2012 Kensico Water Quality Annual Report

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NYC Environmental Protection

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List of Acronyms

BMP	Best Management Practice
CATALUM	Catskill Alum Chamber
CATIC	Catskill Influent Chamber
CATLEFF	Catskill Lower Effluent Chamber
CATUEC	Catskill Upper Effluent Chamber
CDUV	Catskill-Delaware Water Ultraviolet Disinfection Facility Plant
DEL17	Delaware Aqueduct Shaft Building 17
DEL18	Delaware Aqueduct Shaft Building 18 or Site code for the Delaware Aqueduct, untreated sample pump effluent from Kensico Reservoir. Sampled until September 11, 2002 at Shaft 18 downtake, when the location was changed from the downtake to the forebay. As of August 20, 2012 this is no longer the compliance raw source water effluent sample location.
DEL18DT	Site code for the Delaware Aqueduct Shaft 18 Downtake. As of August 20, 2012 this is the pumped compliance raw source water effluent sample location.
DEP	New York City Department of Environmental Protection
DMR	Discharge Monitoring Report
DOH	New York State Department of Health
DOT	Department of Transportation
EOH	East of Hudson
EPA	United States Environmental Protection Agency
FAD	Filtration Avoidance Determination
HEV	Human Enteric Virus
IMR	Inter-Municipal Agreement
MPN	Most Probable Number
MST	Microbial Source Tracking
NTU	Nephelometric Turbidity Units
NYC	New York City
NYSDEC	New York State Department of Environmental Conservation
SEQR	State Environmental Quality Review
SPDES	State Pollution Discharge Elimination System
SVOC	Semivolatile Organic Compound
SWTR	Surface Water Treatment Rule
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WMP	Waterfowl Management Program
WWQMP	Watershed Water Quality Monitoring Plan

Acknowledgements

This report is intended to provide an accurate description of the water quality of Kensico Reservoir during 2012, the watershed events which have affected water quality, and the scientific investigations and monitoring programs conducted by DEP that allow the staff to operate Kensico Reservoir to ensure delivery of safe and high quality water to NYC consumers. In order to accomplish that goal, the Deputy Commissioner of the Bureau of Water Supply, Mr. Paul Rush, P.E.; Assistant Commissioner, Mr. David Warne; Director of Water Quality, Mr. Steven Schindler; and Director of Operations, Ms. Tina L. Johnstone, P.E., provided general direction for operation of Kensico Reservoir and watershed activities throughout 2012. The reservoir undergoes continuously changing conditions that affect water quality and this requires their on-going review of the changing conditions of Kensico, the most important reservoir of the NYC drinking water supply, to provide responsive management.

The members of the Watershed Water Quality Science and Research Division were responsible for coordination, data analysis, and primary authorship roles for the 2012 Kensico Water Quality Annual Report. They include: Dr. Lorraine Janus, Mr. James Mayfield, Ms. Kerri Alderisio, Dr. Don Pierson, Mr. Gerard Marzec, Mr. Rich Van Dreason, Mr. David Quentin, Mr. Christian Pace, Dr. Elliot Schneiderman, Mr. Mark Zion, Mr. David Lounsbury, and Mr. Don Kent. We also acknowledge Mr. Michael Meyer, Section Chief, Community Planning Administrative Project Manager, for providing the information on the Kensico Water Quality Control Program.

The members of Watershed Water Quality Operations, directed by Ms. Lori Emery, provided the watershed field and laboratory work and resulting database for this report. The Waterfowl Management Program (WMP) was directed by Mr. Chris Nadareski, who contributed the written section on the WMP. The East of Hudson Operations directed by Mr. Charles Cutietta-Olson, and the Pathogen Laboratory directed by Ms. Lisa Blancero McDonald, and their staff members, were also contributors.

Thanks are also due to the many people behind the scenes. These include the administrative, information technology, health and safety, and quality assurance staff who support the DEP programs. Although we could not name everyone, thanks go to all those who contributed directly and indirectly to this report.

Executive Summary

The 2007 Filtration Avoidance Determination (Section 4.10 Kensico Water Quality Control Program) requires DEP to produce an annual report that includes a presentation, discussion, and analysis of monitoring data (e.g., keypoint, reservoir, streams). This report satisfies that requirement by analyzing and discussing ongoing water quality data collections as well as any departures from routine operations. Compliance with the Safe Drinking Water Act's Surface Water Treatment Rule (SWTR) is of paramount importance to DEP for maintaining Filtration Avoidance; therefore, fecal coliform and turbidity are focal points of the discussion. DEP's ongoing Waterfowl Management Program, which has been instrumental in keeping coliform bacteria concentrations low, is described. Other sections include information regarding the protozoan pathogens *Cryptosporidium* and *Giardia*, and human enteric viruses.

The Waterfowl Management Program (WMP) continued to maintain a high level of success during 2012. This was demonstrated by full compliance with the SWTR requirements for fecal coliform bacteria in raw water samples, which is only possible when resident and migratory waterfowl populations are minimized. With the exception of a brief period following Hurricane Irene in 2011 low levels of fecal coliform bacteria have been consistently achieved since 1993. The implementation of the WMP continues to be the most cost-effective way to achieve compliance with the SWTR.

DEP continued to meet its reporting obligations for engineering and scientific reports as specified in the Catskill Influent Chamber SPDES permit. As in the past, DEP also conducted visual inspections of the turbidity curtain at the Catskill Upper Effluent Chamber cove in 2012. During the year the boom required only one instance of maintenance.

There were no special investigations conducted within the Kensico Reservoir watershed during 2012. No spills or unusual water quality events occurred in the watershed. However, there were several special sampling efforts made to address potential water quality concerns caused by storm events.

In addition to the routine monitoring and special investigations, DEP also undertook several research projects related to Kensico. DEP continued a scientific collaboration with Harvard School of Public Health (HSPH), and one of those projects is focused on "Hydrodynamic Circulation in Kensico Reservoir" using the CE-QUAL-W2 model. Another project was initiated to examine potential control measures for bryozoan colonies, which were found downstream of Shaft 18 at the Catskill-Delaware Water Ultraviolet Disinfection Facility Plant (CDUV) entry point, and caused clogging issues at the 1" perforated plates located just prior to the UV lamps. The third project calls for additional monitoring in Kensico when a storm is predicted to deliver significant rainfall to the area. The main objectives for this additional monitoring include getting an approximate timeline for any impacts that elevated microbial counts at the streams may have on the outflows of the reservoir, and, if elevated fecal coliforms are detected, attempt to determine whether the source is human or animal through Microbial Source Tracking (MST).

Kensico Reservoir water quality monitoring that was conducted in 2012 included approximately 5,900 samples collected at 35 sites throughout the basin, with the highest frequency of monitoring at the effluent keypoint sites. The next most frequently sampled sites were those located throughout the reservoir itself. Grab samples were taken at the effluent keypoint sites over 4,100 times and in the reservoir 741 times. In addition, 290 pathogen samples were analyzed for *Cryptosporidium* and *Giardia*, and another 203 samples were collected for human enteric viruses (HEV).

DEP continues to monitor the hydrology of the Kensico watershed. Samples were collected monthly 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). All Kensico streams had median fecal coliform values well below 200 coliforms $100mL^{-1}$. For total coliform bacteria, all Kensico streams had annual median values below the DEC guidance value of 2,400 total coliforms $100mL^{-1}$. Eighteen values of more than 5,000 total coliforms $100mL^{-1}$ occurred, most of which were associated with a sample being collected during or immediately following rain events. The median turbidity data for all stream sites was less than 5 NTU. In addition to coliform bacteria, turbidity, and pathogens, DEP also monitors the perennial streams for other analytes, including temperature, pH, specific conductivity, alkalinity, dissolved oxygen, chloride, total suspended solids, and nutrients. Descriptive statistics of the 2012 results for these analytes are presented.

In 2012, 466 total coliform and 473 fecal coliform bacteria samples were collected throughout Kensico Reservoir during routine limnological surveys. The medians for total coliform samples were below the DEP guidelines of 100 coliforms $100mL^{-1}$ at all sites, and none of the samples at sites 7 and 8 exceeded this value. The median fecal coliforms counts were < 1 coliform $100mL^{-1}$ at all sites, and only two values were at or above 20 coliforms $100mL^{-1}$. Total coliform counts typically exceed the guideline in late summer and autumn when most reservoirs experience an increase in bacteria counts. There were 466 turbidity samples collected on routine reservoir surveys in 2012. Site 5 had the highest median turbidity (2.2 NTU), and individual samples for this site exceeded 5.0 NTU only two times. None of the samples collected on the routine surveys exceeded 5 NTU at the sites closest to the effluent chambers (sites 2 and 3).

DEP took over the operation of a robotic monitoring network on the reservoir (not included in the summary table) beginning on December 15, 2011. This network consists of two fixed-depth buoys in front of the intake sites (the buoy for the Catskill intake was relocated outside the Catskill effluent cove when sampling at CATLEFF ended), as well as a profiling buoy at Site 4. The fixed depth buoys monitor for transmissivity at 3 fixed-depths while the profiling buoy can measure temperature, specific conductivity, and turbidity throughout the water column. The robotic monitoring equipment is expected to provide new insights and water quality management opportunities based on high frequency measurements that are not otherwise available. These data are used as model input (initial conditions) and to evaluate reservoir water quality model performance and to assist in guiding operational decisions.

DEP has routinely conducted water quality compliance monitoring at the four 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 CATLEFF and DEL18 effluent keypoints represent Kensico Reservoir water leaving the reservoir and entering the Catskill and Delaware Aqueducts, respectively, at points just prior to disinfection, and are the sites which must meet SWTR "raw water" requirements. As of August 20, 2012 the DEL18 sample was relocated from a pump located within the forebay at Shaft 18 at Kensico to a new sample pump installed in the downtake at Shaft 18. The new site, named DEL18DT, replaced the previous site, DEL18, as the DEL18 effluent keypoint sample. Also, the Catskill-Delaware Water Ultraviolet Disinfection Facility Plant (CDUV) was activated on September 14, 2012. This led to the shutdown of the section of the Catskill Aqueduct from Kensico to Eastview because it is not pressurized and thus not able to deliver water to the plant. With this development CATLEFF was discontinued as a keypoint site.

The median fecal coliform level for 2012 at the Kensico influents (CATALUM and DEL 17) was <1 fecal coliform $100mL^{-1}$ for both sites, and was <1 fecal coliform $100mL^{-1}$ at CATLEFF and was 1 fecal coliform $100ml^{-1}$ at the DEL18 sites (data from DEL18 and DEL18DT combined). In 2012 there were no reported values at the effluent sites that exceeded the 20 fecal coliforms $100mL^{-1}$ guideline. At the influent sites, median turbidity for 2012 was 7 NTU at CATALUM and 1 NTU at DEL17. At the effluent sites, median turbidity for 2012 was 1.0 NTU at DEL18 (again data from DEL18 and DEL18DT combined) and the median turbidity at CATLEFF from January 1 until the shutdown of CATLEFF on September 14, 2012 was 0.80 NTU. The maximum 4-hour turbidity measurements were 5.4 NTU at CATLEFF on April 19 and 6.0 NTU at DEL18DT on October 29. The DEL18DT maximum occurred during a wind event as Hurricane Sandy neared the New Jersey shore. This resulted in a Tier 2 treatment technique violation of the Surface Water Treatment Rule (SWTR).

DEP is responsible for performing compliance and surveillance monitoring of protozoan pathogens (*Cryptosporidium* and *Giardia*) and human enteric viruses (HEV) in the New York City Watershed. In 2012, 290 samples were collected and analyzed for *Giardia* and *Cryptosporidium* in the Kensico Reservoir watershed. Normally, 208 routine samples would be collected among the four keypoints at Kensico in a given year; however, as noted above, this year the Catskill Aqueduct effluent was shut down in September. Therefore, only 193 fixed frequency samples were collected at the two influents and two effluents combined, as well as 96 fixed frequency samples collected at eight perennial tributaries. One additional protozoan sample was collected in 2012 for reasons discussed further in Section 4.4. In addition, 193 routine samples were collected and analyzed for human enteric viruses (HEV), with 184 analyses completed by December 2012. An additional ten samples were collected for alternate virus filter testing, for a combined total of 203 HEV samples. In general, 2012 results were consistent with past data in that *Cryptosporidium* was found infrequently and at low concentrations, while *Giardia* were found more frequently and at higher concentrations than *Cryptosporidium*.

Of the 194 samples collected at the Kensico keypoints, only one sample was positive for *Cryptosporidium* at the influents, and only one at the effluents. In both cases, only a single oocyst was detected. *Giardia* detections were more frequent with 27 (42.8%) samples positive and the reservoir influent and effluent maxima were 5 and 4 cysts $50L^{-1}$, respectively. HEVs were detected in 28 of the 184 completed samples (15.2%). Percent detections for *Cryptosporidium, Giardia,* and HEVs were all lower in 2012 than 2011 (1.8%, 66.4%, and 18.8%, respectively for 2011). However, as mentioned, the Catskill effluent was shut down in September 2012 (last sample September 10), which resulted in fewer samples for the year. This makes it difficult to compare 2012 results with those from prior years, especially since detection rates can vary with the seasons. Notably, 2012 was the first year since monitoring began with

Method 1623 (2001) that one of the Kensico Reservoir effluents (Delaware) had no detections of *Cryptosporidium* for the entire calendar year.

Cryptosporidium detections were quite low in Kensico stream samples (7 out of 96 samples) and although some of the volumes varied for the stream samples, no more than 2 oocysts were detected in a single sample. As is usual, *Giardia* was much more prevalent, with 75.0% (72 of 96) of samples positive, and a maximum of 240 cysts in a 34.8L sample.

The annual surveillance of Kensico Reservoir keypoint DEL18DT for 67 volatile organic compounds (VOCs) and 68 semivolatile organic compounds (SVOCs) resulted in no compounds being detected. CATLEFF was not sampled this year as it was shutdown in September 2012 prior to the sampling, which occurred in December.

During 2012 nine sets of Kensico Reservoir water quality modeling analyses were performed to support operational decisions. The first four simulation sets were related to timing of possible ending of alum treatment which had commenced on August 29, 2011 due to Hurricane Irene and Tropical Storm Lee. Further simulations were required throughout the year to examine the effects of changes in reservoir operations; and to help choose an optimal reservoir operating strategies that would minimize the impacts on Kensico effluent turbidity. Model runs during the fall of 2012 focused on the aftermath of a major storm event in September. These model simulations were effective in helping to determine flow rates that maintained water quality standards while avoiding the use of alum for this event.

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1. Introduction to Kensico Streams, Reservoir, and Keypoint Monitoring Data

The 2007 Filtration Avoidance Determination (Section 4.10, Kensico Water Quality Control Program) calls for semiannual reporting on the implementation of Kensico protection programs. On an annual basis, a report must also be prepared that includes a presentation, discussion, and analysis of water quality monitoring data (e.g., data relating to keypoints, reservoirs, streams, best management practices (BMPs) as well as the status and application of the Kensico Reservoir model. This report fulfills that requirement. In addition to this report, the FAD Assessment Report (DEP 2011a; updated every five years) contains a review of the status of Kensico water quality over the last three years (2007-2009), as well as an examination of the observed trends in water quality from 1993-2009.

The purpose of this report is to analyze and discuss ongoing water quality data collections to assess the efficacy of protection programs and improve management operations if possible. Compliance with the Safe Drinking Water Act's Surface Water Treatment Rule is of paramount importance to DEP for maintaining Filtration Avoidance; therefore, fecal coliform and turbidity are focal points of the discussion. DEP's ongoing Waterfowl Management Program, which has been instrumental in keeping coliform bacteria concentrations low, is also described. Other sections include information regarding the protozoan pathogens *Cryptosporidium* and *Giardia*, and human enteric viruses. The Kensico Water Quality Control Program is designed to reduce fecal coliform, toxic chemicals, and turbidity in Kensico Reservoir. An annual report (e.g. DEP 2013) discusses the status of the components of the Kensico Water Quality Control Program during the year, while a semiannual report is a brief report due on July 31 of each year that discusses the status of the components of the Kensico Water Quality Control Program during the first half of the year (e.g. DEP 2012a).

When operated in its normal "reservoir" mode, water enters Kensico Reservoir at the Catskill Influent Chamber (CATIC) and at Delaware Shaft 17 (DEL17), and leaves the reservoir at the Catskill Upper Effluent Chamber (CATUEC) and Delaware Shaft 18 (DEL18). On September 14, the Catskill Aqueduct between Kensico Reservoir and the new Catskill/Delaware Ultraviolet Disinfection Facility was isolated from the system, and water is no longer diverted through the CATUEC. Kensico Reservoir was operated primarily in "reservoir" mode in 2012.

The Delaware Aqueduct leaving Kensico Reservoir was shutdown 124 times over the course of the entire year, primarily for work associated with construction and start-up of the new Catskill-Delaware UV Facility. The Catskill Aqueduct leaving Kensico Reservoir was shutdown six times for scheduled work and inspections prior to the final shutdown on September 14.

There were no unplanned shutdowns of the Catskill Aqueduct at Kensico due to water quality problems associated with wind or precipitation events in 2012. The Delaware Aqueduct at Kensico was never shut down for water quality reasons, but it was operated in float mode due to severe storms at Kensico during the periods October 29 to 31 (Hurricane Sandy), November 7 to 8, and December 26 to 27. Float operation allows DEP to deliver better quality water from Rondout Reservoir and/or West Branch Reservoir to Hillview, with Kensico Reservoir water added only if needed to meet demand.

2. Water Quality Management

2.1 Waterfowl Management

While DEP's Wildlife Studies Section is responsible for general oversight of the Waterfowl Management Program (WMP), primary program implementation is the responsibility of a consultant, Henningson, Durham, and Richardson, P.C. The current Waterfowl Management Program Contract (WMP-12) is expected to continue through September 17, 2014. For a more detailed account of the WMP, refer to the annual FAD report (DEP 2012b) on this topic dated July 31, 2012 (required under Section 4.1 of the FAD).

The objectives of the WMP are:

- Survey and record daily water bird counts from 5:00am to 8:00am, including spatial and temporal distribution of roosting water birds, and document behavioral changes of the birds from August 1 through March 31. Survey frequency is decreased to weekly from April 1 through July 31. All morning surveys are conducted from a boat and/or the shoreline. The morning survey data are used to evaluate the success of the previous day's bird harassment efforts. The bird data are also compared with reservoir effluent water quality data to assess the impacts of birds on fecal coliform bacteria levels, which are monitored for SWTR requirements.

Figure 2-1 Airboat deployed for waterfowl management at Kensico Reservoir.

- Conduct daily water bird dispersal activities from 8:00am until 1.5 hours past sunset from August 1 through March 31. Dispersal activities include harassment via motorboats, Airboats, (Figure 2-1), and pyrotechnics (Figure 2-2), where needed.
- Record seasonal surveillance of reservoir influent facilities for alewives (*Alosa pseudoharengus*), and other baitfish-sized fish. Dead and dying fish transported through the NYC aqueducts from upstream reservoirs to Kensico attract water bird foraging. To eliminate this feeding attraction, containment booms are used to collect the fish, followed by daily removal and disposal by the DEP contractor.

Figure 2-2 Contractor staff conducting bird dispersal measures at Kensico Reservoir using pyrotechnics.

Additional water bird management measures employed annually include the following:

- Depredation of eggs and nests of Canada Geese (*Branta canadensis*) and Mute Swans (*Cygnus olor*), under federal and state permits, from April through May annually.
- Maintenance of bird netting at the Delaware Shaft 18 (DEL18) facility to deter Barn Swallow (*Hirundo rustica*) and Cliff Swallow (*Hirundo pyrrhonota*) nesting and occasional perching of European Starlings (*Sturnus vulgaris*) and Rock Pigeons (*Columba livia*) to decrease bird fecal contamination of the untreated water entering the facility.
- Annual banding activities conducted with New York State Department of Environmental Conservation (NYSDEC). These activities involve placing identification bands on Canada Geese and Double-crested Cormorants (*Phalacrocorax auritus*) in order to monitor local movements to and from the reservoirs.
- Use of similar management measures at six additional reservoirs on an "as needed" basis as outlined in the 2007 FAD. These additional reservoirs include five which are upstream source waters (or potential source waters) to Kensico (Rondout, West Branch, Ashokan, Croton Falls, and Cross River), and one downstream reservoir (Hillview), which receives water from Kensico.
- Continued consultation with the United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services (USDA) and NYSDEC on water bird management techniques.

2.2 Turbidity Curtain Monitoring

A double turbidity curtain was previously installed at the Catskill Effluent location in Kensico Reservoir to protect water entering into distribution from the impacts of storm events on local streams. DEP's Water Quality Directorate conducts biweekly visual inspections of the turbidity curtain at the Catskill Upper Effluent Chamber cove. Table 2-1 lists the dates and results of the turbidity curtain inspections carried out in 2012. If an observation indicated that maintenance was required, BWS Systems Operations was notified and conducted appropriate repairs or adjustments. For example, the issues observed on December 19, 2012 were reported and the necessary repairs were made.

Table 2-1 2012 visual inspections of the Catskill Upper Effluent Chamber turbidity curtain.

Inspection Date	Observations
1/4/2012	Curtain appears intact and afloat as seen from shore.
1/18/2012	Curtain appears intact and afloat as seen from shore.
2/1/2012	Curtain appears intact and afloat as seen from shore.
2/15/2012	Curtain appears intact and afloat as seen from shore.
2/29/2012	Curtain appears intact and afloat as seen from shore.
3/15/2012	Curtain appears intact and afloat as seen from shore.
3/28/2012	Curtain appears intact and afloat as seen from shore.
4/11/2012	Curtain appears intact and afloat as seen from shore.

Table 2-2 (cont.) 2012 visual inspections of the Catskill Upper Effluent Chamber turbidity curtain.

Inspection Date	Observations
4/25/2012	Curtain appears intact and afloat as seen from shore.
5/9/2012	Curtain appears intact and afloat as seen from shore.
5/23/2012	Curtain appears intact and afloat as seen from shore.
6/6/2012	Curtain appears intact and afloat as seen from shore.
6/20/2012	Curtain appears intact and afloat as seen from shore.
7/5/2012	Curtain appears intact and afloat as seen from shore.
7/19/2012	Curtain appears intact and afloat as seen from shore.
8/1/2012	Curtain appears intact and afloat as seen from shore.
8/15/2012	Curtain appears intact and afloat as seen from shore.
8/31/2012	Curtain appears intact and afloat as seen from shore.
9/12/2012	Curtain appears intact and afloat as seen from shore.
9/25/2012	Curtain appears intact and afloat as seen from shore.
10/10/2012	Curtain appears intact and afloat as seen from shore. Maintenance activities observed.
10/24/2012	Curtain appears intact and afloat as seen from shore.
11/7/2012	Curtain appears intact and afloat as seen from shore.
11/21/2012	Curtain appears intact and afloat as seen from shore.
12/5/2012	Curtain appears intact and afloat as seen from shore.
12/19/2012	Sections of the turb curtain are below the surface of the water. One section is south of CATUEC. The other is across the cove and north of CATUEC.

2.3 Power Line Right-of-Way Management

No significant work was conducted by ConEd on the electric transmission right-of-way at Kensico in 2012. The last work with potential consequences for water quality was done in 2010, which consisted of clearing trees to provide reliability of the power line and replanting the area with native species.

2.4 Alum Treatment and Dredging

The recent history of events leading to alum treatments of turbidity in the Catskill Aqueduct began in 2005. Several extreme rain events were experienced in upstate New York in April 2005, creating record flooding, extensive erosion of stream banks, and high turbidity levels in water entering the Catskill Aqueduct at Ashokan Reservoir. NYSDEC issued two emergency authorizations in 2005 (April and October) and a SPDES permit on December 20, 2006 to authorize the use of alum under appropriate conditions. Subsequent to this, in late August and early September of 2011, Tropical Storms Irene and Lee created major flooding in the Catskills which necessitated additional alum treatment of the Catskill System. This treatment began on August 29, 2011 and ended on May 15, 2012. Details may be found in the After Action Report that was prepared following the end of treatment (DEP 2012c).

NYSDEC and DEP agree that there are potential benefits of deferring dredging at Kensico until the completion of infrastructure projects that are expected to eliminate the need to use alum. In this way, the potential need to dredge more than once could be eliminated, which would reduce the risk of a turbidity event caused by the dredging, reduce operational challenges during dredging, and reduce the impact on the environment within Kensico Reservoir.

2.5 Kensico Research Projects

In addition to the routine monitoring and special investigations, DEP also undertook several research projects related to Kensico, as described below.

Harvard School of Public Health Collaboration

During 2012 DEP continued a scientific collaboration with Harvard School of Public Health (HSPH). One of three specific projects is focused on "Hydrodynamic Circulation in Kensico Reservoir." In this project, Numerical Tracer Experiments using the CE-QUAL-W2 model for Kensico Reservoir have been conducted and visualized to demonstrate changes in stratification, water age, and theoretical movement of a tracer through Kensico. The visualization can provide insight into how substances move through the reservoir under different conditions of stratification and flow. A "numerical tracer" is used as input for a two-dimensional computer model of Kensico reservoir, and the model run can demonstrate how water quality may change during simulations of increased flow through the reservoir. The model output will be evaluated in comparison to both current monitoring at Kensico Reservoir as well as hypothetical weather scenarios created for the purpose of testing hypotheses about transport of materials through Kensico. This modeling work provides greater resolution to the previous approximations of water residence time in Kensico and may provide additional guidance for operations.

The transport of *Giardia*, *Cryptosporidium*, and fecal coliforms at Kensico Reservoir during high flow events is not well understood. While modeling living organisms has its difficulties, an effort is being made to use CEQUAL-W2 to run various scenarios of precipitation, wind, flow, and microbial concentration inputs to attempt to mimic observations at the outflow of Kensico. Modeling of Kensico during high flow events will give insight into how the system may be operated to improve water quality that enters into the distribution system, which may gain importance if more intense storms become more frequent in the future.

Bryozoan Research

Bryozoans were identified in Kensico Reservoir as early as the late 1980s and early 1990s. The predominant type, *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 had not affected operations until the fall of 2012, shortly after the CDUV plant came on line. Bryozoan colonies were found downstream of Shaft 18 at the CDUV plant, and caused clogging issues at the 1" perforated plates located just prior to the UV lamps. The openings were manually cleared of the gelatinous colonies, but this was very labor intensive. It raised the question of whether or not there are some control measures available to DEP to alleviate this problem. A literature search was begun and other water professionals are being contacted to determine if there are 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.

Kensico Storm Event Sampling

As identified in the Kensico Storm Event Sampling Plan, Kensico watershed is sampled more frequently than routine monitoring when a storm is predicted to deliver significant rainfall to the area. DEP performs intensified monitoring at stream, reservoir and outflow locations for turbidity, conductivity and fecal coliforms during these events. The main objectives for this additional monitoring include getting an approximate timeline for any impacts that elevated microbial counts at the streams may have on the outflows of the reservoir, and, if elevated fecal coliforms are detected, attempt to determine whether the source is human or animal through the analysis of *Bacteroides*. *Bacteroides* analysis is a tool used in Microbial Source Tracking (MST) and can help to differentiate the source of fecal contamination. The origin of the fecal bacteria is of interest to determine possible public health risks and to minimize specific sources through targeted watershed protection projects.

3. Routine Sampling Strategy

The routine sampling strategy for Kensico is documented in the 2009 Watershed Water Quality Monitoring Plan (WWQMP) (DEP 2009a). The plan is designed to meet the broad range of DEP's many regulatory and informational requirements. The plan prescribes monitoring to achieve compliance with all federal, state, and local regulations; meet the terms of the 2007 FAD; 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.

The overall water quality sampling effort within the Kensico basin for 2012 is summarized in Table 3-1 and the results from these samples are discussed throughout the remainder of this report. A map of routine sampling sites is shown in Figure 3-1. Aside from the routine monitoring, there were also three special sampling efforts conducted in 2012 related to storm events, as previously, and the results are presented in section 4.5. Kensico Reservoir water quality monitoring that was conducted in 2012 included samples from 29 sites throughout the watershed, including eight stream sites and eight routine limnological sites, with another 13 limnological sites that were sampled once or more during the year for various reasons, mostly related to storm events. In addition, DEP took over the operation of a robotic monitoring network on the reservoir (not included in the summary table) beginning on December 15, 2011. This network consists of two fixed-depth buoys in front of the intake sites [the buoy for the Catskill intake was relocated outside the Catskill effluent cove when sampling at CATLEFF ended (see sec. 3.3)], as well as a profiling buoy at Site 4. The fixed depth buoys monitor for transmissivity at three fixed-depths while the profiling buoy can measure temperature, specific conductivity, and turbidity throughout the water column. In addition to the reservoir and stream sites, the keypoints include the Catskill and Delaware Aqueducts' influent and effluent sites to the reservoir, with the highest intensity of monitoring at the effluent keypoints. These keypoint sites receive the highest level of scrutiny because this is where raw water compliance samples are taken to track quality just prior to chlorination and entry into the distribution system. The next most intensely sampled sites were those located throughout the reservoir itself. Grab samples were taken at the keypoint sites 1,173 times and in the reservoir 741 times. In addition, 290 pathogen samples were collected for *Cryptosporidium* and *Giardia* analysis, and another 184 samples were collected for human enteric viruses (HEV). Supplementary information (not included in the summary table) is collected by probes that provide continuous readings. Continuous monitoring of turbidity is recorded on circular charts (Figure 3-2) and sampled manually at 4-hour intervals. Other parameters that are monitored continuously are pH, temperature, and conductivity.

The inflows of the Catskill and Delaware Aqueducts to Kensico Reservoir are regulated by SPDES permits #NY-026-4652 (CATIC) and NY-026-8224 (DEL17), respectively. These permits require a number of analyses to be reported in monthly Discharge Monitoring Reports (DMRs). Additionally, these monitoring data are used to inform operational decisions. The nutrient data collected by the Water Quality Directorate are transmitted to Operations staff via monthly memo and are combined with data collected by Operations to develop and submit the DMR to NYSDEC as required by the permit.

Table 3-1 Summary of Kensico Reservoir water quality samples collected in 2012.

Kensico Sampling Programs	Turbidity	Bacteria	*Giardia*/ *Cryptosporidium*	Virus	Nutrients	Other Chemistry	Metals	Phyto-plankton
SWTR Compliance	3,428	.	.	.	.	.	.	.
Keypoint Effluent	612	612	88	87	24	669	254	254
Keypoint Influent	561	560	106	106	107	561	.	105
Reservoir	741	540	.	.	203	595	41	119
Streams	96	114	96	.	72	104	.	.

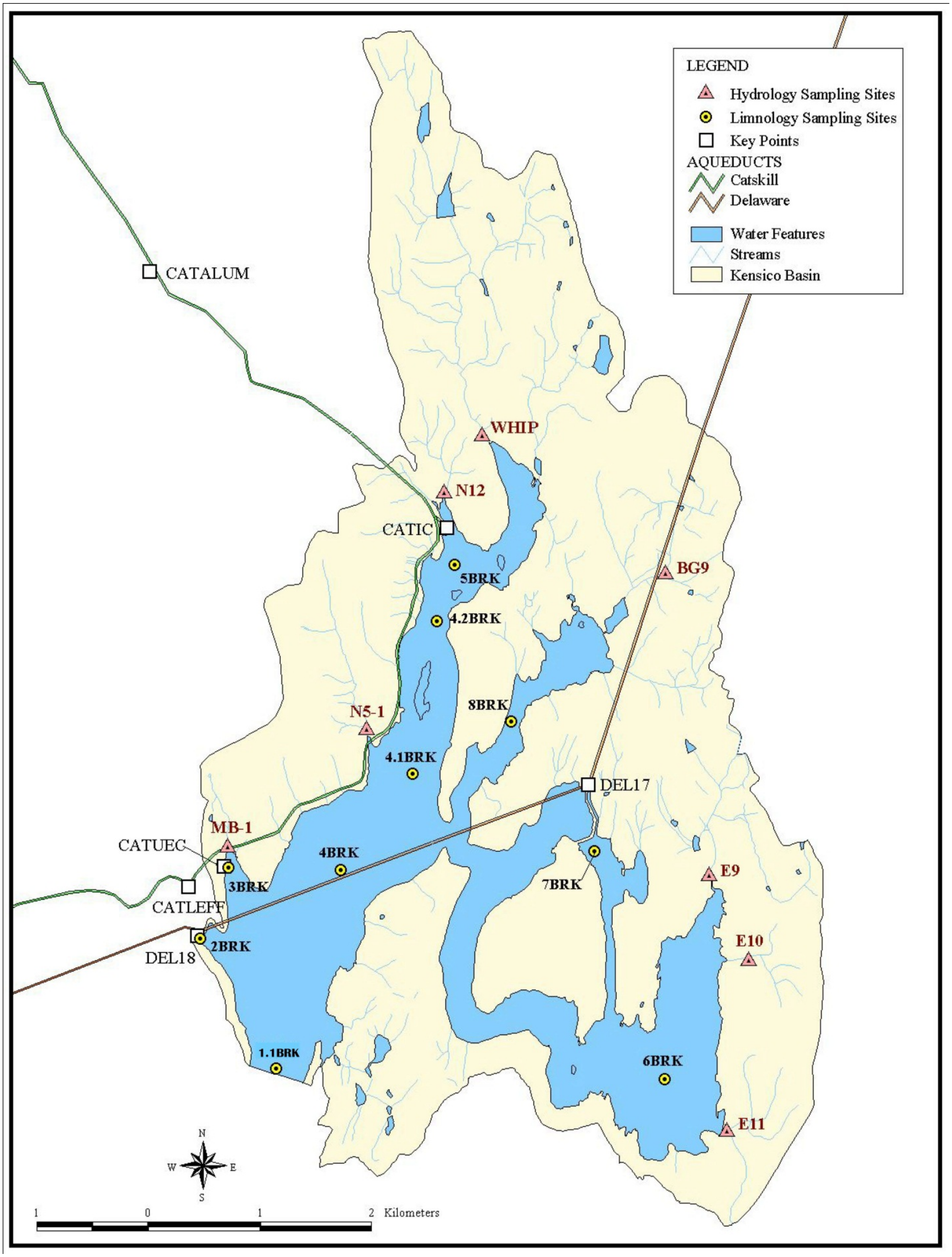

Figure 3-1 Kensico Reservoir, showing limnological and hydrological sampling sites, keypoints, and aqueducts. There is a meteorological station at DEL18.

3.1 Streams

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 3-1. Routine sampling of these streams was conducted monthly in 2012. In addition to the routine program, special investigation samples were collected in response to Hurricane Sandy in October 212 (see sec. 4.5).

Also in 2012, continuous flow measurements were maintained for the year at six of the eight perennial Kensico tributaries. Stage height is recorded on a 15 minute interval and the flow is then calculated based on the appropriate flume, weir or rating curve. Collection of flow data was suspended at the N12 tributary on February 12, 2012 and at the Whippoorwill Creek (WHIP) site on April 27, 2012. In both cases the suspension was due to construction activities, and flow monitoring will be resumed once the construction activity is completed and the necessary flow monitoring equipment is re-installed.

3.2 Reservoir

DEP monitors Kensico Reservoir water quality by routine limnological surveys for a series of physical, chemical, and microbiological parameters. Samples are collected at different depths throughout the water column at fixed sampling locations as shown in Figure 3-1. During the reporting period, routine limnological and supplementary survey monitoring of Kensico Reservoir was conducted twice each month from January through December 2012. The mild winter enabled sampling in January and February.

In addition to the routine surveys, special sampling may be required when a water quality issue or concern develops. These additional surveys involve more frequent sampling at different locations within the reservoir, and/or sampling for additional analytes, as needed. There were 17 turbidity surveys conducted earlier in the year, primarily related to lingering effects of turbidity events initiated by Tropical Storms Irene and Lee in 2011. Four surveys were conducted for fecal coliform and turbidity samples due to localized storm effects, such as the wind-induced turbidity near Shaft 18 after Hurricane Sandy.

Another part of the routine monitoring program was the addition of the robotic monitoring buoys that DEP took over from the Upstate Freshwater Institute (UFI) on December 15, 2011. The profiling buoy at Site 4.1 required routine maintenance and exchange of calibrated sondes. DEP conducted 18 surveys to calibrate and maintain the buoy which provided continuous data from this mid-basin site.

3.3 Keypoints

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 CATLEFF and DEL18 effluent keypoints represent Kensico Reservoir water entering the Catskill and Delaware Aqueducts, respectively, at points 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, except total phosphorus is collected weekly at CATALUM and DEL17 as 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 CATLEFF and DEL18 effluent keypoints are monitored via daily grab samples for fecal coliforms (7 days per week), turbidity (every four hours, in accordance with SWTR regulations, plus a turbidity sample is collected at the same time the fecal coliform samples are collected), and nutrients (monthly). The keypoint sites are also continuously monitored (Figure 3-2) for temperature, pH, conductivity, and turbidity. The exceptional importance of these keypoints for optimal operations (influents) and as source water compliance monitoring sites (effluents) warrants this high intensity monitoring. As described below, there were two changes to the Kensico keypoint monitoring strategy in 2012.

Figure 3-2 Continuous monitoring instrumentation at Kensico Reservoir (Catskill Lower Effluent Chamber).

The DEL18 sample has been collected from a pump located within the forebay at Shaft 18 at Kensico. In 2012, it was determined that under certain operating conditions water pumped from the DEL18 site was not representative of water going into the Delaware Aqueduct. To provide a representative sample during all operational conditions, a new sample pump was installed in the downtake at Shaft 18. This site, named DEL18DT, was placed into service on August 20, 2012, replacing the DEL18 site as the DEL18 effluent keypoint sample.

The activation on September 14, 2012 of the Catskill-Delaware Water Ultraviolet Disinfection Facility Plant (CDUV), located at Eastview, NY, resulted in the shutdown of the Catskill Aqueduct. Aqueduct flow from Kensico Reservoir must be pressurized in order to push water through the CDUV Plant. The 2.5 mile section of the Catskill Aqueduct from Kensico to Eastview is not pressurized, and thus cannot overcome the 40 feet of gravitational pressure needed to convey water from Kensico to the CDUV plant. As such, the CATLEFF effluent keypoint was discontinued, leaving DEL18DT as the Kensico effluent keypoint. It should be noted that in DEP's 2011 strategic plan, *Strategy 2011–2014* (http://www.nyc.gov/html/dep/pdf/strategic_plan/dep_strategy_2011.pdf), pressurizing the

Catskill Aqueduct is one of the one hundred initiatives listed. The plan states that “Pressurizing the Catskill Aqueduct will increase the volume of water available to the city and will re-establish DEP’s ability to bypass Kensico Reservoir when necessary to access the highest quality water.”

3.4 Protozoa and Human Enteric Viruses

DEP is responsible for performing compliance and surveillance monitoring of protozoan pathogens (*Cryptosporidium* and *Giardia*) and human enteric viruses (HEV) in the New York City Watershed. Fixed frequency protozoan and HEV sampling is conducted on a weekly schedule at the Kensico aqueduct influents and effluents, and monthly protozoan samples are collected at the eight Kensico perennial streams. Enhanced monitoring may be done at these sites in response to adverse weather or reservoir conditions which might affect microbial water quality.

Cryptosporidium and *Giardia* monitoring involved the filtration of 50L of water in the field, and analysis by DEP according to Method 1623HV (USEPA 2005). HEV monitoring involved the filtration of 200-300L of water in the field and analysis by a contract laboratory per the Information Collection Rule (ICR) Method (USEPA 1996), until June 1, 2012 when DEP began analyzing virus samples in-house.

Occasionally, after storm events or at some stream sites, samples had elevated turbidity which resulted in clogged filters. When this occurred, sample volumes did not always reach the targeted 50 liter value. As in the past, rather than extrapolating results to the targeted sample volume, the actual sample volume obtained is reported with the data, as well as per liter (L^{-1}) mean values provided by location.

3.5 Chemical Surveillance (VOC and SVOC)

Kensico Reservoir effluent keypoints are tested for volatile and semi-volatile compounds (VOC and SVOC, respectively) annually. The toxics monitoring program is conducted to determine whether or not these compounds are present in the source water. This monitoring is part of a watershed-wide keypoint toxics monitoring program. Volatile compounds were analyzed by potable water method USEPA Method 524.2; semi-volatile compounds were analyzed by potable water method 525.2. Only the DEL18DT effluent keypoint site was sampled in 2012, as CATLEFF was not sampled this year since it was shutdown in September and sampling occurred in December.

A VOC is one that produces vapors readily at room temperature and normal atmospheric pressure, such as benzene, toluene, xylene, and ethylene. Although ubiquitous in nature and modern industrial society, they may also be harmful or toxic. Inhalation effects represent an acute toxic exposure and groundwater contamination represents a route of chronic exposure, with the potential to affect the kidneys, nervous system, heart, and lungs. An SVOC has a low to moderate vapor pressure compared to a volatile compound. Examples of semi-volatile compounds are benzo[a] pyrene, phenol, and the pesticide pentachlorophenol. Some polyaromatic hydrocarbons, phthalates, and phenols are probable human carcinogens and endocrine disruptors. The primary routes of human exposure to SVOCs are ingestion of contaminated food and inhalation of contaminated air, rather than via drinking water.

3.6 Kensico Storm Event Sampling Plan

The Kensico Storm Event Sampling Plan was established (in 2012) to provide guidance for a rapid water quality sampling response in the event of a large storm. In 2011, Tropical Storms Irene and Lee (DEP 2011b) resulted in an increased number of samples that exceeded the benchmark of 20 fecal coliforms $100mL^{-1}$ in raw water effluent samples and this underscored the need for intensified sampling to guide operations. Therefore, an updated sampling plan was developed for the Kensico Watershed. It is a general protocol for water quality sample collection and analysis when storms are likely to increase fecal coliform levels at the Kensico effluents. The plan is intended to track the impacts of significant rainfall events in the reservoir, to identify land-side areas of highest fecal coliform loading that could affect the reservoir effluents, and identify specific sources of fecal coliforms. The sampling approach and primary objectives of the plan include the following:

1) Sample specific streams for fecal coliform contributions that are most likely to increase fecal coliform counts at the effluents of the reservoir and threaten compliance with the SWTR.
2) Sample the reservoir between these potential stream sources and the effluents to determine if a signal can be detected that may help indicate fate and transport characteristics.
3) Perform source tracking analysis on samples with the highest fecal coliform counts to determine the host source of the fecal coliforms, in order to best manage fecal coliform sources.

Significant Rainfall

There are several in-line BMPs installed on streams in the Kensico basin, and they are designed to capture and treat stormwater by detaining runoff generated from a maximum rain event of 1.5” for a period of 48 hours, as approximately 90-95% of all rain events in Westchester County produce less than 1.5” per event. Historical DEP data (January 1, 1995-September 20, 2011) were reviewed to help determine the size of storm events that may lead to exceedances of 20 coliforms $100mL^{-1}$ at the Kensico effluent keypoints. Based on this analysis, for the purposes of this plan, the suggested minimum rainfall to initiate monitoring of the Kensico streams is two inches forecasted over a 48 hour period, with the exception of extremely wet antecedent conditions where sampling may be advisable with less precipitation.

Autosampling Plan

In order to capture times of maximum loading of fecal coliforms, autosamplers will be deployed at each of the proposed stream sampling locations. The goal will be to capture the entire storm, which for the purposes of this plan, is assumed to start and end within 16-24 hours, but of course may vary. As such, two carousels of eight-2L sterile bottles will be prepared for each location, and the second set will be set up after the first carousel is collected (after eight hours, to be adjusted depending on predicted storm duration) (DEP 2009b). Autosamplers will programmed to trigger based on a rise in flow, and for sampling 1L every subsequent 30 minutes (to be adjusted as necessary based on storm prediction). Each 2L bottle will represent two 30 minute intervals, so there will be 16 subsamples collected in an eight hour period. Approximately 6 to 12 samples will be submitted for analysis from each stream site.

Optimal triggers for the autosamplers to begin sampling vary among the different streams due to diverse response times. Starting at base flow, a sampling trigger of approximately 120% (DEP 2009b) rise is recommended for the streams proposed in order to capture at least one base flow sample. This may need to be adjusted depending on the condition of the stream prior to a given storm.

Sampling Locations

There are eight perennial tributaries to Kensico Reservoir. However, historical observation by DEP, and data analysis by the consultant HDR Gannett Flemming after Tropical Storms Irene and Lee, has suggested that the tributaries in closest proximity to the effluents of the reservoir are likely have the most impact on the effluent fecal coliform results (HDR Gannett Fleming. 2012).

While this may be true under certain conditions, many factors (antecedent conditions, water temperature, degree of stratification, intake elevation, etc…) play a role in the transport and fate of fecal coliforms and determine whether they reach the reservoir effluents. As such, in addition to the three routine depths normally collected from the reservoir at each site, the plan calls for an additional sample to be collected at the depth with a temperature most closely matching that of the nearest tributary streams being sampled. Under stratified conditions, there may be quicker transport time, and distant sites may play more of a role than during de-stratified conditions.

Additionally, four non-routine reservoir sites will be sampled along the eastern shoreline of the main basin (along Route 22). Each of these locations is near an outfall from the shoreline and will be sampled by boat, on the reservoir side of any curtain booms, and at 1 meter depth. Table 3-2 provides a summary of the proposed sites, sampling frequency, and parameters.

Proposed sites:

- MB-1 (autosamplers)
- N5-1 (autosamplers)
- BRK (Sites 2, 3, 3.1, and 4; four depths each)
- Eastern shoreline (CL1BRK, CL2BRK, JC1BRK and JC2BRK)

Parameters:

- Rainfall
- Water temperature
- Fecal coliforms
- Flow
- Turbidity
- Conductivity
- Bacteroidales (as needed, corresponding to high fecal coliform results)
- Hydrograph (this and lab capacity will determine number of samples analyzed)

Table 3-2 Field Summary Table

Site	Sample type	Frequency	Temp	Fecal Coliform+	Flow	Turb	Cond.
MB-1	autosampler	q30 min/24h	at site	2L	Y	Y	Y
N5-1	autosampler	q30 min/24h	at site	2L	Y	Y	Y
BRK2 (1)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
(2)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
(3)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
(4)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
BRK3 (1)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
(2)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
(3)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
(4)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
BRK3.1 (1)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
(2)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
(3)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
(4)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
BRK4 (1)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
(2)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
(3)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
(4)	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
CL1BRK	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
CL2BRK	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
JC1BRK	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y
JC2BRK	Limno grab	Day 2 and 3	In situ	2L	N	Y	Y

Note: Fecal Coliform positive samples are poured off for fecal coliform, recapped, and held in refrigerator for Bacteroidales if needed.

Source Tracking

Bacteroidales [total and human (HF183)] analysis is proposed as the initial source tracking tool, as they are more abundant than coliphages in these conditions, and less sensitive to transport holding times. As always, more than one source tracking tool is recommended if, and when, source tracking becomes the primary goal of the study (once primary sites that affect the effluents have been identified). For the purposes of this plan, the source tracking component is intended as a supportive analyte, for use when fecal coliform counts are elevated to a level that warrants further source information. These will most likely be the stream samples collected during the rising limb or peak of the storm. The number of samples to be analyzed will be determined by the fecal coliform count reported by Kensico Laboratory, and analysis of the storm hydrograph provided by EOH field staff.

4. Results and Discussion

4.1 Coliform Bacteria

4.1.1 Waterfowl Management for Fecal Coliform Control

The WMP continued to maintain a high level of success during 2012. This was demonstrated by full compliance with the SWTR requirement for raw water fecal coliform, which states that no more than 10% of source water samples may exceed 20 fecal coliforms $100mL^{-1}$ over the previous six month period. This has been made possible by keeping resident and migratory water bird populations at low levels (Figure 4-1). Figures 4-2 and 4-3 show results for the regulatory source water samples collected from the Kensico effluents (DEL18/DEL18DT and CATLEFF) with respect to fecal coliform bacteria and reservoir bird counts. In 2012 the maximum monthly percentages of source water sample results above 20 fecal coliforms $100mL^{-1}$ were 0% for both DEL18/DEL18DT and for CATLEFF. As previously noted, in September 2012, DEP implemented operational changes in that the Catskill Aqueduct leaving Kensico was taken off-line pending the completion of the Catskill Pressurization project. In addition, the regulatory water sampling location was moved from the Shaft 18 forebay (DEL18) to the Shaft 18 downtake (DEL18DT). The CATLEFF intake system was also temporarily shut-down during part of January 2012 for contract work, thereby reducing the number of regulatory samples collected to 13 for that month. There were nine days with precipitation events greater than 1 inch recorded in 2012, but there were no days during which fecal coliform counts exceeded 20 fecal coliforms $100mL^{-1}$. The annual precipitation recorded at the Westchester County Airport was 34.22 inches.

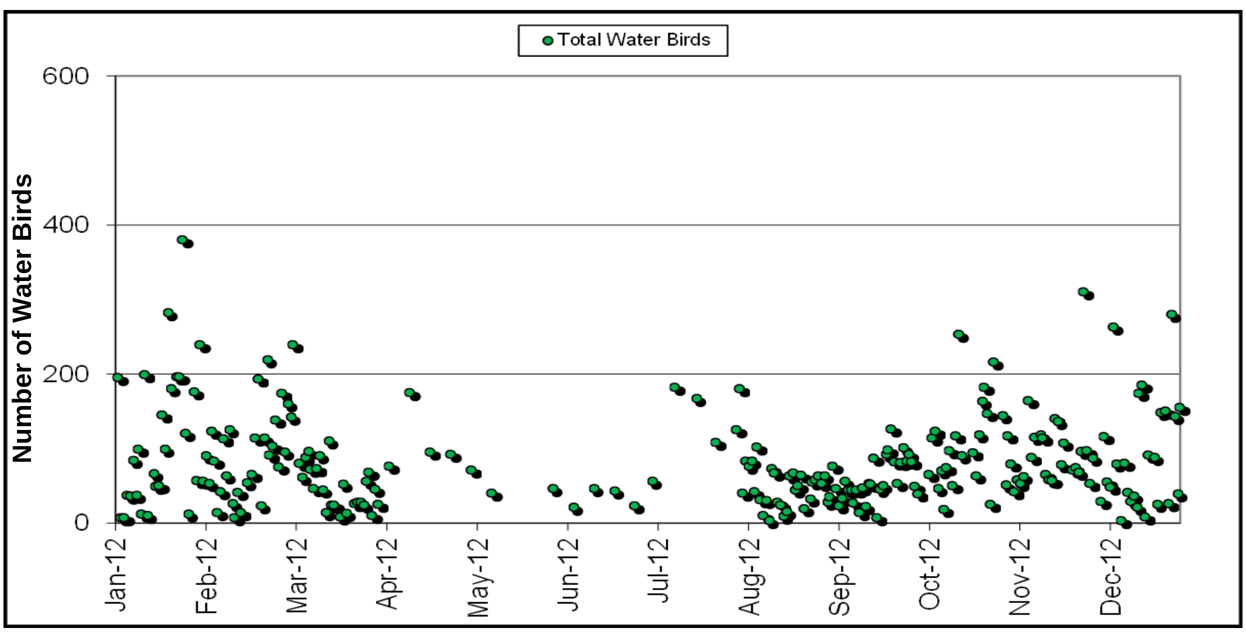

Figure 4-1 Kensico Reservoir total water birds (January 1 to December 31, 2012).

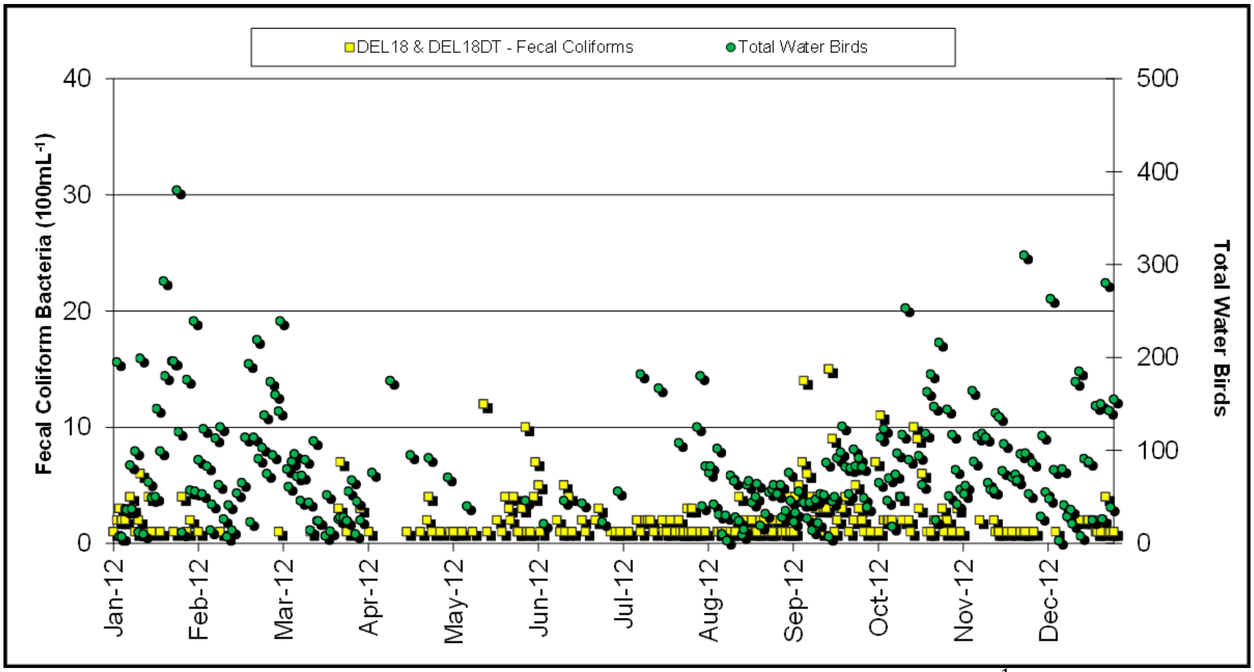

Figure 4-2 Kensico Reservoir DEL18 and DEL18DT fecal coliforms 100mL^{-1} and total water birds.

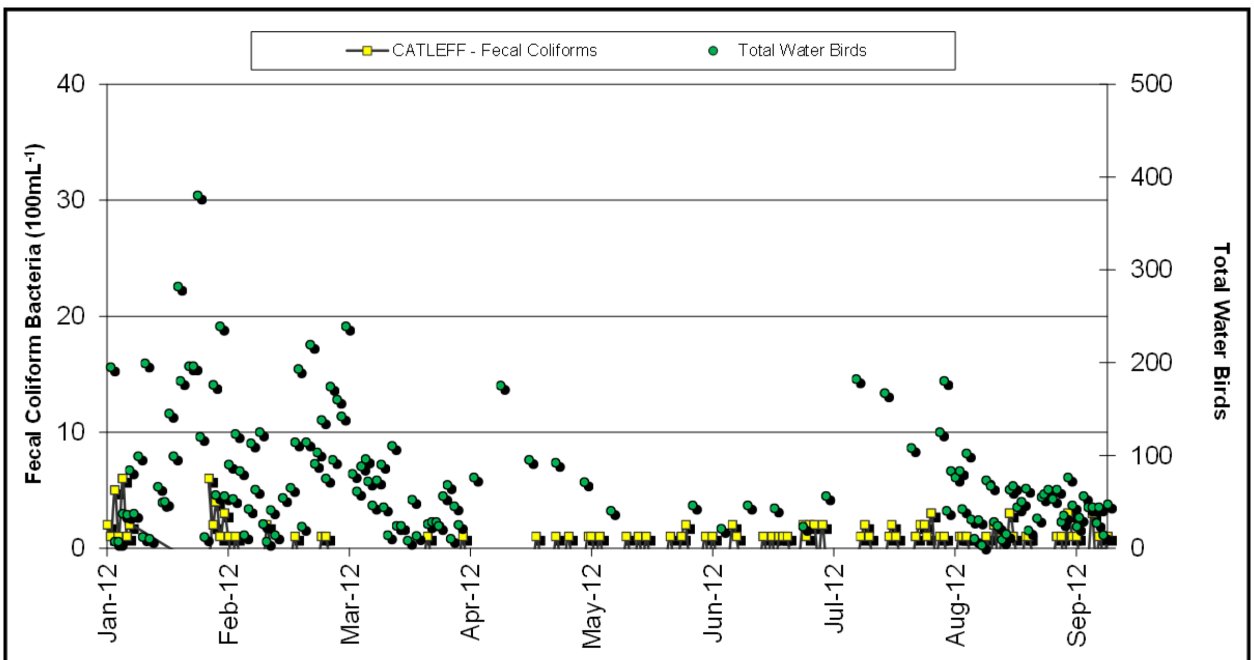

Figure 4-3 Kensico Reservoir CATLEFF fecal coliforms 100mL^{-1} and total water birds.

The Kensico source waters remained in compliance with the SWTR standard for fecal coliforms throughout 2012 (Figure 4-4), and this has been the case since 1993. Long-term water bird data collected from August 1, 1992 through December 31, 2012 are presented in Figure 4-5. Data collected from 1992 to 1993 preceded the inception of bird harassment efforts. Bird counts for 2012 remained relatively low compared to the early 1990's, the period prior to implementation of the bird harassment program. The implementation of the WMP continues to be a cost-effective way to achieve compliance with the SWTR.

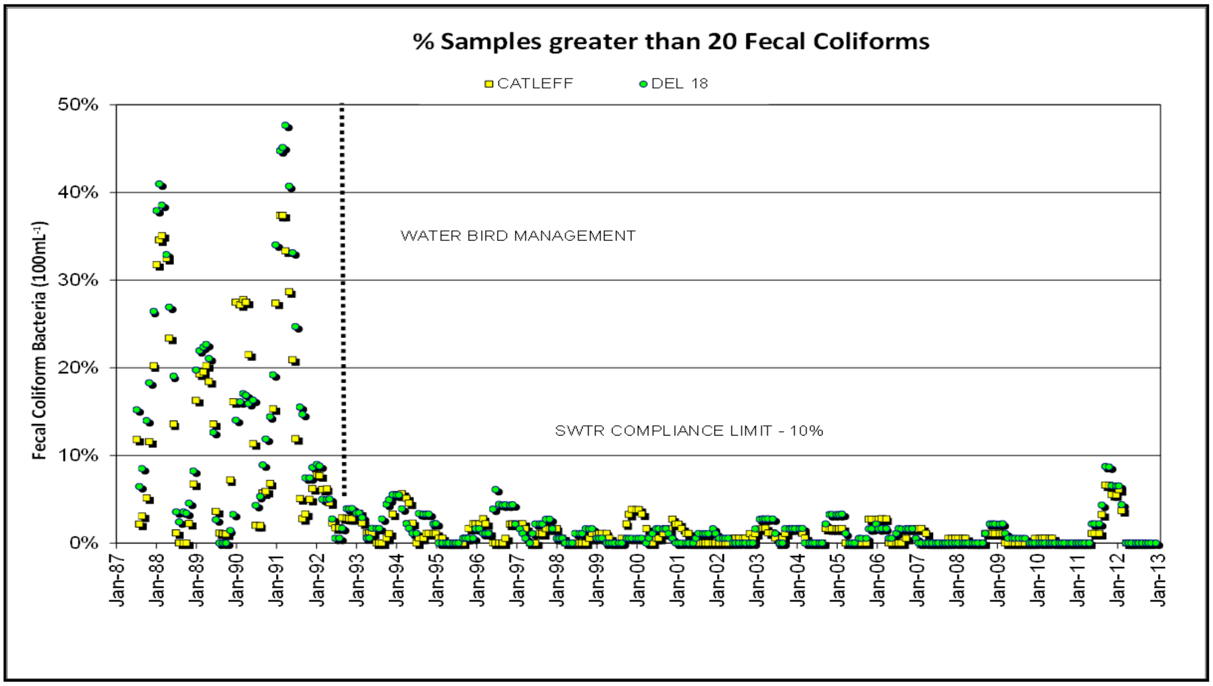

Figure 4-4 Kensico Reservoir SWTR fecal coliforms compliance at CATLEFF and DEL18 and DEL18DT.

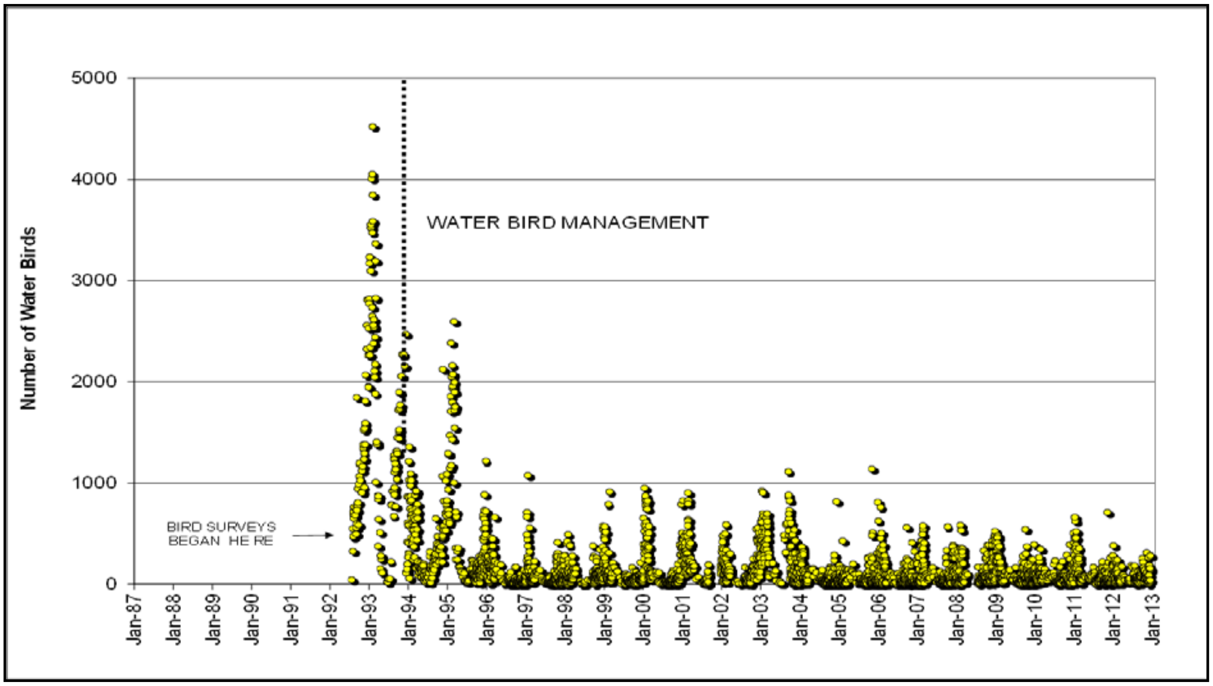

Figure 4-5 Kensico Reservoir long-term water bird totals (1992 to 2012).

4.1.2 Streams

The routine fecal coliform data for the period January 2012 through December 2012 are plotted in Figure 4-6. Boxplots are used to display data which contain censored data (i.e., nondetects, where the data are either less than a detection limit, or, in some cases, greater than a maximum detection limit).

Boxplots are used to describe the distribution of the data, and to compare different subsets, such as individual sites in a sampling network. The "box" is comprised of the median and the interquartile range. The lower line of the box represents the 25th percentile, while the upper line represents the 75th percentile. The median is shown as a horizontal line in the box. Boxplots also contain lines extended vertically away from the box which are called "whiskers." These lines extend up to highest data point within 1.5 times the length of the box (i.e. the interquartile range) and down to the lowest data point within 1.5 times the length of the box. The last components of a boxplot are the values outside the range of the whiskers, which are designated as outliers. However, coliform data often contain censored data, and while boxplots can be used to display these data, a modification is needed. A Minitab® macro written by Dr. Dennis Helsel of Practical Stats® was used for this analysis. The macro assumes the "censored" data follow a lognormal distribution and uses the robust regression on order statistics method of Helsel and Cohn (1988) to estimate the percentiles used to construct the boxplots with censored data. A horizontal line is drawn at the maximum detection limit (Max Det. Limit), and the portions of the boxplot below this limit are estimated by the method mentioned above. The maximum detection limit indicated on the plots is the maximum detection limit of multiple detection limits, because with coliform data we may have various values in the dataset reported as <2, <5, <10, <20, or <100 coliforms 100mL^{-1}depending on what dilution was used.

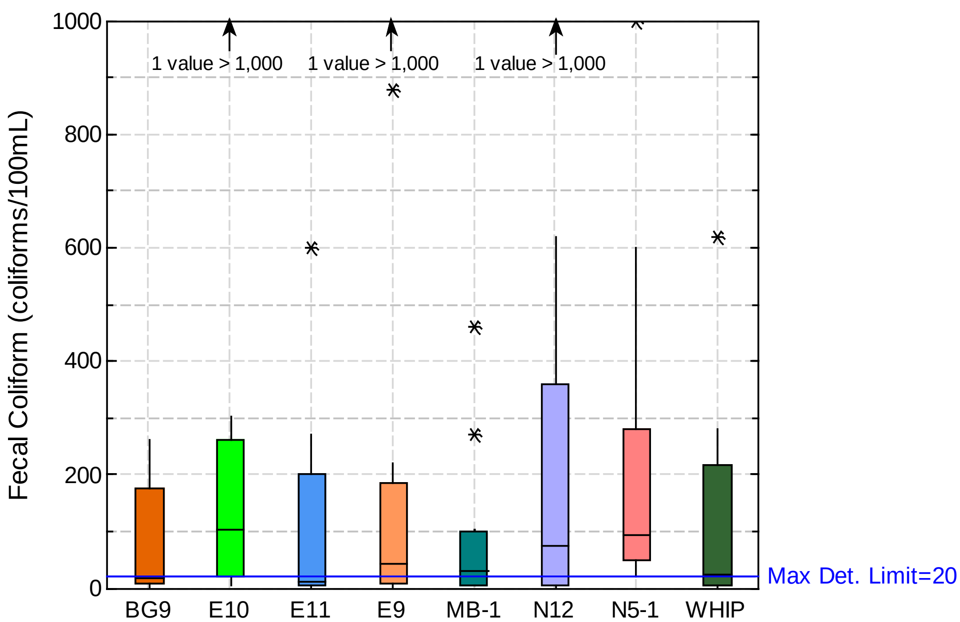

Figure 4-6 Fecal coliform plots for routine Kensico streams monitoring data, January–December, 2012.

NYSDEC Part 703 water quality standards for fecal coliforms have been used as a guideline for the comparison of stream water quality based on DEP's monthly fixed-frequency monitoring program. The fecal coliform standard for classes A, B, C, D is "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 $100mL^{-1}$. E10 had the highest median value at 101 fecal coliforms $100mL^{-1}$, while E11 had the lowest annual median at nine fecal coliforms $100mL^{-1}$. The maximum value for fecal coliform during routine sample collection was 5,400 coliforms $100mL^{-1}$ at E9 on June 5 (The maximum value observed during a special investigations following Hurricane Sandy was also 5,400 coliforms $100mL^{-1}$ at E9 (see section 4.5 for additional details)). The maximum fecal coliform values were generally observed when rain occurred on or just prior to the sampling date.

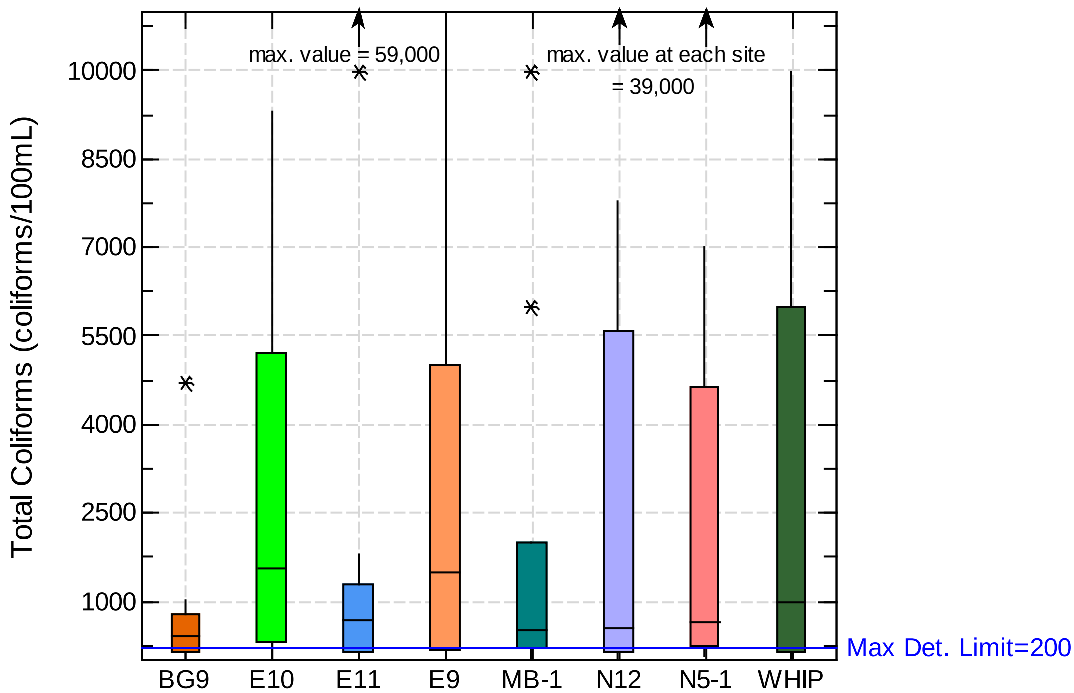

Figure 4-7 Total coliform plots for routine Kensico streams monitoring data, January–December, 2012.

Total coliform samples are also collected monthly from the eight Kensico stream sites (Figure 4-7). As with fecal coliform data, the total coliform data contain censored data, so the robust regression on order statistics method of Helsel and Cohn (1988) was used to estimate the medians. As with fecal coliforms, NYSDEC Part 703 water quality standards for total coliform have been used as a guideline for the comparison of stream water quality based on DEP's monthly fixed-frequency monitoring program. The total coliform standard for classes A, B, C, D is "The monthly median value and more than 20 percent of the samples, from a minimum of five examinations, shall not exceed 2,400 and 5,000, respectively. All Kensico streams had annual median values below 2,400 total coliforms $100mL^{-1}$. E10 had the highest annual median total coliform value (1,550 total coliforms $100mL^{-1}$), while Bear Gutter Creek (BG-9) had the lowest median value (400 total coliforms $100mL^{-1}$).The 2012 data indicate that all of the streams except

Bear Gutter had total coliform occurrences above 5,000 total coliforms 100mL^{-1}. These eighteen occurrences occurred on only 4 dates (June, 5, July 17, August 1, and September 11) during the year and were generally associated with a sample being collected during or immediately following rain events.

4.1.3 Reservoir

The routine bacteria samples collected from Kensico Reservoir provided 466 total coliform and 473 fecal coliform data points during the period January through December 2012. Boxplots for these data are shown in Figure 4-8 and Figure 4-9. The results are compared with SWTR drinking water limits of 100 coliforms 100mL^{-1} for total coliforms and 20 coliforms 100mL^{-1} for fecal coliforms. Although the SWTR limits apply to raw water quality at the effluent chambers, DEP uses these limits as a guideline to identify potential reservoir water quality impacts before they reach the effluent chambers.

During this reporting period, sites 7 and 8 were the only two sites where none of the samples exceeded 100 total coliforms 100mL^{-1} (Figure 4-8) (see section 4.1.2 for a description of boxplots). The interquartile ranges for all sites were well below 100 total coliforms 100mL^{-1} while sites 1.1 through 6 had outliers above this value. The outliers at Site 5 were among the highest, and these occurred in July of 2012. The higher counts of total coliform during the summer could be attributed to the typical seasonal increase observed in many of the NYC reservoirs.

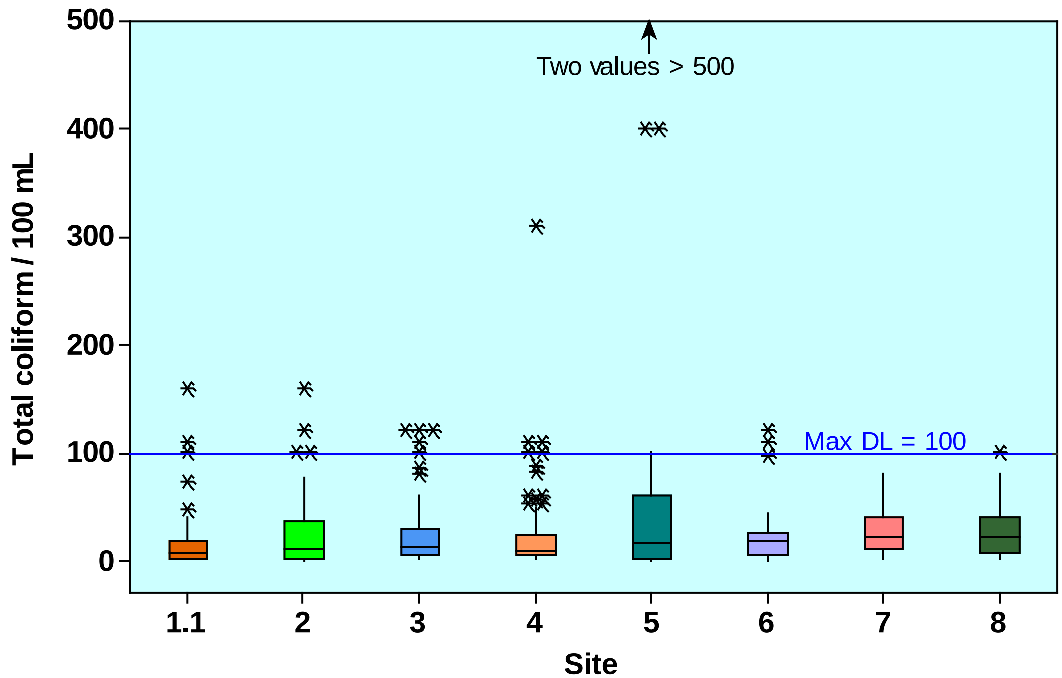

Figure 4-8 Total coliform plots for routine Kensico Reservoir monitoring data, January-December, 2012. Coincidentally, the maximum detection limits for total coliforms correspond to the SWTR benchmark values of 100 coliforms 100mL^{-1}.

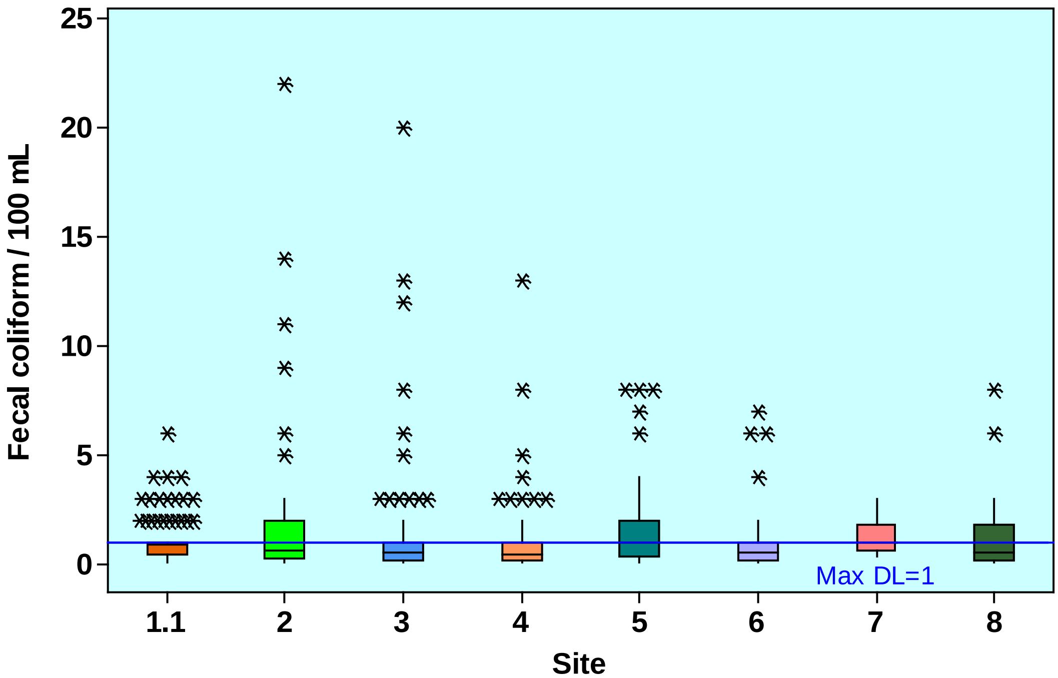

Figure 4-9 Fecal coliform plots for routine Kensico Reservoir monitoring data, January-December, 2012.

During the reporting period all sites from routine surveys had a median fecal coliform count at or below 1 coliform $100mL^{-1}$ (Figure 4-9) (see section for a description of boxplots). Median counts were 1 fecal coliform $100mL^{-1}$ for site 5 and 7, and <1 fecal coliform $100mL^{-1}$ for all other sites. There were only two samples at or above the DEP guideline for fecal coliform counts (20 fecal coliforms $100mL^{-1}$). These occurred at sites 2 and 3 on May 23, 2012, and may have been a localized effect from the 1.75 inches of rain that fell the previous 48 hours.

4.1.4 Keypoints

The Kensico keypoints include the aqueduct influents (CATALUM and DEL17) and effluents (CATLEFF and DEL 18). The effluents are monitored daily for fecal coliforms, whereas the influents are monitored five days per week. As previously noted, the DEL18 sampling location was moved on August 20 from the forebay (site code DEL18) to the downtake (site code DEL18DT) at Shaft 18 and the CATLEFF site was discontinued on September 14 when the section of the Catskill Aqueduct from Kensico Reservoir to the CDUV plant was shutdown.

As discussed in section 4.1.2, coliform bacteria, like most other environmental analytes, have measurement thresholds. When datasets contain censored data, care must be taken while performing statistical analyses. Techniques are available that incorporate the uncertainty of censored values into the calculation of basic statistics (Helsel 2005). For the Kensico keypoints, 49% (DEL18/DEL18DT) to 68% (CATLEFF) of the 2012 fecal coliform values were "censored." The Minitab® macro discussed in section 4.1.2 was also used for this analysis. Also, to indicate the uncertainty in the censored data, a drop line from censored points is used in the plots presented in this section.

For the fecal coliform counts measured at the Kensico **influents** from January 1, 2012 to December 31, 2012, medians of less than 1 fecal coliform $100mL^{-1}$ at both CATALUM and DEL17 were calculated. The maximum fecal coliform counts were 7 fecal coliforms $100mL^{-1}$ at CATALUM (Figure 4-10) and 13 fecal coliforms $100mL^{-1}$ at DEL17 (Figure 4-11). These data demonstrate that the fecal coliform levels of the aqueducts flowing into Kensico were typically low.

For the fecal coliform counts measured at the Kensico **effluents** from January 1, 2012, to December 31, 2012, a median of less than 1 fecal coliform $100mL^{-1}$ at CATLEFF and 1 fecal coliform $100mL^{-1}$ at DEL18/DEL18DT was calculated. The maximum fecal coliform counts were 6 fecal coliforms $100mL^{-1}$ at CATLEFF (Figure 4-12) and 15 fecal coliforms $100mL^{-1}$ at DEL18/DEL18DT (Figure 4-13). As in the past, the elevated fecal coliform levels generally coincided with precipitation events. Overall for 2012, DEP's source water at Kensico met the SWTR limits for fecal coliforms.

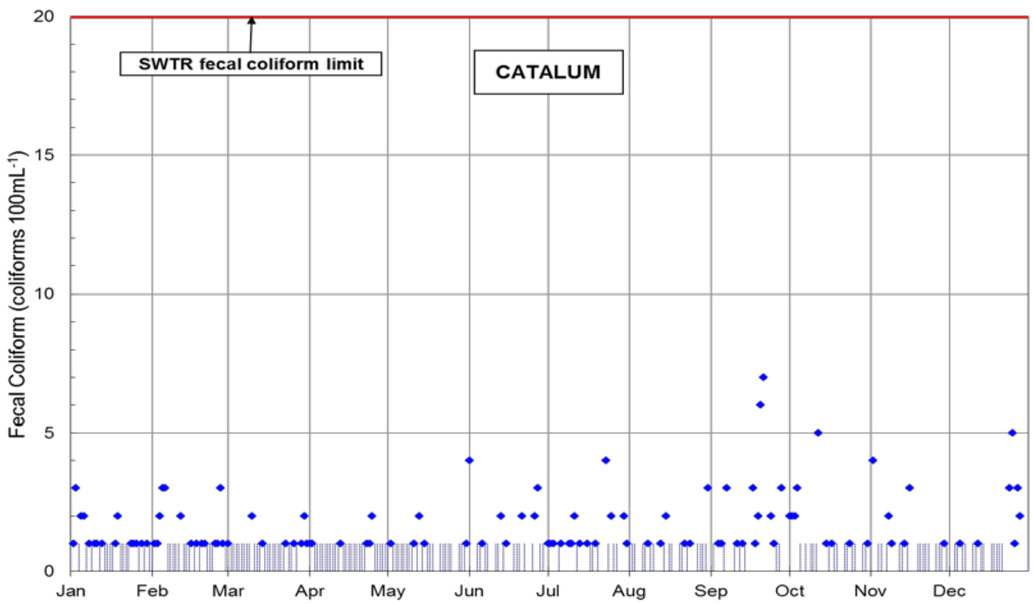

Figure 4-10 Five day per week fecal coliform grab sample results at the Catskill Aqueduct Kensico influent, CATALUM.
The "drop lines" along the x-axis indicate censored (below detection) values. Note: While the SWTR fecal coliform limit is indicated by a reference line, the influent keypoints are not subject to the SWTR.

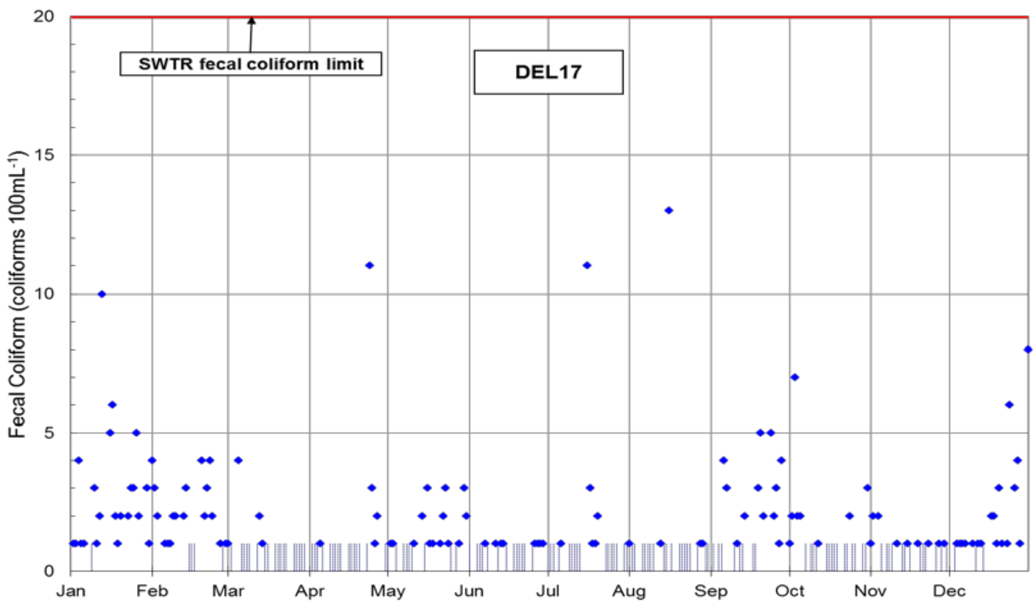

Figure 4-11 Five day per week fecal coliform grab sample results at the Delaware Aqueduct Kensico influent, DEL17.
The "drop lines" along the x-axis indicate censored (below detection) values. Note: While the SWTR fecal coliform limit is indicated by a reference line, the influent keypoints are not subject to the SWTR.

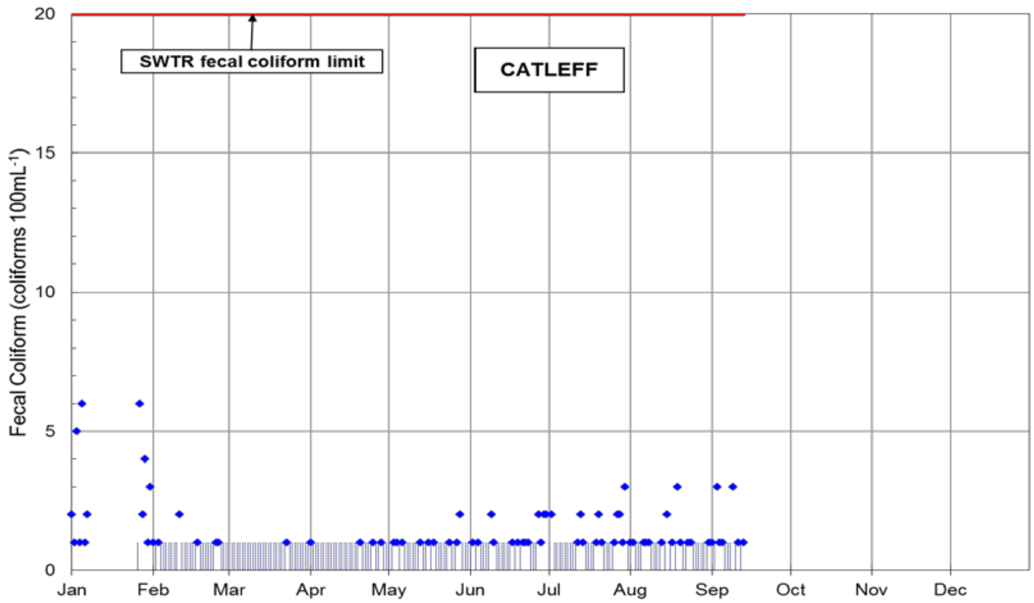

Figure 4-12 Seven day per week fecal coliform grab sample results at the Catskill aqueduct, untreated Kensico Reservoir Effluent site, CATLEFF. The Catskill aqueduct was shutdown from 7:00am on January 7 until 3:00am on January 26, 2012 for work related to the CDUV Plant. Also, as noted in section 3.3, when the CDUV Plant was activated on September 14, 2012, the CATLEFF site was discontinued.
The "drop lines" along the x-axis indicate censored (below detection) values.
Note: The SWTR fecal coliform limit is indicated by a reference line.

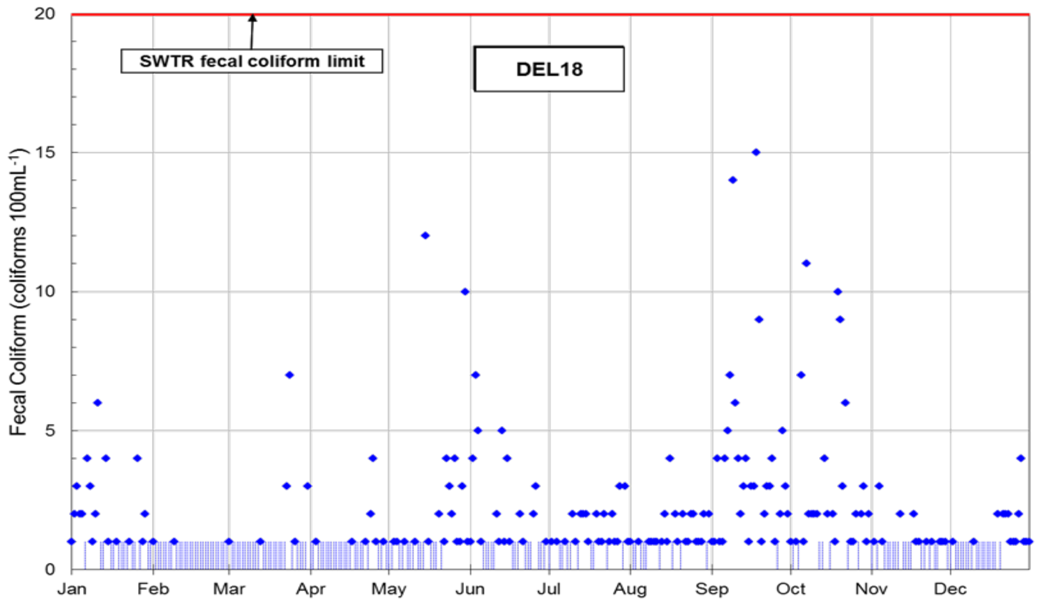

Figure 4-13 Seven day per week fecal coliform grab sample results at the Delaware Aqueduct , untreated Kensico Reservoir Effluent site, DEL18. As noted in section 3.4 the DEL18 site was relocated from the forebay (DEL18) to the downtake shaft (DEL18DT) commencing on August 20, 2012
The "drop lines" along the x-axis indicate censored (below detection) values.
Note: The SWTR fecal coliform limit is indicated by a reference line.

4.2 Turbidity

4.2.1 Streams

The routine turbidity data for the period January 2012 through December 2012 are plotted in Figure 4-14. The median turbidity for all sites is less than 5 NTU. Turbidity values in 2012 were generally consistent with data from previous years, with the annual medians ranging from 0.95 NTU at E10 to 4.2 NTU at Malcolm Brook (MB-1). The maximum turbidity value recorded during the 2012 routine stream monitoring was 15 NTU at E9 on July 17, 2012 when 6 of the 8 stream sites recorded their maximum turbidity value (E10 and WHIP recorded their maximum on May 1.). Both of these sampling dates had rain occur either on or just prior to the sampling date. Notably, the local streams within the Kensico basin are only a small percentage of the total inflow volume, and these values are greatly diluted by the aqueduct inputs.

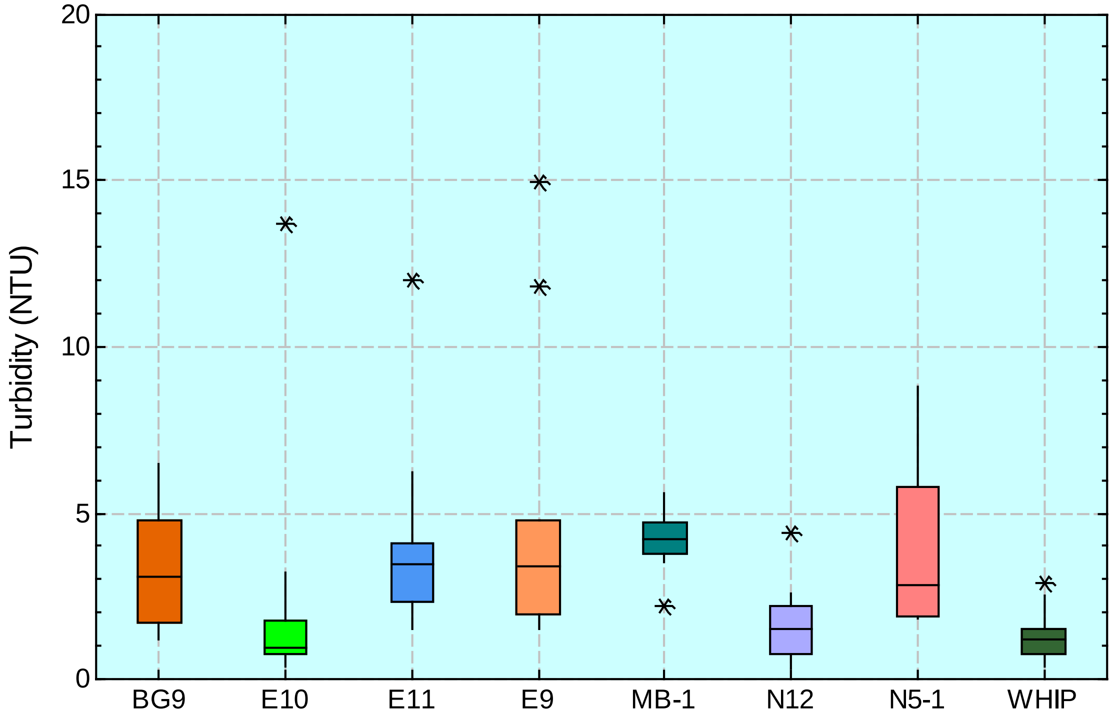

Figure 4-14 Turbidity plots for routine Kensico streams monitoring, January-December, 2012. (see section 4.1.2 for a description of boxplots).

4.2.2 Reservoir

The routine monitoring of Kensico Reservoir during the January through December 2012 period yielded 466 turbidity samples. A boxplot constructed using these data is presented in Figure 4-15. Site 5 showed the highest median turbidity (2.2 NTU), and individual samples for this site only exceeded 5.0 NTU 2 times. None of the samples collected on the routine surveys exceeded 5 NTU at the sites closest to the effluent chambers (sites 2 and 3).

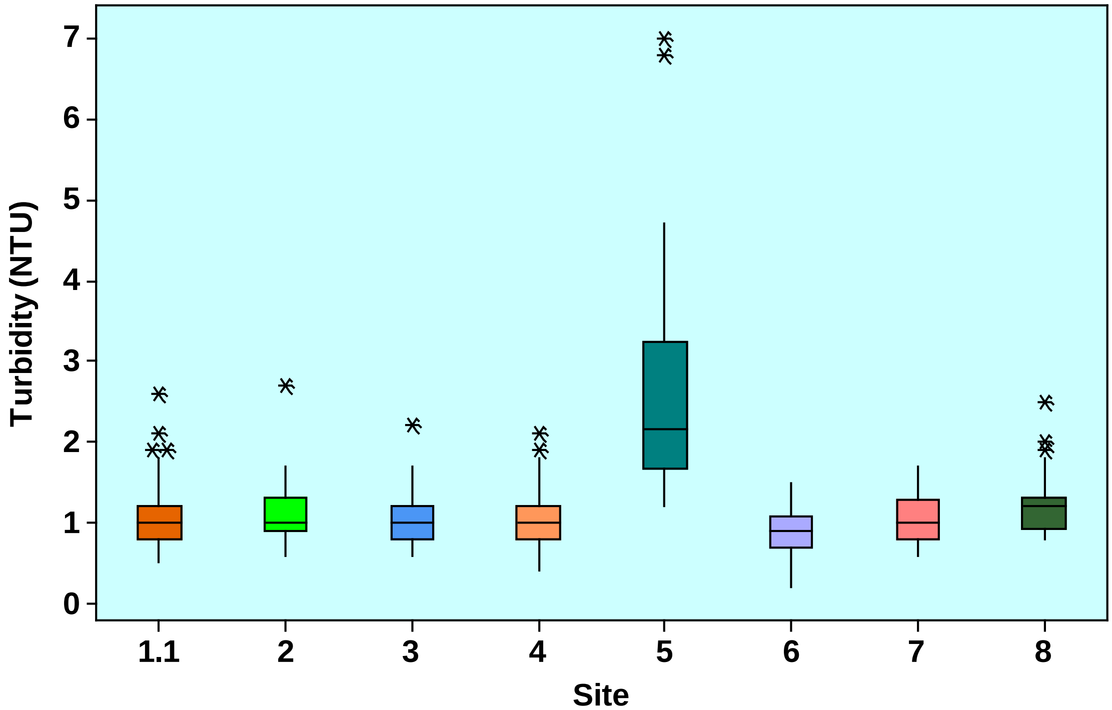

Figure 4-15 Turbidity plots for routine Kensico Reservoir monitoring. (see section 4.1.2 for a description of boxplots).

Special surveys were conducted to monitor turbidity during 2012. The bulk of these surveys occurred early in the year following the lingering effects of Tropical Storms Irene and Lee in 2011. In October 2012, Hurricane Sandy hit the New York metropolitan area. Kensico Reservoir was mainly impacted by high winds which caused a localized turbidity event near the DEL Shaft 18 intake. This event was summarized in an After Action Report (DEP 2012d).

Another set of tools that DEP has been utilizing to manage turbidity is robotic monitoring buoys. DEP took over the operation of these units in 2012, and they include two fixed-depth buoys in front of the intake sites, as well as a profiling buoy up reservoir at Site 4.1. The fixed depth buoys were used after Hurricane Sandy to determine the effect of the wind-induced disturbance in front of Shaft 18. The profiling buoy at Site 4.1 has provided information on the depth of turbidity from the Catskill Influent. Figure 4-16 provides two examples of turbidity profiles during stratification of the reservoir.

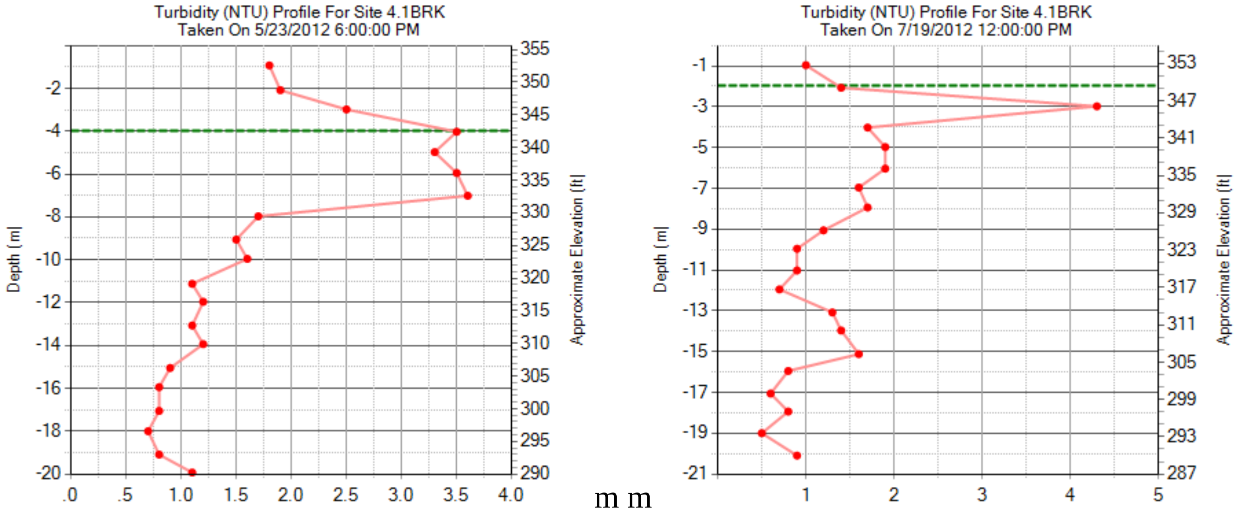

Figure 4-16 Site 4.1 turbidity profiles taken from the robotic monitoring buoy at this site. The green dashed line represents the depth of the thermocline.

4.2.3 Keypoints

A turbidity grab sample is obtained five days per week at the Kensico influent keypoints (CATALUM and DEL17) while the effluent samples (CATLEFF and DEL18/DEL18DT) are sampled every four hours, seven days a week. These data allow DEP to employ the optimal strategy for achieving the best water quality possible at the reservoir effluents, which are subject to the SWTR. Maintaining turbidity below regulatory limits is achieved by constant surveillance of the reservoir and its influent and effluent water quality, anticipation of problems (e.g., large storm events), and careful operation of reservoir gates at the effluents to avoid the re-suspension of sediments.

The median turbidity at CATALUM from January 1to December 31, 2012 was 7 NTU and was 1 NTU at DEL17 from January 2 to December 31, 2012 at DEL17. Mean turbidity for the same time period was 10.7 NTU at CATALUM and 0.95 NTU at DEL17. During this period, the maximum turbidity measurements were 35 NTU at CATALUM and 1.6 NTU at DEL17 (Figure 4-17 and Figure 4-18).

A turbidity grab sample is obtained every four hours at the Kensico effluent keypoints (DEL18/DEL18DT) and CATLEFF) as per the SWTR. Median turbidity from January 1 - December 31, 2012 was 1.0 NTU at DEL18/DEL18DT sites and the median turbidity at CATLEFF from January 1 until the shutdown of CATLEFF on September 14, 2012 was 0.80 NTU. Mean turbidity for the same time period was 0.99 NTU at DEL18 and 0.83 NTU at CATLEFF. During this period, the maximum 4-hour turbidity measurements were 6.0 NTU at DEL18/DEL18DT sites and 5.4 NTU at CATLEFF (Figure 4-19 and Figure 4-20). As the analytical method requires reporting to one decimal place for turbidity values over 1 NTU, the regulatory limit is effectively > 5.4 NTU. As such, other than one occasion, as described below, the Catskill and Delaware Aqueduct effluents from Kensico Reservoir exhibited turbidity levels less than or equal to 5 NTU in water prior to disinfection during the 2012 calendar year.

On October 29, 2012 as Hurricane Sandy neared the New Jersey shore, gale force winds and the resulting wave action in Kensico caused shoreline erosion and a rapid increase in turbidity levels at DEL18. Operational changes to control the event were ultimately successful and turbidity levels rapidly declined after having remained above 5 NTU for about 105 minutes. During this period of elevated turbidity, the 8:00pm raw water turbidity compliance grab sample measured 6.0 NTU, exceeding the 5 NTU limit. This resulted in a Tier 2 treatment technique violation of the Surface Water Treatment Rule (SWTR) as outlined in NYS Part 5-1.30(c). Additional details may be found in the After Action report (DEP 2012d)

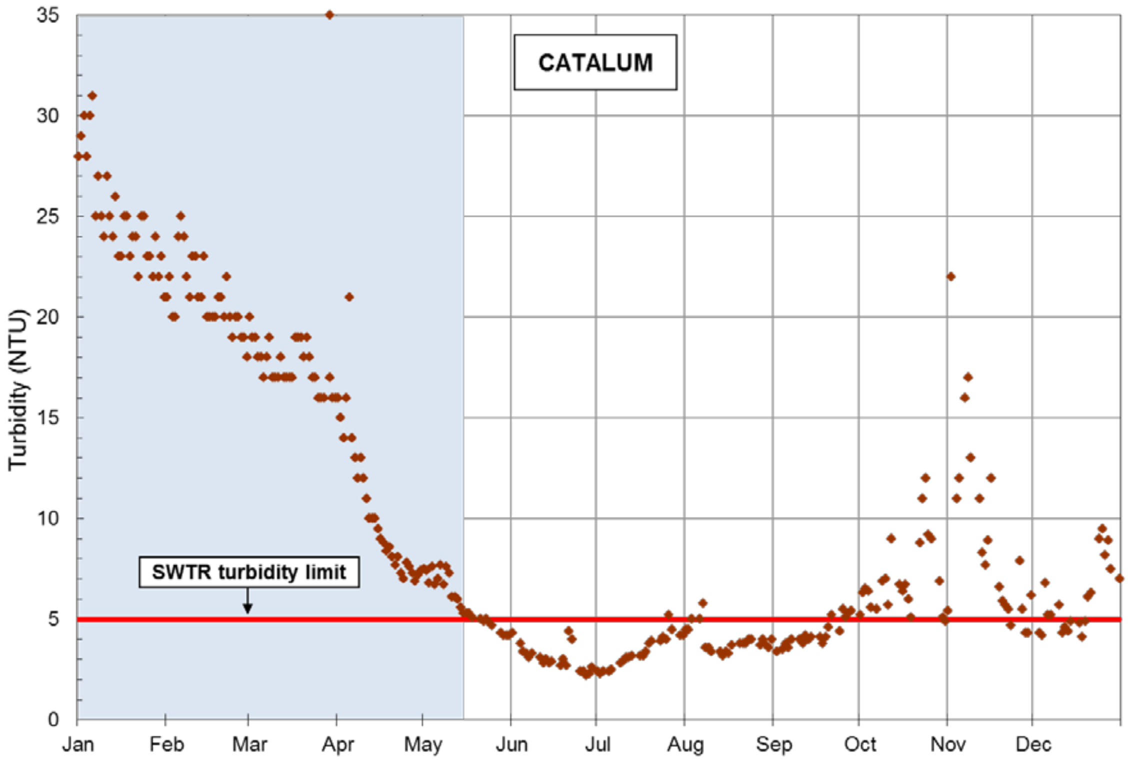

Figure 4-17 Five day per week turbidity grab sample results at Kensico Reservoir's Catskill Aqueduct influent keypoint (CATALUM). Shaded area indicates periods of alum treatment. Note: While the SWTR turbidity limit is indicated as a reference point, the influent keypoint is not subject to the SWTR.

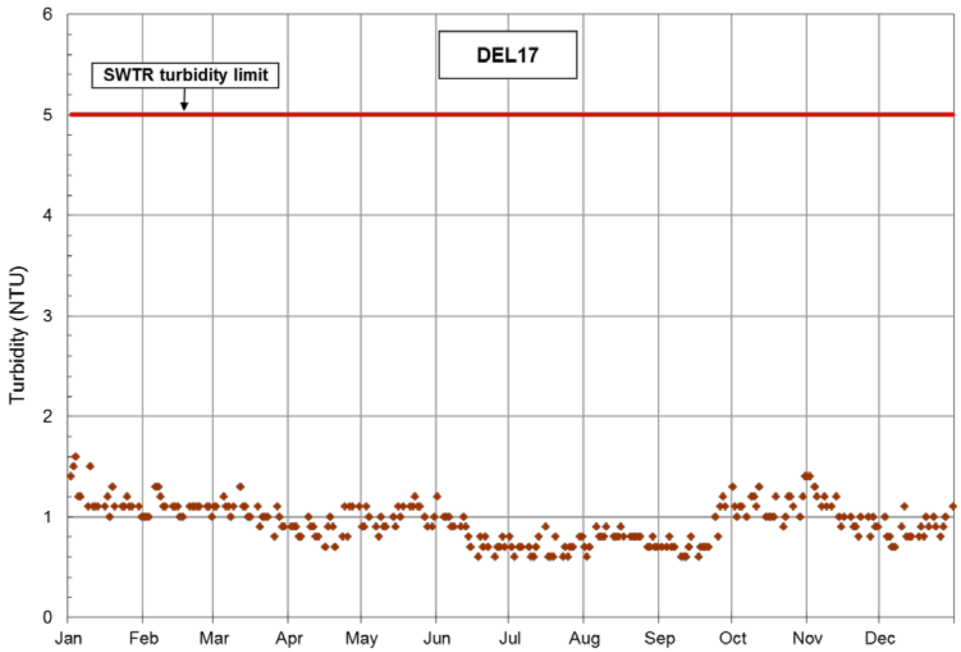

Figure 4-18 Five day per week turbidity grab sample results at Kensico Reservoir's Delaware Aqueduct influent keypoint (DEL17).
Note: While the SWTR turbidity limit is indicated as a reference point, the influent keypoint is not subject to the SWTR.

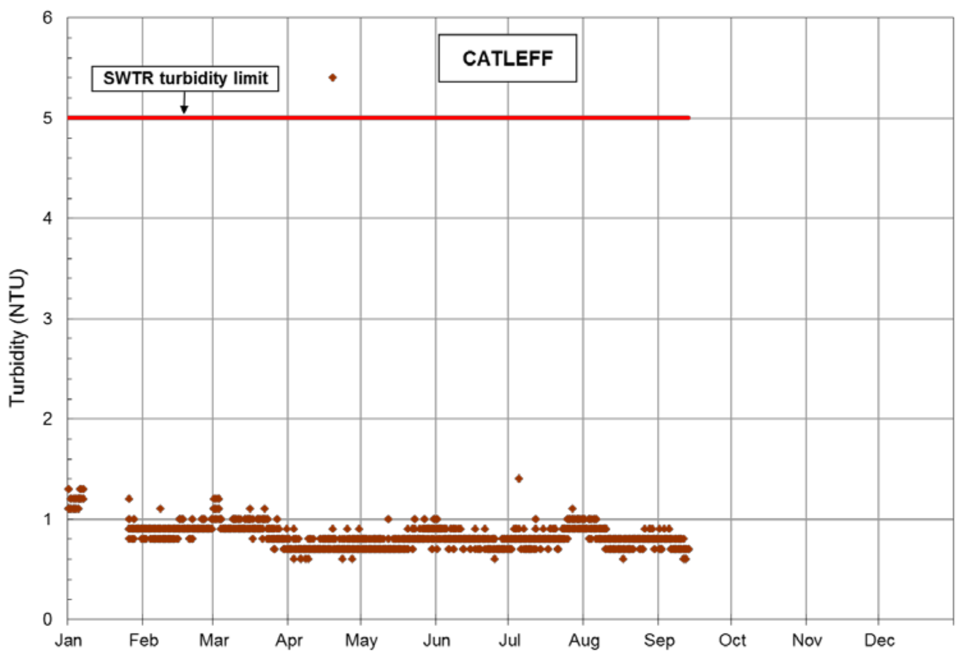

Figure 4-19 Four-hour turbidity grab sample results at Kensico Reservoir's Catskill Aqueduct effluent keypoint (CATLEFF). As noted in section 3.3, when the CDUV Plant was activated on September 14, 2012, the CATLEFF site was discontinued.

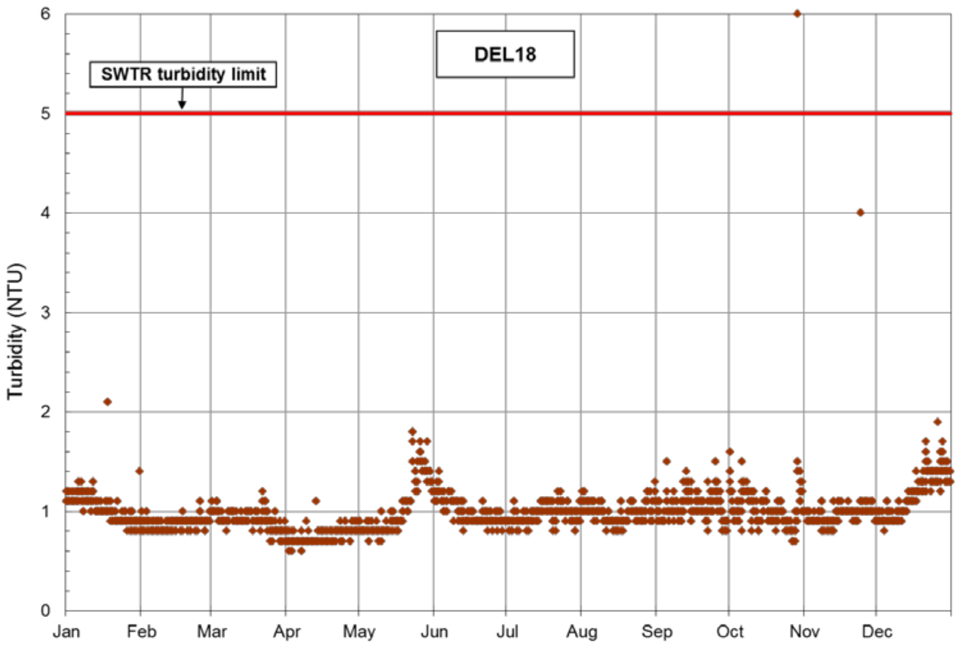

Figure 4-20 Four-hour turbidity grab sample results at Kensico Reservoir's Delaware Aqueduct effluent keypoint (DEL18). As noted in section 3.4 the DEL18 site was relocated from the forebay (DEL18) to the downtake shaft (DEL18DT) commencing on August 20, 2012.

4.3 Protozoa and Human Enteric Viruses

4.3.1 Perennial Streams

Eight perennial streams flow into Kensico Reservoir (Figure 4-21) and they are routinely monitored monthly as per the 2009 Watershed Water Quality Monitoring Plan (WWQMP) (DEP 2009a) to help capture any seasonal variation in protozoan occurrence. Results for these samples are presented in Tables 4-1 through 4-4. No HEV samples were collected at the Kensico perennial streams in 2012.

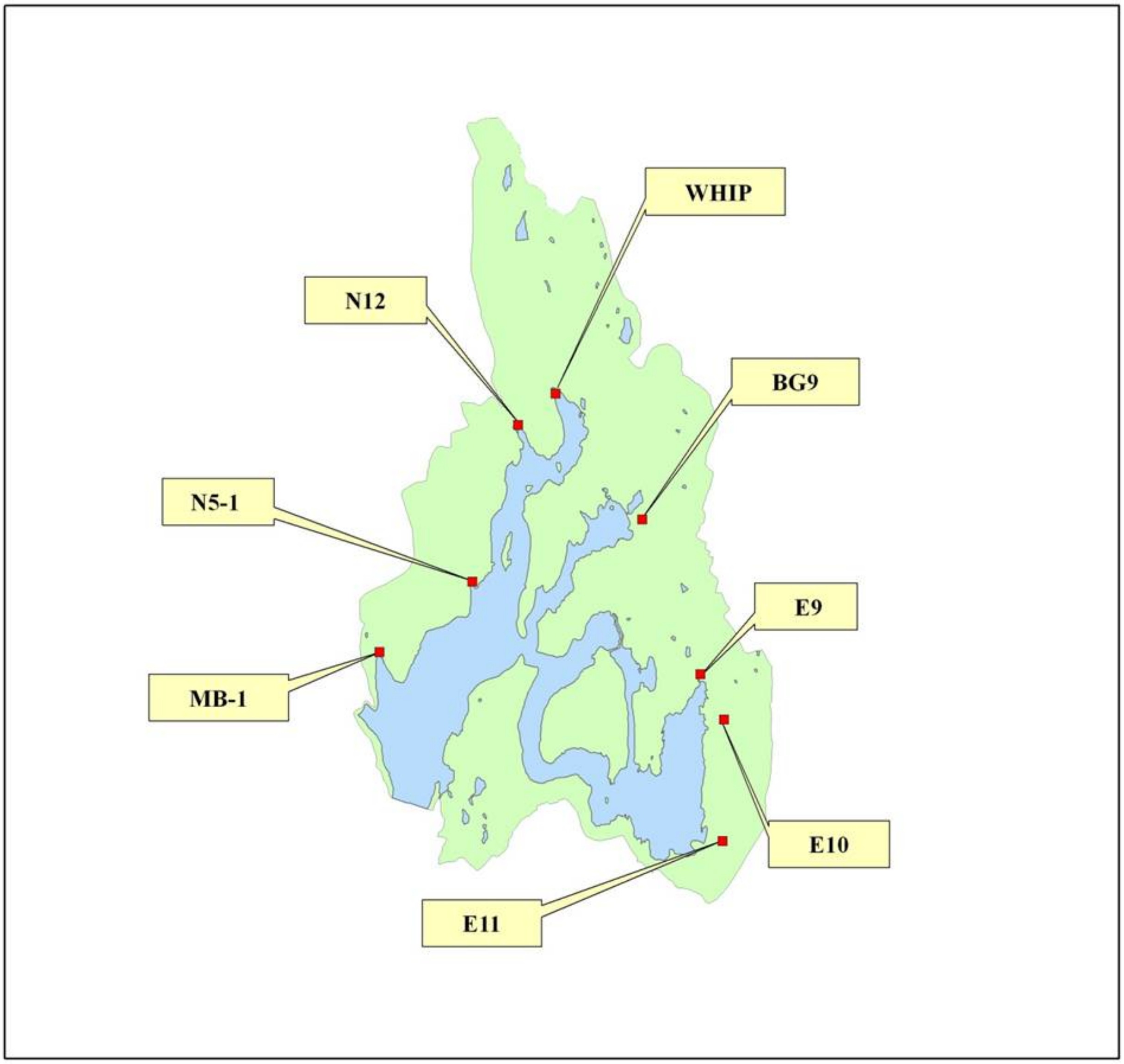

Figure 4-21 Kensico Reservoir routine pathogen stream sites sampled monthly in 2012.

Cryptosporidium occurrence was low at the Kensico perennials with 7 out of 96 (7.3%) samples positive. Two streams, E10 and E9, had no positive *Cryptosporidium* results, and the remaining six streams had mostly non-detects with maxima of 1 oocyst per volume sampled (Table 4-1). One exception was N12 which had 2 oocysts detected in the June sample, and N12 was also found to have the highest detection rate (16.7%) (Table 4-2). Detection rates varied in individual streams in the last five years; however, when data from all eight streams are pooled, *Cryptosporidium* was found less often in 2012. This is interesting considering that the detection in all five years was quite low.

Table 4-1 *Cryptosporidium* results (per 50L +/- 3L unless otherwise noted) from Kensico perennial streams, January 1–December 31, 2012.

Date	BG9	E10	E11	E9	MB-1	N12	N5-1	WHIP
Jan	0	0	0/35L	0	0	0	0	0
Feb	0/32L	0	0	0	0	0	1	0
Mar	0	0	0/43L	0	0	0	0	0
Apr	0/40L	0	0/47L	0/43L	0/29L	0	0	1
May	0/35L	0	0	0	0/42L	0	0	0
Jun	0/40L	0	0	0/44L	0/26L	2	0	0
Jul	0/23L	0	1/40L	0/23L	0	0	0/45L	0
Aug	0/46L	0	0/26L	0/20L	0	0	0/43L	0
Sep	0	0	0/25L	0/32L	0/35L	0	0/32L	0
Oct	0	0	0/30L	0/30L	0	1	0/53L	0
Nov	0	0	0	0/35L	1	0	0	0
Dec	1	0	0/46L	0/28L	0	0	0	0

Table 4-2 Summary of *Cryptosporidium* results for monthly Kensico perennial stream sampling, January 1–December 31, 2012.

	Cryptosporidium							
	BG9	E10	E11	E9	MB-1	N12	N5-1	WHIP
# of Samples	12	12	12	12	12	12	12	12
# of Positive	1	0	1	0	1	2	1	1
% Positive	8.3%	0.0%	8.3%	0.0%	8.3%	16.7%	8.3%	8.3%
Mean (L^{-1})	0.002	0.000	0.002	0.000	0.002	0.005	0.002	0.002
Median (L^{-1})	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Maximum (L^{-1})	0.020	0.000	0.025	0.000	0.020	0.040	0.020	0.020

As seen in past years, there were low concentrations of *Cryptosporidium* in the Kensico streams in 2012 with a mean concentration of 0.002 oocysts L^{-1} for pooled results from all eight streams. Similar to observations above for *Cryptosporidium* detection rates, mean concentrations varied in individual streams in the last five years; however, when data from all eight streams are pooled, *Cryptosporidium* was found at lower mean concentrations in 2012. N12 had the highest mean concentration at 0.005 oocysts L^{-1} (Table 4-2).

Giardia occurrence in the streams was 75.0% this year compared to 93.8% in 2011. The lowest occurrence was found at BG9 and E10 with 50% of samples positive for *Giardia*, while the highest was 100% at E11 (Table 4-4). This is a decrease from last year when the lowest percent positive was 83.3% and four of the 8 sites had 100% *Giardia* occurrence.

As in previous years, 2012 samples from the Kensico streams had higher concentrations of *Giardia* cysts (Table 4-3) when compared to *Cryptosporidium* (Table 4-1). Of the 96 samples taken, 33 samples had volumes less than 50L, with volumes ranging from 20.0 to 52.7L, and cyst results from 0 to 240; therefore, per liter mean concentrations were used to aid in the site comparison (Table 4-4). Using this approach, E9 and E11 revealed the highest means (1.095 and 0.424 cysts L^{-1}, respectively) and maximum *Giardia* concentrations (6.897 and 1.340 cysts L^{-1}, respectively) compared to the other six perennial streams in 2012. These two highest mean concentrations were quite similar to the top two means found at the same sites in 2011 (0.980 and 0.520 cysts L^{-1}, respectively). The two maxima mentioned above were sampled on November 5, seven days after Hurricane Sandy made landfall in New York (October 29). This major event, while not bringing much precipitation, was accompanied by damaging high winds which may have mobilized particles and pathogens for the next several days. MB-1 had the lowest *Giardia* mean (0.036 cysts L^{-1}) and concentrations ranging from 0 to 0.116 cysts L^{-1}. Interestingly, this was the lowest annual mean concentration found at MB-1 since Method 1623HV sampling began at this site in 2002, with the next lowest annual mean being more than twice as high (0.079 cysts L^{-1}) in 2009.

Table 4-3 *Giardia* results (per 50L +/- 3L unless otherwise noted) from perennial Kensico streams, January 1–December 31, 2012.

Date	BG9	E10	E11	E9	MB-1	N12	N5-1	WHIP
Jan	5	0	13/35L	59	3	7	8	15
Feb	2/32L	0	4	28	0	1	2	4
Mar	5	3	5/43L	56	1	2	4	12
Apr	7/40L	14	7/47L	15/43L	0/29L	5	1	18
May	8/35L	4	14	22	4/42L	0	1	18
Jun	0/40L	3	1	40/44L	2/26L	14	0	3
Jul	0/23L	0	12/40L	0/23L	0	11	3/45L	5
Aug	0/46L	3	10/26L	3/20L	0	14	3/43L	14
Sep	0	3	25/25L	17/32L	4/35L	0	13/32L	0
Oct	0	0	28/30L	2/30L	2	2	4/53L	5
Nov	0	0	67	240/35L	1	0	0	1
Dec	2	0	5/46L	26/28L	0	2	2	1

Table 4-4 Summary of *Giardia* results for monthly Kensico perennial stream sampling, January 1–December 31, 2012.

	Giardia							
	BG9	E10	E11	E9	MB-1	N12	N5-1	WHIP
# of Samples	12	12	12	12	12	12	12	12
# of Positive	6	6	12	11	7	9	10	11
% Positive	50.0%	50.0%	100.0%	91.7%	58.3%	75.0%	83.3%	91.7%
Mean(L^{-1})	0.059	0.050	0.424	1.095	0.036	0.097	0.082	0.160
Median (L^{-1})	0.020	0.030	0.290	0.550	0.020	0.040	0.054	0.100
Maximum (L^{-1})	0.231	0.280	1.340	6.897	0.116	0.280	0.409	0.360

4.3.2 Keypoints

As the source water keypoints for New York City's water supply, Kensico Reservoir's aqueduct influents and effluents are monitored weekly for protozoa and HEVs. A total of 193 routine protozoan samples and 193 routine HEV samples were collected at the Kensico keypoint sites in 2012 (analyses for 184 of these samples were complete at the time this report was written). One additional protozoan sample was collected at DEL18DT shortly after, and in response to, Hurricane Sandy. An additional ten HEV samples were collected (alongside routine samples) to assist with alternate virus filter testing.

Influent Keypoints

Kensico Reservoir influent keypoints (CATALUM and DEL17) were sampled weekly for *Cryptosporidium* and *Giardia*. No *Cryptosporidium* oocysts were detected at CATALUM in 2012 (Table 4-5). *Cryptosporidium* was detected in only one sample (out of 53) at DEL17, and at a low concentration (1 oocyst $50L^{-1}$). These results are consistent with results from the last two years; however, they are somewhat lower than many previous years. For example, in 2009 *Cryptosporidium* was detected in seven samples for CATALUM and four samples for DEL17.

Table 4-5 Weekly Kensico Reservoir influent keypoint results, *Cryptosporidium* and *Giardia* summary, January 1–December 31, 2012.

		CATALUM	DEL17
Cryptosporidium($50L^{-1}$)	# of Samples	53	53
	# of Positives	0	1
	% Positives	0.0%	1.9%
	Mean	0.000	0.02
	Median	0.00	0.00
	Maximum	0.000	1.00
Giardia ($50L^{-1}$)	# of Samples	53	53
	# of Positives	8	32
	% Positives	15.1%	60.4%
	Mean	0.17	1.08
	Median	0.00	1.00
	Maximum	2.00	5.00

Giardia was detected in 8 and 32 samples (out of 53 at each site) collected at CATALUM and DEL17 in 2012, with maxima of 2 and 5 cysts $50L^{-1}$ at the respective sites. For comparison, in 2011, *Giardia* detection occurred in 16 and 41 samples (out of 52) collected for CATALUM and DEL17, with maxima of 2 and 5 cysts $50L^{-1}$, respectively. The mean concentration of *Giardia* at CATALUM in 2012 was much lower than 2011 (0.17 compared to 0.54 cysts $50L^{-1}$). The mean *Giardia* concentration at DEL17 was almost half the 2011 mean, dropping from 2.06 to 1.08 cysts $50L^{-1}$, closer to the mean found in 2010 (0.98 cysts $50L^{-1}$). The DEL17 *Giardia* median was also lower in 2012 (1.00 cysts $50L^{-1}$) than in 2011 (2.00 cysts $50L^{-1}$). Changes in operational mode may account for these differences; however, there are many possible reasons throughout a given year, including varied temperature and precipitation amounts, as well as the occurrence of tropical storms and hurricanes, such as those the watershed experienced in 2011 and 2012.

Effluent Keypoints

The effluent keypoints of Kensico Reservoir (CATLEFF and DEL18/DEL81DT) were also sampled weekly for *Cryptosporidium* and *Giardia* in 2012; however, protozoan sampling at CATLEFF was discontinued after September 10, when the Catskill Aqueduct was shut down and all flow leaving Kensico Reservoir was directed through DEL18DT. This change in reservoir operations was necessary due to the commencement of operations at the CDUV Plant.

Cryptosporidium was detected in one sample (out of 34) at CATLEFF and was not found in any samples at DEL18/DEL18DT (Table 4-6). As a comparison, in 2011, *Cryptosporidium* was detected in two samples at CATLEFF and one sample at DEL18. As in past years, the concentration of *Cryptosporidium* was low, with the one positive sample resulting in 1 oocyst $50L^{-1}$. Consequently, the mean concentration for CATLEFF was quite low (0.03 oocysts $50L^{-1}$). While *Cryptosporidium* concentrations have been low for the past several years at both CATLEFF and DEL18, mean concentrations for CATLEFF are the lowest they have been since 2005. This statement must; however, be qualified with the fact that CATLEFF was not sampled for the entire year in 2012 due to the aqueduct shut down. This was also the first calendar year since Method 1623 sampling began (October 2001) when there were no oocyst detections at DEL18/DEL18DT, giving it the record low annual mean of 0.00 oocysts $50L^{-1}$.

Table 4-6 Weekly Kensico Reservoir effluent keypoint results, *Cryptosporidium* and *Giardia* summary, January 1–December 31, 2012.

		CATLEFF	DEL18
Cryptosporidium ($50L^{-1}$)	# of Samples	34	53
	# of Positives	1	0
	% Positives	2.9%	0.0%
	Mean	0.03	0.00
	Median	0.00	0.00
	Maximum	1.00	0.00
Giardia ($50L^{-1}$)	# of Samples	34	53
	# of Positives	18	25
	% Positives	52.9%	47.2%
	Mean	0.91	0.89
	Median	1.00	0.00
	Maximum	4.00	4.00

There were 18 of 34, and 25 of 53 detections of *Giardia* at CATLEFF and DEL18/DEL18DT, respectively, in 2012. This was less frequent than in 2011 when there were 41 *Giardia* detections at CATLEFF, and 40 at DEL18 out of the 52 samples collected. Maximum *Giardia* cyst concentrations at CATLEFF and DEL18/DEL18DT were slightly lower in 2012 (each site having two instances of 4.00 cysts $50L^{-1}$) compared to maximum concentrations from 2011 (6.00 and 5.00 cysts $50L^{-1}$, respectively). This was also the lowest CATLEFF *Giardia* mean since 2005, but as previously noted this mean only accounts for the first 34 weeks of the year, unlike prior annual means which account for the entire year. The DEL18/DEL18DT mean *Giardia* concentration for 2012 (0.89 cysts $50L^{-1}$) was approximately half the prior year's mean (1.69 cysts $50L^{-1}$) and the lowest it has been since the start of Method 1623 sampling at these sites in 2001.

Enhanced Monitoring at Effluent Keypoints

One non-routine sample was collected on October 31, 2012, approximately two days after Hurricane Sandy reached New York. While this event brought less than half an inch of rain to the Kensico watershed area, the accompanying high winds affected other aspects of water quality, so this enhanced sampling was conducted to further test microbial water quality. The protozoan sample was negative for both *Cryptosporidium* and *Giardia*.

Human Enteric Virus Monitoring

All four Kensico Reservoir keypoints were monitored weekly for human enteric viruses in 2012 (Figure 4-22), with the exception that CATLEFF sampling ceased after September 10 when the Catskill Aqueduct leaving Kensico was shut down. Occurrence of HEVs in 2012 was 28 positives out of 184 (15.2%) completed analyses (as of December 10, 2012) compared to 39 positive of 207 samples (18.8%) in 2011. The lowest detection percentage (8.8%) was found at CATLEFF and the highest (18.0%) at CATALUM (Table 4-7). As with the protozoan data, it is difficult to make a simple comparison with prior years because CATLEFF was not sampled for the entire year, however the data suggest a general similarity to those from 2011 (Figure 4-23).

Table 4-7 Summary of weekly human enteric virus results at Kensico keypoints, January 1-December 10, 2012.

	Human enteric viruses (MPN $100L^{-1}$)			
	CATALUM	CATLEFF	DEL17	DEL18
# of Samples	50	34	50	50
# of Positives	9	3	8	7
% Positives	18.0%	8.8%	16.0%	14.0%
Mean*	0.75	0.27	0.52	0.86
Median*	0.00	0.00	0.00	0.00
Maximum	23.00	6.93	11.12	14.36

*Zero values were substituted for non-detect values when calculating mean and median results.

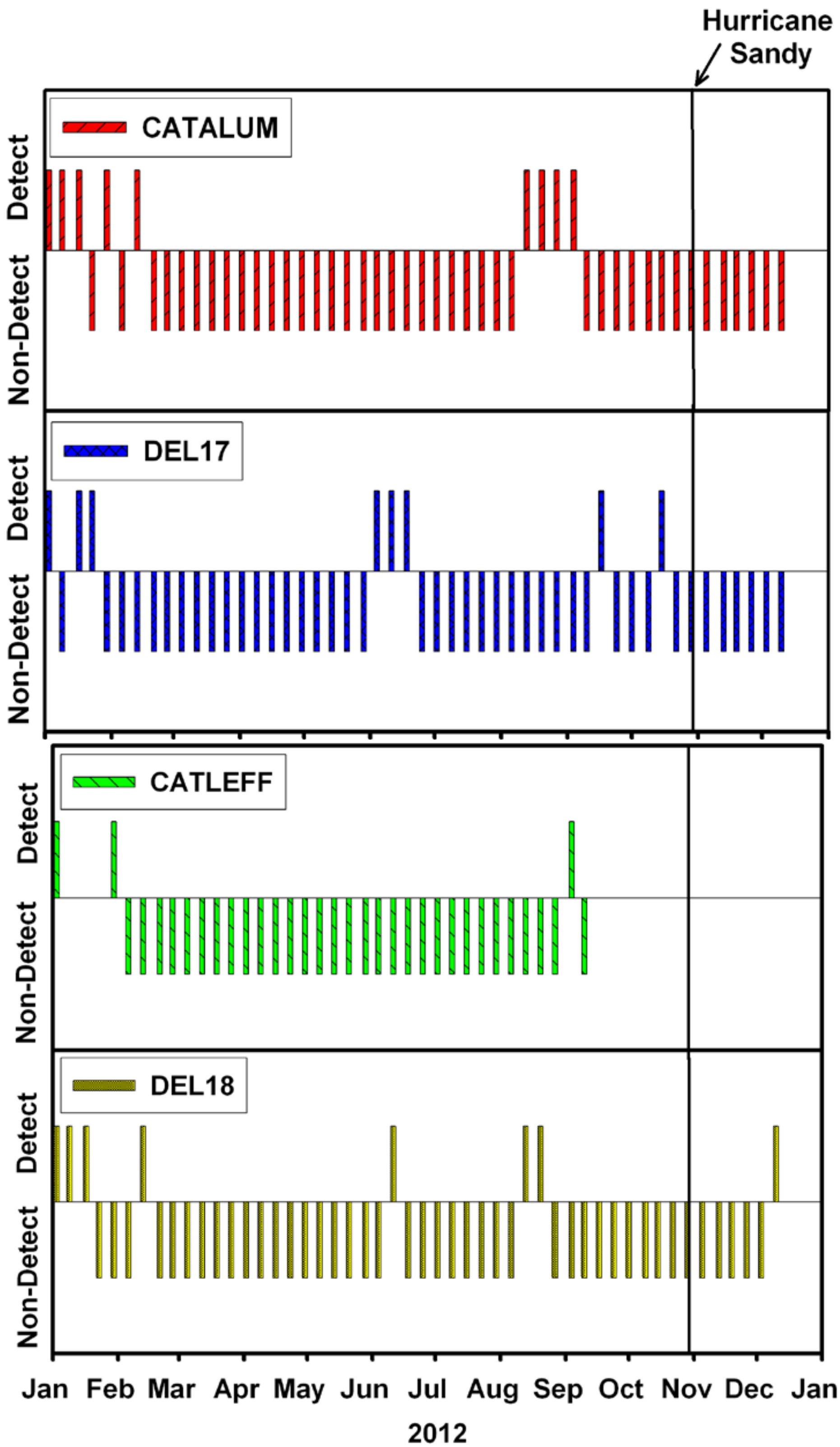

Figure 4-22 Detections of human enteric viruses (HEV) at the four Kensico keypoints, January 1-December 10, 2012. CATLEFF discontinued September 10, 2012 due to aqueduct shut down.

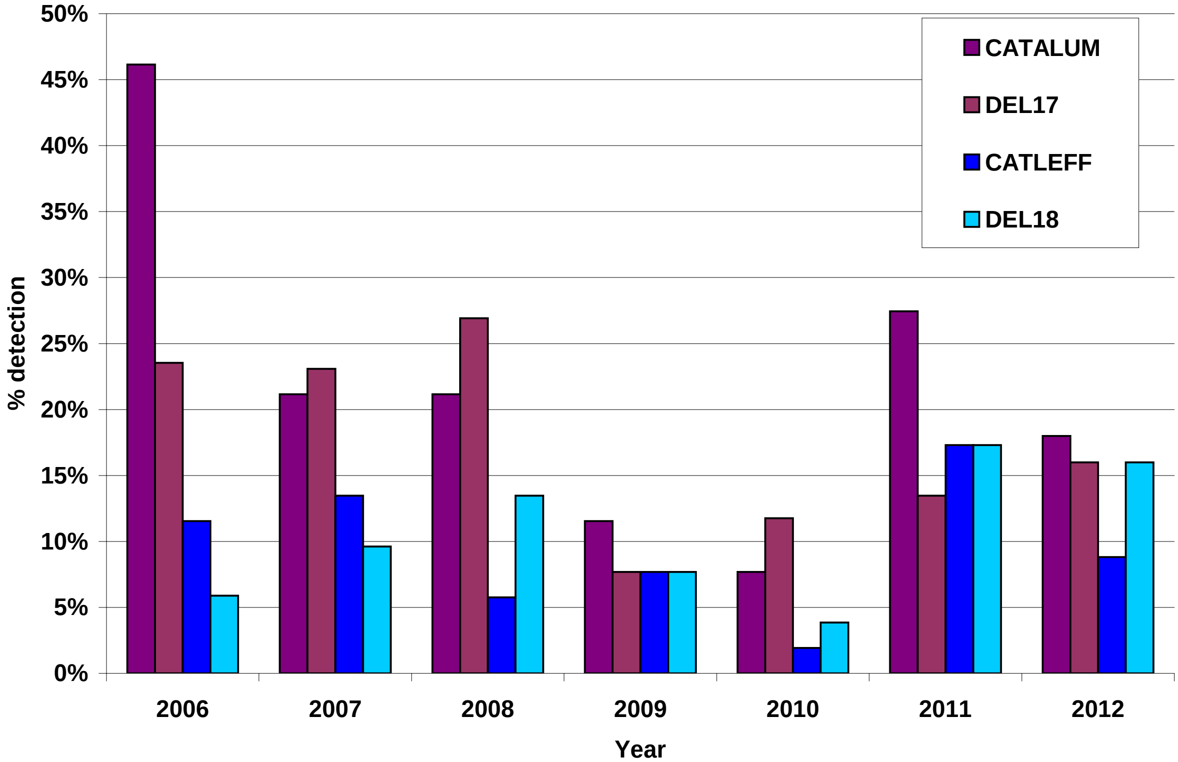

Figure 4-23 Annual occurrence of human enteric virus (HEV) detections at the four Kensico keypoints from 2006 – 2012 (January 1-December 10, 2012).

The highest HEV results in 2012 were found in samples from CATALUM and DEL18/DEL18DT (23.00 and 14.36 MPN $100L^{-1}$, respectively) taken on August 13 (Table 4-7). Mean annual concentrations for the four sites ranged from 0.27 to 0.86 MPN $100L^{-1}$, closely resembling the range seen in 2011 (0.38 to 0.76 MPN $100L^{-1}$). Mean virus concentrations had a pooled influent mean of 0.63 MPN $100L^{-1}$, and a pooled effluent mean of 0.62 MPN $100L^{-1}$, suggesting minimal change as the water passed through the reservoir this year.

4.4 Other Results

4.4.1 Stream Chemistry

Surveillance of Kensico Reservoir is a primary requirement of the 2007 FAD under Section 4.10, “Kensico Water Quality Control Program.” In addition to the coliform bacteria, turbidity, and pathogen results previously discussed, DEP also monitors the eight perennial streams for other analytes, including temperature, dissolved oxygen, specific conductivity, and pH, and six of the eight streams are also monitored for alkalinity, chloride, dissolved organic carbon, total suspended solids, and nutrients. Monitoring for these analytes is an important component of the surveillance program. Descriptive statistics of the 2012 results for these analytes are displayed in Table 4-8. As discussed in section 4.1.2, on occasion environmental data may only be reported 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 Minitab® macro written by Dr. Dennis Helsel of Practical Stats® was again used for sites with censored values. The macro assumes the “censored” data follow a lognormal distribution and uses the robust regression on order statistics method of Helsel and Cohn (1988) to estimate the summary statistics.

Table 4-8 Annual statistics for physical, nutrient, and other chemical analytes in Kensico's perennial streams, January–December, 2012.

Analyte	Site	N	Minimum	25th Percentile	Median	75th Percentile	Maximum
Temperature (°C)	BG9	12	0.9	5.2	11.3	17.8	24.4
	E10	12	0.7	5.8	9.5	15.2	21.3
	E11	12	3.8	5.4	11.6	18.7	26.0
	E9	12	0.6	3.2	8.7	14.5	22.4
	MB-1	12	2.1	4.9	10.0	17.3	22.3
	N12	12	1.1	7.6	11.7	14.7	20.8
	N5-1	12	4.0	5.0	10.9	19.8	22.4
	WHIP	12	0.2	4.3	9.3	15.2	22.9
Dissolved Oxygen (mg L^{-1})	BG9	12	1.8	3.7	9.4	11.6	12.7
	E10	12	7.6	8.9	11.0	13.9	14.5
	E11	12	0.9	5.2	9.2	12.7	13.9
	E9	12	2.8	5.0	6.7	7.6	14.6
	MB-1	12	7.2	8.7	11.0	12.1	13.7
	N12	12	8.6	9.7	11.5	13.6	14.6
	N5-1	12	3.6	6.4	9.5	11.7	12.6
	WHIP	12	8.4	9.9	12.1	13.0	16.4
Specific Conductivity (µmhos cm^{-1})	BG9	12	71	490	620	783	848
	E10	12	769	786	826	996	1044
	E11	12	311	372	402	459	600
	E9	12	377	435	503	554	632
	MB-1	12	293	487	569	619	713
	N12	12	266	273	292	388	444
	N5-1	12	268	362	444	457	616
	WHIP	12	278	296	309	353	386
Chloride (mg L^{-1})	BG9	12	86.2	113.8	141.4	161.9	195.0
	E11	12	26.4	39.5	44.3	52.9	89.4
	MB-1	11	51.4	81.8	103.5	119.8	153.7
	N12	12	26.9	29.0	33.2	42.2	57.6
	N5-1	12	32.1	49.5	62.8	75.0	119.5
	WHIP	12	37.8	42.6	46.4	50.3	66.6

Table 4-8 Annual statistics for physical, nutrient, and other chemical analytes in Kensico's perennial streams, January–December, 2012. (continued)

pH	BG9	12	6.62	6.80	7.27	7.34	7.47
	E10	12	7.65	7.73	7.77	7.80	7.93
	E11	12	7.20	7.41	7.52	7.70	7.84
	E9	12	6.63	6.83	7.10	7.32	7.66
	MB-1	10	6.91	7.08	7.26	7.41	7.55
	N12	10	7.61	7.69	7.80	7.88	8.01
	N5-1	10	6.98	7.12	7.36	7.49	7.77
	WHIP	10	7.60	7.64	7.69	7.83	7.88
Alkalinity (mg L^{-1} $CaCO_3$)	BG9	12	61.30	65.95	80.80	96.78	101.60
	E11	12	94.60	118.20	123.25	146.00	157.10
	MB-1	12	53.80	86.40	88.80	91.50	105.00
	N12	12	53.60	57.85	69.50	99.63	123.80
	N5-1	12	64.20	71.93	81.25	93.73	103.20
	WHIP	12	48.10	49.35	59.45	75.60	82.70
Dissolved Organic Carbon (mg L^{-1})	BG9	12	1.7	2.4	3.4	4.2	4.3
	E11	12	2.8	3.2	4.2	4.4	18.6
	MB-1	12	1.6	1.9	2.5	3.4	5.1
	N12	12	1.3	1.7	2.4	2.7	4.0
	N5-1	12	1.6	2.1	3.2	3.8	5.3
	WHIP	12	1.6	1.8	2.6	2.9	3.6
Total Phosphorus (µg L^{-1})	BG9	12	15	17	32	47	103
	E11	12	14	20	24	52	124
	MB-1	12	21	25	35	53	76
	N12	12	12	14	22	26	75
	N5-1	12	20	26	46	82	106
	WHIP	12	11	13	19	31	35
Total Nitrogen (mg L^{-1})	BG9	12	0	0.27	0.36	0.42	1.90
	E11	12	0.18	0.23	0.27	0.38	3.00
	MB-1	12	0.23	0.35	0.41	0.50	0.54
	N12	12	0.64	0.65	0.76	1.05	1.37
	N5-1	12	0.56	0.70	0.82	0.97	1.11
	WHIP	12	0.56	0.67	0.85	1.08	1.38
NH_3-N (mg L^{-1})	BG9[1]	11	<0.02	0.02	0.04	0.05	0.08
	E11[1]	11	<0.02	0.00	0.00	0.02	0.13
	MB-1	11	0.02	0.03	0.04	0.07	0.09
	N12[1]	11	<0.02	0.00	0.00	0.02	0.08
	N5-1	11	0.04	0.04	0.11	0.13	0.29
	WHIP[2]	11	<0.02	*	*	*	0.02

[1] Due to the presence of censored data, a robust regression on order statistics method was used to estimate the percentiles.

[2] Due to the number of censored data, percentiles could not be estimated.

Table 4-8 Annual statistics for physical, nutrient, and other chemical analytes in Kensico's perennial streams, January–December, 2012. (continued)

NO_3+NO_2-N (mg L^{-1})	BG9[1]	12	<0.02	0.04	0.12	0.29	0.41
	E11[1]	12	<0.02	0.02	0.05	0.11	0.25
	MB-1	12	0.05	0.15	0.26	0.36	0.50
	N12	12	0.57	0.61	0.74	0.99	1.31
	N5-1	12	0.22	0.46	0.61	0.91	1.20
	WHIP	12	0.44	0.60	0.82	1.12	1.45
Total Suspended Solids (mg L^{-1})	BG9[1]	12	<1	1.6	3.4	4.6	12.2
	E11	12	1.2	1.4	3.1	4.7	14.8
	MB-1	12	1.5	2.1	2.9	5.1	7.2
	N12	12	<1	1.2	2.3	5.3	6.5
	N5-1[1]	12	<1	1.4	3.4	10.5	18.0
	WHIP[1]	12	<1	0.3	1.1	2.5	6.9
Total Coliform (coliforms $100mL^{-1}$)	BG9[1]	12	<200	120	400	768	4700
	E10	12	40	293	1550	5225	9300
	E11[1]	11	<50	140	670	1300	10000
	E9	12	40	160	1500	5000	59000
	MB-1	11	40	200	520	2000	10000
	N12[1]	12	<200	130	530	5575	39000
	N5-1	12	80	253	640	4650	39000
	WHI[1]P	12	<200	140	970	6000	10000
Fecal Coliform (coliforms $100mL^{-1}$)	BG9[1]	14	<10	9	28	185	310
	E10[1]	14	<20	17	101	293	2000
	E11[1]	13	<10	3	18	235	1100
	E9[1]	14	<20	13	50	385	5400
	MB-1	18	2	23	88	495	1500
	N12[1]	13	<20	4	55	295	3200
	N5-1	13	18	49	73	268	1000
	WHIP[1]	13	<20	3	9	210	620
Turbidity (NTU)	BG9	12	1.2	1.7	3.1	4.8	6.5
	E10	12	0.4	0.7	1.0	1.8	13.7
	E11	12	1.5	2.3	3.5	4.1	12.0
	E9	12	1.5	2.0	3.4	4.8	15.0
	MB-1	12	2.2	3.8	4.2	4.7	5.6
	N12	12	0.3	0.8	1.5	2.2	4.4
	N5-1	12	1.8	1.9	2.8	5.8	8.8
	WHIP	12	0.4	0.7	1.2	1.5	2.9

[1] Due to the presence of censored data, a robust regression on order statistics method was used to estimate the percentiles.
[2] Due to the number of censored data, percentiles could not be estimated.

4.4.2 Chemical Surveillance (VOC and SVOC)

Annual surveillance monitoring of the Kensico Reservoir effluent keypoint DEL18DT on December 18, 2012 for 67 VOCs and 68 SVOCs resulted in no compounds being detected.

4.5 Kensico Storm Sampling

During 2012, three storm events met criteria for additional monitoring as per the Kensico Storm Event Sampling Plan. This plan was developed in early 2012 in response to the deleterious water quality impacts that the Kensico system experienced after the tropical storms in late 2011. Storm events are selected for monitoring primarily when predicted rainfall is expected to exceed two inches within a 48 hour period. Analytes selected for study were fecal coliform (coliforms $100mL^{-1}$), conductivity (µmhos), and turbidity (NTU). Microbial Source Tracking (MST) is also specified, when appropriate, to help define the source of elevated fecal coliform bacteria. During selected storms, automated grab sample monitoring is conducted at two of Kensico Reservoir's perennial tributaries (N5 and Malcolm Brook) that are nearest to the effluent sampling locations (DEL18DT and CATLEFF). As noted previously, CATLEFF shut down in September 2012. Additional limnological sampling is conducted at preset intervals after the storms. With this sampling approach, DEP is attempting to gain a better understanding of the fecal coliform impact of the streams on the reservoir, and ultimately the effluents, during large events. DEP responded to weather predictions for three such storms in 2012: April 22 - 23, September 18 - 19 and October 29. The following information highlights the results and conclusions of each storm event.

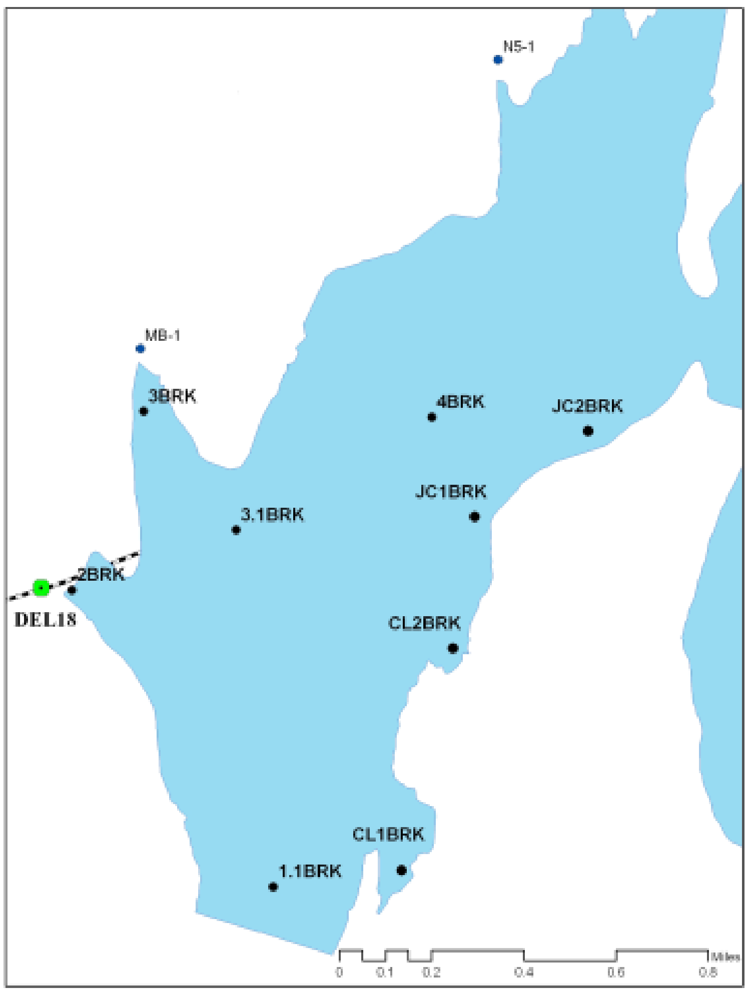

Figure 4-24 Storm event monitoring sites for Kensico Reservoir.

4.5.1 April 22-23, 2012

Approximately 2.36 inches of rain fell between April 22 and 23 in the Kensico Reservoir area. Automated sampling was conducted at the N5-1 and MB-1 sites, and at nearby reservoir limnology sites (Figure 4-24). Six stream samples were taken at N5-1, eleven from MB-1, and approximately 33 samples were collected at reservoir sites 2, 3, 3.1 and 4 for the three analytes. Two samples from each stream were sent for MST analysis. Results from the N5-1 sampling indicated a precipitous rise and fall of all three analytes within the time period of the storm event (Figure 4-25); whereas, MB-1 results showed a more gradual rise and fall in analyte concentrations (Figure 4-26). This is not unusual considering differences in landscape and sub-basin size.

Limnology samples collected on days two and three after the storm resulted in a maximum fecal coliform result of 7 fecal coliforms $100ml^{-1}$ on day two, and 5 fecal coliforms $100ml^{-1}$ on day three. Maximum turbidity was 1.0 NTU on both days. Four stream samples with the highest fecal coliform concentrations were submitted for MST analysis and isolation of the human *Bacteroides* marker, and two of those samples were also analyzed for the cervine biomarker. While the general marker was positive at significant levels in all samples, correlating well with fecal coliform results, no samples were positive for either human or cervine types.

It was concluded that the April storm event had minimal impact on N5 and Malcolm Brook and was not significant enough to adversely affect analyte concentrations at nearby Kensico Reservoir sampling sites or source water effluent quality.

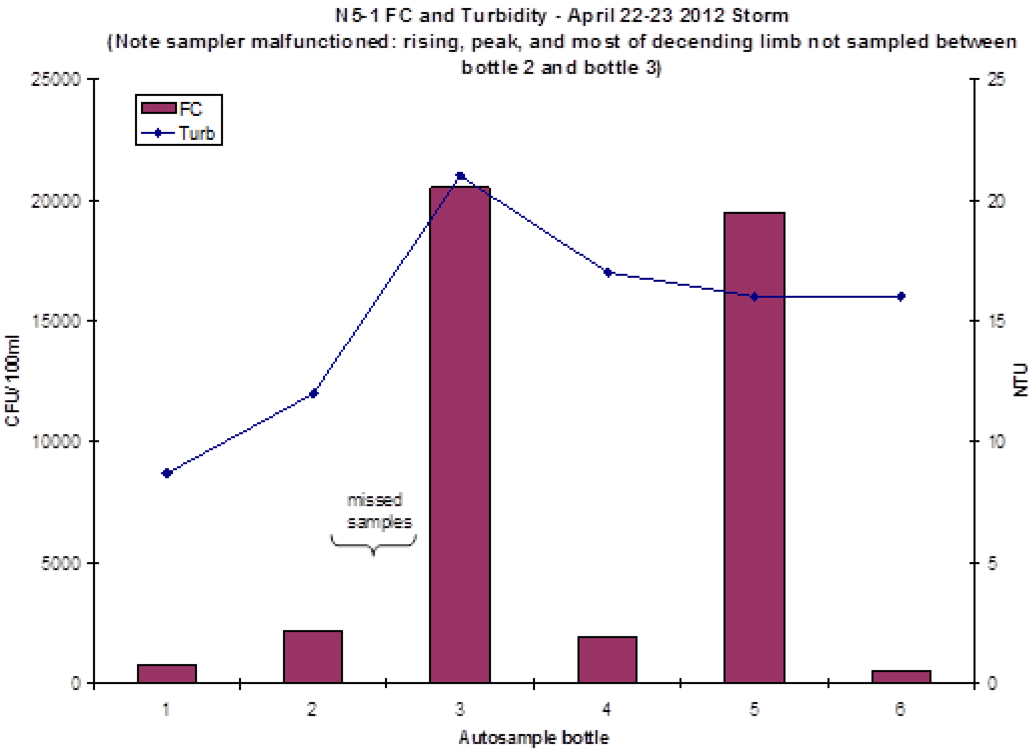

Figure 4-25 Fecal coliform and turbidity results at stream site N5-1 from April 22-23, 2012.

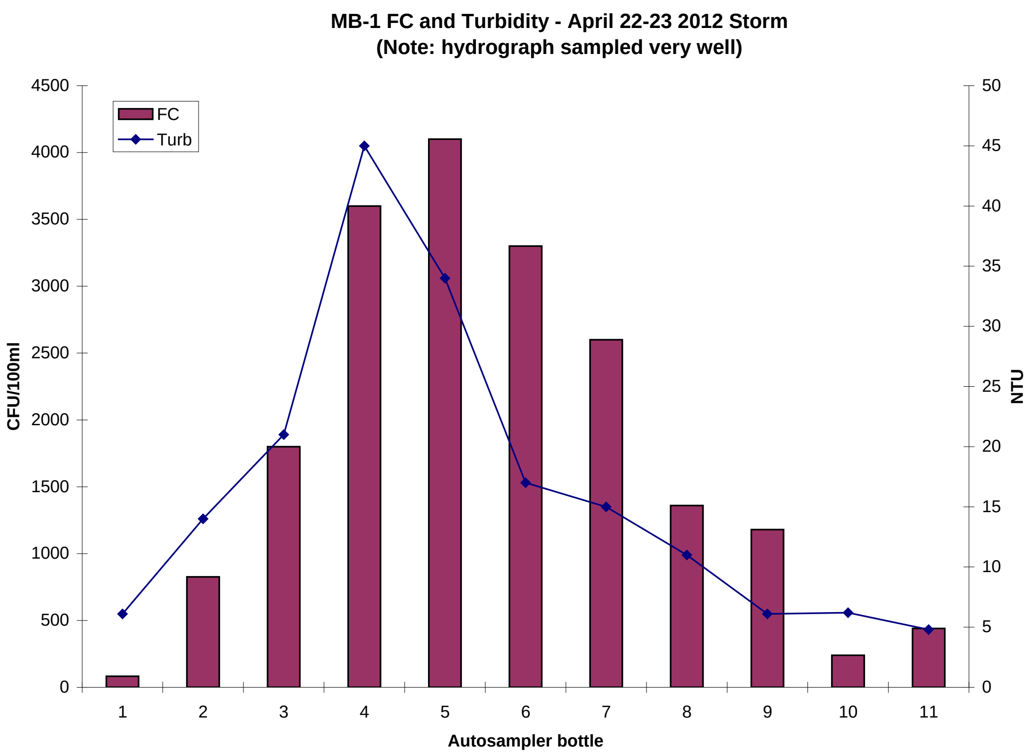

Figure 4-26 Fecal coliform and turbidity results at stream site MB-1 from April 22-23, 2012.

4.5.2 September 18-19, 2012

A major storm was forecasted for September 18 to 19, with actual rainfall for the event totaling 1.80 inches (recorded at the DEL18 meteorological station). The event was sampled at the two streams, Kensico Reservoir limnology sites 2, 3, 3.1 and 4, and four new limnological sites added near the eastern shore of the reservoir to test for possible impact of overland flow (Figure 4-24). Seven stream samples each were taken at MB-1 and N5-1, and approximately 19 samples were collected from reservoir sites 2, 3, 3.1 and 4 for the three analytes, fecal coliform , conductivity, and turbidity .Four of these samples were from specially designated sites, CL1BRK, CL2BRK, JC1BRK and JC2BRK. Six stream samples, three from MB-1 and three from N5-1, were analyzed for MST.

Turbidity and fecal coliform tended to be lower during the September storm compared to April (Table 4-9). The exception was fecal coliform results for Malcolm Brook, which were higher in September than April.

Table 4-9 Comparison of concentrations between the April and September storms for fecal coliform (fecal coliforms $100mL^{-1}$) and turbidity (NTU). Readings are approximate.

Site	Dates of Sampling	Analyte	Concentration Range
MB-1	04/22-04/23	Fecal Coliform	<1,000-4,000
N5-1	04/22-04/23	Fecal Coliform	<1,000-20,000
MB-1	09/18-09/19	Fecal Coliform	<1,000-12,000
N5-1	09/18-09/19	Fecal Coliform	3,600-10,000
MB-1	04/22-04/23	Turbidity	5 – 45
N5-1	04/22-04/23	Turbidity	9-20
MB-1	09/18-09/19	Turbidity	12-16
N5-1	09/18-09/19	Turbidity	5.1- 16

Reservoir sampling indicated a short-term rise in fecal coliform at Site 3, near Malcolm Brook. Samples taken at the DEL18DT keypoint showed a five-fold increase in fecal coliform concentration on the day of the storm (Table 4-10) suggesting that the fecal coliform source was within a few hours of travel time from the effluent.

Table 4-10 Summary of Kensico keypoint effluent site fecal coliform results a few days before, during and after the September 18-19, 2012 storm.

Date	DEL18DT fecal coliforms $100mL^{-1}$	Precipitation (in) Westchester County Airport	Precipitation (in) Del 18 Meteorological Station
09/16/12	3	0.00	0.00
09/17/12	3	0.00	0.02
09/18/12	15	1.21	1.78
09/19/12	9	0.00	*
09/20/12	1	0.00	*
09/21/12	2	0.00	*
09/22/12	3	0.18	*

*** data not available**

Six stream samples, three from each stream, were shipped for MST analysis. Four of these samples, two from each stream, were submitted for the detection of a human *Bacteroides* marker. Two samples, one from each stream, were analyzed for a human *Enterococcus* marker. While all samples were negative for the human *Bacteroides* marker, one sample was positive for detection of the human *Enterococcus* marker. However, since there are many more *Bacteroides* present in feces, and it is a much more specific test for human sources, a positive *Enterococcus* result in the absence of the human *Bacteroides* is not indicative of human contamination. In this case it is likely that the *Enterococcus* marker cross reacted with feces of another mammal.

This storm event, while showing a clear impact on the streams, did not have a sustained impact on Kensico Reservoir water quality at the reservoir effluents as results quickly reverted to background levels by the second day after the event.

4.5.3 October 29 (Hurricane Sandy), 2012

Hurricane Sandy was predicted to bring significant rainfall to the Kensico watershed; however, unexpectedly, only approximately 0.5 inches of rain fell in the area during this event. While rainfall was minimal compared to the two preceding storms, enhanced monitoring was still conducted as wind speed and direction became a factor for water quality. One pre-storm sample (early 10/29) was taken at each of eight sites (BG9, E10, E11, E9, MB-1, N5-1, N12 and WHIP) to measure baseline conditions for turbidity and fecal coliform. Six samples were taken during the storm (10/29-10/30) at MB-1 with an autosampler for the same two analytes. Samples were collected by autosampler at N5-1, but were not analyzed, as the site was inaccessible during and after the storm due to downed trees. One grab sample each was taken at four sites (BG9, E10, E11, E9) during the storm on 10/30 for the two analytes. Due to low fecal coliform results, no samples were analyzed for MST during this event.

Ten samples were taken at reservoir Site 2 at numerous depths for turbidity and fecal coliform on 10/30, and one sample at each of the DEL18 cove shoreline sites (2L and 2.5L) was collected for turbidity on the same day to ascertain the impact of the wind-induced erosion and the ensuing turbidity on water quality at DEL18DT (Figure 4-27). A more extensive survey was conducted on 10/31 where 26 total samples were collected at reservoir sites 1.1, 2, 3, 4 and 5 for turbidity, fecal coliform and other analytes.

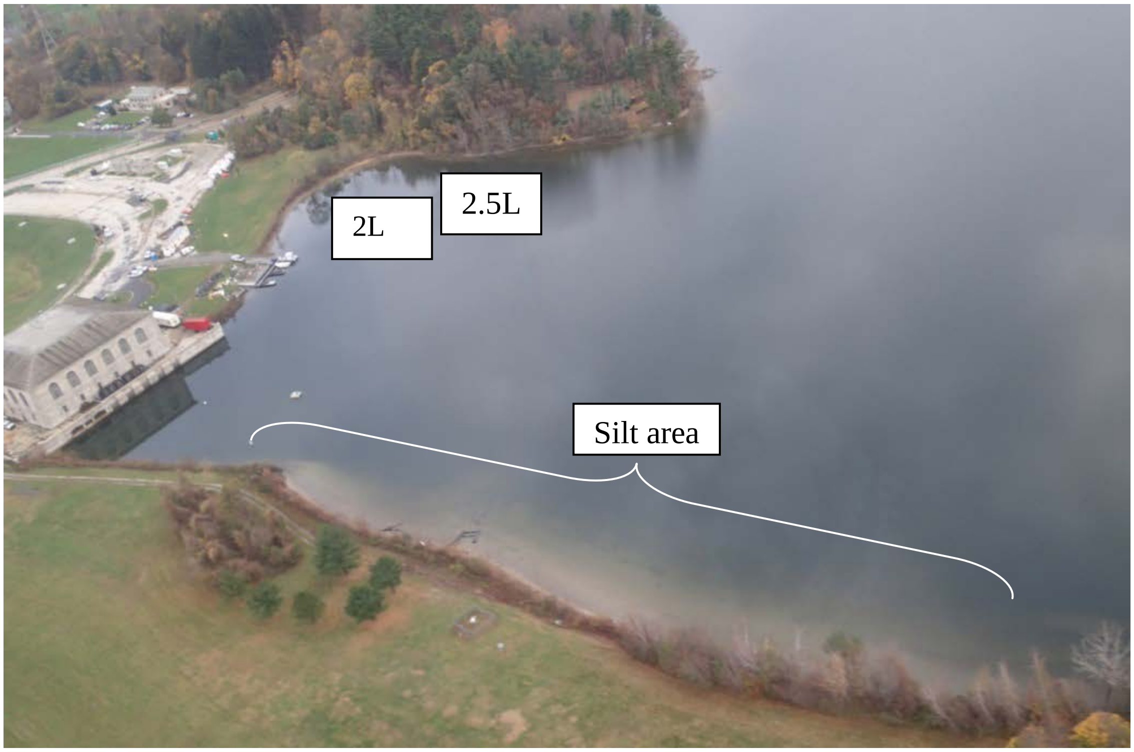

Figure 4-27 Aerial photograph of the DEL 18 cove on October 31, two days after Hurricane Sandy, showing the approximate locations of sites 2L and 2.5L.

Samples were collected once daily at DEL18DT before, during and after the storm (October 27-November 2) for fecal coliform analysis for a total of seven samples. Fecal coliform levels did not exceed 3 fecal coliforms $100ml^{-1}$ during the storm. Samples were collected every four hours for turbidity during this same time period totaling 27 samples and turbidity levels at DEL18DT reached 11 NTU during the storm event causing a SWTR violation, as discussed in Section 4.3.3. Reservoir samples taken at 2L and 2.5L, though showing elevated turbidity levels, were not in a direct flow path of water entering the DEL18DT intake. Therefore the influence from these two sites on the turbidity discovered at DEL18DT remains unclear. No distinct turbidity plume was detected at Site 2, in the flow path of the intake. In this case, it is most likely that eolian effects created a scenario of wave-induced shoreline erosion that led to the turbidity spike at DEL18DT, rather than precipitation run-off causing increased turbidity as is more commonly the cause during most storms (Figure 4-28). Turbidity at the Kensico intake declined to acceptable levels rapidly after operational changes were made.

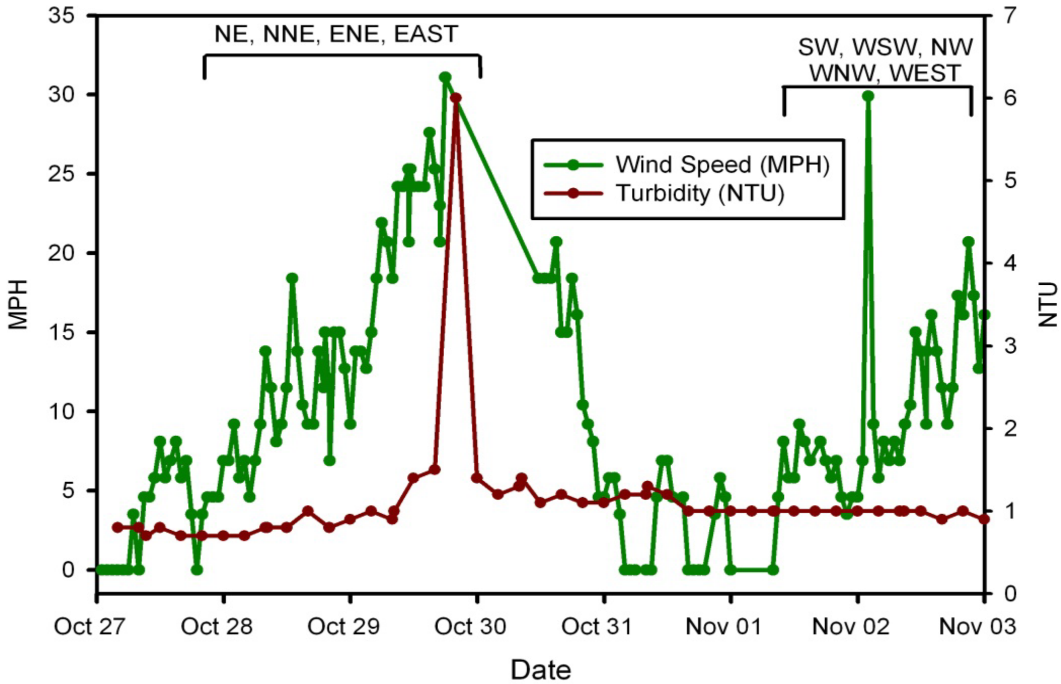

Figure 4-28 Wind speed, direction and turbidity at DEL18DT before, during, and after Hurricane Sandy.

5. Kensico Modeling for 2012

During 2012 nine sets of Kensico Reservoir water quality modeling analyses were performed to support operational decisions. The first four simulation sets were related to timing the future ending of alum treatment which had commenced on August 29, 2011 due to Hurricane Irene and Tropical Storm Lee. The remaining simulations were required throughout the year following the end of alum treatment to examine the effects of changes in reservoir operations and to help choose optimal reservoir operating strategies in response to modest increases in Ashokan turbidity.

5.1 Model Descriptions

For the Kensico Reservoir simulations, LinkRes and its component model 2D reservoir model CEQUAL W2 (DEP 2004, Cole and Buchak 1995) was used to simulate the transport of turbidity within the reservoir, and levels of turbidity both within the reservoir and at aqueduct withdrawals.

Each set of model simulations performed during 2012 consisted of a number of scenarios of different Catskill and Delaware system turbidity and flow inputs that were modeled to predict their effects on Kensico effluent turbidity levels. Model results helped determine Catskill and Delaware Aqueduct flow rates that would allow DEP to continue to deliver Catskill water into Kensico Reservoir, while allowing an acceptably small increase in turbidity at the effluents thereby meeting regulatory limits.

A “positional analysis” strategy was followed for these model runs. Under this strategy, the present conditions of the reservoir at the time of the simulations were used to define the initial conditions that were the starting point for the model simulations. These were generally based on the most recently measured data from a combination of limnological survey data and in-reservoir automated buoy measurements. Then the model was run for a forecast period which was generally 30 days into the future. To produce probabilistic forecasts multiple simulations were run based on separate inputs of meteorology and aqueduct water temperature from each year in the historical record, over the time period for which the forecast was required. During the forecast period aqueduct inflows and influent turbidity loads are set at fixed values associated with the expected conditions. With this method, each year represents a separate realization (or trace) of the simulated model outcome and variability in the traces will result from year-to-year changes in weather conditions only. The major focus of these simulations is to help determine the acceptable ratios of Catskill versus Delaware inputs to Kensico Reservoir to ensure that effluent turbidity will remain at safe levels and not exceed regulatory limits.

5.2 Simulation Descriptions

Table 5-1 summarizes all Kensico Reservoir turbidity analyses performed during 2012. During the winter and spring (February-May) of 2012 four separate Kensico modeling analyses were performed to better understand both the optimum flows into Kensico and to help determine when and if alum treatment should be concluded. (Alum treatment had commenced on August 29, 2011 and ended May 15, 2012.) In July another Kensico turbidity modeling run was performed to refine Catskill Aqueduct operations as warmer surface water from Ashokan Reservoir was being used to avoid more turbid water which was located a deeper depths. In September the Catskill effluent from Kensico was no longer in use due to the start-up of the CDUV facility. To help understand the effects of only using the Delaware effluent from Kensico, a special model sensitivity study was performed that compared the results of runs with and without the use of the Catskill effluent. The results of these runs showed little impact on simulated Delaware effluent turbidity.

A storm event in mid-September 2012 caused elevated turbidity in the Ashokan West Basin. At first, since Ashokan West Basin was drawn down prior to the event, the East Basin was only mildly affected by the event. But as more events impacted the reservoir during the fall, turbidity from the West Basin began to have larger impact on the East Basin and, in turn, the Catskill turbidity inputs to Kensico Reservoir. Eventually, stop shutters were used to limit Catskill flow into Kensico and maintain the water quality of the Kensico effluent. During this fall period, three separate sets of model simulations were run to guide decisions on aqueduct flow rates into Kensico Reservoir that would allow effluent turbidity standards to be maintained. Overall, model runs during this fall period were effective in helping to determine flow rates that maintained water quality standards while not necessitating the use of alum.

Table 5-1 List of modeling analyses performed during the reporting period including descriptions of each analysis.

Turbidity Modeling Runs October 2011-September 2012			
Date	**Background**	**Modeling Description**	**Results**
Feb. 28, 2012	Since the tropical events of the fall of 2011, turbidity in Ashokan East Basin had dropped to about 20 NTU. Stop shutters and alum treatment continued to be implemented.	As Ashokan East Basin turbidity continued to decrease, it may have been possible to end alum use within a few months. These Kensico Reservoir simulations were run to provide guidance as to what levels of turbidity could be tolerated as inputs to Kensico Reservoir from the Catskill aqueduct when alum treatment was ended. The tested flow rates were 150, 200 and 250 MGD in the Catskill Aqueduct with aqueduct turbidity of 12, 16 and 20 NTU.-	Results suggested that Kensico effluent turbidities ranging as low as 1.7-2.5 NTU for inputs of 12 NTU and as high as 2.2-3.7 NTU for input turbidity of 20 NTU. Greater flow in the Catskill Aqueduct produced larger effluent turbidity.
Mar. 13, 2012	Turbidity in Ashokan East Basin had dropped to about 16 NTU. Stop shutters and alum treatment continued to be implemented.	As Ashokan East Basin turbidity continued to decrease, these Kensico simulations were run to provide guidance as to what levels of turbidity could be tolerated as inputs to Kensico Reservoir from the Catskill Aqueduct when alum treatment was ended. The tested flow rates were 175 and 275 MGD in the Catskill Aqueduct with aqueduct turbidity of 12, 14, 16 and 18 NTU.	Results suggested that Kensico effluent turbidities ranging as low as 1.8-3.0 NTU for input of 12 NTU and as high as 2.3-4.2 NTU for input turbidity of 18 NTU. Greater flow in the Catskill Aqueduct produced larger effluent turbidity.
Apr. 10, 2012	Ashokan Reservoir (both basins) had dropped to about 10 NTU. Alum treatment continued to be implemented.	Kensico Reservoir simulations were performed to provide guidance as to what levels of turbidity could be tolerated as inputs to Kensico Reservoir from the Catskill Aqueduct once alum treatment was ended and flow rates were increased. The tested inflow rates were 400, 500 and 600 mgd from the Catskill Aqueduct with aqueduct turbidity of 6, 8, and 10 NTU.	Results suggested that Kensico effluent turbidities ranged as low as 1.8-3.2 NTU for input of 6 NTU and as high as 2.7-5.2 NTU for input turbidity of 10 NTU. Greater flow in the Catskill Aqueduct produced larger effluent turbidity. In addition, the reservoir became thermally stratified during the simulation period. Thermally stratified conditions produced turbidity plumes along the thermocline that reached the vicinity of the effluents.

Table 5-1 List of modeling analyses performed during the reporting period including descriptions of each analysis. (continued)

Turbidity Modeling Runs October 2011-September 2012			
Date	**Background**	**Modeling Description**	**Results**
May 2, 2012	Turbidity in Ashokan Reservoir had deceased to about 6-9 NTU. Alum treatment continued to be implemented.	Kensico Reservoir simulations were run to provide guidance as to what levels of turbidity could be tolerated as inputs to Kensico Reservoir from the Catskill Aqueduct when alum treatment was ended, and aqueduct flows increased. The tested inflow rates are 300, 400, 500 and 600 mgd from the Catskill Aqueduct with aqueduct turbidity of 6, 8 and 10 NTU.	Results suggested that Kensico effluent turbidities could range as low as 1.4-3.1 NTU for input of 6 NTU and as high as 1.8-5.0 NTU for input turbidity of 10 NTU. Greater flow in the Catskill Aqueduct inputs produced larger Kensico effluent turbidity. In addition, thermal stratification of the reservoir intensified during the simulation period. Stratified conditions produced turbidity plumes along the thermocline that might extend close to the effluents.

Jul. 27, 2012	There was a low intensity turbidity plume in both the East and West Basins of Ashokan Reservoir. The plume was generally located near or below the thermocline with turbidity ranging from approximately 4-7 NTU. To avoid the higher turbidity, the upper level of the West Basin of Ashokan was being used to divert water to the Catskill Aqueduct. This water was warmer than under normal historical operations. Delivering warmer water to Kensico Reservoir is expected to affect the thermal structure of Kensico and possibly could change the plume dynamics and mixing with Delaware water also being input to Kensico Reservoir.	Kensico Reservoir model simulations were run to better understand the effects the use of warmer water with slightly elevated turbidity from the Catskill Aqueduct influent on the turbidity of Kensico Reservoir effluents. The tested inflow turbidity from Catskill were 4, 6 and 8 NTU with an inflow of 600 MGD These input values were tested with different alternative time series of Catskill influent water temperatures.	With higher water temperature for Catskill influent, the resulting plume of turbidity tended to form with slightly more intensity and closer to the surface within Kensico Reservoir. Since the plume was simulated at a shallow depth above the depth of effluent withdrawal, the simulated effluent turbidity decreased with higher influent temperature. Based on this simulated behavior, it was recommended that if there was a sustained Catskill influent turbidity of 6 NTU or higher automated monitoring should be closely followed to understand the magnitude and location of any turbidity plume that might form.

Table 5-1 List of modeling analyses performed during the reporting period including descriptions of each analysis. (continued)

Turbidity Modeling Runs October 2011-September 2012

Date	Background	Modeling Description	Results
Sep. 21, 2012	As a result of bringing the UV plant on line the Catskill effluent from Kensico Reservoir was no longer in use. All water leaving Kensico Reservoir would be using the Delaware effluent which delivers water to the UV plant.	The goal of these simulations was to ascertain if the simulated Delaware effluent turbidity is affected once the Catskill effluent is turned off. A previous run from October 1 of 2010 was changed from effluent flow of 400 MGD Catskill / 800 MGD Delaware to 0 MGD Catskill / 1200 MGD Delaware.	There was little or no difference in the Delaware effluent turbidity for the two cases (with and without use of the Catskill effluent).
Oct. 3, 2012	A turbidity event on September 18, 2012 produced a large input of turbidity into the Ashokan West Basin. The event did not fill the West Basin, but caused the East Basin turbidity near the gate house to rise to about 7-9 NTU near the surface with a plume of about 25 NTU at the thermocline and greater turbidity near the bottom.	These simulations were run to provide guidance for inputs to Kensico Reservoir from the Catskill Aqueduct given the current turbidity and possible future turbidity increases as the flow through the dividing weir continued to affect the East Basin turbidity. The tested Catskill inflow rates were 200, 275, 350 and 400 MGD aqueduct turbidity of 8, 10, 12 and 15 NTU.	Results suggested that Kensico effluent turbidities ranging as low as 1.7-2.8 NTU for input of 8 NTU and as high as 2.3-4.6 NTU for input turbidity of 15 NTU. Greater flow in the Catskill Aqueduct produced larger effluent turbidity. Also model results indicated that it was probable that the reservoir would remain thermally stratified through the simulation period.

Table 5-1 List of modeling analyses performed during the reporting period including descriptions of each analysis. (continued)

Turbidity Modeling Runs October 2011-September 2012

Date	Background	Modeling Description	Results
Nov. 2, 2012	Storm events during October had moved elevated turbidity from the West Basin to the East Basin of Ashokan. East Basin turbidity near the gate house was above 15 NTU and the reservoir was isothermal as indicated by the Ashokan East automated buoy. Stop shutters were in place to limit Catskill Aqueduct flow to Kensico. Kensico Reservoir turbidity generally ranged from 0.7-1.5 NTU with higher turbidity of 2.4-2.8 NTU at site 5 near the Catskill influent. In addition, transmissometer measurements indicated higher turbidity in the bottom 3 meters at sites 1.1 and 4. Limnological survey measurements indicated bottom turbidity at site 1.1 of 1.6-2.2 NTU.	These simulations were run to provide guidance on acceptable inputs to Kensico Reservoir from the Catskill Aqueduct given the current turbidity and possible future turbidity increases as the flow over the dividing weir continued to affect the East Basin turbidity. The tested Catskill inflow rates were 50, 150 and 250 MGD with aqueduct turbidity of 15, 20, and 25 NTU.	Results suggested that Kensico effluent turbidities ranging as low as 1.5-3.2 NTU for input of 15 NTU and as high as 1.7-4.8 NTU for input turbidity of 25 NTU. Greater flow in the Catskill Aqueduct produced larger effluent turbidity. Also model results indicated that the reservoir would remain thermally stratified through the simulation period with epilimnion temperatures dropping from 14^{o}C to about 10^{o}C.

Dec. 28, 2012	Ashokan East Basin turbidity near the gate house ranged from 11-14 NTU and the reservoir was isothermal at <4oC as indicated by the Ashokan East automated buoy. The Dec. 26 keypoint measurement for the Ashokan effluent was 8.8 NTU. Stop shutters were being installed to limit Catskill Aqueduct flow to Kensico. Based on limnological survey of Dec. 26, Kensico Reservoir turbidity generally ranges from 1.3-1.7 NTU with higher turbidity of 6.8-7.0 NTU at site 5 near the Catskill influent.	These simulations were run to provide guidance for the levels of turbidity that could be tolerated as inputs to Kensico Reservoir from the Catskill Aqueduct given the current and possible future increases in Ashokan East Basin turbidity. The tested Catskill inflow rates were 50, 150 and 250 MGD with aqueduct turbidity of 8, 10, and 15 NTU.	Results suggested that Kensico effluent turbidities ranging as low as 1.2-2.2 NTU for input of 8 NTU and as high as 1.4-3.4 NTU for input turbidity of 15 NTU. Greater flow in the Catskill Aqueduct produced larger effluent turbidity.

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