New York City Department of Environmental Protection

Bureau of Water Supply

Report on Final Revised Performance Measures/Criteria for Evaluating the Efficacy of Catskill Turbidity Controls.

March 2019

Prepared in accordance with Section 4.11 of the NYSDOH
2017 Filtration Avoidance Determination

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Introduction

This report provides a summary of the final revised performance measures/criteria for evaluating the efficacy of Catskill Turbidity Control Program (CTC) alternatives that have been implemented. The measures take into consideration the National Academy of Sciences, Engineering and Medicine Expert Panel (NASEM EP) recommendations, as required by Section 4.11 of the NYSDOH 2017 Filtration Avoidance Determination (FAD).

The performance measures described in this report provide numeric assessments of the impact of three measures that help manage turbidity in the Catskill System:

- the Catskill-Delaware Interconnection at Shaft 4 (CDIS4 aka Shaft 4)
- the Croton Filtration Plant (CFP)
- the Ashokan Conditional Seasonal Storage Objective (CSSO)

Background

The streams of the Catskill System of the NYC water supply are naturally prone to periods of elevated turbidity when large runoff events destabilize stream banks, mobilize streambeds, and suspend the underlying glacial clays in the water column. Settling of suspended solids in the Catskill System is provided in, from upstream to downstream, the Schoharie Reservoir, the West and East Basins of the Ashokan Reservoir, and the northern section of Kensico Reservoir. Under typical conditions, the extended detention time in these reservoirs is sufficient to allow the suspended solids to settle out of the water column, allowing the Surface Water Treatment Rule turbidity standard of 5 NTU to be met at the effluent of the Kensico Reservoir.

Historically, during extreme turbidity events, DEP addressed elevated turbidity in the Catskill System through the addition of the coagulant aluminum sulfate (alum). The addition of alum increases the settling of suspended solids, including clays, as flow from the Catskill Aqueduct enters Kensico Reservoir. The addition of alum to the Catskill Aqueduct is authorized by the Catalum SPDES Permit, effective January 1, 2007 (NY 026 4652). The Catalum SPDES Permit is valid upon the condition that New York City (the City) continues to work to achieve the goals of turbidity reduction and reduced alum usage in the Kensico Reservoir. The potential negative impacts of alum addition as well as the requirements of the Catalum SPDES Permit have led the City to develop alternative turbidity management strategies.

To manage turbidity in the Catskill System more effectively, the City studied how changes to its infrastructure and operations could reduce potentially negative environmental impacts associated with operation of the water supply and the use of alum. A comprehensive analysis, the Catskill Turbidity Control Study, was conducted by DEP with the Gannett Fleming-Hazen and Sawyer Joint Venture in three phases between 2002 and 2009. Based on the results of this study, DEP implemented several alternatives, including: modification of water supply operations using the Operations Support Tool (OST) and interconnection of the Catskill and Delaware Aqueducts at Shaft 4 (CDIS4).

The Operations Support Tool (OST)

OST allows the City to manage reservoir diversions, releases and other operations for the entire water supply system to balance storage, maximize the probability of reservoir refill by June 1st, optimize water quality and achieve environmental objectives such as minimum flow requirements downstream of selected reservoirs. In the Catskill System, OST incorporates the Ashokan Conditional Seasonal Storage Objective (CSSO), which provides void space in the Ashokan Reservoir to mitigate reservoir spill and high turbidity diversions and releases, and simulates diversions from Schoharie Reservoir via the Shandaken Tunnel. Operation of the Shandaken Tunnel is regulated by NYS Environmental Conservation Law Part 670 and the Shandaken Tunnel Outlet SPDES permit which includes limits for flow, turbidity, temperature, and phosphorus levels in diversions to Esopus Creek. In the Delaware System, OST guides reservoir releases as specified by the 2017 Flexible Flow Management Program (FFMP). These releases are an important part of water supply operations and propagate through the entire system via their impact on reservoir balancing and water availability for diversion.

OST also simulates operation of the Ashokan Release Channel (ARC). The ARC provides a mechanism for releasing water from the Ashokan Reservoir to the lower Esopus Creek for environmental or economic benefit, spill mitigation, and to reduce the impacts of high turbidity water on Kensico Reservoir. The ARC is operated under a consent order between NYSDEC and DEP, which took effect in October 2013. The consent order includes the Ashokan CSSO.

The Catskill-Delaware Interconnection at Shaft 4 (CDIS4)

DEP constructed CDIS4 between the Catskill and Delaware Aqueducts to allow for the increased use of water from the Delaware System during Catskill turbidity events, as well as to improve the flexibility of the water supply. CDIS4 allows lower turbidity Delaware water to blend with higher turbidity Catskill water, reducing turbidity of the water entering Kensico Reservoir via the Catskill Aqueduct. During extreme turbidity events, diversions from the Catskill System can be reduced and additional water from the typically lower turbidity Delaware System can be transferred to Kensico Reservoir via the Catskill Aqueduct.

The Croton Filtration Plant (CFP)

In addition to the above turbidity control measures, the completion of the Croton Filtration Plant allows NYC to deliver up to 290 MGD (approximately 25% of the NYC water demand) from the Croton System. The use of the Croton System further reduces reliance on the Catskill System during high turbidity events, providing robust operational flexibility for overall system operations.

As part of their review of OST, the NASEM EP determined that “OST modeling structure is ready to simulate operations and turbidity levels in the absence of the CTC Program infrastructure and operational improvements (a no-action scenario)” as well as “to compare these simulated results to actual operations and observed turbidity levels with the CTC in place.” The EP recommended NYC take additional steps to ensure the CTC Program is relevant and accountable into the future including:

1. Increased statistical analyses of data pre- and post-CTC implementation.
2. Use of OST to evaluate the impact of CTC measures at the same time DEP continues ensuring OST's capacity to reproduce observations of streamflows and turbidity levels under a wide range of streamflow conditions.

This report describes metrics to evaluate the impact of three actions taken to help manage turbidity:

1. CDIS4 usage
2. Croton System usage via CFP up to 140 MGD
3. Ashokan CSSO

The maximum flow from CFP is 290 MGD. A flow of 140 MGD was simulated to be conservative. Higher flows would presumably provide more benefit.

Methods

NYC initially proposed to evaluate the efficacy of the CTC measures by comparing observed operations and alum usage during turbidity events that occurred after the implementation of the CTC measures with OST simulations of operations and alum usage without the CTC measures (the "no-action" scenario). However, the most recent alum treatment event occurred in August 2011 (Table 1), while the three measures being evaluated were all implemented after 2011. Thus, there are no data available from periods when the turbidity control measures were in place and an alum event occurred to evaluate the efficacy of the CTC measures.

Table 1. Historical alum treatment events in the NYC water supply system.

Alum Event	Start Date	Duration (days)	Average Daily Flow (MGD)	Alum Dose (ppm)	Alum Loading (lbs)
1	4/6/1987	43	350	5-15	927,182
2	1/22/1996	151	200	8-15	2,448,553
3	1/14/1997	15	250	7-8	234,212
4	1/10/2001	23	350	7-8	479,680
5	4/5/2005	76	350	6-15	1,747,297
6	10/13/2005	41	450	7-9	1,171,128
7a*	12/1/2005	129	550	7-11	4,677,689
7b*	5/15/2006	10	600	7	341,932
7c*	6/28/2006	36	600	7-16	1,488,761
8	1/31/2011	11	500	5-7	290,215
9	3/2/2011	79	200	6-14	1,145,749
10	8/29/2011	260	250	7-23	5,946,212

* Events are considered a single turbidity event

Given the inability to perform the analysis as initially proposed, NYC used OST to simulate water supply operations, including alum treatment, over the period 1996 through 2012. Simulations were executed with all combinations of the CTC measures implemented as well as the no-action scenario (Table 2). This revised approach provides a retrospective assessment of the impacts of select CTC measures on the operation of the water supply and management of turbidity.

Operations Baseline Model Development

Prior to the simulation of the CTC measures, the ability of the model to approximate actual operations from 1996-2012 was evaluated. An OST baseline model run was developed to simulate the operational rules and infrastructure in the water supply system. While the Croton System was available for use during the early portion of the simulation period, it was turned off in the baseline run to enable the evaluation of the impacts of the use of the Croton System on alum usage.

The results of this no-action simulation were then compared to the observed water supply operations and alum treatment to determine if the use of OST to simulate historic operations was valid. An analysis of the baseline model and the actual operations of the water supply over the simulation period are presented in the Results and Discussion section.

CTC Measures Implementation Assessment

To assess the efficacy of the CTC measures, OST simulations were run in "open" mode, meaning no operations were forced in the model, and all operation rules were held constant in the model for runs with and without CTC measures implemented. This approach allowed OST to determine the implementation and duration of the alum treatment regimes required to meet the water quality rules used in operation of the water supply. The use of the open simulation allowed the isolation of the impacts of the CTC measures only, eliminating all other differences in system operation.

OST runs were performed in Simulation (SIM) mode, using historical runoff and system storage data, for the period 1946-2012. The water quality (W2) models for Schoharie, Ashokan, Rondout and Kensico reservoirs were active for all runs. Table 2 shows a matrix of all runs performed.

Table 2. Scenario matrix for CTC efficacy evaluation. W2 water quality models were active for all runs.

<table>
<tr><th>Scenario ID</th><th>Ashokan CSSO</th><th>Croton System</th><th>Shaft 4</th></tr>
<tr><td>Base Run</td><td rowspan="4">Off</td><td rowspan="2">Off</td><td>Off</td></tr>
<tr><td>1</td><td>On</td></tr>
<tr><td>2</td><td rowspan="2">On</td><td>Off</td></tr>
<tr><td>3</td><td>On</td></tr>
<tr><td>4</td><td rowspan="4">On</td><td rowspan="2">Off</td><td>Off</td></tr>
<tr><td>5</td><td>On</td></tr>
<tr><td>6</td><td rowspan="2">On</td><td>Off</td></tr>
<tr><td>7</td><td>On</td></tr>
</table>

CTC Evaluation Metrics

The model simulation results from the scenarios listed in Table 2 were assessed to determine their relative impact on turbidity and the operation of the water supply. The metrics used to evaluate the effectiveness of the CTC measures were:

- Simulated mass of alum used for turbidity control
- Number of days of simulated alum treatment

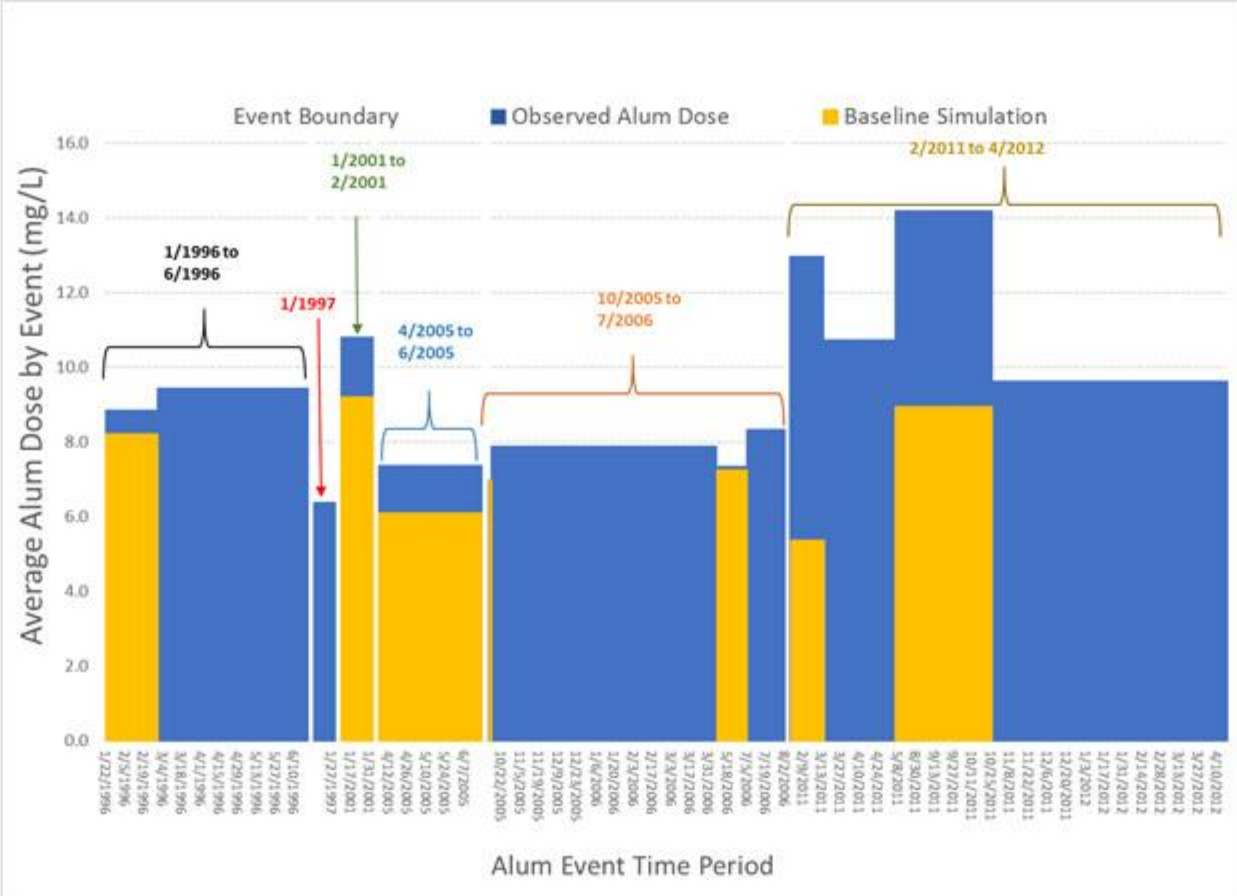
Results and Discussion

Evaluation of Baseline Simulation

The model run with no CTC measures activated and no forced operations was selected as the baseline simulation run for this analysis. While not fully representative of the operations and rules governing the water supply across the simulation period, it was decided that this simulation would allow OST the ability to operate the system realistically while maintaining the flexibility to select the appropriate combinations of source water to meet the demands of the City.

To assess the reasonability of the baseline model simulation, the simulated alum dosing was compared to the actual alum dosing utilized to control turbidity during historical events (Figure 1).

Figure 1. Comparison of actual and simulated alum dosing.



As shown, simulated and observed alum dosages align fairly well during the start of alum treatment events, with simulated alum dosage typically lower than actual dosage. The model simulations commonly terminated alum additions prior to the observed end of alum treatment. The likely explanation for the observed higher dosing and longer duration of alum addition is highly conservative operation of the water supply by managers who did not have the benefit of simulation tools like OST with W2. Another possible reason for these differences between simulated and observed operations is that the model used a fixed set of rules (e.g. 2017 FFMP for Delaware reservoir releases) during the entire simulation period, but different rules may have been in place during the actual events. OST does not have the ability to change the Delaware release program from Rev 1 to 2007, then 2011, then 2017 FFMP during the course of the long-term simulation run. The propagation of these and other rules through system-wide simulated operations could have resulted in simulated operations of the Ashokan Reservoir differing from actual operations.

Comparison of Observed and Simulated Turbidity without CTC Measures

A summary of the maximum and average Turbidity at Kensico Reservoir under both observed and simulated baseline conditions is shown in Table 3.

Table 3. Comparison of maximum and average turbidity at Kensico Reservoir between observed and the no CTC measures activated simulation.

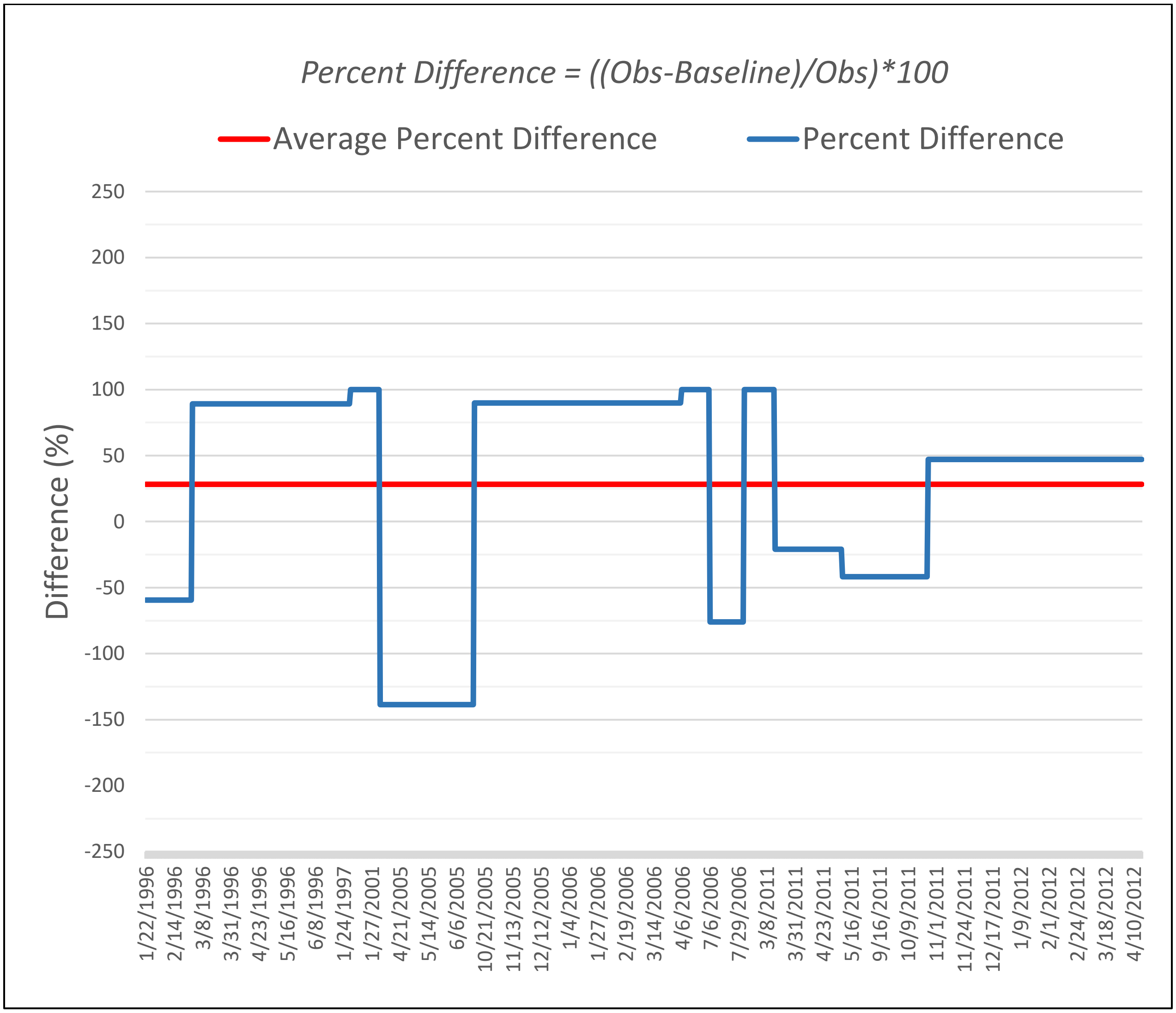
Alum Event	Start Date	Duration (days)	Kensico NTU (Max, OBS)	Kensico NTU (Max, SIM)	Kensico NTU (Avg, OBS)	Kensico NTU (Avg, SIM)
1	4/6/1987	43	NA	NA	NA	NA
2	1/22/1996	151	3.2	3.4	1.7	2.8
3	1/14/1997	15	2.2	2.7	2.0	2.6
4	1/10/2001	23	2.9	1.8	1.6	1.7
5	4/5/2005	76	2.7	3.0	1.5	2.2
6	10/13/2005	41	1.4	3.2	1.0	2.7
7a*	12/1/2005	129	1.5	3.1	0.9	2.8
7b*	5/15/2006	10	1.9	1.9	1.5	1.7
7c*	6/28/2006	36	2.5	2.0	1.1	1.6
8	1/31/2011	11	2.9	3.8	1.4	3.6
9	3/2/2011	79	1.8	4.1	1.2	3.1
10	8/29/2011	260	4.9	3.8	1.1	3.0

The simulated turbidity values are generally higher than the observed turbidity values for both average and maximum conditions. The model rules allow turbidities to go slightly above 3 NTU, but water supply managers without the benefit of OST simulations likely operated conservatively to keep turbidity levels in Kensico Reservoir much lower. In contrast, the model applied a lower dose of alum and terminated dosing sooner while still maintaining turbidity below the 5 NTU threshold.

The ability of OST to simulate turbidity values in Kensico Reservoir and the alum application protocols to achieve those turbidity values could potentially reduce and/or optimize the alum dosage, treatment duration, and mass loading during alum treatment events in the future. NYC will continue to evaluate and refine the use of OST to guide alum treatment should it again be necessary.

The difference in the mass of alum used between the actual and simulated alum treatment events is shown in Figure 2. On average, the applied mass of alum was 25 percent higher than the simulated no-action alum mass. This further suggests the possibility that the predictive capabilities of OST with W2 could reduce the amount of alum used to manage turbidity events.

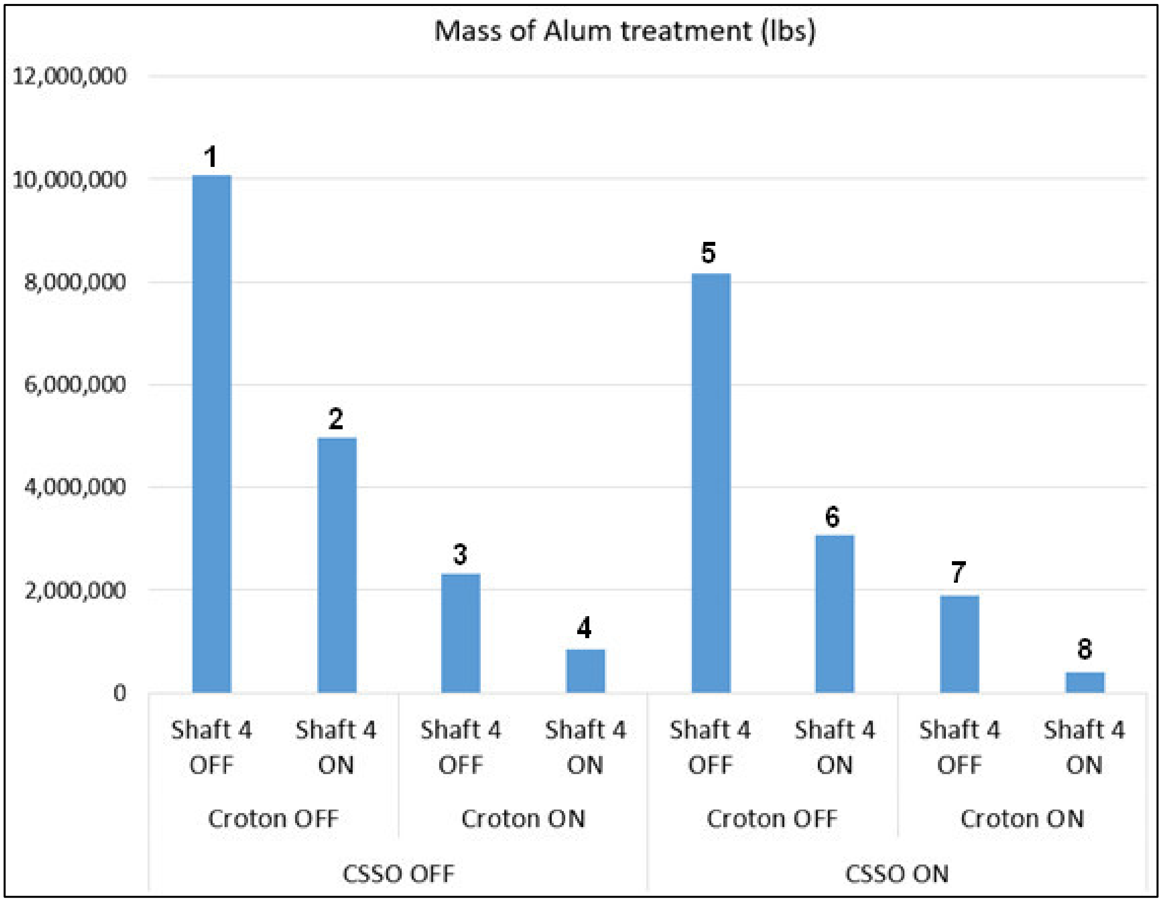
Figure 2. Percent difference in simulated and observed alum mass.



CTC Evaluation Metrics

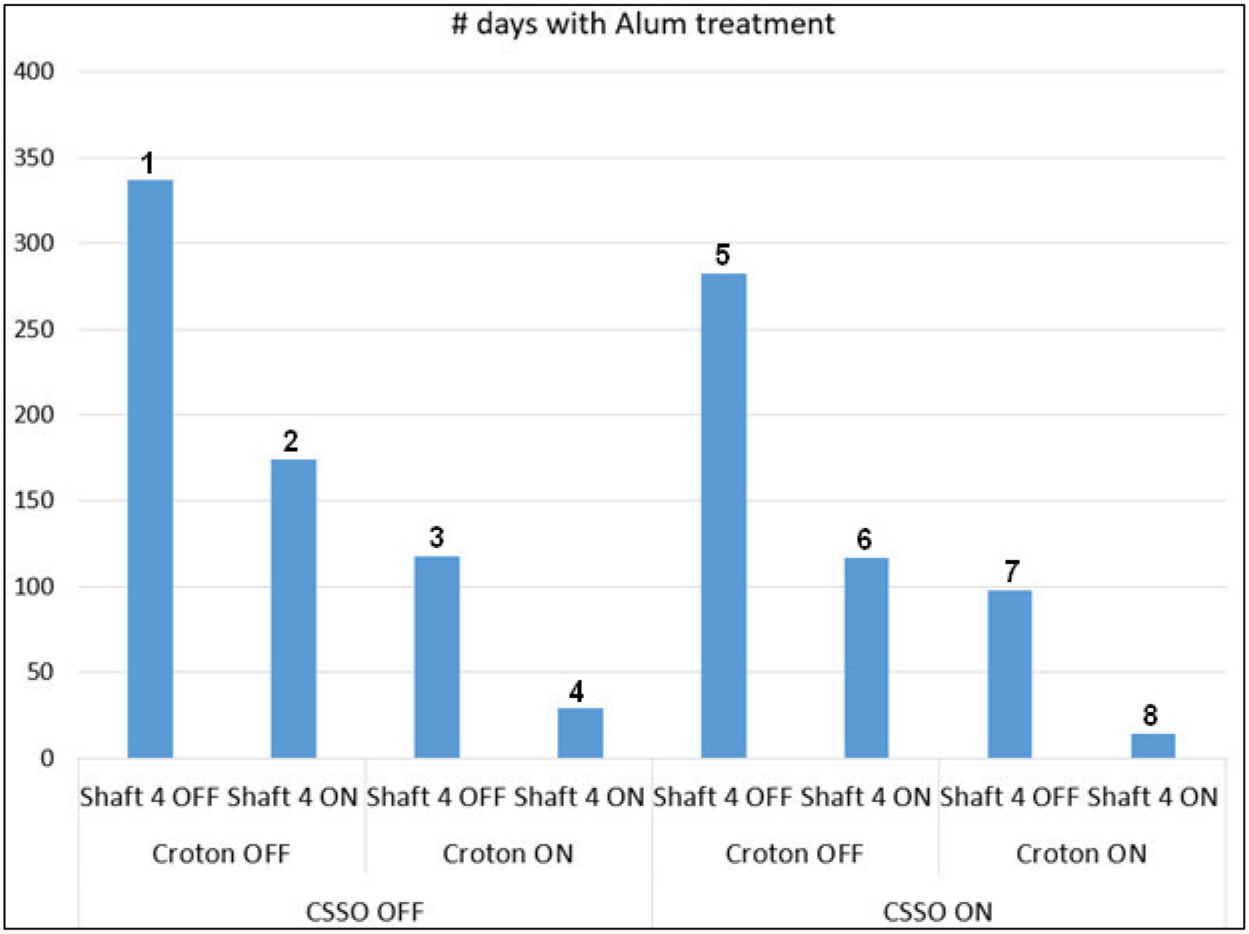
Figure 3 presents the mass of alum used over the period of 1996-2012, with the various combinations of CTC measures in place. The bar on the left side of the graph, Bar 1, represents the no-action scenario, while the bar on the right side of the graph, Bar 8, represents the all CTC measures active scenario.

Figure 3. OST simulated mass of alum used with and without turbidity control measures.



Use of the Croton system (Bar 3) had the greatest individual impact on reducing the mass of alum applied during the simulation period. The use of Shaft 4 individually (Bar 2) had the next largest impact. The use of the Croton System in combination with Shaft 4 (Bar 4) yielded a 91% reduction in simulated alum loading. The addition of the CSSO in combination with the other measures (Bar 8) resulted in a 96% reduction in alum loading compared to the no-action scenario.

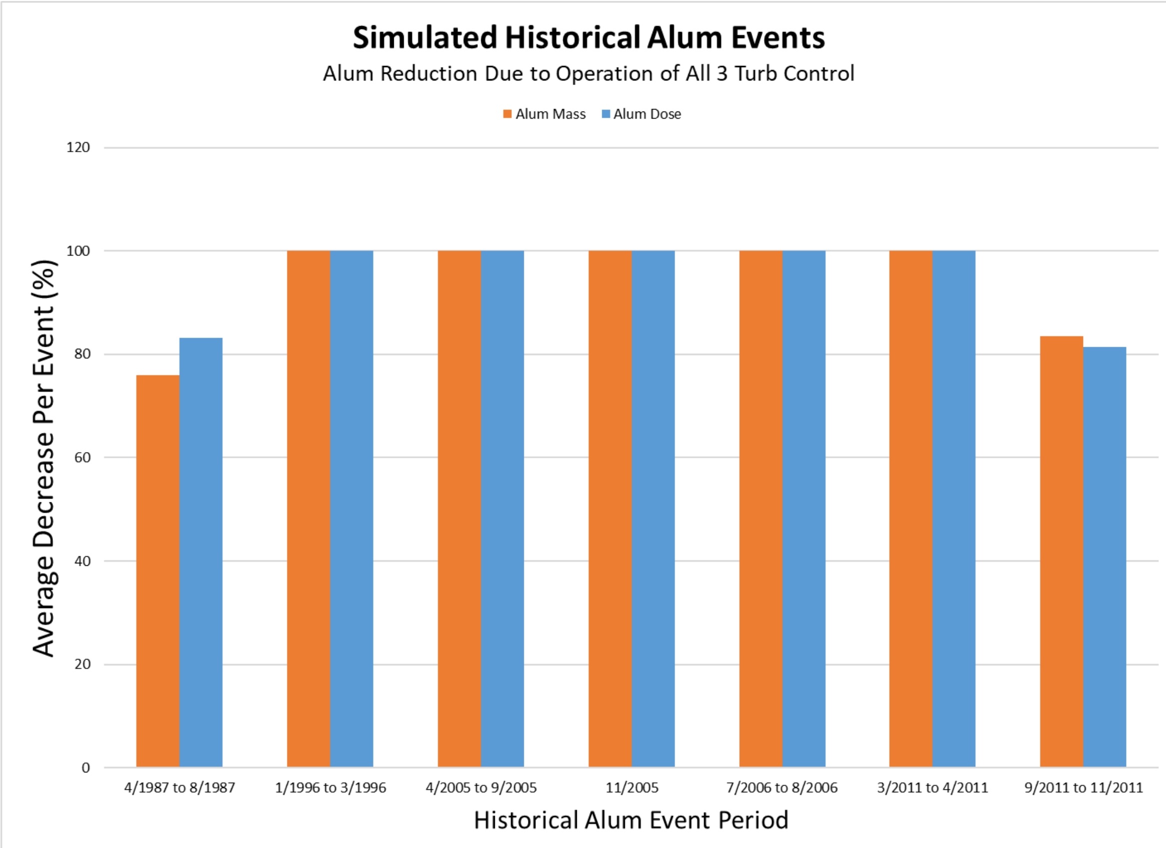
Figure 4. Number of days of alum treatment with and without turbidity control measures.



Similar to the mass of alum results, use of the Croton System (Bar 3) provided the greatest individual reduction in number of days of alum treatment, while the use of Shaft 4 and the CSSO (Bar 6) provided a similar benefit. The use of Croton in combination with Shaft 4 (Bar 4) reduced alum treatment by 308 days (91%). The addition of the CSSO in combination with the other measures reduced alum treatment by 323 days (96%).

The impact of the CTC measures on individual alum treatment events was also evaluated. The mass of alum used for each event was tabulated for the no-action scenario and the all-action scenario. For each simulated treatment event, the percent reduction in total alum mass was calculated (Figure 5). Note that Figure 5 shows the percent reduction in alum only for periods where alum treatment was required in the baseline simulation. The percent change in alum dose and mass varies from +100% to -100% where a positive percent represents a reduction in alum use and a negative percent an increase. All events showed reduced alum use; hence, the Y-axis on Figure 5 does not drop below zero despite the potential to do so.

Figure 5. Simulated alum reduction for each turbidity event with implementation of all CTC measures.



The combination of all CTC measures eliminated alum use in all simulated events except for the April 1987 event and the August 2011 event associated with Hurricane Irene and Tropical Storm Lee.

The calculated percent reductions for each simulated treatment event were applied to their respective actual treatment events to estimate the impact the CTC measures would have had on the actual alum treatment events (Table 4).

Table 4. Actual alum mass used vs. estimated alum used with turbidity control measures implemented.

Alum Event	Start Date	Days	Actual Alum Loading (lbs)	Estimated Alum Reduction w/ Controls (%)*	Estimated Alum Loading with Controls (lbs)
1	4/6/1987	43	927,182	76	222,524
2	1/22/1996	151	2,448,553	100	0
3	1/14/1997	15	234,212	Not Simulated	N/A
4	1/10/2001	23	479,680	Not Simulated	N/A
5	4/5/2005	76	1,747,297	100	0
6	10/13/2005	41	1,171,128	100	0
7a**	12/1/2005	129	4,677,689	Not Simulated	N/A
7b**	5/15/2006	10	341,932	Not Simulated	N/A
7c**	6/28/2006	36	1,488,761	100	0
8	1/31/2011	11	290,215	Not Simulated	N/A
9	3/2/2011	79	1,145,749	100	0
10	8/29/2011	260	5,946,212	84	951,394

Notes:

- * Average reduction in alum usage during the base line run alum event
- ** Events are considered a single turbidity event
- Not Simulated – A treatment event was not simulated in OST during the treatment period i.e. OST W2 model calculations did not call for alum to be applied

The model simulations did not capture all of the actual treatment events observed, i.e., there were several events where alum was used, but the model simulation did not call for the use of alum ("Not Simulated" in Table 4). Likely explanations for this include:

1) conservative operation of the water supply system by managers that did not have the benefit of simulation tools and so chose to add alum at a rate and for a duration greater than OST simulated;
2) application of different rules and regulations in the model simulations than were in place during the actual treatment events, and
3) operational limitations during the actual treatment events such as inactive infrastructure that would not have been captured by the model simulations.

Across the simulation period, the implementation of all three CTC measures was shown to have a 96% reduction in required alum loading. Applying this simulated reduction to the mass of alum used during historical alum treatment events, the CTC Implementation measures are estimated to reduce the alum loading into Kensico Reservoir by approximately 20 million pounds (Table 5Table 5).

Table 5. Total alum mass used vs. estimated alum required with turbidity control measures implemented.

Alum Event Period of Record	Actual Alum Loading (lbs)	Simulated Alum Reduction w/ Controls (%)	Estimated Alum Loading with Controls (lbs)
1996-2012	**20,898,610**	**96**	**835,944**

Conclusions

This report describes performance criteria for evaluating the efficacy of Catskill Turbidity Control (CTC) measures, provides a quantitative estimate of the efficacy of the measures, and suggests that the use of OST in conjunction with these measures could result in a very large reduction in alum use.

The CTC measures evaluated were:

- Croton Filtration Plant (CFP)
- Catskill-Delaware Interconnection at Shaft 4 (CDIS4)
- Ashokan CSSO (not a CTC measure *per se*, but a relevant operational factor now in place that impacts turbidity management)

The following criteria were used:

- Total mass of alum used for turbidity control by event (lbs)
- Number of days of alum treatment by event (days)
- Average alum dose by event (mg/L)
- Maximum Kensico turbidity by event (NTU)
- Average Kensico turbidity by event (NTU)
- Percent difference in alum mass by event (%)
- Average percent difference in alum mass over a period of multiple events (%)
- Total alum loading over a period of multiple events (lbs)
- Average alum mass reduction by CTC(s) and event (%)
- Total alum load reduction over a period of multiple events (%)

The quantitative results showed:

- The CTC measures implemented provided a very large (simulated) reduction in alum use relative to that observed during historical operations, including:
    - 96% reduction in alum mass and number of alum days over the entire period of record, for all CTC measures combined.
    - Complete elimination of alum usage for most events.
- The largest reduction in alum usage was due to the use of the Croton System via CFP.
- The second largest reduction was due to the use of CDIS4.
- The Ashokan CSSO provided some additional benefit.
- Using OST with W2 models on to inform management decisions could result in a large reduction or even complete elimination of alum use.