15 µg L^{-1}.

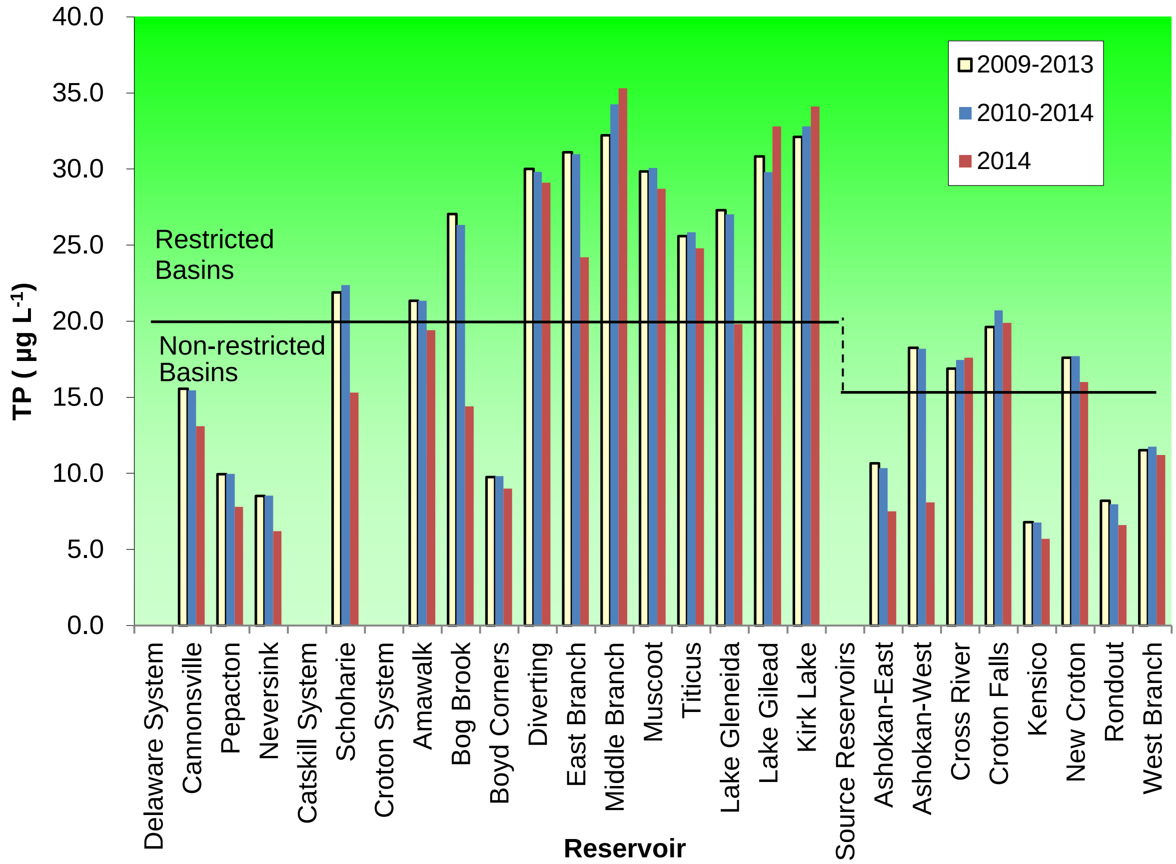

Figure 3.4 Phosphorus-restricted basin assessments, with the current year (2014) geometric mean phosphorus concentration displayed for comparison. The horizontal solid lines at 20 µg L^{-1} and 15 µg L^{-1} represent the WR&R standard for non-source waters and source waters, respectively.

3.5 Reservoir Total Phosphorus Patterns in 2014

Precipitation, and runoff generated by precipitation, are important mechanisms by which total phosphorus (TP), often bound to soil particles, is transported from local watersheds into streams and reservoirs. Primary sources of TP include: human and animal waste, fertilizer runoff, and internal loading from reservoir sediments during anoxic periods.

Annual TP concentrations in all Catskill and Delaware reservoirs ranged from low to normal in 2014 (Figure 3.5) although some seasonal increases were evident. In the Catskill System, Schoharie TP concentrations peaked in the spring following a 1.3 inch rain event in mid-April and again in early summer following a very large rain event (3.0 inches) on June 25. As was the case in 2013, TP concentrations in both Ashokan Reservoir basins were quite low in 2014. Multiple large (>1 inch) storms in July produced high flows but no increase in TP was observed. Low rainfall thereafter, especially in August and September, greatly reduced the chance of TP transport (assuming TP was accumulating in the watershed) for the remainder of the year.

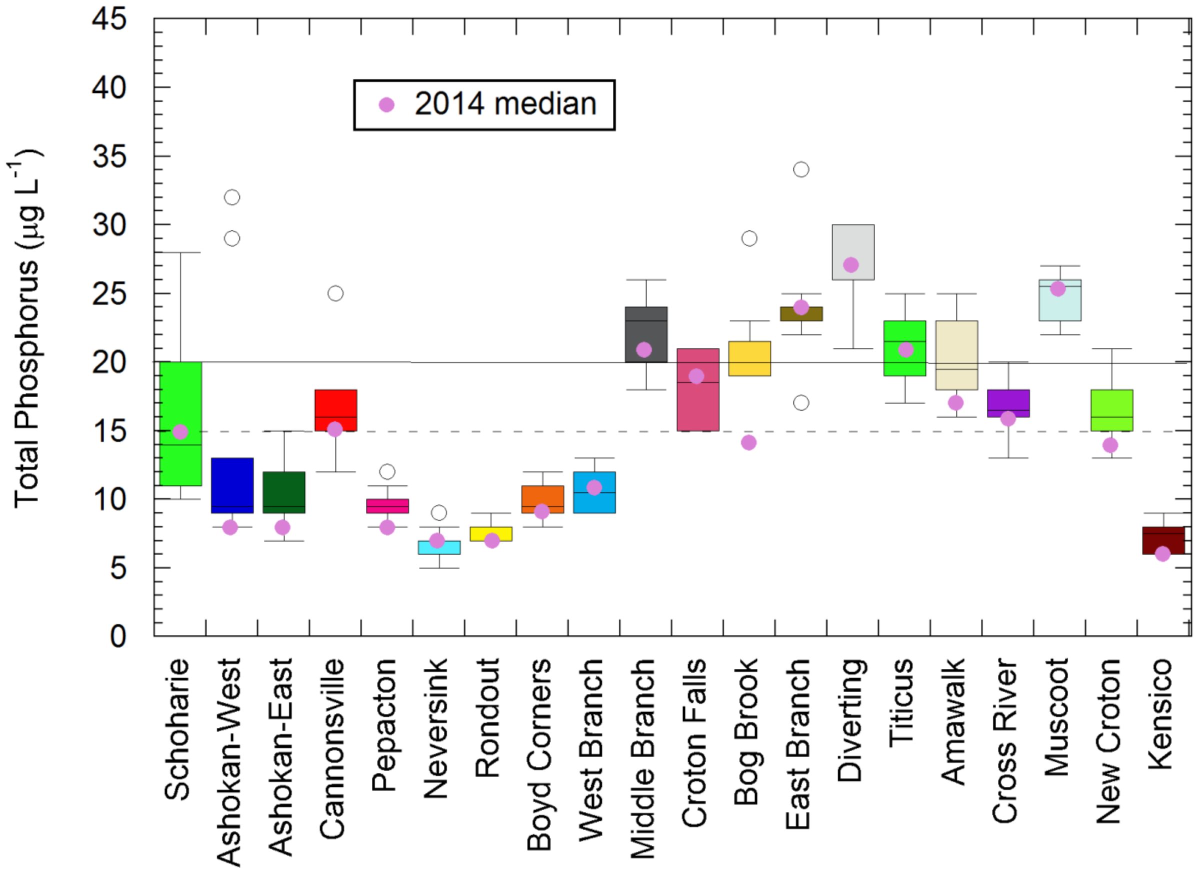

Figure 3.5 Annual median total phosphorus in NYC water supply reservoirs (2014 vs. 2004-2013). The horizontal dashed line at 15 µg L^{-1} refers to the NYC Total Maximum Daily Loads (TMDL) guidance value for source waters. The horizontal solid line at 20 µg L^{-1} refers to the NYSDEC ambient water quality guidance value appropriate for reservoirs other than source waters (the remaining reservoirs). In general, data were obtained from multiple sites, multiple depths, at routine sampling frequencies once per month from April through November. Note that although Kensico and New Croton are usually operated as source waters, these reservoirs can be by-passed so that any or all of the following can be operated as source waters: Rondout, Ashokan-East, Ashokan-West, and West Branch.

In the Delaware System, annual TP concentrations were also relatively low in 2014. Despite multiple large storms in July, no phosphorus increases were observed in any of the Delaware System reservoirs. These results may provide evidence that agricultural BMPs were successful at containing TP on the farms, although declining domesticated animal populations in the watersheds could also be a factor.

The annual TP concentration at West Branch was the same as its 10-year historical median. In 2014, most of the inputs to West Branch were from local streams, including releases from Boyd Corners Reservoir.

The annual TP concentration in Kensico Reservoir was lower than its historical median in 2014 (6 vs. 8 µg L^{-1}), a result of the low TP concentrations of its primary inputs: Rondout Reservoir, and the East Basin of Ashokan.

Compared to the Catskill and Delaware Systems, the Croton watershed has a greater abundance of phosphorus sources; there are 60 wastewater treatment plants, numerous septic systems, and extensive paved surfaces scattered throughout the watershed. Because of this more extensive development as well as geologic differences, TP concentrations in the Croton System reservoirs (Figure 3.5) and controlled lakes (Table 3.6) are much higher than in the reservoirs of the Catskill and Delaware Systems. In 2014, most Croton reservoirs and controlled lakes were on the low side of historical levels, ranging from 9 to 33 µg L^{-1}. Higher than normal concentrations were only observed at Kirk Lake and were associated with an algal bloom in May.

Efforts to reduce phosphorus loads in the Croton watershed are ongoing. Many WWTPs have been upgraded, while others are at some intermittent stage of upgrade. Septic repair and pump out programs continue in Putnam and Westchester Counties, as well as the implementation of farm (usually equestrian-based) BMPs. In addition, stormwater remediation projects are ongoing in the Boyd Corners, West Branch, Croton Falls and Cross River watersheds. These efforts, together with low summer rainfall, are likely responsible for the relatively low TP concentrations observed in the Croton System in 2014.

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

Lake	Median Total Phosphorus (2004-13)	Median Total Phosphorus (2014)
Gilead	20	18
Gleneida	17	12
Kirk	27	33

3.6 Terminal Reservoir Comparisons to Benchmarks in 2014

The New York City reservoirs and water supply system are subject to the federal SWTR standards, NYS ambient water quality standards, and DEP's own guidelines. In this section, the results for 2014 water quality sampling, including a variety of physical, biological, and chemical analytes for the terminal reservoirs, are evaluated by comparing the results to the water quality benchmarks listed in Table 3.7. These benchmarks are based on applicable federal, state, and DEP standards or guidelines, also listed in Table 3.7. Note that the standards in this table are not necessarily applicable to all individual samples and medians described herein (e.g., SWTR limits for turbidity and fecal coliforms apply only to the point of entry to the system). It should also be noted that different values apply to Croton reservoirs than to West of Hudson (WOH) reservoirs. Placing the data in the context of these benchmarks assists in understanding the robustness of the water system and water quality issues

Table 3.7: Reservoir and controlled lake benchmarks as listed in the WR&R (DEP 2010a).

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

[1] (a) WR&R (Appendix 18-B) – based on 1990 water quality results, (b) NYSDOH Drinking Water Secondary Standard, (c) DEP Internal standard/goal, (d) NYSDOH Drinking Water Primary Standard.
[2] Total dissolved solids was estimated by multiplying specific conductivity by 0.65 (van der Leeden 1990).
[3] Dissolved organic carbon was used in this analysis since total organic carbon is no longer analyzed.

Comparison of reservoir water quality data for 2014 to the benchmark values (Table 3.7) is provided in Appendix D for all reservoirs. Data represent samples collected monthly from April to November for multiple reservoir and controlled lake sites and depths as part of the fixed-frequency water quality monitoring program.

Highlights of the benchmark comparisons for terminal reservoirs from 2014 are as follows:

For the majority of reservoir samples, pH was circumneutral (6.5-8.5). Occurrences of pH exceeding 8.5 were associated with algal blooms, with a few occurrences in spring when diatoms were dominant, and the majority occurring in summer and early autumn. The pH values in Kensico were out of range for 33% of the samples, while 13% of West Branch samples exceeded the benchmark. In New Croton Reservoir, pH exceeded the water quality benchmark of 8.5 for 12% of the samples. In the WOH reservoirs with lower alkalinities, samples outside the benchmark range for pH generally fell below 6.5, with 30% of Ashokan-East Basin, 41% of Ashokan-West Basin, and 31% of Rondout samples below the benchmark range.

As in 2013, all chloride samples in New Croton exceeded the Croton System benchmarks of the 40 mg L^{-1} single sample maximum standard and the annual mean benchmark of 30 mg L^{-1} in 2014. All chloride samples in West Branch exceeded the benchmarks when compared to the Catskill/Delaware System standards, with 100% of the samples exceeding the single sample maximum of 12.0, and the 2014 mean of 27.1 exceeding the annual mean standard of 8.0 mg L^{-1}. Rondout, Pepacton, Neversink, Ashokan-East Basin, and Ashokan-West Basin were below the limits for these benchmarks. Kensico exceeded both the single sample maximum and annual mean benchmarks. All chloride samples were well below the health standard of 250 mg L^{-1}.

Turbidity levels in Kensico, Rondout, and West Branch did not exceed the single sample maximum of 5 NTU in 2014. New Croton exceeded the standard for 5 samples, representing 3% of reservoir samples. Ashokan-East Basin exceeded 5 NTU for 22% of the reservoir samples in 2014, an increase from 13% of samples collected the previous year, and Ashokan-West Basin exceeded 5 NTU for 47% of samples, a decline from 64% in 2013.

The TP concentration for the single sample maximum of 15 µg L^{-1} was not exceeded in Kensico, while only one sample exceeded the benchmark for Rondout. Both basins of Ashokan had a few more exceedances of the single sample benchmark in 2014 as compared to 2013, but on a percentage basis, the number of samples that exceeded the benchmark was low (9% for Ashokan-East Basin and 5% for Ashokan-West Basin). West Branch exceeded the benchmark for 16% of the samples, a decline from 31% in the previous year, and New Croton exceeded the benchmark for 48% of samples in 2014, a decline from 56% of the samples in 2013. Nitrate samples exceeded the single sample maximum in New Croton for 14% of the samples, and also exceeded the ammonia benchmark for both the single sample maximum (17% of samples) and annual mean concentration (0.1 as compared with 0.05 mg L^{-1}). No other terminal reservoir exceeded the benchmark values for nitrate or ammonia, with the exception of West Branch, which exceeded the ammonia benchmark for a single sample, representing 1% of samples collected in 2014.

Phytoplankton counts did not exceed the 2000 ASU mL^{-1}benchmark in Kensico, Rondout, New Croton, and both basins of Ashokan in 2014. For West Branch, a single sample exceeded both the single sample maximum of 2000 ASU mL^{-1} and the 1000 ASU mL^{-1} sample maximum for the dominant genus. In New Croton and West Branch, chlorophyll *a* exceeded the single sample maximum for 36% and 19% of the samples, respectively, and both exceeded their annual mean benchmarks. Kensico, Rondout, Ashokan-East Basin, and Ashokan-West Basin did not exceed the chlorophyll *a* criteria in 2014. Color in New Croton was above the benchmark of 15 units for 96% of the samples, while West Branch exceeded the color benchmark for 82% of reservoir samples in 2014. All other terminal reservoirs fell below the benchmark for color in 2014.

Fecal coliform counts did not exceed the single sample maximum in Kensico, Rondout, West Branch, and Ashokan-East Basin in 2014. One sample in New Croton Reservoir exceeded the single sample maximum of 20 fecal coliforms $100mL^{-1}$, and 3 samples exceeded the benchmark (4% of samples collected) in Ashokan-West Basin

3.7 Reservoir Trophic Status in 2014

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*, TP, and Secchi transparency) to delineate the trophic state of a body of water. TSI based on chlorophyll *a* concentration is calculated as:

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

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

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

Historical (2004-2013) annual median TSI based on chlorophyll *a* concentration is presented in boxplots for all reservoirs in Figure 3.6. The 2014 annual median TSI appears in the figure as a circle containing an “x”. Results for the East of Hudson controlled lakes are provided in Table 3.8. This analysis generally indicates that all West of Hudson reservoirs (including Kensico and West Branch) and only three East of Hudson reservoirs (Boyd Corners, Gilead and Gleneida) usually fall into the mesotrophic category. The remaining East of Hudson reservoirs tend to fall into the meso-eutrophic to eutrophic range.

Table 3.8: Trophic State Index (TSI) summary statistics for NYC controlled lakes

Lake	Median TSI (2004-13)	Median TSI (2014)
Gilead	47	48
Gleneida	43	44
Kirk	56	65

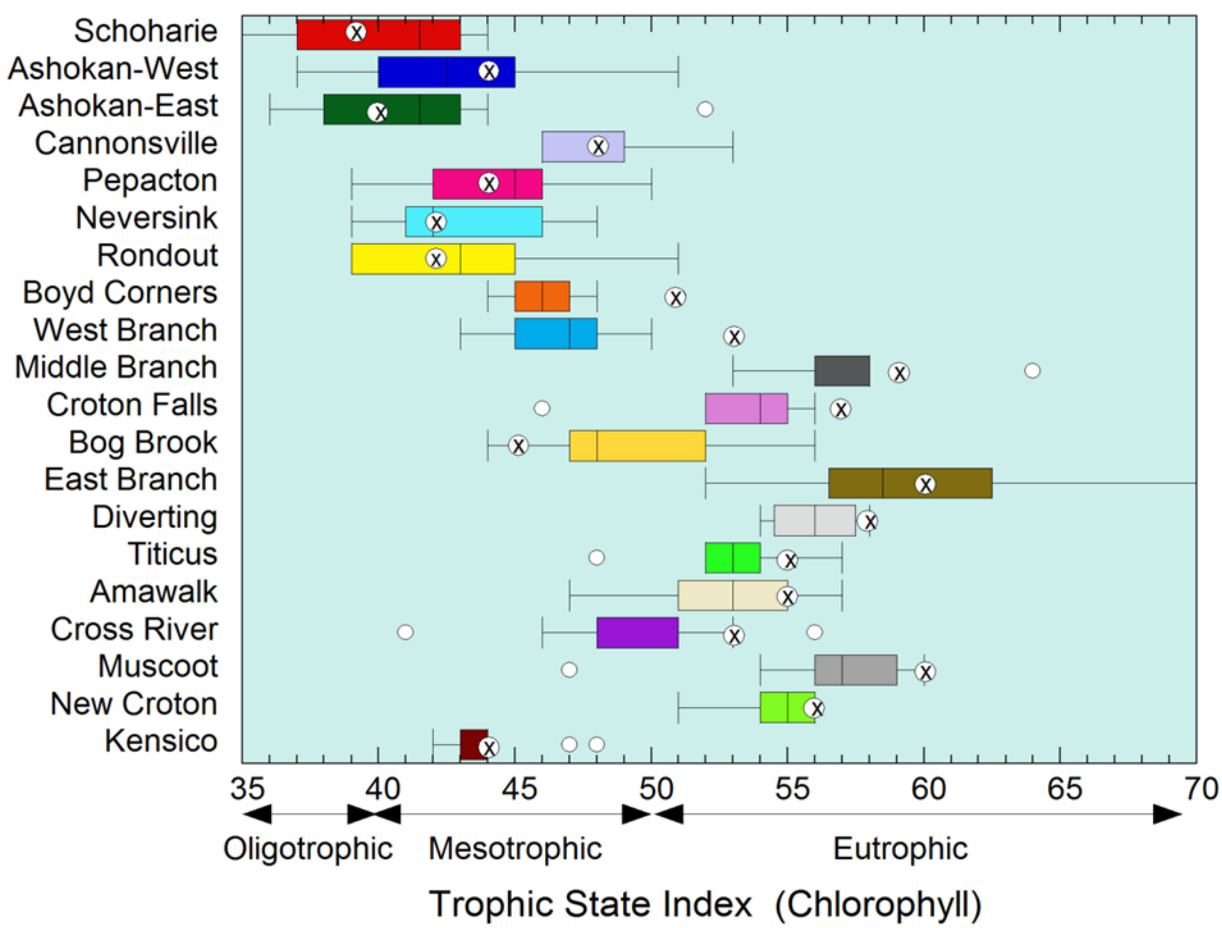

Figure 3.6 Annual median Trophic State Index (TSI) in NYC water supply reservoirs (2014 vs. 2004-2013). In general, data were obtained from epilimnetic depths at multiple sites, at routine sampling frequencies once per month from May through October. TSI is based on Chlorophyll *a* concentration.

In 2014, TSI was within normal ranges for the Catskill reservoirs. However, Ashokan-West Basin was slightly elevated for the year, perhaps a result of the improved water clarity (i.e., low turbidity) that this basin experienced in 2014. Schoharie's clarity, on the other hand, was lower than normal, and the TSI was less than the historical median.

TSI values in the Delaware Reservoirs were normal at Neversink and slightly improved at Cannonsville, Pepacton and Rondout in 2014. Improvements may be related to the generally low nutrient inputs observed for these reservoirs in 2014. Unlike the Catskill reservoirs, turbid conditions that inhibit algal growth are rarely attained in the Delaware System and 2014 was no exception.

As was the case in 2012 and 2013, West Branch Reservoir was borderline eutrophic in 2014. West Branch is usually mesotrophic because, in most years, the bulk of its water is from mesotrophic Rondout Reservoir. In 2012, 2013 and 2014, Rondout input was reduced, and West Branch received a greater proportion of its inputs from warmer, higher nutrient water from local streams, resulting in an increase in productivity.

Kensico Reservoir, the terminal reservoir for the Catskill/Delaware System, is primarily a blend of Ashokan-East Basin and Rondout water (and varying amounts from West Branch), with small contributions from local watershed streams. In 2014, Kensico's TSI fell between that of its major inputs and was well within historical levels.

TSI was generally higher in the reservoirs of the Croton System in 2014. Excess nutrients may explain the productivity increase. Although phosphorus concentrations tended to be lower than historical concentrations for most of the reservoirs (Figure 3.5), nitrogen concentrations (data not shown) were higher than usual in 2014

3.8 Water Quality in the Major Inflow Streams in 2014

The stream sites discussed in this section are listed in Table 3.9, with locations shown in Figure 3.7. These stream sites were chosen because they are the farthest sites downstream on each of the six main channels leading into the six Catskill/Delaware reservoirs and five of the Croton reservoirs. In other words, 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. The exception is New Croton Reservoir, whose major inflow is from the Muscoot Reservoir release; the Kisco River and Hunter Brook are tributaries to New Croton Reservoir and represent water quality conditions in the New Croton watershed

Table 3.9: Site codes and site descriptions for the major inflow streams.

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

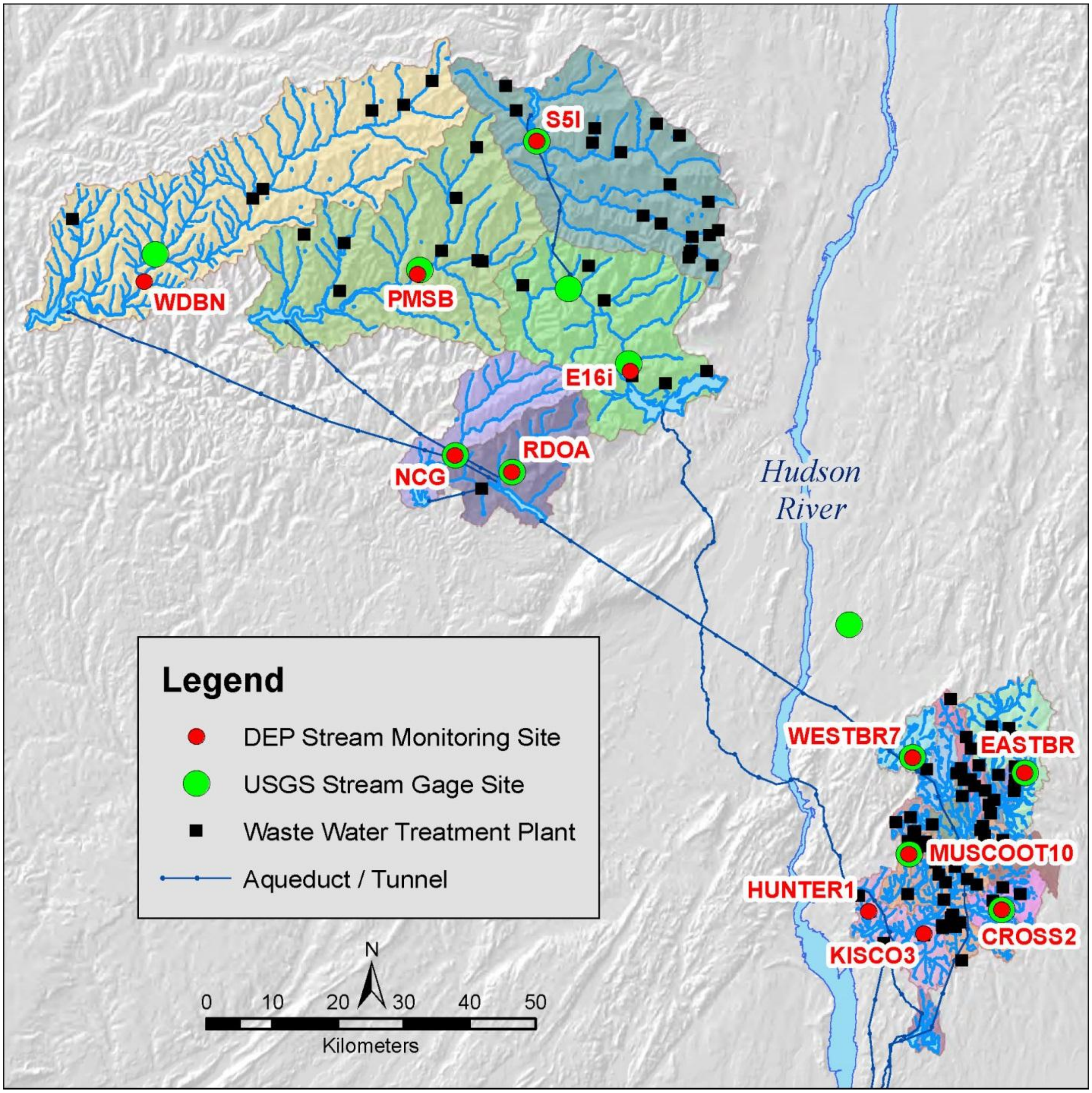

Figure 3.7 Locations of major inflow stream water quality sampling sites and USGS gage stations used to calculate runoff values (see Section 2.3).

Water quality in these streams was assessed by examining those analytes considered to be the most important for the City's water supply. For streams, these are turbidity and fecal coliform bacteria (to maintain compliance with the SWTR), and TP (to control nutrients and eutrophication).

The 2014 results presented in Figure 3.8 are based on grab samples generally collected once a month, except that turbidity data were collected weekly at Esopus Creek at Boiceville bridge (E16I) and three or four times a month at Rondout Creek near Lowes Corners (RDOA) and the Neversink River near Claryville (NCG). The figure compares the 2014 median values against historical median annual values for the previous 10 years (2004-2013).

Turbidity

The turbidity levels for 2014 were generally near normal values for the WOH streams. The annual median turbidities for the EOH inflows were mostly below their historical values, with the inflows to New Croton Reservoir, the Kisco River (KISCO3) and Hunter Brook (HUNTER1) at their lowest annual median in the last 10 years.

Total Phosphorus

In the WOH streams, the 2014 median TP concentrations were generally near their normal historical values, except for the Cannonsville Reservoir inflow (WDBN), which was somewhat above normal and the third highest annual median since 2004, and the Rondout Reservoir inflow (RDOA) which, with the same annual TP median as in 2012 and 2013, was also somewhat above normal. The annual TP median at the Pepacton inflow (PMSB) was the second lowest over the past 10 years. The 2014 TP medians in the Croton System were all somewhat above normal except for Hunter Brook, whose median equaled the second lowest annual median over the past 10 years.

Fecal Coliform Bacteria

The 2014 median fecal coliform bacteria levels in the Catskill/Delaware streams were generally near or somewhat below typical historical levels, except for the Schoharie Reservoir inflow (S5I), which had its lowest annual median in the last 10 years, and the Rondout Reservoir inflow (RDOA), which had its highest annual median in the last 10 years, although it was only 7 coliforms $100mL^{-1}$. For the EOH streams, the results for the annual fecal coliform levels were mixed, with below normal annual medians for the Amawalk and New Croton inflows, but somewhat above the historical annual medians for the Boyd Corners, East Branch (second highest annual median in the last 10 years), and Cross River inflows. A fecal coliform benchmark of 200 coliforms $100mL^{-1}$ is shown as a solid line in Figure 3.8c. This benchmark relates to the NYSDEC water quality standard for fecal coliforms (expressed as a monthly geometric mean of five samples, the standard being <200 coliforms $100mL^{-1}$) (6NYCRR §703.4b). The 2014 median values for all streams shown here lie well below this value.

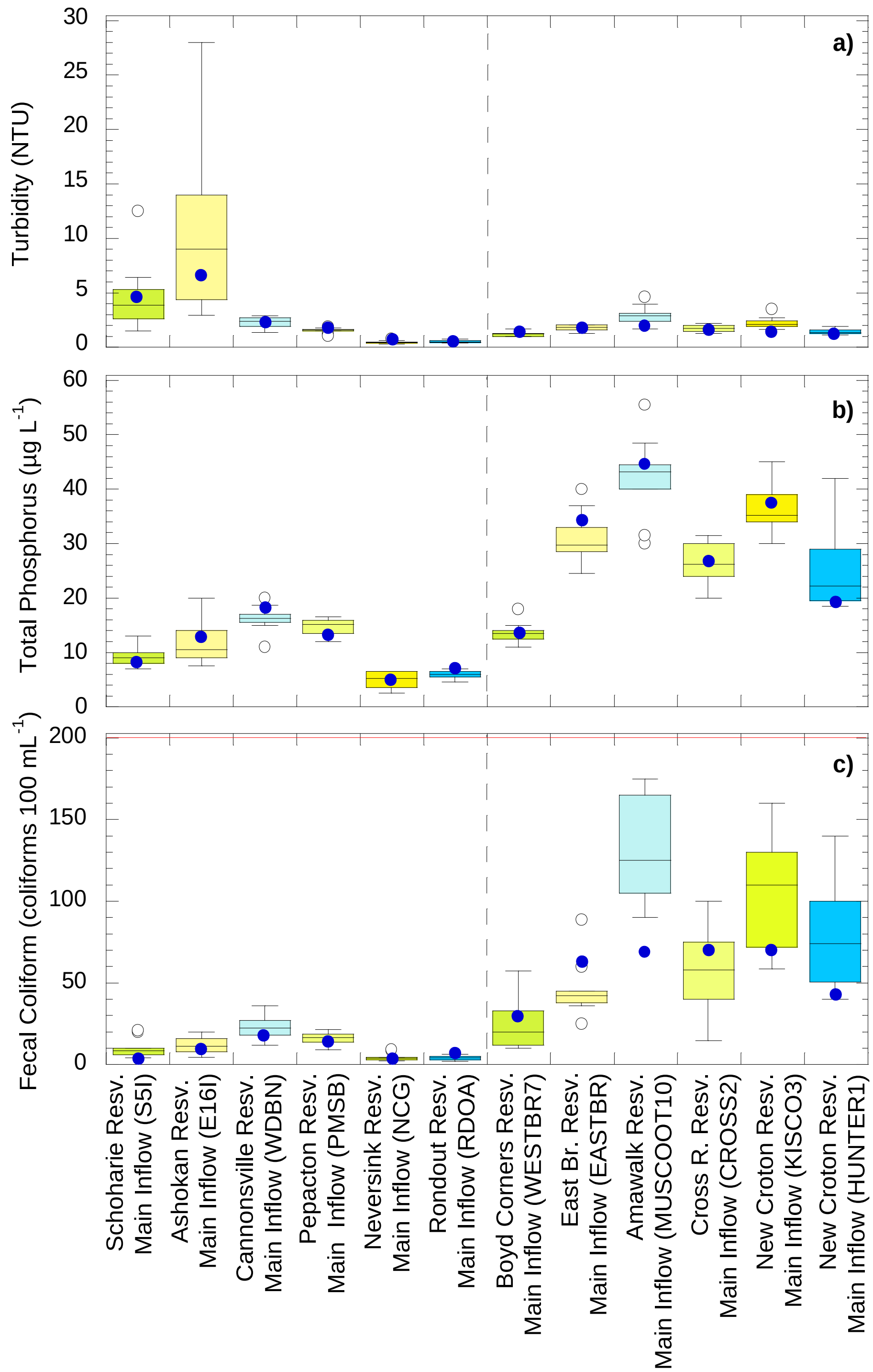

Figure 3.8 Boxplot of annual medians (2004-2013) for a) turbidity, b) total phosphorus, and c) fecal coliform for selected stream (reservoir inflow) sites, with the value for 2014 displayed as a dot. The dotted line separates WOH streams (left) from EOH streams (right). The solid red line indicates the fecal coliform benchmark of 200 coliforms $100 mL^{-1}$.

3.9 Stream Comparisons to Benchmarks in 2014

Selected water quality benchmarks have been established for reservoirs and reservoir stems (any watercourse segment which is tributary to a reservoir and lies within 500 feet or less of the reservoir) in the WR&R (DEP 2010a). In this section, the application of these benchmarks has been extended to 40 streams and reservoir releases in order to evaluate stream status in 2014 (DEP 2009a). The benchmarks are provided in Table 3.10.

Table 3.10: Stream water quality benchmarks as listed in the WR&R (Appendix 18-B) (DEP 2010a). The benchmarks are based on 1990 water quality results.

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

[1] Organic nitrogen is currently not analyzed.
[2] Total dissolved solids are estimated by multiplying specific conductivity by 0.65 (van der Leeden et al. 1990).
[3] Dissolved organic carbon was used in this analysis since TOC is no longer analyzed.

Comparison of stream results to these benchmarks is presented in Appendix E along with site descriptions, which appear next to the site codes. Note that the Catskill/Delaware System criteria are applied to the release from West Branch Reservoir (WESTBRR) since that release usually is dominated by Delaware System water via Rondout Reservoir.

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

In the NYC water supply, the lowest alkalinity levels typically occur in the winter and spring when acidic snowmelt reaches the streams. Streams of the Schoharie basin always met the benchmark in 2014, while occasional excursions were observed in the Cannonsville and Pepacton basins. In the Pepacton basin, excursions slightly below 10 mg L^{-1} occurred in January, March, April and December at Terry Clove (P-7) and in April at Fall Clove (P-8). All winter (except February) and spring months at Mill Brook (P-60) dipped below 10 mg L^{-1}, ranging from 7 to 9.1 mg L^{-1}. Excursions in the Cannonsville basin only occurred in January and April at Trout Creek (C-7) and Loomis Brook (C-8) and in April at the West Branch of the Delaware River. In contrast, excursions below 10 mg L^{-1} were common in most streams of the Ashokan and all streams of the Rondout and Neversink basins. Such low buffering capacity is typical of the surficial materials in this region of the Catskills. A benchmark of 40 mg L^{-1} is used for the Croton System streams, which reflect the much higher natural buffering capacity of this region. However, less buffering capacity does occur in the Boyd Corners and West Branch Reservoir basins. Alkalinity results from stream sites in these basins (GYPSYTRL1, HORSEPD12, WESTBR7 and BOYDR) were often below 40 mg L^{-1}, with average alkalinities ranging from 28.8 to 39.3 mg L^{-1} in 2014.

None of the Catskill or Delaware streams (including WESTBRR) exceeded the single sample chloride benchmark of 50 mg L^{-1} in 2014. However, the annual mean benchmark of 10 mg L^{-1} was exceeded in 9 of the 24 streams monitored in these two systems. The highest annual mean, 32.2 mg L^{-1}, occurred at Kramer Brook above Neversink Reservoir. In contrast, the two other monitored streams in the Neversink watershed, Aden Brook (NK4) and the Neversink River (NCG), averaged 4.2 and 3.6 mg L^{-1}, respectively. The Kramer Brook watershed is very small (<1 sq. mile), is bordered by a state highway and contains pockets of development, all of which may contribute to the relatively high chloride levels. Other high annual means occurred at Bear Kill Creek (20.6 mg L^{-1}), a tributary to Schoharie Reservoir; at Trout Creek (16.4 mg L^{-1}), Loomis Brook (16.6 mg L^{-1}), and the West Branch of the Delaware River (15.6 mg L^{-1}), all tributaries to Cannonsville Reservoir; and at Chestnut Creek (16.5 mg L^{-1}), a tributary to Rondout Reservoir. The outflow from West Branch Reservoir (WESTBRR) was 23.7 mg L^{-1} in 2014 compared to 10.5 mg L^{-1} in 2011. The increase reflects the predominant “float” operational status of West Branch Reservoir in 2014. In float status, inputs to West Branch consist of small quantities of relatively low chloride Rondout water and greater inputs of local, higher chloride Croton water.

In the Croton System, the single sample chloride benchmark of 100 mg L^{-1} was commonly exceeded in the Muscoot River (MUSCOOT10) above Amawalk Reservoir, the release from Amawalk (AMAWALKR), Michael’s Brook (MIKE2) above Croton Falls Reservoir, and in the Kisco River (KISCO3) above New Croton Reservoir. Occasional excursions occurred at the Diverting release (DIVERTR), the Long Pond outflow above West Branch Reservoir (LONGPD1) and at the combined release for Bog Brook and East Branch Reservoirs (BOGEASTBRR). The excursion at BOGEASTBR (237 mg L^{-1}) is likely an outlier since the other monthly chloride results only ranged from 67.6 to 91.2 mg L^{-1} at this location. In addition to the single sample excursions, the annual mean benchmark of 35 mg L^{-1} was exceeded in 12 of the 16 monitored Croton streams. Means exceeding the benchmark ranged from 40.7 to 174.8 mg L^{-1}. The mean 2014 chloride for all 16 Croton streams was 72.0 mg L^{-1}, an increase from the 66.7 mg L^{-1} mean reported in 2013. By comparison, chloride was much lower in the Catskill and Delaware Systems in 2014, averaging 10.8 mg L^{-1} and 11.0 mg L^{-1}, respectively. Road salt is the primary source of chloride in these systems, while secondary sources include septic system leachate, water softening brine waste, and wastewater treatment effluent. The much greater chloride concentrations in the Croton System are due to higher road and population densities in these watersheds. Given the common occurrence of chloride and sodium, it was not surprising that sodium benchmarks were exceeded in much the same pattern as chloride.

Total dissolved solids (TDS) is a measure of the combined content of all inorganic and organic substances in the filtrate of a sample. Although TDS is not analyzed directly by DEP, it is commonly estimated in the water supply industry using measurements of specific conductivity. Conversion factors to compute TDS from specific conductivity relate to the water type (International Organization for Standardization 1985, Singh and Kalra 1975). For NYC waters, specific conductivity was used to estimate TDS by multiplying specific conductivity by 0.65 (van der Leeden et al. 1990). In 2014, 15 of 24 Catskill/Delaware streams had at least one exceedance of the single sample maximum of 50 mg L^{-1}. Fourteen Catskill/Delaware streams also exceeded the annual mean benchmark of 40 mg L^{-1}. Most occurrences of elevated TDS were associated with periods of low summer flow. Occasional winter excursions were correlated to high chloride concentrations. Only streams with very low average chloride concentrations (<7.0 mg L^{-1}) consistently met both TDS benchmarks. In the Croton System only BOYDR (Boyd Corners release) and WESTBR7 (above Boyd Corners Reservoir) met both the annual benchmark of 150 mg L^{-1} and the single sample maximum criterion of 175 mg L^{-1}. As with the Catskill/Delaware streams, these Croton streams and reservoir releases had relatively low chloride concentrations. TDS excursions in the Croton System are most likely associated with one or more of the following sources: elevated salt concentrations from road salt, water softening brine waste, septic system leachate and wastewater treatment effluent.

When present in excess, nitrogen, especially in the bioavailable forms of nitrate and ammonia, is one of the important nutrients that can contribute to excessive algal growth in the reservoirs. The single sample nitrate benchmark of 1.5 mg L^{-1} was exceeded in one Croton stream, Michael's Brook upstream of Croton Falls Reservoir. The benchmark was exceeded in 8 of 12 monthly samples and was especially high in February (7.2 mg L^{-1}), September (7.7 mg L^{-1}) and October (8.3 mg L^{-1}). Four Croton streams equaled or exceeded the annual average benchmark of 0.35 mg L^{-1} for 2014: Horse Pound Brook at HORSEPD12 (0.36 mg L^{-1}), the Kisco River at KISCO3 (0.58 mg L), the Muscoot River at MUSCOOT10 (0.45 mg L), and Michael's Brook at MIKE2 (3.56 mg L^{-1}). These four streams also exceeded the mean annual benchmark in 2013. No streams from the Catskill/Delaware System exceeded the single sample nitrate benchmark of 1.5 mg L^{-1}. However, the average annual benchmark of 0.40 mg L^{-1} was exceeded in the West Branch of the Delaware River at WDBN (0.63 mg L^{-1}), Bear Creek at S6I (0.55 mg L^{-1}), Kramer Brook at NK6 (0.52 mg L^{-1}), and Fall Clove at P-8 (0.45 mg L^{-1}), and was equaled in the East Branch of the Delaware River at PMSB (0.40 mg L^{-1}). The source of the nitrogen is unclear.

None of the true Catskill/Delaware System streams exceeded the ammonia single sample maximum of 0.25 mg L^{-1} or the mean annual benchmark of 0.05 mg L^{-1} in 2014. However, the mean annual benchmark was exceeded in the release from West Branch Reservoir (WESTBRR), a mixture of Croton and Delaware System waters. Because West Branch was operated mostly in float status, favoring warmer, more nutrient-rich local Croton inputs over water from the Delaware System, an increase in productivity was observed for this reservoir in 2014 (see section 3.7). Subsequent decomposition of plankton produced anoxia within the bottom waters of the reservoir, which facilitated the production of ammonia from the reservoir sediments in late summer and corresponded to the increased ammonia observed in the West Branch release. Four Croton System streams exceeded the ammonia single sample maximum in 2014. The reservoir releases from Titicus (TITICUSR), Croton Falls (CROFALLSVC) and Cross River (CROSSRVVC) all exceeded 0.2 mg L^{-1} during the late summer and into the fall. As was the case for West Branch, the increase was associated with the release of ammonia from anoxic reservoir sediments brought about by the decomposition of summer algal blooms. The single sample maximum was also exceeded in February and March at Michael's Brook. In this case the source of the elevated ammonia is probably related to the wastewater treatment plant located upstream. In 2014, the mean annual benchmark of 0.10 mg L^{-1} was reached at this stream and was exceeded at the reservoir releases at Croton Falls and Cross River. All other Croton streams were compliant with this benchmark in 2014.

Neither the single sample maximum (15 mg L^{-1}) nor the annual mean (10.0 mg L^{-1}) benchmarks for sulfate were surpassed in the Catskill and Delaware streams in 2014. All Croton stream results were below the Croton System single sample maximum of 25 mg L^{-1} and most were below the annual average of 15 mg L^{-1}. Exceptions occurred at Michael's Brook and at the Kisco River (KISCO3), with annual averages of 18.5 mg L^{-1} and 16.2 mg L^{-1}, respectively. Wastewater treatment plants are located upstream of these sampling locations and are the probable source of the excess sulfate.

Dissolved organic carbon (DOC) was used in this analysis instead of total organic carbon since the latter is not analyzed as part of DEP's watershed water quality monitoring program. Previous work has shown that DOC constitutes the majority of the organic carbon in stream and reservoir samples. The DOC benchmarks for single sample (25 mg L^{-1}) and annual mean (9.0 mg L^{-1}) were not surpassed by any stream in 2014. The highest single sample DOC in the Catskill/Delaware System, 6.5 mg L^{-1}, occurred at Sawkill Brook (RD4) in the Rondout watershed, while the annual mean Catskill/Delaware DOC ranged from 0.7 to 2.7 mg L^{-1}, well below the annual mean benchmark. Due to a greater percentage of wetlands in their watersheds, Croton streams typically had higher DOC concentrations than those in the Catskill/Delaware watersheds; this is reflected in the 2014 annual means, which ranged from 3.2 to 5.1 mg L^{-1}. The highest single sample DOC was 8.5 mg L^{-1}, which occurred at Gypsy Trail Brook (GYPSYTRL1), a tributary to West Branch Reservoir.

3.10 Stream Biomonitoring

DEP has been performing water quality assessments of watershed streams based on resident benthic macroinvertebrate assemblages since 1994. Assessments are made following protocols developed by the New York State Stream Biomonitoring Unit (SBU) (NYSDEC 2014.) In brief, five metrics, each a different measure of biological integrity, are calculated and averaged to produce a Biological Assessment Profile (BAP) score ranging from 0-10; these scores correspond to four levels of impairment (non-impaired, 7.5-10; slightly impaired, 5-7.5; moderately impaired, 2.5-5; severely impaired, 0-2.5). The five metrics used in the analysis are total taxa; Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa; Hilsenhoff Biotic Index (HBI), Percent Model Affinity (PMA); and, since 2012, Nutrient Biotic Index-Phosphorus (NBI-P).

In 2014, DEP sampled 38 sites in 17 streams throughout New York City's watershed, 12 in the Catskill System, 11 in Delaware, and 15 in Croton. (For site locations, see Appendix F.). Scores in Croton were generally lower than in Catskill and Delaware, which is consistent with previous years' results (see, e.g., DEP 2013a, 2013b, 2014).

Croton System

In the Croton System, 13 sites were slightly impaired and 2 were moderately impaired (Figure 3.9). The high percentage of impaired sites is typical of the Croton System (e.g., 2010—100%, 2011—84.6%, 2012—100%, 2013—90.0%), although it is worth noting that nearly half of the sites for which a long-term mean could be calculated had scores exceeding the mean (Figure 3.9).

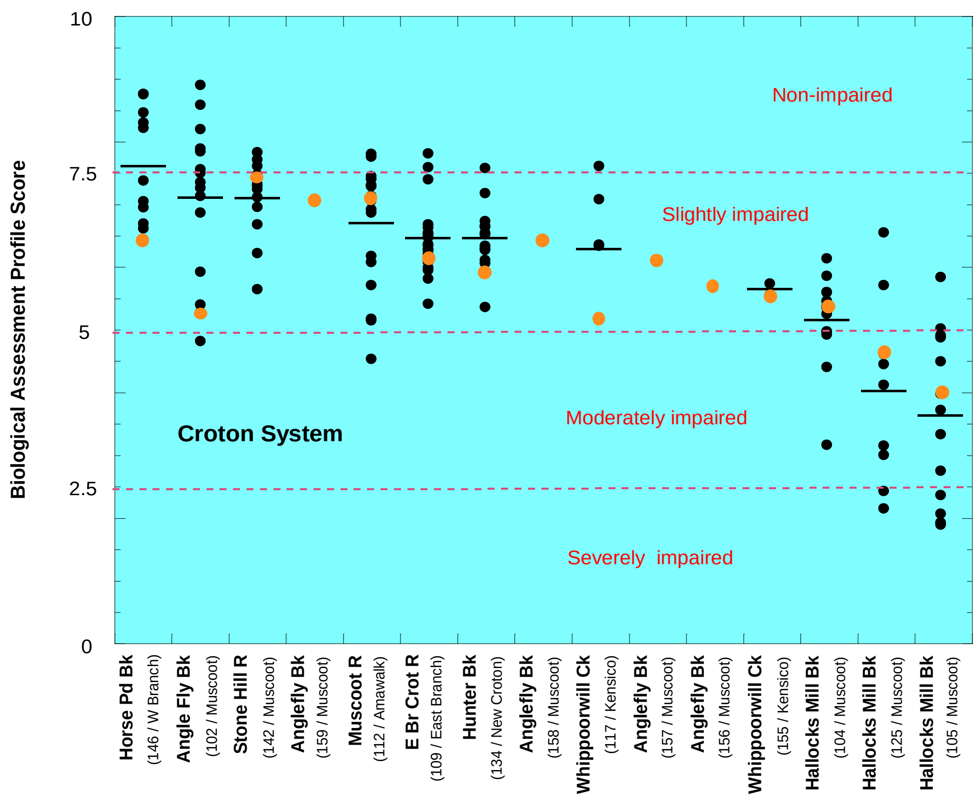

Figure 3.9 Biological Assessment Profile scores for East of Hudson biomonitoring sites sampled in 2014, arranged by mean score from highest to lowest. Horizontal bars represent the mean score, orange dots the 2014 score, and black dots the pre-2014 score. The site's number and watershed are indicated in parentheses following the site name. Mean bars are not shown for Sites 156, 157, 158, and 159 because 2014 is the only year that they have been sampled.

At Site 146 on Horse Pound Brook, the 6.45 BAP score was the lowest recorded since sampling began there in 2004, and is the third consecutive year the score has fallen below 7 (Figure 3.10). This is a site which from 2005 to 2009 consistently scored above 8, making it one of the highest scoring streams East of Hudson. Since then, however, scores have steadily declined, with 2009 marking the last year it assessed as non-impaired. The proximate cause of the drop in scores is a reduced number of taxa, usually, but not always, EPT and/or dipteran taxa. The underlying reason for these declines, however, remains unclear. No issues relating to development in the stream's watershed or to wastewater treatment plant discharges have been identified, nor have changes in water chemistry been noted. DEP will continue to monitor the stream to try to identify the disturbance responsible for this downward trend.

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Figure 3.10 Biological Assessment Profile scores for Sites 102, 146, 206, 301, 304, and 321. The 2011 score at Site 206 has been omitted because of the low subsample count recorded that year.

While the assessment at Anglefly Brook (Site 102) improved to slightly impaired following last year's moderately impaired rating, the site continued to display the low metric values that have produced impaired assessments there since 2004, after years of being one of the highest rated sites in the East of Hudson System (Figure 3.10). As in past years, very high numbers of hydropsychid caddisflies and the absence of mayflies accounted for the poor outcome. DEP sampled several sites upstream of Site 102 in an effort to isolate the source of the problem: two headwaters about 0.8 miles upstream (Sites 156 and 157), and the mainstem (Site 159) and a major tributary (Site 158), both about one-quarter mile upstream (Figure 3.11). The result was inconclusive, with few hydropsychids present at the mainstem site, but with a range in abundances—all high but none approaching the numbers present at Site 102—at the headwaters and tributary (Table 3.11). All four sites were consistent, though, in having few or no mayflies. In the future, DEP will investigate the still unsampled reach between Site 102 and the confluence directly below Sites 158 and 159 to obtain a more complete picture of the range in hydropsychid abundance present in the stream. DEP will also resample all four upstream sites to determine if the numbers of hydropsychids observed there in 2014 provide a true estimate of hydropsychid abundance in those reaches.

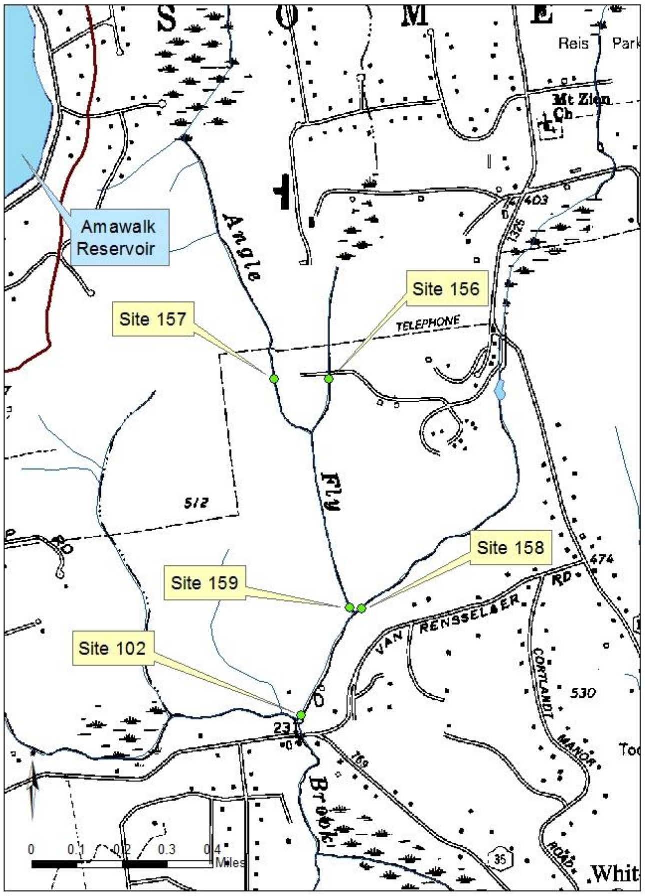


Figure 3.11 Anglefly Brook biomonitoring sites.

Two of the slightly impaired sites, on Whippoorwill Creek in the Kensico basin (Sites 117 and 155), were sampled to evaluate the impact to the stream's macroinvertebrate community of a streambank stabilization project completed in 2012. Site 155 is located above the affected reach, Site 117 below. A report (Rosenfeld 2015) concluded that the project had little or no effect on the downstream community. It cautioned, however, that because of limited data and the likelihood that community composition at the downstream site will change as it continues to recover from the disturbance caused by blowdown from Hurricane Sandy, additional sampling will be needed to obtain a clearer picture. DEP will therefore resample both sites in 2015.

Table 3.11: Percent hydropsychid abundance at 2014 Anglefly Brook biomonitoring sites.

Site No.	Percent Hydropsychidae
102	66.9
156	45.5
157	24.2*
158	33.6*
159	15.6

*Mean of two replicates.

The two moderately impaired assessments occurred at sites on Hallocks Mill Brook, below the upgraded Yorktown Heights WWTP. The BAP score at the site immediately below the plant's outfall (Site 105) was lower than it was last year (3.99 in 2014 vs. 4.89 in 2013), while the score further downstream, just above the confluence with the Muscoot River (Site 125), increased slightly from its previous year of sampling (4.62 in 2014 vs. 4.13 in 2010). While both scores are below the high scores achieved immediately after the upgrade, they still represent significant improvements over pre-upgrade scores. In this regard, it is noteworthy that despite the low score at Site 105, a number of very sensitive taxa were observed there during sampling, even though they were not present in the subsample from which the BAP score was derived. These included glossosomatid caddisflies, mayflies from the genus *Isonychia*, and, most notably, the caddisfly *Rhyacophila*, which has never been recorded at this site before, and has only been observed on two other occasions in Hallocks Mill Brook, both times at Site 125.

Catskill/Delaware System

In the Catskill System, 12 sites were non-impaired and 4 were slightly impaired, while in the Delaware System, 6 sites were non-impaired and 5 slightly impaired (Figure 3.12). High numbers of hydropsychid caddisflies (>30%) were present at two-thirds of the impaired sites and nearly half overall. The increase in percent composition of hydropsychids in West of Hudson streams in recent years has been noted in previous reports (DEP 2013b, 2014). Dominance by a single group of organisms tends to depress the total taxa and PMA metrics, resulting in lower BAP scores. This phenomenon was experienced in both systems in 2014, but most strongly in Delaware, where all five impaired sites had high hydropsychid percent composition, low taxa counts (with the single exception of Site 321), and low PMA (Table 3.12). Note, however, that low taxa numbers, another development of recent years (DEP 2014), were not restricted to sites with high hydropsychid abundance or to impaired streams. In fact, low counts were observed at nearly half the sites, including 5 of the 18 sites receiving a non-impaired assessment and 7 sites where hydropsychid abundance was low to moderate. This represents an improvement over 2013, when 86% of sampled sites had taxa counts below the historical mean. The reason for the continued widespread drop in total taxa nevertheless remains unclear.

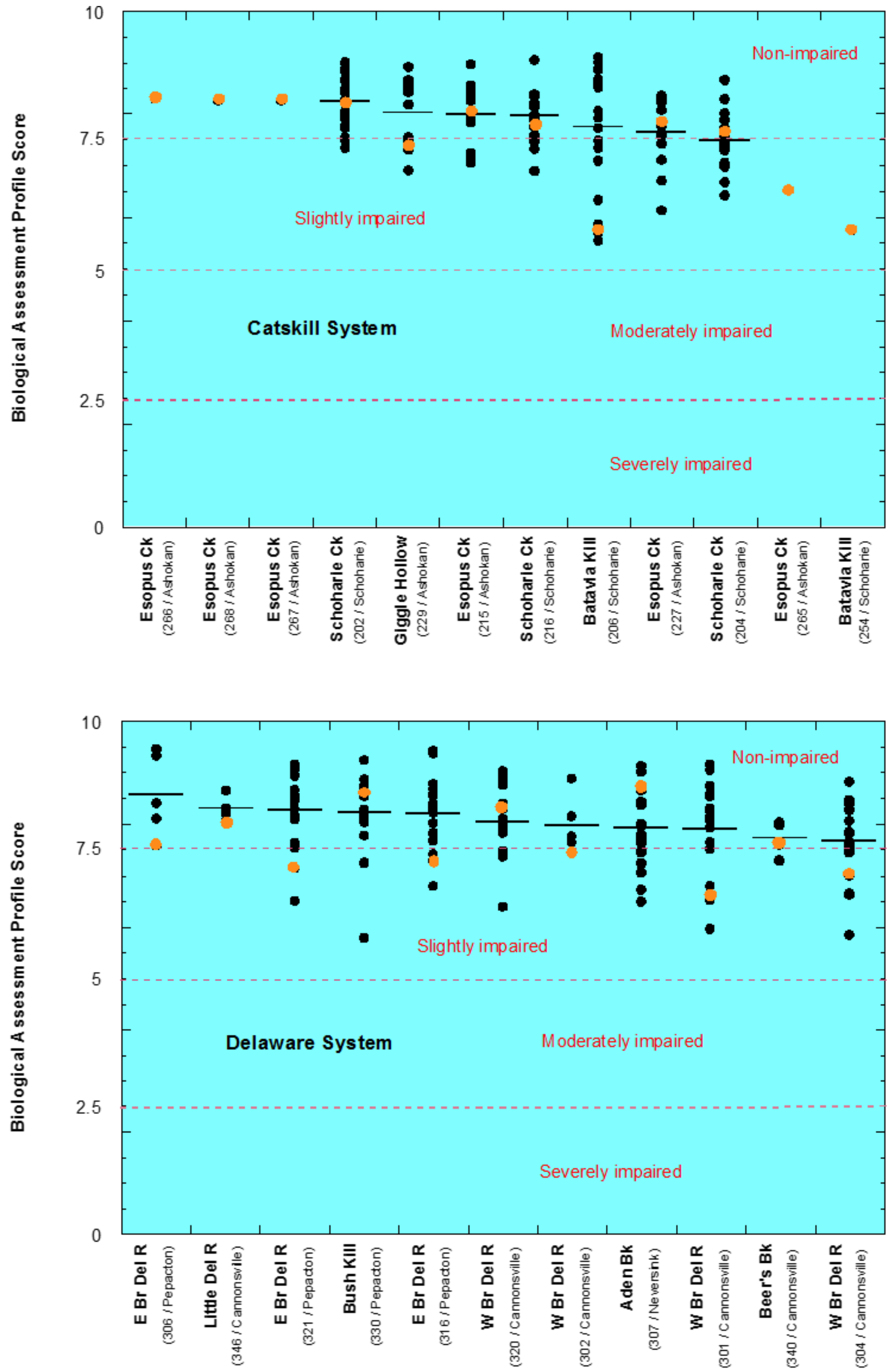


Figure 3.12 Biological Assessment Profile scores for West of Hudson biomonitoring sites sampled in 2014, arranged by mean score from highest to lowest. Horizontal bars represent the mean score, orange dots the 2014 score, and black dots the pre-2014 score. The site's number and watershed are indicated in parentheses following the site name. Mean bars are not shown for Sites 254, 265, 266, 267, and 268 because 2014 is the only year that they have been sampled.

Table 3.12: Total Taxa, Percent Model Affinity (PMA), Nutrient Biotic Index-Phosphorus (NBI-P), and Percent Hydropsychidae for 2014 impaired sites in the Catskill/Delaware watershed. For NBI-P, values between 5 and 6 reflect mesotrophic conditions and between 6 and 10, eutrophic ones.

Site No.	Total Taxa	PMA	NBI-P	Percent Hydropsychidae
206	18	48.9	5.88	57.0
229	21	41.4	3.39	1.0
254	20*	51.1*	6.73*	26.6*
265	23.5*	52.0*	5.63*	9.0*
301	21	55.1	6.07	39.8
302	21	60	5.26	37.9
304	21	59.9	5.65	40.0
316	20	53.6	5.08	50.0
321	27	46.2	5.61	45.8

*Mean of two replicates.

The four slightly impaired sites in the Catskill System were Sites 206 and 254 on the Batavia Kill, Site 265 on Esopus Creek, and Site 229 on Giggle Hollow, a tributary to Esopus Creek. All sites had low total taxa counts, low PMA, and, with the exception of Site 229, high NBI-P values (Table 3.12). The dominance of hydropsychid caddisflies at Site 206 reported last year (DEP 2014) reached a new high in 2014, with well over half the organisms encountered (57%) belonging to that group. This is the sixth consecutive slightly impaired assessment for this formerly non-impaired site, the third with a BAP score below 6 (Figure 3.10). The source of impairment, however, remains unidentified.

Giggle Hollow's slightly impaired assessment is attributable to the dominance of the very sensitive stonefly *Sweltsa* (33% of the community), which skewed the PMA metric, and most likely the total taxa and EPT metrics as well. It is therefore very unlikely that the assessment is an accurate reflection of the stream's water quality. Headwaters are frequently dominated by a few intolerant taxa, which can result in erroneous assessments (NYSDEC 2014).

In addition to Site 206, two other sites —215 and 216 —possessed large numbers of hydropsychids (215—33.6%, 216—42.6%). Both sites, while non-impaired, have seen their hydropsychid populations grow steadily in recent years, Site 215 since 2009, Site 216 since 2008. High numbers have been observed periodically at these sites before, so it is not clear if this represents a developing trend which may ultimately be reflected in poorer water quality assessments. DEP will monitor both sites to track any future developments.

All of the impaired sites in the Delaware System (Sites 301, 302, 304, 316, 321) experienced high numbers of hydropsychids, contributing to low taxa counts, low PMAs, and high NBI-Ps (Table 3.12). For reasons that are unclear, slightly impaired assessments are now becoming the norm at three of these sites, following years of non-impaired scores. Thus, Site 301 in the headwaters of the West Branch Delaware River at Hobart was non-impaired in 13 of 16 years between 1994 and 2009, but has been assessed as slightly impaired in each of the last five years. Site 304, located below the Walton WWTP on the West Branch Delaware River, was non- impaired in 8 of 12 years from 1994 to 2005, but slightly impaired in 7 of 9 years since then. Lastly, Site 321, on the East Branch Delaware River near Halcottsville, which never received an impaired rating in the 11 years between 1996 and 2006, has been slightly impaired in 5 of the last 8 years (Figure 3.10). This site is also the only site in the Delaware System that appears to be experiencing an increase in hydropsychid numbers (Figure 3.13). The decline in BAP scores at Site 321 represents a significant downward trend ($p<0.005$), while at the other two sites, no trend can be identified due to the considerable historical fluctuation in scores. DEP will monitor these sites annually and will continue to investigate possible sources for the declining assessments.

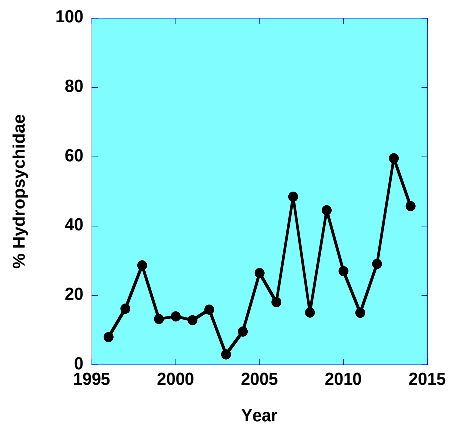


Figure 3.13 Hydropsychid percent composition at Site 321, 1996-2014.

3.11 Supplemental Contaminant Monitoring

DEP monitors a large number of volatile and semi-volatile organic compounds (including the herbicide glyphosate) in the upstate watersheds to supplement the required distribution system monitoring for these compounds. The list of compounds is provided in Appendix G and the sites sampled are provided in Table 3.13 These supplemental samples were collected by DEP personnel in October and shipped to a contract lab for analysis. No detections were observed in 2014 for any of the compounds monitored.

Table 3.13: Sampling sites for VOC and SVOC monitoring.

Site Code	Site Description	Reason for Site Selection
East of Hudson		
CROGH	Croton Gate House	Croton Aqueduct intake
DEL10	Delaware Shaft 10	Delaware intake on West Branch
DEL18DT	Delaware Shaft 18	Delaware intake on Kensico
West of Hudson		
EARCM	Ashokan Intake	Represents Ashokan water
NRR2CM	Neversink Intake	Represents Neversink water
PRR2CM	Pepacton Intake	Represents Pepacton water
SRR2CM	Schoharie Intake monitoring site	Schoharie water entering Esopus
RDRRCM	Rondout Intake	Represents Rondout water
WDTO	West Delaware Tunnel Outlet	Represents Cannonsville water

Note: In the event that one of these diversions is off at the collection time, the sample is drawn from the upstream reservoir elevation tap that corresponds to the tunnel intake depth as if that reservoir were on-line.

3.12 Metals Monitoring

If metals are detected at unusual concentrations, supplemental (non-required) sampling of the Catskill, Delaware and East of Hudson Systems is conducted to better determine more specific contaminant source(s). The following metals (total concentrations in all cases) were analyzed on a quarterly basis: Silver (Ag), Aluminum (Al), Arsenic (As), Barium (Ba), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Manganese (Mn), Nickel (Ni), Lead (Pb), Antimony (Sb), Selenium (Se), Thallium (Tl) and Zinc (Zn). These metals are monitored at the keypoint sites listed in Table 3.14.

Table 3.14: Keypoint sampling sites for trace and other metal occurrence monitoring.

Reservoir Basin	Site(s)
Catskill System	
Ashokan	EARCM[1]
Schoharie	SRR2CM[1]
Delaware System	
Cannonsville	WDTO[1]
Pepacton	PRR2CM[1]
Neversink	NRR2CM[1]
Rondout	RDRR2CM[1]
East of Hudson System	
Kensico	CATALUM, DEL17, DEL18DT, DEL19LAB
Croton	CROGH, CROGH1CM[2], CROGHC, CRO9
West Branch	DEL9, DEL10, CWB1.5

[1]Elevation tap samples will be collected when the reservoir is offline.
[2] Only sampled when blending of Croton waters occurs.

Data are reviewed on an annual basis and compared to the Health (Water Source) standard as stipulated in the New York State, Department of Environmental Conservation, Water Quality Regulations, Title 6, Chapter X, Part 703.5 and the USEPA National Primary and Secondary Drinking Water Standards. Selected metals standards are presented in Tables 3.15 and 3.16.

Table 3.15: USEPA National Primary and Secondary Drinking Water Quality Standards.

Analyte	Primary Standard ($\mu g\ L^{-1}$)	Secondary Standard ($\mu g\ L^{-1}$)
Silver (Ag)		100
Aluminum (Al)		50-200
Arsenic (As)	10	
Barium (Ba)	2000	
Beryllium (Be)	4	
Cadmium (Cd)	5	
Chromium (Cr)	100	
Copper (Cu)	1300	1000
Iron (Fe)		300
Mercury (Hg)	2	
Manganese (Mn)		50
Nickel (Ni)		
Lead (Pb)	15	
Antimony (Sb)	6	
Selenium (Se)	50	
Thallium (Tl)	0.5	
Zinc (Zn)		5000

Table 3.16: Water quality standards for metals from Part 703.5.

Analyte	Primary Standard ($\mu g\ L^{-1}$)	Secondary Standard ($\mu g\ L^{-1}$)
Silver (Ag)	H(WS)	50
Arsenic (As)	H(WS)	50
Barium (Ba)	H(WS)	1000
Cadmium (Cd)	H(WS)	5
Chromium (Cr)	H(WS)	50
Copper (Cu)	H(WS)	200
Mercury (Hg)	H(WS)	0.7
Manganese (Mn)	H(WS)	300
Nickel (Ni)	H(WS)	100
Lead (Pb)	H(WS)	50
Antimony (Sb)	H(WS)	3
Selenium (Se)	H(WS)	10

In 2014, most metal results were well below state and federal benchmarks. Selenium, antimony, arsenic, beryllium, cadmium, lead and thallium were not detected above the detection limit of 1 µg L^{-1} for any sample. Chromium and mercury were not detected above their detection limits of 5 and 0.06 µg L^{-1}, respectively. The highest zinc result was 10.7 µg L^{-1} with all other sample results measured at a detection limit of 10 µg L^{-1}. The highest silver result was 6.9 µg L^{-1}. All other silver results were at the detection limit of 1 µg L^{-1} and well below the most stringent benchmark of 50 µg L^{-1}. Five samples analyzed for nickel were measured above the detection limit of 1 µg L^{-1}, ranging from 1.2 to 1.6 µg L^{-1}. Barium ranged from 6 to 35 µg L^{-1}, and copper from 1 to 20.6 µg L^{-1}. These detected nickel, barium, and copper results were well below their respective benchmarks. Benchmarks were exceeded by three metals: iron, aluminum, and manganese. The iron benchmark of 300 µg L^{-1} was exceeded three times at SSR2CM, the diversion from Schoharie Reservoir. The manganese benchmark of 50 µg L^{-1} was exceeded on nine occasions, while the aluminum benchmark of 50 µg L^{-1} was exceeded on one occasion. Note that these concentrations may pose aesthetic concerns (e.g., taste, staining) but are not considered a risk to health. Moreover, these excursions occurred well upstream of the NYC distribution system. Samples from sites in closest proximity to distribution, DEL18DT and DEL19LAB, were well below the benchmarks, ranging from 15.6 to 36.2 µg L^{-1} for aluminum, 30.0 to 57.0 µg L^{-1} for iron, and 8.0 to 32.0 µg L^{-1} for manganese.

4. Kensico Reservoir

4.1 Kensico Reservoir Overview

Kensico Reservoir, located in Westchester County, is the terminal reservoir for the City's Catskill/Delaware water supply. Because Kensico Reservoir is the last impoundment of Catskill/Delaware water prior to entering the City's distribution system, the protection of this reservoir is critically important to prevent water quality degradation and to maintain Filtration Avoidance. To further that goal, DEP conducts several ongoing water quality monitoring programs at aqueducts, local streams, and the reservoir. The routine sampling strategy for Kensico is documented in the 2009 Watershed Water Quality Monitoring Plan (WWQMP) (DEP 2009a) and the sampling sites are shown in Figure 4.1. The plan prescribes monitoring to achieve compliance with all federal, state, and local regulations; enhance the capability to make current and future predictions of watershed conditions and reservoir water quality; and ensure delivery of the best water quality to consumers through ongoing surveillance. Because Kensico is the raw source water for the unfiltered Catskill/Delaware System, and is immediately upstream of disinfection, monitoring is done at a high frequency here.

A summary of the samples that were collected at Kensico in 2014 is provided in Table 4.1. Because compliance with the Safe Drinking Water Act's Surface Water Treatment Rule (SWTR) (USEPA 1989) is of paramount importance to DEP for maintaining Filtration Avoidance, fecal coliforms and turbidity are focal points in the discussion of Kensico water quality. DEP's data continue to demonstrate that the Waterfowl Management Program has been instrumental in keeping coliform bacteria concentrations well below the limits set by the SWTR.

Only one special investigation (SI) to track and manage stormwater was conducted on Kensico in 2014, and the results are discussed in Section 4.5.2. A detailed discussion of the protozoan pathogens *Cryptosporidium* and *Giardia*, and human enteric viruses, is provided in Chapter 5.

Table 4.1: Summary of Kensico water quality samples collected in 2014.

Kensico Sampling Program	Number of Samples
Drinking Water	70
Keypoint	5,027
Limnology	1,813
Pathogen	388
Release	240
Storm	83
Stream	308
WWTP	676
Total	**8,605**

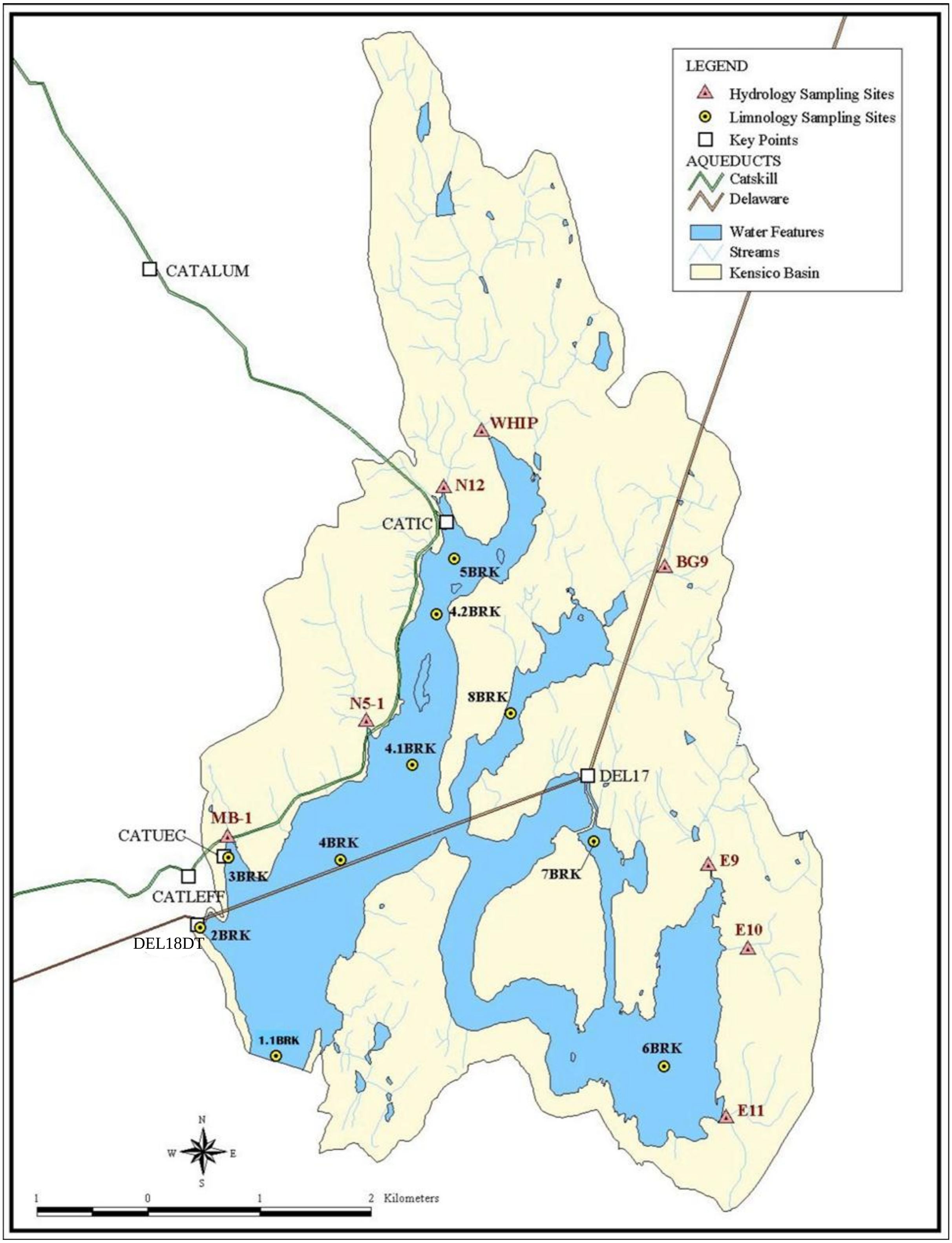


Figure 4.1 Kensico Reservoir, showing limnological and hydrological sampling sites, keypoints, and aqueducts. There is a meteorological station at Delaware Shaft 18.

4.2 Reservoir Raw Water Quality Compliance

DEP routinely conducts water quality compliance monitoring at the aqueduct keypoints at Kensico Reservoir. The CATALUM and DEL17 influent keypoints represent water entering Kensico Reservoir from the NYC upstate reservoirs via the Catskill and Delaware Aqueducts, respectively. The DEL18DT effluent keypoint represents Kensico Reservoir water entering the Delaware Aqueduct at a point just prior to disinfection; this water ultimately travels down to distribution. The CATALUM and DEL17 influent keypoints are monitored via grab samples for fecal coliforms (5 days per week), turbidity (5 days per week), and nutrients (monthly). However, total phosphorus is collected weekly at CATALUM and DEL17 as per one of the monitoring requirements of the CATIC and DEL17 SPDES permits, respectively. The information is used as an indicator of water quality entering Kensico Reservoir, which is in turn used to optimize operational strategies to provide the best possible quality of water leaving the reservoir. The DEL18DT effluent keypoint is monitored via daily grab samples for fecal coliforms (7 days per week), turbidity (every four hours, in accordance with SWTR regulations, and also at the time the fecal coliform samples are collected), and nutrients (monthly). The keypoint sites are also continuously monitored for temperature, pH, conductivity, and turbidity. The exceptional importance of the influent keypoints for optimal operations and the effluent keypoint as the source water compliance monitoring site warrants this high intensity monitoring.

For the fecal coliform counts measured at the Kensico influents from January 1 to December 31, 2014, medians of less than 1 fecal coliform $100mL^{-1}$ at both CATALUM and DEL17 were reported. The maximum fecal coliform counts were 57 fecal coliforms $100mL^{-1}$ at CATALUM (Figure 4.2) and 14 fecal coliforms $100mL^{-1}$ at DEL17 (Figure 4.3). These data demonstrate that the fecal coliform levels of the aqueducts flowing into Kensico were typically low. The median turbidity at CATALUM from January 1 to December 31, 2014 was 2.7 NTU, while at DEL17 it was 0.8 NTU. During this period, the maximum turbidity measurements were 8.0 NTU at CATALUM and 2.4 NTU at DEL17 (Figures 4.4 and 4.5, respectively).

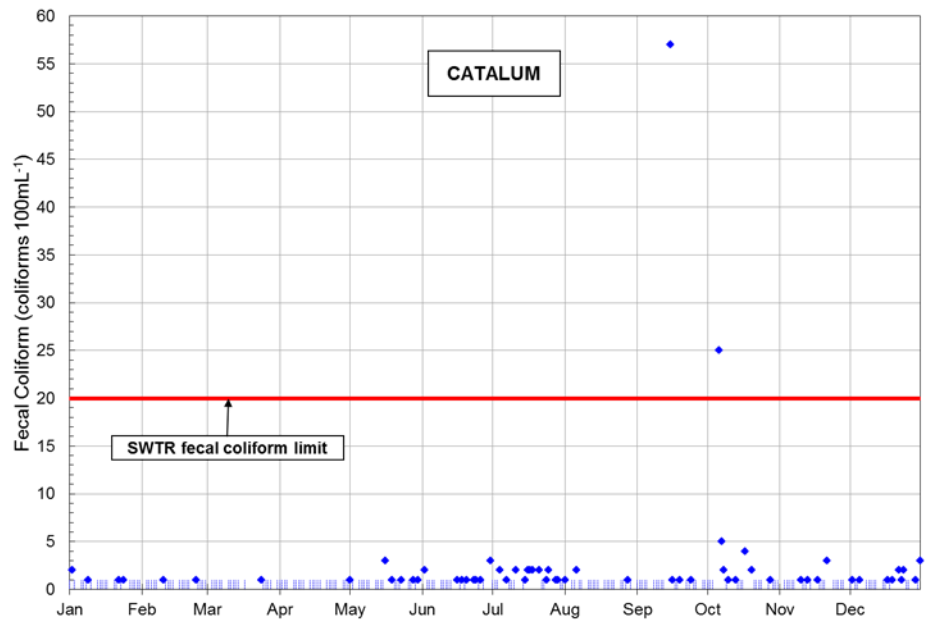


Figure 4.2 Five-day-per-week fecal coliform grab sample results at CATALUM, Kensico Reservoir's Catskill Aqueduct influent keypoint. The "drop lines" along the x-axis indicate censored (below detection) values. Note that while the SWTR fecal coliform limit is indicated by a reference line, the influent keypoints are not subject to the SWTR.

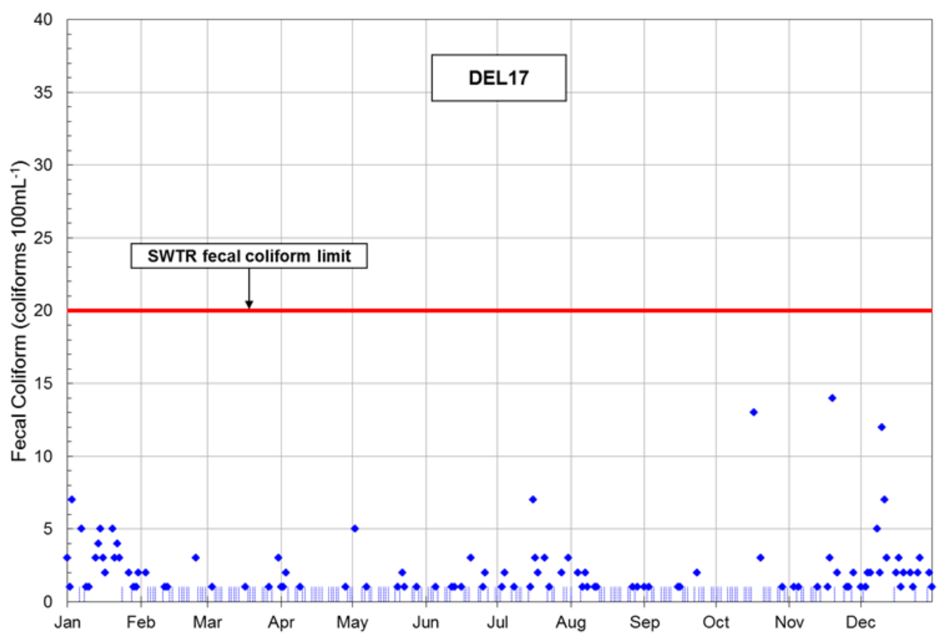


Figure 4.3 Five-day-per-week fecal coliform grab sample results at DEL17, Kensico Reservoir's Delaware Aqueduct influent keypoint. The "drop lines" along the x-axis indicate censored (below detection) values. Note that while the SWTR fecal coliform limit is indicated by a reference line, the influent keypoints are not subject to the SWTR.

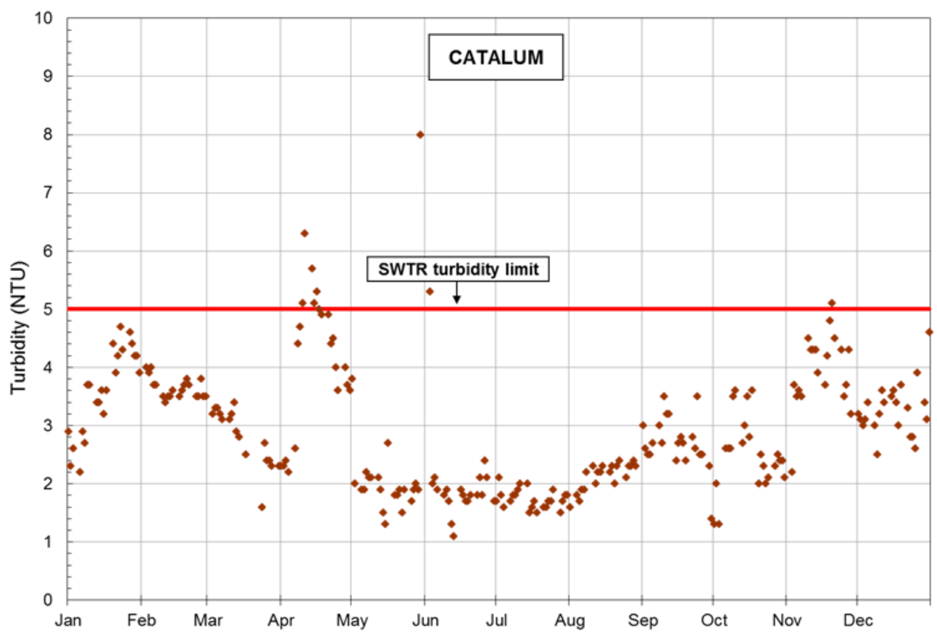


Figure 4.4 Five-day-per-week turbidity grab sample results at CATALUM, Kensico Reservoir's Catskill Aqueduct influent keypoint. Note that while the SWTR turbidity limit is indicated by a reference line, the influent keypoints are not subject to the SWTR.

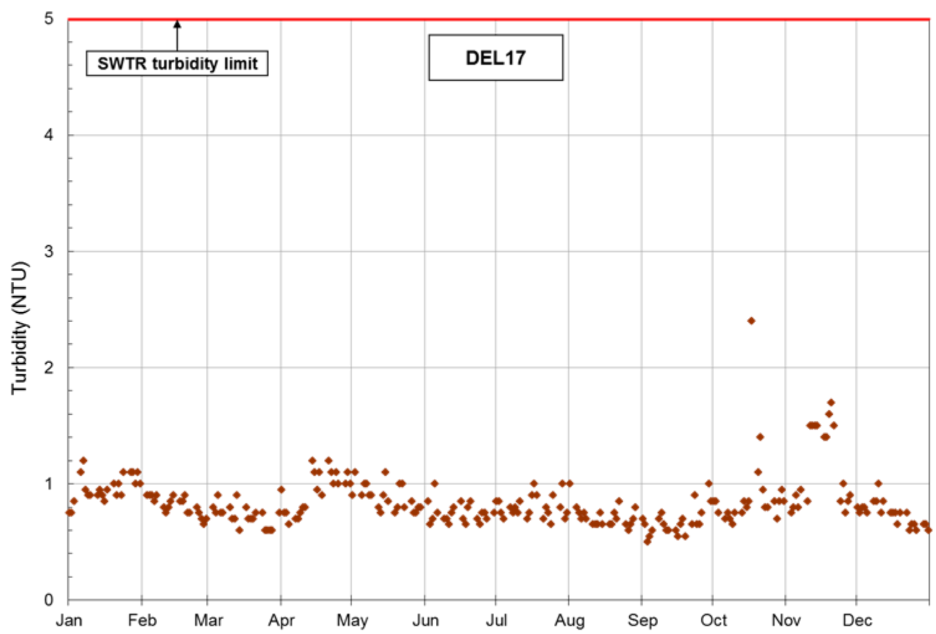


Figure 4.5 Five-day-per-week turbidity grab sample results at DEL17, Kensico Reservoir's Delaware Aqueduct influent keypoint. Note that while the SWTR turbidity limit is indicated by a reference line, the influent keypoints are not subject to the SWTR.

From January 1 to December 31, 2014, the median fecal coliform count at the Kensico effluent (DEL18DT) was 1 fecal coliform 100mL^{-1}. The maximum fecal coliform count, 9 fecal coliform 100 mL^{-1}, occurred on three occasions (Figure 4.6). Median turbidity from January 1 to December 31, 2014 was 0.9 NTU at DEL18DT and the maximum turbidity measurement for the year was 2.4 NTU (Figure 4.7).

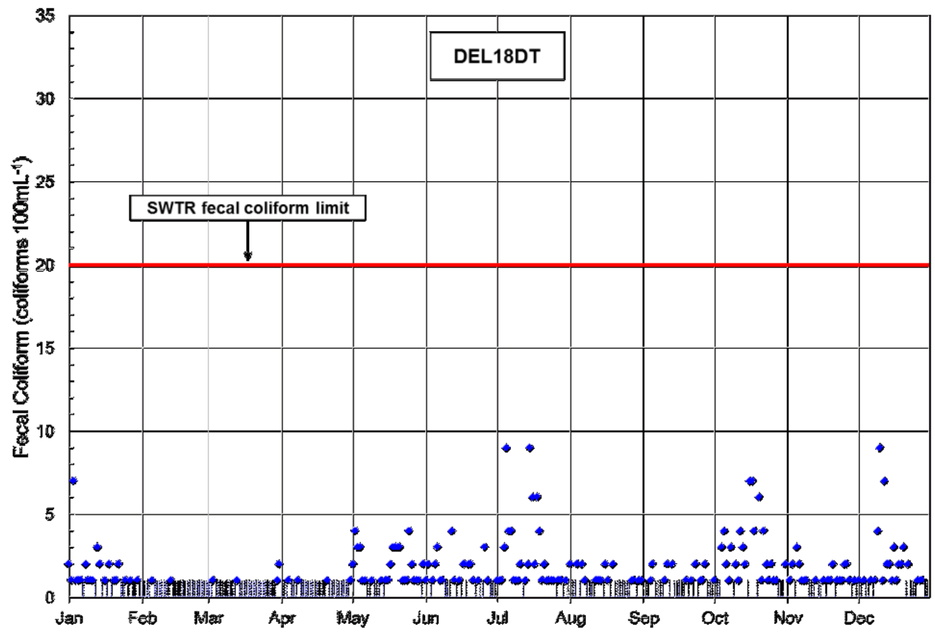


Figure 4.6 Seven-day-per-week fecal coliform grab sample results at DEL18DT, Kensico Reservoir's Delaware Aqueduct effluent keypoint. The "drop lines" along the x-axis indicate censored (below detection) values.

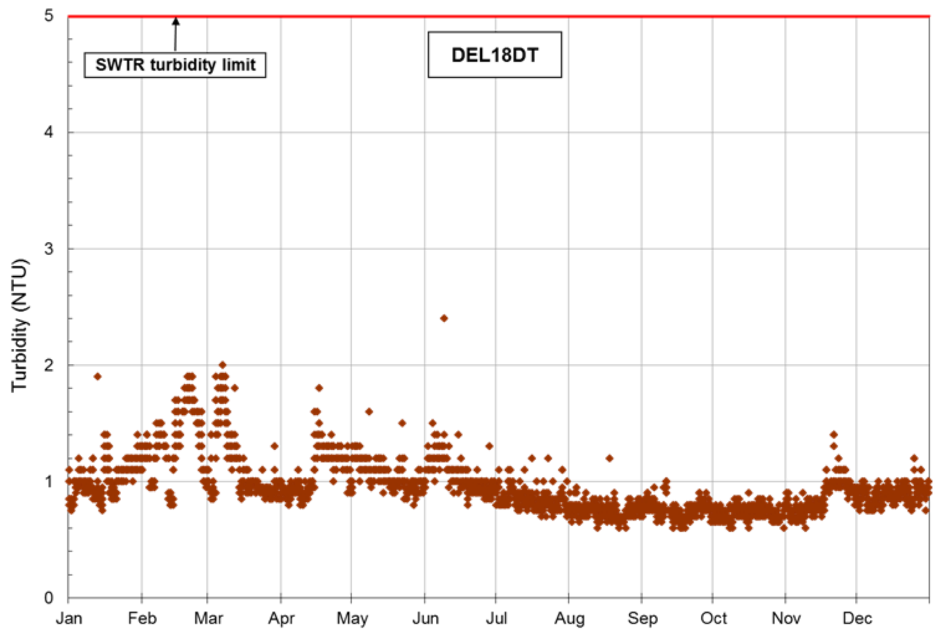


Figure 4.7 Four-hour turbidity and daily grab sample daily results at DEL18DT, Kensico Reservoir's Delaware Aqueduct effluent keypoint. The SWTR turbidity limit of 5 NTU is indicated by a reference line.

Overall, water quality in 2014 was excellent, with the source water at Kensico meeting the SWTR limits for both fecal coliforms and turbidity.

4.3 Reservoir Operations and Waterfowl Management

Migratory populations of waterbirds utilize NYC reservoirs as temporary staging areas and wintering grounds, and in doing so contribute to increases in fecal coliform loadings during the autumn and winter, primarily from direct fecal deposition in the reservoirs. These waterbirds generally roost nocturnally and occasionally forage and loaf diurnally on the reservoirs, although most foraging activity occurs away from the reservoirs. In the past, fecal samples collected and analyzed for fecal coliform bacteria concentrations from both Canada Geese (*Branta canadensis*) and Ring-billed Gulls (*Larus delawarensis*) revealed that fecal coliform concentrations are relatively high per gram of feces (Alderisio and DeLuca 1999). This is consistent with data from water samples collected over several years near waterbird roosting and loafing locations, demonstrating that fecal coliform levels are correlated with waterbird populations at several NYC reservoirs (DEP 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009b, 2010b). Historical water sampling data collected at the two main water influent and effluent facilities at Kensico demonstrated that higher levels of fecal coliform bacteria were leaving the reservoir than what was contributed through aqueducts from the upstate reservoirs (DEP 1992). It was apparent at that time that a local source of fecal coliform bacteria was impacting Kensico. Based on these data, DEP determined that waterbirds were the most important contributor to seasonal fecal coliform bacteria loads to Kensico and other terminal reservoirs (West Branch, Rondout, Ashokan), and that waterbirds can also lead to increased seasonal fecal coliform levels in other reservoirs from which water can be pumped into the Delaware Aqueduct (Croton Falls and Cross River).

In response to these data, which clearly demonstrate the relationship between waterbird population density and reservoir fecal coliform levels, DEP developed and implemented a Waterfowl Management Program (WMP) to reduce or eliminate the waterbird populations inhabiting the reservoir system (DEP 2002). The WMP has implemented standard bird management techniques that are approved by the Wildlife Services unit of the Animal and Plant Health Inspection Service, an agency of the United States Department of Agriculture (USDA); the United States Fish and Wildlife Service (USFWS); and the New York State Department of Environmental Conservation (NYSDEC) at Kensico and Hillview Reservoirs on an as-needed basis. DEP has also acquired a depredation permit from the USFWS and NYSDEC to implement additional avian management techniques.

Bird dispersal measures include non-lethal harassment by pyrotechnics, motorboats, airboats, propane cannons, and physical chasing; bird deterrence measures include waterbird reproductive management, shoreline fencing, bird netting, overhead bird deterrent wires, and meadow management. At Hillview Reservoir, additional wildlife management methods were employed, and continued to be used in 2014. They include lethal removal of resident Ruddy Ducks (*Oxyura jamaicensis*) and other migratory ducks through a USDA contract, and the maintenance of a bird deterrent wire system installed along the reservoir dividing wall and bird netting which covers the shaft openings. In addition, mammals were trapped and removed around the reservoir shaft buildings and shoreline perimeter throughout the year. A federal wildlife depredation permit was also used to eliminate nesting Mallards and two terrestrial nesting species, Barn Swallows and Cliff Swallows. Two additional bird species removed, European Starlings and House Sparrows, did not require a federal permit. These efforts have led to continued reductions in local breeding opportunities around water intake structures, which in turn has led to reduced fecundity.

The SWTR (40 CFR 141.71(a)(1)) states that in no more than 10% of source water fecal coliform samples may counts exceed 20 fecal coliforms 100 mL^{-1} over the previous six-month period. Since the inception of the WMP, no such violation has occurred at Kensico Reservoir. The link between this success and the WMP is demonstrated by comparing source water fecal coliform levels before and after the implementation of the WMP (Figure 4.8). DEP will continue implementation of the WMP to help ensure delivery of high quality water to NYC consumers.

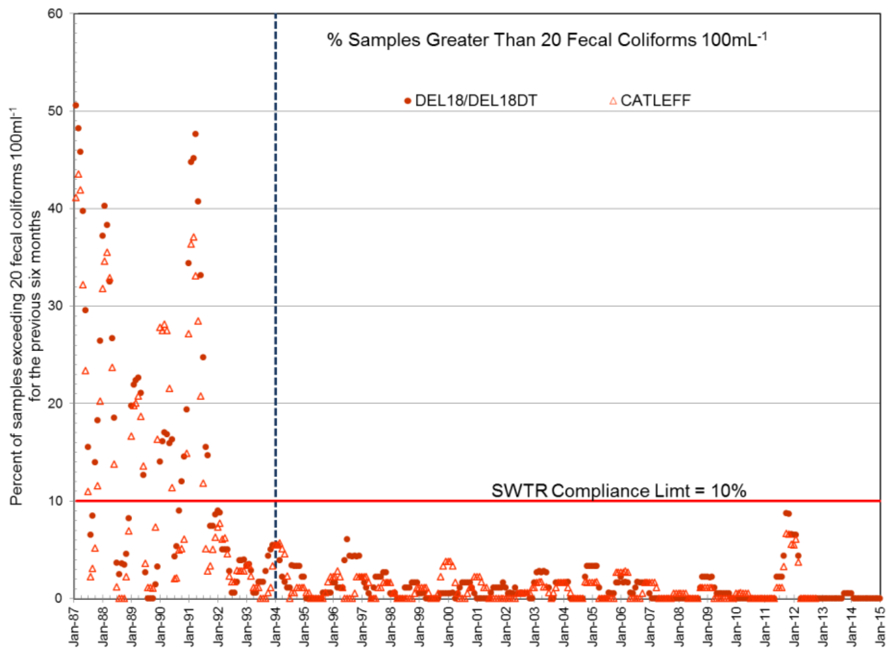


Figure 4.8 Percent of keypoint fecal coliform samples at Kensico Reservoir greater than 20 fecal coliforms $100mL^{-1}$ for the previous six-month period, 1987-2014. The vertical dashed line indicates the year in which the WMP was implemented. Note that the DEL18 site was relocated from the forebay (DEL18) to the downtake shaft (DEL18DT) commencing on August 20, 2012. Also, sampling was discontinued at CATLEFF on September 14, 2012.

4.4 Kensico Streams and Turbidity Curtain Inspections

4.4.1 Kensico Stream Water Quality

DEP continues to monitor the hydrology of the Kensico watershed. Samples are collected at eight fixed sampling sites to quantify water quality at each of the perennial streams (BG9, E10, E11, E9, MB-1, N12, N5-1, WHIP) as shown in Figure 4.1. Routine sampling of these streams was conducted monthly in 2014. In addition to the routine program, special investigation samples were collected in response to a July 2014 storm (see Section 4.5.2).

Continuous flow measurements were also maintained for the year at six of the eight perennial Kensico tributaries. Stage height was recorded at 15-minute intervals and the flow was then calculated based on the appropriate flume, weir, or rating curve. In addition, collection of flow data was resumed at the N12 tributary on May 8, 2014 after being suspended on February 12, 2012 due to construction activities. Likewise, continuous stage readings at Whippoorwill Creek (WHIP) resumed in Spring 2014 after being suspended on April 27, 2012 also due to construction activities. A rating curve to relate the stage height to discharge at Whippoorwill Creek is under development.

Coliforms

The routine fecal coliform data for the period January through December 2014 are plotted in Figure 4.9. Boxplots are used to describe the distribution of the data, and to compare data between different sites. As previously noted, an explanation of the information displayed in boxplots is provided in Appendix A. However, it should also be noted that the Kensico fecal coliform data contain some censored values (i.e., non-detects, where the data are less than a detection limit), and so a Minitab® macro (http://www.practicalstats. com/nada/downloads.html) was used in the analysis to properly account for the censored data in the boxplots. A horizontal line is drawn at the maximum detection limit (Max Det. Limit) because only values above the maximum detection limit are known with certainty, while the distribution of values below the detection limit is uncertain. The maximum detection limit indicated on the plots is the maximum detection limit of multiple detection limits because coliform data may have various detection limits reported in the dataset, such as <1 or <10 coliforms 100mL^{-1}, depending on what dilution is used.

Water quality standards (6 NYCRR Part 703) for fecal coliforms have been used as a guideline against which to compare samples collected through DEP's monthly fixed-frequency monitoring program. The fecal coliform standard for classes A, B, C, D is as follows: "The monthly geometric mean, from a minimum of five examinations, shall not exceed 200." All Kensico streams had annual median values well below 200 fecal coliforms 100mL^{-1}. N5-1 had the highest median value at 54 fecal coliforms 100mL^{-1}, while E11 had the lowest annual median of 16 fecal coliforms 100mL^{-1}. Annual medians at N12 and Whippoorwill Creek (WHIP) were 17 and19 fecal coliforms 100mL^{-1}, respectively. The maximum value for fecal coliforms during routine sample collection was 2,900 coliforms 100mL^{-1} at N12 on October 7, following more than an inch of rain two days previously. A summary of descriptive statistics for all analytes measured on the Kensico perennial streams in 2014 is provided in Table 4.2.

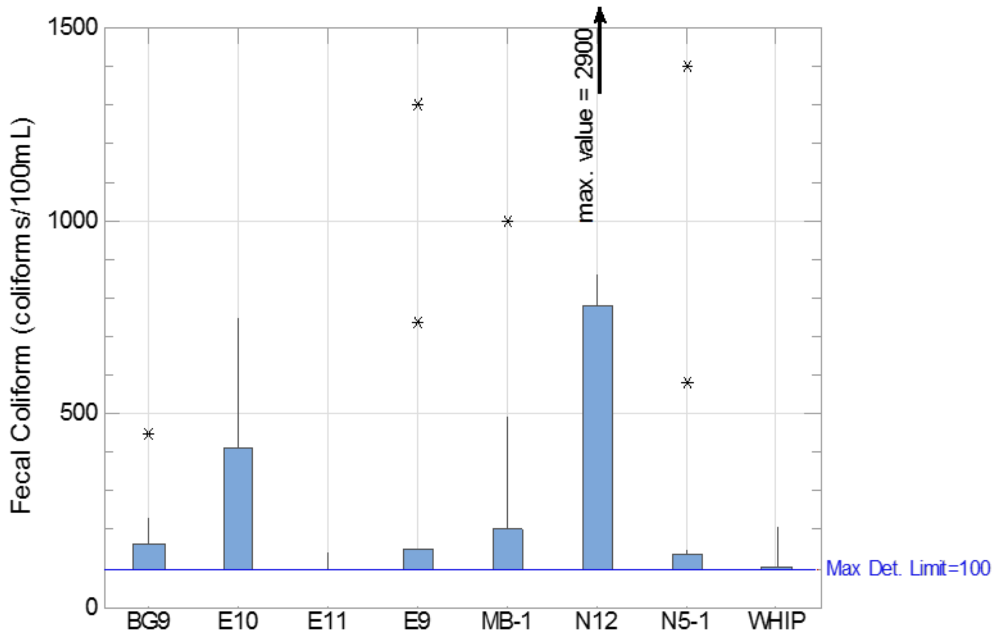


Figure 4.9 Fecal coliform plots for routine Kensico streams monitoring, January-December 2014.

Turbidity

The routine turbidity data for the period January through December 2014 are plotted in Figure 4.10 (An explanation of the information displayed in the boxplot is provided in Appendix A.). The median turbidity for all sites was less than 5 NTU. Turbidity values in 2014 were generally consistent with data from previous years, with the annual medians ranging from 0.6 NTU at N-12 to 4.6 NTU at MB-1. The maximum turbidity value recorded was 30 NTU at E10 on June 3, 2014, when about a quarter of an inch of rain was recorded during the day. The descriptive statistics for turbidity in all of the Kensico perennial streams for 2014 are displayed in Table 4.2.

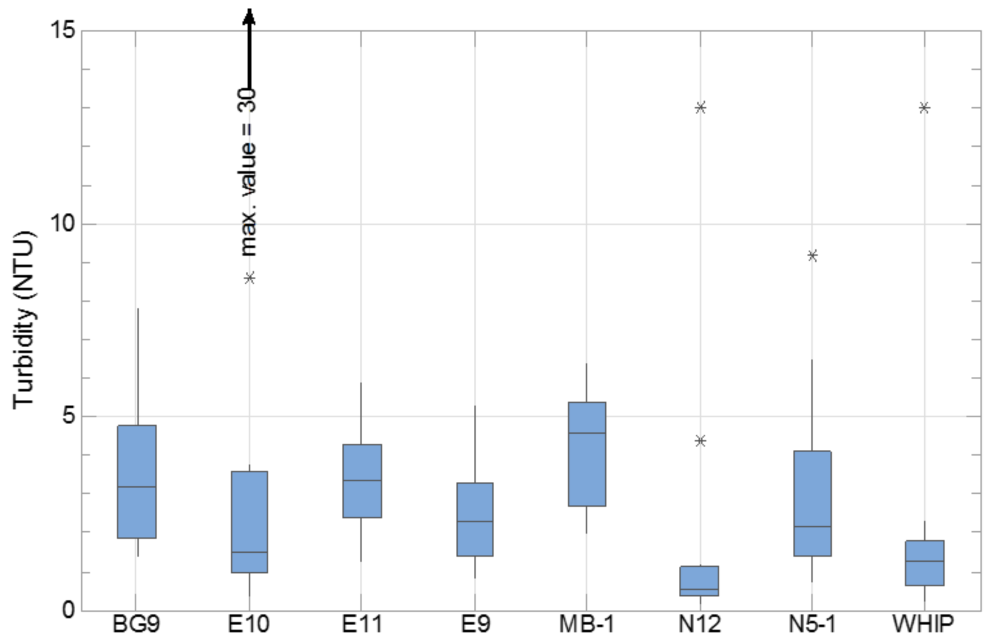


Figure 4.10 Turbidity plots for routine Kensico streams monitoring, January-December 2014.

Other Results

Stream Chemistry

In addition to the coliform bacteria, turbidity, and pathogen sampling, DEP monitors the eight perennial streams for temperature, dissolved oxygen, specific conductivity, and pH. Six of the eight streams were also monitored for alkalinity, chloride, dissolved organic carbon, total suspended solids, and nutrients. Descriptive statistics of the 2014 results for these analytes are provided in Table 4.2. As previously discussed, on occasion environmental data may be reported only as below or above a certain detection limit due to methodological limitations. To address the uncertainty of censored values in the calculation of descriptive statistics, a Kaplan-Meier technique was used to calculate the quartile values when censored data were present (Helsel 2005).

Table 4.2: Annual statistics for physical, nutrient, and other chemical analytes in Kensico's perennial streams, January–December, 2014.

Analyte	Site	n	Minimum	25th Percentile	Median	75th Percentile	Maximum
Temperature (°C)	BG9	12	0.7	2.0	10.6	18.0	24.7
	E10	12	0.0	3.1	10.6	17.0	20.9
	E11	12	0.8	3.2	11.5	20.2	23.1
	E9	11	0.0	0.4	8.7	16.6	21.3
	MB-1	12	0.7	2.7	10.5	18.3	21.5
	N12	12	0.0	3.5	11.9	16.6	18.9
	N5-1	12	1.2	2.5	10.9	19.3	21.2
	WHIP	12	-0.1	1.4	12.4	17.9	22.3
Dissolved Oxygen (mg L^{-1})	BG9	11	2.9	5.2	12.1	13.6	14.1
	E10	11	6.1	7.4	14.0	15.5	18.3
	E11	11	2.9	3.1	6.0	11.4	14.7
	E9	10	4.7	4.8	5.9	8.2	9.6
	MB-1	11	7.7	7.9	11.0	13.3	17.0
	N12	11	7.3	9.7	13.6	14.5	17.3
	N5-1	11	6.6	6.8	10.8	15.6	103.6
	WHIP	11	6.8	9.2	11.6	14.3	16.3
Specific Conductivity (µmhos cm^{-1})	BG9	12	349	675	814	1,043	1,240
	E10	12	837	982	1,250	1,408	3,580
	E11	12	358	393	429	478	557
	E9	11	523	656	740	864	1,160
	MB-1	12	484	563	656	945	1,510
	N12	12	274	336	401	450	1,830
	N5-1	12	362	420	445	597	1,190
	WHIP	12	365	378	425	463	595
Chloride (mg L^{-1})	BG9	12	109.0	149.8	198.0	248.8	279.0
	E11	12	35.6	54.0	58.0	64.7	82.5
	MB-1	12	90.4	111.8	131.5	230.3	416.0
	N12	12	38.9	50.5	55.0	93.9	512.0
	N5-1	12	53.0	68.3	77.1	121.3	309.0
	WHIP	12	61.3	70.3	75.6	85.6	135.0
pH	BG9	12	6.65	7.02	7.13	7.27	7.37
	E10	12	7.24	7.54	7.66	7.74	7.86
	E11	12	7.03	7.27	7.34	7.46	7.59
	E9	11	6.66	6.73	6.82	6.95	7.01
	MB-1	12	6.70	7.15	7.24	7.33	7.42
	N12	12	7.27	7.48	7.62	7.97	8.16
	N5-1	12	7.24	7.29	7.32	7.41	7.96
	WHIP	12	7.27	7.58	7.74	7.89	8.18
Alkalinity (mg L^{-1} $CaCO_3$)	BG9	12	40.00	53.58	69.65	88.72	133.00
	E11	12	73.10	100.75	118.50	138.50	146.00
	MB-1	12	51.50	61.35	79.20	93.07	103.00

Analyte	Site	n	Minimum	25th Percentile	Median	75th Percentile	Maximum
	N12	12	31.40	54.47	68.55	91.15	106.00
	N5-1	12	41.10	58.48	72.20	78.85	91.90
	WHIP	12	28.10	41.68	55.15	86.45	93.10
Dissolved Organic Carbon (mg L^{-1})	BG9	12	1.9	2.7	3.3	3.7	4.8
	E11	12	3.1	4.3	4.6	5.2	14.9
	MB-1	12	1.9	2.4	3.3	3.6	4.7
	N12	12	1.7	2.0	2.4	3.3	5.5
	N5-1	12	1.6	2.0	2.8	3.6	4.1
	WHIP	12	1.6	2.1	2.5	3.2	5.0
Total Phosphorus (µg L^{-1})	BG9	12	14	16	32	51	77
	E11	12	17	24	30	40	90
	MB-1	12	14	24	42	44	64
	N12	12	10	14	18	22	87
	N5-1	12	23	28	48	65	186
	WHIP	12	10	12	20	26	71
Total Nitrogen (mg L^{-1})	BG9	12	0.28	0.37	0.49	0.60	0.62
	E11	12	0.27	0.28	0.35	0.42	0.76
	MB-1	12	0.29	0.47	0.51	0.58	0.76
	N12	12	0.32	0.74	1.04	1.41	1.70
	N5-1	12	0.46	1.04	1.25	1.48	1.72
	WHIP	12	0.51	0.88	1.04	1.35	1.60
NH3-N (mg L^{-1})	BG9[1]	12	<0.02	0.03	0.05	0.06	0.12
	E11[1]	12	<0.02	*	*	*	0.06
	MB-1[1]	12	<0.02	0.03	0.06	0.07	0.08
	N12[1]	12	<0.02	*	*	*	0.03
	N5-1[1]	12	<0.02	0.03	0.04	0.10	0.34
	WHIP[1]	12	<0.02	*	*	*	0.03
NO3+NO2-N (mg L^{-1})	BG9	12	0.03	0.11	0.27	0.50	0.68
	E11[1]	12	<0.02	*	*	0.20	0.24
	MB-1	12	0.08	0.22	0.29	0.41	0.67
	N12	12	0.18	0.51	0.87	1.20	1.78
	N5-1	12	0.26	0.74	1.06	1.32	1.75
	WHIP	12	0.37	0.74	0.92	1.23	1.62
Total Suspended Solids (mg L^{-1})	BG9[1]	12	<1	*	3.5	5.2	10.7
	E11[1]	12	<1	1.2	3.5	4.3	8.2
	MB-1[1]	12	<1	2.2	2.7	4.4	5.6
	N12[1]	12	<1	*	*	*	14.8
	N5-1[1]	12	<1	1.3	1.9	4.8	7.5
	WHIP[1]	12	<1	*	1.8	2.6	17.9
Total Coliforms (coliforms 100mL^{-1})	BG9	12	36	118	520	1,275	13,000
	E10	10	40	164	410	1,725	4,600
	E11[1]	12	<200	135	215	820	3,600
	E9	10	73	250	450	1,400	3,500
	MB-1[1]	11	<500	180	280	400	3,000
	N12	11	29	130	400	2,000	8,600
	N5-1[1]	9	<500	150	260	420	600

Analyte	Site	n	Minimum	25th Percentile	Median	75th Percentile	Maximum
	WHIP	12	14	145	320	1,278	4,400
Fecal Coliforms (coliforms $100mL^{-1}$)	BG9	12	3	5	40	168	450
	E10[1]	12	<5	4	29	320	750
	E11[1]	12	<5	10	16	64	140
	E9	11	3	12	40	150	1,300
	MB-1[1]	12	<5	9	41	166	1,000
	N12[1]	12	<5	3	17	670	2,900
	N5-1[1]	12	<10	24	54	120	1,400
	WHIP[1]	12	<5	7	19	92	210
Turbidity (NTU)	BG9	13	1.4	1.9	3.2	4.8	7.8
	E10	12	0.4	1.0	1.5	3.6	30.0
	E11	12	1.3	2.4	3.4	4.3	5.9
	E9	11	0.9	1.4	2.3	3.3	5.3
	MB-1	13	2.0	2.7	4.6	5.4	6.4
	N12	13	0.2	0.4	0.6	1.2	13.0
	N5-1	13	0.8	1.4	2.2	4.1	9.2
	WHIP	13	0.3	0.7	1.3	1.8	13.0

[1]Due to the presence of censored data, a Kaplan-Meier method was used to estimate the percentiles.
[*]Due to the number of censored data, percentiles could not be estimated.

4.4.2 Turbidity Curtain Monitoring

The three turbidity curtains are maintained at the Catskill Upper Effluent Chamber cove in Kensico Reservoir to protect water entering into distribution from turbidity caused by the impacts of storm events on local streams. DEP conducts biweekly visual inspections of the turbidity curtains at the cove. Table 4.3 lists the dates and results of the turbidity curtain inspections carried out in 2014. When inspections indicate that maintenance is required, Bureau of Water Supply Systems Operations is notified and performs appropriate repairs or adjustments.

Table 4.3: Visual inspections of the Catskill Upper Effluent Chamber turbidity curtains.

Date	Observations
1/2/2014	The curtains appear afloat and intact.
1/15/2014	Afloat and intact.
1/31/2014	Afloat and intact.
2/12/2014	The curtains appear afloat and intact.
2/27/2014	The curtains appear afloat and intact.
3/12/2014	The curtains appear afloat and intact.
3/26/2014	The curtains appear afloat and intact.
4/9/2014	The curtains appear afloat and intact.
4/23/2014	The curtains appear afloat and intact as seen from shore.

Date	Observations
5/7/2014	The curtains appear afloat and intact.
5/21/2014	The curtains appear afloat and intact as seen from shore.
6/4/2014	The curtains appear afloat and intact as seen from shore.
6/17/2014	The curtains appear afloat and intact.
7/2/2014	The curtains appear afloat and intact as seen from shore.
7/17/2014	The curtains appear afloat and intact.
7/30/2014	The curtains appear afloat and intact near the UEC and Malcolm Brook. The curtain near DEL18 is pushed up against the shore.
8/14/2014	The curtains appear afloat and intact.
8/27/2014	The curtains appear afloat and intact.
9/10/2014	The curtains appear afloat and intact as seen from shore.
9/24/2014	The curtains appear afloat and intact.
10/8/2014	The curtains appear afloat and intact.
10/22/2014	The curtains appear afloat and intact.
11/20/2014	The curtains appear afloat and intact as seen from shore.
12/4/2014	The curtains appear afloat and intact as seen from shore.
12/17/2014	The curtains appear afloat and intact as seen from shore.
12/31/2014	The curtains appear afloat and intact.

4.5 Kensico Research Projects

4.5.1 Bryozoan Research

Bryozoans were identified in Kensico Reservoir as early as the late 1980s and early 1990s. The predominant species, *Pectinatella magnifica*, has been seen in coves throughout the reservoir, near the shoreline on branches and rocks, and at the Delaware outflow of the reservoir at Shaft 18. The presence of these organisms did not affect operations until the fall of 2012, shortly after the UV Disinfection Facility came on line. Bryozoan colonies were found downstream of Shaft 18 at the facility, and caused clogging issues at the 1-inch perforated plates located just prior to the UV lamps. The openings were manually cleared of the gelatinous colonies, but this was very labor intensive. A literature search was conducted and other water professionals were contacted to determine if there were other management or preventive measures available to control the growth and reproduction of these large colonial organisms. Control of organisms in a drinking water supply is particularly challenging because many control measures used for other applications are not an option for water that will be consumed.

DEP staff began monitoring the development of bryozoan colonies in the sluice gates at Delaware Shaft 18 using an underwater video camera from April 23 to September 17, 2014. An underwater video camera was lowered on a long set of poles down into the sluice gates (upstream of the traveling screens) and high definition (HD) video recordings were created to document the conditions in each of the five gates. Video monitoring was done approximately every other week, for a total 11 visits with video observations in 2014. Notes on water quality parameters (e.g., temperature, turbidity) and operational conditions (e.g., flow rate) were also taken at the time of the visit. Video monitoring predominantly focused on the access ladder and adjacent wall areas.

Over 1,000 still frame shots documenting the temporal growth of colonies were collected from the videos, usually on specific ladder rungs. The photographs below illustrate how quickly the colonies develop during the later summer months (Figure 4.11). Many large colonies (more than 40 colonies larger than eight inches in diameter) were present by late September when divers were contracted to remove them. The largest of these *P. magnifica* colonies had grown to several feet in circumference. Monitoring will continue in 2015 guided by knowledge gained this year.

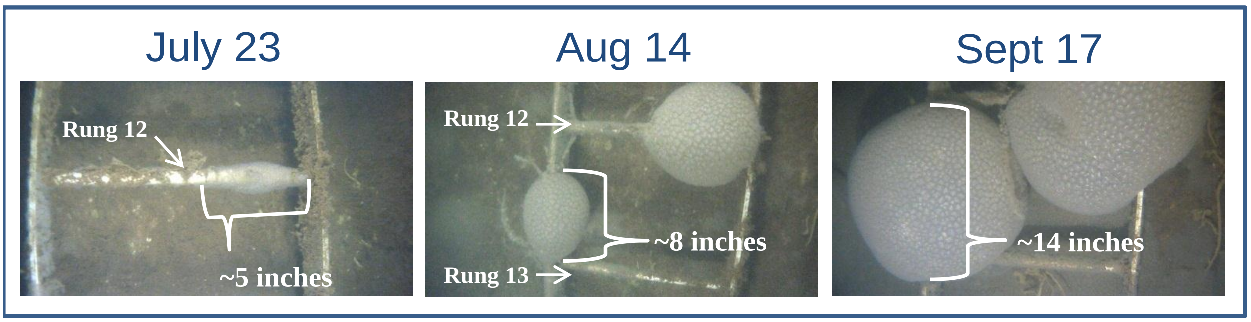


Figure 4.11 Photographs showing progression of *P. magnifica* colony growth on ladder rungs 12 and 13 at Delaware Shaft 18 in Sluice Gate 3.

4.5.2 Special Investigation Report: Kensico Reservoir Storm Event, July 14-16, 2014

During July 14 to 16, 2014, a storm event occurred that resulted in 3.3 inches of rain and triggered storm event monitoring at Kensico Reservoir. There were two main heavy precipitation periods—late in the day on July 14, and then again late in the day on July 15. Analytes investigated included turbidity, fecal coliform, and conductivity; Microbial Source Tracking (MST) was also used. Increases in turbidity and fecal coliforms were observed at the stream sites, as is expected for storm response. However, changes in water quality were minimal at the nearby limnological sampling sites. The reservoir effluent at DEL18DT had no turbidity issues as a result of these storms (<1.3NTU), and fecal coliform results did not exceed 9 fecal coliforms $100ml^{-1}$. MST testing indicated low levels of ruminant fecal biomarkers in three of the six stream samples, and one stream sample was positive for two different human fecal biomarkers.

Investigation Response:

Pre-Storm Stream Samples

Routine, fixed frequency, grab samples were collected on July 8, 2014 from the Kensico stream sites prior to the storm event period. This was a routine monthly survey. Approximately 0.1inches of rain fell on July 7, and 0.25 inches of rain on July 8. Fecal coliform results from July 8 and historical levels are compared in Table 4.4. All July fecal coliform counts were well below historic 95th percentile results.

Table 4.4: Routine monthly sampling fecal coliform results for Kensico stream sites on July 8, 2014, prior to the storm event, and 95th percentile data.

	Fecal Coliform (fecal coliforms 100mL^{-1})	
	July 8, 2014	95th Percentile (2002-2012)
WHIP	120	613
N12	860	1028
E9	150	2650
E11	140	1115
E10	140	2855
BG-9	140	1000
MB-1	490	2700
N5-1	150	4040

Storm Samples - Streams

Hydrographs were produced for the event for both MB-1 and N5-1, and samples were collected at various times during the storm. Some samples were selected for fecal coliform and turbidity analysis and some analyzed for MST. Approximately 80 total samples were collected between MB-1 and N5-1 during the storm event, with 16 samples analyzed.

Turbidity and fecal coliform storm results for MB-1 are shown in Figure 4.12. Turbidity levels ranged between 9.5 and 120 NTU, with the highest level detected on July 14. MB-1 fecal coliform concentrations had a very distinct increase and decrease within a 12-hour period between the evening of July 14 and the morning of July 15 (from 120,000 to 20,000 fecal coliforms 100mL^{-1}). However, the second increase in the storm hydrograph remained fairly level for both fecal coliforms (4300 to 8800 fecal coliforms 100mL^{-1}) and turbidity (9.5 to 15.0 NTU).

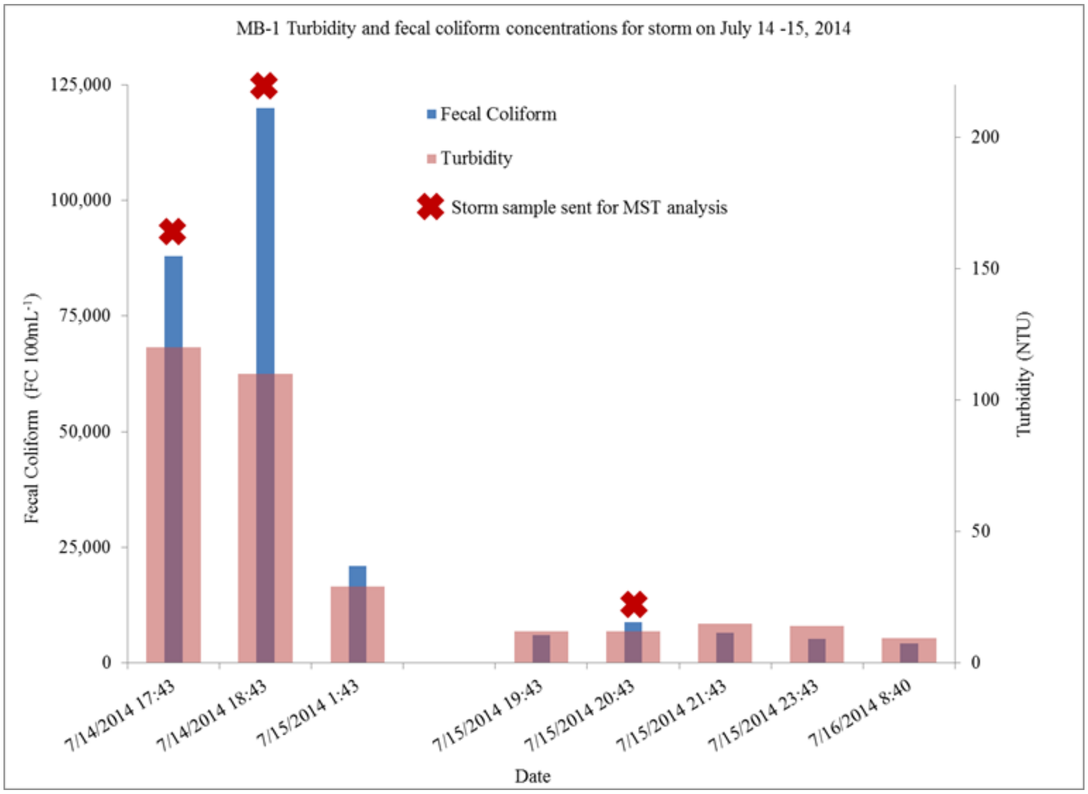


Figure 4.12 Fecal coliforms and turbidity at MB-1 over the course of the storm. The MB-1 95th percentile for 2002-2012 is 2,700 fecal coliforms 100mL^{-1}.

Turbidity and fecal coliforms were also measured at N5-1 throughout the storm (Figure 4.13). Turbidity levels ranged between 9.7 and 200 NTU during the storm, with the highest level detected on July 14. The decline of turbidity was more gradual than that of MB-1, and like MB-1, turbidity also remained fairly level during the second spike of the storm. Of note may be an increase in fecal coliform concentration on July 15 at 21:51. However, the preceding sample result was recorded as <1000 fecal coliforms 100mL^{-1}, so it is difficult to say if counts were increasing or decreasing. Overall, Malcolm Brook had higher fecal coliform levels and N5-1 had slightly higher turbidity values.

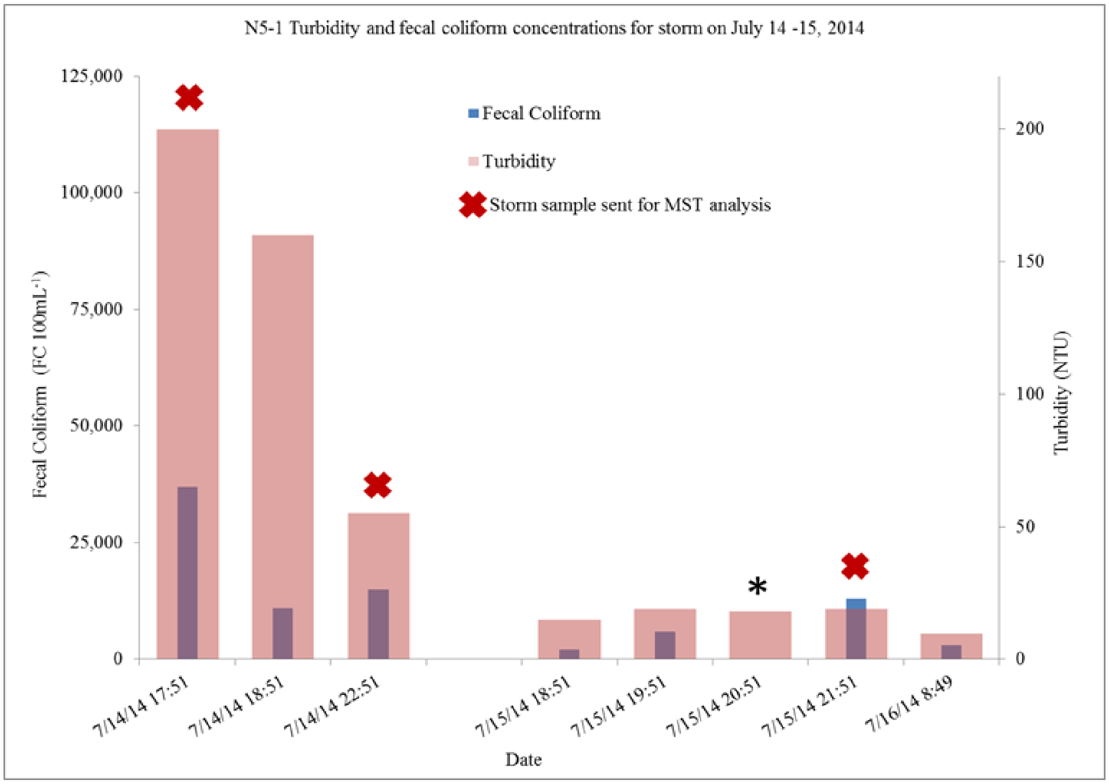


Figure 4.13 Fecal coliforms and turbidity at N5-1 over the course of the storm. N5-1 95th percentile for 2002-2012 is 4040 fecal coliforms $100mL^{-1}$.

*****FC reported as < 1000 CFU $100ml^{-1}$.

Pre-Storm Reservoir Samples

A routine limnology survey of Kensico Reservoir was conducted on July 14. There were no unusually high fecal coliform results from this survey. The highest concentration of 3 fecal coliforms $100mL^{-1}$ was found at Site 2, Site 4 and Site 5, all at 3 meters depth.

During the July 14 reservoir survey, turbidity ranged between 0.5 and 1.5 NTU. The highest reading of 1.5 NTU was recorded at Site 5 at a depth of 7 meters, and the lowest reading of 0.50 NTU was recorded at Site 4 at a depth of 21 meters. Pre-storm conductivity measurements taken during a July 1 survey indicated a range of 68-81 µmhos cm^{-1} between Sites 2, 2.9 and 4.

Storm Samples - Reservoir

The day that the autosampler units were triggered by precipitation is designated as Day 1 of the storm. Site 2 was sampled on Days 1-3; Site 2.9 on Days 1-4; Site 3.1 on Days 3 and 4; and Site 4 on Days 1, 3 and 4.

Conductivity measurements taken on July 15 ranged from 68-79 µmhos cm^{-1} at all sampled limnology sampling sites (2, 2.9, 3.1, 4, JC1, JC2, CL1 and CL2). Measurements taken on July 17, excluding Site 2, ranged from 68 to 80 µmhos cm^{-1}.

Eastern shore fecal coliform sampling was conducted near Jenny Clarkson (Sites JC1 and JC2) and Cranberry Lake (Sites CL1 and CL2), and at times showed increased fecal coliforms (Figure 4.14). Interestingly, while these sites are all on the same shoreline, they did not respond the same temporally with regard to increased fecal coliform concentrations. All sites responded by showing a higher concentration on the first day of reservoir sampling (July 16) and a lower concentration on the second day (July 17). Sites CL2, JC1 and JC 2 showed much higher concentrations on the first day compared to CL1, suggesting a relatively quick flush of bacteria into the water. All four eastern shore sites had some samples with concentrations over 20 fecal coliforms $100mL^{-1}$on July 16. The fecal coliform concentrations found at these sites were most likely influenced by local runoff from the adjacent shoreline, and in the case of CL2, local stream outflow.

A sixfold decrease in fecal coliform concentration occurred between July 16 and July 17 at Site CL2. This was not observed at the other three sites along the eastern shore of the reservoir and perhaps was caused by reservoir dilution or current changes. The likelihood of these concentrations reaching the reservoir effluent on the western shore without significant dilution is unclear, but it appears low.

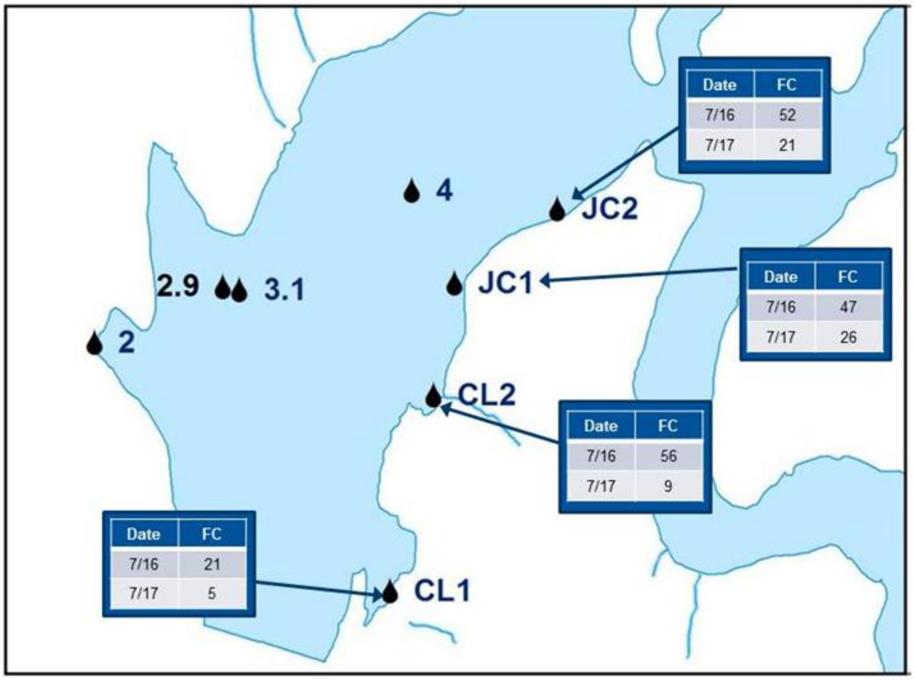


Figure 4.14 Eastern shore limnological sampling sites at 1-meter depth on Kensico Reservoir, with fecal coliform results shown by date (fecal coliforms 100 mL^{-1}).

Routine reservoir sites for storm event monitoring (other than eastern shore locations) were also sampled July 14-17 (Sites 4, 3.1, 2.9 and 2). Fecal coliform data from Site 4 and Site 3.1 were slightly high but overall not remarkable considering rainfall and historical data. Consistent with Sites 4 and 3.1, the more prominent detections of fecal coliform occurred at depths of six meters or less at Site 2.9. Other than this similarity, the data at Site 2.9 differed, displaying a large increase in fecal coliform concentration at 3 meters on July 15 and 16 (Figure 4.15). The highest result (91 fecal coliforms 100mL^{-1}) is the highest fecal coliform value of all the reservoir samples collected for this event. Given the proximity of this site to Malcolm Brook, this stream is the suspected source.

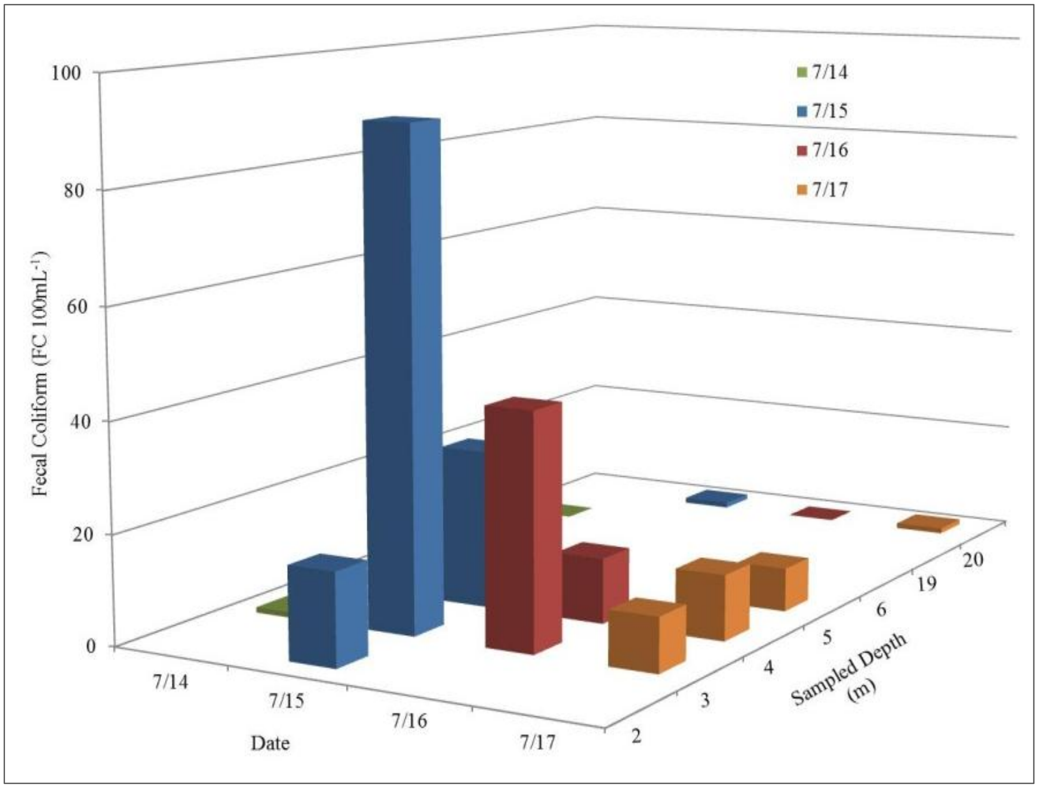


Figure 4.15 Kensico Reservoir Site 2.9 fecal coliform results from limnology surveys conducted July 14-July 17, 2014.

As observed at the other three sites, the highest concentration of fecal coliforms at Site 2 occurred at depths of less than 6 meters (Figure 4.16).

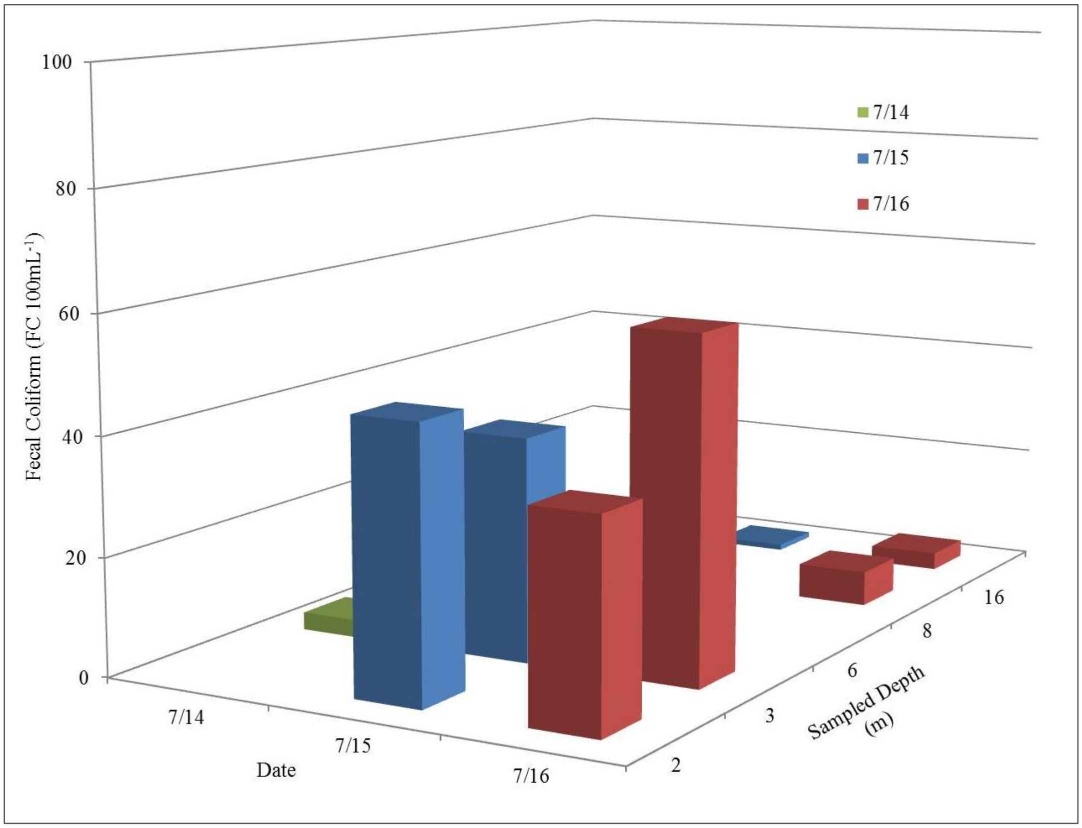


Figure 4.16 Kensico Reservoir Site 2 fecal coliform results from limnology surveys conducted July 14-July 16, 2014.

Aqueduct Keypoint Samples

Samples are taken daily for turbidity and coliform analyses at the aqueduct effluent of Kensico Reservoir (DEL18DT). The scheduled four-hour turbidity reading at DEL18DT ranged between 0.75 and 1.2 NTU during the period of the storm, suggesting only a weak influence of the storm on turbidity levels at this aqueduct keypoint location (Figure 4.17).

Figure 4.17 portrays daily turbidity readings and fecal coliform results at DEL18DT from July 10 through July 24. During the storm event the highest fecal coliform result was 9 fecal coliforms 100mL^{-1}, recorded on July 15, and the lowest fecal coliform concentration was 1 fecal coliform 100mL^{-1}, recorded on July 20. This suggests the storm had a minor and short-lived influence on Kensico Reservoir effluent bacterial water quality. Daily turbidity samples collected during the storms ranged from 0.9 to 1.0 NTU, while four-hour meter readings (not shown in Figure 4.17) were slightly higher, ranging from 0.8 to 1.2 NTU. The four-hour readings suggest a weak impact from the storm at this location.

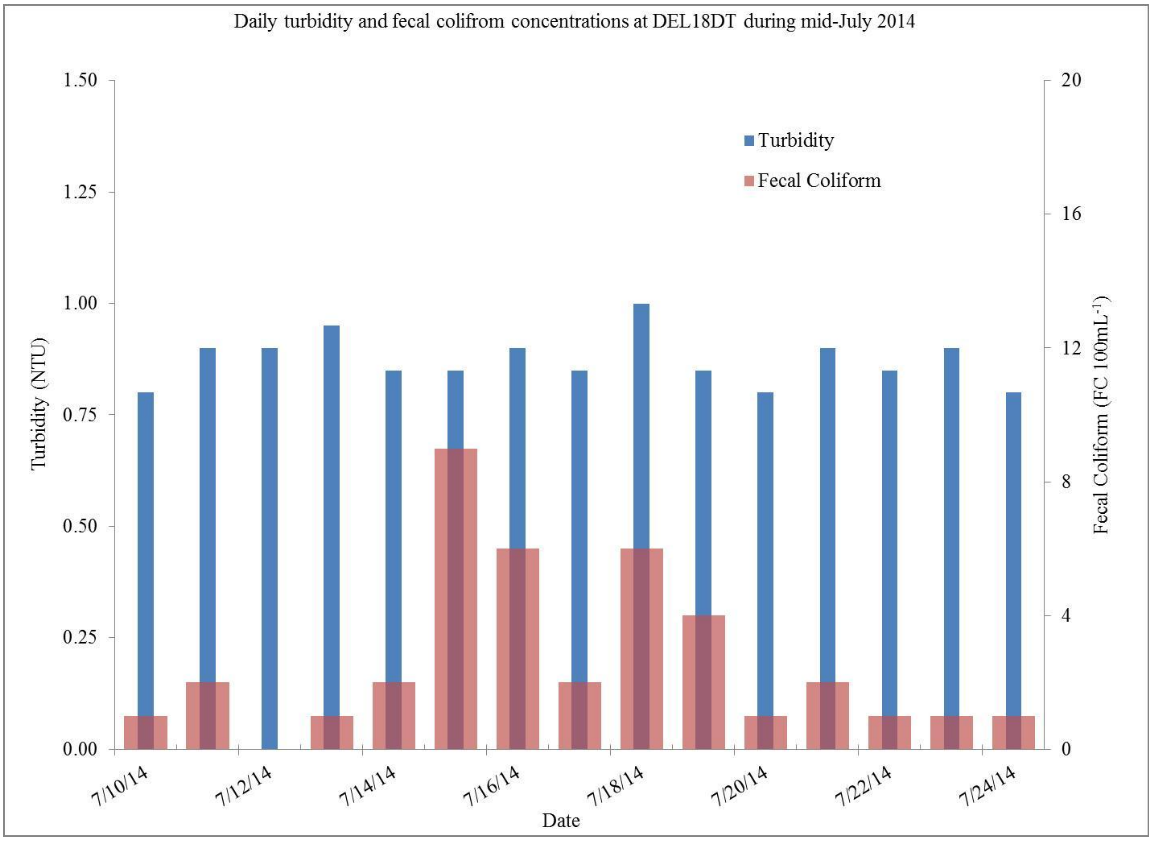


Figure 4.17 Turbidity and fecal coliform results for daily grab samples taken at DEL18DT from July 10 to July 24, 2014.

Specific conductivity measurements from DEL18DT were relatively stable during the storm event period, ranging from a low of 66 µmhos cm^{-1} on July 15 to a high of 69 µmhos cm^{-1} on July 16.

Microbial Source Tracking (MST)

Several samples were selected for MST based on hydrograph location and fecal coliform results. Samples sent for MST analysis were collected both from streams and reservoirs. Samples were examined for microbial markers from human, bird and ruminant sources, as well as for the general marker, which is the total number of all marker types.

All eight samples that were selected for MST analysis were tested for the human and ruminant fecal biomarkers, and three of the eight were also tested for the bird fecal biomarker (Table 4.5). None of the samples were positive for the bird marker, and none of the reservoir samples were positive for either the human or ruminant markers. Three of the six stream samples did test positive, with low concentrations for the ruminant marker, and one stream sample tested positive for the human marker.

Table 4.5: MST results for Kensico stream and reservoir samples, 7/14-7/15/2014. <LOD = below Limit of Detection (10 copy numbers per reaction). <LOQ = below Limit of Quantification. NT = not tested.

Collection Date	Site (autosampler bottle no.)	FC/ 100ml	General Marker	Ruminant Marker	Human Marker	Bird Marker	Comment
7/14/14	MB-1 (1)	88,000	2.67E+05	<LOD	<LOD	NT	
7/14/14	MB-1 (2)	120,000	3.03E+05	<LOQ	<LOD	<LOD	TRACE ruminant
7/15/14	MB-1 (28)	8,800	1.62E+04	<LOQ	<LOD	NT	TRACE ruminant
7/14/14	N5-1 (1)	37,000	1.76E+04	<LOD	<LOD	<LOD	
7/14/14	N5-1 (6)	15,000	2.22E+05	3.87E+02	1.02E+03	NT	Minor contributors
7/15/14	N5-1 (29)	13,000	4.87E+04	<LOD	<LOD	NT	
7/15/14	2BRK2	46	3.84E+03	<LOD	<LOD	NT	
7/15/14	2.9BRK3	91	1.21E+04	<LOD	<LOD	<LOD	

It is not unusual that ruminant markers were detected in source tracking testing of Kensico tributaries. Deer have previously been identified by DEP as sources of fecal bacteria in the Kensico Reservoir basin using other source tracking methods. It is, however, unusual to detect the human marker in one of the stream samples, even at such low levels (0.5% of the total). Since sample N5-1 #6 was positive for the human marker, additional testing was requested to increase the confidence in that result. The sample was subjected to two additional human biomarkers, both highly sensitive and specific for human fecal contamination, one of which is now approved by the USEPA for use in source tracking. Results were positive for one of the two additional human markers (Table 4.6), strengthening the case that somewhere along stream N5 there may have been a minor contribution from a human source. Although results were at a low level (0.2% of the total), having two different human biomarkers test positive is strongly suggestive of a positive source identification. The Watershed Protection Programs Directorate (WPP) was notified of the findings so it could perform a follow-up field survey of the N5-1 area to see if there was evidence of a potential human source (see next section, Field Inspection).

Table 4.6: Supplemental testing for sample N5-1 #6 at Kensico Reservoir. <LOD = below Limit of Detection (10 copy numbers per reaction).

Collection Date	Site (autosampler bottle no.)	Human Marker 183	EPA Human Marker	Steri Human Marker	Comment
7/14/14	N5-1(6)*	1.02E+03	<LOD#	5.31E+02	Low level human source

As obligate anaerobes, these organisms die off relatively quickly in the environment and are suggestive of recent contamination to a water body. Holding time, from the time of collection through shipping time through the time of analysis, also needs to be considered when accepting that the levels identified are likely on the low end of the actual concentration in the original sample. While this type of delay may have had an effect on reducing the population as a whole, it would have no effect on the recovery success of the different types of markers found in the samples, as there is no evidence to suggest different die-off times for different subtypes. In other words, if the ruminant marker was found in a sample, then any other marker would be positive as well if it was present in the sample.

Field Inspection Summary (Watershed Protection Programs (WPP))

WPP staff inspected the Westlake sewer line on foot around the N-5 stream area of concern. Sewer manhole inspections were performed, as well as a search for any potential septic systems in the area. Notable findings included two potential seeps that are believed to drain into the N5 stream:

1) Seep behind 55 Eastview Drive. After additional follow-up, this area was determined to be sewered and has since been deemed a natural seep.

2) Seep onto DEP property, 38 Greenwood Lane (Figure 4.18). After additional follow-up, this area was also determined to be sewered. However, due to its close proximity to the sewer line, and because it appeared to have had recent discharge, WPP followed up with additional inspections. No additional evidence of seeping has been observed since this event; however WPP will continue to inspect during future storms.

Figure 4.18 Seep onto DEP property at 38 Greenwood Lane.

Summary

A two-phase storm event occurred from July 14 to 16, 2014, resulting in 3.33 inches of rain. Samples were collected for turbidity, specific conductivity, and fecal coliforms from two perennial streams and several reservoir locations in order to identify a possible impact, if any, on the reservoir and ultimately the reservoir effluent. MST analyses were also used to narrow down the potential source(s) of the fecal bacteria.

Fecal coliform and turbidity levels at DEL18DT were not remarkable during this series of events, with maximums of 9 fecal coliforms $100mL^{-1}$ and 1.2 NTU, respectively. This suggests minimal impact of this storm on the effluent water quality during the flow through operation of the reservoir. MST testing indicated no positive results for the bird fecal marker, and low levels of ruminant fecal biomarkers in three of the six stream samples. One stream sample was positive for two different human fecal biomarkers. The ruminant finding is not unusual since there are many deer in the area and previous MST testing has indicated deer as a source in the past. Even at low levels, however, the indication of a human source is unusual in this basin. As the target markers used in this study are known to be very specific, it is believed that a low level of human contribution is indicated. WPP will be following up with additional inspection of a potential seep area after future rain events and, if warranted, samples will be collected for fecal coliform and MST analysis.

5. Pathogens

5.1 Introduction

DEP conducts compliance and surveillance monitoring for the protozoan pathogens *Cryptosporidium* and *Giardia*, and human enteric viruses (HEV) throughout the 1,972-square-mile NYC Watershed. DEP staff collected 515 protozoan samples in 2014, of which 506 samples were analyzed, 22 of which were sampled as part of method studies. The remaining 484 protozoan samples will be discussed here. Additionally, 170 HEV samples were collected in 2014, of which 169 samples were analyzed. Source water samples (Kensico and New Croton keypoints) and watershed stream samples comprised the majority of the 2014 protozoan sampling effort, accounting for 35.3% and 33.5% of the sample load, respectively. Sampling at the Hillview Reservoir Catskill downtake, upstate reservoir effluents, and wastewater treatment plants (WWTPs) made up the remaining 31.3% (Figure 5.1). All *Giardia* and *Cryptosporidium* samples were analyzed by Method 1623HV (USEPA 2005) and all HEV samples were analyzed according to the Information Collection Rule (ICR) Manual (USEPA 1996). Results are discussed by site.

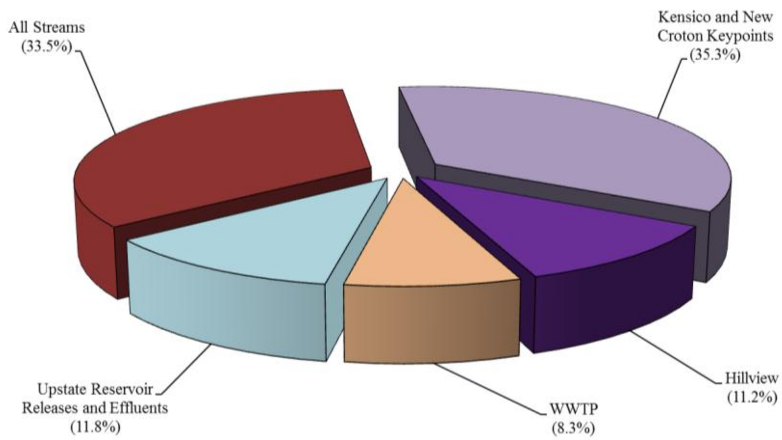


Figure 5.1 DEP protozoan analysis type distribution for 2014.

In 2012, DEP made a series of modifications to the monitoring plan which continued into 2014. These modifications included a reduction in sampling sites and/or frequency required by the Croton Consent Decree (CCD), and the cessation of sampling at the Catskill outflow of Kensico Reservoir, the latter occasioned by the shutdown of the Catskill Aqueduct in 2013 following the initiation of operations at the UV Disinfection Facility in September 2012. The aqueduct south of Kensico Reservoir remained shut down throughout 2014. Kensico outflow results are posted weekly on DEP's website (www.nyc.gov/html/dep/pdf/pathogen/path.pdf), and reported annually in this report.

5.2 Source Water Results

Catskill Aqueduct Inflow

In 2014, 2 samples out of 51 were positive for *Cryptosporidium* (1 oocyst $50L^{-1}$ each) at CATALUM (Catskill inflow to Kensico Reservoir) (Table 5.1). *Cryptosporidium* detections have been very infrequent in the last few years at this site, with only 4 detections (1 oocyst $50L^{-1}$ in each instance) in 260 weekly samples (1.5%) taken from January 2010 through December 2014. As mentioned, no samples were collected at the Catskill outflow of Kensico Reservoir this year.

Giardia was detected in 17 out of 51 samples analyzed for CATALUM (33.3%), with a mean concentration of 1.12 cysts $50L^{-1}$ (Table 5.1). These figures represent a decrease in the percent of detection from 2013 (51.9%). Mean concentration remained within the 2002-2013 historical range for this site (0.17-1.58 *Giardia* cysts $50L^{-1}$). The maximum concentration in 2014 (9 cysts $50L^{-1}$) was the highest since 2005 (Figure 5.2, Panel 1).

Table 5.1: Summary of *Cryptosporidium*, *Giardia* and HEV compliance monitoring data at the five DEP keypoints for 2014.

	Keypoint location	Number of positive samples	Mean**	Maximum
Cryptosporidium oocysts $50L^{-1}$	CATALUM (n= 51)	2	0.04	1
	CATLEFF (n= 0)	NA	NA	NA
	DEL17 (n= 52)	1	0.02	1
	DEL18DT (n=54)	4	0.11	3
	CROGH* (n= 14)	0	0.00	0
Giardia cysts $50L^{-1}$	CATALUM (n= 51)	17	1.12	9
	CATLEFF (n= 0)	NA	NA	NA
	DEL17 (n= 52)	31	1.61	9
	DEL18DT (n= 54)	31	1.43	6
	CROGH* (n= 14)	7	1.57	8
Human Enteric Virus $100L^{-1}$	CATALUM (n= 51)	18	1.20	13.1
	CATLEFF (n= 0)	NA	NA	NA
	DEL17 (n= 52)	7	0.19	2.23
	DEL18DT (n= 52)	8	0.19	2.19
	CROGH* (n= 12)	2	0.29	2.34

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

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

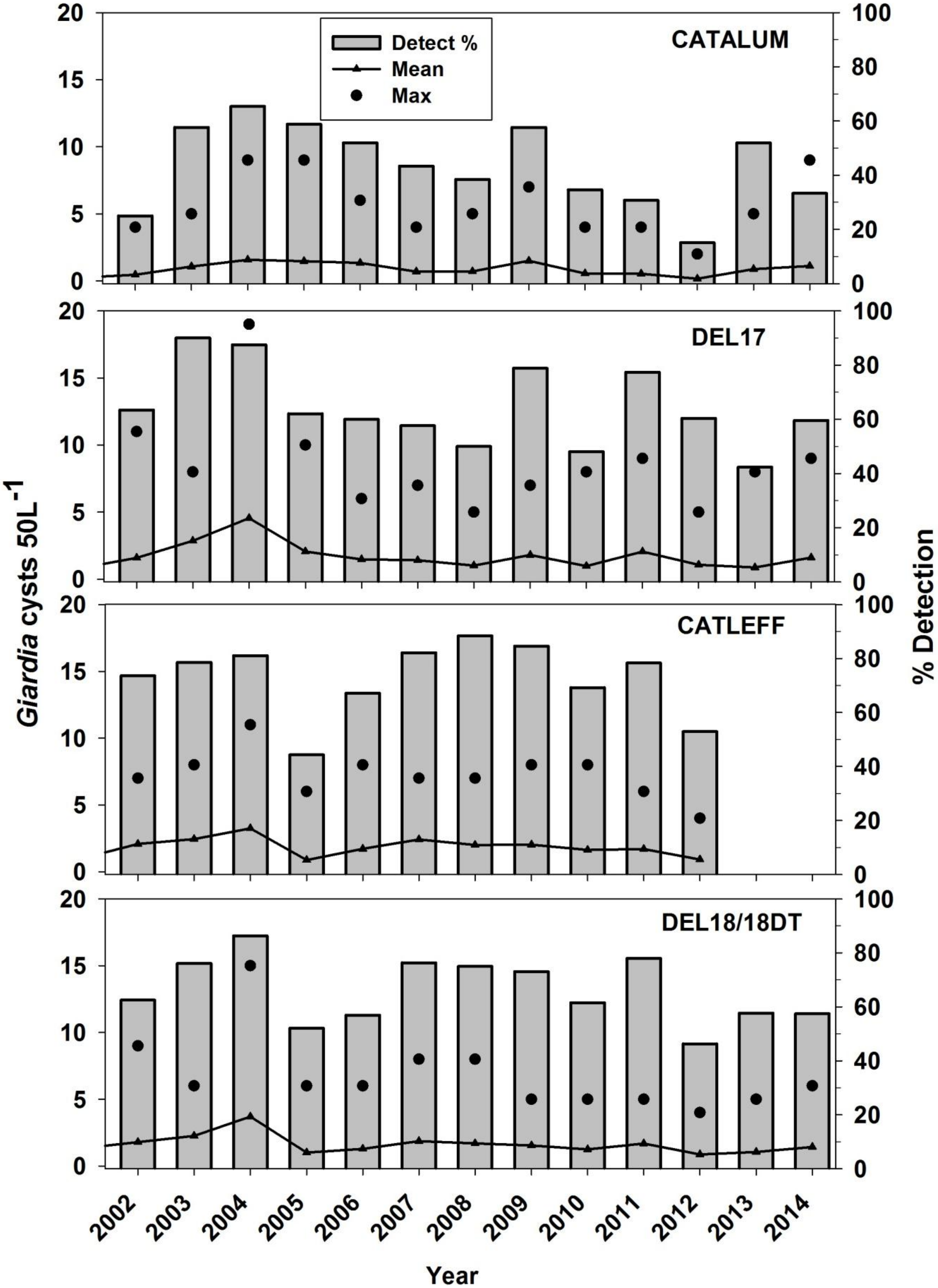


Figure 5.2 Annual percent detection of *Giardia*, mean concentration and maximum result for the Kensico keypoint sites during each year from 2002 to 2014.

HEV detections at CATALUM increased slightly from 15 detections (28.8%) in 2013 to 18 detections (35.3%) in 2014. The mean concentration, as determined by the "most probable number" (MPN) method, of HEVs at CATALUM was quite similar in 2014 (1.20 MPN $100L^{-1}$) to the mean in 2013 (1.10 MPN $100L^{-1}$), and was just under the historical mean of 1.25 MPN $100L^{-1}$ (February 2004-December 2013).

Delaware Aqueduct Inflow and Outflow

The Delaware inflow to Kensico Reservoir (DEL17) *Cryptosporidium* results were low in 2014, with only 1 detection out of 52 samples taken (1.9%) and a mean concentration of 0.02 oocysts $50L^{-1}$ (Table 5.1). This was a decrease from 2013, when there were 6 positive samples and a mean of 0.12 cysts $50L^{-1}$, but identical to results from 2010 to 2012 (1 positive sample in each year and a mean of 0.02 oocysts $50L^{-1}$). The Delaware outflow of Kensico Reservoir (DEL18DT), after two consecutive years without a *Cryptosporidium* detection, had 4 positives out of 54 samples analyzed. All four were found in cold weather months (January, February, March, December), with the first three occurring in the early part of the year. The maximum concentration of 3 oocysts $50L^{-1}$ was found in a special investigation sample taken on March 20 in response to high *Giardia* levels downstream at Hillview Reservoir. The mean *Cryptosporidium* concentration of 0.11 oocysts $50L^{-1}$ was the highest annual mean at DEL18DT since 2006 (0.12 oocysts $50L^{-1}$), but was lower than the mean for years prior to 2006 (range, 0.23-0.45 oocysts $50L^{-1}$).

Giardia was detected in 31 of the 52 samples collected at DEL17 (59.6%), with a mean concentration of 1.61 cysts $50L^{-1}$ (Table 5.1). DEL18DT had the same number of G*iardia* detections, collected from 54 rather than 52 samples (57.4% positive). The two additional samples were non-routine samples taken at the Delaware outflow of Kensico as a follow-up to an elevated *Giardia* result at Hillview Reservoir. DEL18DT had a mean concentration of 1.43 cysts $50L^{-1}$, higher than the annual means observed from 2012 to 2013 (0.87 and 1.06 cysts $50L^{-1}$, respectively), but within the range of means from 2006 to 2011 (1.25-1.87 cysts $50L^{-1}$) (Figure 5.2).

DEL17 had three fewer HEV detections in 2014 (7 detects, 13.5%) than in 2013 (10 detects, 19.2%). HEV mean and maximum concentrations at DEL17 were 0.19 MPN $100L^{-1}$ and 2.23 MPN $100L^{-1}$, respectively. Results for DEL18DT were quite similar, with a mean HEV concentration of 0.19 MPN $100L^{-1}$, a maximum of 2.19 MPN $100L^{-1}$, and 8 positive samples (15.4%).

New Croton Aqueduct

Twelve routinely scheduled protozoan samples and 2 special investigation samples were taken at the New Croton Reservoir outflow in 2014. The two special investigation samples were taken as resamples in response to low *Cryptosporidium* matrix spike recoveries at the site. *Cryptosporidium* was not detected in any of the 14 samples (Table 5.1). *Giardia* was detected in 7 samples (50.0%) and had a mean concentration of 1.57 cysts $50L^{-1}$. HEV detection frequency

(2 out of 12 samples) was similar to 2013's (3 out of 12) but the mean concentration (0.29 MPN $100L^{-1}$) was lower than in 2013 (1.75 MPN $100L^{-1}$).

As in prior years, *Giardia* was detected in higher concentrations and occurred more frequently in winter and spring than in summer and fall (Figure 5.3), which is consistent with historical observations. While there may also be some seasonality associated with *Cryptosporidium* occurrence, there are too few oocysts detected in source water to provide statistical confidence in this hypothesis.

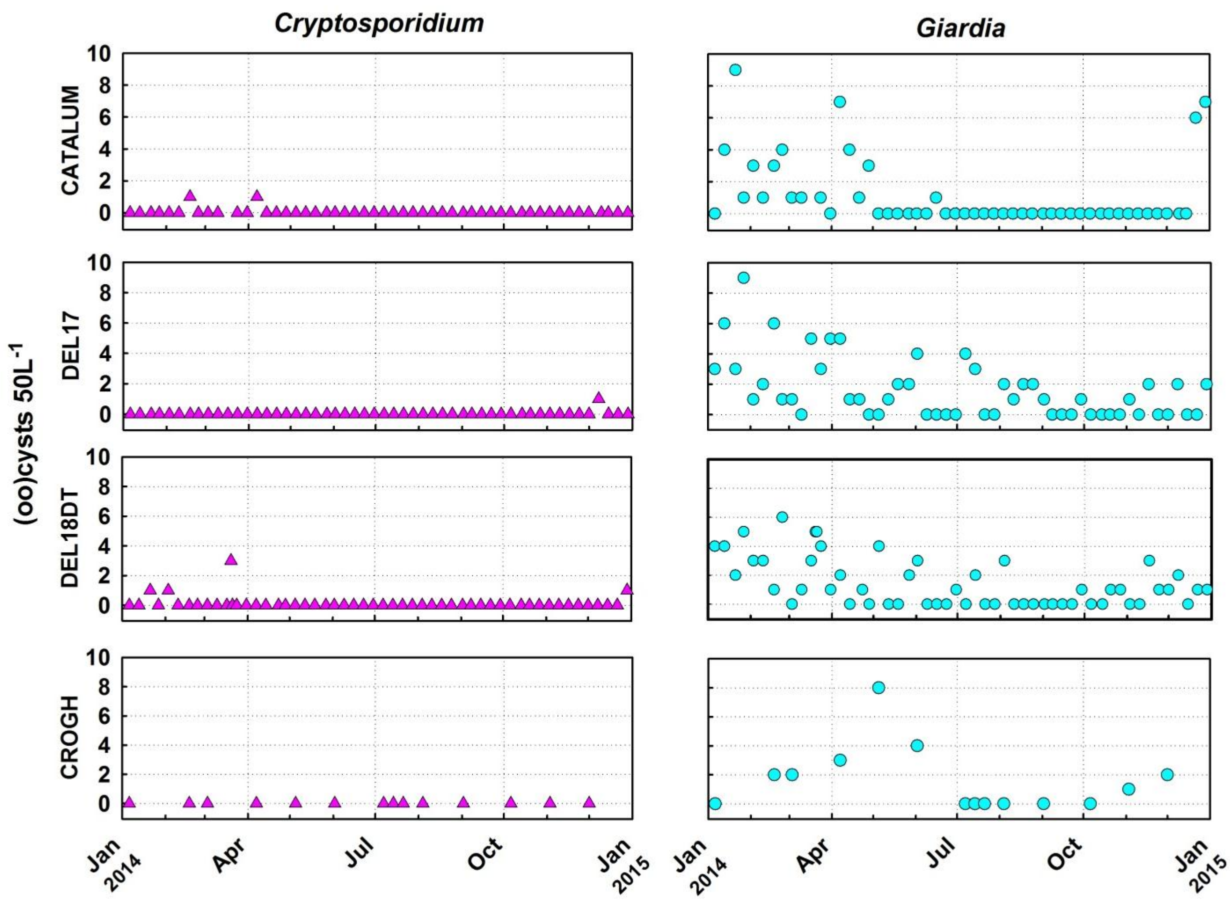


Figure 5.3 Routine weekly source water keypoint monitoring results for 2014.

5.2.1 2014 Source Water Compared to Historical Data

Water quality varies at the source water sites depending on several factors in their respective watersheds, such as stormwater runoff, impacts from land use, effects of other ecological processes, and operational changes. Beginning in October 2001 and continuing until 2012, the five source water sites were sampled weekly for protozoans, using USEPA Method 1623HV (USEPA 2005). With this large dataset, collected over several years, DEP has been able to document seasonal patterns and long-term changes in protozoan concentrations. Modifications to the frequency of monitoring at the New Croton Reservoir outflow (weekly to monthly) and the shutdown of the Catskill Aqueduct outflow from Kensico in 2012, make the comparison of summary statistics for 2014 with statistics from previous years more complex. It is essential to note that the Delaware Aqueduct is currently the only outflow in operation that is sampled from Kensico Reservoir.

In 2014, there were 7 *Cryptosporidium* detections at the four keypoint sites, the same number of detections found in 2013. Six of the seven positive samples had 1 oocyst $50L^{-1}$ and one had 3 oocysts $50L^{-1}$. The Catskill and Delaware influents to Kensico Reservoir had 2 and 1 detection, respectively. This was similar to the number of detections for the Catskill influent in 2013, but a pronounced decrease for the Delaware influent, which had 6 detections in 2013. The remaining 4 detections occurred at DEL18DT, which had no detections during 2012 or 2013 and had only 1 detection each in 2010 and 2011. Prior to those years, there were 4 or more detections each year at the Delaware outflow (Table 5.3). Overall, despite the four detections at DEL18DT, lower oocyst detection and concentration have been observed at the Kensico and New Croton Reservoir keypoints since approximately 2009 (Tables 5.2 and 5.3).

Table 5.2: Annual detection and mean oocyst concentration of *Cryptosporidium* at influent keypoints to Kensico Reservoir 2002 - 2014.

Site	CATALUM			DEL17		
Year	Detects	% Detect	Mean ($50L^{-1}$)	Detects	% Detect	Mean ($50L^{-1}$)
2002	6	11.5	0.17	8	15.4	0.15
2003	8	15.4	0.25	15	25.0	0.28
2004	10	19.2	0.29	11	19.6	0.20
2005	1	1.7	0.02	6	10.2	0.10
2006	3	5.8	0.06	3	6.0	0.06
2007	1	1.9	0.02	4	7.7	0.08
2008	7	13.5	0.13	6	11.5	0.15
2009	7	13.5	0.15	4	7.7	0.08
2010	1	1.9	0.04	1	1.9	0.02
2011	0	0.0	0.00	1	1.9	0.02
2012	0	0.0	0.00	1	1.9	0.02
2013	1	1.9	0.02	6	11.5	0.12
2014	2	3.9	0.04	1	1.9	0.02

Table 5.3: Annual detection and mean oocyst concentration of *Cryptosporidium* at Kensico and New Croton Reservoir effluent keypoints 2002 - 2014.

Site	CATLEFF			DEL18			CROGH		
Year	Detects	% Detect	Mean ($50L^{-1}$)	Detects	% Detect	Mean ($50L^{-1}$)	Detects	% Detect	Mean ($50L^{-1}$)
2002	21	29.2	0.35	18	25.0	0.31	13	20.0	0.28
2003	20	28.6	0.34	21	29.6	0.45	7	11.9	0.17
2004	20	27.0	0.38	25	34.7	0.36	28	40.0	0.51
2005	16	16.3	0.21	15	15.5	0.23	3	5.5	0.05
2006	8	12.5	0.13	7	10.8	0.12	7	13.5	0.13
2007	4	7.1	0.07	2	4.0	0.04	3	5.7	0.06
2008	10	19.2	0.23	1	1.9	0.02	8	14.3	0.21
2009	1	1.9	0.02	4	7.7	0.08	4	7.7	0.12
2010	3	5.8	0.06	1	1.9	0.02	5	9.6	0.10
2011	2	3.3	0.03	1	1.7	0.02	1	1.9	0.02
2012*	1	2.9	0.03	0	0.0	0.00	1	2.8	0.03
2013	NS†	NS	NS	0	0.0	0.00	0	0.0	0.00
2014	NS	NS	NS	4	7.4	0.11	0	0.0	0.00

*Monitoring was discontinued at CATLEFF in September 2012.
†NS = not sampled

In 2014, *Giardia* continued to show seasonal variation in results at all four keypoint sites (Figure 5.4). Seasonality is less apparent in the locally weighted regression (LOWESS) smoothed line for *Giardia* at the Croton effluent because samples were generally taken monthly in the last two years (as compared to weekly from October 2001 to August 2012). Since LOWESS uses specified proportions of a dataset to determine regressions, the collection of fewer samples in a year is less likely to show a signal for seasonality.

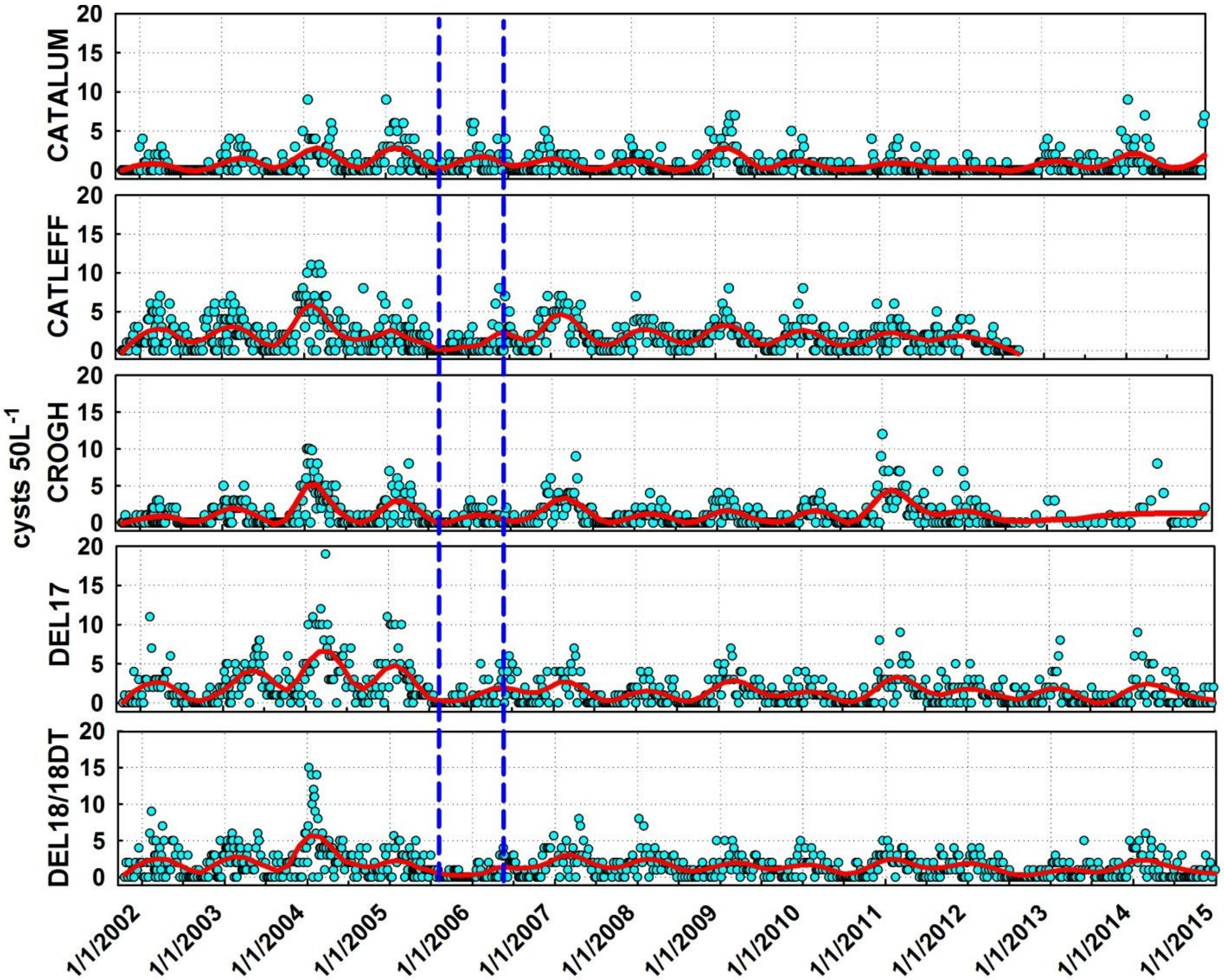


Figure 5.4 Weekly routine source water keypoint results for *Giardia* (LOWESS smoothed - 0.1) from October 15, 2001 to December 31, 2014. The area between the blue dotted lines indicates the period during which DEP temporarily switched to a different EPA-approved stain.

5.2.2 2014 Source Water Compared to Regulatory Levels

The Long Term 2 Enhanced Surface Water Treatment Rule (LT2) (USEPA 2006) required utilities to conduct monthly source water monitoring for *Cryptosporidium* and report data from a two-year period, though a more frequent sampling schedule was permitted. The LT2 requires all unfiltered public water supplies to "provide at least 2-log (i.e., 99 percent) inactivation of *Cryptosporidium*." If the average source water concentration exceeds 0.01 oocysts L^{-1} based on the LT2 monitoring, "the unfiltered system must provide at least 3-log (i.e., 99.9 percent) inactivation of *Cryptosporidium.*" The average source water *Cryptosporidium* concentration is calculated by taking a mean of the monthly *Cryptosporidium* mean concentrations at the source water effluents over the course of two years. Results have been calculated here using data from the most recent two-year period (January 1, 2013-December 31, 2014), using all analyzed routine and non-routine samples (Table 5.4).

Table 5.4: Number and type of samples used to calculate the LT2 bin classification set from January 1, 2013 to December 31, 2014.

Aqueduct	Number of routine samples, 2013-2014	Number of non-routine samples, 2013-2014	Total n
Croton	24	2	26
Delaware	104	2	106

The 2013 to 2014 mean of monthly means for *Cryptosporidium* were 0.0009 oocysts L^{-1} for the Delaware effluent and 0.0000 oocysts L^{-1} for the Croton effluent, well below the LT2 threshold level of 0.01 oocysts L^{-1}. This is consistent with NYC source water historical LT2 calculations (Figure 5.5), which have always remained below the threshold level. With the exception of this year's calculation for the Delaware effluent, the monthly means have generally been declining since 2009. Moreover, despite the four positive samples found at the Delaware effluent in 2014, *Cryptosporidium* detections have generally become less frequent, with no detections at the Delaware effluent in the 2012-2013 period and none at the Croton effluent during the 2013-2014 period.

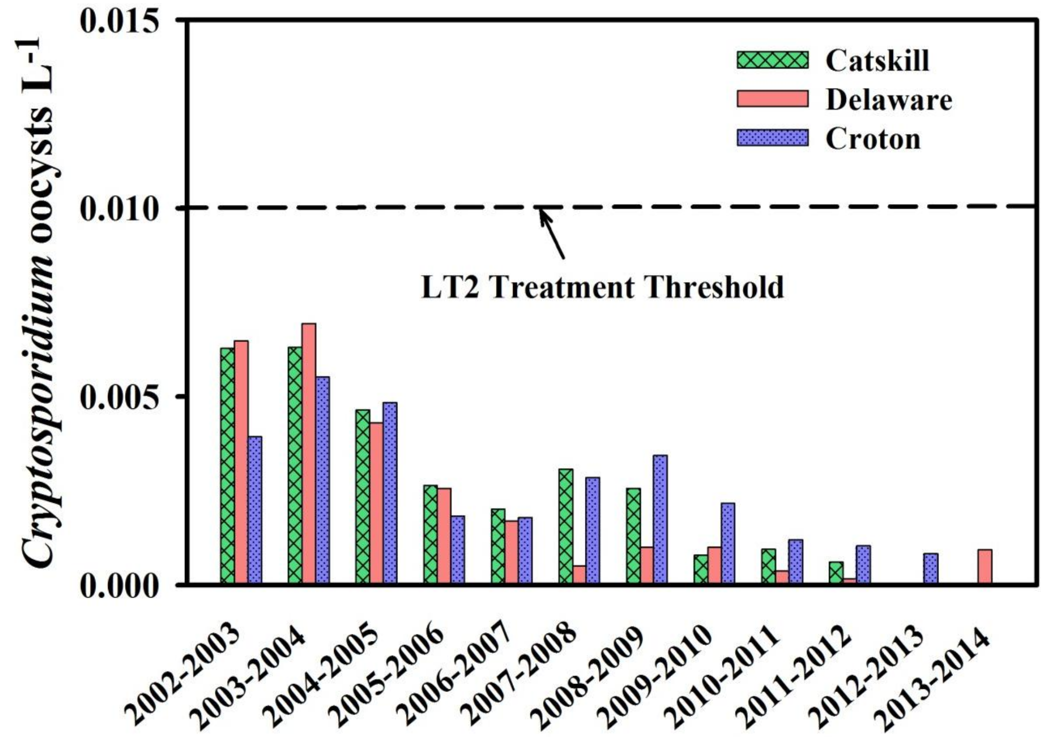


Figure 5.5 LT2 calculated means for *Cryptosporidium* since initiation of Method 1623 at DEP's three source waters; Croton and Delaware Aqueducts 2002-2014 and Catskill Aqueduct 2002-2012. No means were reported for the Catskill Aqueduct for the last two 2-year spans as no samples were collected during these years due to aqueduct shutdown.

5.3 Upstate Reservoir Effluents

Upstream of Kensico Reservoir, along the aqueduct system, are the Catskill and Delaware watersheds (collectively, the West of Hudson (WOH) watershed). These watersheds collect and store water in six upstate reservoirs, which DEP monitors for protozoans to ensure quality prior to water entering downstream reservoirs. Sampling is conducted at the effluents of these WOH reservoirs on a monthly basis (except for CATALUM, representing water from Ashokan Reservoir, which is sampled weekly), and efforts are made to schedule the sampling during times of the month when the water is being conveyed to Kensico Reservoir. However, DEP does not always use water from all six WOH reservoirs every month, and in months when water is not so conveyed, no sampling is conducted. For this reason, three of the WOH reservoirs (Neversink, Cannonsville, and Schoharie) do not have not samples for all 12 months of 2014.

Of 108 samples collected and analyzed from the upstream reservoir outflows in 2014, 7 (6.5%) were positive for *Cryptosporidium* (Table 5.5), quite similar to the detection rate from 2013 (7 positives in 109 samples (6.4%)). Schoharie's outflow had three positive samples in

2014 compared to no detections in 2013. Two other reservoir outflows (Pepacton and Neversink) had one detection each, as was the case in 2013. Concentrations of *Cryptosporidium* in positive samples remained low, with a maximum of 3 oocysts $40.0L^{-1}$ at the Schoharie Reservoir outflow.

Table 5.5: Summary of upstate reservoir effluent protozoan results for 2014.

		Cryptosporidium				*Giardia*			
Site	n	Mean ($50L^{-1}$)	% Detects	Maximum (liters sampled)	Maximum (L^{-1})	Mean ($50L^{-1}$)	% Detects	Maximum (liters sampled)	Maximum (L^{-1})
Schoharie	11	0.61	27.3%	3 (40.0L)	0.08	21.53	90.9%	139 (40.0 L)	3.48
Ashokan (CATALUM)	51	0.04	3.9%	1(50.0 L)	0.02	1.12	33.3%	9 (50.0 L)	0.18
Cannonsville	11	0.00	0.0%	0	0.00	3.00	54.5%	16 (50.0 L)	0.32
Pepacton	12	0.08	8.3%	1 (50.1 L)	0.02	1.16	41.7%	9 (50.1 L)	0.18
Neversink	11	0.09	9.1%	1 (50.5 L)	0.02	1.09	54.5%	3 (50.0 L)	0.06
Rondout	12	0.00	0.0%	0	0.00	1.33	58.3%	6 (50.1 L)	0.12

Giardia was detected in 51 upstate reservoir outflow samples in 2014 (47.2%), compared to 63 (57.8%) in 2013. The Ashokan mean concentration was 1.12 cysts $50L^{-1}$ compared to 0.88 cysts $50L^{-1}$ in 2013, although the percentage of detections fell from 51.9% in 2013 to 33.3% in 2014. The slight increase in the mean occurred because four samples had concentrations above the 2013 maximum (5 cysts $50L^{-1}$), including one value that reached 9 cysts $50L^{-1}$. The Schoharie Reservoir mean concentration of *Giardia* increased by 178%, from 7.75 cysts $50L^{-1}$ in 2013 to 21.53 cysts $50L^{-1}$ in 2014. This mean was influenced by the highest concentration sample (139 cysts $40L^{-1}$), collected in August 2014. Figure 5.6 displays the distribution of *Giardia* sample concentrations among the Catskill and Delaware basins. Because of the variability in sample collection volumes (range, 29.0-51.2L), each sample result was converted to a 50L concentration. That caused some samples to appear higher than their actual per liter concentrations would indicate. For example, the sample with the Schoharie maximum concentration (139 cysts $40L^{-1}$) has a concentration of 173.75 cysts $50L^{-1}$ after the conversion.

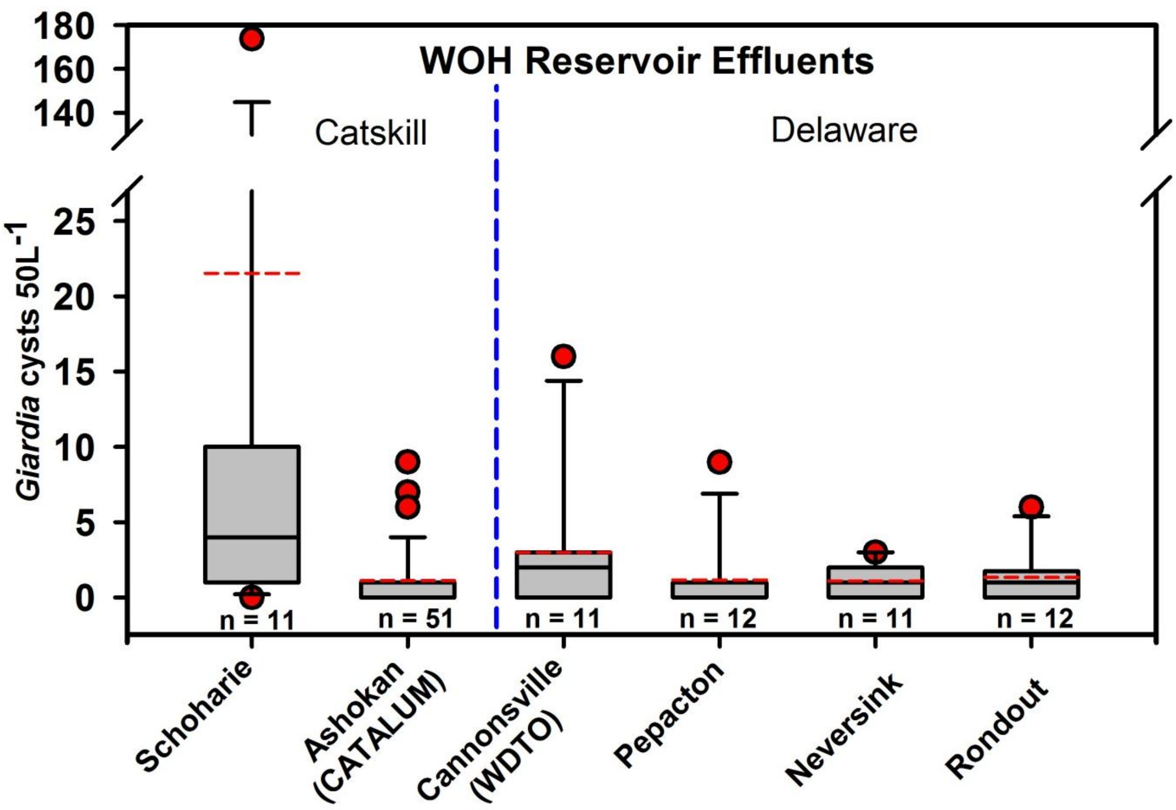


Figure 5.6 2014 summary of *Giardia* distribution among WOH basins (---Mean, —median, ● outliers). To assist in working with results for samples of varying volumes, all results were converted to per liter concentrations and then scaled back up to 50L concentrations.

5.4 Watershed Streams

The 2009 Watershed Water Quality Monitoring Plan (WWQMP) (DEP 2009a) prescribes protozoan monitoring at 18 streams in the NYC watershed. This includes 8 stream sites in the WOH watershed, 8 in the Kensico watershed, and 2 in the Croton watershed, each to be monitored monthly. In 2012, as a result of modifications to the WWQMP, sampling frequency at four of the streams in the WOH watershed was reduced to every other month and, owing to a change to the CCD, monitoring at the two Croton watershed streams was discontinued. Four additional stream sites in the WOH watershed, three of which are being monitored for upstream source identification, and the eight Kensico perennial stream sites were sampled monthly in 2014. A total of 162 samples were collected in 2014, with 66 in the WOH watershed and 96 at the Kensico perennial streams.

West of Hudson Streams

Four of the eight WOH streams were monitored every other month during 2014 (CDG1, S4, S5i, WDBN), while the other four—PROXG, S7i, S7iB, and S7iDPond3—were monitored monthly (Figure 5.7). An additional site along the Manorkill above site S7i (S7iDPond1) was sampled once only, to help determine if it was a potential source of protozoans. *Cryptosporidium* oocysts were detected in a relatively high percentage of WOH watershed stream samples (25 detections in 66 samples (37.9%)), similar to the detection rate observed for this group of sites in 2013 (34.7%). Concentrations, however, were generally low, with 23 of the 25 positive samples having 3 oocysts $50L^{-1}$ or less, which is, again, very similar to the results for 2013. The highest concentration for any of the sampled streams (17 oocysts $50.1L^{-1}$) was found in the March sample at CDG1 (Table 5.6). While there was no precipitation recorded on the day the sample was taken, it is very likely that melting snow increased runoff, potentially increasing transport of protozoans to the stream. This was the only *Cryptosporidium* detection at CDG1 in 2014, but with only 5 samples taken during the 12-month period (one sample was not collected when the site was inaccessible due to ice cover in January) it resulted in an annual mean concentration of 3.39 oocysts $50L^{-1}$, higher than the 2013 mean of 1.92 oocysts $50L^{-1}$.

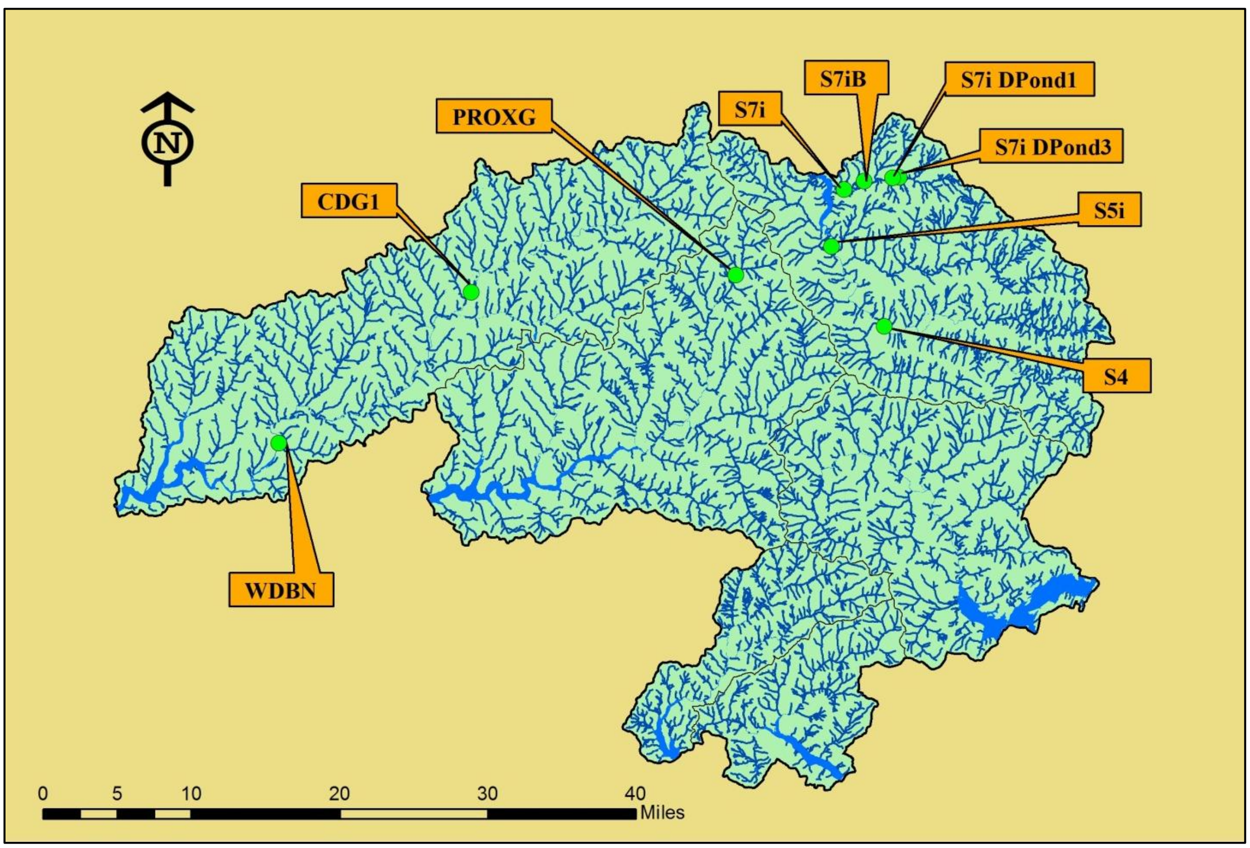


Figure 5.7 WOH stream sites sampled for protozoans in 2014.

Table 5.6: Watershed stream protozoan results summary for WOH sites in 2014.

Site	n	*Cryptosporidium* Mean ($50L^{-1}$)	*Cryptosporidium* Maximum (liters sampled)	*Cryptosporidium* Maximum (L^{-1})	*Giardia* Mean ($50L^{-1}$)	*Giardia* Maximum (liters sampled)	*Giardia* Maximum (L^{-1})
CDG1	5	3.39	17 (50.1 L)	0.34	119.99	245 (50.1 L)	4.89
PROXG	12	0.78	2 (50.0 L)	0.04	214.33	708 (37.8 L)	18.73
S4	6	0.67	2 (50.0 L)	0.04	51.45	125 (50.1 L)	2.50
S5i	6	1.57	5 (39.1 L)	0.13	69.25	135 (39.1 L)	3.45
S7i	10	0.88	2 (50.0 L)	0.08	47.57	89 (50.0 L)	1.78
S7iB	10	0.50	2 (50.3 L)	0.04	26.88	101 (50.3 L)	2.01
S7iDPond1	1	0.00	0	0.00	0.00	0	0.00
S7iDPond3	10	0.40	2 (50.0 L)	0.04	97.37	402 (47.6 L)	8.45
WDBN	6	0.49	3 (51.5 L)	0.06	47.46	122 (50.1 L)	2.44

As in the past, *Giardia* was found far more frequently than *Cryptosporidium*, as reflected in the very high number of positive samples (62 of 66 (93.9%)), and at much higher concentrations (Table 5.6). At six of the nine sites, *Giardia* was found in every sample collected in 2014. The three sites that did not have 100% detection rates were upstream along the Manorkill. Six of the seven sites that were also sampled last year showed increases of more than 50% in annual mean concentration compared to 2013 (the one exception being S7iB), and three sites (PROXG, S4, and WDBN) showed increases over 100%. PROXG had the highest mean concentration (214.33 cysts $50L^{-1}$) and the two highest individual sample concentrations (708 cysts $37.8L^{-1}$ and 675 cysts $49.9L^{-1}$) (October and November samples, respectively) found in WOH streams in 2014.

As part of an effort to determine if point sources could be identified upstream of sites with the highest mean protozoan concentrations, several upstream sites on the Manorkill were sampled. Three of them (S7i and two sites above it, S7iB and a new site S7iDPond3) were sampled monthly, with monitoring for all three sites scheduled on the same day (Figure 5.8). Another new site (S7iDPond1) was sampled once in March, on the same day as the other three Manorkill sites, to determine if it or the nearby S7iDPond3 site were major contributing sources of *Giardia* in this basin. Results from this one round of sampling indicated that S7iDPond3 had *Giardia* levels more in line with those at the downstream sites, as opposed to S7iDPond1, where *Giardia* was not detected. DEP dropped the S7iDPond1 site and continued sampling at S7iDPond3 for the remainder of the year. Samples from S7iDPond3 from August to November indicated a protozoan source could potentially be upstream of this site, which had a mean concentration of 232.4 cysts $50L^{-1}$ for the four-month period. At this point, there appear to be a few areas where there are sources of *Giardia* upstream from S7i, and based on land use and past *Giardia* typing these are believed to be wildlife. Testing wildlife feces from the pond area may be a next step and is under consideration.

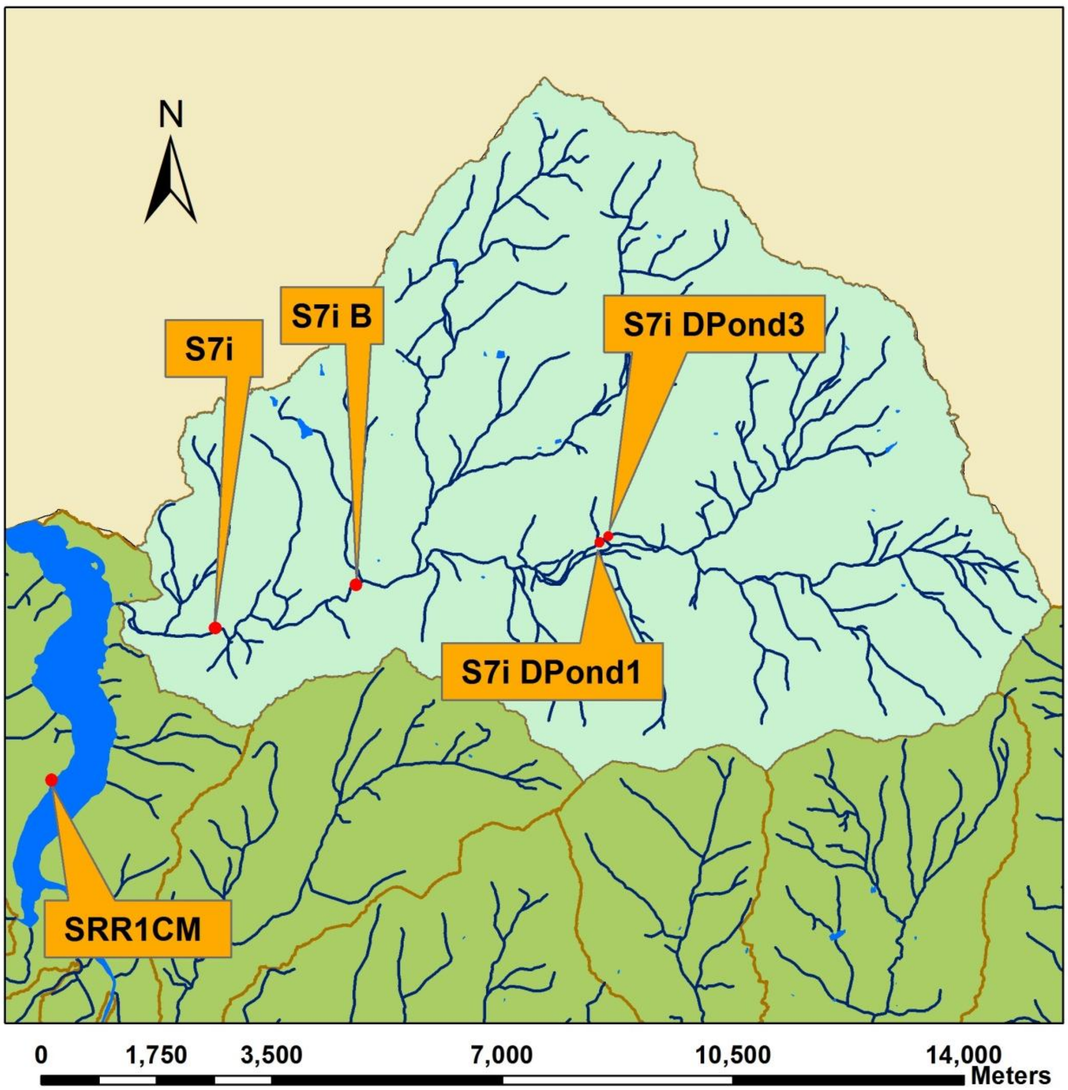


Figure 5.8 The Manorkill sub-basin in the Schoharie watershed, depicting local pathogen monitoring sites sampled in 2014.

East of Hudson Streams

In 2014, eight perennial streams in the Kensico Reservoir watershed (Figure 4.1) were sampled monthly for protozoans, with two exceptions. At E9, one monthly sample was not collected in September, when there was no stream flow, and at E10, one additional sample was taken in September when the monthly routine sample had an elevated *Giardia* result.

Overall, Kensico streams showed a low *Cryptosporidium* detection rate in routine monthly samples (11.6%) and in annual mean concentrations, which were below 1.00 oocysts $50L^{-1}$ at each stream. The highest mean concentration for 2014 was found at E9 (0.82 oocysts $50L^{-1}$), along with the highest individual sample result (5 oocysts $50L^{-1}$) (Table 5.7). These *Cryptosporidium* results were similar to those for the previous four years, when annual mean concentrations at each site did not go over 1.00 oocyst $50L^{-1}$, with the exception of E9 in 2013 (1.32 oocysts $50L^{-1}$). For the second year in a row, there were no *Cryptosporidium* oocysts detected in routine samples at MB-1. There has only been one oocyst detected at this site in 49 samples taken over the last four years (2011-2014).

The overall *Giardia* detection rate for Kensico streams was 74.0% in 2014, very similar to the rates in 2013 and 2012 (69.8 and 75.0%, respectively). The pooled mean concentration for all Kensico stream sites (the mean of all the sample concentrations (96 in total) for all eight sites) was 11.69 cysts $50L^{-1}$. This represents a return to near-2012 levels (12.51 cysts $50L^{-1}$), following a decline in 2013 to 6.23 cysts $50L^{-1}$. Concentrations at individual streams ranged from 1.74 to 44.00 cysts $50L^{-1}$ (Table 5.7). Most of these individual means were little changed from 2013, with the exception of E9, where the 2014 mean (44.00 cysts $50L^{-1}$) was substantially higher than 2013's (9.86 cysts $50L^{-1}$), although still somewhat lower than the historical mean of 60.85 cysts $50L^{-1}$ (based on data from 2002 to 2013 (n=139)). One sample taken at E10 on September 9, 2014, had an elevated *Giardia* concentration (153.00 cysts $50L^{-1}$) that was above the historical 95^{th} percentile for the site (132.00 cysts $50L^{-1}$). A follow-up sample taken on September 22 found a *Giardia* result of 3.00 cysts $50L^{-1}$,which is below the historical mean of 7.11 cysts $50L^{-1}$. Much of the fluctuation in annual means from year to year is a result of the timing of precipitation in relation to routine sample collection. Most often, frequent detections and increases in concentrations occur as a consequence of recent precipitation.

Table 5.7: Watershed stream protozoan results summary for EOH sites in 2014.

Site	n	*Cryptosporidium*			*Giardia*		
		Mean ($50L^{-1}$)	Maximum (liters sampled)	Maximum (L^{-1})	Mean ($50L^{-1}$)	Maximum (liters sampled)	Maximum (L^{-1})
BG9	12	0.27	1 (39.0 L)	0.03	5.58	21 (39.0 L)	0.54
E10	13	0.38	3 (37.8 L)	0.08	18.55	153 (50.0 L)	3.06
E11	12	0.17	2 (50.0 L)	0.04	14.29	57 (41.3 L)	1.38
E9	11	0.82	5 (50.0 L)	0.10	44.00	114 (50.0 L)	2.28

MB-1	12	0.00	0	0.00	3.41	15 (34.2 L)	0.44
N12	12	0.33	3 (50.0 L)	0.06	4.58	18 (50.0 L)	0.36
N5-1	12	0.12	1 (35.0 L)	0.03	1.74	7 (50.0 L)	0.15
WHIP	12	0.00	0	0.00	3.46	9 (50.0 L)	0.18

5.5 Wastewater Treatment Plants

In 2014, DEP monitored 10 WWTP effluents (8 WOH and 2 EOH) quarterly for *Cryptosporidium* and *Giardia.* No *Cryptosporidium* detections, and four *Giardia* detections, were reported from these 40 samples (Table 5.8). Three of the positive samples were collected in the WOH System, all in the Schoharie Reservoir watershed.

Table 5.8: Protozoan detections at WWTPs in 2014.

Date	Site	Plant	Sample Volume	*Crypto* Result	*Giardia* Result
1/15/2014	Hunter WTP	Hunter	50.0	0	2
2/12/2014	Hunter Highlands BD	Hunter Highlands	50.0	0	1
2/24/2014	Mahopac STP	Mahopac	50.0	0	4
11/13/2014	Windham WTP	Windham	50.0	0	1

The first positive sample—a 50 L filtered sample containing 2 *Giardia* cysts—was taken on January 15 at the Hunter plant. The Hunter plant reported no abnormalities in its treatment processes, but the plant did push high flows through the system from January 14 through January 16 (bracketing the sample date) in an effort to reduce tank levels in preparation for the busy Martin Luther King, Jr. holiday weekend. As a note, the Hunter plant had a positive *Giardia* sample just after the Martin Luther King, Jr. holiday weekend in 2013.

The second sample with a positive *Giardia* result in 2014 (1 cyst $50L^{-1}$) was taken at the Hunter Highlands plant on February 12. This detection may have been indirectly caused by a freeze up in the outdoor splitter box, which redirected all plant flow to one of two aeration trains; that in turn caused abnormal short-cycling of the dual sand filters. There were no effluent violations of the plant's SPDES permit and no other operational abnormalities at the time of the pathogen sample collection. The operator has indicated that during the ski season when it receives heavy flows it will modify the prescribed schedule for air lancing the filters, from quarterly to monthly.

The Mahopac plant had the third *Giardia* detection at WWTPs for the year (4 cysts $50L^{-1}$), on February 24. No abnormalities in the treatment or filtration process were noted. A micro-filter unit was cleaned the day of sample collection; however, it was cleaned offline and was not contributing to the forward flow of the plant. Turbidities from the online portion of the plant, where the sample was collected, remained below 0.5 NTU (maximum of 0.153 NTU for the day), with a flow of 0.215 MGD.

The fourth positive sample was at the Windham plant (1 cyst $50L^{-1}$) on November 13. No malfunction of the filtration process or the chemical addition system was reported. Moreover, the daily turbidity report showed that 24 samples had been taken that day on an hourly basis, with no turbidity increases recorded. The maximum turbidity for the day was 0.11 NTU, well under the instantaneous limit of 5.0 NTU and within the 0.5 NTU limit 95% of the time. On the day of the incident, the plant operator was conducting a sludge press run, which sends an extra 90 gallons per minute (GPM) to the equalization tank, but there were no known mechanical or process abnormalities which might have led to the positive detection.

5.6 Hillview Monitoring

After an assessment of data collected from 2006 to 2008, and as part of the Hillview Administrative Order, a routine sampling program for *Giardia* and *Cryptosporidium* was developed for the Catskill outflow from Hillview Reservoir at Site 3. Weekly monitoring began at Hillview Site 3 in August 2011.

5.6.1 Annual Results - 2014

In 2014, at Hillview Site 3 54 samples were collected, with two samples positive for *Cryptosporidium* (3.7%) and 19 samples positive for *Giardia* (35.2%) (Table 5.9). In 2013, 52 samples were taken, also resulting in two *Cryptosporidium* detections. *Giardia* percent detection in 2013 (34.6%) was very similar to the percent detection in 2014.

Table 5.9: Hillview Site 3 monitoring results summary for 2014.

	Cryptosporidium	*Giardia*
n	54	54
Detects	2	19
% Detects	3.7	35.2
Mean ($50L^{-1}$)	0.04	0.67
Maximum ($50L^{-1}$)	1.00	8.00

5.6.2 CGAP Activation – March 2014

Hillview Reservoir has a “stepped” action level system for response to elevated protozoan results, referred to as the Hillview *Cryptosporidium* and *Giardia* Action Plan (CGAP). On March 17, 2014, a protozoan sample collected at Hillview Reservoir Site 3 had a concentration of 8 *Giardia* cysts $50L^{-1}$, which is above the 7-15 cysts $50L^{-1}$ limit for the first action level (AL-1) of the CGAP. Laboratory analysis was completed on March 19, and the elevated result and subsequent CGAP activation were reported to regulators the same day. Pursuant to the plan, DEP commenced a review of relevant data (e.g., historical protozoan and meteorological data, wildlife surveys, reservoir operations data, disease surveillance data), and followed that up with discussions with regulators about what further actions should be taken. Upon agreement with the regulators, the following steps were adopted to insure the safety of the water supply: DEP increased the chlorine dose for 2-log inactivation, additional daily protozoan samples were taken at Site 3 and DEL18DT with expedited analysis, additional wildlife surveys at DEL18 and Hillview were conducted, and the original slide with the elevated result was sent for genotyping.

A wildlife survey at Hillview on March 17 found two fecal deposits on the catwalk near Site 3, and an additional survey on March 21 found one deposit on the Hillview Reservoir dividing wall. (Both sets of deposits were believed to be raccoon feces.)

The follow-up sampling at DEL18DT and Hillview Site 3 took place on March 20 and March 21. The expedited results, obtained on March 21, indicated that *Giardia* concentrations had fallen below the lower limit for AL-1 (<7 cysts $50L^{-1}$) (Table 5.10). Since the CGAP allows DEP to de-escalate from AL-1 after two consecutive samples below the action limit, these results permitted DEP, after discussions with regulators, to de-escalate on the afternoon of March 21. In summary, no definitive source of the elevated level of *Giardia* was identified (no DNA was recovered from the original slide). A Special Investigation report detailing activities throughout the event was completed and distributed to all the parties involved.

Table 5.10: Protozoan sampling results at DEL18DT and Hillview Site 3 from March 17 to March 31, 2014. Sample from March 17 initiated CGAP AL-1.

	DEL18DT		Hillview Site 3	
	Giardia	*Cryptosporidium*	*Giardia*	*Cryptosporidium*
March 17	3	0	8	0
March 20	5	3	3	0
March 21	5	0	2	0
March 24	4	0	1	0
March 31	1	0	0	0

6. Modeling for Watershed Management

6.1 Introduction

Models are used by DEP to evaluate the impact of changes in land use, population density, wastewater treatment plant effluent, septic system performance, ecosystem and reservoir processes, and reservoir and water system operation on the quantity and quality of the water supply. The DEP model system consists of mechanistic models that simulate the movement of water and dissolved and suspended mass from watersheds, through reservoirs and in drinking water withdrawn from reservoirs.

To allow operation of the models for current or historical conditions, DEP maintains a large database of historical data including meteorological (e.g., precipitation, air temperature, wind speed), tributary streamflow, tributary constituent concentrations and mass loading, and constituent concentrations in reservoir water column, withdrawal and release. To allow prediction of future conditions which account for climate change as a part of the Climate Change Integrated Modeling Project (CCIMP), time series of predicted future meteorological conditions (forecasts) has been developed. In CCIMP forecasts completed through 2014, these predicted time series have been relatively simple additive or multiplicative adjustments of historical conditions (change factor approach). However, future work will investigate the development and use of synthetic meteorological time series predicted by weather generator techniques.

Conditions in the watersheds of the West of Hudson reservoirs are considered in terrestrial or watershed models. Given precipitation and other weather data, and a description of watershed characteristics, these models simulate the rate of runoff from rainfall and snowmelt, suspended sediment/turbidity, and nutrients (phosphorus, nitrogen, carbon, silica). DEP has applied the relatively simple Generalized Watershed Loading Function (GWLF) model, which utilizes spatially-averaged or “lumped” descriptions of watershed characteristics in computing watershed runoff and constituent loads. GWLF has served as a stepping stone to more detailed, physically-based models that utilize discretized or spatially-variable descriptions of watershed characteristics such as land slope, soil characteristics, and land use. The Soil Water Assessment Tool (SWAT) and the Regional Hydro-Ecologic Simulation System (RHESSys) models are both undergoing application and testing for West of Hudson watersheds.

Given the streamflow and mass loading predicted by these terrestrial/watershed models, reservoir hydrothermal and water quality models are used. These models consider physical and biochemical processes in the prediction of temperature, sediment/turbidity, nutrients, and measures of eutrophication in the water column and drinking water withdrawal. The models UFI-1D (one-dimensional, areally-averaged) and CE-QUAL-W2 (two-dimensional, laterally-averaged; Cole and Buchak 1995) have been used to compute hydrothermal and transport characteristics within the reservoirs as well as the spatial and temporal variations in sediment/turbidity and nutrients. CE-QUAL-W2, together with the water supply system model OASIS, are the primary modeling components of the Operations Support Tool (OST). This model uses near-real-time observations of streamflow and stream and reservoir water quality, together with meteorological and streamflow forecasts, to evaluate operational strategies that minimize the turbidity of drinking water while meeting water demand.

In past applications of these models, a “top down” approach has been used, where meteorological conditions (either historical or future predictions) are used to sequentially drive watershed and reservoir models. As a part of the CCIMP, DEP is exploring the use of a “bottom up” approach, where simulations are conducted for a synthetic time series of meteorological conditions. These predictions are used to identify the meteorological conditions that lead to problems in delivery of water of low turbidity in required quantities.

6.2 Overview of Model Development and Applications

An important component of DEP’s approach to managing turbidity in the NYC Water Supply System is the Operations Support Tool (OST). OST is a multiple-component model that links submodels for reservoir water quality, water and turbidity passing through aqueducts, the operation of aqueducts, and meteorological and hydrologic forecasts, to allow evaluation of alternative water supply system operations in order to meet water supply demands and minimize turbidity in water withdrawals. OST is a suite of interconnected CE-QUAL-W2 reservoir water quality models and the OASIS (Operational Analysis and Simulation of Integrated Systems) reservoir system model, linked with data acquisition, database and data visualization tools. Progress continued in 2014 on the development and application of the OST as an integral component of the Catskill Turbidity Control Program and as a supporting tool for reservoir operations.

In addition, the LinkRes model is used by DEP to evaluate and predict turbidity in the Catskill/Delaware reservoirs. LinkRes allows simulation of water movement and turbidity in individual or multiple reservoirs within this system using the same CE-QUAL-W2 model frameworks for individual reservoirs as in OST. However, LinkRes does not include OASIS, and is not directly linked to a weather forecasting tool. LinkRes allows simulation for a specified time series of meteorological and hydrologic reservoir inputs, and specified time series of reservoir operation (reservoir release and drinking water withdrawal).

In 2014, OST and LinkRes were used routinely to forecast water quantity conditions in the reservoir and aqueduct system. In progressing toward the goal of integration of OST water quality modeling functionality into reservoir and water system operations, in 2014 DEP focused on: (i) testing new capabilities as they were integrated into the OST modeling framework; (ii) continued testing the newly-developed W2 model for Rondout Reservoir in the LinkRes modeling framework and (iii) accelerating the full integration of existing W2 water quality models in the new OST modeling framework. While progress was made in these areas in 2014, the current functionality of OST support for water quality operations is not yet complete. As a part of the ongoing development, testing and application of OST and LinkRes in 2014, monthly conference calls were conducted between DEP staff and OST contractors (Hazen & Sawyer, Hydrologics, and Upstate Freshwater Institute). These meetings covered a number of topics, including:

• Release and testing of revisions of the model software

• Analysis of alternative methods of forecasting stream turbidity, including Auto Regressive Moving Average (ARMA)-based forecasts, and other potential improvements to stream turbidity forecasting

• Improvements to the OST Graphical User Interface (GUI) and Dashboard to facilitate more efficient model operation, and processing and visualization of water quality predictions

• Discussion and results of analysis of alternative approaches for use of OST in spill response modeling

• Discussion of the planned inclusion of two-dimensional reservoir model simulations for Rondout Reservoir within the OST framework

• Additions and enhancements to animation and visualization capabilities in the OST software for displaying model results, including addition and testing of an output animation tool using the Animation and Graphics Portfolio Management (AGPM) software

• Analysis of possible adjustment of W2 model predictions for Ashokan Reservoir to account for the occurrence of short circuiting in the vicinity of the dividing weir associated with the close proximity of the East Basin intake structure to inflows to the East Basin from the West Basin at the dividing weir. Such an adjustment has been implemented in OST.

• Analysis of alternative strategies for specifying initial conditions for positional analysis model runs

• Extending the meteorology input time series data through 2012 and creating the capability within the OST framework to derive input data in near-real-time, to support short-term operational simulations by using empirical relationships to local airport stations, including Binghamton (for the Delaware basin reservoirs), Albany (for Catskill basin reservoirs), and White Plains (for EOH basin reservoirs)

As a part of testing the water quality forecasting capabilities of OST, the water quality modeling group performed seven turbidity modeling analyses to support operating decisions for Schoharie, Ashokan, and/or Kensico Reservoirs in 2014. As an example, OST was used to simulate conditions in Ashokan Reservoir in mid- to late May, 2014. A moderate runoff event was predicted to occur the weekend of May 17-18. On the morning of May 14, monitoring buoys indicated turbidity ranging from 2.5–5.5 NTU at site 4.2 near the gatehouse in the East Basin; 4.7–17.3 NTU at site 1.4 in the West Basin; and 1.9–4.6 NTU at site 3.1 near the gatehouse in the West Basin. Schoharie Reservoir samples on May 13 indicated turbidity in the range 9.1–18 NTU. The OST was used to forecast the turbidity in Schoharie and Ashokan Reservoirs through mid-June. The OST was initialized using observed conditions on May 14, and was operated in “position analysis” mode, where predictions were made for a range of possible time series of weather and streamflow conditions for the May 14-June 16 interval; the prediction from one of these time series is known as a “trace”. Ashokan West Basin turbidity was simulated to exceed 10 NTU in only one of the 48 forecast traces simulated, while East Basin turbidity was not predicted to exceed 4 NTU in any of the forecast traces.

6.3 CUNY Modeling Support Contract

In August 2014, a four-year contract was signed between DEP and the Research Foundation of the City University of New York (CUNY). Under this contract, CUNY is supplying support for the DEP water quality modeling program in areas defined by the recent Filtration Avoidance Determination (FAD) (NYSDOH 2014). This support is in the form of providing model development and application expertise, modeling software, and data sets, and in three project areas:

1. Evaluation of the effects of climate change on watershed processes and reservoir water quality as a part of the CCIMP;

2. Evaluation of FAD programs and land use changes on watershed processes and stream and reservoir water quality;

3. Development of the modeling capability to simulate watershed loading of dissolved organic carbon (DOC), and reservoir and water supply concentrations of DOC and disinfection byproduct formation potential (DBPFP).

In order to complete the work in these areas, full-time post-doctoral support scientists, and accompanying part-time faculty advisors, will be supported for the duration of the contract. The support scientists will be based in DEP’s Kingston, NY office, and will complete the bulk of the work associated with the project areas described above. The faculty advisors will give support and guidance based on their extensive and diverse experience to ensure that the resulting models, underlying assumptions, and application approaches represent state-of-the art products that meet the practical water management goals of DEP, while at the same time exploring and developing new modeling approaches. An overview of the work to be completed in the three project areas above follows.

Climate Data Analysis and Modeling: a key task is to update and improve the future climate change scenarios that will be used to drive DEP watershed and reservoir models. Climate change projections from various sources, including Coupled Model Intercomparison Project Phase 5 (CMIP5), will be downloaded and downscaling methods will be applied and tested. Change factor methods, including those previously used by the DEP Water Quality Modeling Section, will be tested and evaluated. The use of weather generators as an alternative to the change factor methods will be investigated. The simulation of the frequency and magnitude of extreme events is a point of emphasis. The primary product of this work will be projected time series of future meteorology that reflect climate change. Using a traditional “top-down" approach, these future scenarios will be appropriate for use with DEP terrestrial and reservoir models to evaluate the impact of future climate conditions on watershed hydrology and biogeochemistry, forest processes, reservoir nutrient loading and trophic status, reservoir turbidity, and water supply operation. In addition, use of a "bottom-up" will be studied with the goal of identifying the critical climate conditions that lead to water quality and supply problems.

Watershed Modeling (Streamflow and Nutrient Loads): an important component of this task is the evaluation of the impact of watershed management programs and land use changes on the loading of phosphorus, nitrogen and organic carbon to downstream reservoirs. In particular, the SWAT model will be applied to the Cannonsville and Pepacton watersheds with the goal of developing improved projections of nutrient loads, with particular emphasis on the effects of watershed management including agricultural programs. The predictions of organic carbon loading will be used to support DOC and DBPFP simulations in downstream reservoirs under project area 3 above. In addition, the databases on land use and agricultural practices that support model simulations for these two watersheds will be updated and improved.

Watershed Modeling (Forest Hydrology and Biogeochemistry): the primary focus of this work is the hydrology and biogeochemistry of forested portions of the watersheds. The RHESSys model (Tague and Band 2004) will be applied in order to simulate these processes. This model will be used in all three project areas: to evaluate the effect of climate change (project area 1 above), the effects of watershed and agricultural management programs (project area 2), and in developing projections of DOC export from watersheds to support project area 3 above.

Reservoir Modeling: the key task in this area is the development and testing of DOC and DBPFP modeling capabilities in project area 3 above. An important component of this work is identification of external (allochthonous) and internal (autochthonous) inputs of DOC and DBPFP to reservoirs, and the relative importance of these sources to conditions in the reservoir water column and drinking water withdrawal. In addition, this effort will contribute to DEP's continued work on the CCIMP.

6.4 Climate Change Integrated Modeling Project

The Climate Change Integrated Modeling Project (CCIMP) is an ongoing effort led by the Water Quality Modeling Section at DEP. This project has the goal to evaluate the effects of future climate change on the quantity and quality of water in the NYC water supply. The CCIMP is designed to address three issues of concern to NYC: (1) overall quantity of water in the entire water supply; (2) turbidity in the Catskill System of reservoirs, including Kensico; and (3) eutrophication in Delaware System reservoirs. The first phase of the CCIMP was completed in 2013, and the second phase was begun in 2014.

Ten of the nation's largest water providers, including DEP, make up the Water Utility Climate Alliance (WUCA). WUCA was formed in 2007 in order to increase understanding of the effects of climate change on the ability of water utilities to deliver high quality drinking water in desired quantities, including effects on infrastructure and operations. Under the umbrella of WUCA, DEP is one of four of the ten WUCA utilities participating in the Piloting Utility Modeling Applications (PUMA) project. The goal of PUMA is to identify state-of-the-art modeling tools and techniques that can be used by water utilities to assess potential climate change impacts on their watersheds and water supply systems. DEP's participation in PUMA is a component of DEP's Climate Change Integrated Modeling Project (CCIMP) that has been under way at DEP since 2008.

As outlined in the PUMA Final Report (WUCA 2015), DEP has followed a "chain of models" approach to evaluating the effects of climate change. In this approach, a suite of models are applied in a sequential manner in evaluating the impacts of climate change. This model suite includes general circulation, or global climate, models to predict future meteorological conditions, downscaling techniques to determine the meteorological conditions at the spatial scale of an individual watershed, hydrologic models to simulate watershed response, and reservoir and operations models that consider water demand and reservoir operations in predicting drinking water quality. Some particular issues that were addressed as a part of DEP's collaboration with the PUMA partners are methods to evaluate alternative general circulation/global climate models using local historical data, development of future climate scenarios using the change factor method, and addressing water quality issues such as turbidity caused by extreme events.

As an example of the application of sequential model application, DEP staff made projections of turbidity in Ashokan Reservoir for the 2080 to 2100 time interval, using five different future climate scenarios (Figure 6.1). This analysis shows an increase in average turbidity in winter and early spring, with relatively little impact during the remainder of the year.

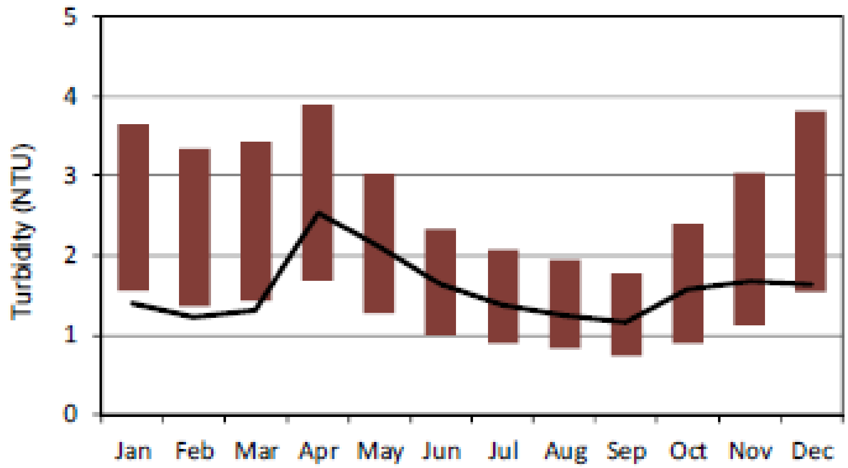


Figure 6.1 Mean monthly observed turbidity for Ashokan Reservoir from historical operations (black line) and the range of predicted mean monthly turbidity for 2080 to 2100 from five climate change scenarios (maroon bars).

Recent extreme events, including Hurricane Sandy in 2012 and Tropical Storms Irene and Lee in 2011, have led to a generally increased interest in climate change issues within DEP, and to increased support for climate change research undertaken by the water quality modeling group. As described above, modeling climate change impacts on the water supply is a major component of the CUNY modeling support contract. DEP has begun, on a proactive basis, to include the results of climate research in reports supporting USEPA's Filtration Avoidance Determination. Participation in the PUMA group has helped prepare the water quality modeling group to offer assistance in the form of quantitative evaluations to other individuals and groups within DEP.

7. Further Research

The analytical, monitoring, and research activities of DEP are supported through a variety of contracts, participation in research projects conducted by the Water Research Foundation, and interactions with national groups such as the Water Utility Climate Alliance. Participation with external groups is an efficient way for DEP to bring specialized expertise into the work of the Water Quality Directorate (WQD) and to remain aware of the most recent developments in the water supply industry. The ongoing contracts and projects in which the WQD is involved are described in the three sections below.

7.1 Contracts Managed by the Water Quality Directorate in 2014

In 2014, the WQD managed seven water quality-related contracts to enhance its ability to monitor and model the watershed. The contracts supported surveillance, model development, and management goals. A brief description of each contract is provided below.

7.1.1 *Cryptosporidium* Infectivity Analysis for Hillview

The current method for determining the presence of *Cryptosporidium* in water (US EPA Method 1623/1623.1) does not identify viability, infectivity or the genotype of the oocysts observed within samples. The oocysts are conservatively counted and recorded. This, however, may lead to an overestimation of risk to public health since oocysts counted may be dead, non-infectious, or of a genotype not associated with human illness.

In the interest of exploring the possibility of determining the infectivity of oocysts from water samples, a spiking study was designed to determine if cell-culture immunofluorescent assay (CC-IFA) would be an effective tool in New York City's water matrix. Samples collected from the outlet of Hillview Reservoir were spiked with 100 viable flow sorted *C. parvum* oocysts, in addition to low doses of 5, 3 and 1 oocyst $100L^{-1}$ sample. Samples were pre-processed at the DEP laboratory and then cell culture analysis was performed at the University of Texas Public Health Laboratory.

Results indicated an agreement in results between Method 1623 and the CC-IFA Method (Table 7.1). In Round 1 (spring) the mean recovery of infectious oocysts using Method 1623 in matrix spiked samples was 55.3% compared to 52.3 % recovery for the CC-IFA method. Similarly, Round 2 samples (autumn) resulted in 36.3% and 39.3% recovery of infectious oocysts, respectively, for Method 1623 and CC-IFA. While there is a difference in the recoveries between the spring and fall samples, there is no significant difference between the overall means for the two methods.

Table 7.1 *C. parvum* infectious oocyst recovery data for samples collected at Hillview Reservoir, spiked with 100 oocysts and analyzed using Method 1623 and CC-IFA.

	Event 1 (n=1)	Event 2 (n=1)	Event 3 (n=1)	3 Event Mean (1623)	CC-IFA (n=9)
Round 1 (spring)	60%	56%	50%	55.3%	52.3%
Round 2 (autumn)	39%	43%	28%	36.7%	39.3%

Similarly, spiking of water samples with low doses of viable oocysts indicated a comparable ability to recover infectious *Cryptosporidium* oocysts from the Hillview matrix when compared to control samples (Table 7.2). Both the infection control and trip control samples recovered 93% of infectious oocysts when 5 or less were present, and the matrix recovery was an overall 83%. Data thus far in this study suggest no adverse effect on oocyst recovery or detection of infection by the Hillview matrix, and that CC-IFA is suitable for refining *Cryptosporidium* risk assessment.

Table 7.2 Recovery of infectious *C. parvum* oocysts in spike doses of 5, 3 and 1 oocyst in control and Hillview matrix samples.

Spike Dose	Infection Control	Trip Control	MS Hillview
5 oocysts	9/10	9/10	9/10
3 oocysts	10/10	10/10	9/10
1 oocyst	9/10	9/10	7/10
Overall positivity (n= 30)	93%	93%	83%

7.1.2 Laboratory Analytical Support

Eurofins Eaton Analytical Inc., under contract, conducts various analyses for which DEP's laboratories are not certified. The contract is managed by DEP's Distribution Water Quality Operations Laboratory.

In 2014, contracted analyses included: volatile organic carbon (VOC) and semivolatile organic carbon (SVOC) analyses on selected aqueduct samples; total Kjeldahl nitrogen analyses on wastewater samples; and additional organics analyses (e.g., Diesel Range Organics (DRO)) on special investigation (SI) samples.

Other laboratories used for contracted analyses in 2014 included:

• York Analytical Laboratories. Pepacton Reservoir spill event samples collected at the keypoint or elevation tap were sent to the laboratory for DRO analysis on a monthly basis from June through December. The collections for DRO were reestablished following visible observations of the product surfacing in the reservoir. An oil plume on Schoharie Reservoir was also investigated, and samples were sent to the laboratory in August for VOC and SVOC analysis.

• Source Molecular Laboratories. Eight samples from a storm event occurring at Kensico Reservoir in April 2014 were sent to this laboratory for microbial source tracking analysis. The results are discussed further in Chapter 5. Also, storm event samples related to the Ashokan Community Septic special investigation program were sent out for the same analysis in October 2014.

• Watershed Assessment Associates. Samples of benthic macroinvertebrates collected in Croton, Catskill, and Delaware System streams were sent to the laboratory for identification to levels that meet the taxonomic targets set forth in the New York State Stream Biomonitoring Unit's Standard Operating Procedure. The results were used to calculate metrics and Biological Assessment Profile scores for each stream, as reported in Section 3.10.

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

DEP contracted with the United States Geological Survey (USGS) for a project titled, "Water Quality Operation and Maintenance for the Hydrological Monitoring Network." Under this agreement, the USGS measures stage and discharge at 57 stream gauges throughout the Croton, Catskill, and Delaware watersheds along with turbidity at two gauges and water temperature at four gauges. The operation and maintenance of the gauges involves: (1) retrieving the stage, water temperature, and/or turbidity data; measuring stream flow; and/or collecting sediment samples at specified gauges, (2) ensuring the integrity of the data, (3) maintaining the automatic monitoring equipment used to collect the data, (4) preparing selected data for real-time distribution over the Internet, (5) analyzing stage, water temperature, turbidity, and stream flow data, and (6) preparing an annual summary report. The data support DEP's development of multi-tiered water quality models, which is a requirement of the Revised 2007 Filtration Avoidance Determination (FAD) (NYSDOH 2014). The data also support the following FAD-mandated programs: Land Acquisition, the Watershed Agricultural Program, the Watershed Forestry Program, the Stream Management Program, the Wetlands Protection Program, and Catskill Turbidity Control.

7.1.4 CUNY Postdoctoral Support

This contract between DEP and the City University of New York–Research Foundation (CUNY-RF) provides modeling support for the WQD and allows DEP to pursue research that will lead to model improvement. In August of 2014 a new four-year contract was registered. It provides for four post-doctoral research associates who are jointly advised by CUNY faculty, external faculty advisors, and DEP scientists. The post-doctoral associates are stationed in Kingston, New York and work with the Water Quality Modeling Section staff on a day-to-day basis. The positions are for an initial two-year period, with the possibility of an additional two-year extension.

The areas of research that the associates pursue are:

• Climate data analysis

• Watershed nutrient modeling

• Forest ecosystem modeling

• Reservoir eutrophication modeling

Three of four post-doctoral scientists were hired in 2014. An additional research associate to cover the forest ecosystem modeling will be hired in 2015. This contract has been very successful leading to the development and testing of improved modeling tools, new and improved data sets including future climate scenarios used by the CCIMP, and modeling-based evaluations of climate change impacts. To date, 25 peer-reviewed publications (2014 publications are listed below) have resulted from the CUNY-RF contracts. The sections of this report describing modeling-based evaluation, model development, and data analysis have benefited greatly from the work of the post-doctoral scientists.

Huang, Y. 2014a. Comparison of general circulation model outputs and ensemble assessment of climate change using a Bayesian approach. Global Planet. Change. 122:362-370. doi: 10.1016/j.gloplacha.2014.10.003.

Huang, Y. 2014b. Multi-objective calibration of a reservoir water quality model in aggregation and non-dominated sorting approaches. J. Hydrol. 510:280-292. doi:10.1016/j.jhydrol.2013.12.036.

Mukundan, R. and R. Van Dreason. 2014. Predicting trihalomethanes in the New York City water supply. J. Environ. Qual. 43:611-616. doi: 10.2134/jeq2013.07.0305.

Pradhanang, S. M., R. Mukundan, M. S. Zion, E. M. Schneiderman, D. Pierson, and T. S. Steenhuis. 2014. Quantifying In-Stream Processes on Phosphorus Export Using an Empirical Approach. J. Water Resour. Protect. 6:120-131. dx.doi.org/10.4236/jwarp.2014.62017.

Tang, G., T. Hwang, and S. Pradhanang. 2014. Does consideration of water routing affect simulated water and carbon dynamics in terrestrial ecosystems? Hydrol. Earth Syst. Sci. 18:1423-1437. doi:10.5194/hess-18-1423-2014.

7.1.5 Waterfowl Management

The Waterfowl Management Program (WMP) was developed in response to seasonal elevations of fecal coliform bacteria first identified at Kensico Reservoir from the late 1980s to the early 1990s. In 1993, DEP identified a direct relationship between the waterfowl populations present and the concentrations of fecal coliforms in reservoirs, and this highly effective management program was developed based on this scientific finding. A contract was first let in 1995 to a private environmental consulting firm and has been re-bid every three to four years since to help meet the requirements of the federal Surface Water Treatment Rule for fecal coliform bacteria (USEPA 1989). The current WMP contract (WMP-12 Renewal), with Henningson Durham & Richardson, requires staffing of up to 21 contractor personnel annually to cover waterfowl management activities at several upstate reservoirs. It is intended to run through July 31, 2015.

7.1.6 Zebra Mussel Monitoring

DEP has been monitoring all 19 New York City reservoirs for the presence of zebra mussel larvae (veligers) and the settlement of mature zebra mussels since the early 1990s, via contract with a series of laboratories that have professional experience in identifying zebra mussels. All East of Hudson reservoirs are monitored on a monthly basis between May and October, while West of Hudson reservoirs are monitored in July and October of each year. The contract laboratory analyzes the samples and provides a monthly report to the project manager indicating whether or not zebra mussels have been detected. To date, no infestations have been found.

7.1.7 Bathymetric Surveys of the Six West of Hudson Reservoirs

Under an inter-governmental agreement with the United States Geological Survey (USGS), bathymetric surveying work was completed during the summer of 2014 for three of the six West of Hudson reservoirs: Ashokan, Neversink, and Rondout. Survey work on Schoharie Reservoir was delayed until fall while final construction of the Gilboa Dam was being completed. Draft data were delivered for the Ashokan West Basin in late fall 2014 in the form of a bathymetric Digital Elevation Model (DEM) and resulting 2-foot depth contours. These data were reviewed and comments sent back to USGS in early winter for data revision. The remaining field survey work for Cannonsville and Pepacton Reservoirs will be ongoing through summer 2015, with subsequent data processing occurring into spring 2016. Final data deliverables for each reservoir will eventually include raw and corrected survey points, a derived topographic surface of the reservoir bottom from those points, 2-foot contours of reservoir depth derived from the topographic surface, and a stage-area-volume table in 0.01-foot increments. The spatial data and information delivered under this contract will help DEP, as manager of the reservoirs, to more accurately regulate storage in the reservoirs and to improve water-quality models used in reservoir management.

7.2 Water Research Foundation Project Participation by WQD in 2014

In 2014, two upper management personnel participated on Advisory Councils for the Water Research Foundation (WRF). Mr. Paul Rush, P.E., is currently serving on the Focus Area Council (for a term running from 2012 to 2015) and Mr. Steven Schindler is serving on the Technical Advisory Council for Contaminants of Emerging Concern (CECs) and Risk Communication: Developing Core Messages and Engaging Critical Stakeholders (for a term running from 2012 to 2017). As Council members, they serve an important role in identifying key needs of the water industry and guiding decisions of what areas of research to fund.

WRF activity by WQD staff in 2014 included involvement by Anne Seeley as a member of two Project Advisory Committees. The first project is #4350 "Water Industry Contribution to Epidemiological and Health Effects Studies Involving Distribution System Water Quality". The second project is #4589 " Evaluation of Scientific Literature on Increased Turbidity Associated with the Risk of GI Illness." Both projects are designed to contribute to enhanced national assessment of potential health risks associated with water systems, and both are multi-year projects. More information on these projects can be found on the WRF website at www.waterrf.org.

7.3 Water Utility Climate Alliance: Piloting Utility Modeling Applications

In 2014, the Modeling Section of WQD participated in monthly conference calls with the Water Utility Climate Alliance (WUCA), a consortium of water utilities nationwide. These information exchanges between utilities keep DEP current with climate change information.

DEP contributed to the Piloting Utility Modeling Applications (PUMA) effort by contributing a case study for a white paper entitled: Actionable Science in Practice: Co-Producing Climate Change Information for Water Utility Vulnerability Assessments.

The PUMA project featured four water utilities (New York, Tampa Bay, Seattle, and Portland) that worked in collaboration with local climate science consortiums to hand-pick or develop locally appropriate tools, projections, and approaches to understand the impact of climate change on drinking water supplies. These utilities pursued customized approaches based on specific utility needs and learned important lessons in conducting assessments that may be of interest to the wider adaptation community. In addition, these projects attempted to create a "climate services" environment in which utility managers worked collaboratively and iteratively with climate scientists to understand both utility concerns and the ability or limitations of today's climate science to respond to those concerns. These broader lessons that cut across the pilots are presented in a closing chapter entitled "Conclusions for an Applied Research Agenda for Climate Services." A Final Report of the PUMA Project will be completed in 2015 (WUCA 2015).

7.4 Global Lake Ecological Observation Network (GLEON)

Water Quality Science and Research participated in the GLEON16 meeting in Montreal in 2014 in an effort to begin learning the readily available software tools to analyze the high-frequency data generated by the ROBOMON network. This network has proved invaluable to DEP and the program is in a growth phase. It is therefore necessary to find efficient ways to display and use the data generated by the systems DEP has invested in.

The five-day meeting in 2014 was a forum for bringing together current research and technological developments for sharing and interpreting high-resolution sensor data to understand and predict responses of lakes and reservoirs in a changing environment. Several internationally renowned GLEON scientists presented ideas and tools to analyze landscape data and high-frequency lake sensor data, a series of intensive hands-on workshops to introduce complex software, and led discussions on opportunities for collaboration to advance DEP's understanding of lake and reservoir systems. Attendance at GLEON16 established DEP's representation in GLEON and opened the door for formalizing DEP's participation in the future.

References

Alderisio, K.A. and N. DeLuca. 1999. Seasonal enumeration of fecal coliform bacteria from thefeces of Ring-billed gulls (*Larus delawarensis*) and Canada geese (*Branta canadensis*). Appl. Environ. Microb. 65:5628-5630.

Carlson, R. E. 1977. A trophic state index for lakes. Limnol. Oceanogr. 22:361-369.

Carlson, R. E. 1979. A review of the philosophy and construction of trophic state indices. *In*: T.Maloney (ed.). Lake and reservoir classification systems. US Environmental ProtectionAgency Report No. EPA-600/3-79-074, p.1-52.

Cole T. M. and E. M. Buchak. 1995. CE-QUAL-W2: A two-dimensional, laterally averaged, hydrodynamic and water quality model, Version 2.0. U.S. Army Corps of Engineers, Vicksburg, MS.

DEP. 1992. Kensico Watershed Study 1991-92. Drinking Water Quality Control and Sources Divisions. Valhalla, NY. 213 p.

DEP. 1997. A Methodology for Determining Phosphorus-Restricted Basins. Valhalla, NY.

DEP. 2002. Continued Implementation of Final Waterfowl Management Plan. Division of Drinking Water Quality Control. Valhalla, NY.

DEP. 2003. Waterfowl Management Program. July 31, 2003. Bureau of Water Supply. Valhalla,NY. 38 p.

DEP. 2004. Waterfowl Management Program. July 31, 2004. Bureau of Water Supply. Valhalla,NY. 24 p.

DEP. 2005. Waterfowl Management Program. July 31, 2005. Bureau of Water Supply. Valhalla,NY. 29 p.

DEP. 2006. 2006 Long-Term Watershed Protection Program. Bureau of Water Supply. Valhalla,NY. 66 p.

DEP. 2007. Waterfowl Management Program. July 31, 2007. Bureau of Water Supply. Valhalla,NY. 59 p.

DEP. 2008. Waterfowl Management Program. July 31, 2008. Bureau of Water Supply. Valhalla,NY.

DEP. 2009a. 2009 Watershed Water Quality Monitoring Plan. Valhalla, NY. 240 p.

DEP. 2009b. Waterfowl Management Program. July 31, 2009. Bureau of Water Supply. Valhalla, NY.

DEP. 2010a. New York City Watershed Rules and Regulations. 1997, amended April 4, 2010. Rules and Regulations for the Protection from Contamination, Degradation and Pollution of the New York City Water Supply and its Sources. RCNY Title 15, chapter 18. http://www.nyc.gov/html/dep/pdf/recrules/regulations.pdf (accessed 7/7/15).

DEP. 2010b. Waterfowl Management Program. July 31, 2010. Bureau of Water Supply. Valhalla, NY., 59 p.

DEP. 2013a. 2011 Watershed Water Quality Annual Report, revised January 2013. Valhalla, NY. 144 p.

DEP. 2013b. 2012 Watershed Water Quality Annual Report. Valhalla, NY. 156 p.

DEP. 2014. 2013 Watershed Water Quality Annual Report. Valhalla, NY. 186 p.

Helsel, D. R. 2005. Nondetects and Data Analysis: Statistics for Censored Environmental Data. John Wiley & Sons, Inc. Hoboken, NJ.

International Organization for Standardization. 1985. Water quality—determination of electrical conductivity. Geneva, 1985 (ISO 7888:1985).

NYSDEC [New York State Department of Environmental Conservation]. 2014. Standard Operating Procedure: Biological Monitoring of Surface Waters in New York State. Albany, NY. 171 p.

NYSDOH [New York State Department of Health]. 2014. New York City Filtration Avoidance Determination. Final Revised 2007 FAD. 99 p. http://www.health.ny.gov/environmental/water/drinking/nycfad/docs/final_revised_2007_fad_may_2014.pdf (accessed 7/21/15).

Rosenfeld, M. 2015. Report on the condition of benthic macroinvertebrate communities in Whippoorwill Creek following construction of the CRO-498 streambank stabilization project. New York City Department of Environmental Protection. Bureau of Water Supply. Valhalla, NY. 7 p.

Singh, T. and Y. P. Kalra. 1975. Specific conductance method for in situ estimation of total dissolved solids. J. Am. Water Works Assn. 67:99-100.

Tague, C. L. and L. E. Band. 2004. RHESSys: Regional hydro-ecologic simulation system—An object-oriented approach to spatially distributed modeling of carbon, water and nutrient cycling. Earth Interact. 8:1-42.

USEPA [United States Environmental Protection Agency]. 1989. Drinking Water: National Primary Drinking Water Regulations; Filtration, Disinfection; Turbidity, Giardia lamblia, Viruses, Legionella, and Heterotrophic Bacteria; Final Rule. 54 Fed. Reg. 27486. June 29, 1989. WH-FRL-3607-7. Washington, D.C.

USEPA [United States Environmental Protection Agency]. 1996. ICR Microbial Laboratory Manual. EPA/600/R-95/178. Office of Research and Development, U. S. Environmental Protection Agency. Washington, D.C. 233 p.

USEPA [United States Environmental Protection Agency]. 2005. US EPA Method 1623: *Cryptosporidium* and *Giardia* in Water by Filtration/IMS/FA. EPA/815-R-05-002. Office of Water, U. S. Environmental Protection Agency. Washington, D.C. 76 p.

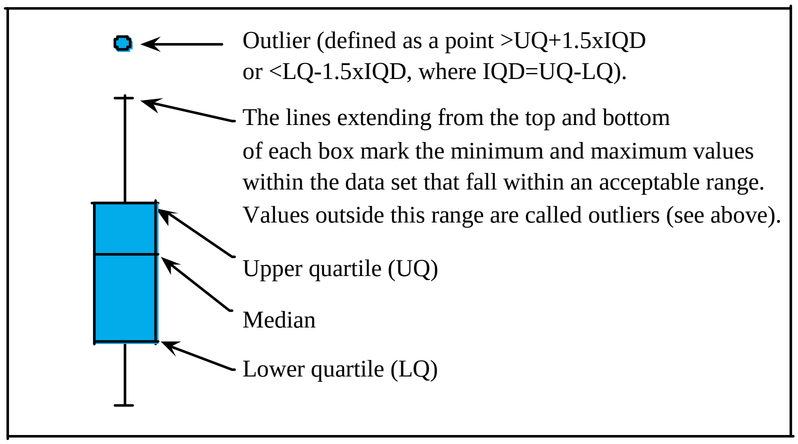
USEPA [United States Environmental Protection Agency]. 2006. Long Term 2 Enhanced Surface Water Treatment Rule. EPA-HQ-2002-0039. Washington, D.C. http://www.federalregister.gov/a/06-4 (accessed 7/21/15).

van der Leeden, F., F. L. Troise, and D. K. Todd. 1990. The Water Encyclopedia. 3rd ed. Lewis Publishers, Chelsea, MI.

WUCA [Water Utility Climate Alliance]. 2015. Actionable Science in Practice: Co-producing Climate Change Information for Water Utility Vulnerability Assessments. Final Report of the Piloting Utility Modeling Applications (PUMA) Project. Prepared by Stratus Consulting, Boulder CO.

Appendix A

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



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

Appendix B

Monthly Coliform-Restricted Calculations for Total Coliform Counts on Non-Terminal Reservoirs

Appendix Table 1: Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs in 2014. 6NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class[1] & Standard (median, value not > 20% of samples)	Collection date	n	Median total coliform[2] (coliform 100mL $^{-1}$)	Percentage > standard
Amawalk	A (2400, 5000)	Apr-14	5	15	0
Amawalk		May-14	5	12	0
Amawalk		Jun-14	5	41	0
Amawalk		Jul-14	5	<10	0
Amawalk		Aug-14	5	200	0
Amawalk		Sep-14	0	40	0
Amawalk		Oct-14	5	<50	0
Amawalk		Nov-14	5	<20	0
Bog Brook	AA (50, 240)	Apr-14	6	8	0
Bog Brook		May-14	6	4	0
Bog Brook		Jun-14	5	16	0
Bog Brook		Jul-14	5	17	0
Bog Brook		Aug-14	5	20	0
Bog Brook		Sep-14	5	<20	0
Bog Brook		Oct-14	7	27	0
Bog Brook		Nov-14	6	8	0
Boyd Corners	AA (50, 240)	Apr-14	7	6	0
Boyd Corners		May-14	7	1	0
Boyd Corners		Jun-14	6	50	0
Boyd Corners		Jul-14	7	82	0
Boyd Corners		Aug-14	6	110	0
Boyd Corners		Sep-14	6	55	0
Boyd Corners		Oct-14	6	64	0
Croton Falls	A/AA (50, 240)	Apr-14	8	4	0
Croton Falls		May-14	8	16	0
Croton Falls		Jun-14	8	12	0
Croton Falls		Jul-14	6	8	0
Croton Falls		Aug-14	8	17	17
Croton Falls		Sep-14	8	25	0
Croton Falls		Oct-14	8	42	0
Croton Falls		Nov-14	8	58	0
Cross River	A/AA (50, 240)	Apr-14	6	12	0
Cross River		May-14	6	24	0
Cross River		Jun-14	6	4	0
Cross River		Jul-14	6	<50	0
Cross River		Aug-14	6	14	0

Appendix Table 1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs in 2014. 6NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class[1] & Standard (median, value not > 20% of samples)	Collection date	n	Median total coliform[2] (coliform 100mL $^{-1}$)	Percentage > standard
Cross River		Sep-14	6	5	0
Cross River		Oct-14	6	4	0
Cross River		Nov-14	6	20	0
Diverting	AA (50, 240)	Apr-14	5	12	0
Diverting		May-14	5	130	40
Diverting		Jun-14	5	120	20
Diverting		Jul-14	5	<200	40
Diverting		Aug-14	5	170	20
Diverting		Sep-14	5	80	0
Diverting		Oct-14	5	18	0
Diverting		Nov-14	5	120	40
East Branch	AA (50, 240)	Apr-14	6	34	0
East Branch		May-14	6	33	0
East Branch		Jun-14	5	33	0
East Branch		Jul-14	5	50	0
East Branch		Aug-14	6	33	0
East Branch		Sep-14	6	67	0
East Branch		Oct-14	5	33	0
East Branch		Nov-14	6	20	0
Lake Gilead	A (2400, 5000)	Apr-14	5	<1	0
Lake Gilead		May-14	5	4	0
Lake Gilead		Jun-14	5	<5	0
Lake Gilead		Jul-14	5	10	0
Lake Gilead		Aug-14	5	<100	0
Lake Gilead		Sep-14	5	<100	0
Lake Gilead		Oct-14	5	<20	0
Lake Gilead		Nov-14	5	<10	0
Lake Gleneida	AA (50, 240)	Apr-14	5	1	0
Lake Gleneida		May-14	5	4	0
Lake Gleneida		Jun-14	5	<5	0
Lake Gleneida		Jul-14	5	<5	0
Lake Gleneida		Aug-14	5	<100	0
Lake Gleneida		Sep-14	5	<100	0
Lake Gleneida		Oct-14	5	<20	0
Lake Gleneida		Nov-14	5	<10	0
Kirk Lake	B (2400, 5000)	Apr-14	5	16	0
Kirk Lake		May-14	5	TNTC[2]	0
Kirk Lake		Jun-14	5	<50	0
Kirk Lake		Jul-14	5	200	0
Kirk Lake		Aug-14	5	83	0
Kirk Lake		Sep-14	5	<500	0

Appendix Table 1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs in 2014. 6NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class[1] & Standard (median, value not > 20% of samples)	Collection date	n	Median total coliform[2] (coliform 100 mL $^{-1}$)	Percentage > standard
Kirk Lake		Oct-14	5	<100	0
Muscoot	A (2400, 5000)	Apr-14	6	42	0
Muscoot		May-14	7	120	0
Muscoot		Jun-14	6	1165	0
Muscoot		Jul-14	7	170	0
Muscoot		Aug-14	7	<200	0
Muscoot		Sep-14	7	67	0
Muscoot		Oct-14	7	420	0
Muscoot		Nov-14	7	40	0
Middle Branch	A (2400, 5000)	Apr-14	5	TNTC[2]	0
Middle Branch		May-14	5	27	0
Middle Branch		Jun-14	5	9	0
Middle Branch		Jul-14	5	TNTC[2]	0
Middle Branch		Aug-14	5	<100	0
Middle Branch		Sep-14	5	<50	0
Middle Branch		Oct-14	5	33	0
Middle Branch		Nov-14	5	50	0
Titicus	AA (50, 240)	Apr-14	5	<10	0
Titicus		May-14	5	160	20
Titicus		Jun-14	5	9	0
Titicus		Jul-14	5	18	0
Titicus		Aug-14	5	100	20
Titicus		Sep-14	5	83	0
Titicus		Oct-14	5	<100	0
Titicus		Nov-14	5	14	0
Pepacton	A/AA (50, 240)	Apr-14	17	4	0
Pepacton		May-14	17	3	0
Pepacton		Jun-14	16	1	0
Pepacton		Jul-14	14	4	0
Pepacton		Aug-14	16	<10	0
Pepacton		Sep-14	15	<10	0
Pepacton		Oct-14	14	10	0
Pepacton		Nov-14	14	8	0
Neversink	AA (50, 240)	Apr-14	13	1	0
Neversink		May-14	13	6	0
Neversink		Jun-14	13	20	0
Neversink		Jul-14	13	24	0
Neversink		Aug-14	12	<5	0
Neversink		Sep-14	12	<5	0
Neversink		Oct-14	11	2	0
Neversink		Nov-14	10	10	0

Appendix Table 1: (Continued) Monthly coliform-restricted calculations for total coliform counts on non-terminal reservoirs in 2014. 6NYCRR Part 703 requires a minimum of five samples per month. Both the median value and >20 % of the total coliform counts for a given month need to exceed the stated value for a reservoir to exceed the standard.

Reservoir	Class[1] & Standard (median, value not > 20% of samples)	Collection date	n	Median total coliform[2] (coliform 100 mL^{-1})	Percentage > standard
Schoharie	AA (50, 240)	Apr-14	11	40	0
Schoharie		May-14	11	44	0
Schoharie		Jun-14	12	TNTC[2]	10
Schoharie		Jul-14	11	<1000	100
Schoharie		Aug-14	11	<1000	100
Schoharie		Sep-14	11	100	0
Schoharie		Oct-14	8	100	0
Schoharie		Nov-14	11	4	0
Cannonsville	A/AA (50, 240)	Apr -14	15	14	0
Cannonsville		May-14	15	4	0
Cannonsville		Jun-14	15	20	0
Cannonsville		Jul-14	14	30	0
Cannonsville		Aug-14	15	<50	0
Cannonsville		Sep-14	14	<20	0
Cannonsville		Oct-14	12	<10	0
Cannonsville		Nov-14	12	5	0

[1]The reservoir class is defined by 6 NYCRR Chapter X, Subchapter B. For those reservoirs that have dual designations, the more stringent standard was applied.
[2]The median could not be estimated for samples determined to be "Too Numerous To Count" (TNTC).

Appendix C
Phosphorus-Restricted Basin Assessment Methodology

A phosphorus-restricted basin is defined in the New York City Watershed Regulations, amended April 4, 2010, as "(i) the drainage basin of a source water reservoir in which the phosphorus load to the reservoir results in the phosphorus concentration in the reservoir exceeding 15 micrograms per liter, or (ii) the drainage basin of a reservoir other than a source water reservoir or of a controlled lake in which the phosphorus load to the reservoir or controlled lake results in the phosphorus concentration in the reservoir or controlled lake exceeding 20 micrograms per liter in both instances as determined by the Department pursuant to its annual review conducted under §18-48 (e) of Subchapter D" (DEP 2010a). The phosphorus-restricted designation prohibits new or expanded wastewater treatment plants with surface discharges in the reservoir basin. The list of phosphorus-restricted basins is updated annually in the Watershed Water Quality Annual Report.

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

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

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

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

Reservoir Basin	2009 µg L^{-1}	2010 µg L^{-1}	2011 µg L^{-1}	2012 µg L^{-1}	2013 µg L^{-1}	2014 µg L^{-1}
Non-Source Waters (Delaware System)						
Cannonsville Reservoir	14.0	16.4	16.3	12.4	15.0	13.1
Pepacton Reservoir	7.6	9.9	11.9	8.4	7.9	7.8
Neversink Reservoir	5.9	6.5	10.2	9.7	6.0	6.2
Non-Source Waters (Catskill System)						
Schoharie Reservoir	11.2	13.4	29.4	20.0	15.0	15.3
Non-Source Waters (Croton System)						
Amawalk Reservoir	19.4	20.5	18.3	22.3	22.3	19.4
Bog Brook Reservoir	22.8	31.1	23.6	27.9	20.0	14.4
Boyd Corners Reservoir	8.6	8.4	8.7	10.1	10.7	9.0
Diverting Reservoir	*	29.1	31.1	26.8	29.5	29.1
East Branch Reservoir	26.1	33.8	32.3	28.5	27.5	24.2
Middle Branch Reservoir	22.4	25.5	29.8	37.6	32.5	35.3
Muscoot Reservoir	24.9	28.7	28.8	31.5	29.9	28.7
Titicus Reservoir	20.8	26.4	26.9	24.4	24.4	24.8
Lake Gleneida	22.7	25.9	31.9	25.1	22.2	19.8
Lake Gilead	36.0	30.1	28.9	16.4	26.7	32.8
Kirk Lake	31.4	27.6	33.1	34.6	24.9	32.8
Source Waters (all systems)						
Ashokan-West Reservoir	8.6	12.9	31.0	10.2	7.3	8.1
Ashokan-East Reservoir	9.5	9.8	13.5	8.4	6.4	7.5
Cross River Reservoir	13.8	15.4	18.7	17.0	15.4	17.6

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

Reservoir Basin	**2009 μg L^{-1}**	**2010 μg L^{-1}**	**2011 μg L^{-1}**	**2012 μg L^{-1}**	**2013 μg L^{-1}**	**2014 μg L^{-1}**
Croton Falls Reservoir	14.7	13.3	20.6	18.7	23.0	19.9
Kensico Reservoir	5.8	6.6	7.5	6.4	6.2	5.7
New Croton Reservoir	14.4	15.7	18.2	18.7	17.0	16.0
Rondout Reservoir	8.1	8.0	8.9	7.2	7.2	6.6
West Branch Reservoir	9.6	9.4	11.1	11.8	12.6	11.2

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

Appendix D

Comparison of Reservoir Water Quality Results to Benchmarks

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Kensico Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	24			>10	13
Chloride (mg L^{-1})	12	24	2	8	8	10.3
Chlorophyll *a* (µg L^{-1})	12	64	0	0	7	4.7
Color (Pt-Co units)	15	199	7	4	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	199	0	0	3	1.7
Fecal coliforms (coliform $100mL^{-1}$)	20	199	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	199	0	0	0.3	<u>0.18</u>
pH (units)	6.5-8.5	199	65	33	na	na
Sodium, undig., filt. (mg L^{-1})	16	24	24	100	3	6.3
Soluble reactive phosphorus (µg L^{-1})	15	199	0	0	na	na
Sulfate (mg L^{-1})	15	24	0	0	10	4.3
Total ammonia-N (mg L^{-1})	0.10	199	0	0	0.05	<0.02
Total dissolved phosphorus (µg L^{-1})	15	199	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	199	81	41	40	48
Total phosphorus (µg L^{-1})	15	199	0	0	na	na
Total phytoplankton (ASU mL^{-1})	2000	96	0	0	na	na
Primary genus (ASU mL^{-1})	1000	96	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	95	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	70	0	0	5	<1.0
Turbidity (NTU)	5	199	0	0	na	na
Amawalk Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	6			>40	78
Chloride (mg L^{-1})	40	0			30	
Chlorophyll *a* (µg L^{-1})	15	16	2	13	10	11.7
Color (Pt-Co units)	15	38	38	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			6	
Fecal coliforms (coliform $100mL^{-1}$)	20	40	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	35	6	17	na	na
Sodium, undig., filt. (mg L^{-1})	20	0			15	
Soluble reactive phosphorus (µg L^{-1})	15	0			na	na

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Sulfate (mg L^{-1})	25	0			15	
Total ammonia-N (mg L^{-1})	0.10	0			0.05	na
Total dissolved phosphorus (µg L^{-1})	15	0			na	na
Total dissolved solids (mg L^{-1})[3]	175	0			150	343
Total phosphorus (µg L^{-1})	15	38	38	84	na	na
Total phytoplankton (ASU mL^{-1})	2000	38	32	0	na	na
Primary genus (ASU mL^{-1})	1000	16	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	2.1
Turbidity (NTU)	5	38	1	3	na	na
Boyd Corners Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	5			>40	30
Chloride (mg L^{-1})	40	5	2	40	30	39.2
Chlorophyll *a* (µg L^{-1})	15	7	0	0	10	6.4
Color (Pt-Co units)	15	18	18	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	18	0	0	6	3.2
Fecal coliforms (coliform $100mL^{-1}$)	20	45	4	9	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	18	0	0	0.3	0.07
pH (units)	6.5-8.5	45	5	11	na	na
Sodium, undig., filt. (mg L^{-1})	20	5	5	100	15	22.7
Soluble reactive phosphorus (µg L^{-1})	15	18	0	0	na	na
Sulfate (mg L^{-1})	25	5	0	0	15	6.8
Total ammonia-N (mg L^{-1})	0.10	18	0	0	0.05	0.02
Total dissolved phosphorus (µg L^{-1})	15	18	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	175	18	0	0	150	137
Total phosphorus (µg L^{-1})	15	18	0	0	na	na
Total phytoplankton (ASU mL^{-1})	2000	7	0	0	na	na
Primary genus (ASU mL^{-1})	1000	7	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	7	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	5	0	0	5	<1.0
Turbidity (NTU)	5	18	0	0	na	na
Croton Falls Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	18			>40	69
Chloride (mg L^{-1})	40	18	18	100	30	73.4
Chlorophyll *a* (µg L^{-1})	15	23	9	39	10	18.6

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Color (Pt-Co units)	15	62	60	97	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	62	0	0	6	3.4
Fecal coliforms (coliform 100mL^{-1})	20	62	2	3	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	62	6	10	0.3	0.23
pH (units)	6.5-8.5	62	8	13	na	na
Sodium, undig., filt. (mg L^{-1})	20	18	18	100	15	40.2
Soluble reactive phosphorus (µg L^{-1})	15	62	1	2	na	na
Sulfate (mg L^{-1})	25	18	0	0	15	9.7
Total ammonia-N (mg L^{-1})	0.10	62	8	13	0.05	0.05
Total dissolved phosphorus (µg L^{-1})	15	62	3	5	na	na
Total dissolved solids (mg L^{-1})[3]	175	62	62	100	150	283
Total phosphorus (µg L^{-1})	15	62	45	73	na	na
Total phytoplankton (ASU mL^{-1})	2000	23	1	4	na	na
Primary genus (ASU mL^{-1})	1000	23	3	13	na	na
Secondary genus (ASU mL^{-1})	1000	23	1	4	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.9
Turbidity (NTU)	5	62	11	18	na	na
Cross River Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	48
Chloride (mg L^{-1})	40	8	0	0	30	36.1
Chlorophyll *a* (µg L^{-1})	15	16	1	6	10	11
Color (Pt-Co units)	15	48	47	98	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	48	0	0	6	3.5
Fecal coliforms (coliform 100mL^{-1})	20	48	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	47	0	0	0.3	0.08
pH (units)	6.5-8.5	42	10	24	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	19.4
Soluble reactive phosphorus (µg L^{-1})	15	47	1	2	na	na
Sulfate (mg L^{-1})	25	8	0	0	15	8
Total ammonia-N (mg L^{-1})	0.10	48	10	21	0.05	0.08
Total dissolved phosphorus (µg L^{-1})	15	48	4	8	na	na
Total dissolved solids (mg L^{-1})[3]	175	48	0	0	150	154
Total phosphorus (µg L^{-1})	15	48	32	67	na	na
Total phytoplankton (ASU mL^{-1})	2000	16	1	6	na	na
Primary genus (ASU mL^{-1})	1000	16	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	16	0	0	na	na

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	2.9
Turbidity (NTU)	5	48	7	15	na	na
Diverting Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	6			>40	87
Chloride (mg L^{-1})	40	0			30	
Chlorophyll *a* (µg L^{-1})	15	16	9	56	10	26.9
Color (Pt-Co units)	15	26	26	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			6	
Fecal coliforms (coliform 100mL^{-1})	20	38	7	18	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	40	2	5	na	na
Sodium, undig., filt. (mg L^{-1})	20	0			15	
Soluble reactive phosphorus (µg L^{-1})	15	0			na	na
Sulfate (mg L^{-1})	25	0			15	
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	0			na	na
Total dissolved solids (mg L^{-1})[3]	175	26	26	100	150	245
Total phosphorus (µg L^{-1})	15	26	25	96	na	na
Total phytoplankton (ASU mL^{-1})	2000	16	1	6	na	na
Primary genus (ASU mL^{-1})	1000	16	1	6	na	na
Secondary genus (ASU mL^{-1})	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	3.1
Turbidity (NTU)	5	26	4	15	na	na
East Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	6			>40	78
Chloride (mg L^{-1})	40	6	6	100	30	46.1
Chlorophyll *a* (µg L^{-1})	15	7	5	71	10	22.4
Color (Pt-Co units)	15	24	24	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	24	0	0	6	3.9
Fecal coliforms (coliform 100mL^{-1})	20	45	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	24	0	0	0.3	0.03
pH (units)	6.5-8.5	39	5	13	na	na
Sodium, undig., filt. (mg L^{-1})	20	6	6	100	15	25
Soluble reactive phosphorus (µg L^{-1})	15	24	1	4	na	na
Sulfate (mg L^{-1})	25	6	0	0	15	7.8

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Total ammonia-N (mg L^{-1})	0.10	24	4	17	0.05	0.05
Total dissolved phosphorus (µg L^{-1})	15	24	3	13	na	na
Total dissolved solids (mg L^{-1})[3]	175	24	24	100	150	217
Total phosphorus (µg L^{-1})	15	24	18	75	na	na
Total phytoplankton (ASU mL^{-1})	2000	8	0	0	na	na
Primary genus (ASU mL^{-1})	1000	8	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	8	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	2.7
Turbidity (NTU)	5	24	4	17	na	na
Lake Gilead						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	45
Chloride (mg L^{-1})	40	9	9	100	30	47
Chlorophyll *a* (µg L^{-1})	15	3	0	0	10	6.1
Color (Pt-Co units)	15	9	5	56	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	9	0	0	6	3.3
Fecal coliforms (coliform $100mL^{-1}$)	20	15	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	9	0	0	0.3	<0.02
pH (units)	6.5-8.5	15	4	27	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	25.3
Soluble reactive phosphorus (µg L^{-1})	15	9	3	33	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	7.2
Total ammonia-N (mg L^{-1})	0.10	9	3	33	0.05	0.18
Total dissolved phosphorus (µg L^{-1})	15	9	3	33	na	na
Total dissolved solids (mg L^{-1})[3]	175	9	3	33	150	170
Total phosphorus (µg L^{-1})	15	9	7	78	na	na
Total phytoplankton (ASU mL^{-1})	2000	3	0	0	na	na
Primary genus (ASU mL^{-1})	1000	3	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	3	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.7
Turbidity (NTU)	5	9	0	0	na	na
Bog Brook Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	5			>40	74
Chloride (mg L^{-1})	40	5	5	100	30	55.2
Chlorophyll *a* (µg L^{-1})	15	8	2	25	10	9.8
Color (Pt-Co units)	15	18	13	72	na	na

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Dissolved organic carbon (mg L^{-1})[2]	7.0	18	0	0	6	3.4
Fecal coliforms (coliform 100mL^{-1})	20	42	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	18	0	0	0.3	<u>0.04</u>
pH (units)	6.5-8.5	37	6	16	na	na
Sodium, undig., filt. (mg L^{-1})	20	5	5	100	15	30.2
Soluble reactive phosphorus (µg L^{-1})	15	18	0	0	na	na
Sulfate (mg L^{-1})	25	5	0	0	15	9
Total ammonia-N (mg L^{-1})	0.10	18	2	11	0.05	<u>0.04</u>
Total dissolved phosphorus (µg L^{-1})	15	18	1	6	na	na
Total dissolved solids (mg L^{-1})[3]	175	18	18	100	150	227
Total phosphorus (µg L^{-1})	15	18	8	44	na	na
Total phytoplankton (ASU mL^{-1})	2000	8	0	0	na	na
Primary genus (ASU mL^{-1})	1000	8	1	13	na	na
Secondary genus (ASU mL^{-1})	1000	8	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	5	0	0	5	<u>2.2</u>
Turbidity (NTU)	5	18	0	0	na	na
Lake Gleneida						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>40	69
Chloride (mg L^{-1})	40	9	9	100	30	103.6
Chlorophyll *a* (µg L^{-1})	15	3	0	0	10	6.1
Color (Pt-Co units)	15	9	3	33	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	9	0	0	6	2.9
Fecal coliforms (coliform 100mL^{-1})	20	15	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	9	0	0	0.3	<0.02
pH (units)	6.5-8.5	15	4	27	na	na
Sodium, undig., filt. (mg L^{-1})	20	9	9	100	15	56.2
Soluble reactive phosphorus (µg L^{-1})	15	9	2	22	na	na
Sulfate (mg L^{-1})	25	9	0	0	15	6.4
Total ammonia-N (mg L^{-1})	0.10	9	2	22	0.05	<u>0.13</u>
Total dissolved phosphorus (µg L^{-1})	15	9	2	22	na	na
Total dissolved solids (mg L^{-1})[3]	175	9	9	100	150	320
Total phosphorus (µg L^{-1})	15	9	4	44	na	na
Total phytoplankton (ASU mL^{-1})	2000	3	0	0	na	na
Primary genus (ASU mL^{-1})	1000	3	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	3	0	0	na	na

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	1.9
Turbidity (NTU)	5	9	1	11	na	na
Kirk Lake						
Alkalinity (mg $CaCO_3$ L^{-1})	na	3			>40	60
Chloride (mg L^{-1})	40	3	3	100	30	78.9
Chlorophyll *a* (µg L^{-1})	15	3	3	100	10	41.6
Color (Pt-Co units)	15	3	3	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	3	0	0	6	4.7
Fecal coliforms (coliform 100mL^{-1})	20	15	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	3	0	0	0.3	<0.02
pH (units)	6.5-8.5	15	1	7	na	na
Sodium, undig., filt. (mg L^{-1})	20	3	3	100	15	40
Soluble reactive phosphorus (µg L^{-1})	15	3	0	0	na	na
Sulfate (mg L^{-1})	25	3	0	0	15	8
Total ammonia-N (mg L^{-1})	0.10	3	0	0	0.05	<u>0.02</u>
Total dissolved phosphorus (µg L^{-1})	15	3	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	175	3	3	100	150	258
Total phosphorus (µg L^{-1})	15	3	3	100	na	na
Total phytoplankton (ASU mL^{-1})	2000	3	1	33	na	na
Primary genus (ASU mL^{-1})	1000	3	2	67	na	na
Secondary genus (ASU mL^{-1})	1000	3	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	3	0	0	5	4.8
Turbidity (NTU)	5	3	2	67	na	na
Muscoot Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	4			>40	78
Chloride (mg L^{-1})	40	4	4	100	30	76.4
Chlorophyll *a* (µg L^{-1})	15	32	19	59	10	24.3
Color (Pt-Co units)	15	54	54	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	54	0	0	6	3.9
Fecal coliforms (coliform 100mL^{-1})	20	54	7	13	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	54	5	9	0.3	<u>0.21</u>
pH (units)	6.5-8.5	54	3	6	na	na
Sodium, undig., filt. (mg L^{-1})	20	4	4	100	15	41.2
Soluble reactive phosphorus (µg L^{-1})	15	54	2	4	na	na
Sulfate (mg L^{-1})	25	4	0	0	15	7.7

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Total ammonia-N (mg L^{-1})	0.10	54	15	28	0.05	0.2
Total dissolved phosphorus (µg L^{-1})	15	54	4	7	na	na
Total dissolved solids (mg L^{-1})[3]	175	54	54	100	150	275
Total phosphorus (µg L^{-1})	15	54	52	96	na	na
Total phytoplankton (ASU mL^{-1})	2000	32	3	9	na	na
Primary genus (ASU mL^{-1})	1000	32	3	9	na	na
Secondary genus (ASU mL^{-1})	1000	32	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	4	1	25	5	4.3
Turbidity (NTU)	5	54	11	20	na	na
Middle Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12			>40	63
Chloride (mg L^{-1})	40	0			30	
Chlorophyll *a* (µg L^{-1})	15	15	8	53	10	16.4
Color (Pt-Co units)	15	40	40	100	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			6	
Fecal coliforms (coliform $100mL^{-1}$)	20	40	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	40	7	18	na	na
Sodium, undig., filt. (mg L^{-1})	20	0			15	
Soluble reactive phosphorus (µg L^{-1})	15	0			na	na
Sulfate (mg L^{-1})	25	0			15	
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	0			na	na
Total dissolved solids (mg L^{-1})[3]	175	40	40	100	150	317
Total phosphorus (µg L^{-1})	15	42	39	93	na	na
Total phytoplankton (ASU mL^{-1})	2000	16	0	0	na	na
Primary genus (ASU mL^{-1})	1000	16	1	6	na	na
Secondary genus (ASU mL^{-1})	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	9	0	0	5	3.4
Turbidity (NTU)	5	40	7	18	na	na
New Croton Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	30			>40	69
Chloride (mg L^{-1})	40	30	30	100	30	74.5
Chlorophyll *a* (µg L^{-1})	15	56	20	36	10	12.6
Color (Pt-Co units)	15	167	161	96	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	167	0	0	6	3.4

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Fecal coliforms (coliform 100mL^{-1})	20	167	1	1	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	167	23	14	0.3	0.22
pH (units)	6.5-8.5	167	20	12	na	na
Sodium, undig., filt. (mg L^{-1})	20	30	30	100	15	40.4
Soluble reactive phosphorus (µg L^{-1})	15	167	6	4	na	na
Sulfate (mg L^{-1})	25	30	0	0	15	10
Total ammonia-N (mg L^{-1})	0.10	166	29	17	0.05	0.1
Total dissolved phosphorus (µg L^{-1})	15	167	10	6	na	na
Total dissolved solids (mg L^{-1})[3]	175	167	167	100	150	266
Total phosphorus (µg L^{-1})	15	169	81	48	na	na
Total phytoplankton (ASU mL^{-1})	2000	64	0	0	na	na
Primary genus (ASU mL^{-1})	1000	64	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	64	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	49	0	0	5	1.4
Turbidity (NTU)	5	167	5	3	na	na
Titicus Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	6			>40	71
Chloride (mg L^{-1})	40	0			30	
Chlorophyll *a* (µg L^{-1})	15	16	4	25	10	12.6
Color (Pt-Co units)	15	35	33	94	na	na
Dissolved organic carbon (mg L^{-1})[2]	7.0	0			6	
Fecal coliforms (coliform 100mL^{-1})	20	38	2	5	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	0			0.3	
pH (units)	6.5-8.5	35	4	11	na	na
Sodium, undig., filt. (mg L^{-1})	20	0			15	
Soluble reactive phosphorus (µg L^{-1})	15	0			na	na
Sulfate (mg L^{-1})	25	0			15	
Total ammonia-N (mg L^{-1})	0.10	0			0.05	
Total dissolved phosphorus (µg L^{-1})	15	0			na	na
Total dissolved solids (mg L^{-1})[3]	175	35	34	97	150	192
Total phosphorus (µg L^{-1})	15	35	30	86	na	na
Total phytoplankton (ASU mL^{-1})	2000	16	1	6	na	na
Primary genus (ASU mL^{-1})	1000	16	1	6	na	na
Secondary genus (ASU mL^{-1})	1000	16	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	6	0	0	5	2.4
Turbidity (NTU)	5	35	5	14	na	na

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
West Branch Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	14			>10	26
Chloride (mg L^{-1})	12	14	14	100	8	27.1
Chlorophyll *a* (µg L^{-1})	12	31	6	19	7	9.7
Color (Pt-Co units)	15	68	56	82	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	68	0	0	3	2.4
Fecal coliforms (coliform 100mL^{-1})	20	68	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	67	0	0	0.3	<u>0.06</u>
pH (units)	6.5-8.5	68	9	13	na	na
Sodium, undig., filt. (mg L^{-1})	16	13	13	100	3	15.3
Soluble reactive phosphorus (µg L^{-1})	15	67	0	0	na	na
Sulfate (mg L^{-1})	15	14	0	0	10	5.8
Total ammonia-N (mg L^{-1})	0.10	68	1	1	0.05	<u>0.01</u>
Total dissolved phosphorus (µg L^{-1})	15	68	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	68	66	97	40	101
Total phosphorus (µg L^{-1})	15	68	11	16	na	na
Total phytoplankton (ASU mL^{-1})	2000	43	1	2	na	na
Primary genus (ASU mL^{-1})	1000	43	1	2	na	na
Secondary genus (ASU mL^{-1})	1000	43	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	8	0	0	5	<u>1.4</u>
Turbidity (NTU)	5	68	0	0	na	na
Ashokan East Basin Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>10	13
Chloride (mg L^{-1})	12	9	0	0	8	6.8
Chlorophyll *a* (µg L^{-1})	12	24	0	0	7	2.7
Color (Pt-Co units)	15	63	4	6	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	64	0	0	3	1.9
Fecal coliforms (coliform 100mL^{-1})	20	64	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	68	0	0	0.3	<u>0.03</u>
pH (units)	6.5-8.5	64	19	30	na	na
Sodium, undig., filt. (mg L^{-1})	16	9	9	100	3	4.3
Soluble reactive phosphorus (µg L^{-1})	15	64	0	0	na	na
Sulfate (mg L^{-1})	15	9	0	0	10	3.6
Total ammonia-N (mg L^{-1})	0.10	65	3	5	0.05	<0.02
Total dissolved phosphorus (µg L^{-1})	15	66	3	5	na	na
Total dissolved solids (mg L^{-1})[3]	50	63	1	2	40	39

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Total phosphorus (µg L^{-1})	15	64	6	9	na	na
Total phytoplankton (ASU mL^{-1})	2000	39	0	0	na	na
Primary genus (ASU mL^{-1})	1000	39	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	39	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	64	5	8	5	2.9
Turbidity (NTU)	5	64	14	22	na	na
Ashokan West Basin Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12			>10	12
Chloride (mg L^{-1})	12	12	0	0	8	7.8
Chlorophyll *a* (µg L^{-1})	12	24	0	0	7	3.9
Color (Pt-Co units)	15	73	2	3	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	76	2	3	3	2.1
Fecal coliforms (coliform $100mL^{-1}$)	20	74	3	4	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	75	0	0	0.3	0.24
pH (units)	6.5-8.5	75	31	41	na	na
Sodium, undig., filt. (mg L^{-1})	16	12	12	100	3	4.7
Soluble reactive phosphorus (µg L^{-1})	15	75	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	3.5
Total ammonia-N (mg L^{-1})	0.10	76	0	0	0.05	<0.02
Total dissolved phosphorus (µg L^{-1})	15	75	1	1	na	na
Total dissolved solids (mg L^{-1})[3]	50	75	0	0	40	40
Total phosphorus (µg L^{-1})	15	75	4	5	na	na
Total phytoplankton (ASU mL^{-1})	2000	40	0	0	na	na
Primary genus (ASU mL^{-1})	1000	40	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	40	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	75	8	11	5	4.4
Turbidity (NTU)	5	75	35	47	na	na
Pepacton Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	21			>10	13
Chloride (mg L^{-1})	12	21	0	0	8	7.3
Chlorophyll *a* (µg L^{-1})	12	40	1	3	7	4.4
Color (Pt-Co units)	15	124	13	10	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	124	0	0	3	1.8
Fecal coliforms (coliform $100mL^{-1}$)	20	124	1	1	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	124	0	0	0.3	0.22
pH (units)	6.5-8.5	107	38	36	na	na

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Sodium, undig., filt. (mg L^{-1})	16	21	21	100	3	4.6
Soluble reactive phosphorus (µg L^{-1})	15	124	0	0	na	na
Sulfate (mg L^{-1})	15	21	0	0	10	4
Total ammonia-N (mg L^{-1})	0.10	125	0	0	0.05	<u>0.02</u>
Total dissolved phosphorus (µg L^{-1})	15	124	0	0	na	na
Total dissolved solids (mg L^{-1})[3]	50	124	1	1	40	42
Total phosphorus (µg L^{-1})	15	124	13	10	na	na
Total phytoplankton (ASU mL^{-1})	2000	60	0	0	na	na
Primary genus (ASU mL^{-1})	1000	60	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	60	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	60	0	0	5	<u>0.8</u>
Turbidity (NTU)	5	124	11	9	na	na
Neversink Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	11			>10	3
Chloride (mg L^{-1})	12	11	0	0	8	3.9
Chlorophyll *a* (µg L^{-1})	12	24	0	0	7	3.1
Color (Pt-Co units)	15	74	58	78	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	75	0	0	3	2.2
Fecal coliforms (coliform 100mL^{-1})	20	74	2	3	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	73	0	0	0.3	<u>0.25</u>
pH (units)	6.5-8.5	74	63	85	na	na
Sodium, undig., filt. (mg L^{-1})	16	11	0	0	3	2.4
Soluble reactive phosphorus (µg L^{-1})	15	73	0	0	na	na
Sulfate (mg L^{-1})	15	11	0	0	10	3
Total ammonia-N (mg L^{-1})	0.10	74	0	0	0.05	<u>0.02</u>
Total dissolved phosphorus (µg L^{-1})	15	74	1	1	na	na
Total dissolved solids (mg L^{-1})[3]	50	74	0	0	40	21
Total phosphorus (µg L^{-1})	15	74	0	0	na	na
Total phytoplankton (ASU mL^{-1})	2000	40	0	0	na	na
Primary genus (ASU mL^{-1})	1000	40	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	40	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	24	0	0	5	<u>1.4</u>
Turbidity (NTU)	5	74	3	4	na	na
Rondout Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	12			>10	10
Chloride (mg L^{-1})	12	12	0	0	8	7.5

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Chlorophyll *a* (µg L^{-1})	12	24	0	0	7	3
Color (Pt-Co units)	15	80	5	6	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	56	0	0	3	1.9
Fecal coliforms (coliform $100mL^{-1}$)	20	80	0	0	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	56	0	0	0.3	0.23
pH (units)	6.5-8.5	80	25	31	na	na
Sodium, undig., filt. (mg L^{-1})	16	12	12	100	3	4.7
Soluble reactive phosphorus (µg L^{-1})	15	56	0	0	na	na
Sulfate (mg L^{-1})	15	12	0	0	10	3.8
Total ammonia-N (mg L^{-1})	0.10	56	0	0	0.05	<0.02
Total dissolved phosphorus (µg L^{-1})	15	56	1	2	na	na
Total dissolved solids (mg L^{-1})[3]	50	80	0	0	40	39
Total phosphorus (µg L^{-1})	15	83	1	1	na	na
Total phytoplankton (ASU mL^{-1})	2000	48	0	0	na	na
Primary genus (ASU mL^{-1})	1000	48	0	0	na	na
Secondary genus (ASU mL^{-1})	1000	48	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	32	0	0	5	0.9
Turbidity (NTU)	5	80	0	0	na	na
Schoharie Reservoir						
Alkalinity (mg $CaCO_3$ L^{-1})	na	9			>10	18
Chloride (mg L^{-1})	12	9	0	0	8	8.7
Chlorophyll *a* (µg L^{-1})	12	31	0	0	7	2.7
Color (Pt-Co units)	15	68	51	75	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	61	0	0	3	2.7
Fecal coliforms (coliform $100mL^{-1}$)	20	84	5	6	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	69	0	0	0.3	0.19
pH (units)	6.5-8.5	84	10	12	na	na
Sodium, undig., filt. (mg L^{-1})	16	6	6	100	3	5.9
Soluble reactive phosphorus (µg L^{-1})	15	69	1	1	na	na
Sulfate (mg L^{-1})	15	9	0	0	10	3.8
Total ammonia-N (mg L^{-1})	0.10	61	0	0	0.05	0.01
Total dissolved phosphorus (µg L^{-1})	15	61	2	3	na	na
Total dissolved solids (mg L^{-1})[3]	50	84	42	50	40	52
Total phosphorus (µg L^{-1})	15	84	51	61	na	na
Total phytoplankton (ASU mL^{-1})	2000	47	0	0	na	na
Primary genus (ASU mL^{-1})	1000	47	0	0	na	na

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

Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Secondary genus (ASU mL^{-1})	1000	47	0	0	na	na
Total suspended solids (mg L^{-1})	8.0	73	18	25	5	6.6
Turbidity (NTU)	5	84	74	88	na	na
Cannonsville Reservoir.						
Alkalinity (mg $CaCO_3$ L^{-1})	na	17			>10	16
Chloride (mg L^{-1})	12	17	7	41	8	11.5
Chlorophyll *a* (µg L^{-1})	12	40	6	15	7	6.8
Color (Pt-Co units)	15	113	74	65	na	na
Dissolved organic carbon (mg L^{-1})[2]	4.0	113	0	0	3	2.1
Fecal coliforms (coliform 100mL^{-1})	20	111	1	1	na	na
Nitrate+nitrite-N (mg L^{-1})	0.5	124	42	34	0.3	0.37
pH (units)	6.5-8.5	113	32	28	na	na
Sodium, undig., filt. (mg L^{-1})	16	17	17	100	3	7.7
Soluble reactive phosphorus (µg L^{-1})	15	124	0	0	na	na
Sulfate (mg L^{-1})	15	17	0	0	10	5
Total ammonia-N (mg L^{-1})	0.10	113	2	2	0.05	0.03
Total dissolved phosphorus (µg L^{-1})	15	113	2	2	na	na
Total dissolved solids (mg L^{-1})[3]	50	113	109	96	40	60
Total phosphorus (µg L^{-1})	15	113	60	53	na	na
Total phytoplankton (ASU mL^{-1})	2000	56	6	11	na	na
Primary genus (ASU mL^{-1})	1000	56	9	16	na	na
Secondary genus (ASU mL^{-1})	1000	56	1	2	na	na
Total suspended solids (mg L^{-1})	8.0	42	2	5	5	2.5
Turbidity (NTU)	5	113	25	22	na	na

[1]Means were estimated using recommended techniques according to Helsel (2005). For 100% uncensored data the arithmetic mean is reported. For <50% censored data the mean is estimated using the Kaplan-Meier Method. These estimates are underlined with one line. For 50-80% censored data, the robust ROS method was used. These estimates are underlined using two lines. In cases where >80% of data are censored, the mean cannot be estimated and here we report the detection limit with the prefix "<".
[2]Dissolved organic carbon replaced *total* organic carbon in 2000. In New York City reservoirs, the dissolved portion comprises the majority of the total organic carbon.
[3]Total dissolved solids estimated from specific conductivity according to the USGS in van der Leeden et al. (1990).

Appendix E

Comparison of Stream Water Quality Results to Benchmarks

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

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
E10I (Bushkill inflow to Ashokan)						
Alkalinity (mg L^{-1})	≥10.0	12	8	67	na	7.8
Chloride (mg L^{-1})	50	12	0	0	10	3.9
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	0.9
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.13
Sulfate (mg L^{-1})	15	4	0	0	10	3.8
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	26
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.4
E16I (Esopus Creek at Coldbrook)						
Alkalinity (mg L^{-1})	≥10.0	12	3	25	na	15.2
Chloride (mg L^{-1})	50	12	0	0	10	9.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.8
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.27
Sulfate (mg L^{-1})	15	1	0	0	10	4.3
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	5	42	40	48
Dissolved sodium (mg L^{-1})	10	1	0	0	5	6.2
E5 (Esopus Creek at Allaben)						
Alkalinity (mg L^{-1})	≥10.0	12	5	42	na	11.5
Chloride (mg L^{-1})	50	12	0	0	10	7.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.1
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.23
Sulfate (mg L^{-1})	15	4	0	0	10	3.6
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	4	33	40	40
Dissolved sodium (mg L^{-1})	10	4	0	0	5	3.6
S5I (Schoharie Creek at Prattsville)						
Alkalinity (mg L^{-1})	≥10.0	12	2	17	na	21.8
Chloride (mg L^{-1})	50	12	0	0	10	12.5

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

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.8
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.29
Sulfate (mg L^{-1})	15	4	0	0	10	4.9
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	11	9	82	40	68
Dissolved sodium (mg L^{-1})	10	4	0	0	5	8.5
S6I (Bear Creek at Hardenburgh Falls)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	29.9
Chloride (mg L^{-1})	50	12	0	0	10	20.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.8
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.55
Sulfate (mg L^{-1})	15	4	0	0	10	7.6
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	11	10	91	40	101
Dissolved sodium (mg L^{-1})	10	4	3	75	5	12.9
S7I (Manor Kill)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	29.4
Chloride (mg L^{-1})	50	12	0	0	10	10.1
Dissolved organic carbon (mg L^{-1})	25	13	0	0	9	1.6
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.15
Sulfate (mg L^{-1})	15	4	0	0	10	5.6
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	11	9	82	40	72
Dissolved sodium (mg L^{-1})	10	4	0	0	5	6.4
SRR2CM (Schoharie Reservoir Diversion)[3]						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	17.6
Chloride (mg L^{-1})	50	12	0	0	10	11.0
Dissolved organic carbon (mg L^{-1})	25	53	0	0	9	2.4
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.29
Sulfate (mg L^{-1})	15	3	0	0	10	3.9
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	0.01
Total dissolved solids (mg L^{-1})[2]	50	47	29	62	40	57
Dissolved sodium (mg L^{-1})	10	4	0	0	5	6.8
C-7 (Trout Creek above Cannonsville Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	2	17	na	16.0

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

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Chloride (mg L^{-1})	50	12	0	0	10	16.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.34
Sulfate (mg L^{-1})	15	4	0	0	10	6.0
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	0.01
Total dissolved solids (mg L^{-1})[2]	50	12	12	100	40	69
Dissolved sodium (mg L^{-1})	10	4	1	25	5	9.2
C-8 (Loomis Brook above Cannonsville Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	2	17	na	15.6
Chloride (mg L^{-1})	50	12	0	0	10	16.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.25
Sulfate (mg L^{-1})	15	4	0	0	10	5.9
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	12	100	40	69
Dissolved sodium (mg L^{-1})	10	4	1	25	5	8.8
WDBN (West Branch Delaware River at Beerston Bridge)						
Alkalinity (mg L^{-1})	≥10.0	12	1	8	na	21.5
Chloride (mg L^{-1})	50	12	0	0	10	15.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.6
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.63
Sulfate (mg L^{-1})	15	4	0	0	10	6.3
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	10	83	40	77
Dissolved sodium (mg L^{-1})	10	4	2	50	5	9.3
NCG (Neversink Reservoir near Claryville)						
Alkalinity (mg L^{-1})	≥10.0	11	11	100	na	3.2
Chloride (mg L^{-1})	50	11	0	0	10	3.6
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	1.7
Nitrate+nitrite-N (mg L^{-1})	1.5	11	0	0	0.40	0.31
Sulfate (mg L^{-1})	15	4	0	0	10	3.3
Total ammonia-N (mg L^{-1})	0.25	11	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	11	0	0	40	20
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.2
NK4 (Aden Brook above Neversink Reservoir)						

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

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Alkalinity (mg L^{-1})	≥10.0	11	8	73	na	7.4
Chloride (mg L^{-1})	50	11	0	0	10	4.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+nitrite-N (mg L^{-1})	1.5	11	0	0	0.40	0.28
Sulfate (mg L^{-1})	15	4	0	0	10	4.3
Total ammonia-N (mg L^{-1})	0.25	11	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	11	0	0	40	27
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.5
NK6 (Kramer Brook above Neversink Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	11	9	82	na	8.4
Chloride (mg L^{-1})	50	11	0	0	10	32.2
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	2.7
Nitrate+nitrite-N (mg L^{-1})	1.5	11	0	0	0.40	0.52
Sulfate (mg L^{-1})	15	4	0	0	10	5.4
Total ammonia-N (mg L^{-1})	0.25	11	0	0	0.05	0.03
Total dissolved solids (mg L^{-1})[2]	50	11	11	100	40	101
Dissolved sodium (mg L^{-1})	10	4	4	100	5	20.9
P-13 (Tremper Kill above Pepacton Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	18.0
Chloride (mg L^{-1})	50	12	0	0	10	12.5
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.36
Sulfate (mg L^{-1})	15	4	0	0	10	5.0
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	9	75	40	62
Dissolved sodium (mg L^{-1})	10	4	0	0	5	7.4
P-21 (Platte Kill at Dunraven)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	20.0
Chloride (mg L^{-1})	50	12	0	0	10	10.2
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.27
Sulfate (mg L^{-1})	15	4	0	0	10	4.8
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	8	67	40	58
Dissolved sodium (mg L^{-1})	10	4	0	0	5	5.7

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

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
P-60 (Mill Brook near Dunraven)						
Alkalinity (mg L^{-1})	≥10.0	12	5	42	na	12.8
Chloride (mg L^{-1})	50	12	0	0	10	1.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	0.9
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.32
Sulfate (mg L^{-1})	15	4	0	0	10	4.0
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	28
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.0
P-7 (Terry Clove above Pepacton Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	4	33	na	14.8
Chloride (mg L^{-1})	50	12	0	0	10	1.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.39
Sulfate (mg L^{-1})	15	4	0	0	10	5.0
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	33
Dissolved sodium (mg L^{-1})	10	4	0	0	5	1.5
P-8 (Fall Clove above Pepacton Reservoir)						
Alkalinity (mg L^{-1})	≥10.0	12	2	17	na	14.2
Chloride (mg L^{-1})	50	12	0	0	10	2.6
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.3
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.45
Sulfate (mg L^{-1})	15	4	0	0	10	5.1
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	0	0	40	36
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.1
PMSB (East Branch Delaware River near Margaretville)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	20.0
Chloride (mg L^{-1})	50	12	0	0	10	12.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	1.4
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.40
Sulfate (mg L^{-1})	15	4	0	0	10	4.9
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	12	9	75	40	61

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

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Dissolved sodium (mg L^{-1})	10	4	2	50	5	9.4
RD1 (Sugarloaf Brook near Lowes Corners)						
Alkalinity (mg L^{-1})	≥10.0	11	11	100	na	4.8
Chloride (mg L^{-1})	50	11	0	0	10	7.0
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	1.3
Nitrate+nitrite-N (mg L^{-1})	1.5	11	0	0	0.40	0.20
Sulfate (mg L^{-1})	15	4	0	0	10	4.4
Total ammonia-N (mg L^{-1})	0.25	11	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	11	0	0	40	31
Dissolved sodium (mg L^{-1})	10	4	0	0	5	4.0
RD4 (Sawkill Brook near Yagerville)						
Alkalinity (mg L^{-1})	≥10.0	11	11	100	na	5.2
Chloride (mg L^{-1})	50	11	0	0	10	6.7
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	2.1
Nitrate+nitrite-N (mg L^{-1})	1.5	11	0	0	0.40	0.12
Sulfate (mg L^{-1})	15	4	0	0	10	5.2
Total ammonia-N (mg L^{-1})	0.25	11	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	11	0	0	40	32
Dissolved sodium (mg L^{-1})	10	4	0	0	5	4.0
RDOA (Rondout Creek near Lowes Corners)						
Alkalinity (mg L^{-1})	≥10.0	11	11	100	na	3.5
Chloride (mg L^{-1})	50	11	0	0	10	4.3
Dissolved organic carbon (mg L^{-1})	25	11	0	0	9	1.3
Nitrate+nitrite-N (mg L^{-1})	1.5	11	0	0	0.40	0.25
Sulfate (mg L^{-1})	15	4	0	0	10	3.9
Total ammonia-N (mg L^{-1})	0.25	11	0	0	0.05	<0.02
Total dissolved solids (mg L^{-1})[2]	50	11	0	0	40	22
Dissolved sodium (mg L^{-1})	10	4	0	0	5	2.6
RGB (Chestnut Creek below Grahamsville STP)						
Alkalinity (mg L^{-1})	≥10.0	11	8	73	na	8.0
Chloride (mg L^{-1})	50	11	0	0	10	16.5
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.5
Nitrate+nitrite-N (mg L^{-1})	1.5	11	0	0	0.4	0.37
Sulfate (mg L^{-1})	15	4	0	0	10	5.1
Total ammonia-N (mg L^{-1})	0.25	11	0	0	0.05	<0.02

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

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Total dissolved solids (mg L^{-1})[2]	50	11	8	73	40	58
Dissolved sodium (mg L^{-1})	10	4	2	50	5	10.9
AMAWALKR (Amawalk Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	80.5
Chloride (mg L^{-1})	100	12	10	83	35	103.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.6
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	<u>0.24</u>
Sulfate (mg L^{-1})	25	4	0	0	15	9.8
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<u>0.05</u>
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	340
Dissolved sodium (mg L^{-1})	20	3	3	100	15	59.1
BOGEASTBRR (Combined release for Bog Brook and East Branch Reservoirs)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	82.1
Chloride (mg L^{-1})	100	12	1	8	35	72.4
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.9
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.16
Sulfate (mg L^{-1})	25	4	0	0	15	9.3
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<u>0.06</u>
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	274
Dissolved sodium (mg L^{-1})	20	4	4	100	15	30.8
BOYDR (Boyd Corners Release)[3]						
Alkalinity (mg L^{-1})	≥40.0	12	12	100	na	33.0
Chloride (mg L^{-1})	100	12	0	0	35	37.5
Dissolved organic carbon (mg L^{-1})	25	55	0	0	9	3.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	<u>0.09</u>
Sulfate (mg L^{-1})	25	4	0	0	15	6.3
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<u>0.04</u>
Total dissolved solids (mg L^{-1})[2]	175	55	0	0	150	135
Dissolved sodium (mg L^{-1})	20	4	4	100	15	22.2
CROFALLSVC (Croton Falls Reservoir Release)[3]						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	68.8
Chloride (mg L^{-1})	100	12	0	0	35	74.4
Dissolved organic carbon (mg L^{-1})	25	54	0	0	9	3.2
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	<u>0.28</u>
Sulfate (mg L^{-1})	25	3	0	0	15	9.5

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

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Total ammonia-N (mg L^{-1})	0.20	12	2	17	0.10	0.12
Total dissolved solids (mg L^{-1})[2]	175	54	52	96	150	262
Dissolved sodium (mg L^{-1})	20	4	4	100	15	44.2
CROSS2 (Cross River near Cross River Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	59.1
Chloride (mg L^{-1})	100	12	0	0	35	40.9
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.0
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.19
Sulfate (mg L^{-1})	25	4	0	0	15	9.8
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.01
Total dissolved solids (mg L^{-1})[2]	175	12	4	33	150	178
Dissolved sodium (mg L^{-1})	20	3	2	67	15	21.6
CROSSRVVC (Cross River Reservoir Release)[3]						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	51.5
Chloride (mg L^{-1})	100	12	0	0	35	38.8
Dissolved organic carbon (mg L^{-1})	25	54	0	0	9	3.4
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.16
Sulfate (mg L^{-1})	25	4	0	0	15	7.5
Total ammonia-N (mg L^{-1})	0.20	12	2	17	0.10	0.12
Total dissolved solids (mg L^{-1})[2]	175	54	2	4	150	157
Dissolved sodium (mg L^{-1})	20	3	0	0	15	19.1
DIVERTR (Diverting Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	82.9
Chloride (mg L^{-1})	100	12	1	8	35	68.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.9
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.24
Sulfate (mg L^{-1})	25	4	0	0	15	9.6
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.05
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	265
Dissolved sodium (mg L^{-1})	20	4	4	100	15	38.9
EASTBR (East Branch Croton River above East Branch River)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	90.6
Chloride (mg L^{-1})	100	12	0	0	35	48.9
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.09

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

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Sulfate (mg L^{-1})	25	4	0	0	15	8.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	231
Dissolved sodium (mg L^{-1})	20	4	4	100	15	27.1
GYPSYTRL1 (Gypsy Trail Brook)						
Alkalinity (mg L^{-1})	≥40.0	12	10	83	na	28.8
Chloride (mg L^{-1})	100	12	0	0	35	33.9
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.3
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.06
Sulfate (mg L^{-1})	25	5	0	0	15	6.0
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	12	2	17	150	125
Dissolved sodium (mg L^{-1})	20	3	2	67	15	20.0
HORSEPD12 (Horse Pound Brook)						
Alkalinity (mg L^{-1})	≥40.0	12	7	58	na	39.3
Chloride (mg L^{-1})	100	12	0	0	35	47.1
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.36
Sulfate (mg L^{-1})	25	4	0	0	15	7.4
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	<0.02
Total dissolved solids (mg L^{-1})[2]	175	12	4	33	150	167
Dissolved sodium (mg L^{-1})	20	3	2	67	15	21.8
KISCO3 (Kisco River above New Croton Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	83.1
Chloride (mg L^{-1})	100	12	9	75	35	121.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.2
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.58
Sulfate (mg L^{-1})	25	4	0	0	15	16.2
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	382
Dissolved sodium (mg L^{-1})	20	3	3	100	15	43.0
LONGPD1 (Long Pond outflow above West Branch Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	1	8	na	54.7
Chloride (mg L^{-1})	100	12	2	17	35	84.9
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.1

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

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.22
Sulfate (mg L^{-1})	25	5	0	0	15	9.1
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	≤0.02
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	266
Dissolved sodium (mg L^{-1})	20	4	4	100	15	43.6
MIKE2 (Michael's Brook)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	75.5
Chloride (mg L^{-1})	100	12	10	83	35	174.8
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	4.1
Nitrate+nitrite-N (mg L^{-1})	1.5	12	8	67	0.35	3.56
Sulfate (mg L^{-1})	25	4	0	0	15	18.5
Total ammonia-N (mg L^{-1})	0.20	12	2	17	0.10	0.10
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	519
Dissolved sodium (mg L^{-1})	20	3	3	100	15	67.2
MUSCOOT10 (Muscoot River above Amawalk Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	84.0
Chloride (mg L^{-1})	100	12	11	92	35	131.0
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	5.1
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.45
Sulfate (mg L^{-1})	25	4	0	0	15	10.9
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.05
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	406
Dissolved sodium (mg L^{-1})	20	4	4	100	15	62.0
TITICUSR (Titicus Reservoir Release)						
Alkalinity (mg L^{-1})	≥40.0	12	0	0	na	73.3
Chloride (mg L^{-1})	100	12	0	0	35	40.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	3.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.20
Sulfate (mg L^{-1})	25	4	0	0	15	8.3
Total ammonia-N (mg L^{-1})	0.20	12	2	17	0.10	0.08
Total dissolved solids (mg L^{-1})[2]	175	12	12	100	150	196
Dissolved sodium (mg L^{-1})	20	4	3	75	15	20.9
WESTBR7 (West Branch Croton River above Boyd Corners Reservoir)						
Alkalinity (mg L^{-1})	≥40.0	12	9	75	na	35.0
Chloride (mg L^{-1})	100	12	0	0	35	33.7

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

Site/Analyte	Single sample maximum (SSM)	Number samples	Number exceeding SSM	Percent exceeding SSM	Annual mean standard	2014 Mean[1]
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	5.0
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.35	0.04
Sulfate (mg L^{-1})	25	4	0	0	15	5.5
Total ammonia-N (mg L^{-1})	0.20	12	0	0	0.10	0.02
Total dissolved solids (mg L^{-1})[2]	175	12	0	0	150	128
Dissolved sodium (mg L^{-1})	20	4	2	50	15	19.2
WESTBRR (West Branch Reservoir Release)						
Alkalinity (mg L^{-1})	≥10.0	12	0	0	na	25.6
Chloride (mg L^{-1})	50	12	0	0	10	23.7
Dissolved organic carbon (mg L^{-1})	25	12	0	0	9	2.5
Nitrate+nitrite-N (mg L^{-1})	1.5	12	0	0	0.40	0.10
Sulfate (mg L^{-1})	15	4	0	0	10	5.7
Total ammonia-N (mg L^{-1})	0.25	12	0	0	0.05	0.06
Total dissolved solids (mg L^{-1})[2]	50	12	12	100	40	94
Dissolved sodium (mg L^{-1})	10	4	4	100	5	13.5

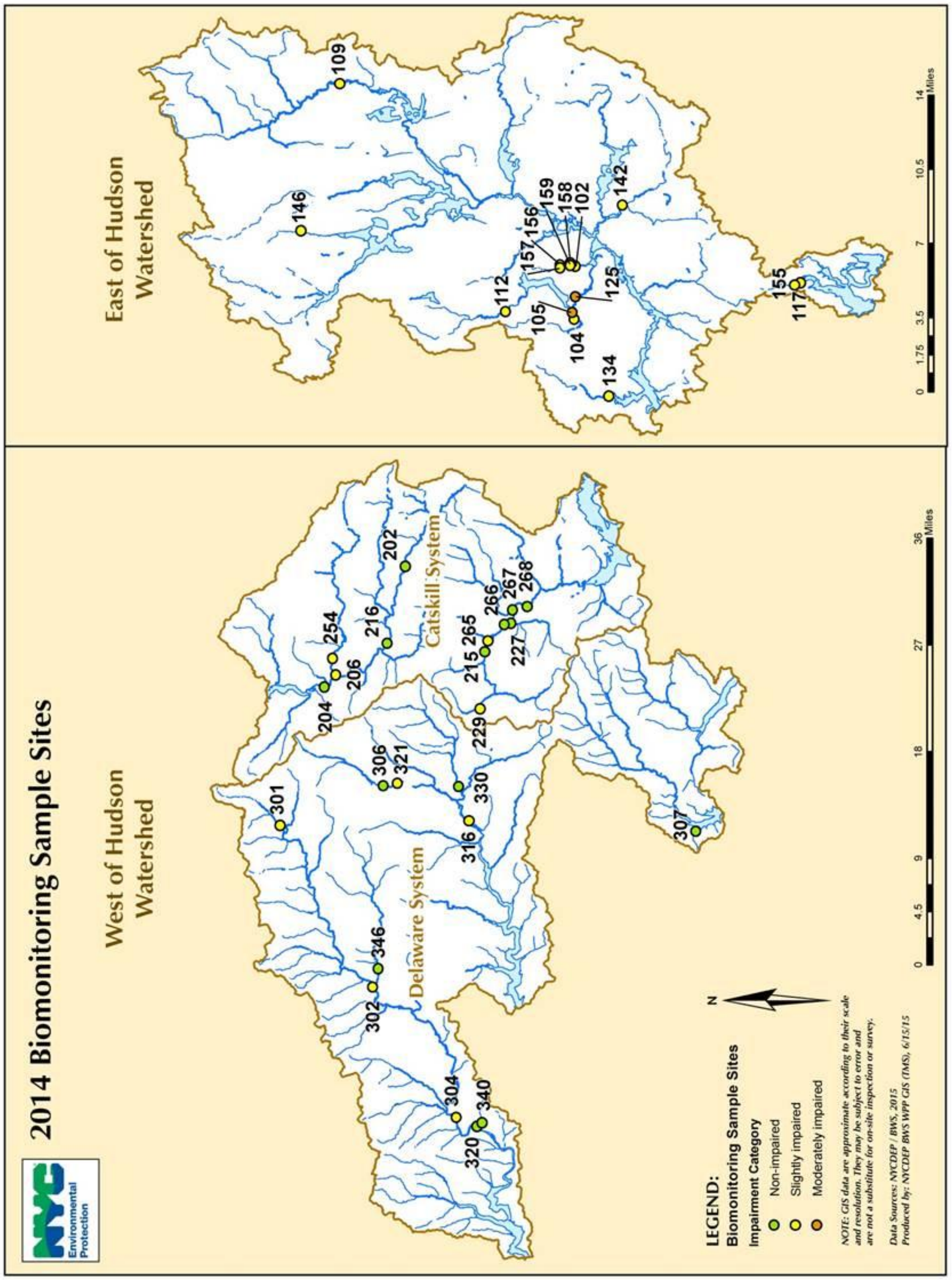
[1]Means were estimated using recommended techniques according to Helsel (2005). For 100% uncensored data the arithmetic mean is reported. For <50% censored data the mean is estimated using the Kaplan-Meier Method as described in Helsel (2005). These estimates are underlined with one line. For 50-80% censored data, the robust ROS method was used. These estimates are underlined using two lines. In cases where >80% of the data is censored, the mean cannot be estimated and here we report the detection limit with the prefix "<".

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

[3]In 2014, CROFALLSVC, CROSSRVVC, SRR2CM and BOYDR were sampled weekly for dissolved organic carbon and total dissolved solids. SRR2CM was sampled approximately weekly for the entire year, while BOYDR was sampled monthly from January to June and weekly thereafter.

Appendix F

Biomonitoring Sampling Sites



Appendix Figure 1. Biomonitoring sampling sites.

Appendix G
Semivolatile and Volatile Organic Compounds

EPA 525.2 – Semivolatiles

2,4-Dinitrotoluene, 2,6-Dinitrotoluene, 4,4-DDD, 4,4-DDE, 4,4-DDT, Acenaphthene, Acenaphthylene, Acetochlor, Alachlor, Aldrin, Alpha-BHC, alpha-Chlordane, Anthracene, Atrazine, Benz(a)Anthracene, Benzo(a)pyrene, Benzo(b)Fluoranthene, Benzo(g,h,i)Perylene, Benzo(k)Fluoranthene, Beta-BHC, Bromacil, Butachlor, Butylbenzylphthalate, Caffeine, Chlorobenzilate, Chloroneb, Chlorothalonil(Draconil,Bravo), Chlorpyrifos (Dursban), Chrysene, Delta-BHC, Di-(2-Ethylhexyl)adipate, Di(2-Ethylhexyl)phthalate, Diazinon, Dibenz(a,h)Anthracene, Dichlorvos (DDVP), Dieldrin, Diethylphthalate, Dimethoate, Dimethylphthalate, Di-n-Butylphthalate, Di-N-octylphthalate, Endosulfan I (Alpha), Endosulfan II (Beta), Endosulfan Sulfate, Endrin, Endrin Aldehyde, EPTC, Fluoranthene, Fluorene, gamma-Chlordane, Heptachlor, Heptachlor Epoxide (isomer B), Hexachlorobenzene, Hexachlorocyclopentadiene, Indeno(1,2,3,c,d)Pyrene, Isophorone, Lindane, Malathion, Methoxychlor, Metolachlor, Metribuzin, Molinate, Naphthalene, Parathion, Pendimethalin, Pentachlorophenol, Permethrin (mixed isomers), Phenanthrene, Propachlor, Pyrene, Simazine, Terbacil, Terbuthylazine, Thiobencarb, trans-Nonachlor, Trifluralin, 1,3-Dimethyl-2-nitrobenzene, Acenaphthene-d10, Chrysene-d12, Perylene-d12, Phenanthrene-d10, Triphenylphosphate

EPA 524.2 - Volatile Organics

1,1,1,2-Tetrachloroethane, 1,1,1-Trichloroethane, 1,1,2,2-Tetrachloroethane, 1,1,2-Trichloroethane, 1,1-Dichloroethane, 1,1-Dichloroethylene, 1,1-Dichloropropene, 1,2,3-Trichlorobenzene, 1,2,3-Trichloropropane, 1,2,4-Trichlorobenzene, 1,2,4-Trimethylbenzene, 1,2-Dichloroethane, 1,2-Dichloropropane, 1,3,5-Trimethylbenzene, 1,3-Dichloropropane, 2,2-Dichloropropane, 2-Butanone (MEK), 4-Methyl-2-Pentanone (MIBK), Benzene, Bromobenzene, Bromochloromethane, Bromodichloromethane, Bromoethane, Bromoform, Bromomethane (Methyl Bromide), Carbon disulfide, Carbon Tetrachloride, Chlorobenzene, Chlorodibromomethane, Chloroethane, Chloroform (Trichloromethane), Chloromethane(Methyl Chloride), cis-1,2-Dichloroethylene, cis-1,3-Dichloropropene, Dibromomethane, Dichlorodifluoromethane, Dichloromethane, Di-isopropyl ether, Ethyl benzene, Hexachlorobutadiene, Isopropylbenzene, m,p-Xylenes, m-Dichlorobenzene (1,3-DCB), Methyl Tert-butyl ether (MTBE), Naphthalene, n-Butylbenzene, n-Propylbenzene, o-Chlorotoluene, o-Dichlorobenzene (1,2-DCB), o-Xylene, p-Chlorotoluene, p-Dichlorobenzene (1,4-DCB), p-Isopropyltoluene, sec-Butylbenzene, Styrene, tert-amyl Methyl Ether, tert-Butyl Ethyl Ether, tert-Butylbenzene, Tetrachloroethylene (PCE), Toluene, Total 1,3-Dichloropropene, Total THM, Total xylenes, trans-1,2-Dichloroethylene, trans-1,3-Dichloropropene, Trichloroethylene (TCE), Trichlorofluoromethane, Trichlorotrifluoroethane(Freon 113), Vinyl chloride (VC), 1,2-Dichloroethane-d4 4-Bromofluorobenzene, Toluene-d8

Herbicides

glyphosate