New York City Department of Environmental Protection

2011 Kensico Water Quality Annual Report

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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
DEL17	Delaware Aqueduct Shaft Building 17
DEL18	Delaware Aqueduct Shaft Building 18
DEC	New York State Department of Environmental Conservation
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
NTU	Nephelometric Turbidity Units
NYC	New York City
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
WQD	Water Quality Directorate
WWQMP	Watershed Water Quality Monitoring Plan

Acknowledgements

The Deputy Commissioner of the Bureau of Water Supply, Mr. Paul Rush, and the Director of the Water Quality Directorate (WQD), Mr. Steven Schindler, continued to provide general direction for operation of Kensico Reservoir and watershed activities throughout 2011 The reservoir undergoes continuously changing conditions that affect water quality in a variety of ways and this requires their constant attention. This report is intended to provide an accurate description of the water quality of Kensico Reservoir, 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 a safe water supply to NYC consumers.

The members of the Watershed Water Quality Science and Research Division were responsible for coordination, data analysis, and primary authorship roles for the 2011 Kensico Water Quality Annual Report. They include: Dr. Lorraine Janus, Mr. James Mayfield, Mr. Gerard Marzec, Mr. David Quentin, Ms. Kerri Alderisio, Mr. Christian Pace, Dr. Don Pierson, Dr. Elliot Schneiderman, Mr. Mark Zion, Mr. David Lounsbury, Mr. Richard Van Dreason, and Mr. Don Kent.

The members of Watershed Water Quality Operations, directed by Ms. Lori Emery, provided the watershed field and laboratory work and resulting database for Part II of 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 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 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 2011. This was demonstrated by full compliance with the SWTR requirements for fecal coliform bacteria in raw water samples, which is possible when resident and migratory waterfowl populations are minimized. Low levels of fecal coliform bacteria have been consistently achieved since 1993. The implementation of the WMP continues to be a key component to achieving compliance with the source water fecal coliform requirements of 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 conducted visual inspections of the turbidity curtain at the Catskill Upper Effluent Chamber cove in 2011.

There were two special investigations conducted within the Kensico Reservoir watershed during 2011. One after a large storm in May, and another due to sewer main break that did not impact the reservoir. Also additional weather-related surveys were conducted to determine the extent of fecal coliform and turbidity distribution in the reservoir after the tropical storms in late August and early September.

Con Edison ("ConEd") maintains an electric transmission corridor that traverses 2.1 miles of land in the Kensico Reservoir drainage basin along the western shore of the reservoir However, no significant work was conducted by ConEd on the electric transmission right-of-way at Kensico in 2011.

Kensico Reservoir water quality monitoring that was conducted in 2011 included approximately 7600 samples collected at 31 sites throughout the basin, with the highest intensity of monitoring at the effluent keypoint sites. The next most intensely sampled sites were those located throughout the reservoir itself. Grab samples were taken at the effluent keypoint sites 4,417 times and in the reservoir 597 times. In addition, 322 pathogen samples were analyzed for *Cryptosporidium* and *Giardia*, and another 209 samples were collected for human enteric viruses (HEV).

Annual samples for surveillance monitoring of Kensico Reservoir effluent keypoints, DEL18 and CATLEFF, for 67 VOCs and 68 SVOCs, resulted in one compound, chloroform (CAS. No. 67-66-3), being detected at both locations.

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 values less than 200 fecal coliforms 100 mL^{-1}, except E9 with the highest median value at 225 fecal coliforms 100 mL^{-1}. The 2011 data indicate that some of the streams have total coliform occurrences above 5,000 total coliforms 100 mL^{-1}, which were generally associated with a sample being collected during or immediately following storm 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 2011 results for these analytes are presented.

In 2011, 395 total coliform and 423 fecal coliform bacteria samples were collected throughout Kensico Reservoir for coliform analyses. The medians for total coliform samples only exceeded the DEP guidelines of 100 coliforms 100 mL^{-1} at Site 7, while the median fecal coliforms counts were below 20 coliforms 100 mL^{-1}at all sites. Total coliform counts typically exceed the guideline in late summer and autumn when most reservoirs experience an increase in bacteria counts. In 2011, two tropical storms in the fall were the primary cause of the median counts exceeding 100 total coliform 100 mL^{-1} at sites 5 through 8. Fecal coliform counts also increased as a result of these storms and there were fecal coliform samples that exceeded the DEP guideline at all reservoir sites. There were 439 turbidity samples collected on routine reservoir surveys in 2011. Site 5 had the highest median turbidity (2.9 NTU), and individual samples for this site were equal to or exceeded 5.0 NTU 11 times. Only one other routine sample exceeded this value at Site 1.1 (8.0 NTU). 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 routinely conducts 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 entering the Catskill and Delaware Aqueducts, respectively, at points just prior to disinfection, and are the sites which must meet SWTR "raw water" requirements.

The median fecal coliform level for 2011 at the Kensico influents (CATALUM and DEL 17) was 1 and 1.5 coliforms 100 mL^{-1}, respectively, and was 1 coliform 100 mL^{-1} for both of the effluent sites (CATLEFF and DEL18). At the influent sites, median turbidity for 2011 was 25 NTU at CATALUM and 1.2 NTU at DEL17. At the effluent sites, median turbidity for 2011 was 1.1 NTU at CATLEFF and 1.2 NTU at DEL18. Although storm events led to elvated turbidities at CATLEFF and the need for alum treatment, the SWTR limit of 5 NTU was consistently met at both effluent keypoints.

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 2011, 322 samples were collected and analyzed for *Giardia* and

Cryptosporidium in the Kensico Reservoir watershed. This includes 208 fixed frequency samples collected at the two influents and two effluents combined, as well as 96 fixed frequency samples collected at eight perennial tributaries. Eighteen additional protozoan samples were collected in 2011 for various reasons, and they are discussed further in Section 4.5. In addition, 209 samples were collected and analyzed for human enteric viruses (HEV). In general, 2011 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*. Although some of the volumes varied per sample, no more than 4 oocysts were detected in any of the stream samples, and no more than 1 oocyst was detected at the influents or effluents of the reservoir in 2011. *Giardia* results were more variable and the reservoir influent and effluent maxima were 9 and 6 cysts $50L^{-1}$, respectively. HEV were detected more frequently in 2011, especially at the end of the year.

During 2011 there were three periods (Jan.-Feb.; May; Sept.-Oct.) in which Kensico Reservoir water quality modeling was necessary to support operational decisions. The three periods coincide with elevated levels of turbidity in the Catskill System and during one case also in the Delaware System. Alum treatment was needed during portions of all three events, and model runs were used to both minimize the duration of alum treatment and the amount of alum used when treatment was necessary. Kensico Reservoir turbidity simulations were run to forecast future reservoir turbidity levels; to develop scenarios that examined the consequence of changes in reservoir operations; and to help choose an optimal reservoir operating strategy that would both minimize the impacts on Kensico effluent turbidity, and minimize the use of alum. In total, 23 separate modeling analyses were performed.

There were a series of unique issues that affected the modeling effort including the influence of an ice cover at Kensico Reservoir (early in 2011), the uncertainty of the appropriate turbidity size class partitioning to use with both alum-treated Catskill influent and untreated Delaware turbidity input (fall 2011), and the challenge of simulating a significant plume of turbidity in the Catskill branch of the reservoir (fall 2011). Detailed limnological survey data included transmissometer readings at 1 m vertical resolution and automated turbidity profile measurements at 6 hour temporal resolution. These data when combined with the modeling provided an essential information stream that aided in operating the system in all of these cases. Modeling runs helped to identify data that would be of importance, and data helped to define initial reservoir conditions and input parameters that ensured the most accurate model simulations. This combination of data and modeling provided simulations and forecasts of sufficient detail that allowed water quality requirements to be maintained during this challenging period.

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 semi-annual 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 2011) contains a review of the status of Kensico water quality based on the 2007-2009 time period, 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 in order 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.

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). Kensico Reservoir was largely operated in "reservoir" mode in 2011.

The Delaware Aqueduct leaving Kensico Reservoir was shutdown 102 times over the course of the entire year, primarily for work associated with construction of the new ultraviolet disinfection facility.

Unplanned shutdowns of the Catskill Aqueduct due to water quality problems associated with storm events occurred on August 29, and September 9 and 12, 2011. The Delaware aqueduct was never completely shut down for water quality reasons, but was switched to float mode of operation on January 30, August 27, September 14 and October 19 and switched to by-pass mode from September 9 to September 11 to avoid potential water quality problems at Kensico Reservoir. Float mode allows water from Rondout Reservoir and/or West Branch Reservoir to pass around Kensico Reservoir with Kensico Reservoir water added only if needed to meet demand. In by-pass mode, water flows directly from Rondout Reservoir and/or West Branch Reservoir to Hillview Reservoir and New York City distribution.

2. Water Quality Management

2.1 Waterfowl Management

DEP's Wildlife Studies Section is responsible for oversight of the Waterfowl Management Program (WMP), while partial program implementation is the responsibility of a consultant, Henningson, Durham, and Richardson, P.C. The most recent Waterfowl Management Program Contract (WMP-12) was awarded and commenced on September 18, 2011, and is expected to continue through September 17, 2014. For a more detailed account of the WMP, refer to the annual FAD report (DEP 2011b) on this topic dated July 31, 2011 (required under section 4.1 of the FAD).

The objectives of the WMP are:

- Survey and record daily waterbird counts from 0500 to 0800 hours, including spatial and temporal distribution of roosting waterbirds, 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 water quality data to assess the impacts of birds on fecal coliform bacteria levels, which are monitored for the Surface Water Treatment Rule (SWTR).
- Conduct daily waterbird dispersal activities from 0800 hours until 1.5 hours past sunset from August 1 through March 31. Dispersal activities include harassment via motorboats, Airboats, and pyrotechnics, where needed.
- Record seasonal surveillance of water influent facilities for alewives (*Alosa pseudoharengus*), a baitfish. Dead and dying alewives transported through the NYC aqueducts from upstream reservoirs to Kensico attract waterbird foraging. To eliminate this feeding attraction, containment booms are used to collect the fish.

Additional waterbird 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 Shaft 18 (DEL18) facility to deter Barn Swallow (*Hirundo rustica*) and Cliff Swallow (*Hirundo pyrrhonota*) nesting to decrease bird fecal contamination of the untreated water entering the facility.
- Annual banding activities conducted with DEC. 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 the New York

State Department of Environmental Conservation on waterbird management techniques. The USDA was under contract with the Westchester County Airport in compliance with Wildlife Hazard Management Plan (Federal Aviation Administration citation) for Westchester County Airport, located to the east of Kensico Reservoir. DEP's Wildlife Studies Section worked cooperatively with the USDA in the removal of 8 Canada geese from reservoir property in July 2011.

2.2 Turbidity Curtain Monitoring

A double turbidity curtain was 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 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 2011. If an observation indicated that maintenance was required, BWS Systems Operations was notified and conducted appropriate repairs or adjustments.

Table 2-1 2011 visual inspections of the Catskill Upper Effluent Chamber turbidity curtain.

Inspection Date	Observations
1/5/2011	Curtain appears intact and afloat as seen from shore.
1/19/2011	Appeared intact and frozen in place- small portion on ground near MB b/c of lowered water.
2/2/2011	Curtain appears intact and frozen in as seen from shore.
2/16/2011	Curtain appears intact and mostly frozen in as seen from shore.
3/2/2011	Curtain appears intact and frozen in as seen from shore.
3/17/2011	Curtain appears intact and afloat as seen from shore.
3/30/2011	Curtain appears intact and afloat as seen from shore.
4/13/2011	Curtain appears intact and afloat as seen from shore.
4/27/2011	Curtain appears intact and afloat as seen from shore.
5/11/2011	Curtain appears intact and afloat as seen from shore.
5/24/2011	Curtain appears intact and afloat as seen from shore.
6/8/2011	Curtain appears intact and afloat as seen from shore.
6/22/2011	Booms appear intact as seen from shore. Some yellow fabric seen floating under surface next to yellow boom.
7/6/2011	Curtain appears intact and afloat as seen from shore.
7/20/2011	Curtain appears intact and afloat as seen from shore.
8/3/2011	Curtain appears intact and afloat as seen from shore.
8/17/2011	Curtain appears intact and afloat as seen from shore.
8/31/2011	Curtain appears intact and afloat as seen from shore.
9/9/2011	Curtain appears intact and afloat as seen from shore. This inspection was in response to crew concerns. Earlier in the day a crew noticed some bunching and sinking during a turbidity limno survey. An additional inspection was done on 9/10/2011 by boat w/ HAZMAT.
9/14/2011	Curtain appears intact and afloat as seen from shore.

Table 2-1 2011 visual inspections of the Catskill Upper Effluent Chamber turbidity curtain.

Inspection Date	Observations
9/29/2011	Curtain appears intact and afloat as seen from shore.
10/12/2011	Curtain appears intact and afloat as seen from shore.
10/26/2011	Curtain appears intact and afloat as seen from shore.
11/9/2011	Curtain appears intact and afloat as seen from shore.
11/23/2011	Curtain appears intact and afloat as seen from shore.
12/7/2011	Curtain appears intact and afloat as seen from shore.
12/21/2011	Curtain appears intact and afloat as seen from shore.

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 2011. 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. One hundred and twenty trees of nine species were planted and protected from deer with 5’ tall tubes. The tubes will be removed when the trees are large enough to survive deer pressure, in approximately five years (2015) and this will not have any consequences for water quality.

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 streambanks, and high turbidity levels in water entering the Catskill Aqueduct at Ashokan Reservoir. DEC 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 has necessitated additional alum treatment of the Catskill System.

A condition of the SPDES permit to treat with alum is that DEP remove the alum floc resulting from such use. Alum floc in the reservoir settles in the vicinity of the Catskill Influent Chamber (CATIC), where water from the Catskill Aqueduct enters Kensico Reservoir. This floc will be removed at some time in the future by dredging. Initial scientific investigations, to define the area of floc deposition, detail the bathymetric, benthic, core sampling, computer modeling, and flow study findings, were completed by Malcolm Pirnie, Inc. in 2007.

More recently, DEP has discussed with DEC the potential benefits of deferring dredging until the completion of certain 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 Special Investigations

There were two special investigations conducted within the Kensico Reservoir watershed during 2011. One investigation occurred after a storm that resulted in over 5 inches of rainfall in the Kensico watershed from May 14-18, 2011. Following the storm a total of six instances of fecal coliforms above 20 coliforms $100mL^{-1}$ occurred between the DEL18 and CATLEFF source water locations. Additional weather-related surveys were conducted to determine the extent of fecal coliform and turbidity distribution in the reservoir after the tropical storms in late August and early September.

The other special investigation concerned a sewer main break in the vicinity of 1548 Old Orchard Road, Harrison, N.Y. On 08/31/2011, East of Hudson Watershed Water Quality Operations collected water samples from a Kensico tributary stream above and below the sewer main break. Samples were analyzed for total and fecal coliforms. No distinct increase in the coliform results downstream of the sewer spill site was observed compared to the upstream site. Considering the topography, the greater than one half mile of stream water course, three in-line ponds and the substantial wetland areas, the likelihood of a significant fecal coliform contribution reaching Kensico Reservoir was low. No follow-up investigation was warranted.

3. Routine Sampling Strategy

The overall water quality sampling effort within the Kensico basin 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. Kensico Reservoir water quality monitoring that was conducted in 2011 included samples at 31 sites throughout the basin, with the highest intensity of monitoring at the effluent keypoint sites. 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 1,441 times and in the reservoir 1,035 times. In addition, 322 pathogen samples were collected for *Cryptosporidium* and *Giardia*, and another 209 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 3-1) and sampled manually at 4-hour intervals. Other parameters that are monitored continuously are pH, temperature, and conductivity.

Table 3-1 Summary of Kensico Reservoir water quality monitoring conducted in 2011.

Kensico Sampling Programs	# of sites	Parameters	Routine Frequency	Sampling Agency	Number of Samples Collected in 2011
Streams	18	bacteria, turbidity, physicals, nutrients[1], other chemistry[1]	monthly	DEP	182[2]
Reservoir	9	bacteria[3], turbidity, physicals, nutrients[3], other chemistry[3]	2x monthly[3], Mar-Dec only	DEP	1035[4]
Keypoints at effluents	2	bacteria, turbidity, physicals, nutrients[5], other chemistry[5]	7x/week	DEP	844
Keypoints at influents	2	bacteria, turbidity, physicals, nutrients[6], other chemistry	5x/week	DEP	597
Toxic Chemicals at effluents	2	VOCs, SVOCs	annually	DEP	2
Pathogens	12	*Cryptosporidium*, *Giardia*	4 keypoints weekly, 8 streams monthly	DEP	322
	4	HEV	4 keypoints weekly	DEP	209
SWTR Compliance	2	Turbidity	every 4 hours	DEP (operators)	4417
Total	31	-	-	-	7608

[1] At 6 sites only.

[2] 72 samples for nutrients.

[3] Nutrients and other chemistry collected monthly. Bacteria collected at selected sites.

[4] 200 samples for nutrients and 1035 for bacteria.

[5] Nutrients and other chemistry collected monthly.

[6] TP weekly at CATALUM and DEL17 per SPDES permits.

The outlets of the Delaware and Catskill Aqueducts into 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 DEC as required by the permit.

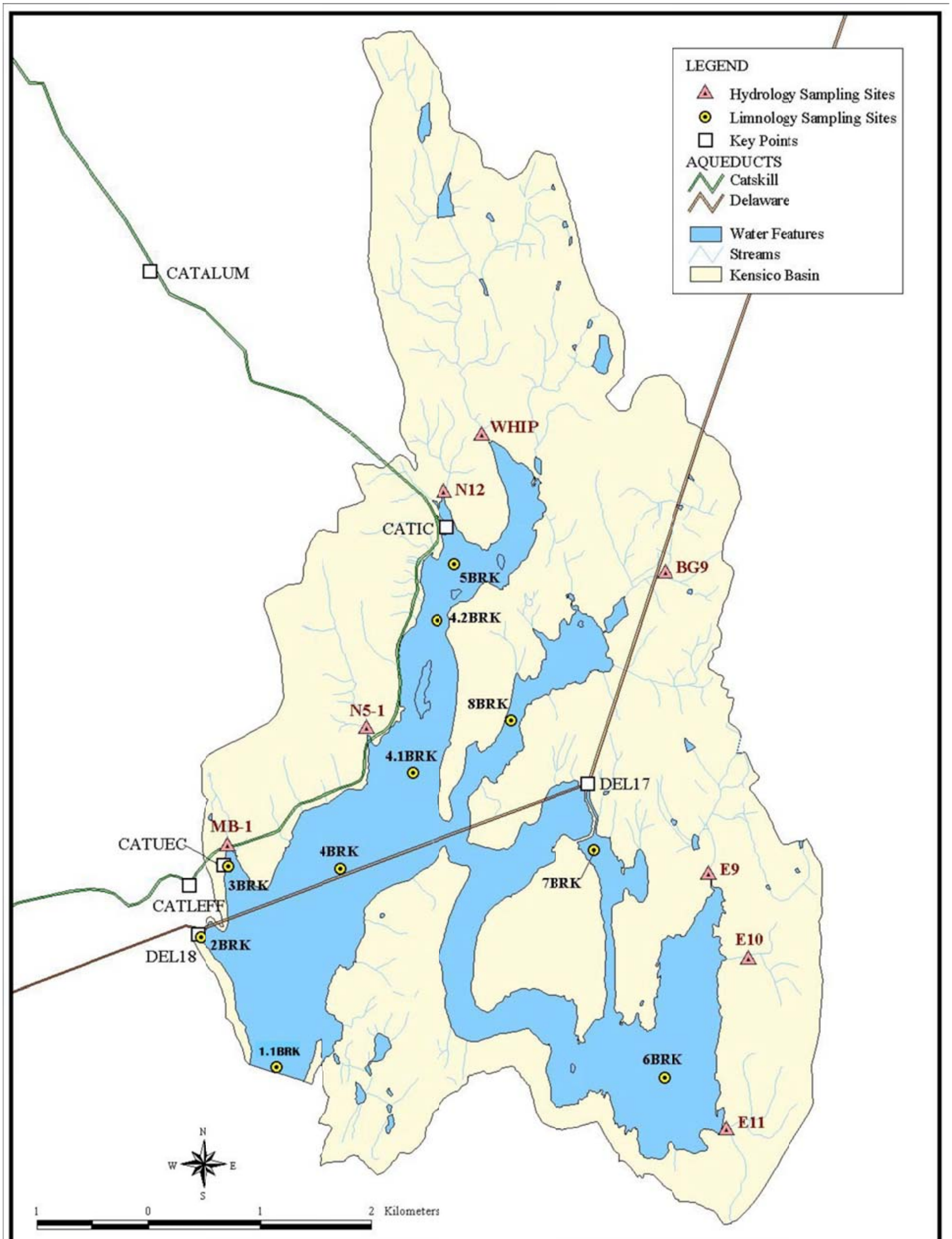


Figure 3-1 Kensico Reservoir, showing limnological and hydrological sampling sites, keypoints, and aqueducts. There is a meteorological station at DEL18.

3.1 Groundwater (DOT data)

No ground water monitoring was conducted during 2011 by the Westchester County Airport. The airport sampling contract expired in the latter half of 2010, and the Volunteer Groundwater Monitoring program was stopped. The program will be evaluated by the airport's environmental management staff for possible future modification.

3.2 Toxic Chemical Surveillance

DEP annually samples 10 upstate reservoir aqueduct keypoints to complement required surveillance of volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) conducted within the NYC Water Supply distribution system. VOCs were analyzed by potable water method USEPA Method 524.2; semivolatile compounds were analyzed using USEPA Method 525.2. The 2011 survey includes the sampling of two aqueduct keypoints: Delaware (at DEL18) and Catskill (at CATLEFF) leaving Kensico Reservoir.

3.3 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 2011. In addition to the routine program, special investigation samples were collected in response to several significant storm events.

Also in 2011, continuous flow measurements were maintained at all 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.

3.4 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 March through December 2011.

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. Special surveys conducted in 2011 were primarily related to turbidity events initiated by Tropical Storms Irene and Lee in late August and early September, respectively. Site 5 on Kensico was sampled weekly after these storms due to the SPDES requirement for monitoring that site during alum treatment. All routine and additional data collected during the sampling period were distributed through weekly water quality reports, and source water briefs. An after-action report has not been completed for the alum treatment since treatment has continued as of the writing of this report.

3.5 Keypoints

DEP routinely conducts 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 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). All four 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.

3.6 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. In 2011, 322 samples were collected and analyzed for *Cryptosporidium* and *Giardia* within the Kensico Reservoir watershed between January 1 and December 31, 2011. This sample set includes 208 routine fixed-frequency samples plus 17 additional samples that were taken at, or were representative of, the four keypoints (Kensico Reservoir influent and effluent aqueducts), and 96 fixed frequency samples, plus one additional sample, at the eight perennial Kensico tributaries. In addition, 207 routine samples were collected and analyzed for HEV at the four Kensico Reservoir keypoints, with two additional samples collected (one for alternate filter testing and the other after Tropical Storm Irene).

Cryptosporidium and *Giardia* monitoring involved the filtration of 50 L of water in the field, and analysis by DEP according to Method 1623HV (USEPA 2005). HEV monitoring involved the filtration of 200-300 L of water in the field and analysis by the contract laboratory per the Information Collection Rule (ICR) Method (USEPA 1996). As of November 7, 2011, DEP changed virus filters from the CUNO 1MDS filter to the Argonide NanoCeram filter, at all sites except CATALUM. The CUNO filters were continued at CATALUM as a result of the high turbidities that were persistent after Tropical Storms Irene and Lee. Both filters are approved by the EPA for recovering viruses from surface water. Additionally, on December 19, 2011, DEP began to implement the 10 flask option of the ICR virus method in place of the 20 flask version.

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 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 mean values provided by location.

4. Results and Discussion

4.1 Toxic Chemical Surveillance

Annual samples for surveillance monitoring of Kensico Reservoir effluent keypoints, DEL18 and CATLEFF, for 67 VOCs and 68 SVOCs, resulted in one compound, chloroform (CAS. No. 67-66-3), being detected at both locations. The results, from October 19, 2011, are stated below in Table 4-1.

Table 4-1 2011 chloroform results from the annual surveillance of the Kensico Reservoir effluent keypoints.

Keypoint Site	Compound	Detection (µg/L)	MRL	USEPA MCL	NYSAWQS
CATLEFF	chloroform	2.1	0.5	N/A	7.0
DEL18	chloroform	2.7	0.5	N/A	7.0

MRL – Minimum Reporting Limit
USEPA MCL – United States Environmental Protection Agency Maximum Contaminant Level
NYSAWQS – New York State Ambient Water Quality Standard

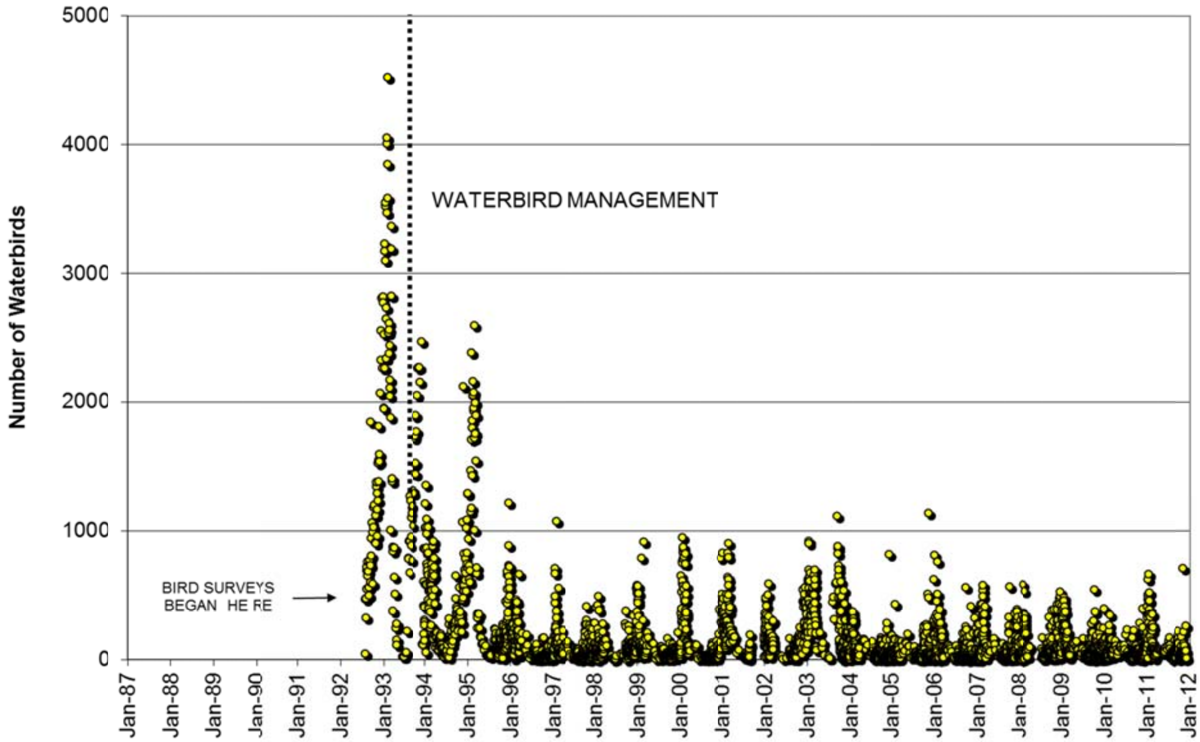
Results indicate a detection of chloroform above the MRL at CATLEFF and DEL 18. Pre-chlorination sources of chloroform lending themselves to detection are volcanic gases, biomass burning and soil microorganisms (Ivahnenko T. and Barbash J.E., 2004). Other sources include inadvertent discharges from swimming pools, spas, chlorinated water used to irrigate lawns, golf courses, parks and gardens and other institutions involved in a suburban setting (Ivahnenko T. and Zorgorski, 2006). Detections are well below the NYSAWQS, indicative of posing no threat to NYC potable water quality.

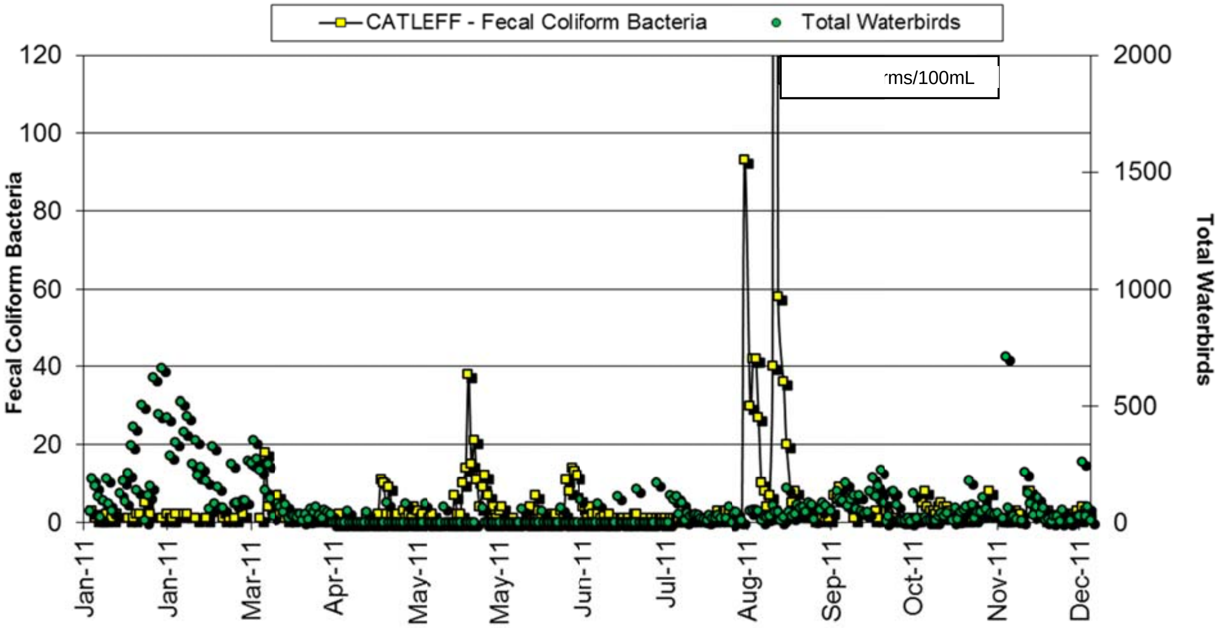
4.2 Coliform Bacteria

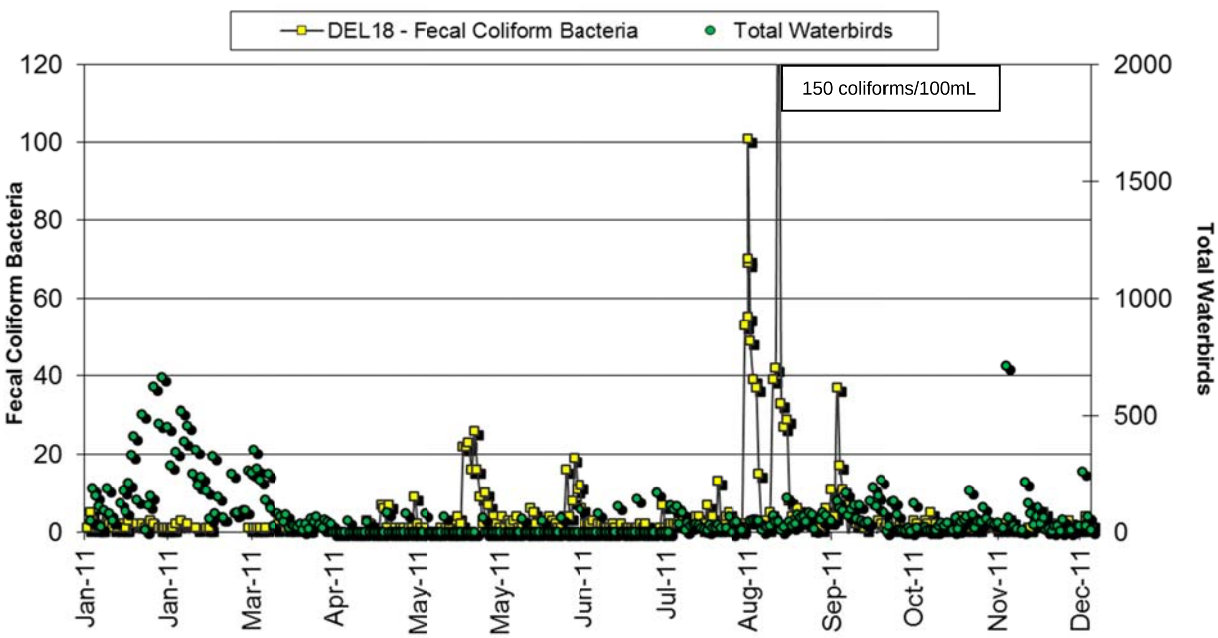
4.2.1 Waterfowl Management for Fecal Coliform Control

The WMP continued to maintain a high level of success during 2011. This was demonstrated by full compliance with the SWTR requirements for fecal coliform in raw water, which requires that no more than 10% of source water samples exceed 20 fecal coliform $100mL^{-1}$. This is only possible when resident and migratory waterbird populations are kept at low levels (Figure 4-1). Figures 4-2 and 4-3 compare the regulatory source water samples collected from DEL18 and CATLEFF (the Kensico effluents) with respect to fecal coliform bacteria and reservoir bird counts. In 2011 the maximum monthly percentages of source water sample results above 20 fecal coliform $100mL^{-1}$ were 8.7% for DEL18 and 6.6% for CATLEFF (Figure 4-4). There were three important precipitation events recorded during 2011 that coincided with elevated fecal coliform counts during May, August, and September. During the May precipitation event (May 15-18) a total of 2.5 inches of rain was recorded resulting in 6 consecutive double-digit fecal coliform results at CATLEFF (collected May 18-23), two of which were above 20 fecal coliform $100mL^{-1}$. There were also 6 double-digit fecal coliform sample results at DEL18 from May 18 through May 23, 4 of which were above 20 fecal coliform $100mL^{-1}$. In late August and early September 2011, the region was struck by Tropical Storms Irene and Lee. Over 7 inches of rain was recorded during Tropical Storm Irene on August 27-28.

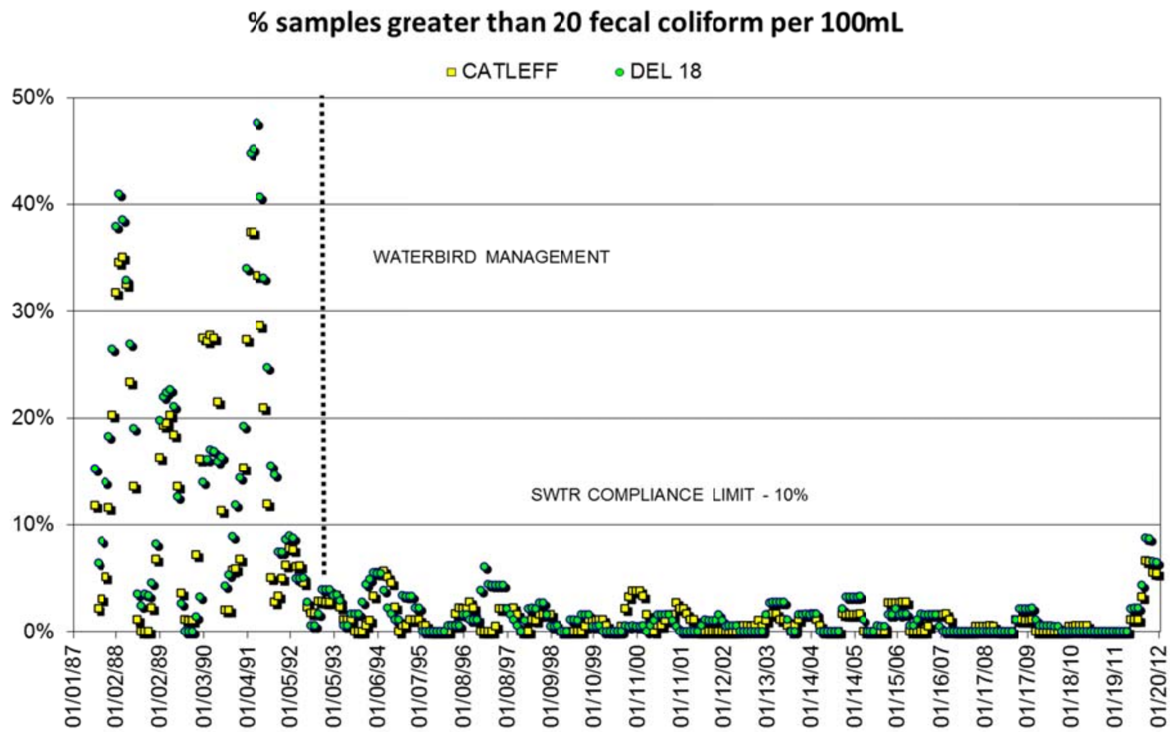
This storm resulted in 7 double-digit fecal coliform bacteria sample results at CATLEFF from August 28 through September 3, 6 of which were above 20 fecal coliform 100mL^{-1}. There were also 7 double-digit fecal coliform bacteria sample results at DEL18 from August 28 through September 3, 5 of which were above 20 fecal coliform 100mL^{-1}. Rainfall associated with Tropical Storm Lee in early September totaled 6.2 inches at Kensico. During the time period of September 6 to September 8, 4 samples from CATLEFF and 6 samples from DEL18 were above 20 fecal coliform 100mL^{-1}.




CATLEFF - Fecal Coliform Bacteria
Total Waterbirds
rms/100mL
Fecal Coliform Bacteria
Total Waterbirds
120
100
80
60
40
20
0
2000
1500
1000
500
0
Jan-11
Jan-11
Mar-11
Apr-11
May-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11


DEL18 - Fecal Coliform Bacteria
Total Waterbirds
150 coliforms/100mL
Fecal Coliform Bacteria
Total Waterbirds
120
100
80
60
40
20
0
2000
1500
1000
500
0
Jan-11
Jan-11
Mar-11
Apr-11
May-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Nov-11
Dec-11

The Kensico source waters remained in compliance with the SWTR standard for fecal coliforms throughout 2011 (Figure 4-4). Levels fecal coliform bacteria have been consistently compliant with the SWTR since 1993. Long-term waterbird data collected from August 1, 1992 through December 31, 2011 are presented in Figure 4-1 . Data collected from 1992 to 1993 preceded the inception of bird harassment efforts. Bird counts for 2011 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 the most cost-effective way to achieve compliance with the SWTR.



4.2.2 Streams

The routine fecal coliform data for the period January 2011 through December 2011 are plotted in Figure 4-5. 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 often 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 sometimes called "whiskers". These lines extend up to highest data point with 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 DL), and the portions of the boxplot below this limit are estimated by the method discussed above.

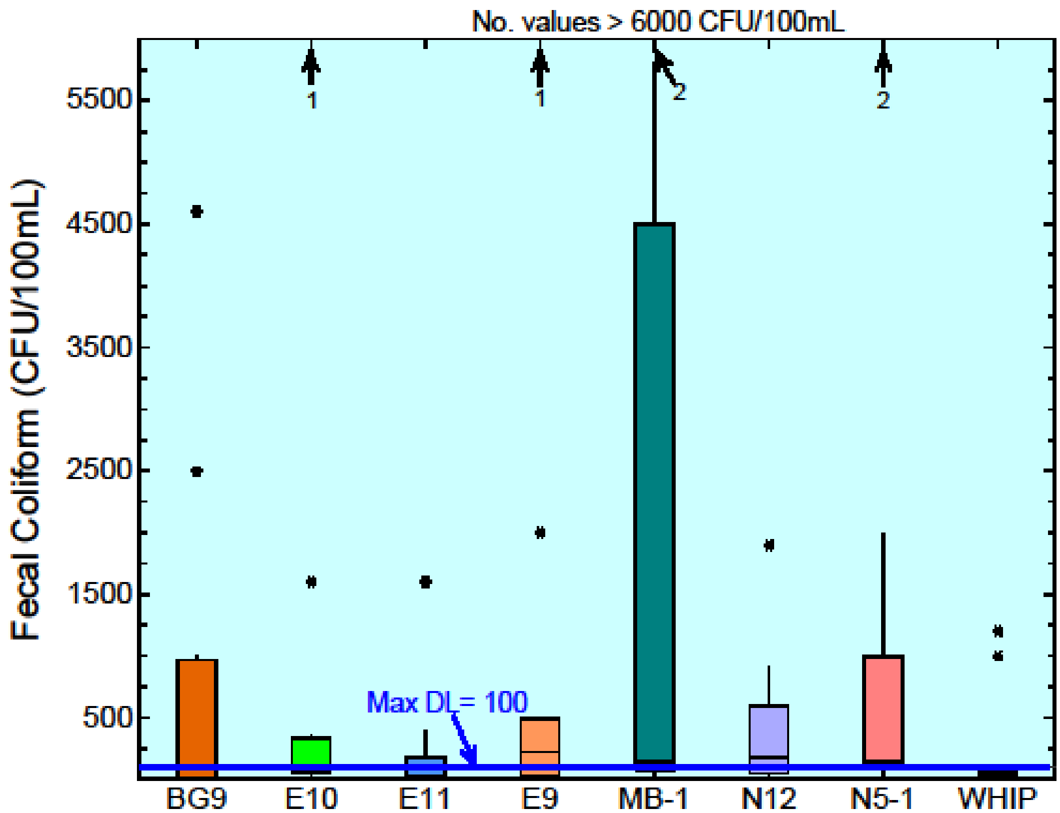


Figure 4-5 Fecal coliform plots for routine Kensico streams monitoring data, January–December, 2011.

All Kensico streams had median values less than 200 fecal coliforms 100 mL-1, except E9 with the highest median value at 225 fecal coliforms 100 mL-1, while E11 had the lowest at 14 fecal coliforms 100 mL-1. Fecal coliform values this year were somewhat higher than previous years due to the impact of several significant storm events.

Total coliform samples are also collected monthly from the eight Kensico stream sites. 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. N5-1 had the highest median total coliform value (3,550 total coliforms 100 mL^{-1}), while Bear Gutter Creek (BG-9) had the lowest median value (875 total coliforms 100 mL^{-1}). 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 2011 data indicate that some of the streams have total coliform occurrences above 5,000 total coliforms 100 mL^{-1}, which were generally associated with a sample being collected during or immediately following storm events.

4.2.3 Reservoir

The routine bacteria samples collected from Kensico Reservoir provided 395 total coliform and 423 fecal coliform data points during the period March through December 2011. Boxplots for these data are shown in Figure 4-6 and Figure 4-7. The results are compared with Surface Water Treatment Rule (SWTR) drinking water limits of 100 coliforms 100 mL^{-1} for total coliforms and 20 coliforms 100 mL^{-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, Site 7 near the Delaware influent was the only site that exceeded the guideline with a median total coliform count of 117 total coliforms 100 mL^{-1} (Figure 4-6) (see section 4.2.2 for a description of boxplots). The interquartile range extended above 100 total coliforms 100 mL^{-1} at sites 5 through 8. At all the sites there were samples that exceeded the guidance value for total coliformThe higher counts of total coliform occurred during the summer. Some of these higher counts could be attributed to the typical seasonal increase observed in many of the NYC reservoirs. A bigger factor in 2011 was the combination of Tropical Storms Irene and Lee. These two storms caused a widespread increase in total coliform that eventually attenuated in the fall.

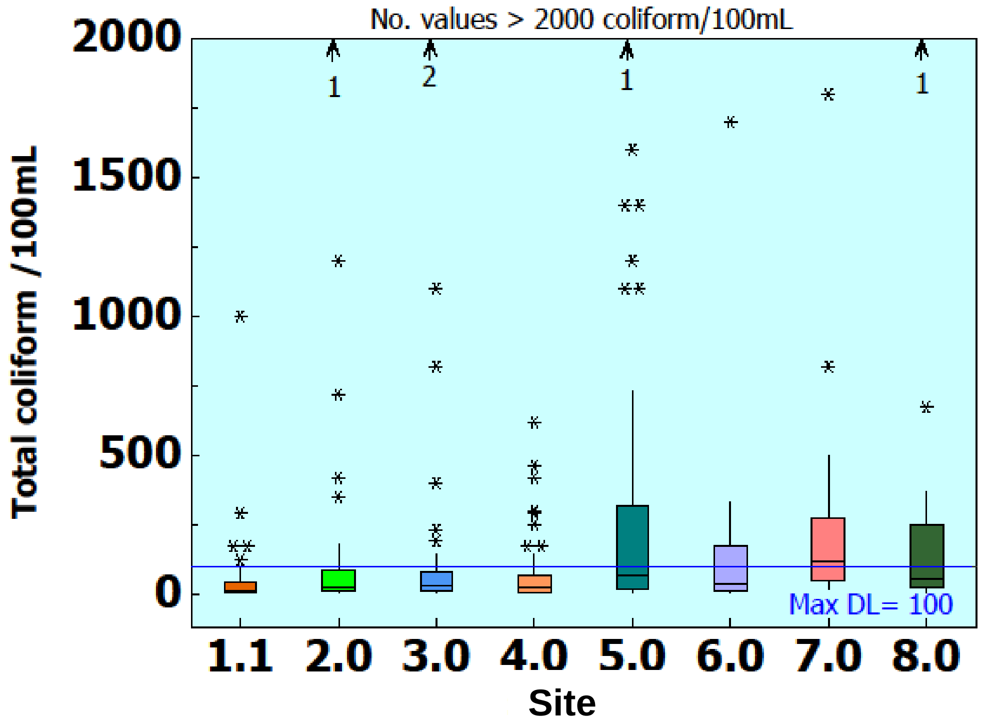


Figure 4-6 Total coliform plots for routine Kensico Reservoir monitoring data, March-December, 2011.

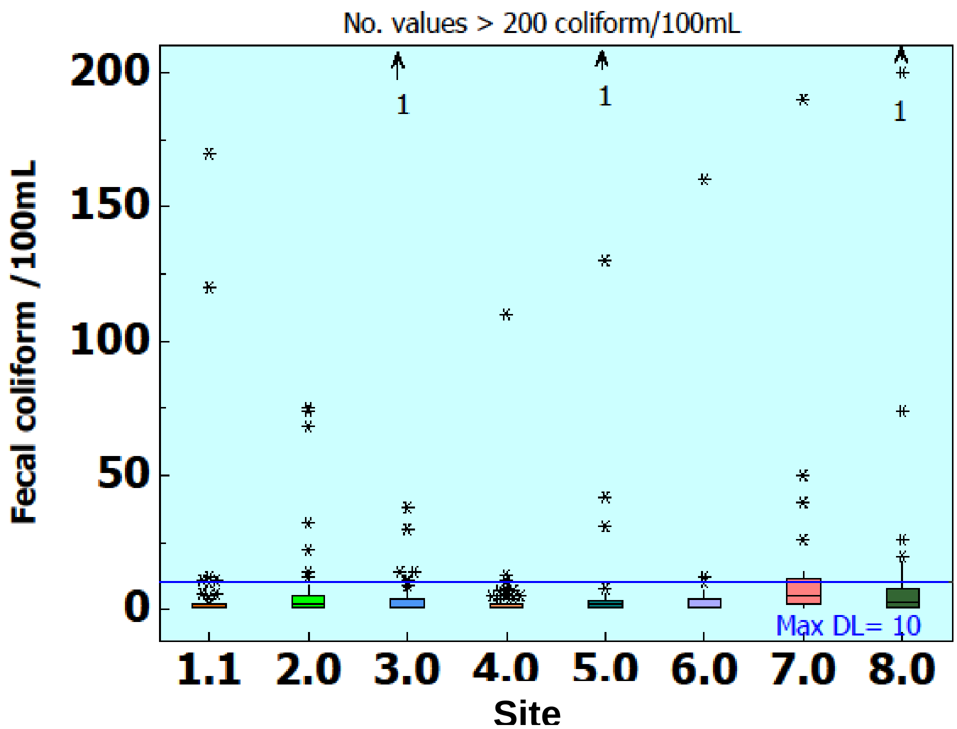


Figure 4-7 Fecal coliform plots for routine Kensico Reservoir monitoring data, March-December, 2011.

During the reporting period all sites from routine surveys had a median fecal coliform count at or below 5 coliforms 100 mL^{-1} (Figure 4-7) (see section 4.2.2 for a description of boxplots). Median counts were 1 fecal coliform 100 mL^{-1} for Site 1.1, 2 fecal coliforms 100 mL^{-1} for Site 2, 1 fecal coliform 100 mL^{-1} for Site 3, 1 fecal coliform 100 mL^{-1} for site 4, 2 fecal coliforms 100 mL^{-1} for Site 5, 1 fecal coliform 100 mL^{-1} for Site 6, 5 fecal coliforms 100 mL^{-1} for Site 7, and 3 fecal coliforms 100 mL^{-1} for Site 8. There were samples at each site that were above the DEP guideline for fecal coliform counts (20 fecal coliforms 100 mL^{-1}). The highest fecal coliform counts occurred shortly after Tropical Storm Irene. Fecal coliform counts were also elevated after Tropical Storm Lee, but to a lesser extent. The tracking of Hurricane Irene brought it close to the coast providing a greater effect on Kensico than did Tropical Storm Lee. The impact of these storms on fecal coliform counts in Kensico and the upstream reservoirs was the subject of additional studies performed by DEP and by DEP's consulting firm, HDR. Results of the HDR report is discussed in 2012.

4.2.4 Keypoints

The monitored Kensico keypoints included the aqueduct influents (CATALUM and DEL17) and effluents (CATLEFF and DEL 18). The effluents are monitored daily for fecal coliforms regardless of effluent turbidity levels. The influents are monitored for fecal coliforms five days per week.

As discussed in section 4.2.2, 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, 30% (DEL18) to 36% (CATALUM) of the 2011 fecal coliform values were "censored." The Minitab® macro discussed in section 4.2.1 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 2 2011 to December 31, 2011, medians of 1.0 fecal coliform 100 mL^{-1} at CATALUM and 1.5 fecal coliforms 100 mL^{-1} at DEL17 were calculated. The maximum fecal coliform counts were 98 fecal coliforms 100 mL^{-1} at CATALUM and 167 fecal coliforms 100 mL^{-1} at DEL17 (Figure 4-8). Other than following significant storm events, these data demonstrate that the fecal coliform levels of the aqueducts flowing into Kensico were typically quite low.

For the fecal coliform counts measured at the Kensico effluents from January 1, 2011 to December 31, 2011 a median of 1 fecal coliform 100 mL^{-1} at both CATLEFF and DEL18 was calculated. The maximum fecal coliform counts were 760 fecal coliforms 100 mL^{-1} at CATLEFF and 150 fecal coliforms 100 mL^{-1} at DEL18. As in the past, the elevated fecal coliform levels generally coincided with precipitation events. It should be noted that as per directive from NYSDOH, DEP reported flow proportioned coliform results based on data from DEL17 and 2BRK on 2/2 and 2/3, and from DEL17 and DEL18W for 2/2 – 2/11. This is due to a non-representative sample at routine sampling site DEL18 during this period when the reservoir was being operated in float mode. Overall for 2011, DEP's source water at Kensico met the SWTR limits for fecal coliforms.

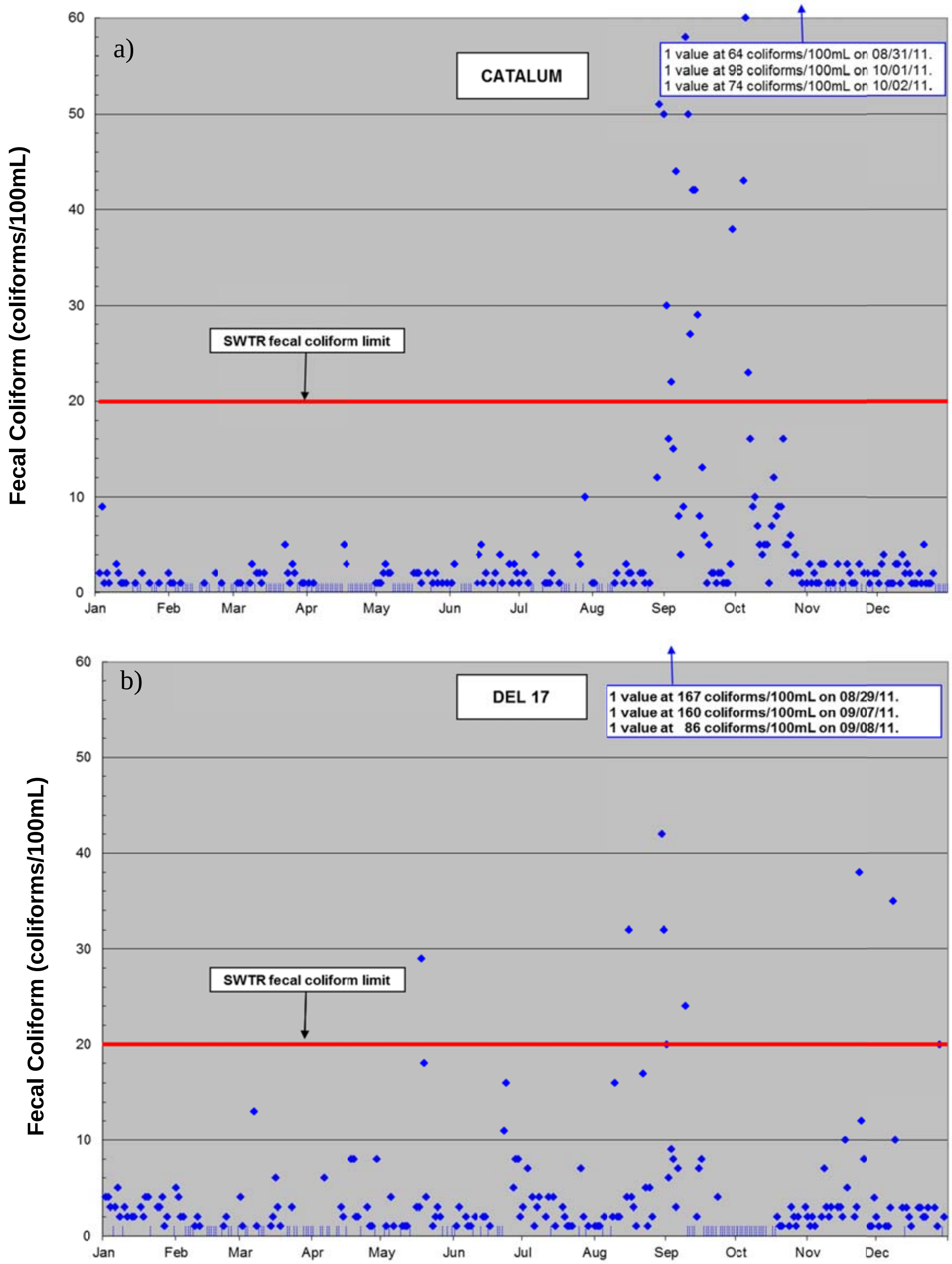


Figure 4-8 Five day per week fecal coliform grab sample results at the Catskill and Delaware Aqueduct Kensico influents: a) CATALUM, b) DEL17.
The “drop lines” along the x-axis indicate censored (below detection) values. Note: While the SWTR fecal coliform limit is indicated by a reference line, the influent keypoints are not subject to the SWTR.

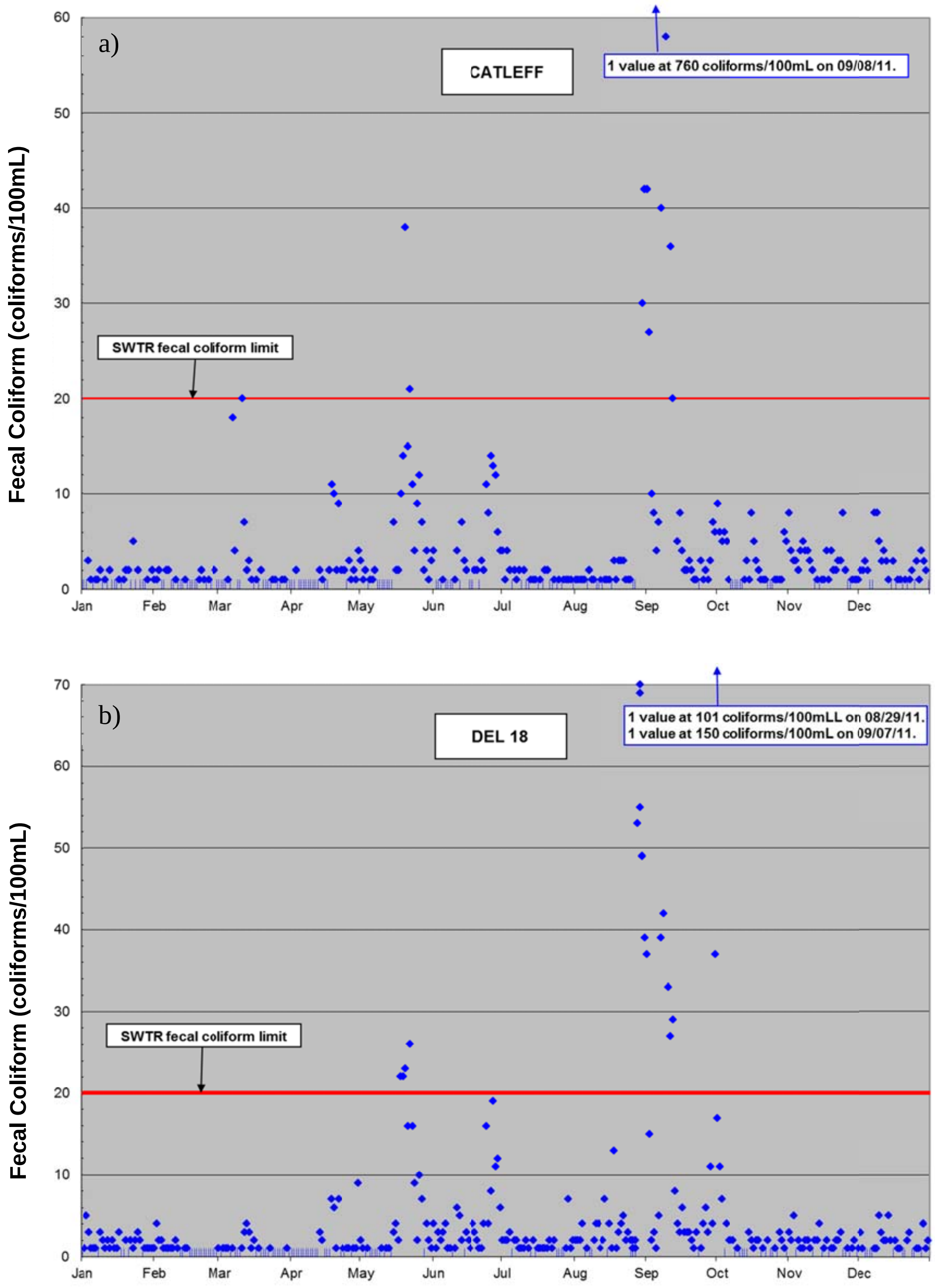


Figure 4-9 Seven day per week fecal coliform grab sample results at the Catskill Aqueduct Kensico effluents: a) CATLEFF, b) DEL18.
Note: The SWTR fecal coliform limit is indicated by a reference line.

4.3 Turbidity

4.3.1 Streams

The routine turbidity data for the period January 2011 through December 2011 are plotted in Figure 4-10. The median turbidity for all sites is less than 5 NTU. Turbidity values in 2011 were generally consistent with data from previous years, with the annual medians ranging from 0.85 NTU at N12 to 3.45 NTU at Malcolm Brook (MB-1). The maximum value of 17 NTU at E10 occurred on May 4, 2011, and was preceded the previous two days by well over an inch of rain. 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.

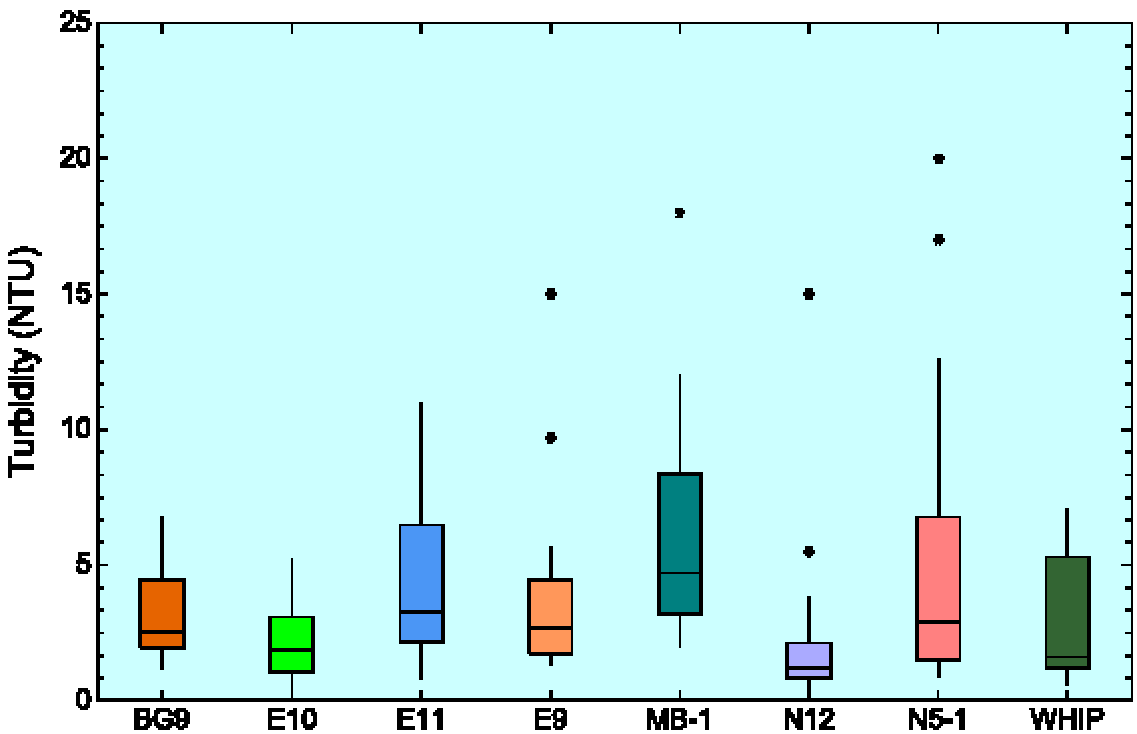


Figure 4-10 Turbidity plots for routine Kensico streams monitoring, January-December, 2011. (see section 4.2.2 for a description of boxplots).

4.3.2 Reservoir

The routine monitoring of Kensico Reservoir during the March 2011 through December 2011 period yielded 439 turbidity samples. A boxplot constructed using these data is presented in Figure 4-11. Site 5 showed the highest median turbidity (2.9 NTU), and individual samples for this site were equal to or exceeded 5.0 NTU 11 times. Only one other routine sample exceeded this value at Site 1.1 (8.0 NTU). None of the samples collected on the routine surveys exceeded 5 NTU at the sites closest to the effluent chambers (sites 2 and 3).

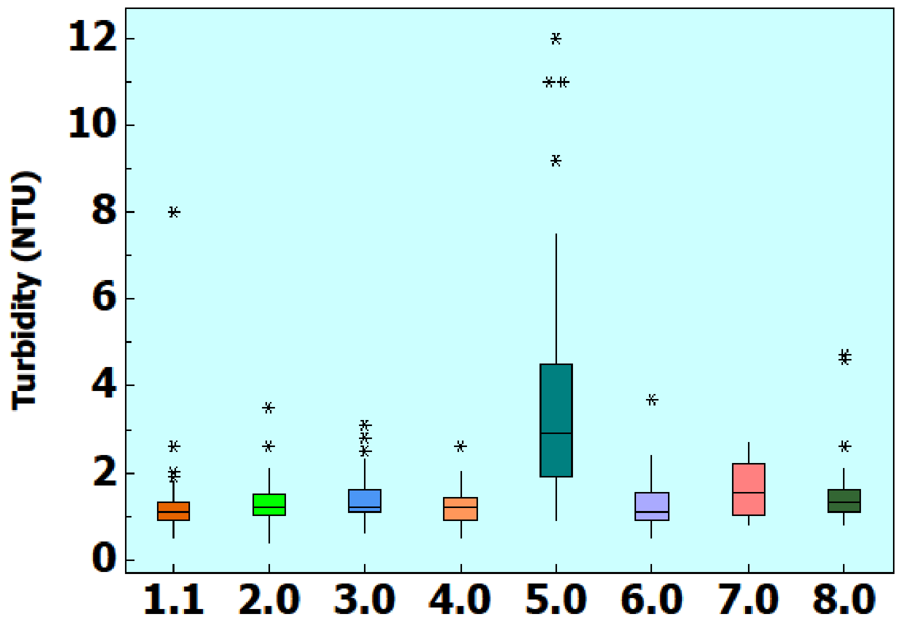


Figure 4-11 Turbidity plots for routine Kensico Reservoir monitoring. (see section 4.2.2 for a description of boxplots).

Special surveys were conducted to monitor turbidity during 2011. The bulk of these surveys occurred during the aftermath of Tropical Storms Irene and Lee in late August and early September, respectively. The high input of turbidity from the Catskill System required the application of alum to settle particulates. Operational changes were also required to manage increased turbidity in the Delaware System. As of the writing date of this report, alum addition to the Catskill Aqueduct continues. Upon completion of this event, the details of alum treatment and the special surveys will be summarized in an after-action report.

4.3.3 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) 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.

Median turbidity from January 2, 2011 to December 31, 2011 was 25 NTU at CATALUM and 1.2 NTU at DEL17. Mean turbidity for the same time period was 30.6 NTU at CATALUM and 1.5 NTU at DEL17. During this period, the maximum turbidity measurements were 180.0 NTU at CATALUM and 4.6 NTU at DEL17 (Figure 4-12 and Figure 4-13).

A turbidity grab sample is obtained every four hours at the Kensico effluent keypoints (CATLEFF and DEL18) as per the SWTR. Median turbidity from January 1, 2011 to December 31, 2011 was 1.1 NTU at CATLEFF and 1.2 NTU at DEL18. Mean turbidity for the same time period was 1.3 NTU at CATLEFF and 1.3 NTU at DEL18. During this period, the maximum 4-hour turbidity measurements were 4.6 NTU at CATLEFF and 5.1 NTU at DEL18 (Figure 4-14 and Figure 4-15). Both the Catskill and Delaware Aqueduct effluent from Kensico Reservoir exhibited turbidity levels less than or equal to 5 NTU in water prior to disinfection for the entire 2011 calendar year. As the analytical method requires reporting to one decimal place for turbidity values over 1 NTU, the regulatory limit is effectively 5.4 NTU. Turbidity values did not exceed 5.1 NTU for the Catskill and Delaware Systems in 2011.

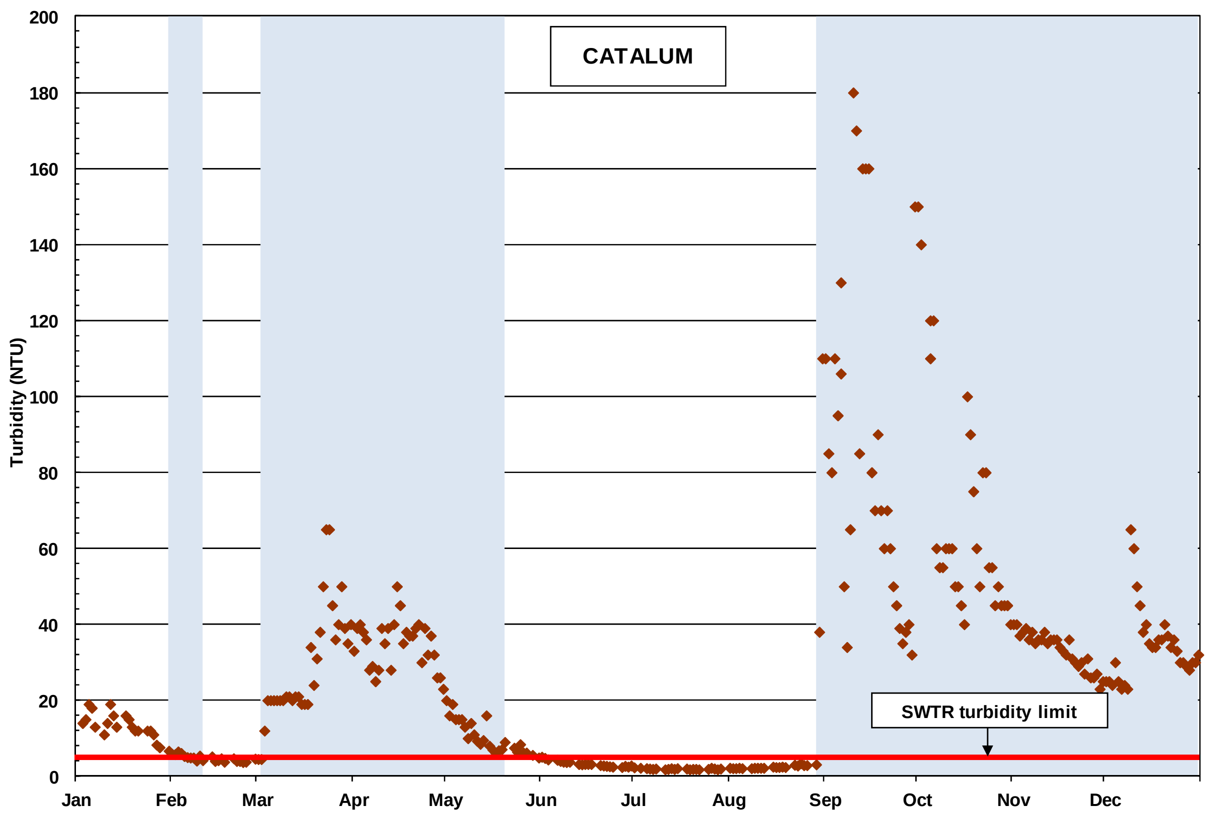


Figure 4-12 Five day per week turbidity grab sample results at Kensico Reservoir's Catskill Aqueduct influent keypoint (CATALUM). Shaded area indicates periods of alum treatment. Note: While the SWTR turbidity limit is indicated as a reference point, the influent keypoint is not subject to the SWTR.

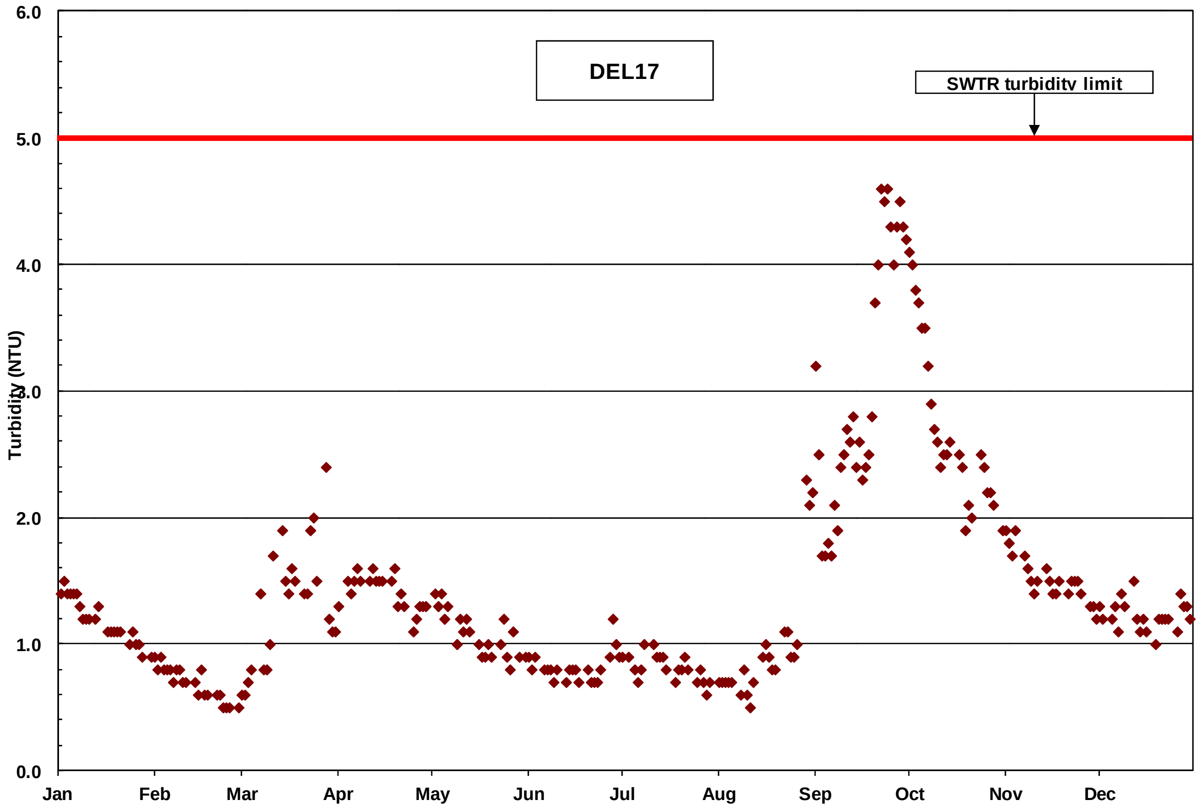


Figure 4-13 Five day per week turbidity grab sample results at Kensico Reservoir's Delaware Aqueduct influent keypoint (DEL17).
Note: While the SWTR turbidity limit is indicated as a reference point, the influent keypoint is not subject to the SWTR.

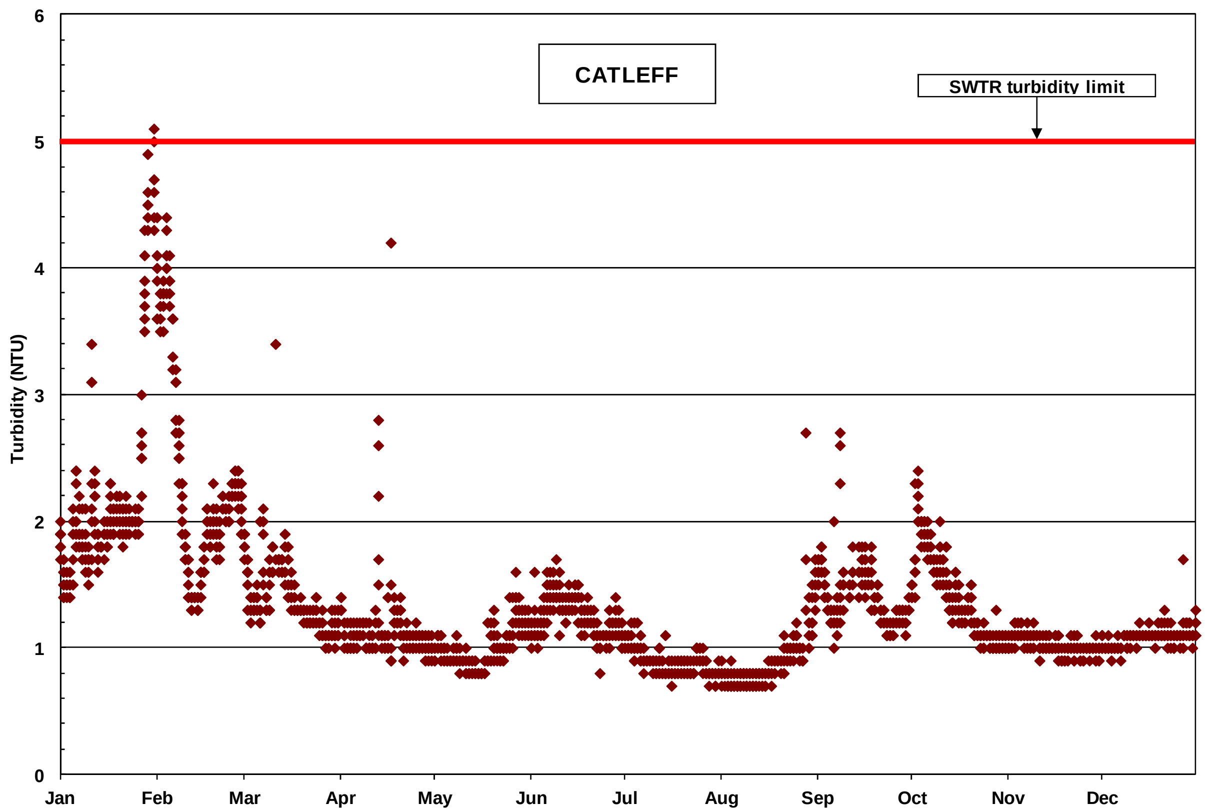


Figure 4-14 Four-hour turbidity grab sample results at Kensico Reservoir's Catskill Aqueduct effluent keypoint (CATLEFF).

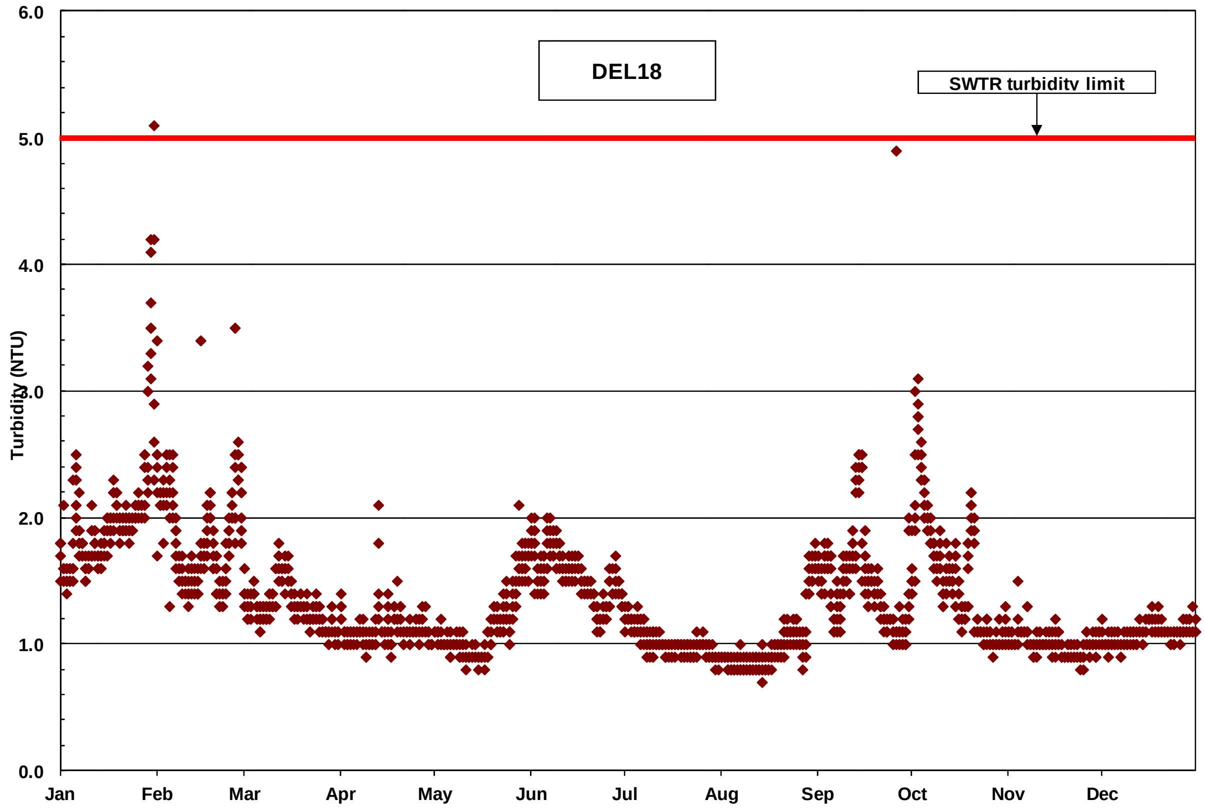


Figure 4-15 Four-hour turbidity grab sample results at Kensico Reservoir's Delaware Aqueduct effluent keypoint (DEL18).

4.4 Protozoa and Human Enteric Viruses

4.4.1 Perennial Streams

Eight perennial streams flow into Kensico Reservoir (Figure 4-16). The 2009 Watershed Water Quality Monitoring Plan (DEP 2009) set the protozoan monitoring interval for all Kensico stream sites to monthly in order to help capture some of the seasonal variation in protozoan occurrence. Results for these samples are presented in Tables 4-2- 4-5. No HEV samples were collected at the Kensico perennial streams in 2011.

As seen in past years, there were low concentrations of *Cryptosporidium* in the Kensico streams in 2011 (Table 4-2). Two streams, E10 and MB-1, had no positive *Cryptosporidium* results, and the remaining six streams had results ranging from 0 to 4 oocysts per volume collected.

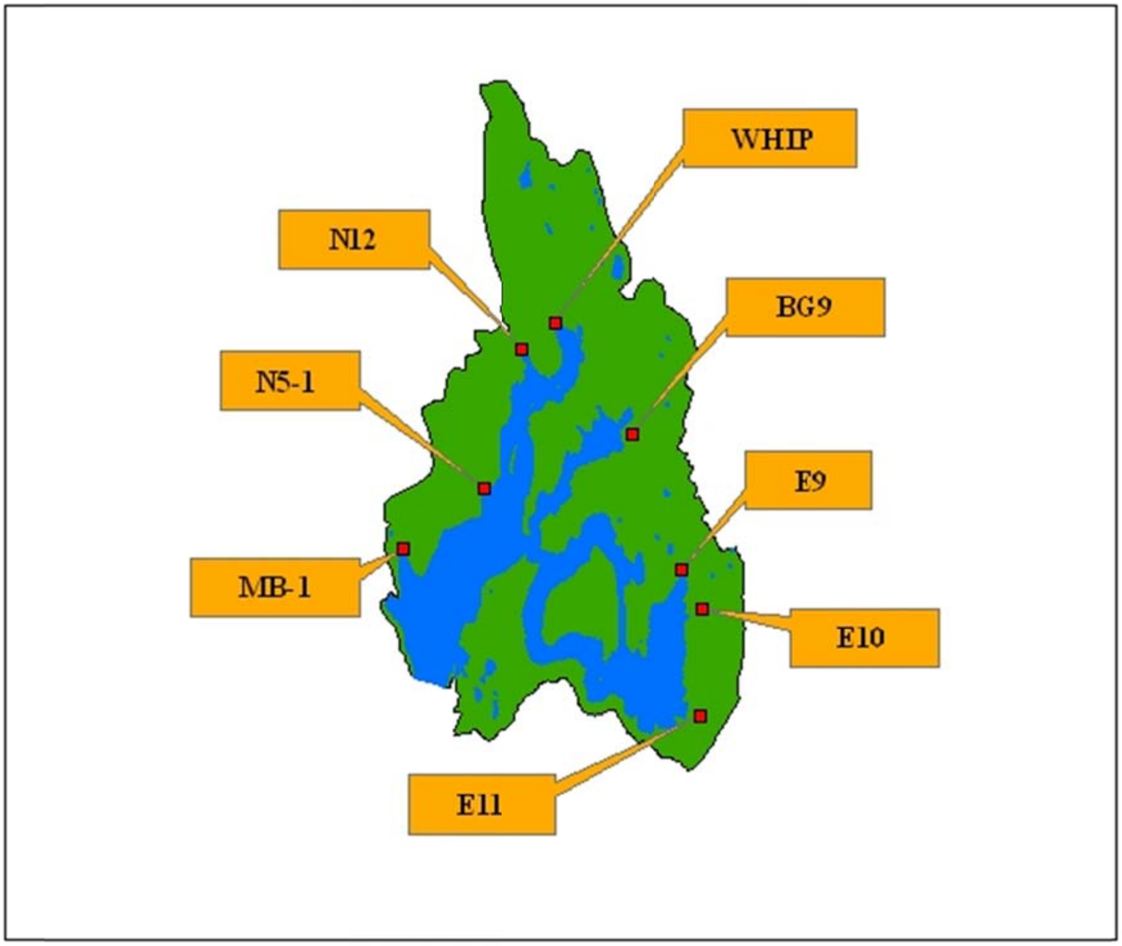


Figure 4-16 Kensico Reservoir routine pathogen stream sites sampled monthly in 2010.

Table 4-2 *Cryptosporidium* results (per 50L +/- 3L unless otherwise noted) from perennial Kensico streams, January 1– December 31, 2011.

Date	*BG9*	*E10*	*E11*	*E9*	*MB-1*	*N12*	*N5-1*	*WHIP*
Jan	0	0	0	4/42L	0	0	0	0
Feb	1	0	0/55L	2/42L	0	0	1	2
Mar	0	0	0/27L	1	0/45L	0	0/34L	2
Apr	0	0	0	0	0	0	0	0
May	0	0	1	0	0/41L	0	0	0
Jun	0/31L	0	0	0/22L	0/36L	0	1	0
Jul	0	0	0	0/22L	0/24L	0	0	0
Aug	0/38L	0	0	0/10L	0/14L	0	0/14L	1
Sep	0/26L	0/32L	0/21L	0/23L	0/20L	0	0/18L	0/31L
Sep*					0			
Oct	0	0	0/27L	0	0/20L	0	0/24L	0
Nov	0	0	0	0	0	0	0	0
Dec	0	0	0	2	0	1	0	0

* Special investigation sample at Malcolm Brook in response to Tropical Storms Irene and Lee.

Cryptosporidium occurrence was low with an 88% non-detection rate when all stream data are pooled. Overall, 12 out of 96 samples were positive for all streams, with a combined mean of 0.004 oocysts L^{-1}. E9 had the highest detection rate at 33.3 %, the highest per liter mean concentration (0.017 oocysts L^{-1}), and the highest per liter maximum concentration which occurred in January (Table 4-3). *Cryptosporidium* results from 2011 are slightly lower than results in 2008 and 2009, and similar to results in 2010; though oocyst detection in all four years was quite low.

Table 4-3 Monthly Kensico perennial stream *Cryptosporidium* results summary, January 1 – December 31, 2011.

	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	4	0	1	2	3
% Positive	8.3%	0.0%	8.3%	33.3%	0.0%	8.3%	16.7%	25.0%
Mean (L^{-1})	0.002	0.000	0.002	0.017	0.000	0.002	0.003	0.008
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	0.020	0.096	0.000	0.019	0.020	0.040

As in previous years, 2011 samples from the Kensico streams had higher concentrations of *Giardia* cysts (Table 4-4), and were more frequently positive for *Giardia* (Table 4-5), when compared to *Cryptosporidium* (Table 4-3). Thirty percent of the samples (29) had volumes less than 50L, with volumes ranging from 9.5 to 54.6L, and cyst results from 0 to 143; therefore, per liter mean concentrations were used to aid in the data comparison (Table 4-4). Using this approach, E9 and E11 revealed the highest means (0.980 and 0.520 cysts L^{-1}, respectively) and maximum *Giardia* values compared to the other six streams for 2011. Conversely, E10 had the lowest mean concentration (0.075 cysts L^{-1}) and maximum, with *Giardia* concentrations ranging from 0 to 0.180 cysts L^{-1}.

Table 4-4 *Giardia* results (per 50L +/- 3L unless otherwise noted) from perennial Kensico streams, January 1 – December 31, 2011.

Date	*BG9*	*E10*	*E11*	*E9*	*MB-1*	*N12*	*N5-1*	*WHIP*
Jan	22	5	28	56/42L	8	2	11	9
Feb	36	6	5/55L	18/42L	3	12	12	27
Mar	14	3	4/27L	11	13/45L	3	9/34L	23
Apr	3	4	5	7	8	24	5	14
May	3	0	72	14	5/41L	0	8	7
Jun	1/31L	1	0	22/22L	3/36L	6	2	5
Jul	2	0	6	43/22L	0/24L	0	2	2
Aug	1/38L	1	36	7/10L	1/14L	5	7/14L	8
Sep	10/26L	2/32L	4/21L	16/23L	17/20L	59	19/18L	10/31L
Sep*					2			
Oct	11	6	54/27L	72	9/20L	8	38/24L	6
Nov	8	7	37	36	6	7	9	4
Dec	12/47L	9	6	143	2	3	6	6

* Special investigation sample at Malcolm Brook in response to Tropical Storms Irene and Lee.

While *Cryptosporidium* had an 88% non-detection rate, *Giardia* had a 94% detection rate at Kensico streams. The lowest cyst occurrences were at E10 and N12 with 83% of samples positive for *Giardia*, while the greatest occurrence of cysts was 100% at BG9, E9, N5-1 and WHIP (Table 4-5). With the exception of the increase from 67% positive to 100% positive at N5-1, and a greater than fourfold increase in the mean *Giardia* concentrations at E11 and N5-1, these results are consistent with last year's data.

Table 4-5 Monthly Kensico perennial stream *Giardia* results summary, January 1 – December 31, 2011.

	Giardia							
	BG9	E10	E11	E9	MB-1	N12	N5-1	WHIP
# of Samples	12	12	12	12	12	12	12	12
# of Positive	12	10	11	12	11	10	12	12
% Positive	100.0%	83.3%	91.7%	100.0%	91.7%	83.3%	100.0%	100.0%
Mean(L^{-1})	0.224	0.075	0.520	0.980	0.202	0.220	0.376	0.212
Median (L^{-1})	0.190	0.071	0.170	0.721	0.121	0.110	0.200	0.150
Maximum (L^{-1})	0.720	0.180	2.000	2.854	0.872	1.239	1.583	0.540

Enhanced Stream Sampling

One additional sample was taken at Malcolm Brook (MB-1) on September 12, 2011, as part of the enhanced monitoring response to Tropical Storms Irene and Lee. The results were 2 *Giardia* cysts and 0 *Cryptosporidium* oocysts 50 L^{-1}.

4.4.2 Keypoints

As per the WWQMP, Kensico Reservoir's aqueduct influents and effluents are monitored weekly for protozoa and HEVs as the source water keypoints for New York City's watershed. A total of 208 routine protozoan samples and 207 routine HEV samples were collected at the Kensico keypoint sites in 2011. Seventeen additional protozoan samples were collected at, or were representative of, the four keypoints.

Influent Keypoints

Kensico Reservoir influent keypoints (CATALUM and DEL17) were sampled weekly for *Cryptosporidium* and *Giardia*. No *Cryptosporidium* oocysts were detected at CATALUM in 2011 (Table 4-6). In 2011, *Cryptosporidium* was detected in only one sample (out of 52) at DEL17, and at a low concentration (1 oocyst 50 L^{-1}). These results are consistent with results from last year; 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 4-6 Weekly Kensico Reservoir influent keypoint results, *Cryptosporidium* and *Giardia* summary, January 1 – December 31, 2011.

		CATALUM	DEL17
Cryptosporidium(50L^{-1})	# of Samples	52	52
	# of Positives	0	1
	% Positives	0.0%	1.9%
	Mean	0.00	0.02
	Median	0.00	0.00
	Maximum	0.00	1.00
Giardia (50L^{-1})	# of Samples	52	52
	# of Positives	16	41
	% Positives	32.0%	78.8%
	Mean	0.54	2.06
	Median	0.00	2.00
	Maximum	4.00	9.00

Giardia was detected in 16 and 41 samples (out of 52) collected at CATALUM and DEL17 in 2011, with maxima of 4 and 9 cysts 50 L^{-1} at the respective sites. For comparison, in 2010, *Giardia* detection occurred in 18 and 25 samples (out of 52) collected for CATALUM and DEL17, with maxima of 4 and 8 cysts 50 L^{-1}, respectively. The mean concentration of *Giardia* at CATALUM in 2011 was almost unchanged from the concentration in 2010 (0.56 to 0.54 cysts 50 L^{-1}). The mean *Giardia* concentration at DEL17 was approximately two times higher than 2010, increasing from 0.98 to 2.06 cysts 50 L^{-1}. These 2011 values are more consistent with those seen in 2009. Changes in operational mode may account for these differences; however, there are other possible reasons, including varied temperature and precipitation amounts throughout a given year, as well as the occurrence of tropical storms, such as those the watershed experienced this year.

Enhanced Monitoring at Influent Keypoints

On August 31, a few days after Tropical Storm Irene, an additional protozoan sample was taken at the Delaware influent; this sample was negative for *Giardia* and *Cryptosporidium*.

Effluent Keypoints

The effluent keypoints of Kensico Reservoir (CATLEFF and DEL18) were also sampled weekly for *Cryptosporidium* and *Giardia* in 2011. *Cryptosporidium* was detected in 2 samples at CATLEFF and 1 sample at DEL18 (Table 4-7). For comparison, in 2010, *Cryptosporidium* was detected in 3 samples at CATLEFF and 1 sample at DEL18. As in past years, *Cryptosporidium* was found only at low levels at the Kensico effluents, with a maximum of 1 oocyst 50 L^{-1} at both sites. Consequently, the mean values for these sites were low as well (0.04 and 0.02 oocysts 50 L^{-1} CATLEFF and DEL18, respectively.) This is approximately the same as the 2010 CATLEFF value (0.06 oocyst 50 L^{-1}), and there was no change in the mean at DEL18.

Table 4-7 Weekly Kensico Reservoir effluent keypoint results, *Cryptosporidium* and *Giardia* summary, January 1 – December 31, 2011.

		CATLEFF	DEL18
Cryptosporidium ($50L^{-1}$)	# of Samples	52	52
	# of Positives	2	1
	% Positives	3.8%	1.9%
	Mean	0.04	0.02
	Median	0.00	0.00
	Maximum	1.00	1.00
Giardia ($50L^{-1}$)	# of Samples	52	52
	# of Positives	41	40
	% Positives	78.8%	76.9%
	Mean	1.71	1.69
	Median	2.00	2.00
	Maximum	6.00	5.00

There were 41 and 40 detections of *Giardia* at CATLEFF and DEL18, respectively, out of 52 samples collected in 2011. This was comparable to 2010, when there were 36 *Giardia* detections at CATLEFF, and 42 at DEL18. Maximum *Giardia* cyst concentrations were the same for 2010 and 2011 for DEL18 at 5 cysts, and nearly the same for CATLEFF with 8 cysts in 2010 compared to 6 cysts 50 L^{-1} this year. The mean *Giardia* concentration at CATLEFF for 2011 (1.71 cysts 50 L^{-1}) was similar to that for 2010 (1.63 cysts 50 L^{-1}). The DEL18 mean *Giardia* concentration for 2011 (1.69 cysts 50 L^{-1}) was similar to those in past years, with only a slight increase from 2010 (1.25 cysts 50 L^{-1}).

Enhanced Monitoring at Effluent Keypoints

Enhanced monitoring was conducted during two time periods in 2011 (January through February; and August through October) relating to elevated turbidity events. During the first time period, five additional protozoan samples were taken at the Catskill effluent, and all samples were negative for *Cryptosporidium,* while *Giardia* results ranged from 0 to 3 cysts 50L^{-1}. Two additional samples were taken, one at the Delaware Aqueduct downtake (DEL18DT) and one from the reservoir (2BRK). Both of these samples were negative for *Cryptosporidium* and positive for *Giardia* (cysts ranging from 1 to 2 cysts 50 L^{-1}).

During the second period, in the wake of Tropical Storms Irene and Lee, DEP took an additional nine protozoan samples at Kensico effluents (three from Catskill and six from Delaware) from August 29 to October 5. Two of the DEL18DT were collected concurrently with DEL18 samples, to ensure the most representative effluent samples were taken on days when the reservoir operation mode was changed. All nine samples were negative for *Cryptosporidium*. *Giardia* cysts were detected in 2 of the 3 samples at the Catskill effluent and 5 of 6 samples at the Delaware effluent, with results ranging from 0 to 4 cysts 50 L^{-1} at both sites.

Human Enteric Virus Monitoring

All four Kensico Reservoir keypoints were monitored weekly for human enteric viruses in 2011, except on one occasion in early September when the CATALUM virus sample was cancelled due to high turbidity.

Mean virus concentrations had a pooled influent mean of 0.48 MPN 100L^{-1}, and a pooled effluent mean of 0.70 MPN 100L^{-1}. While it is known that Catskill and Delaware water mixes in the reservoir, results did not indicate a statistically significant difference in mean virus concentrations between the Catskill and Delaware systems (p-value >0.05), although the Catskill influent and effluent means were slightly higher than their Delaware counterparts (Table 4-8). Moreover, as a consequence of the higher concentrations of the several consecutive detections of viruses at the end of the year, this is the first year that the mean concentrations and maximum values of HEV were higher at the effluents of Kensico Reservoir rather than at the influents.

Table 4-8 Summary of weekly human enteric virus results at Kensico keypoints, January 1 - December 31, 2011.

	Human enteric viruses (MPN $100L^{-1}$)			
	CATALUM	CATLEFF	DEL17	DEL18
# of Samples	51	52	52	52
# of Positives	14	9	7	9
% Positives	27.5%	17.3%	13.5%	17.3%
Mean*	0.58	0.76	0.38	0.63
Median*	0	0	0	0
Maximum	4.87	9.16	4.46	8.32

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

Compared to 2010 data, when all four Kensico sites had 6 or fewer detections, these results show an increase in HEV detection at both the influents and the effluents of the reservoir for 2011. Interestingly, most of the detections at the influents, and nearly all of those at the effluents, occurred consecutively and after Tropical Storms Irene and Lee passed through the watershed (Figure 4-17). The detections occurred later at the effluents, suggesting time needed to move through the system. Two additional considerations for a cause of the increased detections are: 1) historically there are more detections of viruses in the colder months in Kensico Reservoir anyway, and 2) DEP changed to a different field collection filter in November. As for the former, observed increases related to colder months in previous years occurred at all four sites whereas the observed increase in 2011 was proportionately larger at the effluents. Also, initially, it was believed that the new filter may have been part of the cause of the increased detection; however, the data do not support this at DEL17, (Figure 4-18) and the new filter was never implemented at CATALUM due to high turbidities (the CUNO filter does not clog as quickly as the NanoCeram). Furthermore, DEP performed five side by side analyses during this period with both filters, and results to date (only 2 of the 5 are available) indicate equal recovery rates. As more data become available the cause(s) of the increased effluent detections is more likely to be identified.

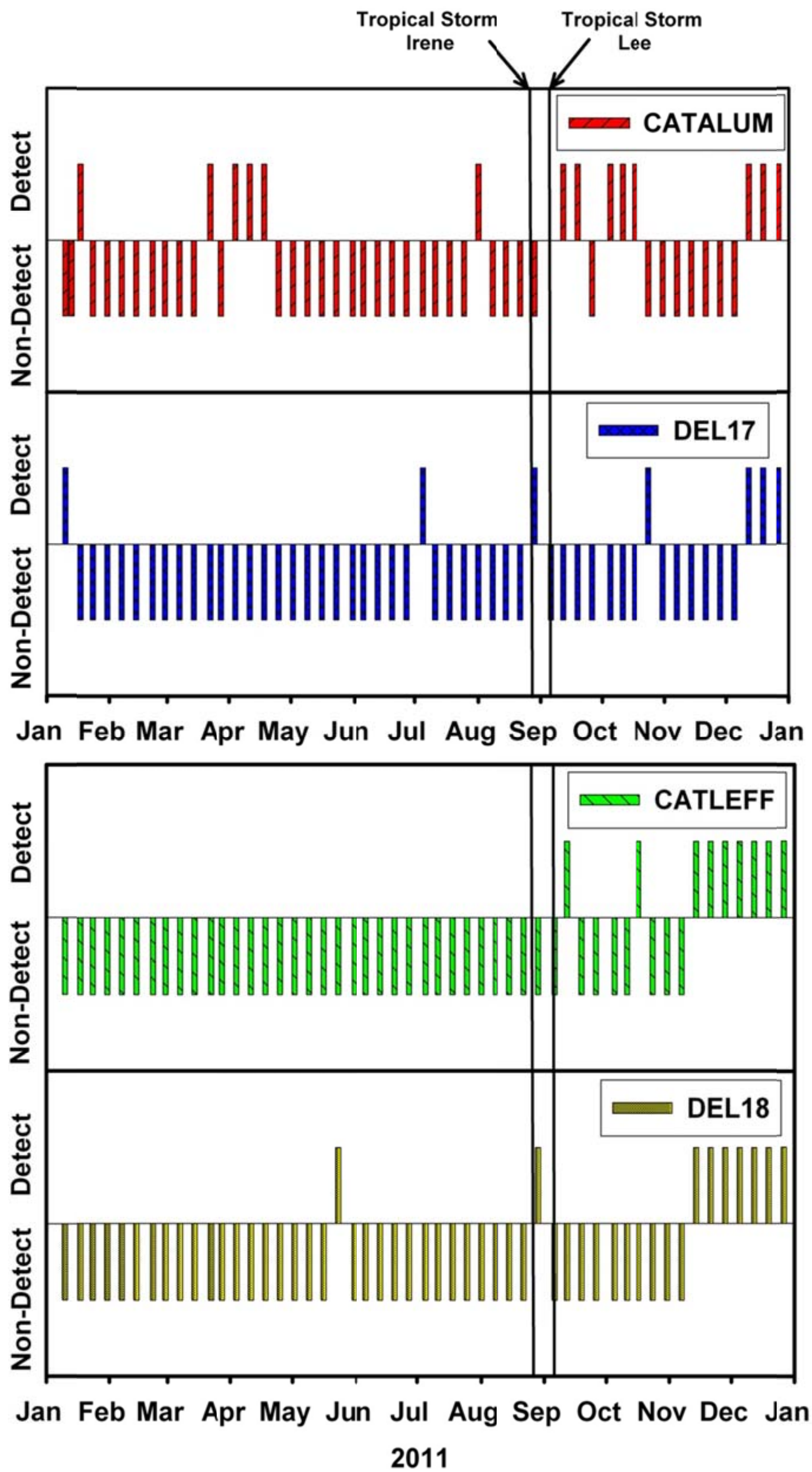


Figure 4-17 Detections of human enteric viruses (HEV) at the four Kensico keypoints, January 1 – December 31, 2011.

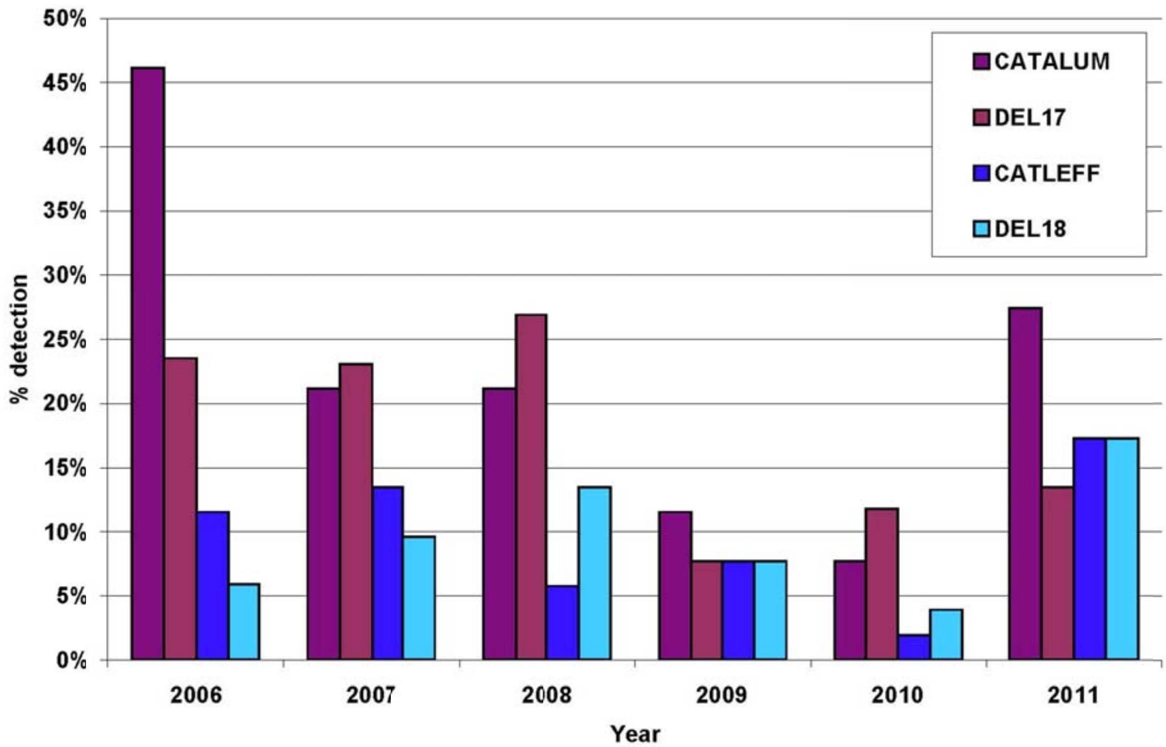


Figure 4-18 Annual frequency of human enteric virus (HEV) detections at the four Kensico keypoints from 2006 - 2011.

Enhanced Keypoint Monitoring for Human Enteric Viruses

An additional HEV sample was taken at CATALUM as part of a filter comparison study in January of this year. Both filters (CUNO Virosorb® 1-MDS 10-inch filter and the Argonide NanoCeram® 5-inch filter) are approved for recovering viruses from water; however, there is a significant cost savings with the Argonide filter. On November 17, 2011, DEP switched from the CUNO to the Argonide filter for all virus samples except those taken at CATALUM due to elevated turbidity and filter pressure issues.

Shortly after Tropical Storm Irene, with elevated turbidity causing DEP to make changes to reservoir operation mode, DEP sampled DEL18DT in addition to the routinely sampled DEL18 site, in order to be sure of having a representative sample of the Delaware aqueduct effluent from Kensico. The additional HEV sample results matched the routine site (both 1.03 MPN $100L^{-1}$.)

4.5 Other Results

4.5.1 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 2011 results for these analytes are displayed in Table 4-9. As discussed in section 4.2.4, 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 4-9 Annual Statistics for physical, nutrient, and other chemical analytes in Kensico's perennial streams, January–December, 2011.

Analyte	Site	N	Minimum	25th Percentile	Median	75th Percentile	Maximum
Temperature (°C)	BG9	12	-0.1	3.9	11.8	22.1	24.1
	E10	12	-0.1	4.6	11.4	17.5	23.2
	E11	12	2.7	4.2	11.6	20.2	22.8
	E9	12	-0.1	1.0	10.9	19.9	23.3
	MB-1	12	0.6	3.7	10.7	18.9	22.2
	N12	12	-0.2	5.7	12.0	17.1	20.4
	N5-1	12	0.8	4.7	10.4	19.0	22.4
	WHIP	12	-0.2	4.2	11.8	18.9	23.0
Dissolved Oxygen (mg L^{-1})	BG9	11	5.0	6.9	9.8	12.4	14.2
	E10	11	4.9	9.4	10.3	13.4	14.4
	E11	11	1.0	4.4	8.1	9.9	11.1
	E9	11	2.6	3.8	5.0	6.8	8.1
	MB-1	12	7.4	8.3	9.3	11.1	13.7
	N12	12	9.0	9.8	12.0	13.4	14.0
	N5-1	12	6.3	8.4	11.0	13.2	14.8
	WHIP	12	8.1	9.5	12.1	13.1	13.7
Specific Conductivity (µmhos cm^{-1})	BG9	12	229	498	593	715	849
	E10	12	331	572	883	1050	1191
	E11	12	187	326	419	454	464
	E9	12	246	374	463	523	593
	MB-1	12	218	399	615	799	1301
	N12	12	275	307	338	389	453
	N5-1	12	218	311	450	550	764
	WHIP	12	214	284	337	371	636
Chloride (mg L^{-1})	BG9	4	95.7	100.7	127.3	192.4	210.3
	E10						
	E11	4	27.2	30.5	45.3	51.4	51.8
	E9						
	MB-1	4	53.3	60.2	100.1	283.8	338.7
	N12	4	30.0	34.6	49.2	71.3	78.3

Analyte	Site	N	Minimum	25th Percentile	Median	75th Percentile	Maximum
	N5-1	4	27.6	32.8	65.8	139.9	158.8
	WHIP	4	42.6	42.7	50.9	124.8	146.9
pH	BG9	11	6.90	7.08	7.20	7.25	7.30
	E10	11	7.50	7.54	7.74	7.80	7.82
	E11	11	6.70	7.00	7.24	7.40	7.41
	E9	11	6.78	6.90	7.00	7.09	7.60
	MB-1	11	7.20	7.25	7.41	7.50	9.08
	N12	11	7.12	7.61	7.76	7.85	8.39
	N5-1	10	7.10	7.31	7.49	7.56	7.68
	WHIP	11	7.28	7.49	7.65	7.83	8.19
Alkalinity (mg L^{-1} $CaCO_3$)	BG9	12	37.40	57.80	63.65	69.73	84.90
	E10						
	E11	12	61.00	100.20	115.80	129.23	136.10
	E9						
	MB-1	12	42.10	55.20	78.25	92.50	103.60
	N12	12	49.90	57.63	65.70	74.70	112.90
	N5-1	12	47.10	53.73	72.25	78.73	88.80
	WHIP	12	34.90	41.63	47.75	53.13	63.30
Dissolved Organic Carbon (mg L^{-1})	BG9	12	1.9	2.4	3.2	3.6	5.3
	E10						
	E11	12	3.1	3.7	4.6	5.0	7.6
	E9						
	MB-1	12	1.8	2.4	3.5	4.6	6.5
	N12	12	1.8	2.1	2.2	3.0	4.7
	N5-1	12	2.0	2.3	3.1	4.5	6.6
	WHIP	12	2.2	2.3	2.7	3.8	4.9
Total Phosphorus (µg L^{-1})	BG9	12	10	14	20	48	71
	E10						
	E11	12	13	18	33	44	76
	E9						
	MB-1	12	16	20	34	76	136
	N12	12	9	13	21	25	44
	N5-1	12	16	25	42	82	137
	WHIP	12	10	13	22	30	51
Total Nitrogen (mg L^{-1})	BG9	12	0.31	0.35	0.43	0.54	0.67
	E10						0.00
	E11	12	0.27	0.30	0.36	0.41	0.66
	E9						0.00
	MB-1	12	0.37	0.47	0.56	0.75	0.93
	N12	12	0.81	0.87	1.06	1.26	1.66
	N5-1	12	0.86	0.93	1.14	1.36	1.49
	WHIP	12	0.65	0.78	1.00	1.14	1.33
NO_3+NO_2-N (mg L^{-1})	BG9	12	0.14	0.17	0.22	0.40	0.55
	E10						
	E11	12	0.02	0.08	0.11	0.28	1.31
	E9						

Analyte	Site	N	Minimum	25th Percentile	Median	75th Percentile	Maximum
	MB-1	12	0.23	0.28	0.34	0.47	0.72
	N12	12	0.75	0.84	0.94	1.18	1.74
	N5-1	12	0.53	0.80	0.99	1.14	1.48
	WHIP	12	0.24	0.64	0.84	1.01	1.30
Total Suspended Solids (mg L^{-1})	BG9	12	<1	1.0 *	2.1*	5.2*	39.2
	E10						
	E11	12	<1	1.1*	2.4*	4.1*	8.6
	E9						
	MB-1	12	1.4	1.8	2.8	8.9	17.3
	N12	12	<1	0.3*	1.1*	1.6*	6.6
	N5-1	12	<1	0.9*	2.7*	9.6*	13.6
	WHIP	12	<1	0.3*	1.1*	5.3*	8.3
Total Coliform (coliforms $100mL^{-1}$)	BG9	12	<100	355*	875*	5900*	27,000
	E10	12	200	463	1,750	4,600	92,000
	E11	11	170	580	2,000	5,800	38,000
	E9	12	330	520	1,600	4,325	41,000
	MB-1	11	250	580	1,600	7,400	66,000
	N12	12	420	940	1,650	3,400	27,000
	N5-1	12	250	903	3,550	22,500	75,000
	WHIP	12	290	460	2,100	5,350	35,000
Fecal Coliform (coliforms $100mL^{-1}$)	BG9	12	<10	17*	94*	970*	4,600
	E10	12	<5	55*	101*	333*	16,000
	E11	10	<5	4*	14*	141*	1,600
	E9	12	5	33	225	495	10,000
	MB-1	12	14	74	125	4,555	19,000
	N12	12	29	51	185	598	1,900
	N5-1	12	45	110	165	1,610	9,600
	WHIP	12	20	29	59	88	1,200
Turbidity (NTU)	BG9	12	1.2	1.8	2.4	4.5	6.8
	E10	12	0.7	1.1	1.9	3.0	5.2
	E11	12	0.8	1.6	2.9	5.9	7.6
	E9	12	1.3	1.6	2.6	4.5	9.7
	MB-1	12	2.0	2.4	4.1	5.2	18.0
	N12	12	0.4	0.7	1.1	1.4	15.0
	N5-1	12	0.9	1.3	2.7	11.1	20.0
	WHIP	12	0.6	1.0	1.3	1.9	6.0

* Due to the presence of censored data, Kaplan Meier methods were used to estimate the percentiles.

5. Kensico Modeling for 2011

During 2011 there were three periods in which Kensico Reservoir water quality modeling was necessary to support operational decisions. The three periods coincide with elevated levels of turbidity in the Catskill System and during one case also in the Delaware System. Alum treatment was needed during portions of all three events, and model runs were used to both minimize the duration of alum treatment and the amount of alum used when treatment was necessary. Kensico Reservoir turbidity simulations were run to forecast future reservoir turbidity levels; to develop scenarios that examined the consequence of changes in reservoir operations; and to help choose an optimal reservoir operating strategy that would minimize the impacts on Kensico effluent turbidity. In total, 23 separate modeling analyses were performed. The dates and the reservoirs included in each analysis are listed in Table 5-1.

The first period was during January 2011. At that time turbidity in Ashokan Reservoir was already elevated due to a combination of storm events that had occurred between October and December of 2010. During the fall 2010, model simulations were helpful in successfully mitigating the effects of these events without the use of alum. Continuing model runs were used to develop strategies that were successful in avoiding alum use, while maintaining acceptable Kensico effluent turbidity. Mitigation based on operations alone was successful throughout most of January despite a prolonged period of relatively high Catskill turbidity. However, by the end of January, water quality conditions in Kensico Reservoir had declined. A plume of turbid Catskill water that traveled directly under the ice, had reached the effluents, necessitating alum treatment of water entering Kensico from the Catskill influent. In February alum treatment ended early in the month, and more modeling simulations were required to optimize aqueduct flows in the absence of alum treatment.

The second modeling period occurred in May 2011. DEP began using alum on Catskill influent to Kensico Reservoir again in March, due to late winter/early spring snowmelt events increasing turbidity in the Ashokan Reservoir. The modeling simulations in May were used to help determine the best time to end alum treatment and the appropriate flow rates after alum treatment was concluded.

The final set of 2011 modeling simulations was performed during the fall. Due to the effects of tropical systems Irene and Lee on both Ashokan and Rondout reservoirs, alum treatment was initiated on the Catskill influent to Kensico Reservoir immediately following the storms. Kensico Reservoir water quality modeling during September and October informed decisions on aqueduct flow rates into Kensico Reservoir given alum treatment on the Catskill influent combined with unusually elevated turbidity from the Delaware influent.

Table 5-1 List of Kensico modeling analyses performed during 2011 including the additional reservoirs simulated in each analysis. The year was split into three turbidity events.

Kensico Turbidity Modeling Runs 2011			
Date	Ashokan West	Ashokan East	Kensico
Jan. 3, 2011			X
Jan. 12, 2011	X	X	X
Jan. 18, 2011	X	X	X
Jan. 21, 2011			X
Jan. 27, 2011	X	X	X
Feb. 17, 2011			X
May 3, 2011			X
May 18, 2011			X
Aug. 30, 2011			X
Aug. 31, 2011			X
Sept. 2, 2011			X
Sept. 7, 2011			X
Sept. 23, 2011			X
Sept. 30, 2011			X
Oct. 3, 2011			X
Oct. 21, 2011			X

5.1 Model Descriptions

Two types of models - reservoir and system - were used for the simulations during 2011. For all of the simulations, LinkRes and its component model 2D reservoir model CEQUAL W2 (DEP 2004, Cole and Buchak 1995) were used to simulate the transport of turbidity within the reservoir, and levels of turbidity both within the reservoir and at aqueduct withdrawals. The model has been set up and tested for the Ashokan West Basin, the Ashokan East Basin and the Kensico Reservoir. LinkRes has been adapted for "positional analysis" (described below) using software developed by DEP. In addition a number of simulations utilized the OASIS system model (HydroLogics, Inc., 2007; Gannett Flemming and Hazen and Sawyer, 2007) as set up for the New York City supply to simulate aqueduct flows.

For each set of model simulations run during 2011, a number of scenarios of different Catskill and Delaware system turbidity and flow inputs were modeled to predict their effects on Kensico effluent turbidity levels. In general, model runs were used to guide reservoir operations to ensure that simulated turbidity levels at both the CATLEFF and DEL18 Kensico effluents would not exceed safe levels and regulatory limits. 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.

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-lake automated buoy measurements. Then the model was run for a forecast period which ranged from 1 to 6 months into the future, depending on the simulation goals. For the forecast period multiple simulations were run based on separate inputs of meteorology and aqueduct water temperature from each year in the historical record, which was between 1948-2004 for the Ashokan model runs and between 1987-2004 for Kensico model runs.

For independent simulations of Kensico Reservoir, flows and derived turbidity loads are set at fixed values associated with the forecast 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 the Reservoir to ensure that effluent turbidity will not exceed regulatory limits.

Combined Ashokan-Kensico simulations examined the effects of different operational strategies on Ashokan storage and effluent turbidity, as well as the consequence of the Ashokan effluent releases on Kensico reservoir. For these simulations, the input flow, water temperature and turbidity load to Ashokan Reservoir, as well as reservoir meteorological data were based on the historical measurements. In these cases, each trace in a positional analysis represents a simulated outcome that incorporates both climatic and flow variability in the historical record.

In the case of either independent or coupled reservoir simulations, the complete set of positional analysis traces, taken in total, can be used to develop a statistical probability of simulated reservoir storage levels and effluent turbidity.

5.2 Model Simulation Summaries

January 3, 2011

Background

Storm events in early and mid-December 2010 led to significant movement of high turbidity water from the West Basin to the East Basin of Ashokan Reservoir. Turbidity entering Kensico Reservoir from the Catskill Aqueduct had varied over the previous week from about 11-20 NTU with stop shutters in place in the aqueduct. Turbidity entering Kensico Reservoir from the Delaware Aqueduct was about 1.3 NTU. Turbidity in Kensico Reservoir ranged from about 2 NTU near effluent intakes to about 6 NTU near Catskill Influent.

Simulation Description

The simulations examined what levels of turbidity could be tolerated as inputs to Kensico Reservoir with the Catskill Aqueduct at 100, 150, 200 and 250 mgd flow rates and Catskill Aqueduct turbidity ranging from 10-20 NTU and Delaware Aqueduct turbidity of 1.3 NTU.

Results

Simulated effluent turbidity remained generally below 2.5 NTU with the following inflow and influent turbidity combinations: 10 NTU at 150 mgd; 13 NTU at 150 mgd; and 17 NTU at 100 mgd. None of the simulations with 20 NTU influent turbidity yielded simulated effluent turbidity consistently less than 2.5 NTU.

January 12, 2011

Background

The Ashokan Reservoir Release Channel was being operated to create a void of storage in the West Basin that would reduce the probability of future storms leading to an uncontrolled flow of turbid water across the Dividing Weir. Also at this time there was a small (~30 mgd) flow of turbid water between the West and East Basins of Ashokan Reservoir. This turbid inflow (~60 NTU) may have been leading to a fluctuation of turbidity in the Catskill Aqueduct withdrawal, which, in turn, required periodic reductions in Catskill Aqueduct flow. Finally, due to an extended reduction in Catskill Aqueduct flow that started in early December, greater Catskill Aqueduct flow was now needed to help maintain West Branch Reservoir minimum storage levels.

Simulation Description

These simulations predicted whether or not alum treatment would be necessary, and the levels of reservoir storage and probability of refill by June 1 under two possible courses of action:

1. Closing the Release Channel and opening the Dividing Weir gates to maximize flow between Ashokan West and East basins.

2. Continuing the Release Channel for 30 days and completely closing the Dividing Weir gates.

Results

Continuing to use the Ashokan Release Channel at 600 mgd for 30 additional days with the Dividing Weir gate closed did not greatly reduce the prospects for long term storage in Ashokan Reservoir. Even with continuing use of the Release Channel about 90% of the traces had a 90% probability of refill by May 15 – Jun 15 period (Figure 5-1). In addition if the Release Channel was immediately closed, alum use was simulated to occur in all traces, while alum use was required in only 3 out of 18 traces when Release Channel use was continued for 30 days. Thus the risk of alum use was greatly reduced with continued use of the Ashokan Release Channel (Figure 5-2), while the long term impacts on water storage were relatively small. Following these simulations the Dividing Weir was closed and Ashokan Release Channel usage continued.

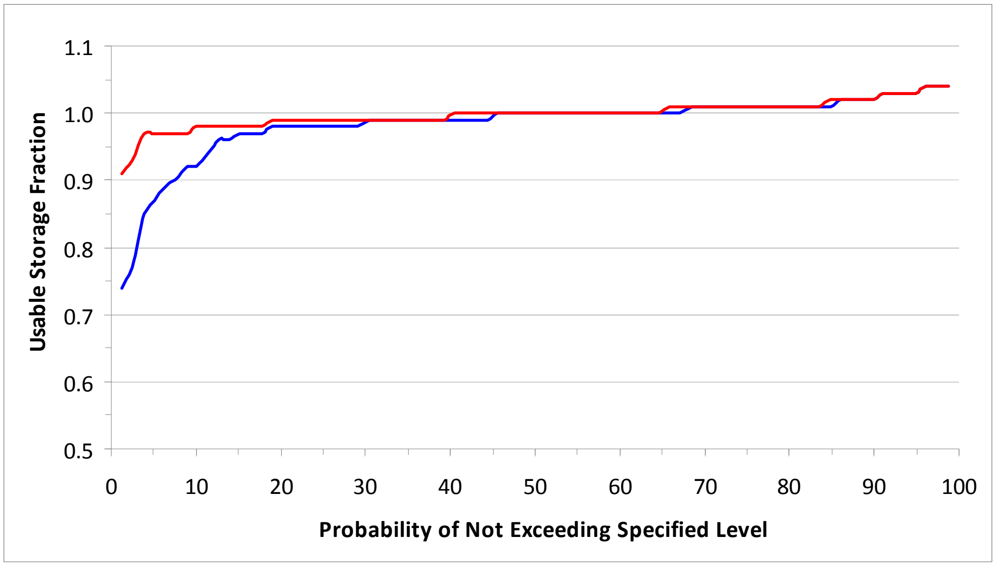
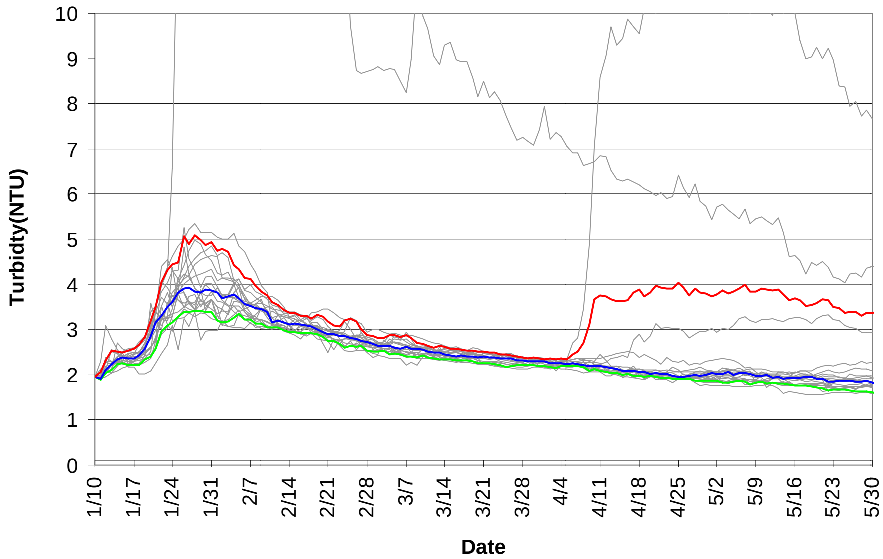


Figure 5-1 Comparison of simulated refill probability between May 15 – June 15.
The red line shows results for immediately closing the Ashokan Release Channel and the blue line shows results for the Release Channel to remain in use for 30 more days. The x-axis shows the percent of traces not exceeding the specified usable storage fraction on the y-axis. For example there is roughly a 10 % probability of not reaching at least 90% storage capacity between May 15 – June 15 for the scenarios that include the 30 day Release Channel use (blue line). Note that storage fractions greater than 1.0 occur when the reservoir spills.

(a) Case of immediately closing Ashokan Release Channel



(b) Case of closing Ashokan Release Channel after 30 days

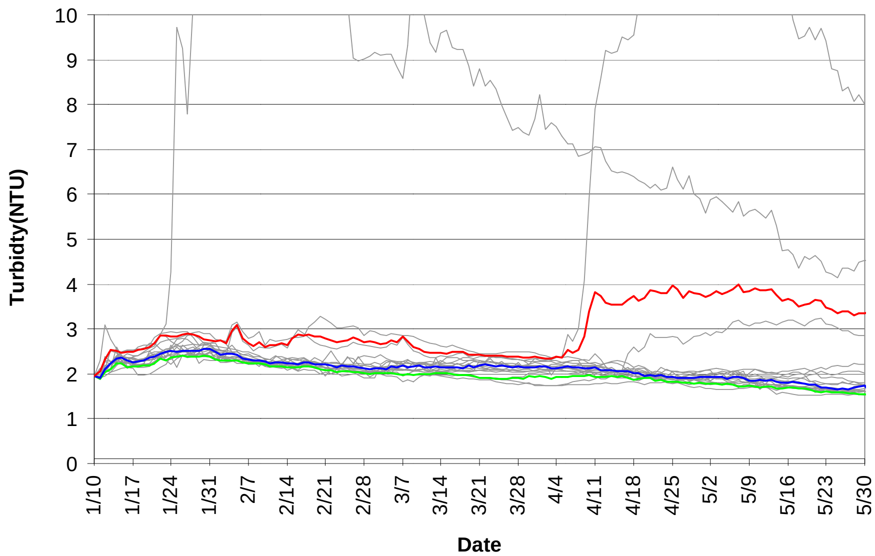


Figure 5-2 Simulated Catskill Aqueduct effluent from Kensico Reservoir for (a) immediately closing Ashokan Release Channel and for (b) closing Ashokan Release Channel after 30 days. The grey lines show all individual traces of the simulation. The red, blue and green lines show the 90th percentile, the median and the 10th percentile of the traces. The simulation shows that the Kensico effluent is predicted to be much higher when the Release Channel was immediately shut down (a) versus continuing to run the Release Channel for 30 more days (b).

January 18, 2011

Background

Conditions were similar to those on January 12 (See background description above).

Simulation Description

Simulations were similar to January 12 runs. An additional scenario evaluated the effect of running the Ashokan Release Channel for 20 rather than 30 days.

Results

Running the Release Channel for 20 rather than 30 days increased risk of alum use only slightly. There was an increase in the number of traces that simulated alum use from 3 of 18 traces to 5 of 18 traces.

January 21, 2011

Background

Based on the previous simulations (Jan 12), the Ashokan Dividing Weir gate was closed, and this resulted in a decline in East Basin turbidity. At the time of these simulations, the turbidity in the Catskill Aqueduct influent to Kensico Reservoir was approximately 10 NTU and was expected to continue to decline over the next weeks. Stop shutters were being removed to allow more flow in the Catskill Aqueduct. In addition turbidity in the Delaware Aqueduct continued to be less than 1.2 NTU. Turbidity in Kensico Reservoir ranged from 2.0-2.5 NTU near the effluent intakes to about 13 NTU near the Catskill Influent.

Simulation Description

These simulations provided guidance for setting Catskill Aqueduct flows into Kensico Reservoir with the East Basin diversion turbidity at 6, 8 10 or 12 NTU. The tested flow rates were 250, 300, 350 and 400 MGD. Higher than usual Kensico turbidity levels at the beginning of the simulations were accounted for by initializing the model to recent limnology survey data.

Results

All model simulations showed a slight increase in turbidity over the following week as flow was increased and existing turbidity already in the reservoir was moved toward effluent locations.

Simulated effluent turbidity remained generally below 3 NTU with the following inflow and influent turbidity combinations: 6 NTU at 400 mgd; 8 NTU at 350 mgd; and 10 NTU at 250 mgd. None of the simulations with 12 NTU influent turbidity yielded simulated effluent turbidity consistently less than 3 NTU.

A number of the traces showed a surface plume of high turbidity (>5 NTU) (Figure 5-3). Generally this plume was simulated to mix with water from the Delaware Aqueduct. In cases of high turbidity input from Catskill Aqueduct (12 NTU), this plume sometimes extended to model segments near effluent locations, although the simulated effluent turbidity did not show major effects of these plumes. However, a simulated surface plume under the ice did impact the effluent later in January, causing effluent turbidity to rise above 4 NTU. Based on this result, and that such behavior was observed in Kensico Reservoir as ice cover developed, the model simulation of transport of turbidity under ice covered conditions is being evaluated and improved as part of model development efforts being pursued under the Operations Support Tool (OST) project.

January 27, 2011

Background

Catskill Aqueduct influent to Kensico Reservoir continued to decline and was about 6 NTU. Kensico Reservoir continued to have elevated turbidity along the branch from the Catskill influent with a plume of about 5 NTU just under the ice cover which had recently developed.

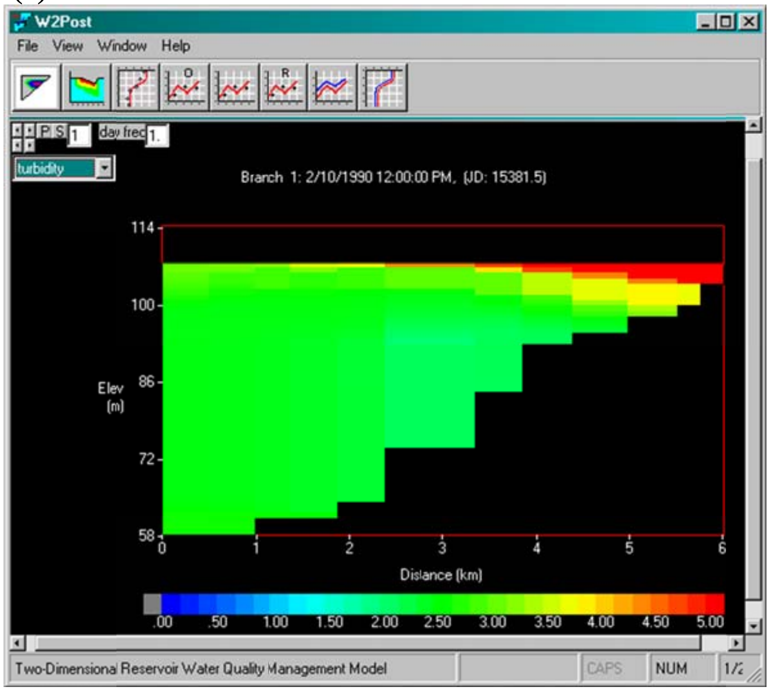
Simulation Description

OST Simulations based on previous runs from January 12 and 18 were updated to better understand the impact of closing the Ashokan Release Channel on January 28 versus closing the Release Channel on February 18.

Results

Results showed little difference in the risk of alum use for either case.

(a)



(b)

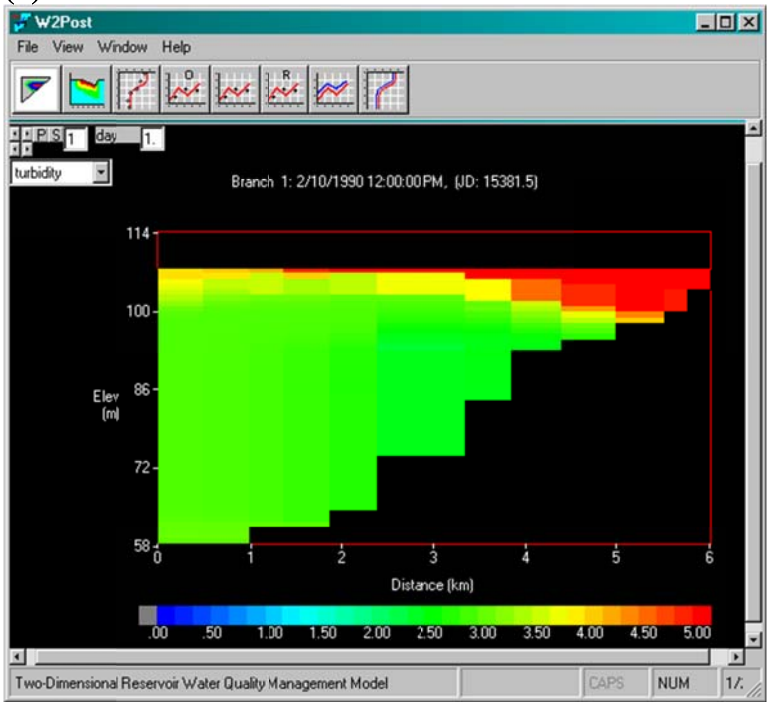


Figure 5-3 Results for Kensico modeling simulation of January 21. Simulated contour plot of turbidity along transect from Catskill Influent (right side) to Kensico Dam (left side) for a single example trace with Catskill Influent turbidity of (a) 6 NTU and (b) 12 NTU.
Note that simulated turbidity at effluent was 2-3 NTU, but plume of higher turbidity (> 5 NTU) was simulated at surface. In the 6 NTU input case the plume was less pronounced that in 12 NTU input scenario. This feature was present in some, but not all traces.

February 17, 2011

Background

On January 31 alum treatment of the Catskill water entering Kensico reservoir was initiated. Despite reduced Ashokan effluent turbidity, ice cover in Kensico Reservoir resulted in a plume of relatively high turbidity being transported to areas adjacent to the effluent locations (see also Figure 5-3). In the absence of ice cover (commonly the case in Kensico) it is likely that the operational strategy developed during the Jan 12 simulations (Figure 5-2b) would have allowed DEP to avoid alum treatment despite a prolonged period of elevated Ashokan Reservoir turbidity. By the time of the February 17 simulations, alum use ended for the Catskill influent to Kensico Reservoir. Turbidity entering Kensico Reservoir at the Catskill Influent was about 3.5-5 NTU. In addition turbidity in the Delaware Aqueduct entering Kensico Reservoir was at or below 1.0 NTU. Turbidity in Kensico Reservoir generally ranged from 1-4 NTU and the reservoir was ice covered.

Simulation Description

These simulations were run to provide guidance for setting Catskill Aqueduct flows into Kensico Reservoir with the Catskill Influent turbidity at 4 or 6 NTU. The tested flow rates were 500 and 600 mgd.

Results

With sustained Catskill Aqueduct Turbidity of 6 NTU, Kensico effluent turbidity after 30 days approached 3 NTU with Catskill inflow of 600 mgd and approached 2.5 NTU if the Catskill inflow was 500 mgd. With sustained Catskill Aqueduct Turbidity of 4 NTU, both 500 mgd and 600 mgd produced effluent turbidity levels of about 2 NTU during the simulation period.

May 4, 2011

Background

Additional spring storms and snowmelt runoff again increased levels of turbidity in Ashokan Reservoir and necessitated alum use which commenced in early March. During alum use Catskill Aqueduct flows had been reduced through the use of stop shutters. At the time of these simulations, turbidity in the Ashokan Reservoir - East Basin effluent was about 14 NTU and was expected to slowly decline over the next months. However, fluctuating increases in Ashokan effluent turbidity were also possible as a result of: 1) strong stratification of turbidity in the East Basin; and 2) continued high turbidity levels in the West Basin, coupled with the possibility of additional spring runoff events. Delaware Aqueduct influent to Kensico was about 1.5 NTU. Turbidity in Kensico Reservoir ranged from ~0.7 – 1.5 NTU.

Simulation Description

These simulations were run to provide guidance for setting Catskill Aqueduct flows into Kensico Reservoir if alum use was ended. The tested Catskill influent turbidities were 10, 20 and 30 NTU and the tested flow rates were 150, 250 and 350 mgd.

Results

With sustained Catskill Aqueduct turbidity of 10 NTU, Catskill Aqueduct inflow of 250 mgd produced simulated Kensico effluent turbidity that reached the 2 - 3 NTU range. With sustained Catskill Aqueduct turbidity of 20 NTU, Catskill Aqueduct flow of 150 mgd produced simulated Kensico effluent turbidity between 2.5 – 3.5 NTU. With sustained Catskill Aqueduct turbidity of 30 NTU, Catskill Aqueduct flows of 150 mgd produced simulated Kensico effluent turbidity of 3 – 4.5 NTU.

May 18, 2011

Background

By mid-May turbidity in the Ashokan Reservoir - East Basin effluent had declined to about 6-8 NTU and was expected to continue to slowly decline over the next months. Stop shutters had been removed and alum continued to be used. Delaware Aqueduct influent to Kensico was less than 1.2 NTU. Turbidity in Kensico Reservoir ranged from ~0.5 – 1.3 NTU.

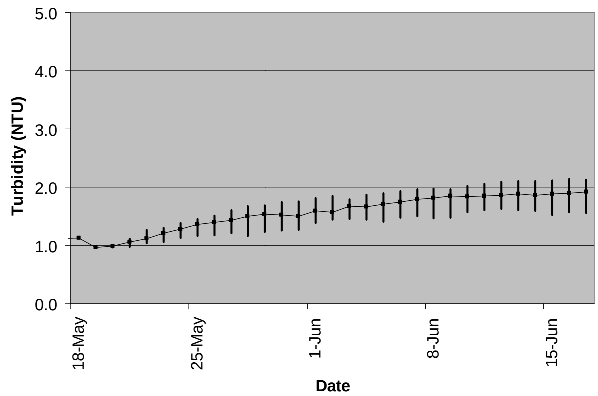
Simulation Description

These simulations were run to examine the effects of stopping alum treatment and to provide guidance for setting Catskill Aqueduct flows into Kensico Reservoir in the absence of alum treatment of the Catskill influent. The tested influent turbidity values were 6, 8, 10 and 12 NTU with inflow rates of 300 and 400 mgd.

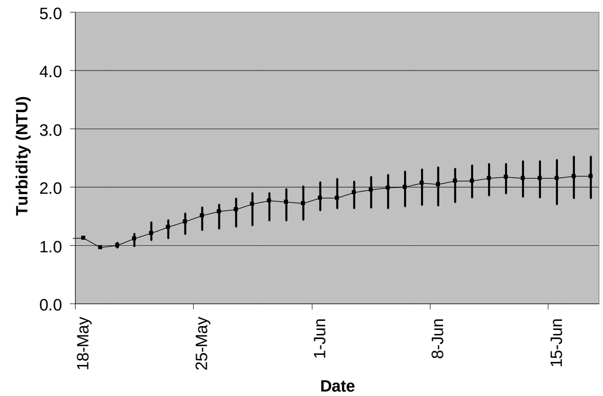
Results

In Figure 5-4 results of a sub-set of the simulations covering the 300 and 400 mgd flow rates and 6 and 12 NTU influent turbidity are shown. With sustained Catskill Aqueduct Turbidity of 6 NTU, Catskill Aqueduct flow of 400 mgd produced simulated Kensico effluent turbidity of 1.8 – 2.5 NTU (Figure 5-4b). With sustained Catskill Aqueduct turbidity of 8 NTU, Catskill Aqueduct flow of 300 mgd produces simulated Kensico effluent turbidity of 2 – 2.5 NTU. With sustained Catskill Aqueduct turbidity of 10 NTU, Catskill Aqueduct flows of 300 mgd produces simulated Kensico effluent turbidity of 2 – 3 NTU. With sustained Catskill Aqueduct turbidity of 12 NTU, Catskill Aqueduct flows of 300 mgd produces simulated Kensico effluent turbidity of 2.5 – 3.5 NTU (Figure 5-4c).

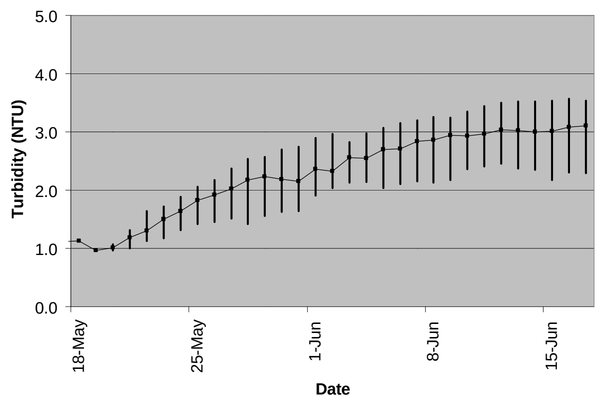
(a) Catskill influent: 300 mgd; 6 NTU



(b) Catskill influent: 400 mgd; 6 NTU



(c) Catskill influent: 300 mgd; 12 NTU



(d) Catskill influent: 400 mgd; 12 NTU

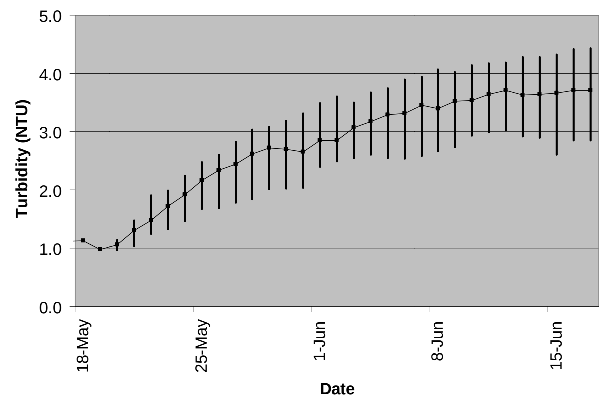


Figure 5-4 Selected results of Kensico Reservoir turbidity simulations of May 18, 2011. Simulated Catskill Aqueduct effluent turbidity with constant input from Catskill Aqueduct of (a) 6 NTU at 300 mgd, (b) 6 NTU at 400 mgd, (c) 12 NTU at 300 mgd and (d) 12 NTU at 400 mgd.

August 30, 2011

Background

Tropical Storm Irene caused record flooding in Esopus Creek and led to elevated turbidity in both the West and East Basins of Ashokan Reservoir and Rondout Reservoir. Turbidity in Rondout Reservoir diversion was 4-8 NTU. Profiles from the Rondout automated monitoring buoy indicated a plume of high turbidity (~8-24 NTU) in the upper layers of the reservoir. However, routing water through West Branch Reservoir was effective in reducing turbidity entering Kensico. Ashokan Reservoir East Basin diversion turbidity was ~70 NTU and was expected to increase, given the state of the West Basin (Figure 5-5). Alum was in use for the Catskill influent to Kensico Reservoir. Turbidity in the Kensico Reservoir ranged from ~0.5 – 4.8 NTU, with the highest levels near the Catskill Influent.

Simulation Description

During most turbidity events with alum treatment of Catskill water, the strategy would be to reduce Catskill Aqueduct flow in order to minimize alum use. In this extreme case our strategy was to maximize flow of alum treated water, since this treated water could be of lower turbidity than the untreated Delaware System water. These simulations were run to provide guidance as to what levels of turbidity from the Delaware Aqueduct could be tolerated as inputs to Kensico Reservoir with the Catskill Aqueduct influent at 600 mgd of flow and with a 75 NTU input of turbidity treated with alum. Input Delaware turbidity of 4, 8 and 12 NTU was tested.

Results

All model simulations showed a significant increase in effluent turbidity as Catskill and Delaware input began to influence the Kensico effluent. Delaware input turbidity of 4 NTU generally raised simulated effluent turbidity to about 3.5-6.0 NTU over a 30 day period. Input Delaware turbidity of 8 and 12 NTU raised simulated effluent turbidity to even higher values.

One of the challenges of these runs was simulating the settling properties of the alum-treated turbidity entering Kensico Reservoir from the Catskill Influent. The turbidity component of the Kensico W2 model partitions turbidity causing particles into three size classes, each with its own settling rate based on the particle size. Under non-alum treated conditions, the turbidity input from the Catskill System is partitioned into the three size classes by 72.5% smallest size (slowest settling), 25% (medium size) and 2.5% larger size (fastest settling). Under alum treated conditions, this partitioning was changed for these runs to 5% in the smallest size class and 95% in the largest size class. The underlying assumption of using this alternative size distribution was that alum treatment would effectively remove 95% of the turbidity from the Catskill Influent.

The model results indicated that high turbidity Catskill System water, even following alum treatment, was simulated to be an important source of turbidity to Kensico Reservoir. This result was largely based on the above assumptions of turbidity partitioning with alum treatment. Close monitoring of Site 5 (near the Catskill Influent) in Kensico Reservoir was recommended to better understand the settling properties for the alum treated turbidity in the Catskill influent.

In addition to the particle size considerations, the simulation also indicated that turbidity entering Kensico would move as a plume along the thermocline. The nature of the plume that might actually occur could greatly affect the effluent concentrations, and added uncertainty to the model predictions. For this reason, it was also recommended to continue to monitor Kensico closely, including transmissometer profiles at 1 m depth interval at each sampling location to understand if and how this plume might evolve.

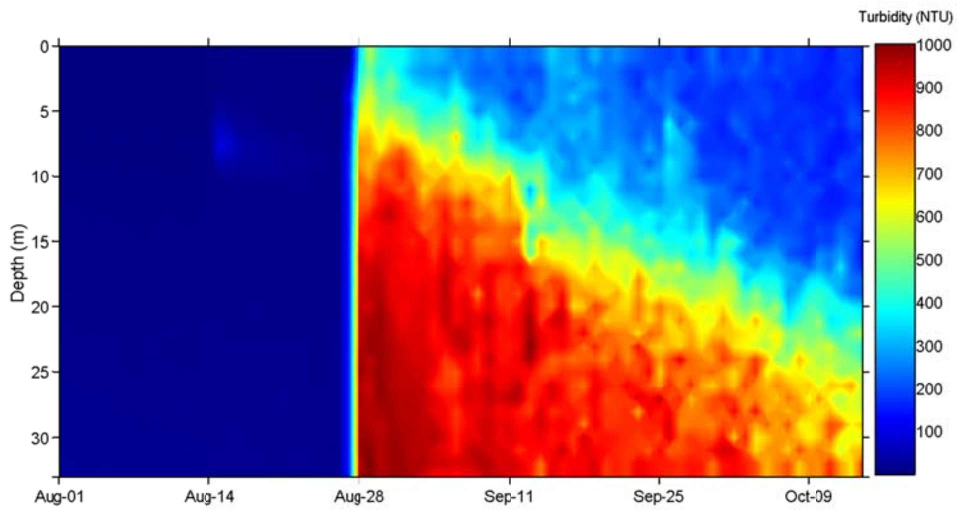


Figure 5-5 Isopleths of turbidity in the West Basin of Ashokan Reservoir. The effects of tropical storm Irene (Aug 28, 2011) led to some of the highest recorded turbidity levels in the reservoir.
The isopleths were created by interpolating between 6 hour turbidity profiles collected by an automated monitoring buoy near the center of the West Basin (Site 1.4).

August 31, 2011

Background

The conditions were similar to those described above for August 30.

Simulation Description

These simulations were run to provide guidance on the tolerable levels of turbidity from the Delaware Aqueduct inputs to Kensico Reservoir with the Catskill Aqueduct Influent at 300 MGD of flow and 75 NTU turbidity treated with alum. Input Delaware turbidity of 4, 8 and 12 NTU at a flow rate of 800 mgd was tested.

Results

In simulations with influent Delaware Aqueduct turbidity of 4 NTU, median effluent turbidity was 3-5 NTU with Catskill Aqueduct inflow of 300 mgd. Simulations with influent Delaware Aqueduct turbidity of 8 and 12 NTU yield higher effluent turbidity.

Other issues noted in the August 30 results still applied for these runs. This included the effects of uncertainty in the effective particle size partitioning of alum treated turbidity at the Catskill Influent and the potential effects of any plume behavior in the reservoir. Detailed monitoring continued to better ascertain the exact nature of these processes.

September 2, 2011

Background

At this date, turbidity in the Rondout Reservoir diversion was ~15 NTU with profiles from an automated buoy indicating a plume of 10-55 NTU in the upper layers of the reservoir near the intake, and a limnological survey indicating a sub-surface plume of ~70 NTU in the upstream area of the reservoir. The Ashokan Reservoir diversion turbidity was ~100 NTU. Alum was in use for the Catskill influent to Kensico Reservoir. Based on the limnological survey on August 31, turbidity in the Kensico Reservoir ranged from ~0.6 – 3.4 NTU, with the higher levels near the Catskill Influent and in the Bear Gutter Creek branch of the reservoir.

Simulation Description

These simulations were run to provide guidance on the tolerable levels of turbidity from the Delaware Aqueduct inputs to Kensico Reservoir with the Catskill Aqueduct influent at 300, 400 or 600 mgd, and turbidity of 100 NTU treated with alum. Delaware Aqueduct influent turbidity was set to 2.5, 4, 6, and 8 NTU, assuming that the higher turbidity levels in Rondout Reservoir continue to be avoided, and that the moderate reductions in turbidity occur as the water moves through West Branch Reservoir. Total inflow to Kensico was maintained at 1100 mgd, so that Delaware Aqueduct flow rates were 800, 700, or 500 mgd.

For these runs the method for estimating the turbidity entering Kensico Reservoir after alum treatment of the Catskill Influent was changed from previous runs. Investigation of previous model runs showed that much of the simulated effluent turbidity was in the largest (fastest settling) particle size class, and was therefore the remnants of the alum treated turbidity that was added to this size class under the assumption that it would rapidly sink out. The fact that significant amounts of the large size class turbidity were influencing the simulated effluent turbidity, suggested that the settling rate of the largest size class may not have been representative of alum treated material. Monitoring from the reservoir also indicated that the previous model simulations may have over-estimated the influence of the alum-treated Catskill influent. Based on this information, the alum-treated influent turbidity to Kensico Reservoir was set to 5% of the untreated value, and all of this turbidity was assigned the slowest settling particle size class.

Results

At Delaware influent turbidity of 4 NTU or less, Kensico effluent turbidity levels increased with increasing Catskill inflow. At Delaware influent turbidity of 8 NTU, Kensico effluent turbidity decreased with increasing Catskill inflow. At Delaware influent turbidity of 6 NTU, effluent turbidity was not sensitive to changing Catskill inflow since the treated Catskill influent turbidity was simulated to be at a similar level of 5 NTU. Under these conditions the median effluent turbidity ranged from 2-4 NTU.

Although correction to the partitioning (and the resulting effective settling rate) of the alum-treated Catskill influent turbidity was performed for this run, there was still some uncertainty with the exact effects of the alum on model input. Continued limnological sampling was recommended to ensure that appropriate effective settling rates could be better ascertained in future model runs.

September 7, 2011

Background

System conditions were similar to those described above for September 2, except Kensico Reservoir turbidity ranged from ~0.9 – 2.6 NTU based on a limnological survey on September 5 that was used to set the initial conditions of the model simulations.

Simulation Description

During the previous days, it was possible that a small pulse of high turbidity water may have entered Kensico Reservoir. The first simulation performed here attempted to simulate the effects of a one day pulse of untreated water entering Kensico from the Catskill Aqueduct at 75 NTU. After the 1-day pulse the Catskill influent was set to 100 NTU treated with alum. This was effectively 5 NTU (5% of 100 NTU) based on the previous assumption of alum treatment effects on Catskill influent. The influent flow rates for this analysis were set to 275 mgd and 825 mgd for Catskill and Delaware, respectively.

Another set of simulations investigated the possibility of reduced Catskill inflow (50 mgd) through the use of stop shutters, assuming turbidity of 100 NTU with and without alum treatment.

Results

Simulation results suggested that a single day pulse of 75 NTU turbidity from the Catskill Aqueduct would raise effluent turbidity to about 2-3 NTU after about a 4-5 day delay. Variability in the simulated pulse magnitude and arrival time at the Kensico effluent locations were dependent on the transport of the turbidity plume that traveled along the top of the existing thermocline in Kensico Reservoir.

Untreated Catskill influent turbidity of 100 NTU at a flow rate of 50 mgd with current Delaware influent turbidity of 2.5 NTU produced a steady increase in effluent turbidity to above 4 NTU after 30 days, and at the end of the 30 day simulation it appeared that turbidity would continue to increase. The results also indicated that Catskill alum treatment significantly reduced the predicted effluent turbidity and as Delaware influent turbidity increased above 6 NTU, it became more advantageous to increase use of alum treated Catskill system water.

September 23, 2011

Background

At the time of these simulations, turbidity leaving the Ashokan East Basin via the Catskill Aqueduct was ~60 NTU and was being treated with alum prior to entering Kensico Reservoir. Recent surveys showed that alum treatment decreased input turbidity (as measured at Kensico limnological survey Site 5) to about 1.5 – 2.8 NTU. Turbidity was also elevated in the Rondout Reservoir, and turbidity entering Kensico Reservoir at DEL17 was approaching 3-4 NTU. Based on limnological survey on September 21, turbidity in Kensico Reservoir ranged from ~0.7-4 NTU, with higher values near the Delaware influent.

Simulation Description

These simulations estimated the levels of turbidity from the Delaware Aqueduct that could be tolerated as inputs to Kensico Reservoir when the Catskill Aqueduct influent flow was 300, 400 or 500 mgd and the turbidity was at the current level of 60 NTU treated with alum. Based on limnological survey results, Catskill influent turbidity was set the 1.8 NTU (average at Site 5) and assigned to the slowest settling class. Potential Delaware Aqueduct influent turbidity is set to 4 and 6 NTU. The total inflow to Kensico was set at 1100 mgd, and Delaware Aqueduct flows were therefore, set to 800, 700, or 600 mgd.

Results

All model simulations showed a steady increase in effluent turbidity as elevated Delaware turbidity input began to influence the Kensico effluents. The simulation result indicated median effluent turbidity at the end of the 30 day simulation period of 1.9-2.1 NTU with 4 NTU Delaware influent and a median effluent range of 2.4-2.8 NTU with 6 NTU Delaware influent

For these and previous simulations the Delaware influent turbidity was assigned to particle size classes that were consistent with non-alum treated Catskill influent partitioning. To better understand the sensitivity of the partitioning of Delaware influent turbidity into appropriate size classes, the runs were repeated partitioning the turbidity to 100% into the slowest settling particle size class. Figure 5-6 shows a comparison of the two results. Over the 30 day simulation, the difference in using the two different partitioning schemes produced about a 10% difference in the resulting Kensico effluent turbidity. The results of this simulation coupled with the rising influence of Delaware turbidity indicated that limnological survey information collected at sites 9 and 7 (located along branch from Rye Lake to main basin and at Delaware influent, respectively) in Kensico Reservoir should be closely monitored in the following weeks to better ascertain the transport of turbidity from DEL17 to the effluents.

(a) Catskill inflow = 300 mgd; Delaware inflow = 800 mgd

(b) Catskill inflow = 500 mgd; Delaware inflow = 600 mgd

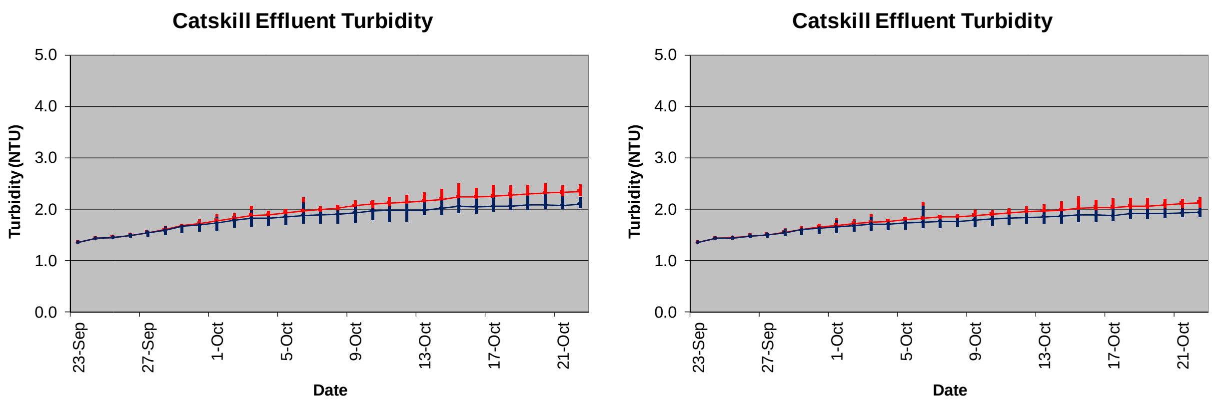


Figure 5-6 Modeling results from September 23, 2011.
Comparison of simulated Catskill effluent turbidity using Delaware influent turbidity assigned to particle size classes that were consistent with non-alum treated Catskill influent partitioning (75% class 1; 25% class 2; 2.5% class 3) (blue line) and assigning all Delaware influent to class 1 (slowest settling class) (red line). The input total turbidity is 4 NTU from Delaware and 1.8 NTU from Catskill for all cases.

September 30, 2011

Background

On September 27 a storm event in the Esopus watershed led to inputs to the West Basin of Ashokan that caused high turbidity water to move across the Dividing Weir from the West to the East Basin. This, in turn, caused the East Basin Catskill diversion to rise to ~200 NTU and despite alum treatment, resulted in a plug of high turbidity water entering Kensico Reservoir from September 29-30. Turbidity continued to be elevated in the Rondout Reservoir, with turbidity entering Kensico Reservoir at DEL17 being ~4 NTU. In Kensico reservoir there was a plume of turbidity detected at Site 4.1 (along branch from Catskill influent) that ranged from ~2.5 - 6.6 NTU between the depths of 2-8 m.

Simulation Description

These simulations were run to estimate the tolerable levels of turbidity from the Delaware Aqueduct inputs to Kensico Reservoir with the Catskill Aqueduct influent at 300, 400 or 500 mgd and the current turbidity of 200 NTU treated with alum. To simulate the effects of alum treatment, an effective input turbidity of 3 and 4 NTU were used based on monitoring data collected at Site 5 in Kensico Reservoir during a period in early September when the Catskill Aqueduct influent turbidity was also at a high level and treated with alum. Potential Delaware Aqueduct influent turbidity was set to 4 and 6 NTU for these runs, and Delaware inflow levels were set to so that there was a total inflow of 1100 mgd to the reservoir.

Results

All model simulations exhibited a rapid increase in effluent turbidity as the plume of turbidity in the reservoir began to affect the Kensico effluents. The initialization of the simulation used data collected from a limnological survey that included 1 meter resolution transmissometer measurements, and from an automated monitoring buoy. These data were helpful in representing the turbidity plume in the simulation results. However, the actual effects of the turbidity plume were somewhat uncertain since the exact spatial distribution of the elevated turbidity was not known and since the exact movement and dynamics of the plume relative to the effluent intake can be difficult to simulate.

The optimum mixing of the Catskill and Delaware waters was dependent on the difference between alum treated Catskill influent turbidity and the untreated Delaware influent turbidity. Generally it was determined that it was best to favor Catskill system inputs of lower turbidity source, and that the influent location (due to potential settling of particulates) was of lesser importance. In addition, the simulated effluent turbidity levels were daily averages and since simulated levels were approaching 3 NTU it might be possible that short term (sub daily) variations in turbidity could have led to turbidity levels higher than that predicted by our model. Close monitoring of the reservoir and the existing plume continued to further ensure that effluent turbidity remained below acceptable levels.

October 3, 2011

Background

At this time, Ashokan East Basin turbidity was ~100 NTU, and, two plugs of high turbidity water had entered Kensico Reservoir between Sep. 29 and Oct 1. Turbidity continued to be elevated in the Rondout Reservoir, and turbidity entering Kensico Reservoir at DEL17 was ~3 - 4.5 NTU. Combined limnological survey, transmissometer and automated buoy measurements indicated a plume of turbidity in the Catskill branch of the reservoir. The plume turbidity was ~4 – 13 NTU with the peak turbidity at 9 m of depth.

Simulation Description

These simulations were run to help determine the appropriate Catskill Aqueduct flow rate (with or without stop shutters) to minimize the movement of the turbidity plume in the Catskill arm of Kensico Reservoir to the reservoir effluents. Two flow rates are tested: 50 mgd (minimum with stop shutters) and 275 mgd (minimum without stop shutters). These runs used 4 NTU and 6 NTU inputs from Delaware and 2 NTU and 3 NTU from Catskill influent for sensitivity. The total inflow to the reservoir was set to 1100 mgd.

Results

All model simulations exhibited a rapid increase in effluent turbidity as the plume of turbidity currently in reservoir began to influence the Kensico effluents. Simulations with Catskill flow of 50 mgd resulted in a less immediate increase in turbidity at effluents (Figure 5-7). At Catskill flow of 50 mgd, simulated maximum Catskill effluent turbidity over the following week was about 2.9-3.0 NTU, while for Catskill inflow of 275 mgd simulated maximum Catskill effluent turbidity over the following week was about 3.2 NTU

For the longer term, the modeling indicated that the optimum mixing of the Catskill and Delaware waters was dependent on the difference between the effective Catskill influent turbidity (following alum treatment) and Delaware influent turbidity. Generally it was best to favor input from lesser turbidity source (Delaware vs. effective alum-treated Catskill). Many of the uncertainties with the previous modeling results still applied to these runs including the settling rates for alum-treated Catskill influent, the settling rates for Delaware influent turbidity, and the exact extent and behavior of the turbidity plume in the reservoir. Close monitoring of the reservoir and the existing plume continued to further ensure that effluent turbidity remained within acceptable levels.

(a) Catskill inflow = 50 mgd; Delaware inflow = 1050 mgd

(b) Catskill inflow = 275 mgd; Delaware inflow = 825 mgd

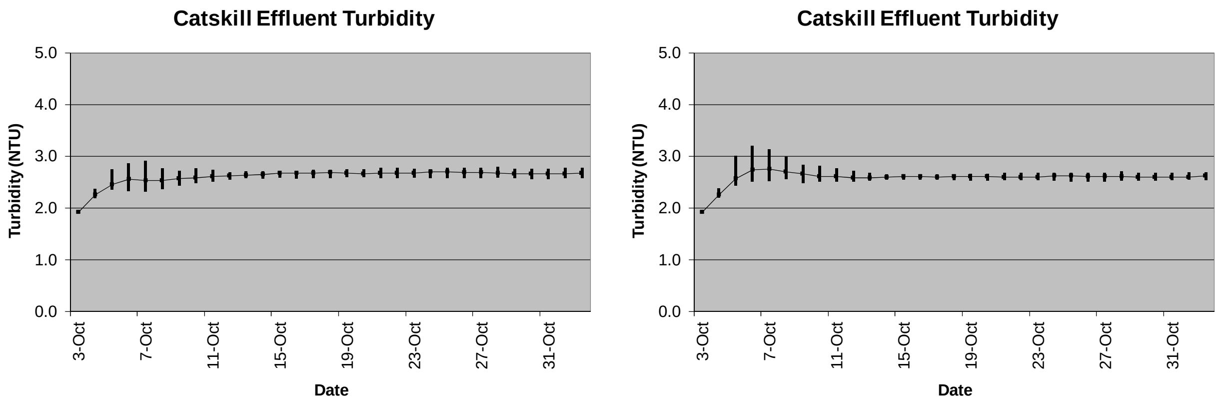


Figure 5-7 Modeling results from October 3, 2011. Simulated effects on Catskill effluent from Kensico Reservoir using an inflow from Catskill Aqueduct of (a) 50 mgd or (b) 275 mgd. The turbidity plume in reservoir reaches effluent slightly later and with less intensity using 50 mgd versus 275 mgd Catskill inflow. Influent turbidity for these simulations was 3 NTU for Catskill and 4 NTU for Delaware.

October 21, 2011

Background

At this time, turbidity leaving the Ashokan East Basin via the Catskill Aqueduct was about 50-100 NTU and was being treated with alum. In addition, stop shutters were in place and the flow rate from Catskill Aqueduct into Kensico was 250 MGD. Recent surveys showed that alum treatment decreased input turbidity (as measured at Kensico limnological survey Site 5) to about 3 NTU. The Delaware Aqueduct was on float mode with turbidity of about 2 NTU.

Simulation Description

These simulations were run to provide guidance for a number of operational changes that were soon going to occur, including (1) going off float mode for the Delaware Aqueduct and passing Delaware aqueduct water through Kensico Reservoir; and (2) removing stop shutters from the Catskill Aqueduct.

Three simulations were performed:

1. a simulation of Delaware float mode to understand the effects of not loading Delaware water into Kensico Reservoir;
2. a simulation of routing Delaware water into Kensico and continuing with a 250 mgd Catskill inflow; and
3. a simulation of routing Delaware water into Kensico and removing Catskill stop shutters with a resulting increase of Catskill inflow to 350 MGD.

The settling rates used for Delaware influent turbidity assumed the size dependence as for untreated Catskill System turbidity. In addition, these runs assumed Catskill influent turbidity after alum treatment of 3 NTU, based on in-reservoir sampling information. An input of 6 NTU for the Catskill System was also used to provide guidance in case alum treatment was not as effective as in previous cases.

Results

Simulations showed that operation of the Delaware aqueduct in float mode had little effect on Catskill effluent turbidity when the Catskill input was 3 NTU. When Catskill influent turbidity was 6 NTU, Catskill effluent slowly increased to about 2 NTU at the end of a 30 day period

Simulations which allow Delaware inputs to be routed through Kensico Reservoir (reservoir mode) show little effects on Catskill effluent with Catskill input turbidity of 3 NTU (with or without stop shutters). With Catskill influent turbidity of 6 NTU, the Catskill effluent turbidity increases to about 2.1 NTU with Catskill inflow of 250 mgd and about 2.3 NTU with Catskill inflow of 350 mgd.

5.3 Summary

During the three turbidity event periods that occurred in 2011, reservoir turbidity modeling was used extensively to inform reservoir operation decisions that were needed to maintain Kensico effluent turbidity at acceptable levels. These periods presented a series of unique issues to the modeling effort including the influence of an ice cover at Kensico Reservoir (early in 2011), the uncertainty of the appropriate turbidity size class partitioning to use with both alum-treated Catskill influent and untreated Delaware turbidity input (fall 2011), and the challenge of simulating a significant plume of turbidity in the Catskill branch of the reservoir (fall 2011). In many of these cases, the combination of detailed limnological survey data including transmissometer readings at 1 m vertical resolution and automated turbidity measurements at 6 hour temporal resolution, when combined with the modeling provided a powerful information stream that aided in operating the system. Modeling runs helped to point out data that would be of importance, and data helped to define modeling initial conditions and input parameters that ensured the most accurate model simulations. This combination of data and modeling was effective in providing simulations and forecasts of sufficient detail to support reservoir operational decisions that allowed water quality requirements to be maintained during this challenging period.

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