New York City
Department of Environmental Protection

Annual Report for the Kensico Water Quality Control Program

March 2011

Prepared in accordance with Section 4.10 Kensico Water Quality Control Program of the New York City Filtration Avoidance Determination, July 2007 and New York City's December 2006 Long-term Watershed Protection Program

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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
CFU	Colony Forming Units
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 2010. 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 2010 Kensico Water Quality Annual Report. They include: Dr. Lorraine Janus, Mr. James Mayfield, Mr. Gerard Marzec, Mr. David Quentin, Dr. Yucel Tokuz, Ms. Kerri Alderisio, Mr. Christian Pace, Dr. Don Pierson, Dr. Elliot Schneiderman, Mr. Mark Zion, Mr. David Lounsbury, 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 Blancero McDonald, and their staff members, were also contributors.

Ms. Diane McGowan, of the East of Hudson Operations staff, contributed the update on plans for dredging for alum removal at the Catskill Upper Influent Cove.

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 2010. This was demonstrated by full compliance with the SWTR requirements for fecal coliform bacteria in raw water samples, which is only possible when resident and migratory waterfowl populations are minimized. Low levels of fecal coliform bacteria have been consistently achieved since 1993. The implementation of the WMP continues to be the most cost-effective way to achieve compliance with the SWTR.

DEP continued to meet its reporting obligations for engineering and scientific reports as specified in the Catskill Influent Chamber SPDES permit. As in the past, DEP conducted visual inspections of the turbidity curtain at the Catskill Upper Effluent Chamber cove in 2010. The boom only required one instance of maintenance.

There were no special investigations conducted within the Kensico Reservoir watershed during 2010, indicating that there were no spills or unusual water quality events in the watershed. However, there were several special reservoir sampling efforts made to address potential water quality concerns.

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. ConEd approached DEP in the summer of 2009 to request permission to remove trees along the corridor to increase the reliability of the electric system per their maintenance plan filed with the New York State Public Service Commission. DEP granted approval to ConEd, and tree removal work began in December 2009 and was completed in 2010. Where staff deemed necessary, large cleared area and areas close to the reservoir were seeded in order to maintain adequate vegetative cover.

Kensico Reservoir water quality monitoring that was conducted in 2010 included approximately 6700 samples collected at 77 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 4,838 times and in the reservoir 597 times. In addition, 304 pathogen samples were analyzed for *Cryptosporidium* and *Giardia*, and another 206 samples were collected for human enteric viruses (HEV).

In 2010, DEP continued to receive and review results of the ongoing voluntary sampling of Westchester County Airport groundwater monitoring wells. Samples were collected in May and December; however, December data were not yet available at the time of this report. The parameters analyzed in May were volatile, semi-volatile, and non-halogenated organic compounds, and these results were compared to the New York State Department of Environmental Conservation (DEC) Technical and Operational Guidance Series (TOGS) guidance values. Dissolved metals were detected above TOGS guidance values in 42 wells surrounding Westchester County Airport. The dissolved metals which were detected above guidance values were iron, manganese, magnesium, zinc, and sodium. Based on the data reviewed and the nature of the rocks underlying the airport, it is believed that the occurrences of metals observed in the groundwater samples are naturally occurring.

The annual surveillance of Kensico Reservoir keypoints DEL18 and CATLEFF for 67 volatile organic compounds (VOCs) and 68 semivolatile organic compounds (SVOCs) resulted in no compounds being detected.

DEP continues to monitor the hydrology of the Kensico watershed. Samples were collected monthly at eight fixed sampling sites to quantify water quality at each of the perennial streams (BG9, E10, E11, E9, MB-1, N12, N5-1, WHIP). All Kensico streams had median fecal coliform values less than 200 CFU 100 mL^{-1}. For total coliform bacteria, twelve values of more than 5000 CFU 100 mL^{-1} occurred, most of them when over 1.36 inches of precipitation had fallen within the week before the sample date. 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 2010 results for these analytes are presented.

In 2010, 348 total coliform and 357 fecal coliform bacteria samples were collected throughout Kensico Reservoir for coliform analyses. The medians for total and fecal coliform samples were below their DEP guidelines of 100 CFU 100 mL^{-1} and 20 CFU 100 mL^{-1}, respectively. As in previous years, there were several times when total coliform concentrations exceeded the guideline, typically in late summer and autumn when most reservoirs experience an increase in bacteria counts. There were five instances where fecal coliform samples exceeded the DEP guideline. Turbidity exceeded 5 NTU 3 times at Site 3, and 17 times at Site 5 out of the 366 samples collected reservoir-wide. As in the past, Site 5 near the Catskill Influent had the highest median turbidity (1.8 NTU) of the eight sites. At the sites closest to the effluent chambers (sites 2 and 3), the turbidity was less than 3.0 NTU for the 90^{th} percentile of the data.

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 2010 at the Kensico influents (CATALUM and DEL 17) was 0.4 and 1 CFU 100 mL^{-1}, respectively, and was 1 CFU 100 mL^{-1} for both of the effluent sites (CATLEFF and DEL18). In 2010 there were no reported values at the effluent sites that exceeded the 20 CFU 100 mL^{-1}guideline. At the influent sites, median turbidity for 2010 was 3.3 NTU at CATALUM and 1.0 NTU at DEL17. At the effluent sites, median turbidity for 2010 was 0.90 NTU at both CATLEFF and DEL18. The maximum 4-hour turbidity measurements were 4.3 NTU at CATLEFF and 2.7 NTU at DEL18. Thus, the SWTR limit of 5 NTU was consistently met at both effluent keypoints.

DEP is responsible for performing filtration avoidance and surveillance monitoring of protozoan pathogens (*Cryptosporidium* and *Giardia*) and human enteric viruses (HEV) in the New York City Watershed. In 2010, 304 samples were collected and analyzed for *Giardia* and *Cryptosporidium* in the Kensico Reservoir watershed. This includes a total of 208 fixed frequency samples collected at the two influents and two effluents, as well as 96 fixed frequency samples collected at eight perennial tributaries. In addition, 206 samples were collected and analyzed for HEV. In general, 2010 results were consistent with past data in that *Cryptosporidium* oocysts were found infrequently and at low concentrations, and *Giardia* cysts were found more frequently and at higher concentrations than *Cryptosporidium*. The maximum protozoan concentrations for the influent locations were 2 oocysts and 8 cysts in 50 liter sample. The highest *Cryptosporidium* detected at both of the reservoir effluents was 1 oocyst, whereas the maximum *Giardia* concentration was 8 cysts in a 50 liter sample. Stream sample volumes varied more than the aqueduct samples and the maximum *Cryptosporidium* detected was 2 oocysts in a 15.7 liter sample, and the maximum *Giardia* was 75 cysts in 15 liters.

Finally, 2010 was the second year of a three-year effort, performed under contract by the Upstate Freshwater Institute (UFI), to deploy, operate, and maintain a robotic monitoring network on portions of the NYC system of reservoirs, including Kensico Reservoir. In Kensico, the robotic network consists of a profiling buoy manufactured by YSI, Inc. and two fixed-depth buoys developed by UFI. The profiling buoy is located in the Catskill influent arm of the reservoir. The fixed depth buoys are located near the Delaware (Station 2) and Catskill (Station 3) effluent chambers. Data are automatically downloaded at least every three hours. The robotic monitoring equipment is expected to provide new insights and water quality management opportunities based on high frequency measurements that are not otherwise available. These data are used as model input (initial conditions) and to evaluate reservoir water quality model performance and to assist in guiding operational decisions. Examples of modeling simulations for turbidity events in the spring and fall of 2010 are provided along with discussion of how they were used to guide operations.

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 over the last three years (2007-2009), as well as an examination of the observed trends in water quality from 1993-2009.

The purpose of this report is to analyze and discuss ongoing water quality data collections 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 2010.

The Catskill Aqueduct leaving Kensico Reservoir was shut down for planned maintenance six times in January, three times in May, once in June and once in December. The Delaware Aqueduct leaving Kensico Reservoir was shut down 112 times over eight months in 2010. These planned shutdowns were mostly associated with construction of the new ultraviolet disinfection facility.

Unplanned shutdowns of the Catskill Aqueduct due to weather-induced storm events occurred on January 25, March 13 and December 1, 2010. The Delaware Aqueduct experienced some very brief unplanned shutdowns due to turbidity caused by gate-testing operations on January 7 and March 10.

The Delaware System was placed on "float" mode from March 13 to March 16 and from September 29 to October 1 to reduce water quality impacts from storm events. 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.

2. Water Quality Management

2.1 Waterfowl Management

The Waterfowl Management Program (WMP) continued to maintain a high level of success during 2010. This was demonstrated by full compliance with the SWTR requirements for fecal coliform bacteria in raw water samples, which is only possible when resident and migratory waterbird populations are kept at low levels. These low levels of fecal coliform bacteria have been consistently achieved since 1993. The implementation of the WMP continues to be the most cost-effective way to achieve compliance with the SWTR.

DEP's Wildlife Studies Section is responsible for oversight of the WMP, while program implementation is largely the responsibility of a consultant, Henningson, Durham, and Richardson, P.C. The most recent Waterfowl Management Program Contract (WMP-08) extension was awarded and commenced on August 1, 2010, and is expected to continue through the end of July 2011. For a more detailed account of the WMP, refer to the annual FAD report on this topic dated July 31, 2010 (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).

Figure 2.1 Airboat being deployed at Kensico for bird harassment.

- 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 (shown in Figure 2.1) and pyrotechnics, where needed.
- Record seasonal surveillance of water influent facilities for alewives (*Alosa pseudoharengus*), a baitfish. Dead and dying alewives transported through the

Figure 2.2 Mute Swan nest targeted for egg depredation as part of the Waterfowl Management Program.

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*) (shown in Figure 2.2) under federal and state permits, from April through June annually.
- Meadow management, including maintenance of shoreline fencing to discourage nesting geese from occupying the area around Delaware Shaft 18 (DEL18), as well as maintenance of a meadow-like field to eliminate mowed lawns, which attract goose foraging.
- Maintenance of bird netting at the 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 and the New York State Department of Environmental Conservation on waterbird management techniques.

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 2010. If an observation indicated that maintenance was required, BWS Systems Operations was notified and conducted appropriate repairs or adjustments. For example, when the turbidity curtain was found to be broken on December 8, System Operations was notified and the boom was repaired by December 9. In addition to the inspections carried out by the Water Quality Directorate, Systems Operations performs its own routine inspections and maintenance of the turbidity curtain.

Table 2.1 2010 visual inspections of the Catskill Upper Effluent Chamber turbidity curtain.

Inspection Date	Observations
01/06/10	Curtain appears intact and afloat as seen from shore.
01/20/10	Curtain appears intact and afloat as seen from shore- ice encasing it.
01/25/10	Curtain appear intact, some overtopping in the wave action. Curtain inspected due to high turbs at CATUEC.
02/03/10	Curtain appears intact and afloat as seen from shore- ice encasing it.
02/17/10	Curtain appears intact and afloat as seen from shore- ice encasing it.

Table 2.1 2010 visual inspections of the Catskill Upper Effluent Chamber turbidity curtain.

Inspection Date	Observations
03/03/10	Curtain appears intact and afloat as seen from shore- ice encasing it, 2 small trees resting on curtain.
03/18/10	Curtain appears intact and afloat as seen from shore.
03/31/10	Curtain appears intact and afloat as seen from shore.
04/14/10	Curtain appears intact and afloat as seen from shore.
04/28/10	Curtain appears intact and afloat as seen from shore.
05/04/10	Curtain appears intact and afloat as seen from shore.
05/26/10	Curtain appears intact and afloat as seen from shore.
06/09/10	Curtain appears intact and afloat as seen from shore.
06/22/10	Curtain appears intact and afloat as seen from shore.
07/07/10	Curtain appears intact and afloat as seen from shore.
08/04/10	Curtain appears intact and afloat as seen from shore.
08/18/10	Curtain appears intact and afloat as seen from shore.
09/01/10	Curtain appears intact and afloat as seen from shore.
09/22/10	Curtain appears intact and afloat as seen from shore.
09/29/10	Curtain appears intact and afloat as seen from shore.
10/13/10	Curtain appears intact and afloat as seen from shore.
10/27/10	Curtain appears intact and afloat as seen from shore.
11/10/10	Curtain appears intact and afloat as seen from shore.
11/24/10	Curtain appears intact and afloat as seen from shore.
12/08/10	Inner boom closest to MB-1 appears to not be attached.
12/22/10	Curtain appears intact and in good condition as seen from shore.

2.3 Power Line Right-of-Way Management

In 1915, the City granted a right-of-way to Con Edison (“ConEd”) to establish and maintain an electric transmission corridor along City land from Yonkers to Millwood. The transmission corridor traverses 2.1 miles of land in the Kensico Reservoir drainage basin along the western shore of the reservoir. ConEd approached DEP in the summer of 2009 to request permission to remove trees along the corridor to increase the reliability of the electric system per their maintenance plan filed with the New York State Public Service Commission. DEP granted approval to ConEd, with restrictions, to remove trees along the corridor that were currently tall enough, or would grow tall enough in the next three years, to pose a hazard to the transmission system. Tree removal work was completed in 2010. To protect the water supply during and after work, oil used in chainsaws was biodegradable and no mechanized equipment was allowed off established roads. All areas where trees were removed were reviewed for adequate vegetative cover by DEP staff. Where staff deemed necessary, large cleared areas were seeded with a native seed mix, and areas close to the reservoir were seeded, mulched, and then replanted with trees of species compatible with ConEd’s equipment. 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.

2.4 Alum Dredging Status

Recent history of current activities began in April 2005, several heavy rain events were experienced in upstate New York, creating record flooding, which in turn led to extensive erosion of streambanks and channels throughout the Catskill System and a significant increase in turbidity in water entering the Catskill Aqueduct at Ashokan Reservoir. DEC issued two emergency authorizations in 2005 (April and October) to allow for the use of aluminum sulfate (alum) and sodium hydroxide to coagulate the suspended solids in Catskill water entering Kensico Reservoir during this period of high turbidity. These Emergency Authorizations also required the removal of the resulting alum floc, including the entrained solids, from Kensico Reservoir. The SPDES permit issued to DEP on December 20, 2006 which, among other things, authorizes the continued use of alum under appropriate conditions, also includes a condition that DEP remove the alum floc resulting from such continued use.

DEP has been advancing the project design to remove the floc from the reservoir in the vicinity of the Catskill Influent Chamber (CATIC), where water from the Catskill Aqueduct enters Kensico Reservoir.

Hydraulic dredging and mechanical dewatering, with disposal of the resultant concentrated cake at an offsite location, was determined to be the best method at this time. The scientific investigations of the area of floc deposition were completed in 2007. DEP and the design consultants at Malcolm Pirnie, Inc., submitted reports to DEC in October 2007 detailing the bathymetric, benthic, core sampling, computer modeling, and flow study findings.

After reviewing all of the scientific data, DEC requested additional clarification. DEP submitted a supplemental report to DEC dated December 2007 on the “Extent and Depth of Alum Floc in Kensico Reservoir”. In June 2008 DEC requested modifications to the DEP Dredging Plan and clarification. DEP and Malcolm Pirnie procured the services of an independent third party expert to review all scientific data collected during the investigation of the alum floc deposition in Kensico Reservoir. In September 2008 DEC was sent a supplemental technical report on the “Impacts of Dredging the Estimated Area of Alum Floc Deposition in Kensico Reservoir”. This report included the conclusions of the independent third party expert. In July 2009 DEC responded to DEP with a request for a joint habitat assessment/evaluation to identify unidentified potential impacts to fisheries and the status of the reservoir’s aquatic ecosystems and factors which are affecting it. A decision on next steps is pending further discussion between DEP and DEC. DEP, Malcolm Pirnie, and Arcadis US, Inc., have initiated a Constructability Analysis for the proposed dredging.

In addition to the engineering and scientific reports specified in the SPDES permit, DEP has provided DEC and DOH with monthly progress reports since October 2005 on the investigations conducted to finalize the construction contract for the project.

Contract work was re-initiated in December 2010. However, DEP has recently discussed with DEC the idea 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 DEP will face during dredging, and reduce the impact on the environment within Kensico Reservoir.

2.5 Special Investigations

There were no Special Investigations conducted within the Kensico Reservoir watershed during 2010, indicating that there were no spills or unusual water quality events in the watershed. However, there were several special reservoir sampling efforts made to address potential water quality concerns. In response to detections of *Chrysosphaerella*, 16 additional DEL18 and CATLEFF keypoint samples were collected between September 28 and November 23 for phytoplankton, and all phytoplankton slides were completely scanned for the presence of the alga. In order to examine laboratory procedures, a separate collection of unpreserved phytoplankton slides led to nine additional keypoint phytoplankton sample collections in August to compare side-by-side with preserved samples. The results indicated that preserved samples provided the most accurate counts. Ultimately, *Chrysosphaerella* counts never rose to problematic levels in 2010.

Three separate weather-induced turbidity events resulted in 92 additional turbidity samples being collected from Kensico Reservoir in the vicinity of the Catskill Upper Effluent Chamber. Late fall storm events in the Catskill mountains created turbid conditions in Ashokan Reservoir, and required additional surveys of Kensico Reservoir to track turbidity and provide data for turbidity modeling runs. Over four separate surveys, 88 non-routine grab turbidity samples were taken and 1-meter interval profiles were recorded with a transmissometer. All of this work was conducted in addition to routinely scheduled monitoring.

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 2010 included samples at 77 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 effluent keypoint sites 4838 times and in the reservoir 597 times. In addition, 304 pathogen samples were collected for *Cryptosporidium* and *Giardia*, and another 206 samples were collected for human enteric viruses (HEV). Supplementary information (not included in the summary table) is collected by probes that provide continuous readings. Continuous monitoring of turbidity is recorded on circular charts (Figure 3.2) and sampled manually at 4-hour intervals. Other parameters that are monitored continuously are pH, temperature, and conductivity.

Table 3.1 Summary of Kensico Reservoir water quality monitoring conducted in 2010.

Kensico Sampling Programs	# of sites	Parameters	Routine Frequency	Sampling Agency	Number of Samples Collected in 2010
Streams	8	bacteria, turbidity, physicals, nutrients[1], other chemistry[1]	monthly	DEP	94[2]
Reservoir	8	bacteria[3], turbidity, physicals, nutrients[3], other chemistry[3]	2x monthly[3], Mar-Dec only	DEP	597[4]
Keypoints at effluents	2	bacteria, turbidity, physicals, nutrients[5], other chemistry[5]	7x/week	DEP	736
Keypoints at influents	2	bacteria, turbidity, physicals, nutrients[6], other chemistry	5x/week	DEP	541
Toxic Chemicals at effluents	2	VOCs, SVOCs	annually	DEP	2
Groundwater at county airport	57	VOCs, SVOCs, metals	semiannually	Westchester Co. DOT	114
Pathogens	12	*Cryptosporidium*, *Giardia*	4 keypoints weekly, 8 streams monthly	DEP	304
	4	HEV	4 keypoints weekly	DEP	206
SWTR Compliance	2	Turbidity	every 4 hours	DEP (operators)	4103

Total	77	-	-	-	6697

[1] At 6 sites only.

[2] 78 samples for nutrients and chemistry.

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

[4] 201 samples for nutrients and 403 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.

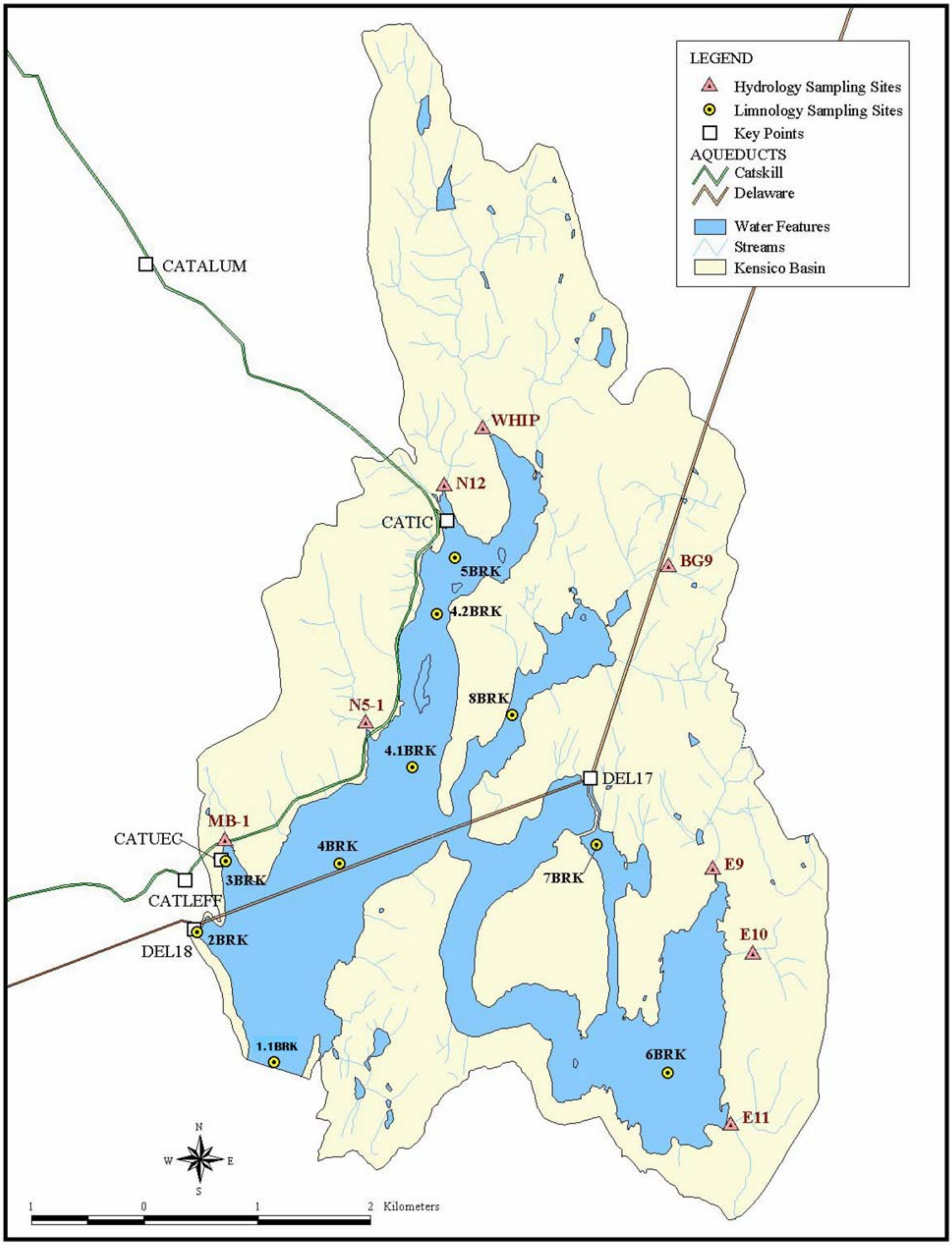


Figure 3.1 Kensico Reservoir, showing limnological and hydrological sampling sites, keypoints, and aqueducts. There is a meteorological station at DEL18.

3.1 Groundwater (DOT data)

The Kensico Groundwater Monitoring Program began in 1995 to determine whether groundwater could be contributing significant levels of pollutants to Kensico Reservoir. Results of this program were included in subsequent Kensico reports. By agreement with EPA, as of 2007, DEP ended its routine groundwater monitoring program because groundwater quality was excellent and showed no signs of contamination. However, a stipulation of this agreement was that DEP would continue to receive and review results from the Westchester County Airport voluntary groundwater monitoring program. Groundwater samples are collected twice yearly (usually May and November) at 57 wells, and data are shared with DEP for review.

3.2 Toxic Chemical Surveillance

On October 26, 2010, two Kensico Reservoir keypoints were sampled for volatile compounds and semivolatile compounds (SVOCs). Ten keypoints are sampled on an annual basis at this time of the year as part of a watershed-wide keypoint toxics monitoring program. Kensico Reservoir keypoints sampled were DEL18 and CATLEFF. Volatile compounds were analyzed by potable water method USEPA Method 524.2; semivolatile compounds were analyzed by potable water method 525.2.

A volatile organic compound is one that readily produces vapors at room temperature and normal atmospheric pressure, such as benzene, toluene, ethylbenzene and xylene (aka BTEX). Although ubiquitous in nature and modern industrial society, they may also be harmful or toxic. Inhalation effects represent an acute toxic exposure and groundwater contamination represents a route of chronic exposure, with the potential to affect the kidneys, nervous system, heart, and lungs. A semivolatile compound has a low to moderate vapor pressure compared to a volatile compound. Examples of semivolatile compounds are benzo[a] pyrene, phenol, and the pesticide pentachlorophenol. Some polyaromatic hydrocarbons, phthalates, and phenols are probable human carcinogens and endocrine disruptors. The primary routes of human exposure for SVOCs are ingestion of contaminated food and inhalation of contaminated air, rather than via drinking water. The toxics monitoring program is conducted to determine whether these compounds are present or absent from the drinking water supply.

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 2010. Also in 2010, continuous flow measurements were maintained at six of the eight perennial Kensico tributaries: Malcolm Brook, N5, N12, E9, E10, and E11. Plans are also being developed to re-establish this capability at Whippoorwill Creek and Bear Gutter Creek. The contract for this work is currently at the 60% design phase.

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 2010.

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, sampling at different locations within the reservoir, and/or sampling for additional analytes, as needed. Additional surveys conducted in 2010 were related to turbidity events during five separate months of the year. These events were either the result of wind-induced turbidity in the Catskill Upper Effluent Chamber cove or turbidity from Ashokan Reservoir. An additional survey was conducted in response to increasing numbers of *Chrysosphaerella* in Kensico, since these algae can cause taste complaints by drinking water consumers. The counts of *Chrysosphaerella* never rose to problematic levels in 2010. All routine and additional data collected during the sampling period were distributed through weekly water quality reports, source water briefs, and after action reports.

3.5 Keypoints

Figure 3.2 Continuous monitoring instrumentation at Kensico Reservoir (Catskill Lower Effluent Chamber).

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 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 filtration avoidance and surveillance monitoring of protozoan pathogens (*Cryptosporidium* and *Giardia*) and human enteric viruses (HEV) in the New York City Watershed. In 2010, 304 samples were collected and analyzed for *Cryptosporidium* and *Giardia* within the Kensico Reservoir watershed between January 1 and December 31. This sample set includes 208 routine fixed-frequency samples from four keypoints (Kensico Reservoir influent and effluent aqueducts), and 96 fixed-frequency samples at the eight perennial Kensico tributaries. In addition, 206 samples were collected and analyzed for HEV at the Kensico Reservoir influent and effluent aqueducts.

Cryptosporidium and *Giardia* monitoring involved the collection of 50 L samples filtered in the field and analysis according to Method 1623 (USEPA 2005). HEV monitoring involved the collection of 200-300 L field-filtered samples and laboratory analysis as per the Information Collection Rule (ICR) method (USEPA 1996). All HEV samples were analyzed by Environmental Associates Limited (EAL) in Ithaca, NY.

Occasionally (i.e., after storm events or at some stream sites), samples have elevated turbidity which can result in filter clogging. When this occurs, sample volumes do not always reach the targeted value. As in the past, rather than extrapolating results to the targeted sample volume, the actual sample volume collected is also reported with the data.

4. Results and Discussion

4.1 Groundwater

DEP reviews results of ongoing sampling of Westchester County Airport groundwater monitoring wells by the Westchester County Department of Transportation (DOT) as a matter of voluntary routine surveillance. Reports are generated bi-annually by the consultant for the airport, SAIC, Inc. In 2010, sampling was conducted in May and December; however, at this time the December sampling report has not yet been submitted to Westchester County Airport. December 2010 data will be discussed in the 2011 Kensico Report, while May 2010 results are discussed here.

Metals

According to SAIC, due to elevated turbidity in the groundwater, water samples were also collected for dissolved metals since the higher turbidity tends to bias the results of a total metals analysis. For this reason, results from the Target Analyte List (TAL) for dissolved metals analysis were compared to the DEC Technical and Operational Guidance Series (TOGS) guidance values. Dissolved metals from the TAL were detected above TOGS guidance values in 42 wells surrounding Westchester County Airport. The dissolved metals which were detected above guidance values were iron, manganese, magnesium, zinc, and sodium. The groundwater samples also contained dissolved concentrations of aluminum, calcium, and potassium that were above the method detection limit (MDL), but for which there is no guidance value. The dissolved metals that were detected above TOGS guidance values and the dissolved metals that were above the MDL concentrations with no guidance value are also the primary elements that comprise the underlying bedrock in and around the airport.

Saprolite, which is a silt/clay-rich weathered bedrock, overlies the competent bedrock and is most likely the reason for the occurrences of elevated concentrations of both total and dissolved metals in the groundwater. After the consultant reviewed the boring logs for the monitored wells, it was determined that the boring for each well was terminated at the top of the bedrock contact, but within the saprolitic material. This explains the highly turbid water samples and elevated concentrations of total and dissolved metals in the groundwater samples collected. Based on the data reviewed and the nature of the rocks underlying the airport, it is believed that the occurrences of metals observed in the groundwater samples are naturally occurring.

Organics

Listed in the following table (Table 4.1) are outstanding results of organic constituents (e.g., VOCs) for wells located within the Kensico Reservoir drainage basin. Outstanding results can be defined as those that are at or above the concentration for the principal organic contaminant standard of 5.0 $\mu g\ L^{-1}$. This standard can be found in the NYSDEC Part 703.5 regulations. Ethylene glycol and propylene glycol were not detected in any of the samples analyzed.

Table 4.1 Principal organic contaminant detection at Westchester County Airport wells within the Kensico Reservoir drainage basin. Standard is 5.0 $\mu g\ L^{-1}$.

Well Name	Compound Name	CAS No.	Concentration ($\mu g\ L^{-1}$)

FMW-14	Chlorobenzene	108-90-7	26

Chlorobenzene is a chlorinated solvent, found as a constituent in adhesives, paints and polishes, and tar and grease removers.

4.2 Toxic Chemical Surveillance

Annual surveillance monitoring of Kensico Reservoir effluent keypoints DEL18 and CATLEFF on October 26, 2010 for 67 VOCs and 68 SVOCs resulted in no compounds being detected; this duplicates the results from last year.

4.3 Coliform Bacteria

4.3.1 Bird Management for Fecal Coliform Control

The WMP continued to maintain a high level of success during 2010. This was demonstrated by full compliance with the SWTR requirements for fecal coliform bacteria in raw water samples, which is only possible when resident and migratory waterbird populations are kept at low levels. Figures Figure 4.1 and Figure 4.2 compare the regulatory source water samples collected from DEL18 and CATLEFF (the Kensico effluents) with respect to fecal coliform bacteria and reservoir bird counts. Of the 364 daily regulatory samples analyzed from DEL18 and 355 samples from CATLEFF in 2010, none were above the 20 CFU 100 mL^{-1} SWTR standard. (The rule allows for 18 values above 20 CFU 100 mL^{-1} in any six-month period.) Therefore, Kensico Reservoir remained well within compliance limits for fecal coliforms throughout 2010. These low levels of fecal coliform bacteria have been consistently achieved since 1993. Bird counts for 2010 remained relatively low compared to the early 1990s, 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.

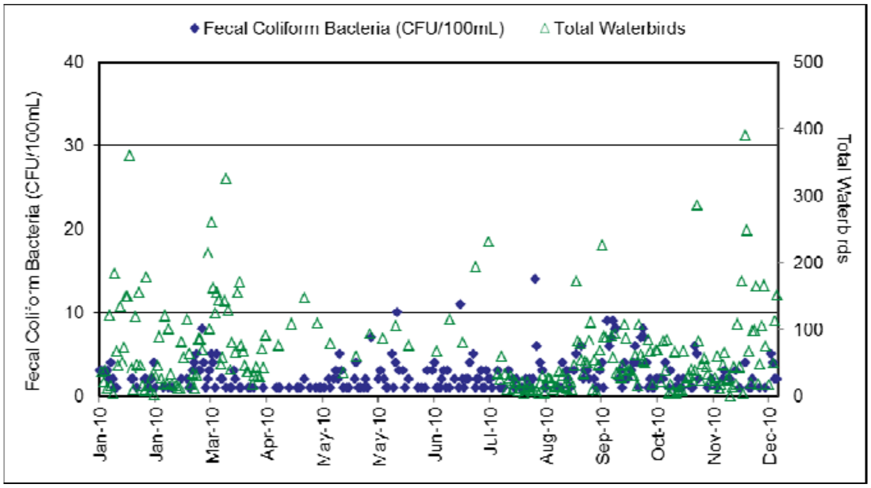


Figure 4.1 Kensico Reservoir fecal coliform bacteria (CFU/100mL) at DEL18 versus total waterbirds (1/1/10 to 12/31/10).

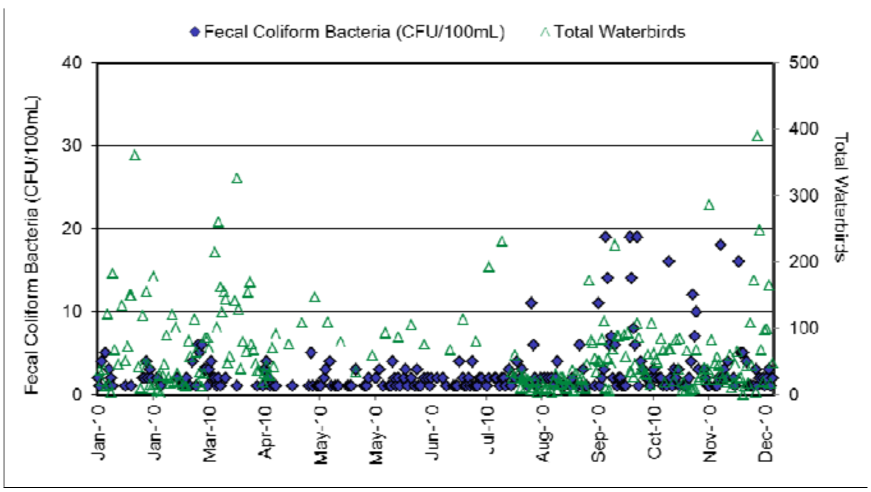


Figure 4.2 Kensico Reservoir fecal coliform bacteria (CFU/100mL) at CATLEFF versus total waterbirds (1/1/10 to 12/31/10).

4.3.2 Streams

The routine fecal coliform data for the period January 2010 through December 2010 are plotted in Figure 4.3. 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.

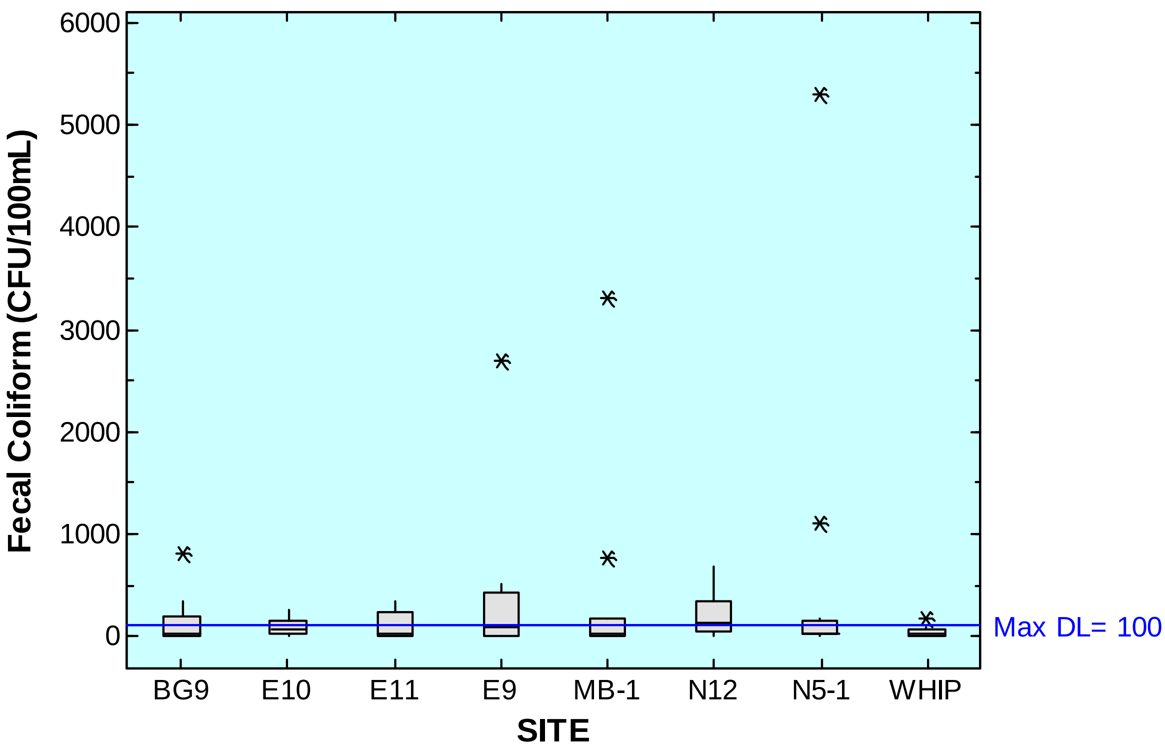


Figure 4.3 Fecal coliform plots for routine Kensico streams monitoring data, January–December, 2010. (see section 4.3.2 for a description of boxplots).

All Kensico streams had median values less than 200 CFU 100 mL^{-1}. The stream designated N12 had the highest median value at 125.5 CFU 100 mL^{-1}, while E11 had the lowest at 18 CFU 100 mL^{-1}. Fecal coliform values this year were consistent with previous years. As in the past, the highest values were generally seen when rain occurred during the week prior to the sample date.

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. N12 had the highest median total coliform value (2900 CFU 100 mL^{-1}), while Bear Gutter Creek (BG-9) had the lowest median value (670 CFU 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 2010 data indicate that some of the streams have an occasional occurrence above 5,000 CFU 100 mL^{-1}, which are generally associated with a fixed-frequency sample being collected during or immediately following wet weather. Of the 12 reported values of more than 5,000 CFU 100 mL^{-1}, seven occurred when over 1.36 inches of precipitation had fallen within the week before the sample date.

4.3.3 Reservoir

The routine bacteria samples collected from Kensico Reservoir provided 348 total coliform and 357 fecal coliform data points during the period March through December 2010. Boxplots for these data are shown in Figure 4.4. The results are compared with Surface Water Treatment Rule (SWTR) drinking water limits of 100 CFU 100 mL^{-1} for total coliforms and 20 CFU 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 all sites had estimated median total coliform values less than 100 CFU 100 mL^{-1}. Site 5 was the only location where the boxplot extended above 100 CFU 100 mL^{-1}. The median value for this site was estimated as 49 CFU 100 mL^{-1}. At all the sites there were occasions where the total coliform exceeded the guidance value. Site 6 may have exceeded the guidance value, since three values were <200 CFU 100 mL^{-1}. However, these values are not visible in Figure 4.4a, because the non-detect statistics did not estimate these values to be outside the boxplot. The higher levels of total coliforms found at some of the sites were typically observed in late summer and autumn. Seasonality of total coliform levels is a routine observation in many of the NYC reservoirs.

During the reporting period all sites from routine surveys had a median fecal coliform level at or below 2 CFU 100 mL^{-1}. Median values were 0.5 CFU 100 mL^{-1} for Site 1.1, 0.4 CFU 100 mL^{-1} for Site 2, 0.6 CFU 100 mL^{-1} for Site 3, 0.7 CFU 100 mL^{-1} for site 4, 2 CFU 100 mL^{-1} for Site 5, and 1 CFU 100 mL^{-1} for Sites 6, 7, and 8. There were 5 instances where fecal coliform levels from discrete samples were above the DEP guideline (20 CFU 100 mL^{-1}). The highest individual fecal coliform value of 190 CFU 100 mL^{-1} occurred at Site 2 on September 13 (sample from a depth of 10 feet). The other fecal coliform levels that were above 20 CFU 100 mL^{-1} were as follows: Site 2, 92 CFU 100 mL^{-1}, on June 7; Site 3, 25 CFU 100 mL^{-1}, on March 15; Site 6, 120 CFU 100 mL^{-1}, on July 13; and Site 7, 16 CFU 100 mL^{-1}, on September 13.

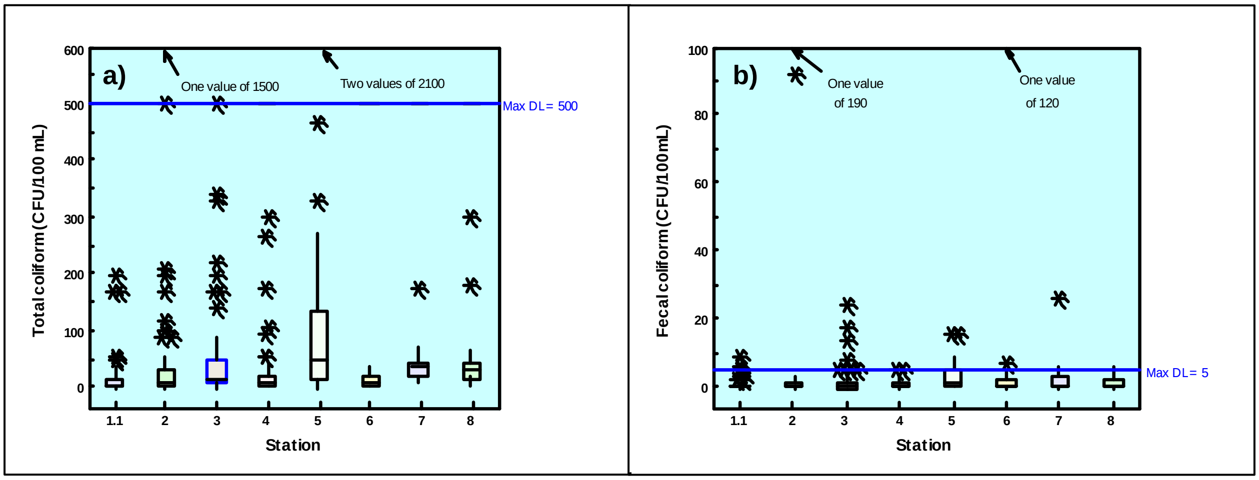


Figure 4.4 Coliform plots for routine Kensico Reservoir monitoring data, March-December, 2010. a) Total Coliform, b) Fecal Coliform. (see section 4.3.2 for a description of boxplots).

4.3.4 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 4.3.2, coliform bacteria, like most other environmental analytes, have measurement thresholds When datasets contain censored data, care must be taken when 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, 35% (CATLEFF)–67% (CATALUM) of the 2010 fecal coliform values were “censored.” The Minitab® macro discussed in section 4.3.2 was also used for this analysis. Also, to indicate the uncertainty in the censored data, a drop line from censored points is used in the plots presented in this section.

For the fecal coliform counts measured at the Kensico influents from January 4, 2010 to December 31, 2010, medians of 0.4 CFU 100 mL^{-1} at CATALUM and 1 CFU 100 mL^{-1} at DEL17 were calculated. The maximum fecal coliform counts were 46 CFU 100 mL^{-1} at CATALUM and 150 CFU 100 mL^{-1}at DEL17 (Figure 4.5). These data demonstrate that the fecal coliform levels of the aqueducts flowing into Kensico were typically very low.

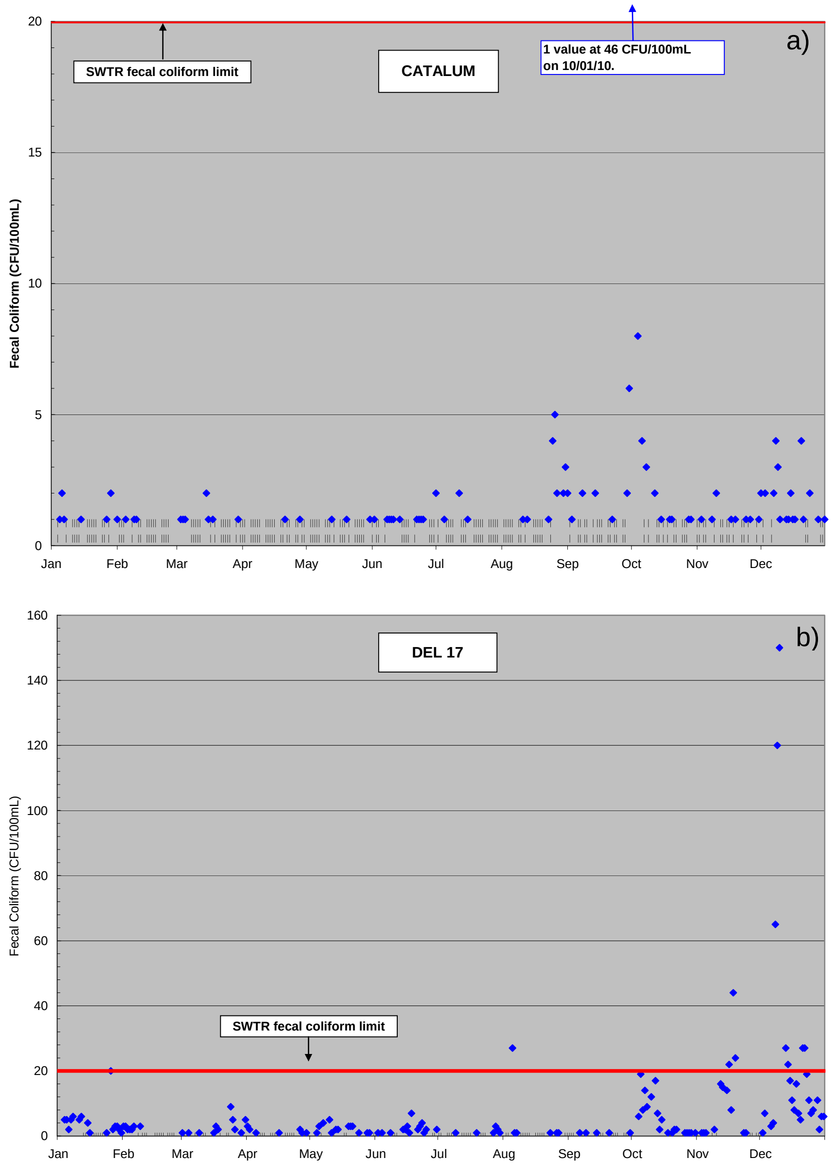
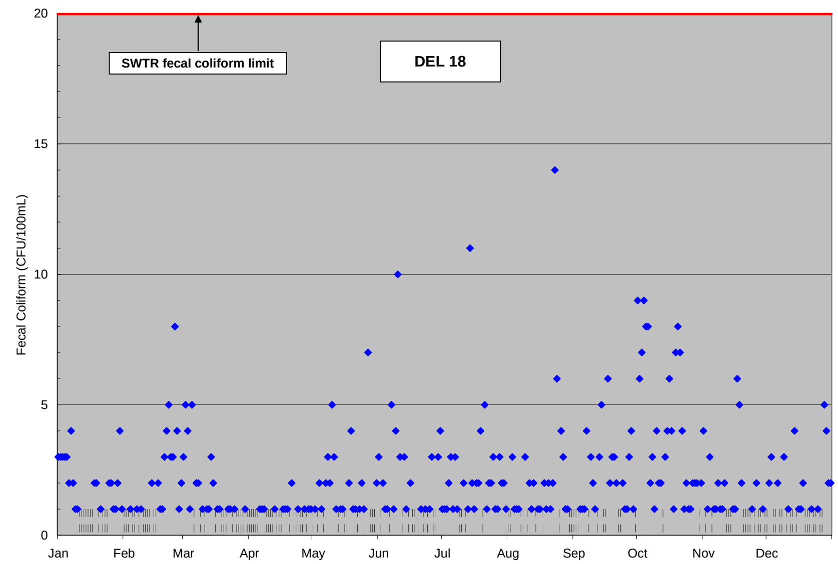


Figure 4.5 Five day per week fecal coliform grab sample results at the Catskill Aqueduct Kensico influents: a) CATALUM, b) DEL17. The black drop lines indicate censored values. Note: While the SWTR fecal coliform limit is indicated as a reference point, the influent keypoints are not subject to the SWTR. Also note the y-axis scales are differ in the two plots.

For the fecal coliform counts measured at the Kensico effluents from January 1, 2010 to December 31, 2010 (Figure 4.6), a median of 1 CFU 100 mL^{-1} at both CATLEFF and DEL18 was calculated. During 2010, the regulatory limit of 20 CFU 100 mL^{-1} was never exceeded. The maximum fecal coliform counts were three samples of 19 CFU 100 mL^{-1} at CATLEFF and 14 CFU 100 mL^{-1} at DEL17. As in the past, the elevated fecal coliform levels generally coincided with precipitation events occurring within a few days prior to the elevated fecal coliform counts. Overall for 2010, DEP's source water at Kensico met the SWTR limits for fecal coliforms.



b)

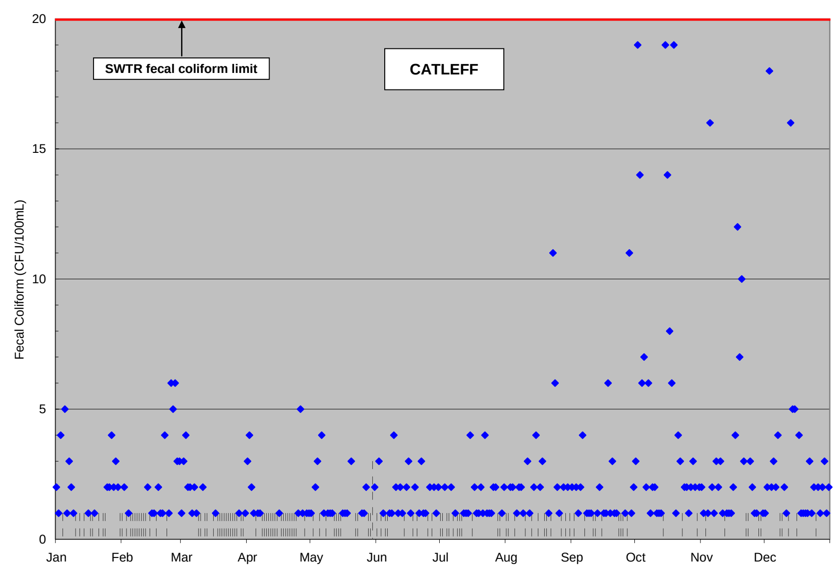


Figure 4.6 Seven day per week fecal coliform grab sample results at the Catskill Aqueduct Kensico effluents: a) CATLEFF, b) DEL18. Note: The SWTR fecal coliform limit is indicated as a reference point.

4.4 Turbidity

4.4.1 Streams

The routine turbidity data for the period January 2010 through December 2010 are plotted in Figure 4.6. The median turbidity for all sites is less than 5 NTU. Turbidity values in 2010 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-a). The maximum value of 17 NTU at E10 occurred on May 4, 2010, 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.

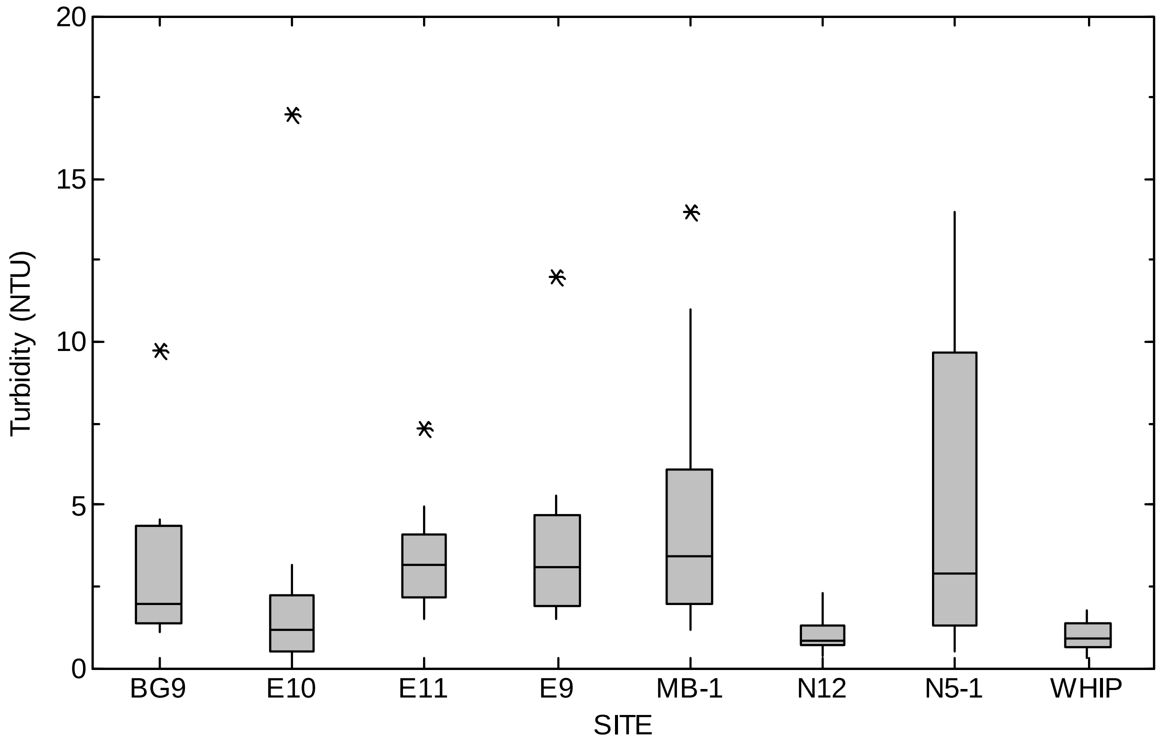


Figure 4.7 Turbidity plots for routine Kensico streams monitoring, January-December, 2010. (see section 4.3.2 for a description of boxplots).

4.4.2 Reservoir

The routine monitoring of Kensico Reservoir during the March 2010 through December 2010 period yielded 366 turbidity samples. A boxplot constructed using these data is presented in Figure 4.8. As in the past, Site 5 showed the highest median turbidity (1.8 NTU), and individual samples for this site were equal to or exceeded 5.0 NTU 17 times. At the sites closest to the effluent chambes (sites 2 and 3), the 90th percentile of the turbidity data was less than 3.0 NTU. Site 3 had three samples that exceeded 5 NTU.

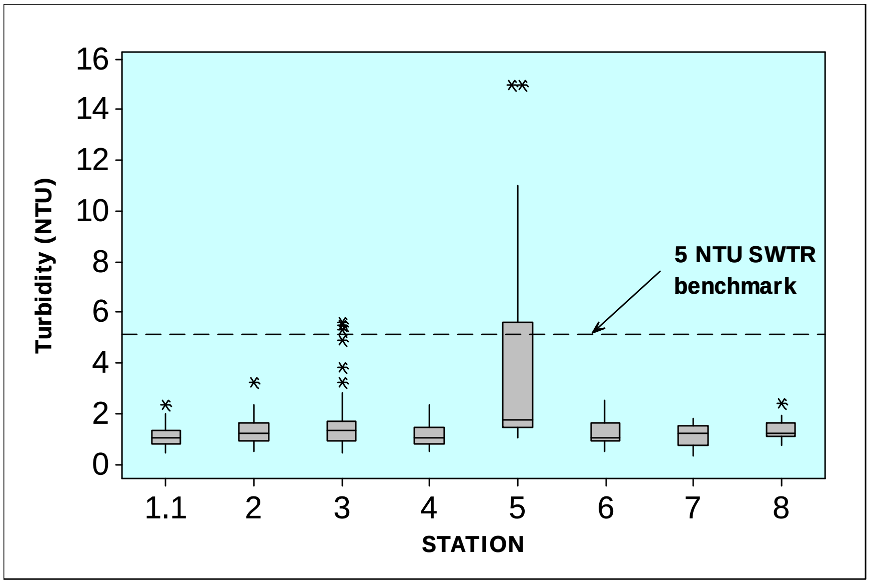


Figure 4.8 Turbidity plots for routine Kensico Reservoir monitoring. (see section 4.3.2 for a description of boxplots).

Special surveys were conducted to monitor turbidity during five separate months in 2010. In January, surveys were conducted to assess the effect of wind-induced turbidity increases in the Catskill Upper Effluent Chamber cove. During March, there were similar surveys that also included some up reservoir sites for assessment of turbidity from Ashokan Reservoir. Some additional surveys continued into April. During September, transmissometer readings were taken to determine if storm activity had affected the incoming water from Ashokan. December surveys were conducted as a result of much larger turbidity events in Ashokan. All of these special surveys throughout the year were conducted to assist management in making operational decisions for the water supply.

4.4.3 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 4, 2010 to December 31, 2010 was 3.3 NTU at CATALUM and 1.0 NTU at DEL17. Mean turbidity for the same time period was 5.9 NTU at CATALUM and 1.0 NTU at DEL17. During this period, the maximum turbidity measurements were 46.0 NTU at CATALUM and 2.8 NTU at DEL17 **(**Figure 4.9 and Figure 4.10). These data indicate that the SWTR limit of 5 NTU at the effluents was consistently met by sources upstream of the reservoir.

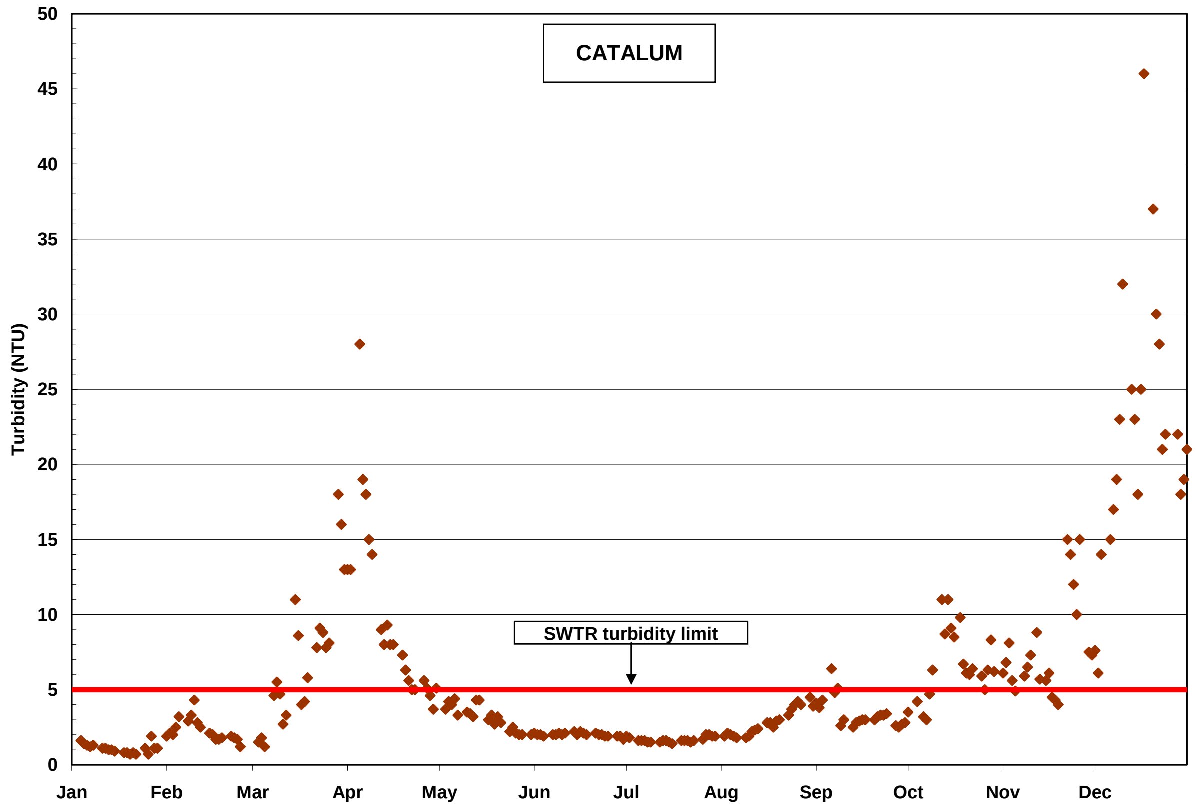


Figure 4.9 Five day per week turbidity grab sample results at Kensico Reservoir's Catskill Aqueduct influent keypoint (CATALUM). Note: While the SWTR turbidity limit is indicated as a reference point, the influent keypoint is not subject to the SWTR.

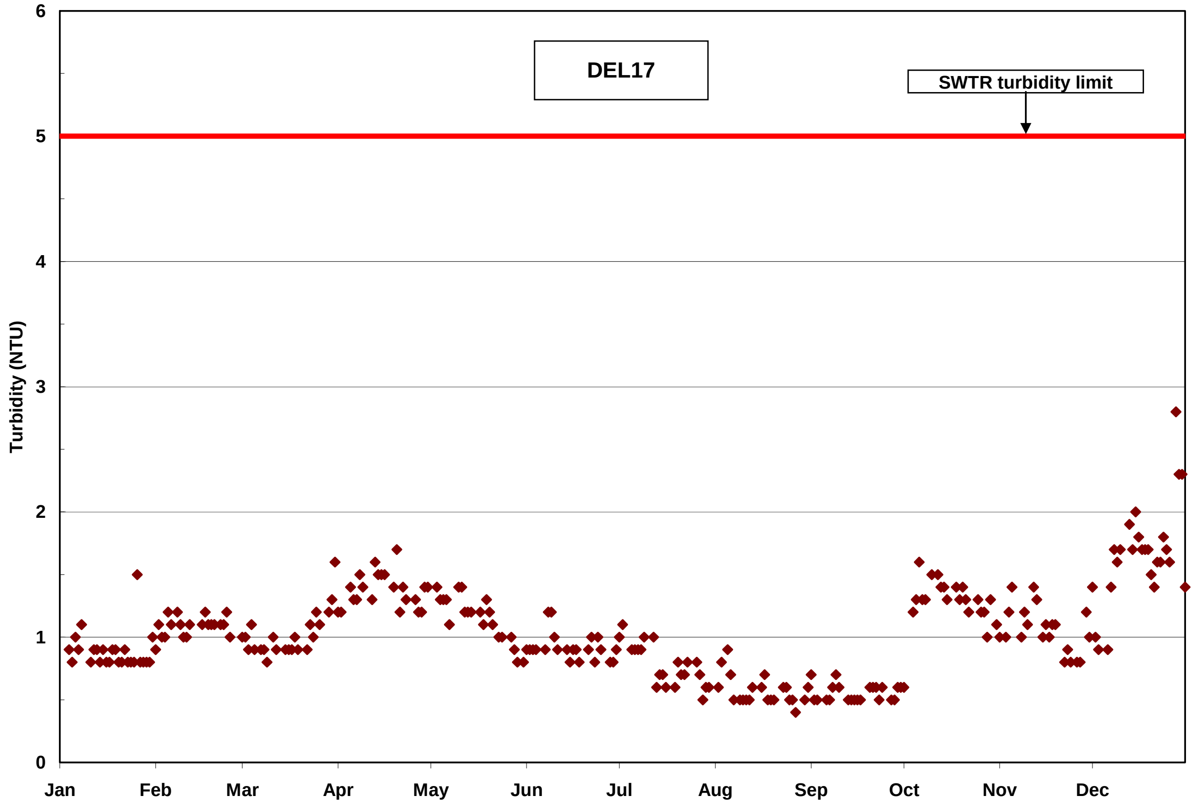


Figure 4.10 Five day per week turbidity grab sample results at Kensico Reservoir's Delaware Aqueduct influent keypoint (DEL17). Note: While the SWTR turbidity limit is indicated as a reference point, the influent keypoint is not subject to the SWTR.

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, 2010 to December 31, 2010 was 0.90 NTU at CATLEFF and 0.90 NTU at DEL18. Mean turbidity for the same time period was 1.0 NTU at CATLEFF and 1.0 NTU at DEL18. During this period, the maximum 4-hour turbidity measurements were 4.3 NTU at CATLEFF and 2.7 NTU at DEL18 (Figure 4.11 and Figure 4.12). Thus, for 2010 the SWTR limit of 5 NTU was never exceeded.

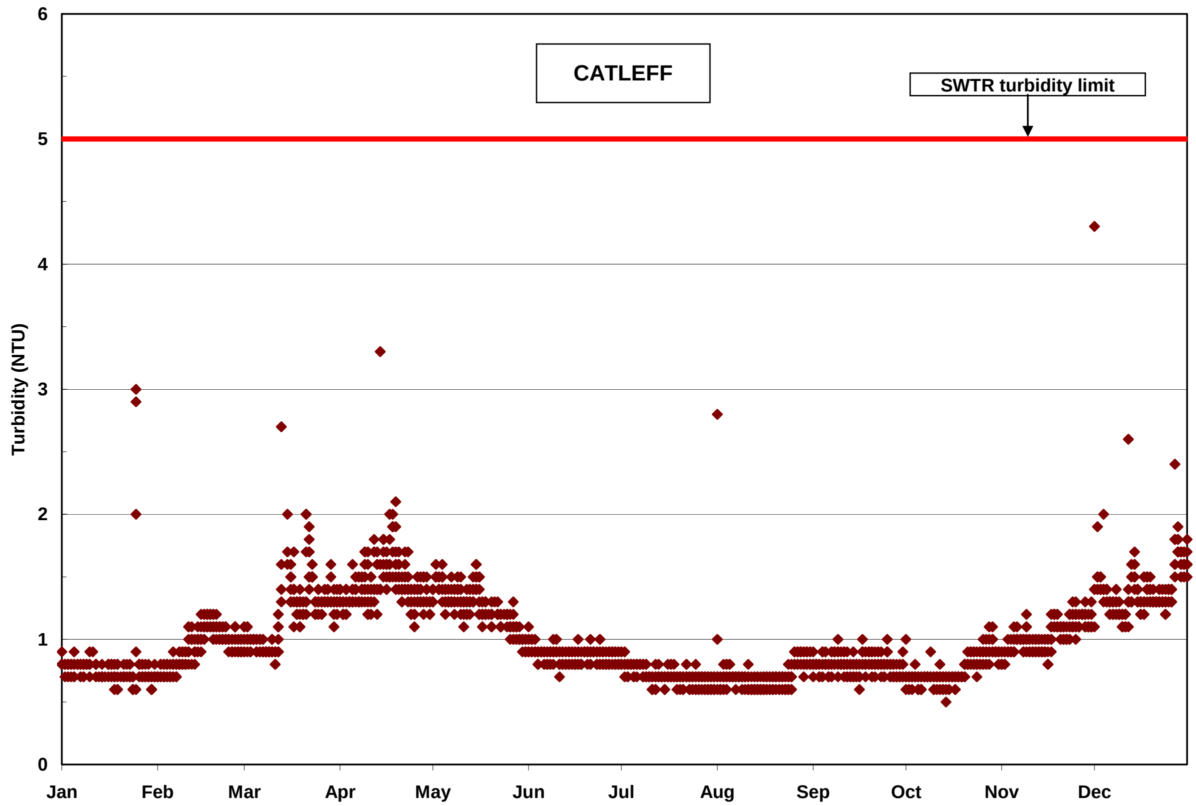


Figure 4.11 Four-hour turbidity grab sample results at Kensico Reservoir's Catskill Aqueduct effluent keypoint (CATLEFF).

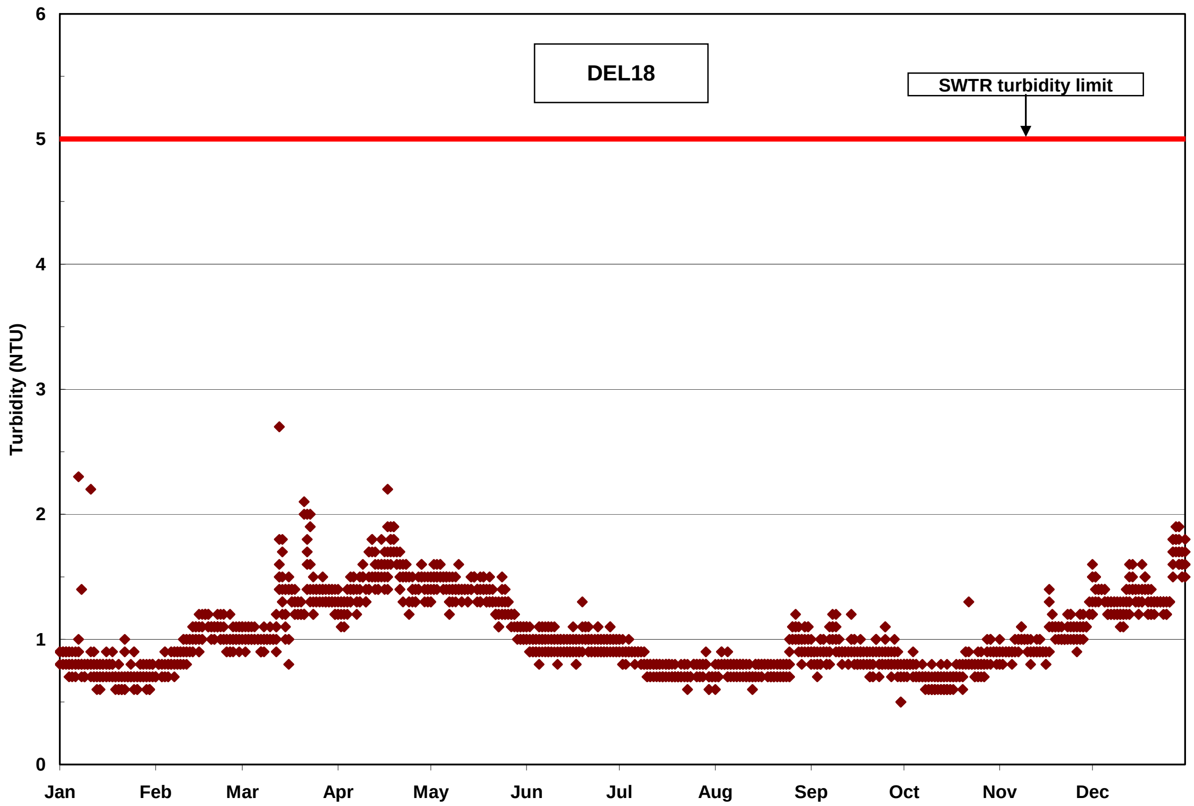


Figure 4.12 Four-hour turbidity grab sample results at Kensico Reservoir's Delaware Aqueduct effluent keypoint (DEL18).

4.5 Protozoa and Human Enteric Viruses

Eight perennial streams flow into Kensico Reservoir (Figure 4.13). In past years, the sampling interval at these sites varied; however, the 2009 Watershed Water Quality Monitoring Plan (WWQMP) (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 Table 4.2 through Table 4.5.

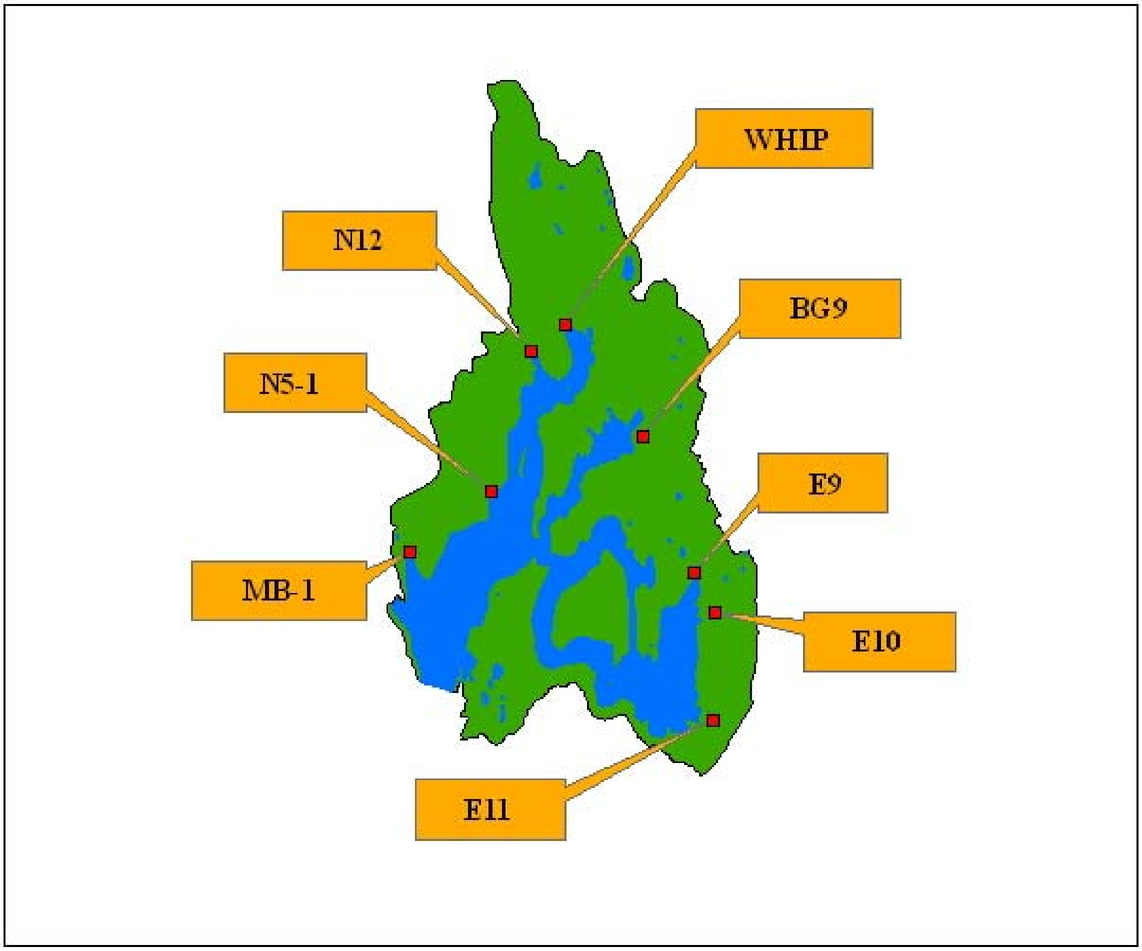


Figure 4.13 Kensico Reservoir routine pathogen stream sites sampled monthly in 2010.

As seen in past years, there were low concentrations of *Cryptosporidium* in Kensico streams in 2010 (Table 4.2). Two streams, E11 and N12, had no positive *Cryptosporidium* results, and the remaining six streams had concentrations ranging from only 0 to 2 oocysts per volume collected.

Table 4.2 *Cryptosporidium* results and volumes analyzed from perennial Kensico streams, January 1–December 31, 2010.

	BG9		E10		E11		E9		MB-1		N12		N5-1		WHIP	
Date	*C*	*Vol(L)*	*C*	*Vol(L)*	*C*	*Vol(L)*	*C*	*Vol(L)*	*C*	*Vol(L)*	*C*	*Vol(L)*	*C*	*Vol(L)*	*C*	*Vol(L)*
Jan	1	50	0	50	0	50	2	50	0	50	0	50	1	50	0	50
Feb	0	50	0	50	0	50	0	50	0	50	0	50	0	50	0	50
Mar	0	50	0	50	0	50	0	50	0	50	0	50	0	50	0	50
Apr	0	50	0	50	0	50	0	50	0	50	0	50	0	50	0	50
May	0	18.8	0	49.9	0	13.6	0	13	2	38	0	50	0	20	0	50
Jun	0	50	0	50	0	50	0	8.5	0	29.8	0	50	0	15.7	1	50
Jul	1	79	0	50	0	50	0	39	0	27.3	0	50	0	21.4	0	50
Aug	0	50	0	50	0	37	1	13	0	50	0	50	0	18	0	50
Sep	0	50	0	50	0	47.1	0	15	0	50	0	50	0	24.5	0	50
Oct	0	50	1	50	0	41.5	1	35.3	0	50	0	50	1	50	0	50
Nov	1	50	0	50	0	50	0	19.7	0	50	0	50	1	50	0	50
Dec	0	50	0	50	0	50	1	50	0	50	0	50	2	50	0	50

Cryptosporidium occurrence was also low, with an 85% non-detection rate when all stream data were pooled. Overall, 14 out of 96 samples were positive, with a range of 0 to 2 oocysts per volume sampled, and a combined mean of 0.004 L^{-1}. E9 and N5-1 had the highest detection rates at 33.3 %, and E9 had the highest per liter mean concentration at 0.014 oocysts L^{-1} (Table 4.3) in August. The overall per sample result, however, was still quite low, at 1 oocyst in a 13 L sample. These results are somewhat lower than those for 2008 and 2009, though oocyst detection in all three years was quite low.

Table 4.3 Monthly Kensico perennial stream *Cryptosporidium* results summary, January 1–December 31, 2010.

	Cryptosporidium							
	BG9	E10	E11	E9	MB-1	N12	N5-1	WHIP
# of Samples	12	12	12	12	12	12	12	12
# Positive	3	1	0	4	1	2	4	1
% Positive	25.0%	8.3%	0.0%	33.3%	8.3%	0.0%	33.3%	8.3%
Mean (L^{-1})	0.004	0.002	0.000	0.014	0.004	0.000	0.008	0.002
Median (L^{-1})	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Maximum (L^{-1})	0.020	0.020	0.000	0.077	0.053	0.000	0.040	0.020

As in previous years, 2010 samples from 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). Consequently, the fact that not all samples had the same volume had a greater potential impact on the interpretation of these results. Two of the eight streams

(N12 and WHIP) had volumes of at least 50 L throughout the year. Unfortunately, samples collected at the remaining six streams had volumes ranging from 8.5 to 79.0 L, and cyst results from 0 to 75. These broad ranges made it challenging to compare the data. To aid the comparison, per liter values have been provided (Table 4.5). Using this approach, BG9 and E9 stand out as having the highest mean and maximum *Giardia* values for 2010 compared to the other six streams. Conversely, N5-1 had the lowest mean and maximum values, with *Giardia* concentrations ranging from only 0 to 10 cysts.

Table 4.4 *Giardia* results and sample volumes from perennial Kensico streams, January 1–December 31, 2010.

	BG9		E10		E11		E9		MB-1		N12		N5-1		WHIP	
Date	*G*	*Vol(L)*	*G*	*Vol(L)*	*G*	*Vol(L)*	*G*	*Vol(L)*	*G*	*Vol(L)*	*G*	*Vol(L)*	*G*	*Vol(L)*	*G*	*Vol(L)*
Jan	26	50	1	50	0	50	24	50	1	50	8	50	3	50	12	50
Feb	8	50	9	50	3	50	5	50	24	50	1	50	6	50	19	50
Mar	21	50	2	50	3	50	5	50	6	50	4	50	0	50	2	50
Apr	3	50	3	50	0	50	0	50	5	50	3	50	0	50	1	50
May	6	18.8	2	49.9	1	13.6	1	13	2	38	17	50	4	20	0	50
Jun	6	50	0	50	11	50	3	8.5	0	29.8	13	50	0	15.7	2	50
Jul	0	79	1	50	0	50	0	39	0	27.3	3	50	2	21.4	0	50
Aug	3	50	23	50	0	37	31	13	0	50	0	50	0	18	0	50
Sep	16	50	0	50	1	47.1	75	15	0	50	8	50	1	24.5	1	50
Oct	7	50	6	50	34	41.5	24	35.3	2	50	3	50	4	50	2	50
Nov	7	50	0	50	11	50	6	19.7	2	50	4	50	5	50	0	50
Dec	40	50	3	50	2	50	3	50	6	50	11	50	10	50	26	50

While *Cryptosporidium* had an 85% non-detection rate, *Giardia* had a 76% detection rate at Kensico streams. The lowest cyst occurrences were at E11, MB-1, N5-1, and WHIP, with 67 % of samples positive for *Giardia*, while the greatest occurrence of cysts was 92% at BG9 and N12. With the exception of an increase from 50% positive in 2009 to 92% positive this year, and a tenfold increase in the mean *Giardia* concentration at N12, these rankings are consistent with last year's data.

Table 4.5 Monthly Kensico perennial stream *Giardia* summary data, January 1–December 31, 2010.

	Giardia							
	BG9	E10	E11	E9	MB-1	N12	N5-1	WHIP
# of Samples	12	12	12	12	12	12	12	12
# Positive	11	9	8	10	8	11	8	8
% Positive	91.7%	75.0%	66.7%	83.3%	66.7%	91.7%	66.7%	66.7%
Mean (L^{-1})	0.255	0.083	0.126	0.795	0.081	0.125	0.075	0.108
Median (L^{-1})	0.150	0.040	0.050	0.202	0.040	0.080	0.070	0.030
Maximum (L^{-1})	0.800	0.460	0.819	5.000	0.480	0.340	0.200	0.520

4.5.1 Keypoints

As per the WWQMP (DEP 2009), 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 protozoan samples and 206 HEV samples were collected at the Kensico keypoint sites in 2010.

Influent Keypoints

Kensico Reservoir influent keypoints (CATALUM and DEL17) were sampled weekly for *Cryptosporidium* and *Giardia*. The summary results are presented in Table 4.6. In 2010, *Cryptosporidium* was detected in only one sample each (out of 52) for both CATALUM and DEL17, and at low concentrations (maxima = 2 and 1 oocysts 50 L^{-1}, respectively). These maxima are consistent with results from previous years; however, the detection rate is somewhat lower. 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, 2010.

		CATALUM	DEL17
Cryptosporidium (50 L^{-1})	# of Samples	52	52
	# Positive	1	1
	% Positive	1.9 %	1.9 %
	Mean	0.04	0.02
	Median	0.00	0.00
	Maximum	2.00	1.00
Giardia (50 L^{-1})	# of Samples	52	52
	# Positive	18	25
	% Positive	34.6 %	48.1 %
	Mean	0.56	0.98
	Median	0.00	0.00
	Maximum	4.00	8.00

Giardia was detected in 18 and 25 samples (out of 52) collected at CATALUM and DEL17, respectively, in 2010, with maxima of 4 and 8 cysts 50 L^{-1} at the respective sites. For comparison, in 2009, *Giardia* detection occurred in 29 and 25 samples (out of 52) collected for CATALUM and DEL17, respectively, with maxima of 7 cysts 50 L^{-1} at both sites. The mean concentration of *Giardia* at CATALUM in 2010 was just over one third the concentration in 2009, decreasing from 1.49 to 0.56 cysts 50 L^{-1}. The mean *Giardia* concentration at DEL17 was approximately 47% lower, decreasing from 1.84 to 0.98 cysts 50 L^{-1}. These 2010 values are more consistent with those seen in 2008. Changes in operational mode may account for these differences; however, all possibilities are being investigated.

Effluent Keypoints

The effluent keypoints of Kensico Reservoir (CATLEFF and DEL18) were also sampled weekly for *Cryptosporidium* and *Giardia* in 2010. *Cryptosporidium* was detected in 3 samples at CATLEFF and 1 sample at DEL18 (Table 4.7). For comparison, in 2009, *Cryptosporidium* was detected in 1 sample at CATLEFF and 4 samples at DEL18. As in past years, *Cryptosporidium* was found only at low levels at the Kensico effluents, with a maximum count of 1 oocyst 50 L^{-1} for both sites. The mean *Cryptosporidium* concentrations were low for these sites as well, at 0.06 and 0.02 oocyst 50 L^{-1} (CATLEFF and DEL18, respectively.) This represents a small increase at CATLEFF when compared to the 2009 value of 0.02 oocyst 50 L^{-1} and a modest decrease at DEL18.

Table 4.7 Weekly Kensico Reservoir effluent keypoint results, *Cryptosporidium* and *Giardia* summary, January 1–December 31, 2010.

		CATLEFF	DEL18
Cryptosporidium (50 L^{-1})	# of Samples	52	52
	# Positive	3	1
	% Positive	5.8 %	1.9 %
	Mean	0.06	0.02
	Median	0.00	0.00
	Maximum	1.00	1.00
Giardia (50 L^{-1})	# of Samples	52	52
	# Positive	36	32
	% Positive	69.2 %	61.5 %
	Mean	1.63	1.25
	Median	1.00	1.00
	Maximum	8.00	5.00

There were 36 and 32 detections of *Giardia* at CATLEFF and DEL18, respectively, out of 52 samples collected in 2010. This was comparable to 2009, when there were 43 *Giardia* detections at CATLEFF and 38 at DEL18. Maximum *Giardia* cyst concentrations were the same for 2009 and 2010, at 8 cysts for CATLEFF, and 5 cysts for DEL18. Mean *Giardia* concentration at CATLEFF for 2010 (1.63 cysts 50 L^{-1}) was similar to that of 2009 (2.00 cysts 50 L^{-1}). The DEL18 mean *Giardia* concentration for 2010 (1.25 cysts 50 L^{-1}) was similar to those in past years, with only a slight decline from 2009 (1.57 cysts 50 L^{-1}).

Human Enteric Virus Monitoring

All four Kensico Reservoir keypoints were monitored weekly for human enteric viruses in 2010. A summary of the results is presented in Table 4.8. One set of Delaware influent and effluent samples from August 9, 2010, however, is not included in this report, because samples arrived at the contract laboratory with visible ice crystals and these samples were not analyzed.

Table 4.8 Summary of human enteric virus results at Kensico keypoints, January 1–December 31.

	*Human Enteric Viruses (MPN 100 L^{-1})			
	CATALUM	CATLEFF	DEL17	DEL18
# of Samples	52	52	51	51
# Positive	4	1	6	2
% Positive	7.7 %	1.9 %	11.8 %	3.9 %
Mean	0.19	0.04	0.21	0.04
Median	0	0	0	0
Maximum	4.46	2.11	4.46	1.03

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

Average HEV detection rates at Kensico were quite low for all sites (Figure 4.14). Percent detection at the influent sites was higher than at the effluents (9.6% vs. 2.9%, respectively). As observed in past years, a majority of the detections of viruses (61.5%) occurred in the winter/spring period (8 in the winter/spring compared to 5 in summer/fall of 2010). Mean virus concentrations were also low at each site, with a combined influent mean of 0.20 MPN 100 L^{-1}, and a pooled effluent mean of 0.04 MPN 100 L^{-1}.

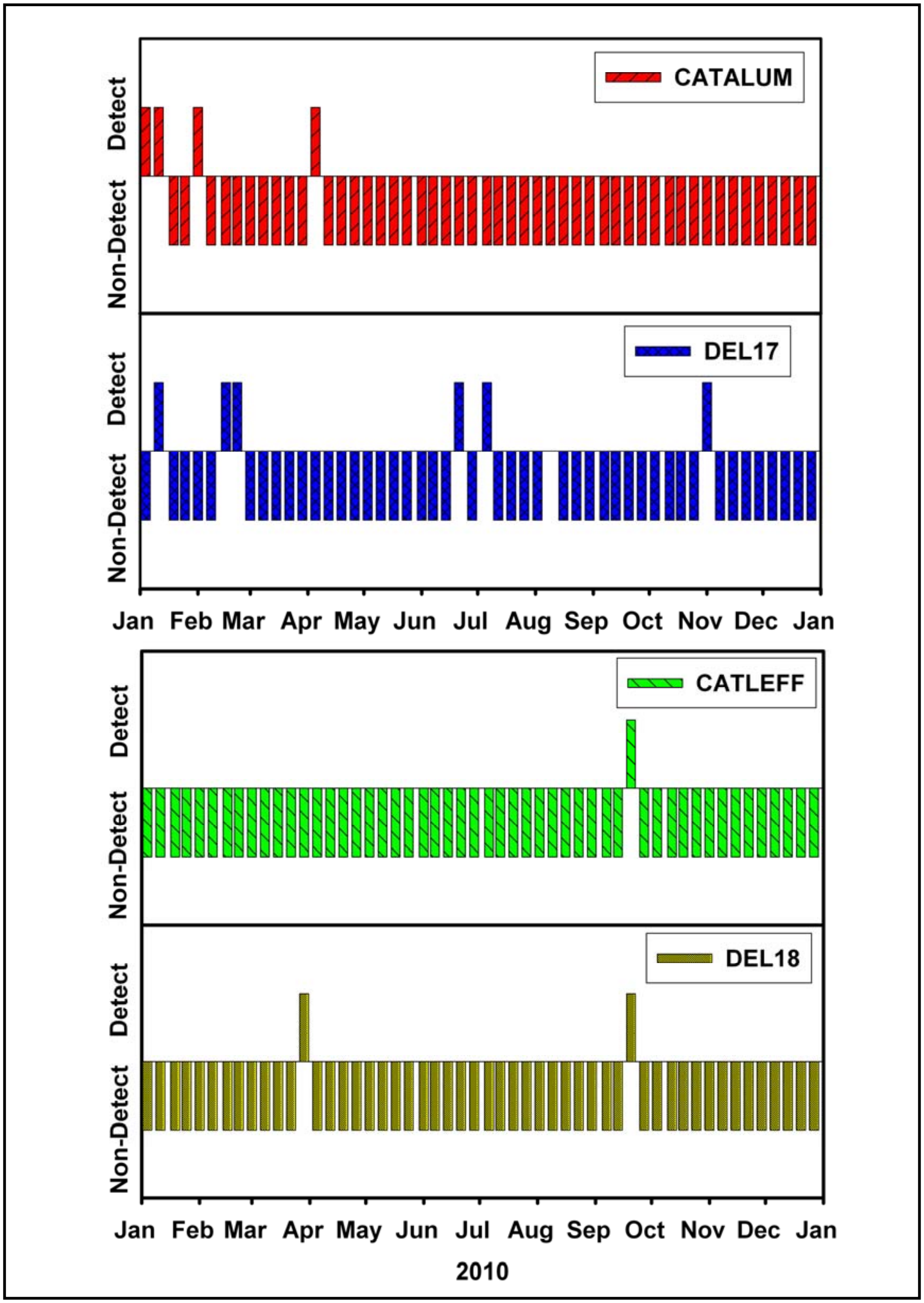


Figure 4.14 Positive detection frequency of human enteric viruses at the four Kensico keypoints, January 1–December 31, 2010.

4.6 Other Results

4.6.1 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, while six of the eight 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 2010 results for these analytes are displayed in Table 4.9. As discussed in section 4.3.4, on occasion environmental data may only be reported to be 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, 2010.

Analyte	Site	N	Minimum	25th Percentile	Median	75th Percentile	Maximum
Temperature (°C)	BG9	9	1.3	4.8	15.2	21.8	28.4
	E10	10	0.7	4.2	14.7	20.0	24.1
	E11	10	2.4	7.0	16.8	23.6	28.4
	E9	8	0.6	1.9	13.1	19.5	25.0
	MB-1	10	1.0	3.9	15.6	20.1	22.9
	N12	10	1.1	5.9	14.1	20.0	22.1
	N5-1	10	1.0	4.2	15.5	20.3	21.9
	WHIP	10	0.5	4.6	15.4	19.1	20.8
Dissolved Oxygen (mg L^{-1})	BG9	9	1.4	5.7	6.8	12.1	12.8
	E10	8	7.8	8.8	10.5	14.3	14.6
	E11	9	1.7	2.9	6.5	11.8	13.2
	E9	7	2.1	3.3	4.8	9.1	13.4
	MB-1	10	6.8	7.6	9.3	13.3	14.8
	N12	10	8.6	9.5	10.5	13.3	13.9
	N5-1	10	0.8	3.8	8.7	13.1	15.5
	WHIP	10	8.9	9.3	9.9	13.3	14.1
Specific Conductivity (µmhos cm^{-1})	BG9	12	334	497	610	907	1010
	E10	12	462	799	898	1166	1231
	E11	12	298	370	417	526	578
	E9	10	286	366	417	534	573
	MB-1	12	300	428	648	676	895
	N12	12	322	338	448	516	637
	N5-1	12	287	459	508	567	607
	WHIP	12	305	335	373	412	588

Table 4.9 Annual statistics for physical, nutrient, and other chemical analytes in Kensico's perennial streams, January–December, 2010.

Analyte	Site	N	Minimum	25th Percentile	Median	75th Percentile	Maximum
Chloride ($mg\ L^{-1}$)	BG9	5	74.3	97.7	124.2	171.6	216.7
	E11	5	31.7	37.9	50.1	57.0	61.4
	MB-1	5	65.5	87.8	146.5	183.2	196.0
	N12	5	45.3	45.6	51.8	104.6	131.2
	N5-1	5	39.4	60.0	83.1	105.7	119.9
	WHIP	5	50.8	51.5	55.5	64.9	71.0
pH	BG9	9	6.7	6.9	7.1	7.3	7.5
	E10	10	7.3	7.6	7.7	7.8	7.9
	E11	10	7.1	7.2	7.4	7.5	7.6
	E9	8	6.7	6.9	7.0	7.1	7.2
	MB-1	10	7.1	7.3	7.4	7.5	7.6
	N12	10	7.1	7.6	7.8	8.1	8.2
	N5-1	10	7.2	7.3	7.5	7.6	7.6
	WHIP	10	7.3	7.7	7.7	7.8	7.9
Alkalinity ($mg\ L^{-1}\ CaCO_3$)	BG9	9	48.7	51.2	62.1	102.6	146.2
	E11	10	89.5	98.3	117.5	142.1	152.0
	MB-1	10	55.1	67.3	91.2	105.0	107.7
	N12	10	46.8	52.2	66.6	106.6	124.4
	N5-1	10	58.0	60.4	78.3	114.2	121.5
	WHIP	10	38.1	43.1	53.7	83.6	92.3
Dissolved Organic Carbon ($mg\ L^{-1}$)	BG9	9	1.8	2.0	3.3	4.3	5.5
	E11	10	2.9	3.4	4.7	5.3	6.7
	MB-1	10	1.7	2.0	2.9	3.8	5.5
	N12	10	1.4	1.8	2.3	3.3	3.7
	N5-1	10	1.4	2.0	2.8	3.6	5.7
	WHIP	10	1.3	1.5	1.9	2.7	3.5
Total Phosphorus ($\mu g\ L^{-1}$)	BG9	9	8	10	25	51	57
	E11	10	13	14	27	43	60
	MB-1	10	14	20	36	50	97
	N12	10	9	13	19	23	28
	N5-1	10	13	20	75	116	164
	WHIP	10	11	14	21	31	33
Total Nitrogen ($mg\ L^{-1}$)	BG9	9	0.41	0.44	0.56	0.63	0.70
	E11	10	0.26	0.32	0.42	0.48	0.56
	MB-1	10	0.30	0.38	0.55	0.70	0.75
	N12	10	0.56	0.66	1.23	1.66	2.03
	N5-1	10	0.60	0.63	1.30	1.87	1.99
	WHIP	10	0.71	0.82	0.93	1.21	1.46
NH_3-N ($mg\ L^{-1}$)	BG9*	3	<0.02	<0.02	0.04	0.05	0.05
	E11*	3	<0.02	<0.02	<0.02	<0.02	<0.02
	MB-1*	3	<0.02	<0.02	<0.02	0.05	0.05
	N12*	3	<0.02	<0.02	<0.02	<0.02	<0.02
	N5-1*	3	<0.02	<0.02	<0.02	<0.02	<0.02

Table 4.9 Annual statistics for physical, nutrient, and other chemical analytes in Kensico's perennial streams, January–December, 2010.

Analyte	Site	N	Minimum	25th Percentile	Median	75th Percentile	Maximum
	WHIP*	3	<0.02	<0.02	<0.02	<0.02	<0.02
NO_3+NO_2-N (mg L^{-1})	BG9	8	0.10	0.20	0.31	0.56	0.60
	E11*	9	<0.02	<0.02	0.09	0.29	0.44
	MB-1	9	0.10	0.13	0.27	0.61	0.68
	N12	9	0.52	0.67	0.96	1.52	1.71
	N5-1	9	0.06	0.21	1.17	1.53	1.91
	WHIP	9	0.58	0.73	0.88	1.25	1.41
Total Suspended Solids (mg L^{-1})	BG9*	11	<1	0.3	0.8	4.5	11.2
	E11*	12	<1	1.1	3.7	4.4	14.3
	MB-1*	12	<1	1.2	2.5	4.5	9.8
	N12*	12	<1	0.1	0.5	2.6	15.2
	N5-1*	12	<1	0.9	3.3	10.0	17.0
	WHIP*	12	<1	0.1	0.3	1.3	4.5

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

5. Kensico Modeling for 2010

During 2010 there were two periods during which Catskill System turbidity levels increased to a point where there was a threat to Kensico Reservoir water quality. In response, 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.

The first period occurred during January 2010. At that time turbidity in Ashokan Reservoir was elevated throughout the spring until late May (Figure 5.1), when normal reservoir operations were resumed. Model simulations were successfully used to mitigate the effects of this event. Detailed descriptions of the simulations run during this period are available in the Water Quality Modeling Group Annual Status report (DEP 2010) and in the five-year summary and assessment report (DEP 2011). Here we provide an overview of the Kensico Reservoir simulations that were performed during the event.

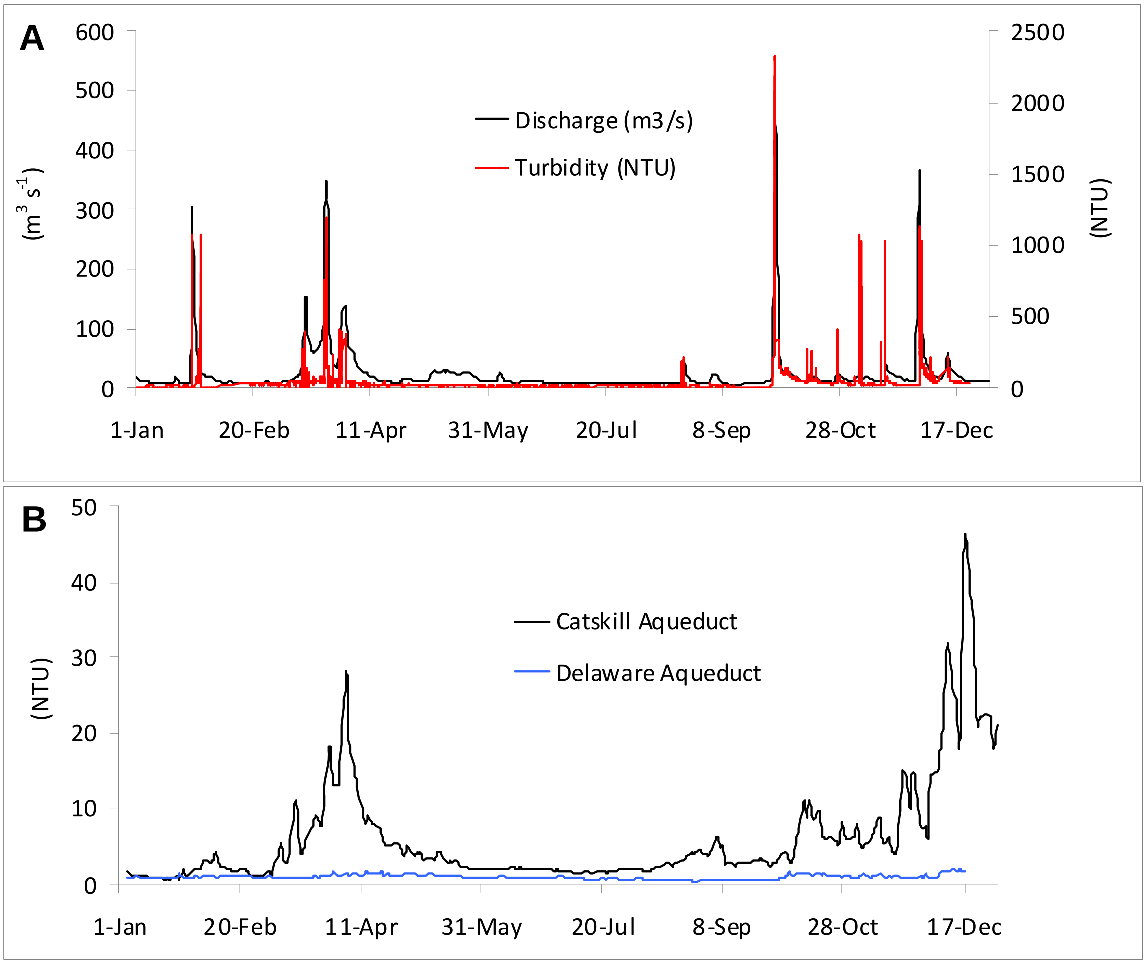


Figure 5.1 Conditions during the two major turbidity events that occurred during 2010. A) Discharge and turbidity measured in Esopus Creek near its confluence with Ashokan Reservoir. This is the major source of turbidity to the water in Ashokan Reservoir, which is transferred to Kensico Reservoir by the Catskill Aqueduct. B) Turbidity levels measured in the Catskill (CATALUM) and Delaware (DEL17) inputs to Kensico Reservoir.

The second period occurred starting in October 2010, and consisted of a large storm followed by a series of small events and another large storm in December 2010 (Figure 5.1). This event has continued into 2011. As a result of additional storms that occurred during 2011, the Catskill System turbidity remained high for the late winter- spring period, and the use of alum to reduce Catskill System turbidity was eventually needed. A complete analysis of the modeling scenarios used during this event will be made once it is over, and will be reported on in the 2011 version of the Water Quality Modeling Group Annual Status report. Here we summarize information on the simulations that were run during 2010.

5.1 Model Descriptions

For all of the simulations, LinkRes and its component 2D reservoir model CEQUAL W2 (DEP 2004, Cole and Buchak 1995) were used to simulate turbidity values within Kensico Reservoir and in aqueduct withdrawals. Scenarios of different constant flow and turbidity inputs to Kensico Reservoir were chosen based on the current conditions and the most probable future changes in reservoir operations (aquedect flows) as well as on an expected range in future input turbidity levels.

For each scenario, a “positional analysis” strategy was followed. Under this strategy, the initial conditions of the reservoir are used as the starting point for the model simulations. Then the model is run for a –1 to 3-month period (the forecast period) into the future using constant aqueduct turbidity and flow levels, and meteorological and aqueduct water temperature data associated with the forecast period in the years between 1987-2004. With this method, each year represents a separate realization (or trace) of the simulated model outcomes based on present conditions and possible future variations in these conditions. Comparison of the scenarios allowed the effects of changing inputs to Kensico Reservoir to be evaluated, while the variability of the positional analysis traces within the scenarios allows the uncertainty in the forecasts due to variability in the weather to be estimated.

5.2 January – May 2010 Turbidity Event

During the winter of 2010 there were a series of storm events that resulted in elevated turbidity in the Ashokan Reservoir, and could potentially have caused the turbidity in the water withdrawn from Kensico Reservoir to exceed the regulatory limit of 5 NTU. Figure 5.1 shows the time series of flows and turbidity, based on provisional data collected by DEP, USGS, and the Upstate Freshwater Institute (UFI), for Esopus Creek at Coldbrook, the major tributary input to Ashokan Reservoir, and from the aqueduct effluents that serve as inputs to Kensico Reservoir. This period was characterized by five major events: one combined snowmelt and rain event in January; a large snowfall in early March coupled with a snowmelt and rain event several days later; another large snowmelt and rain event about a week later; and finally, a medium-sized rain event at the end of March. As each of these events occurred or was forecast, the Water Quality Modeling group performed a number of model simulations to better guide the operations of the Catskill System, and to define the acceptable input flows to Kensico Reservoir to ensure the delivery of high quality water, and reduce or eliminate the need for alum treatment.

Table 5.1 Kensico Reservoir simulations used to inform operational decisions for maintaining water quality during January–May 2010.

Date	Background	Simulation Description
March 10	A large snow event in the beginning of March added to the already developed snow pack, creating a risk of a potentially large streamflow event when the snow melted. Due to this concern a series of reservoir model simulations was performed to better understand the risks and to plan for possible scenarios.	Kensico Reservoir simulations were run to ascertain the sensitivity of Kensico effluent turbidity levels to the turbidity coming from the Catskill Aqueduct at a Catskill Aqueduct flow rate of 300 MGD. Catskill Aqueduct turbidity levels in the sensitivity simulations were 8, 10, and 15 NTU.
March 17	A rain and snowmelt event entered, but did not fill, the West Basin of Ashokan Reservoir. Due to the concern of more storms and rising East Basin turbidity, a further understanding of the impact of	Kensico Reservoir simulations were run to examine the impact of decreasing the Catskill Aqueduct flow rate to 300 MGD, 200 MGD, or 100 MGD, assuming that the Catskill Aqueduct turbidity levels would range between 15-35 NTU.

	potentially elevated Catskill turbidity entering Kensico Reservoir was necessary.	
March 25	A large rain and snowmelt event occurred on March 22, filling both the West and East Basins of Ashokan Reservoir. The storm also elevated East Basin turbidity. Stop shutters were installed in the Catskill Aqueduct to permit reduced flows from Catskill into Kensico Reservoir.	Kensico Reservoir simulations were run to examine the impact of decreasing the Catskill Aqueduct flow rate to 200 MGD, 150 MGD, 100 MGD, or 50 MGD, assuming that the Catskill Aqueduct turbidity would range between 30-50 NTU.
March 31	The large rain and snowmelt events that occurred in late March also had a small effect on turbidity entering Kensico from the Delaware Aqueduct. Further simulations were necessary to understand the effects of small increases in Delaware Aqueduct turbidity on the previous Catskill sensitivities for Kensico Reservoir.	Kensico Reservoir simulations were run to examine the impact of decreasing the Catskill Aqueduct flow rate to 100 MGD or 50 MGD, assuming that the Catskill Aqueduct turbidity levels would range between 20-50 NTU and that Delaware Aqueduct turbidity would range between 2-3 NTU.
April 15	By this time, Catskill Aqueduct turbidity levels were following a declining trend. Further simulations were performed to better understand the impact of increasing Catskill Aqueduct flows into Kensico Reservoir.	Kensico Reservoir simulations were run to examine the impact of increasing the Catskill Aqueduct flow rate to 200 MGD, 300 MGD, or 400 MGD, assuming that the Catskill Aqueduct turbidity levels would range between 8-20 NTU.

The large turbidity loads during the first event in January did not greatly increase the Ashokan East Basin effluent turbidity (Figure 5.1) since most of the inputs replenished storage in the West Basin and did not enter the East Basin of the reservoir. The March events had a much greater impact on Ashokan effluent turbidity, and it was as a result of these events that Kensico turbidity simulations were run. A summary of the model simulations, the conditions that brought them about, and forecasting goals are given in Table 5.1. Each set of simulations is discussed briefly below.

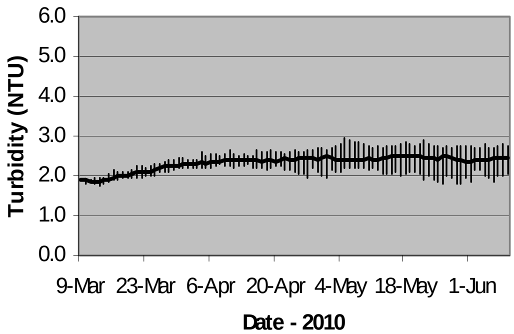
5.2.1 March 10-12, 2010 Simulations

After a period of relative calm during February, a large snow event in the beginning of March created a risk of a potentially large streamflow event. The snow pack in the Ashokan watershed became unusually large, with an estimated 31 billion gallons (BG) of snow water equivalent estimated by a snow survey conducted on March 1, compared to an historical average of about 11 BG. This level of snow water storage created a risk of a large streamflow event that could potentially lead to large increases in Catskill System turbidity. Due to this concern, a series of reservoir model simulations was performed to better understand the risks associated with increased Catskill System turbidity levels and to plan for possible mitigation measures.

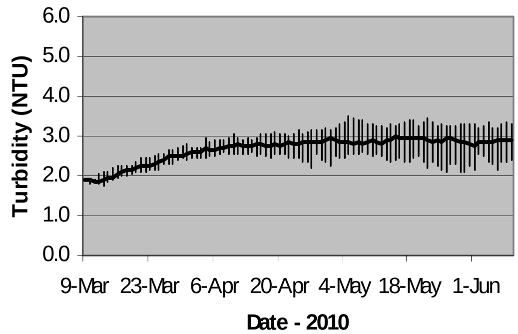
For these simulations, a Catskill Aqueduct flow of 300 MGD, which corresponds to the minimum needed to prevent supply disruptions to upstate communities without use of stop shutters, was used. Delaware Aqueduct inputs to Kensico were set to 800 MGD and flow outputs from Kensico were set to 400 MGD and 700 MGD via Catskill and Delaware Aqueducts, respectively. For all runs, the input turbidity from the Delaware Aqueduct was set to 1 NTU based on conditions at the time. Kensico effluent sensitivity was tested by performing three sets of simulations with input Catskill turbidity of 8, 10, and 15 NTU. These simulations assume that the inputs and outputs are constant for the three-month forecast period from March 10–June 10. Initial conditions in the reservoir were based on robotic monitoring information collected on March 9.

Figure 5.2 shows the results for the three input turbidity scenarios. The plots show the median and range of Kensico Reservoir effluent turbidity via the Catskill Aqueduct for the 18 traces. Delaware Aqueduct effluents from Kensico were of a similar magnitude and showed similar trends in turbidity, and are therefore not shown. Effluent turbidity was predicted to rise to about 2-3 NTU with a sustained Catskill Aqueduct input of 8 NTU, while the effluent turbidity prediction was about 3-5 NTU with sustained Catskill input of 15 NTU. These results indicated that inputs of greater than 10 NTU from the Catskill Aqueduct would cause the effluent turbidity levels to come close to or exceed the 5 NTU regulatory limit for the Kensico effluent.

(a) Catskill influent turbidity = 8 NTU:



(b) Catskill influent turbidity = 10 NTU:



(c) Catskill influent turbidity = 15 NTU:

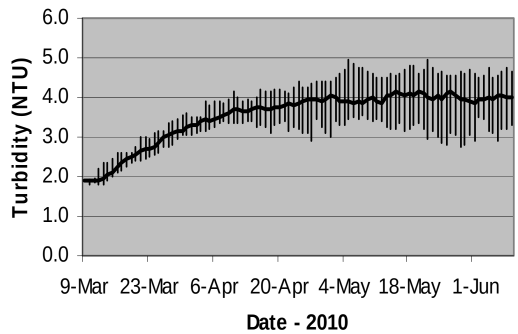


Figure 5.2 Results of CEQUAL-W2 simulations from March 10, 2010. Catskill effluent turbidity levels leaving Kensico Reservoir with influent Catskill turbidity of (a) 8 NTU, (b) 10 NTU, and (c) 15 NTU. The line on the graph shows the median of the 18 traces for the positional analysis; the error bars show the range of values for all traces.

5.2.2 March 17 2010, Simulations

As a number of storm events combining rain with melt of the large snow pack began to impact Ashokan Reservoir, further Kensico Reservoir sensitivity runs were performed to help inform operational decisions. For the first storm in March, the use of the waste channel earlier in the winter mitigated the effects of this storm by preventing spill over the dividing weir from the West Basin to the East Basin. In mid-March, after the first storm, a set of Kensico Reservoir simulations was performed to define Ashokan effluent turbidity levels beyond which Catskill Aqueduct flow would need to be reduced through the use of stop shutters.

The simulations were run for a three-month forecast period from March 15–June 15. Initial conditions in the reservoir were based on robotic monitoring information collected on March 15. Aqueduct flow outputs from Kensico were set to 400 MGD and 700 MGD via Catskill and Delaware Aqueducts, respectively. For all runs, the input turbidity from the Delaware Aqueduct was set to 1 NTU based on conditions at the time. To test various inflow and turbidity combinations input from the Catskill Aqueduct to Kensico Reservoir, flows were set to 100, 200, and 300 MGD and input turbidities were set to 15, 25, and 35 NTU. Delaware Aqueduct inflows were set to balance the Catskill Aqueduct flows so total inflow of the two aqueducts equaled 1,100 MGD. Each of the simulations assumes that these inputs and outputs are constant for the three-month forecast period.

Figure 5.3 shows the results for the scenarios with 300 MGD input from the Catskill System. The plots show the median and range of effluent turbidity for the 18 traces. For the case of 15 NTU input from the Catskill System, Kensico effluent turbidity would rise close to 5 NTU. Figure 5.4 shows the results for the 100 MGD Catskill input scenarios. In this case the reduced input flow from the Catskill Aqueduct results in a reduced Kensico effluent turbidity of about 2-2.5 NTU with a 15 NTU input from Catskill, and a Kensico effluent turbidity of about 2.5-4 NTU with a 35 NTU input from Catskill. These runs indicated that if turbidity in the East Basin of Ashokan Reservoir were to increase beyond 15 NTU, use of stop shutters to reduce Catskill Aqueduct flow to below 300 MGD would be necessary.

(a) Catskill inflow 300 MGD, 15 NTU: (b) Catskill inflow 300 MGD, 35 NTU:

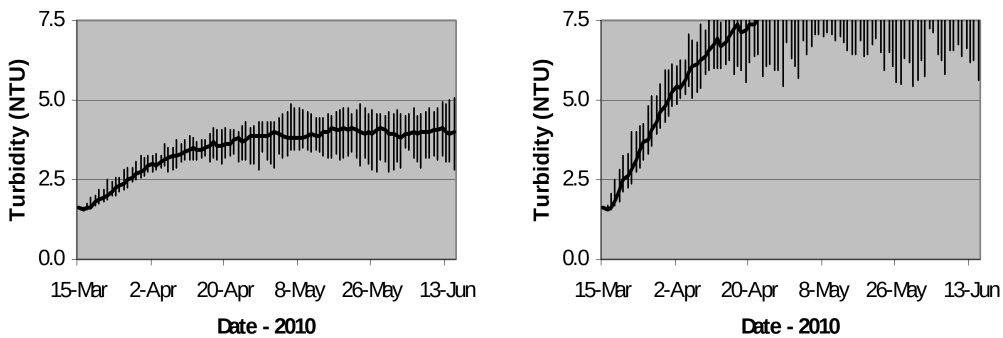


Figure 5.3 Results of CEQUAL-W2 simulations from March 17, 2010 for Catskill effluent turbidity levels leaving Kensico Reservoir with Catskill Aqueduct inflow of 300 MGD and influent Catskill turbidity of (a) 15 NTU and (b) 35 NTU. The line on the graph shows the median of the 18 traces for the positional analysis; the vertical bars show the range of values for all traces.

(a) Catskill inflow 100 MGD, 15 NTU: (b) Catskill inflow 100 MGD, 35 NTU:

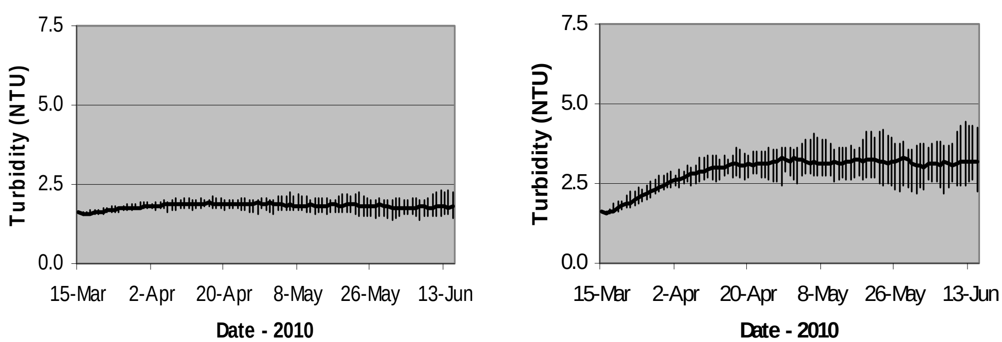


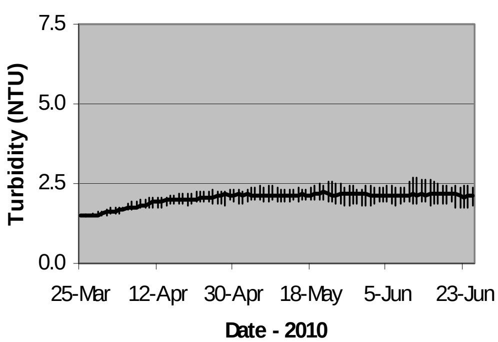
Figure 5.4 Results of CEQUAL-W2 simulations from March 17, 2010 for Catskill effluent turbidity from Kensico Reservoir with Catskill Aqueduct inflow of 100 MGD and influent Catskill turbidity of (a) 15 NTU and (b) 35 NTU. The line on the graph shows the median of the 18 traces for the positional analysis; the vertical bars show the range of values for all traces.

5.2.3 March 25, 2010 Simulations

A large storm event on March 22 filled Ashokan Reservoir and water began to spill from the West Basin to the East Basin. East Basin turbidity began to rise and stop shutters were employed to reduce Catskill Aqueduct flow to Kensico Reservoir. A series of Kensico sensitivity simulations were run to better define acceptable levels of reduced flow in the Catskill Aqueduct. The simulations were run for a three-month forecast period from March 25–June 25. Initial conditions in the reservoir were based on robotic monitoring information collected on March 25. Aqueduct flow outputs from Kensico were set to 400 MGD and 700 MGD via Catskill and Delaware Aqueducts, respectively. For all runs, the input turbidity from the Delaware Aqueduct was set to 1.5 NTU based on conditions at the time. To test various inflow and turbidity combinations input from the Catskill Aqueduct to Kensico Reservoir, flows were set to 50, 100, 150, and 200 MGD and input turbidities were set to 30, 40, and 50 NTU. Delaware Aqueduct inflows were set to balance the Catskill Aqueduct flows so total inflow of the two aqueducts equaled 1,100 MGD. Each of the simulations assumes that these inputs and outputs are constant for the three-month forecast period.

Figure 5.5 shows the results for the minimum flow scenarios, which used a 50 MGD input from the Catskill System. For the case of a 30 NTU input from the Catskill System, the Kensico effluent turbidity was predicted to rise to about 2.5 NTU, while for the case of a 50 NTU Catskill input, Kensico effluent turbidity was predicted to rise to about 2.5-3.5 NTU. Figure 5.6 shows the other extreme of the inflow scenarios, with the Catskill input fixed at 200 MGD. As expected, in this case the high turbidity from the Catskill Aqueduct has a more detrimental effect on the simulated Kensico effluent turbidity, with levels rising to over 5 NTU for all the input scenarios. The full set of forecast runs indicated that if Catskill influent turbidity was in the 30-50 NTU range for a sustained period of time, the Catskill Aqueduct flow into Kensico should be reduced to 50-100 MGD.

(a) Catskill inflow 50 MGD, 30 NTU:



(b) Catskill inflow 50 MGD, 50 NTU:

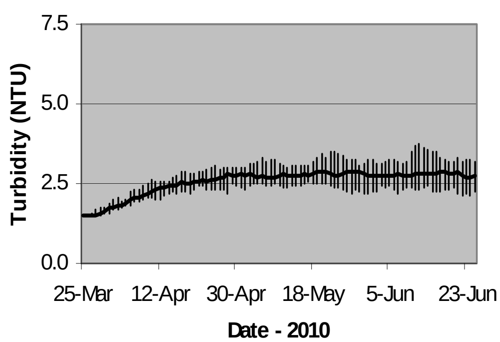


Figure 5.5 Results of CEQUAL-W2 simulations from March 25, 2010 for Catskill effluent turbidity from Kensico Reservoir with Catskill Aqueduct inflow of 50 MGD and influent Catskill turbidity of (a) 30 NTU and (b) 50 NTU. The line on the graph shows the median of the 18 traces for the positional analysis; the error bars show the range of values for all traces.

(a) Catskill inflow 200 MGD, 30 NTU: (b) Catskill inflow 200 MGD, 50 NTU:

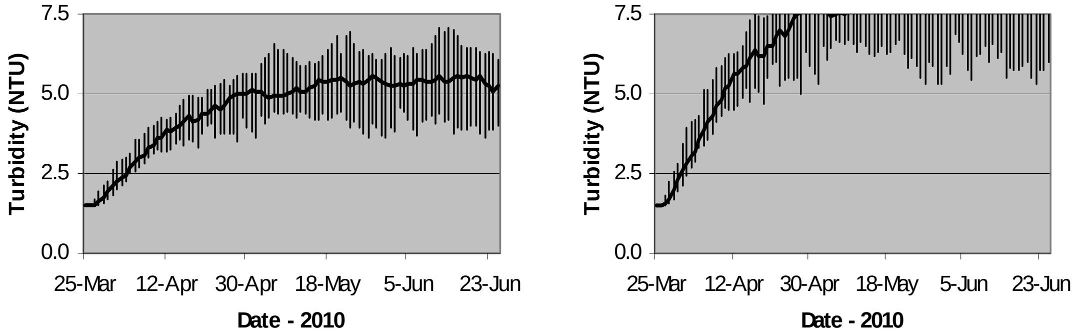


Figure 5.6 Results of CEQUAL-W2 simulations from March 25, 2010 for Catskill effluent turbidity from Kensico Reservoir with Catskill Aqueduct inflow of 200 MGD and influent Catskill turbidity of (a) 30 NTU and (b) 50 NTU. The line on the graph shows the median of the 18 traces for the positional analysis; the error bars show the range of values for all traces.

5.2.4 March 31, 2010 Simulations

A final large rain and snowmelt event occurred on March 31 and demanded further Kensico simulations with higher turbidity inputs from the Delaware Aqueduct than were used in previous runs. These runs build on the simulations of March 25, only in this case turbidity levels in the Delaware Aqueduct input to Kensico Reservoir were increased and the sensitivity of Kensico effluent turbidity to Delaware input turbidity levels of 2 NTU and 3 NTU were examined. As an example of the results from these simulations, Figure 5.7 shows the plots of simulated Kensico effluent turbidity for the 50 MGD scenarios with the lowest and highest combined input turbidity loads. For the lowest turbidity loads the Kensico effluent was simulated to rise to about 2-3 NTU, while for the highest turbidity loading, the Kensico effluent was simulated to rise to about 2.5-4 NTU, a level that is close to the acceptable threshold. Based on these runs, it was predicted that with a Delaware input turbidity of 2 NTU, a Catskill input turbidity of about 50 NTU could be tolerated at a flow rate of 50 MGD, while with a Delaware input turbidity of 3 NTU, a Catskill turbidity of no more than 40 NTU could be tolerated. These runs highlight the importance of low turbidity Delaware System water in maintaining low turbidity at the Kensico effluent during Catskill turbidity events, and that the system is fairly resilient as long as large flow reductions of turbid Catskill System water are possible.

(a) Catskill inflow 50 MGD, 30 NTU
Delaware inflow 1,050 MGD, 2 NTU:

(b) Catskill inflow 50 MGD, 50 NTU
Delaware inflow 1,050 MGD, 3 NTU:

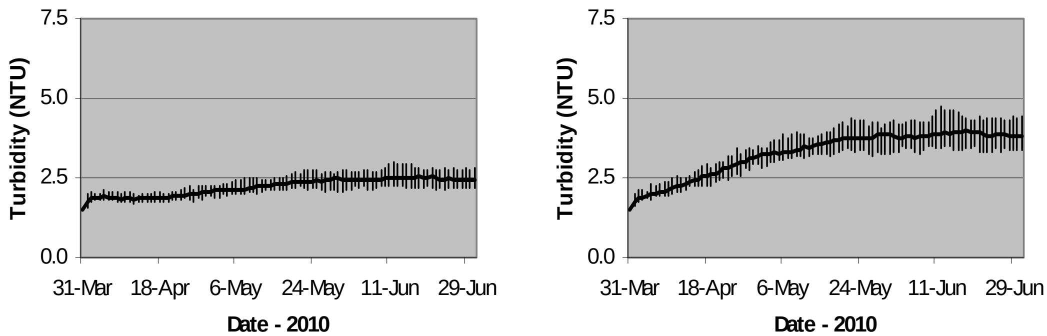


Figure 5.7 Results of CEQUAL-W2 simulations from March 31, 2010 for Catskill effluent turbidity from Kensico Reservoir with Catskill Aqueduct inflow of 50 MGD and Delaware Aqueduct inflow of 1,050 MGD. Influent turbidity is (a) 30 NTU for Catskill and 2 NTU for Delaware, and (b) 50 NTU for Catskill and 3 NTU for Delaware. The line on the graph shows the median of the 18 traces for the positional analysis; the error bars show the range of values for all traces.

5.2.5 April 15, 2010 Simulations

In mid-April, once turbidity in the East Basin declined as a result of reduced inputs and particle settling, additional Kensico Reservoir sensitivity simulations were performed to forecast the effects of increased Catskill Aqueduct flow. These simulations were used to help inform decisions about the timing of stop shutter removal and the level of increased flow that could be used after stop shutter removal.

The simulations were run for a three-month forecast period from April 15–July 15. Initial conditions in the reservoir were based on robotic monitoring information collected on April 12. Aqueduct flow outputs from Kensico were set to 400 MGD and 700 MGD via Catskill and Delaware Aqueducts, respectively. For all runs, the input turbidity from the Delaware Aqueduct was set to 1.5 NTU based on conditions at the time. To test various inflow and turbidity combinations input from the Catskill Aqueduct to Kensico Reservoir, flows were set to 200, 300, and 400 MGD and input turbidities were set to 8, 10, 15, and 20 NTU. Delaware Aqueduct inflows were set to balance the Catskill Aqueduct flows so total inflow of the two aqueducts equaled 1,100 MGD. Each of the simulations assumes that these inputs and outputs are constant for the three-month forecast period.

The results (not shown) indicate that at Catskill Aqueduct turbidity levels of 8 NTU, Catskill Aqueduct flows up to 400 MGD would lead to Kensico effluent turbidity of 2.5-3.5 NTU. At Catskill Aqueduct turbidity levels of 10 NTU, Catskill Aqueduct flows of up to 300 MGD would lead to acceptable Kensico effluent turbidity. If sustained input turbidity levels exceeded 15 NTU, the simulations suggested that flow levels below that possible in the absence of stop shutters would be needed. It was therefore recommended that the stop shutters not be removed until turbidity levels fell below 15 NTU.

5.3 Turbidity Event Beginning in October 2010

The second turbidity event impacting the Catskill System and requiring Kensico Reservoir turbidity simulations began in October 2010 (Figure 5.1) and continues at the time of this writing. In general, the same type of Kensico Reservoir turbidity forecasts that are discussed for the January to May event above were also used for this event. The overall goal was to examine the sensitivity of Kensico effluent turbidity levels to variations in Catskill turbidity loading that could be expected as Ashokan Reservoir turbidity levels and operational flow changes occurred. The conditions leading up to the simulations, and the combinations of input flow and turbidity levels used for the Kensico Reservoir turbidity forecasts, are listed in Table 5.2. A number of additional simulations have already been run in 2011, and more will be required before the event is over. A complete reporting of the event will be made in the October 2011 Multi-Tiered Modeling Program Status Report. Here we provide one example of a typical set of simulations that was run during 2010, the year covered by this report.

Table 5.2 Kensico reservoir simulations used to inform operational decisions for maintaining water quality during October–December 2010.

Date	Background	Simulation Description
October 1	A storm event led to a large turbidity load entering the West Basin of Ashokan Reservoir. At the time of these simulations it was not clear what the impact would be on the water entering the Catskill Aqueduct.	Simulations were run to examine what levels of Catskill turbidity could be tolerated at 600 MGD and 300 MGD flow rates from the Catskill Aqueduct. Catskill turbidity levels ranged between 8-30 NTU.
October 4	It was expected that Ashokan effluent turbidity levels would reach at least 10 NTU and that flow reductions through the use of stop shutters (below 300 MGD) could be required.	Simulations were run at higher Catskill turbidity levels of 20 and 40 NTU, and at lower Catskill Aqueduct flow rates of 50 and 150 MGD.
October 6	Turbidity levels in the Ashokan East Basin continued to increase and approached 20 NTU. Stop shutters had been installed. There was a concern that turbidity levels could still increase further in the Ashokan East Basin and Catskill Aqueduct effluent.	Simulations were run to examine the effects of even higher Catskill turbidity inputs to Kensico Reservoir. Catskill Aqueduct flow levels of 50, 100, and 150 MGD were examined in combination with turbidity levels of 60, 80, and 100 NTU.
October 15	The Delaware Aqueduct flow was bypassed around Kensico to reduce taste issues due to a Kensico algal bloom. Moderate (8 NTU) turbidity water was still entering the reservoir from the Catskill System.	Kensico Reservoir simulations were run to examine the effect of a sustained 250 MGD input of 8 NTU water from the Catskill Aqueduct in the absence of inputs of low turbidity Delaware System water.
November 3	Ashokan East Basin turbidity levels remained at approximately 10 NTU. Kensico Reservoir was weakly stratified with a 15-20 m mixed layer. Delaware water was again flowing through the reservoir.	Given continued elevated turbidity levels and changing thermal conditions in Kensico, simulations were again run to check the sensitivity of Kensico effluent turbidity to Catskill inputs of 10, 20, or 30 NTU at flow rates of 150 or 250 MGD.

December 3	Another large storm occurred between November 30 and December1, which further increased Ashokan Reservoir turbidity. At the time of the simulations Ashokan effluent turbidity levels were approaching 20 NTU and increasing. Stop shutters were still in use to reduce Catskill Aqueduct flow, and Kensico Reservoir was isothermal.	Simulations were run to examine the effects of further increases in Catskill Aqueduct input turbidity on Kensico effluent turbidity. The simulations accounted for isothermal conditions that would lead to more complete mixing of the turbid inputs into the reservoir. Catskill Aqueduct inputs to Kensico were simulated at 50, 100, and 150 MGD flows and at 20, 40, and 60 NTU turbidity.
December 15	By the time of these simulations the effects of the November 30–December 1 storm had caused Ashokan effluent turbidity to rise to 50 NTU, while at the same time there was a small, but potentially important, increase in Delaware System turbidity from 1.5 to 2.0 NTU.	Simulations were very similar to the ones run on December 3, except that in this case the effects of increasing Delaware System turbidity were examined. Two sets of simulations were run using Delaware System turbidity levels of 1.5 and 2.0 NTU. In each set, Catskill Aqueduct inputs of 50, 100, 150 MGD and 20, 30, 40, 50 NTU turbidity were used.

5.3.1 December 15, 2010 Simulations

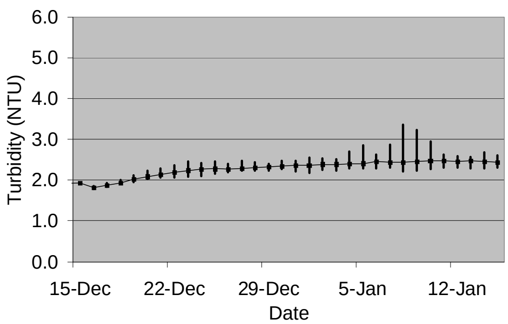
This was the final set of simulations run during 2010 and were made in response to worsening turbidity conditions in Ashokan Reservoir, as turbidity inputs from an early December storm moved through the West Basin and into the East Basin of Ashokan Reservoir, eventually leading to peak Catskill Aqueduct turbidity levels of nearly 50 NTU (Figure 5.1). These simulations were made just past the peak in aqueduct turbidity, and consequently 50 NTU was taken as the upper limit of Catskill Aqueduct turbidity. Lower Catskill Aqueduct turbidity levels down to 20 NTU were also examined. Since Catskill Aqueduct stop shutters were in place, low aqueduct flow levels were tested. The December storm event also led to small increases in the turbidity level of Rondout Reservoir, where Delaware System water enters the Delaware Aqueduct prior to entering West Branch and then Kensico Reservoirs. At the time of the simulations, Delaware Aqueduct inputs to Kensico Reservoir had increased from 1.5 to 2.0 NTU. Since Kensico effluents must remain below 5 NTU, there was concern that this small increase in Delaware System turbidity could be significant, given the large volumes of Delaware System water that are mixed with relatively small volumes of high turbid Catskill System water.

The simulations were run for a one-month forecast period from December 15–January 15. Initial conditions in the reservoir were based on a limnological survey conducted on December 14 and on robotic monitoring information also collected on that date. Aqueduct flow outputs from Kensico were set to 600 MGD and 500 MGD via Catskill and Delaware Aqueducts, respectively. To test various flow and turbidity combinations from the Catskill Aqueduct to Kensico Reservoir, flows were set to 50, 100, and 150 MGD and input turbidities were set to 20, 30, 40, and 50 NTU. Delaware Aqueduct inflows were set to balance the Catskill Aqueduct flows so total inflow of the two aqueducts equaled 1,100 MGD. Each of the simulations assumes that these inputs and outputs are constant for the three-month forecast period. The combination of three Catskill Aqueduct flow levels and four possible turbidity levels gave a total of 12 sets of Kensico positional analysis simulations. To examine the consequences of increasing Delaware

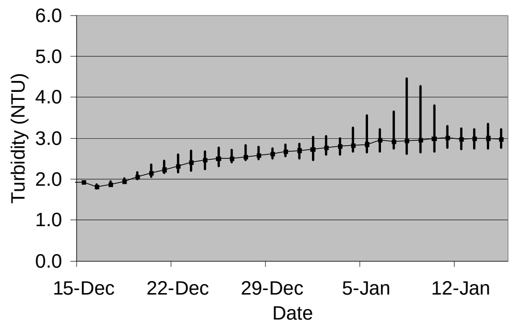
System turbidity, the set of 12 simulations was run once using a Delaware Aqueduct turbidity level of 1.5 NTU and a second time using a Delaware Aqueduct turbidity level of 2 NTU.

This was a complex set of simulations, leading to a total of 24 sets of positional analysis runs, each of which was driven using 18 traces of historical meteorological data. An example of the simulation results for the intermediate flow level of 100 MGD and an assumed Delaware System turbidity level of 1.5 NTU is shown in Figure 5.9. This figure is for the Delware aqueduct effluent which in this case had somewhat higher simulated turbidity levels than was the case for the Catskill effluent. The results suggest that at Catskill aqueduct flow levels of 100 MGD, Catskill input turbidity levels of 20 – 30 could be tolerated, although some the 30 NTU traces came close to the 5 NTU limit. At Catskill input turbidity of 30 and above aqueduct flows would need to be reduced to below 100 MGD.

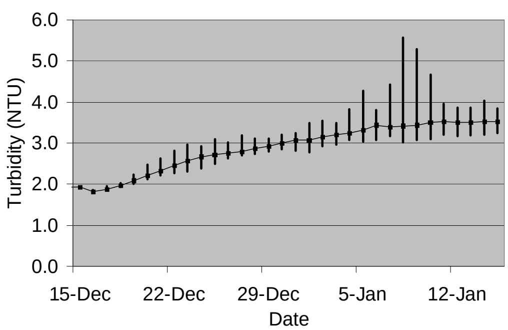
(a) Catskill inflow 100 MGD, 20 NTU
Delaware inflow 1,000 MGD, 1.5 NTU:



(b) Catskill inflow 100 MGD, 30 NTU
Delaware inflow 1,000 MGD, 1.5 NTU:



(c) Catskill inflow 100 MGD, 40 NTU
Delaware inflow 1,000 MGD, 1.5 NTU:



(d) Catskill inflow 100 MGD, 50 NTU
Delaware inflow 1,000 MGD, 1.5 NTU:

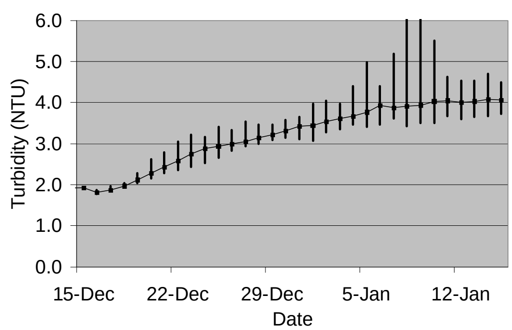


Figure 5.8 Results of CEQUAL-W2 simulations from December 15, 2010 for Delaware effluent turbidity from Kensico Reservoir with Catskill Aqueduct inflow of 100 MGD and Delaware Aqueduct inflow of 1,000 MGD. Influent turbidity for the Delaware System is 1.5 NTU and for the Catskill System is a) 20 NTU, b) 30 NTU, c) 40 NTU, and d) 50 NTU. The line on the graph shows the median of the 18 traces for the positional analysis; the error bars show the range of values for all traces. The two extreme events in graph (d) exceed 6 NTU.

To gain an overview of the entire set of December 15 simulations, Figure 5.9 was prepared. This figure shows the range in turbidity simulated for each of the 24 positional analysis simulations using the combined results from both the Catskill and Delaware effluents. Based on this figure, it was recommended that for Catskill turbidity inputs of 30-50 NTU, aqueduct flows should not exceed 50 MGD. For Catskill input turbidity levels of 20-30 NTU, flow levels of 100 MGD could be tolerated, and if the turbidity levels fell below 20, 150 MGD flows could be used It was also found that increasing the Delaware input turbidity from 1.5 NTU to 2.0 NTU led to relatively small increases in Kensico effluent turbidity levels and thus had little effect on Catskill Aqueduct flow recommendations.

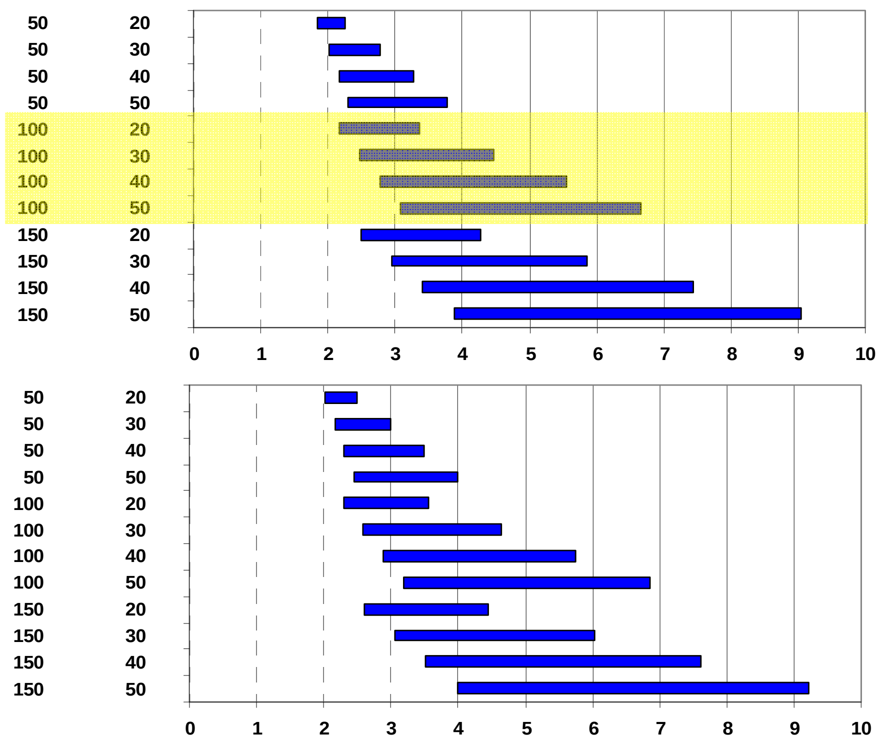


Figure 5.9 Summary of the results of all CEQUAL-W2 simulations from December 15, 2010. The different combinations of Catskill influent flow and turbidity levels used for each set of positional analysis simulations is show in the columns to the left of the graphs. The range of the bars shows the range of turbidity simulated by all positional analysis traces over the one-month simulation period when combining data from both the Delaware and Catskill effluent locations. The yellow shading shows the input condition that corresponds to the individual simulation results in Figure 5.9.

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