New York City Department of Environmental Protection
Bureau of Water Supply

Catskill Turbidity Control Alternatives Summary Report

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Prepared by:
Dr. Kimberlee Kane
Watershed Protection Programs
Bureau of Water Supply

Table of Contents

1. Introduction ... 1

2. Background ... 1
2.1 NYC Water Supply ... 1
2.1.1 Shandaken SPDES Permit ... 2
2.1.2 Catalum SPDES Permit ... 2
2.2 Catskill Turbidity Control ... 4
2.2.1 The Catskill Turbidity Control Study ... 4
2.2.2 Alternatives Analysis ... 5
2.2.3 Watershed Management Studies ... 5
2.2.4 Alum Deposition in Kensico Reservoir ... 5
2.2.5 Catalum Environmental Review ... 6
2.3 Modeling Overview ... 6
2.4 Supporting Documents ... 7

3. Catskill Turbidity Control Phase I ... 8
3.1 Methodology ... 8
3.1.1 Performance Screening ... 9
3.1.2 Feasibility Screening ... 9
3.2 Description of Alternatives ... 9
3.2.1 Multi-level Intake in Schoharie Reservoir ... 9
3.2.2 Turbidity Curtain ... 10
3.2.3 In-Reservoir Baffle ... 10
3.2.4 Schoharie Modified Reservoir Operations ... 11
3.2.5 Engineered Treatment Facilities ... 11
3.2.6 Ashokan Modified Reservoir Operations ... 11
3.2.7 Intake Channel Dredging ... 12
3.3 Summary of Findings ... 12
3.3.1 Multi-Level Intake ... 12
3.3.2 Turbidity Curtain ... 12
3.3.3 In-Reservoir Baffle ... 12
3.3.4 Modification of Reservoir Operations ... 13
3.3.5 Engineered Treatment Facilities ... 13
3.3.6 Ashokan Reservoir Modifications ... 13
3.3.7 Intake Channel Dredging ... 13

4. Catskill Turbidity Control High Rate Sedimentation Facility ... 15
4.1 Description ... 16
4.2 Summary of Findings ... 17
4.2.1 Water Quality ... 17
4.2.2 Reliability ... 17
4.2.3 Ease of Operation ... 17
4.2.4 Estimated Costs ... 17
4.2.5 Constructability ... 17
4.2.6 Environmental/Permitting Issues ... 18
4.2.7 Public Acceptance ... 18

5. Catskill Turbidity Control Phase II 18
5.1 Methodology 18
5.2 Description of Alternatives 19
5.2.1 Multi-level Intake in Schoharie Reservoir 19
5.2.2 In-Reservoir Baffle 20
5.2.3 Schoharie Modified Reservoir Operations 20
5.3 Summary of Findings 21
5.4 Implementation Plan 22
5.5 Supplemental Studies 23
5.5.1 Model Updates 23
5.5.2 Performance Evaluation of Alternatives 23
5.5.3 Sensitivity Testing 24

6. Catskill Turbidity Control Phase III 25
6.1 Methodology 25
6.2 Description of Alternatives 26
6.2.1 West Basin Outlet 26
6.2.2 Dividing Weir Crest Gates 26
6.2.3 East Basin Diversion Wall Improvements 27
6.2.4 Upper Gate Chamber Modification 27
6.2.5 East Basin Intake 27
6.2.6 Catskill Aqueduct Improvements – Shaft 4 Interconnection 27
6.2.7 Catskill Aqueduct Improvements – Aqueduct Stop Shutters 28
6.2.8 Modified Operations 28
6.3 Summary of Findings 29
6.3.1 West Basin Outlet Structure 30
6.3.2 Dividing Weir Crest Gates 30
6.3.3 East Basin Diversion Wall Improvements 30
6.3.4 Upper Gate Chamber Modifications 31
6.3.5 East Basin Intake 31
6.3.6 Catskill Aqueduct Improvements and Modified Operations 31
6.4 Value Engineering 32
6.4.1 Summary 32
6.4.2 Recommendations for West Basin Outlet Structure 32
6.4.3 Recommendations for Catskill Aqueduct Improvements 34
6.4.4 Recommendations for System Modeling 36
6.4.5 Recommendations for East Basin Diversion Wall 37
6.4.6 Recommendations for Upper Gate Chamber Improvements 38
6.4.7 Recommendations for New East Basin Intake 39
6.4.8 Miscellaneous Recommendations 40
6.5 Implementation Plan 41
6.5.1 West Basin Drawdown 42
6.5.2 Ashokan Release Channel Operation 42
6.5.3 Catskill Aqueduct Improvements 42
6.6 Turbidity Control Alternatives Analysis 45
6.6.1 Summary 45
6.6.2 Results 47

7. Watershed Management Alternatives 47
7.1 Schoharie Watershed Analysis 47
7.2 Ashokan Watershed Analysis 48

8. Kensico Alum Alternatives 49
8.1 Methodology 49
8.2 Description of Alternatives 50
8.2.1 Non-Structural Alternatives 50
8.2.2 Structural Alternatives 51
8.3 Summary of Findings 51

9. Modification of the Catalum SPDES Permit EIS 52
9.1 Ashokan Reservoir Alternatives 52
9.2 Alternatives along the Catskill Aqueduct 53
9.3 Alternatives at Kensico Reservoir 54

10. Conclusion 54

List of Figures

Figure 1. New York City Water Supply Watersheds 3
Figure 2. Phase III Ashokan Alternatives 29

List of Tables

Table 1. Summary of CTC Phase I Screening Evaluation 14
Table 2. Summary of CTC Phase II Evaluation. 22
Table 3. Summary of CTC Phase III Evaluation 44
Table 4. Catskill Turbidity Control Alternatives 55

1. Introduction

Turbidity in Catskill streams is a naturally occurring phenomenon due to the geologic history of the region. Over a hundred years ago when New York City (City) engineers designed the Catskill water supply system, episodic turbidity was recognized as a water quality issue and, in the decades that followed, the City has continued to refine approaches to manage these naturally occurring turbidity events.

Following the floods of April 1987, the New York City Department of Environmental Protection (DEP) undertook a study of turbidity in the Catskill System. The data analysis of routine monitoring data indicated that storm events, reservoir/watershed morphology and bedrock type may each play a role in the turbidity in the reservoirs. As a result of that information, in the 1990s DEP expanded its water quality monitoring program and conducted a targeted, regional study of water quality to identify areas of concern and develop a comprehensive understanding of sources and fate of materials contributing to turbidity. This study concluded that certain subbasins contribute a disproportionate amount of the turbidity and that the suspended sediment is predominantly from in-stream sources (stream banks and bottoms).

In accordance with the 2002 and 2007 Filtration Avoidance Determinations (FAD), DEP conducted the Catskill Turbidity Control Study (CTC Study) to provide a comprehensive analysis of engineering and structural alternatives to reduce turbidity levels in the Catskill System. The results have been compiled in a series of technical documents and, over the past decade, have been the subject of numerous peer reviewed publications.

This report summarizes the structural and nonstructural alternatives that DEP has evaluated, as well as the effectiveness of measures implemented by DEP, to address turbidity in the Catskill System and satisfies a condition of the Revised 2007 FAD. The Catskill Turbidity Control section of the Revised 2007 FAD requires the City to "*submit a report summarizing the structural and non-structural measures that have been considered, and/or are under consideration in the environmental review, to control the turbidity of Catskill water entering the Kensico Reservoir. This summary will include available information about cost, feasibility, and effectiveness of the measures considered, providing a single document that describes the assessments that have been or are being done pursuant to the FAD and the environmental review*." The environmental review referenced in the Revised 2007 FAD is an Environmental Impact Statement for which the New York State Department of Environmental Conservation (NYSDEC) is lead agency. That environmental review is being conducted to support DEP's request to modify its Catalum State Pollutant Discharge Elimination System (SPDES) Permit.[1]

2. Background

2.1 NYC Water Supply

The New York City water supply system consists of three surface water sources (the Croton, the Catskill, and the Delaware) and a system of wells in Queens (the Jamaica system). The three upstate water collection systems include 19 reservoirs and three controlled lakes with a total

[1] The Catalum SPDES Permit authorizes DEP to add alum to the Catskill aqueduct when necessary to control turbidity entering Kensico Reservoir. As explained in detail below, the proposed modifications to the Catalum SPDES Permit will incorporate an operating protocol for the Ashokan Release Channel. The environmental review is being conducted in accordance with the terms of an administrative consent order between DEP and DEC.

storage capacity of approximately 580 billion gallons. They were designed and built with various interconnections for flexibility to meet quality and quantity goals and to mitigate the impact of localized droughts or storm events. The system supplies drinking water to almost half the population of the State of New York—more than 8 million residents of New York City and one million people in Westchester, Putnam, Orange, and Ulster Counties—plus the millions of commuters and tourists who visit the City throughout the year. Overall consumption averages about one billion gallons a day. DEP is the City agency charged with primary responsibility for overseeing the operation, maintenance, and management of the water supply infrastructure and the protection of the 1,972- square-mile watershed.

The Catskill System consists of two reservoirs—Schoharie and Ashokan—located west of the Hudson River in Ulster, Schoharie, Delaware, and Greene Counties. The Catskill System was constructed early in the twentieth century, beginning with Ashokan Reservoir, which went into service in 1915. Water flows southeast from Schoharie Reservoir via the 18-mile Shandaken Tunnel, emptying into Esopus Creek at Allaben. From there water continues to flow another 12 miles in Esopus Creek before entering the West Basin of Ashokan Reservoir. The Ashokan Reservoir is designed as two separate basins to allow extended settling time before water that enters the West Basin flows across the Dividing Weir into the East Basin. Water leaves Ashokan through the 75-mile-long Catskill Aqueduct, which connects to Kensico Reservoir in Westchester County. On average, the Catskill System provides over 40% of the City's daily water supply. The Catskill watershed is prone to elevated levels of turbidity during storm events due to the underlying geology. High stream flows can destabilize stream banks and mobilize stream beds, resulting in the erosion of glacial clays. These eroded clay particles are the predominant cause of elevated turbidity levels in Catskill streams and reservoirs.

2.1.1 Shandaken SPDES Permit

In 2006, NYSDEC issued a SPDES Permit for the Shandaken Tunnel, including permit limits for flow, turbidity, temperature, and phosphorus levels in diversions to Esopus Creek. The permit established a requirement for continuous turbidity and temperature monitoring, reporting, notification, and specified programmatic compliance actions with the goal of reducing turbidity in the Shandaken Tunnel diversions. While the Shandaken Tunnel can carry highly turbid water, the Tunnel is generally shut down following high flow events and the turbidity delivered to the Ashokan Reservoir from in-basin sources overwhelms any contribution from the Shandaken Tunnel. DEP's permit modification and variance request is currently pending with NYSDEC.

2.1.2 Catalum SPDES Permit

The Catskill Aqueduct was designed to enable addition of aluminum sulfate (alum) and sodium hydroxide just prior to Kensico Reservoir in order to periodically treat elevated levels of turbidity. The ability to reduce turbidity in the Kensico Reservoir is important to ensure that turbidity does not exceed 5 nephelometric turbidity units (NTU) in representative samples of the source water immediately prior to the first point of disinfection, as required by applicable State and federal regulations.

In June 2005, the City applied for a SPDES permit from NYSDEC for alum addition as needed for water supply purposes. NYSDEC issued the Catalum SPDES Permit, effective January 1, 2007 (NY 026 4652) which authorizes the addition of alum into the Catskill Aqueduct upon the condition that the City continues to work to achieve the goals of turbidity reduction and reduced alum usage in the Kensico Reservoir.

Figure 1. New York City Water Supply Watersheds

Rain events in early October and early December 2010 caused elevated turbidity levels in the Ashokan Reservoir. In addition to alum at Kensico, DEP also utilized the Ashokan Release Channel as part of a strategy previously approved by NYSDOH and EPA to ensure that all drinking water standards were met. This use of the Release Channel raised concerns from communities along the Esopus Creek downstream of the reservoir. In February 2011, NYSDEC commenced an administrative enforcement action against the City for alleged violations of the Catalum SPDES Permit regarding operation of the Ashokan Release Channel and alum addition. NYSDEC and DEP negotiated a consent order to resolve the alleged violations, which took effect in October 2013. The consent order includes penalties, environmental benefit projects, a schedule of compliance and an Interim Release Protocol for operation of the Ashokan Release Channel.

2.2 Catskill Turbidity Control

Since 2002, DEP has undertaken a number of studies and implemented significant changes to its operations in order to better control turbidity in the Catskill System. Many of these measures have been implemented pursuant to the 2002 and 2007 FADs and the Shandaken Tunnel and Catalum SPDES Permits. This section provides background on the major research projects and turbidity control efforts that DEP has undertaken since 2002 and which DEP plans to undertake going forward.

2.2.1 The Catskill Turbidity Control Study

The Catskill Turbidity Control Study (CTC Study) was conducted by DEP with the Gannett-Fleming-Hazen and Sawyer Joint Venture (JV). The CTC Study also included Upstate Freshwater Institute (UFI) and HydroLogics, Inc, as subconsultants. The CTC Study was conducted in three phases between 2002 and 2009.

Phase I, completed in December 2004, provided a preliminary screening-level assessment of turbidity control alternatives at Schoharie. As required by the 2002 FAD, the Phase I study identified potentially feasible, suitable, and cost effective measures at Schoharie Reservoir for additional evaluation. In addition, based on DEP's assessment of the comparative contributions of turbidity in the Catskill System, the Phase I study recommended further assessment of potential turbidity control measures at Ashokan Reservoir.

Phase II, completed in September 2006 in accordance with the 2002 FAD, consisted of detailed conceptual design, cost estimation, and performance evaluation of three alternatives for improving turbidity and temperature in diversions from Schoharie Reservoir: a Multi-Level Intake, In-Reservoir Baffle, and Modification of Reservoir Operations. The Phase II Implementation Plan was submitted in December 2006. DEP selected the Modification of Reservoir Operations as the most feasible, suitable and cost-effective alternative for improving turbidity and temperature control at Schoharie Reservoir. A critical component of this alternative was the development of a system-wide Operations Support Tool (OST) that would allow DEP to optimize reservoir releases and diversions to balance water supply, water quality, and environmental objectives. In July 2009, DEP completed the Phase II Implementation Plan: Updates and Supporting Analyses. This report presented results of model updates, analyses, and sensitivity testing conducted to support evaluation of turbidity and temperature control alternatives at Schoharie Reservoir. The performance evaluation results were consistent with the conclusions previously reached in the Phase II study.

Phase III, completed in December 2007 in accordance with the 2007 FAD, focused on turbidity control alternatives at Ashokan Reservoir that could reduce turbidity levels delivered to Kensico Reservoir via the Catskill Aqueduct. Phase III included conceptual design and performance evaluation of six alternatives: West Basin Outlet, Dividing Weir Crest Gates, East Basin Diversion Wall Improvements, Upper Gate Chamber Modifications, East Basin Intake, Catskill Aqueduct Improvements and Modified Operations. The Phase III Implementation Plan was submitted in July 2008 and Catskill Aqueduct Improvements and Modified Operations were selected for implementation. The Catskill Aqueduct Improvement alternative consisted of three options for further consideration. All three options accomplish the same goal, specifically to allow reduced diversions from Ashokan during turbidity events while maintaining Catskill Aqueduct flows at a level sufficient to maintain service to outside community taps along the Catskill Aqueduct. DEP decided to proceed with construction of an interconnection at Shaft 4, to improve overall system dependability, and to improve stop shutter facilities. DEP also proceeded with Modified Operations with the development and use of OST which includes strategic use of the Ashokan Release Channel.

2.2.2 Alternatives Analysis

Subsequent to the Phase III Implementation Plan, DEP conducted additional modeling of the alternatives selected for implementation using an updated version of the linked water supply-water quality modeling framework that was developed and applied in Phase III, over a 61-year simulation period, and two different water supply demand scenarios. The performance of each alternative was evaluated based on simulated daily turbidity levels in diversions from Ashokan and Kensico Reservoirs, the frequency and duration of alum treatment events, and the mass of alum used during treatment events. DEP concluded that the need for alum treatment of Catskill System water in the future would be limited and projected to be reduced to zero once the infrastructure projects that were in design or construction were completed.

2.2.3 Watershed Management Studies

The Shandaken SPDES and Catalum SPDES permits both required DEP to identify and evaluate the potential benefits of heightened or more expansive implementation of watershed protection programs established under the 1997 NYC Watershed Memorandum of Agreement or the Filtration Avoidance Determination in the Schoharie and Ashokan basins, respectively. The analyses showed that in-stream sources accounted for the vast majority of the turbidity and therefore enhancing watershed programs would not achieve any measurable turbidity reductions. The reports also found that stream management programs cannot significantly reduce turbidity levels at very high flows – the critical period when turbidity levels most impact the reservoir system.

2.2.4 Alum Deposition in Kensico Reservoir

Separate from the CTC Study, several studies have been completed at the Kensico Reservoir evaluating alum deposition and environmental impacts. The Catalum SPDES Permit required DEP to develop and submit a bathymetric/benthic report to establish a scientific basis for the quantity of alum floc deposits that must be removed to meet the water quality standard for suspended, colloidal and settleable solids in the Kensico Reservoir. In 2006, technical investigations were performed to determine the approximate location and depth of the alum floc depositions in Kensico Reservoir. These investigations were summarized in a report entitled *Extent and Depth of Alum Floc in Kensico Reservoir*, submitted in October 2007. In December 2007, a supplement to the report was submitted that identified a rationale for an area to be

dredged based on minimizing the environmental impacts of dredging. The impacts of dredging the proposed area were evaluated in a report entitled *Impacts of Dredging the Estimated Area of Alum Floc Deposition in Kensico Reservoir* in September 2008. The Catalum SPDES Permit also required DEP to develop a report to analyze alternatives to minimize the area of floc deposition resulting from the addition of alum and sodium hydroxide. That report, entitled *Feasibility of Minimizing the Area of Alum Floc Deposition in Kensico Reservoir*, was submitted in October 2007.

2.2.5 Catalum Environmental Review

In June 2012, consistent with the Catalum consent order, DEP requested a modification to the Catalum SPDES Permit to incorporate measures to control turbidity in water diverted from Ashokan Reservoir and to postpone dredging of alum floc at Kensico Reservoir until completion of certain infrastructure projects. The proposed permit modification is subject to environmental review under the State Environmental Quality Review Act (SEQRA), for which NYSDEC is serving as lead agency.

NYSDEC released a draft scope for the Environmental Impact Statement (Catalum EIS) for public comment in April 9, 2014; the comment period is scheduled to close on August 22, 2014. The Catalum EIS will evaluate the potential for significant adverse environmental impacts to both the Ashokan Reservoir/lower Esopus Creek and Kensico Reservoir that may occur from implementation of the turbidity control measures proposed to be incorporated into the Catalum SPDES Permit as well as from the postponement of dredging of Kensico Reservoir. The EIS will evaluate a suite of alternatives at Ashokan Reservoir, along the Catskill Aqueduct and at Kensico Reservoir as well as implementation of DEP's turbidity control measures as a whole. Where potential adverse impacts are identified, reasonable and practicable measures that have the potential to avoid, mitigate, or minimize these impacts will be identified.

2.3 Modeling Overview

Water quality models for Schoharie, Ashokan and Kensico Reservoirs are based on the widely accepted CE-QUAL-W2 (W2) hydrothermal/transport model. DEP customized the W2 models to provide explicit simulation of turbidity within each reservoir. The Operational Analysis and Simulation of Integrated Systems (OASIS) model simulates operation of the entire New York City Reservoir System. The W2 models provide, to the OASIS model, the turbidity of water available for withdrawal each simulated day, and the OASIS model projects diversions and releases from each reservoir in the system based on demand levels, release requirements, storage balancing and, in the case of Schoharie and Ashokan Reservoirs, turbidity levels. These daily diversion and release projections in turn inform the following simulated day's water quality and quantity, thereby providing a dynamic simulation of reservoir operations within the context of the system-wide water supply needs and constraints, while accounting for daily water quality variations.

In 2007, DEP substantially upgraded the linked model framework to meet Phase III analytical objectives by adding 2-D water quality models for Ashokan and Kensico Reservoirs, revising operating rules for system balancing and Ashokan operations, updating Delaware Basin operating rules, and incorporating short-term Esopus Creek streamflow forecasts and long-term system inflow forecasts. Detailed monitoring and process studies were conducted to support the development and testing of the Ashokan and Kensico Reservoir water quality models; a 3-D

water quality model of Ashokan East Basin was also developed to support the evaluation of East Basin Diversion Wall Improvements Alternative.

Model development is not a static, one-time event but rather a continuing process of development and refinement as new data is available, new techniques are identified and new tools are needed. The Catskill Turbidity Control Study extended over many years and the models and assumptions evolved over time. This report is intended to provide an overview of the Catskill turbidity alternatives analyzed by DEP. A detailed description of the modeling tools and assumptions can be found in the original technical reports.

2.4 Supporting Documents

Research into the sources and possible management options for turbidity in the Catskill System has generated numerous studies, reports and journal articles over the past 20 years. The key supporting documents for the alternatives summarized in this report are as follows:

- Catskill Turbidity Control Study Phase I Final Report, prepared for DEP by Gannett Fleming/Hazen and Sawyer (Joint Venture) under CAT-211, December 2004.
- Catskill Turbidity Control Study Technical Memorandum: High Rate Sedimentation Facility, prepared for DEP by Gannett Fleming/Hazen and Sawyer (Joint Venture) under CAT-211, January 2006.
- Catskill Turbidity Control Study Phase II Final Report, prepared for DEP by Gannett Fleming/Hazen and Sawyer (Joint Venture) under CAT-211, September 2006.
- Catskill Turbidity Control Study Phase II Implementation Plan, prepared for DEP by Gannett Fleming/Hazen and Sawyer (Joint Venture) under CAT-211, December 2006.
- Catskill Turbidity Control Study Phase II Implementation Plan: Updates and Supporting Analyses, prepared for DEP by Gannett Fleming/Hazen and Sawyer (Joint Venture) under CAT-211, July 2009.
- Catskill Turbidity Control Study Phase III Final Report, prepared for DEP by Gannett Fleming/Hazen and Sawyer (Joint Venture) under CAT-211, December 2007.
- Catskill Turbidity Control Study Phase III Value Engineering Final Draft Report, NYC Office of Management and Budget, April 2008.
- Catskill Turbidity Control Study Phase III Implementation Plan, prepared for DEP by Gannett Fleming/Hazen and Sawyer (Joint Venture) under CAT-211, July 2008.
- Turbidity Control Alternatives Analysis, prepared for DEP by HDR/Hazen and Sawyer (Joint Venture) under RTC-08, February 2011.
- Schoharie Watershed Turbidity Reduction Report: Evaluation of Watershed Management Programs, DEP September 2007 (rev. November 2008).
- Evaluation of Turbidity Reduction Potential through Watershed Management in the Ashokan Basin, DEP July 2008 (rev. November 2008).
- Feasibility of Minimizing the Area of Alum Floc Deposition in Kensico Reservoir, prepared for DEP by Malcolm Pirnie, Inc., October 2007.

- Extent and Depth of Alum Floc in Kensico Reservoir, prepared for DEP by Malcolm Pirnie, Inc., October 2007.
- Impacts of Dredging the Estimated Area of Alum Floc Deposition in Kensico Reservoir, prepared for DEP by Malcolm Pirnie, Inc., September 2008.
- Draft Scope for the Modification of the Catalum SPDES Permit EIS, released by NYSDEC on April 9, 2014, available from www.dec.ny.gov/lands/79771.html.

3. Catskill Turbidity Control Phase I

Phase I of the Catskill Turbidity Control Study consisted of a preliminary screening assessment of turbidity control alternatives. The goal of the Phase I study was to identify alternatives at Schoharie Reservoir that might reduce turbidity levels entering Esopus Creek and were feasible and cost-effective. DEP also considered whether the alternatives could help control temperatures in the diversions to Esopus Creek. Six major groups of alternatives were considered in Phase I, including:

- Multi-Level Intake (MLI)
- Turbidity Curtain
- In-Reservoir Baffle
- Modification of Reservoir Operations
- Engineered Treatment Facilities
- Ashokan Reservoir Modifications[2]

Some alternatives had different design options referred to as sub-alternatives, such as the seven possible sub-alternatives under the MLI alternative.

3.1 Methodology

The Phase I evaluation consisted of three primary steps: (1) review of relevant historical data, reports, and regulations, to gain insight into the factors influencing turbidity transport in the Catskill System; (2) development of alternatives, using techniques such as utility benchmarking, computerized modeling, and bench and pilot testing; and (3) evaluation of alternatives, including pre-screening to eliminate infeasible and/or ineffective alternatives, followed by more in-depth analysis to identify the most promising alternatives.

The Phase I evaluation considered five alternatives that had the potential to reduce the turbidity of the Shandaken Tunnel diversions, as well as Ashokan Reservoir Modifications, which have the potential to reduce turbidity entering the Catskill Aqueduct. The evaluation methods and tools used within each individual alternative category were uniformly applied to each sub-alternative within the alternative. This consistency enabled selection of the most promising options within each alternative. However, since the performance assessment tools differed significantly between the alternatives, a purely quantitative comparison of the alternatives themselves was not performed in Phase I. Instead, a pass-fail screening process was developed to

[2] As noted above, DEP included alternatives at Ashokan Reservoir even though the focus of the FAD requirements was on diversions from Schoharie Reservoir.

identify potentially feasible, effective, and cost-effective turbidity control measures for further development and evaluation.

3.1.1 Performance Screening

The performance screening step ensured that each surviving alternative had the potential to provide some turbidity or temperature control benefit. An alternative did not need to provide both turbidity and temperature benefits if it could be combined with another alternative to achieve these goals. Selection of evaluation methods was determined by the nature of the alternative and the availability of appropriate tools. Performance of multi-level intakes and baffles was quantified using two- and three-dimensional models, respectively; turbidity curtain performance was evaluated with bench-testing and in-reservoir pilot-testing; treatment alternatives were predicted based on jar-testing and previous treatment process experience. Performance assessment for modified reservoir operations and Ashokan Reservoir Modifications were carried forward to Phase II for the development of the modeling tools necessary to evaluate performance potential.

3.1.2 Feasibility Screening

A preliminary feasibility screening step identified an alternative's serious flaws or drawbacks that had the potential to prevent successful implementation. Six major feasibility parameters were considered, including:

- Constructability: an alternative had to be constructible with respect to logistic concerns, such as space constraints, location, interference with existing facilities, and schedule.
- Reliability: an alternative had to afford an adequate degree of reliability such that it would perform the desired function in a dependable manner throughout the year, avoiding any impacts on water system operations.
- Cost: an alternative failed this screening step if its preliminary conceptual cost estimate was significantly higher than that of an alternative that provided equivalent or greater benefits.
- Environmental impacts: an alternative was eliminated if it could impose significant negative environmental impacts that could not be feasibly mitigated.
- Permitting: the necessary permits for an alternative had to be able to be obtained from the governing agencies in a reasonable timeframe.
- Public acceptance: an alternative failed if it could face overwhelming public opposition

3.2 Description of Alternatives

3.2.1 Multi-level Intake in Schoharie Reservoir

Selective withdrawal systems using multi-level intake structures have been successfully implemented to address a number of reservoir water quality issues. These structures operate by selectively withdrawing water from reservoir strata with the desired water quality characteristics.

A screening-level assessment of potential locations for a multi-level intake at Schoharie Reservoir was conducted to identify locations for multi-level intake water quality model simulations and provide a basis for development of conceptual designs and cost estimates. The site locations described below were used for planning purposes. The assessment was based primarily on reservoir bathymetric data, topographic maps, water quality data, and previous

project experience with intake structures and in-reservoir construction. Four potential multi-level intake locations were identified for the purposes of water quality modeling and conceptual cost estimation:

- Site 1 – Roughly 12,000 ft. north of the existing intake, this location near Gilboa Dam would provide limited access to water down to Elev. 1035. This location would provide a moderate increase in available storage compared to the current intake location, and is potentially less susceptible to peak turbidity levels as well.
- Site 1.5 – Roughly 9,800 ft. north of the existing intake, this location opposite Manor Kill would provide limited access to water down to Elev. 1035. This location would provide a moderate increase in available storage compared to the current intake location, and is potentially less susceptible to peak turbidity levels as well.
- Site 2 – Roughly 6,000 ft. north of the existing intake, this location midpoint in the reservoir would provide access to water down to Elev. 1050. This location would provide a moderate increase in available storage compared to the current intake location, and may offer reduced turbidity levels.
- Site 3 – Adjacent to the existing intake, this location would provide access to water down to roughly Elev. 1070. Storage volume would be the same as the existing intake, as would the overall turbidity in the water column. Turbidity control benefits would be provided by selective withdrawal from low turbidity strata.

For each location, a shoreline intake structure and a free-standing in-reservoir intake structure were considered.

3.2.2 Turbidity Curtain

A turbidity curtain is a permeable fabric curtain suspended in a water body for the purpose of reducing the concentration of particles in water passing through the curtain. Turbidity curtains are typically used to control runoff from construction sites located in or near a water body. Turbidity curtains have also been used, though not as often, to reduce solids and coliform bacteria entering reservoirs from localized runoff sources. In these cases, the curtain redistributes flow patterns such that flow velocity and short circuiting are reduced, allowing particles to settle out on the upstream side of the barrier. In addition, some filtration may occur across the fabric, further enhancing particle removal. Phase I conducted a comprehensive turbidity curtain study, including bench-testing, in-reservoir pilot testing, preliminary conceptual design, and evaluation.

3.2.3 In-Reservoir Baffle

The Schoharie Reservoir's volume and surface area are both small relative to the size of its watershed and the magnitude of peak flows delivered by its main tributary, Schoharie Creek. These factors result in a short hydraulic residence time and rapid refill during storm events, compared to other Catskill/Delaware reservoirs. Due to the shape of the reservoir and the location of the Shandaken Tunnel Intake, inflows from Schoharie Creek tend to short-circuit into the intake without moving into the main body of the reservoir north of the intake. A baffle constructed near the Shandaken Tunnel Intake has the potential to reduce short-circuiting into the intake, thereby increasing dilution of inflows, increasing residence time, and improving particle deposition. Two potentially feasible design options were identified: an impermeable curtain wall and a concrete block wall.

3.2.4 Schoharie Modified Reservoir Operations

With an over 75-year operating history with the Catskill system by the time of the Phase I analysis, DEP had developed a strong institutional knowledge and framework for operating the system of reservoirs and connecting streams and tunnels. However, DEP recognized that system reliability needs and future stresses on the system, such as water quality issues, new regulations, environmental constraints, climate change, and facilities being taken out of service for maintenance or due to malicious attack, would challenge the established guidelines. At the time of the Phase I analysis, DEP did not have any predictive tools that could guide operational decisions to meet both water quality and water quantity objectives. Several options to meet this need were identified:

- Improved LinkRes Model - update/expand LinkRes capabilities and use the model to test operational scenarios.
- Coordinated Use of OASIS and W2 Models - use the OASIS model and LinkRes or individual W2 models separately but sequentially as part of a single study.
- Linkage of OASIS and W2 Models - link the models so they actually run in parallel, and system operations may be simulated based on both water quantity and water quality constraints.

3.2.5 Engineered Treatment Facilities

Engineered treatment and settling facilities are a proven technology that could improve control over turbidity in diversions through Shandaken Tunnel. A number of treatment process alternatives were evaluated, including: in-reservoir coagulation, conventional sedimentation, high-rate sedimentation, in-reservoir sedimentation, swirl concentrators, ballasted flocculation, constructed treatment wetlands, and localized destratification.

3.2.6 Ashokan Modified Reservoir Operations

Modification of hydraulic controls at Ashokan Reservoir would not have an impact on water quality in Esopus Creek, but could improve DEP's overall ability to control turbidity entering the Catskill Aqueduct. This alternative consisted of a screening-level evaluation of potential modifications at Ashokan Reservoir that could further improve turbidity reduction in Ashokan Reservoir and increase the level of reliability of delivering low turbidity water to the Catskill Aqueduct and Kensico Reservoir. Multiple approaches for modifying the hydraulic controls at the Ashokan Reservoir were analyzed, including:

- Ashokan Releases - During and after periods of heavy runoff, release turbid West Basin water to Esopus Creek via a spillway or piped outlet device.
- Increase West Basin storage - Increase storage, and thus detention time for turbid inflows, in the West Basin.
- Selective transfer – Modify the Dividing Weir spillway and/or Gate House to allow for transfer from the West Basin to the East Basin at multiple elevations.
- In-Reservoir Baffle - Decrease short-circuiting by installing a baffle between the Dividing Weir (and Dividing Weir Gate House) and the East Basin intake.
- Permeable turbidity curtains - Reduce turbidity export by installing permeable turbidity curtains around the Catskill Aqueduct intake.

3.2.7 Intake Channel Dredging

Localized dredging of the Shandaken Intake Channel was required under the terms of the 2002 FAD. Dredging of the intake channel was expected to provide operational benefits, since it would remove debris and accumulated sediment from the intake channel, barracks, and intake chambers. In addition, DEP evaluated whether channel dredging could have an impact on the turbidity or temperature of water withdrawn from the reservoir by developing a computational fluid dynamics (CFD) model of the existing intake structure and intake channel.

3.3 Summary of Findings

A summary of the cost estimates and screening results for the Phase I analysis is provided in Table 1.

3.3.1 Multi-Level Intake

Results of a two-dimensional modeling effort indicated that selective withdrawal capability through a multi-level intake could help reduce turbidity export from Schoharie Reservoir and provide additional control over the temperature of the diversions. Further modeling over longer simulation periods to accurately quantify the long-term performance of selective withdrawal structures under a wider range of demand and climactic conditions was recommended for Phase II. Four potential sites for a new intake with selective withdrawal capability were evaluated. Of these, three sites were recommended for further evaluation in Phase II. Modifications to provide selective withdrawal capability at the existing Shandaken Tunnel Intake were also recommended for further evaluation in Phase II. Such modifications could provide benefits associated with selective withdrawal capability, but in a more cost-effective manner.

3.3.2 Turbidity Curtain

A comprehensive turbidity curtain study was conducted, including bench-testing, in-reservoir pilot testing, and conceptual design of a full-scale system. In-reservoir pilot testing indicated that a permeable turbidity curtain showed some potential for reducing turbidity export from Schoharie Reservoir. However, the ability of a full-scale system to provide consistent turbidity control performance was determined to be questionable. Factors contributing to this assessment included the inconsistent performance exhibited in the majority of bench and pilot tests; the potential negative impact of the air cleaning process on the overall particle removal provided by curtain system. In addition, a turbidity curtain at Schoharie Reservoir would constitute a large-scale implementation of a novel, complex technology in a challenging physical environment. Based on performance and reliability concerns, this alternative was not recommended for further development in Phase II, either as an interim or a long-term measure.

3.3.3 In-Reservoir Baffle

Preliminary three-dimensional modeling indicated that an impermeable baffle structure around the existing intake would reduce the short-circuiting of Schoharie Creek inflows into the intake, thus increasing mixing, dilution of inflows, and settling time. These factors have the potential to reduce turbidity export from Schoharie Reservoir. A baffle structure at the Schoharie intake could be constructed using either a floating, anchored impermeable membrane material, or a more conventional concrete barrier. The impermeable membrane curtain would have significantly lower life cycle cost than the concrete barrier, and this alternative was recommended for further evaluation in Phase II.

3.3.4 Modification of Reservoir Operations

This alternative involves modifying the operation of Schoharie and Ashokan Reservoirs to reduce the turbidity of diversions to Esopus Creek and to the Catskill Aqueduct. These alternative management strategies could also provide improved control over peak summer temperatures in water diverted to Esopus Creek. To further assess the feasibility of modifying reservoir operations to meet water quality objectives while still meeting supply constraints, a linked water quality/quantity modeling tool was proposed for Phase II, using the two-dimensional CE-QUAL-W2 reservoir water quality models established by UFI for the Catskill/Delaware reservoirs, and the OASIS reservoir operations model developed by HydroLogics for the DEP reservoir system.

3.3.5 Engineered Treatment Facilities

Various engineered treatment and settling facilities were evaluated in Phase I. Several of the sub-alternatives considered (including ballasted flocculation, or coagulation, flocculation and clarification using inclined plate settlers) could reduce turbidity export from Schoharie Reservoir and could reliably reduce the turbidity of Shandaken Tunnel diversions to low levels. However, due to the very high cost of such large capacity treatment facilities, as well as the significant environmental, permitting, and public acceptance issues involved in their implementation, none of the engineered treatment facilities were recommended for further evaluation in Phase II.

3.3.6 Ashokan Reservoir Modifications

Under this alternative, five Ashokan Reservoir modifications that could potentially reduce the turbidity of water entering the Catskill Aqueduct were evaluated. These modifications included providing capacity to release turbid West Basin water downstream, increasing West Basin storage capacity to allow longer detention time of turbid inflows, providing selective transfer capacity between West and East Basins, installing a baffle wall in the East Basin to reduce short-circuiting, and installing permeable turbidity curtain(s) around the Catskill Aqueduct intake(s). Three of these five alternatives were found to be potentially feasible and effective and were recommended for further evaluation, including: increasing West Basin storage; increasing release capacity in the West Basin; and installing a baffle wall in the East Basin.

3.3.7 Intake Channel Dredging

Two outputs from the CFD modeling were evaluated to assess the impact of dredging on water flowing into the intake: velocity and temperature. These results suggested that overall trends of particle scour and deposition within the intake channel were likely to remain much the same before and after dredging. That is, since bottom velocities would remain similar, particles that were large enough to settle out in the intake channel before dredging (e.g., primarily sands), would continue to do so after dredging. The temperature profile in the Shandaken Intake Channel would remain substantially similar in pre- and post-dredging conditions and for all scenarios would be predominantly stratified. There would be some vertical mixing but because the intake elevation is low, and the bottom water is colder (therefore heavier), a strong withdrawal flow from near the reservoir bottom was observed. Overall, the CFD evaluations suggest that dredging is not likely to have a substantial impact on withdrawal temperature.

Table 1. Summary of CTC Phase I Screening Evaluation

ALTERNATIVES	COST ($M)[1]	SCREENING RESULT
Multi-Level Intake[2]		
Site 1 – In-Reservoir Intake	256	Rejected on the basis of cost and performance compared to Site 1.5
Site 1.5 – In-Reservoir Intake	236	Recommended for further evaluation
Site 2 – Shoreline Intake	168	
Site 3 – Shoreline Intake	82	
Modifications to Existing Intake[3]	---	
Turbidity Curtain		
Double Layer Dual Filter Barrier with Air Cleaning	375	Rejected on the basis of reliability, performance, and cost
In-Reservoir Baffle		
Impermeable Curtain	53	Recommended for further evaluation
Concrete Block Wall	111	Rejected on the basis of cost compared to impermeable curtain
Modification of Reservoir Operations[4]		
Proof of Concept Model	0.6	Recommended for implementation in Phase II
Operations Support Tool	3.2	Recommended for further evaluation
Engineered Treatment Facilities		
High-Rate Sedimentation N. of Gatehouse	993	Rejected on the basis of cost, environmental, permitting, and public acceptance issues
Ballasted Flocculation N. of Gatehouse	954	
High-Rate Sedimentation NE of Hardenburgh Falls	848	
Ballasted Flocculation NE of Hardenburgh Falls	809	
Ballasted Flocculation at Allaben, NY	770	
Ashokan Reservoir Modification		
Increase West Basin Storage Capacity		
Hydroplus Fusegate	114	Recommended for further evaluation
Variable Elev. Inflatable Crest Gates	117	
Variable Elev. Inflatable Crest Gates (stainless steel)	145	

ALTERNATIVES	COST ($M)[1]	SCREENING RESULT
East Basin Baffle Wall		
Impermeable Curtain	34	Recommended for further evaluation
Jetty Wall Placement	47	
Panel Wall Construction	55	
Concrete Black Wall	70	
Precast Concrete Fall Sections	148	Rejected on the basis of cost
Bypass Drainage Channel	501	
West Basin Release Capacity[5]	34	Recommended for further evaluation
Selective transfer capability at the Dividing Weir	---	Rejected on the basis of performance
Permeable turbidity curtain in the East Basin	---	Rejected on the basis of reliability and performance

Notes:

1. Costs include construction and operation/maintenance costs, estimated in 2004.

2. Costs were evaluated for shoreline and in-reservoir intakes at each location. Costs are presented for the lowest cost option at each location. Shoreline and in-reservoir intakes were evaluated further in Phase II.

3. Performance, feasibility and cost were evaluated in Phase II.

4. Proof of concept model was developed in Phase II. The Operations Support Tool was further evaluated in Phase II.

5. This option was further evaluated in Phase II.

Under the 2002 FAD, DEP was required to dredge the intake channel. The dredging operation commenced on December 27, 2007 and was completed on February 7, 2008. A total of 423 tons of debris was removed from the area around the existing bar racks and 4510 cubic yards of sediment from the intake channel.

4. Catskill Turbidity Control High Rate Sedimentation Facility

A high-rate sedimentation facility was evaluated in a separate technical memorandum subsequent to the Phase I Catskill Turbidity Control Study in response to EPA's request. This facility would treat raw water from the portion of the Catskill Aqueduct between the Ashokan and Kensico Reservoirs. The evaluation included preparation of a conceptual design of a high rate sedimentation facility, identification of potential sites for the facility, cost estimating, and life-cycle economics.

High-rate sedimentation processes have been used extensively in the water industry to reduce particle concentrations prior to filtration and have experienced increased usage in recent years due to their smaller footprint and lower construction cost relative to conventional sedimentation processes. Although the use of high-rate sedimentation processes to address reservoir turbidity is

uncommon, such facilities have been proven highly successful in water treatment facilities throughout the U.S. and abroad.

4.1 Description

This alternative would involve withdrawing water directly from the Ashokan Reservoir or from a connection to the Catskill Aqueduct for treatment. The entire flow would be diverted, treated, and reintroduced either to the Catskill Aqueduct or directly into the Kensico Reservoir. To provide effective particle removal, treatment processes would be required prior to sedimentation, including coagulant addition, pH adjustment, rapid-mix and flocculation. The resultant treatment train would be similar to a conventional water treatment plant, but without the filtration or disinfection processes.

The conceptual design was based on several factors, including standard industry design references, previous project experience, manufacturer's information, and engineering judgment. In order to make the facility a manageable size and allow for redundancy and layout flexibility, the treatment plant was divided into four modules of equal capacity.

For dependability reasons, the treatment facility was designed to treat 600 million gallons per day (mgd), representing the maximum Ashokan Reservoir diversion as dictated by the capacity of the Catskill Aqueduct. The concept of treating a portion of the Ashokan Reservoir diversion and blending the treated water back with the remaining raw water was considered early in the study but was dropped from further consideration due to its limited effectiveness.

The high-rate sedimentation facility would be operated intermittently (i.e., only during periods of high turbidity in the Catskill System associated with extreme storm events) and could sit unused for years at a time. For the purpose of the evaluation, it was assumed that the facility would be in intermittent operation for 30 days per year. This intermittent operation schedule presents many operational challenges resulting in relatively high operations and maintenance (O&M) costs even if the facility is not operating.

The facility footprint was determined primarily by the amount and size of equipment. In addition to the sedimentation basin component, other structures required included: raw water pump station, chemical storage and feed facilities, solids handling facilities, solids storage facilities, dewatering buildings, electrical substations, generator buildings, a truck inspection and weigh-in station and security building were also included in the facility design. Taking all structures into account, a 35-acre footprint was determined necessary for the entire facility. Four potential sites were selected which have at least 35 acres of available land, and are within close proximity to the Ashokan Reservoir, Catskill Aqueduct and/or Kensico Reservoir.

- Site 1: Ashokan Site – DEP-owned 40-acre parcel of land located south of the Ashokan Reservoir in the area between Esopus Creek, the Catskill Aqueduct and Ashokan Dam. This site offered several advantages. In addition to its relatively flat topography, water could be diverted directly from the Ashokan Reservoir to the high-rate sedimentation facility.
- Site 2: Plattekill Site – Privately-owned 400-acre area north of Anderson Road, east of 208 and south of Rte. 55. This location was selected due to its flat elevation, lack of any interfering structures or conflicting interests, and proximity to the Catskill Aqueduct.

- Site 3: Yorktown Site – Privately-owned 100-acre parcel located in the predominantly residential area surrounding Stayback Hill adjacent to the Catskill Aqueduct in Yorktown, Westchester County. This site was selected due to its proximity to the New Croton Reservoir and the fact that the Catskill Aqueduct is not pressurized at this point.
- Site 4: Kensico Site – DEP-owned 45-acre parcel surrounding the Catskill Aqueduct outfall to the Kensico Reservoir. There were engineering and legal difficulties associated with construction in this location.

4.2 Summary of Findings

The feasibility of implementing a high-rate sedimentation treatment facility was evaluated according to the following factors: Water Quality, Reliability, Ease of Operation, Cost, Constructability, Environmental/Permitting Issues, and Public Acceptance. The findings for each of these factors are discussed below.

4.2.1 Water Quality

Although the use of high-rate sedimentation to reduce reservoir turbidity would be a novel application of a proven and widely used technology, it was expected that the treatment process would be able to provide control over Kensico influent turbidity from the Catskill System.

4.2.2 Reliability

Most water treatment plants undergo treatment challenges when they first start up, either after initial construction is completed or after a planned or unplanned shutdown. Because the treatment facility would be operated intermittently as dictated by raw water quality, reliability issues associated with infrequent startups would be expected. DEP concluded that this could result in difficulty achieving desired effluent turbidity during the early days of operation as the treatment facility is brought on line.

4.2.3 Ease of Operation

The treatment facility would involve multiple mechanical equipment items and chemical feed systems that would require optimization and troubleshooting as well as solids handling facilities, electrical substations, and a raw water pump station. Since the size of each component system would be relatively large, the buildings would occupy a relatively large area in a campus-type layout. The large area that would be occupied by the facility and the amount of mechanical equipment needed would require intensive O&M of the treatment facility, even during periods when the facility was not in use.

4.2.4 Estimated Costs

Capital costs for the high-rate sedimentation facility were estimated to be approximately $1.32 billion. Costs were estimated using a combination of good engineering judgment and typical rule of thumb values. An estimate of the costs associated with O&M of the high-rate sedimentation facility included costs for staffing, power, chemicals, and equipment maintenance. Total annual O&M costs were estimated to be approximately $2,310,000 per year. The 75-year life-cycle cost for a high-rate sedimentation facility was estimated to be $1.39 billion.

4.2.5 Constructability

Four potential sites were evaluated for locating the high-rate sedimentation facility. The subsequent analyses performed under the study deemed three of these sites as potentially suitable for the high-rate sedimentation facility, from the standpoints of topography, favorable hydraulics, and proximity to the Catskill Aqueduct. However, the three potential sites all involved

construction issues related to site access, equipment staging, labor availability, and the need for aqueduct shutdown during construction. Further study would be required to identify the most suitable of the three potentially feasible sites.

4.2.6 Environmental/Permitting Issues

If this alternative were selected then an Environmental Impact Statement would have to be performed for any proposed facility and location to determine the impact that development would have on the local area and environment. The construction and operation of a high-rate sedimentation facility would also require extensive permitting and approval.

4.2.7 Public Acceptance

DEP determined that none of the three recommended site locations would be completely acceptable to the general public. Numerous factors could negatively impact public opinion, including deforestation, visual impacts, increased truck traffic (both solids and chemicals), as well as a general desire not to have a large treatment facility constructed in a relatively pristine area. Further studies would be required to address these issues.

High-rate sedimentation is a proven water treatment process that could be innovatively applied to improve control over reservoir turbidity. However, its high cost of construction and operation, operational and maintenance complexity, infrequent use, and siting challenges pose significant drawbacks. For these reasons, high-rate sedimentation was not recommended for Catskill turbidity reduction.

5. Catskill Turbidity Control Phase II

The goal of Phase II was to identify and evaluate feasible, effective, and cost-effective measures for reliably improving turbidity and temperature control in diversions from Schoharie Reservoir to Esopus Creek. The following three alternatives, which were identified in the Phase I study as having reasonable potential to improve turbidity and temperature control in Schoharie Reservoir diversions, were further evaluated:

- Multi-Level Intake in Schoharie Reservoir, to allow selective withdrawal of water from strata with preferred temperature and turbidity levels;
- Impermeable Baffle Curtain in Schoharie Reservoir, to reduce short-circuiting of Schoharie Creek inflows into the intake, increase travel time, and improve settling; and
- Modification of Reservoir Operations, to improve turbidity and temperature control by modifying Schoharie Reservoir operating rules.

5.1 Methodology

The performance of each alternative was evaluated based on daily predicted turbidity, solids loading, and temperature in the Shandaken Tunnel diversion over a 57-year period. Predictions were developed using an advanced modeling framework that links a mechanistic reservoir water quality model of Schoharie Reservoir with a model of the NYC Reservoir system. This modeling framework allows each alternative to be evaluated on a dynamic and long-term basis under realistic operating conditions and a wide range of meteorological conditions. The Phase II analysis also produced detailed conceptual designs and cost estimates for each alternative, as well as an evaluation of reliability, constructability, maintenance requirements, potential environmental issues and permitting requirements for each alternative.

5.2 Description of Alternatives

5.2.1 Multi-level Intake in Schoharie Reservoir

A total of seven potential multilevel intake options at Schoharie Reservoir were evaluated. Conceptual designs and cost estimates were developed for new onshore and offshore intake structures at three locations in the reservoir. A conceptual design and cost were also developed for modifications to the existing Shandaken Intake that would provide multi-level intake capability at that structure. Long-term performance evaluation was conducted for these alternatives using the linked OASIS-W2 model described previously. The four potential multi-level intake sites were:

- Site 1.5 – This location was evaluated in Phase I. Detailed conceptual designs and cost estimates were developed for both an onshore and an offshore option at this location.
- Site 2A – This was a revision of Phase I, Site 2, located approximately 500 feet to the south. After detailed site evaluation, Site 2A appeared more favorable. The reservoir in the vicinity of Site 2A had a bottom elevation of roughly 1050 ft. and had the potential to provide access to water down to this elevation. Of the potential sites in this zone on the western shore of the reservoir, the shoreline was closest to the thalweg (at a distance of approximately 600 ft.) at this site allowing for easier access to deeper water. Detailed conceptual designs and cost estimates were developed for both an onshore and an offshore option at this location.
- Site 2E – This site, located at the eastern shore of the reservoir, was added for consideration because it was closer than Site 2A both to the reservoir thalweg (approximately 300 ft.) and the Shandaken Intake, and therefore involved a shorter tunnel length (5,650 ft. onshore, 5,220 ft. offshore). Like Site 2A, this site had a bottom elevation of roughly 1050 feet and had the potential to provide access to water down to this elevation. Detailed conceptual designs and cost estimates were developed for both an onshore and an offshore option at this location.
- Site 3 – The reservoir in the vicinity of Site 3 has a bottom elevation of roughly 1070 feet. A new multilevel intake at this site would provide selective withdrawal capability and access to water storage volume comparable to the current intake. After careful review of alternative multi-level intake options for this site, detailed conceptual design had been developed for a single option which involves constructing a MLI addition directly in front of the existing intake facility. This option was judged to represent the best approach for adding MLI capability at the existing intake.

In Phase II, more advanced modeling was performed over longer simulation periods to better quantify the long-term performance of selective withdrawal structures under a wider range of demand and environmental forcing conditions and to optimize MLI structure design. In addition to modeling results, further design evaluation included comparison of hydraulic limitations between proposed locations, the identification of more suitable locations from a construction perspective, evaluation of benefits of onshore versus offshore intake structures, and evaluation of the feasibility of modifying the existing Shandaken Tunnel intake to provide selective withdrawal capability. All MLI alternatives represented conventional structures that were expected to provide long-term, reliable service.

5.2.2 In-Reservoir Baffle

Inflows from Schoharie Creek tend to short-circuit into the Shandaken Tunnel Intake, located about a mile from the reservoir headwaters, without full benefit of the dilution and settling that occurs along the roughly four-mile path from the headwaters to Gilboa Dam. Preliminary three dimensional modeling performed in Phase I indicated that an impermeable in-reservoir baffle structure (also known as a "baffle curtain"), placed in front of the existing Shandaken Tunnel Intake, could reduce the short-circuiting of Schoharie Creek inflows into the intake and increase mixing, dilution of inflows, and settling time prior to withdrawal. Preliminary design activities indicated that the baffle structure could be constructed using either a floating, anchored impermeable membrane material, or a more conventional concrete barrier; however, the latter was not recommended for further evaluation based on its complex structural requirements and associated high cost.

In Phase II, additional modeling with explicit turbidity/particle transport over longer simulation periods was performed to better quantify baffle performance under a wider range of conditions. The results suggested that theoretically a baffle could reduce turbidity loading to the intake. Further research into baffle design with baffle manufacturers concluded that the installation of a baffle curtain of the required length and depth in Schoharie Reservoir was physically possible; however, conditions at the reservoir (e.g., wind and wave loads, reservoir depth, and ice, among other factors) presented a challenging environment for the curtain. Furthermore, there are no known permanent baffle curtain installations that are comparable to that being considered for Schoharie, with respect to similar design and operating conditions. Hence, the long-term performance, robustness and reliability of a baffle installation was determined to be questionable.

5.2.3 Schoharie Modified Reservoir Operations

Phase II evaluated ways in which operating rules for Schoharie Reservoir could be modified to reduce diversion turbidity and solids load as well as limit peak summer diversion temperatures. Several sets of operating rules were developed that would modify baseline Schoharie operations to improve turbidity and temperature control. The alternative operating rules were coded into the OASIS-W2 model, and long-term (1948-2004) simulations were conducted to evaluate the operating rules for water quality benefits and water supply impacts. In summary these options were:

- <u>Baseline Operations</u> – Under Baseline Operations, Schoharie diversions were not contingent on water quality-based operating rules or objectives. Diversions were made for water supply purposes, and also in order to comply with 6 NYCRR Part 670, which regulates Schoharie diversions based on the "combined flow" in Esopus Creek. The combined flow was calculated as the sum of the Shandaken Tunnel diversion plus flow at the Allaben gage. When Ashokan was spilling, diversions were made to maintain a maximum combined flow of 100 mgd. This reflected operation of the tunnel to maintain minimum flow levels in Esopus Creek, even if the water would be spilled from Ashokan.

- <u>Modified Operations 1</u> – consisted of Baseline Operations plus three modifications: eliminating Schoharie diversions when the turbidity of water available for diversion was greater than 100 NTU; eliminating Schoharie diversions when Ashokan was spilling; and reducing Schoharie diversions to minimum required levels when Ashokan was likely to refill by June 1.

- Modified Operations 2 – consisted of Modified Operations 1 plus two water quality operating rules: reducing Schoharie diversions to minimum required levels when the turbidity of water available for diversion was greater than 15 NTU, and reducing Schoharie diversions to minimum required levels when the temperature of water available for diversion was greater than 70°F.

In Phase II of this study, the concept of modifying existing operations at Schoharie Reservoir to provide additional turbidity and temperature control over Schoharie export was further advanced through the development of the linked water quality-water supply simulation tool, capable of simulating test reservoir operating rules. The water supply model, OASIS, was substantially upgraded, tested and validated for the Catskill Turbidity Control Study to represent current operating rules throughout the entire NYC reservoir system. In addition, the Schoharie Reservoir two-dimensional water quality model, W2, was rigorously developed to provide explicit simulation of temperature and turbidity within Schoharie Reservoir. The upgraded OASIS model was linked to the W2 water quality model of Schoharie. The linked tool was used to simulate operation of the reservoir system, and to make daily decisions about the quantity of water withdrawn from Schoharie Reservoir based on water quality, water temperature, physical constraints, regulatory requirements, demand, and water supply conditions in the rest of the system. In these simulations, these daily diversion and release decisions in turn affected the following day's water quality, thereby providing a dynamic simulation in which the reservoir was operated within the context of system-wide water supply needs and constraints, while taking into consideration daily water quality variations.

5.3 Summary of Findings

DEP concluded that all of the MLI alternatives would be reliable and easy to maintain; all would involve major construction, though this would be substantially more costly and disruptive for the downstream intakes (Site 2 or Site 1.5) due to the extensive excavation and tunneling involved; and all the MLI alternatives could be expected to modestly improve turbidity control compared to either baffle or Modified Operations alternatives in May and June (and, in some years, July). An MLI would provide minimal turbidity control benefit the remainder of the year. MLI alternatives would also be able to provide reliable control of peak summer temperatures; optimum temperature control requires operation under thermal banking rules that reduce flows to a minimum during the summer months. Downstream intakes provided slightly better temperature performance than the intake location in challenge years.

The study found that a baffle would be relatively easy to implement and could improve turbidity control during storm events. However, Schoharie is a challenging environment, and there is minimal industry experience with baffles in such conditions. A baffle at Schoharie would be a first-of-its-kind installation: failure and design modifications could be expected in the first few years, with no guarantee of long-term success. A baffle was determined to be a potentially unreliable alternative, and maintenance requirements could be onerous.

Model simulations conducted for the Study indicated that Schoharie Reservoir operations could be modified to reduce peak summer temperatures and the incidence of elevated turbidity levels, and to substantially lower solids loading to Esopus Creek. Some of these modified operations could be implemented in the near-term, though full implementation would require development of OST. With OST, it was expected that operators could improve upon the modified operating

rules evaluated in Phase II. OST would also provide a range of benefits beyond turbidity and temperature control at Schoharie.

5.4 Implementation Plan

A summary of the cost estimates and screening results for the Phase II analysis is provided in Table 2. As noted above, the baffle alternative was eliminated as infeasible and downstream MLI alternatives were eliminated because they provide no significant water quality or temperature benefits compared to an MLI at Site 3, while the costs are significantly higher. The remaining alternatives were evaluated based on cost vs. performance for solids loading reduction, turbidity reduction and temperature.

DEP selected the Modification of Reservoir Operations as the most feasible, suitable and cost-effective alternative for improving turbidity and temperature control at Schoharie Reservoir. A critical component of this alternative was the development of a system-wide OST that would allow operators to optimize reservoir release and diversion decisions to balance water supply, water quality, and environmental objectives. Of all the alternatives, DEP determined that modifying reservoir operations through the development of an OST would result in the highest benefit per cost. While implementing an MLI or baffle in conjunction with modified reservoir operations could provide marginal improvement in turbidity and temperature control, the additional expenditure was exorbitant for such an incremental enhancement in performance and would have a negligible impact on water quality and supply in the Catskill System.

Table 2. Summary of CTC Phase II Evaluation.

ALTERNATIVES	CAPITAL COST[1] ($M)	O&M COST ($M/YR)	LIFE-CYCLE COST ($M)	SCREENING RESULT
Operations Support Tool (OST)	$6	$1	$30	Selected for Implementation
Baffle (1,000 ft)	$12	$2	$70	Rejected on the basis of performance, robustness and reliability
MLI at Site 3	$75	$0.5	$90	Rejected on the basis of cost compared to OST
MLI at Site 2	$290	$1	$320	Rejected on the basis of performance and cost compared to MLI at Site 3
MLI at Site 1.5	$360	$1	$390	

Notes:

1. Costs were estimated in 2006.

5.5 Supplemental Studies

When NYSDOH, NYSDEC, and EPA conditionally approved the Phase II Implementation Plan in August 2008, there were some modeling-related questions. The Phase II Supplemental Studies addressed those questions and verified the performance of Schoharie alternatives using updated modeling tools and operating rules that reflect recent and proposed structural changes at Schoharie Reservoir, namely the Low-Level Outlet (LLO).

5.5.1 Model Updates

Turbidity and temperature control performance of Schoharie alternatives was evaluated in Phase II using an early version of the OASIS-W2 linked model. Numerous updates to this model were conducted during the Phase III study, including integration of Ashokan and Kensico water quality models, development of detailed operating rules for Ashokan hydraulic structures, and substantial revisions to the operating rules for the Delaware Basin. These additional model updates were included in the Supplemental Studies analysis, notably the addition of new Schoharie hydraulic structures (Gilboa Dam notch, crest gates, and Low-Level Outlet), extension of the simulation period to capture recent hydrologic conditions, updates to the Schoharie water quality model, and detailed evaluation of Schoharie Creek flow-turbidity relationships.

5.5.2 Performance Evaluation of Alternatives

Alternatives carried forward from the Phase II analysis included hypolimnetic banking, a multilevel intake (MLI) at Site 3 (the current intake location), and an MLI at Site 1.5. In addition, the Low-Level Outlet, designed for dam safety, was included as a potential turbidity control alternative. Baseline operating rules for all simulations included operation of Schoharie to reduce diversions to minimum levels whenever the diversion exceeds allowable thresholds for temperature (70°F) or turbidity (15 NTU). These rules corresponded to those evaluated as part of the Modified Operations alternative in the original Phase II evaluation and are consistent with the terms of the SPDES Permit for the Shandaken Tunnel, which was finalized subsequent to the Phase II Final Report. Additionally, the SPDES Permit established a turbidity increase limit for the Shandaken Tunnel diversion based on the background turbidity in Esopus Creek plus 15 NTU, referred to subsequently as the “delta-15 NTU” limit.

The results of the Supplemental Studies performance evaluation were qualitatively similar to those of the original Phase II evaluation and corroborated the findings of the Phase II Final Report. Major findings of the Supplemental Studies analysis included:

- No alternative would completely eliminate the occurrence of elevated diversion turbidity levels at Schoharie Reservoir. However, the predicted frequency of diversions that would exceed the delta- 15 NTU turbidity threshold was low over the 61-year simulation period, and all alternatives could be operated in compliance with the SPDES Permit limits.
- <u>Modified Reservoir Operations</u> – Consistent with Phase II findings, the Supplemental Studies analysis indicated that operation of the existing intake could be modified to substantially reduce the frequency of diversions that exceed the delta-15 NTU and 70°F thresholds. Shutting off the Shandaken Tunnel when the turbidity exceeds 100 NTU and reducing flow to minimum required levels whenever turbidity exceeds delta-15 NTU could substantially reduce the load of turbidity-causing particles delivered to Esopus Creek. Further, hypolimnetic banking could be implemented as an additional component of Modified Reservoir Operations to reduce peak summer diversion temperatures and

reduce the occurrence of diversions that exceed 70°F. Banking could also be combined with other alternatives to provide improved temperature control.

- Multi-Level Intake – Consistent with Phase II findings, the simulation results indicated that an MLI at either the existing intake location (Site 3) or downstream at Site 1.5 would provide little additional turbidity control benefit beyond that provided by Modified Reservoir Operations. Both MLI sites provide similar overall turbidity performance. As was observed in Phase II, an MLI at either site was predicted to provide a slight reduction in diversion turbidity levels in early summer, relative to Modified Reservoir Operations. An MLI at either location could provide control over peak summer temperatures by allowing withdrawals from warmer upper strata in the spring and early summer, thereby conserving the cold water pool for late summer diversions.
- Low-Level Outlet – The Low-Level Outlet at Gilboa Dam could be operated to implement a snowpack management program at Schoharie Reservoir. This operation was included as a baseline operating rule for all alternatives. The Supplemental Studies analysis also indicated that the Low-Level Outlet could potentially be operated to improve turbidity control in Shandaken Tunnel diversions by making releases from the reservoir subsequent to turbidity events. Operation of the Low-Level Outlet for turbidity control purposes was predicted to provide slightly better overall turbidity performance than either Modified Reservoir Operations or a Multi-Level Intake, and could also be combined with hypolimnetic banking to control peak summer diversion temperatures. Operation of the Low-Level Outlet for turbidity control would require detailed analysis of potential downstream impacts, as well as further refinement and testing of operating rules that balance water quality and water supply reliability objectives.

The Phase II Study concluded that OST would provide DEP with the monitoring and predictive capability necessary to refine, adopt, and implement formal operating rules for Schoharie Reservoir that balances turbidity and temperature control objectives while maintaining water supply reliability for the overall NYC water supply system.

5.5.3 Sensitivity Testing

Sensitivity testing of model parameters was also conducted and demonstrated that the water quality model and linked OASIS-W2 model were largely insensitive to the majority of model parameters examined (i.e., the model results are robust and not driving by a single parameter). The major exception was the Schoharie Creek turbidity-flow relationship used to drive long-term OASIS-W2 linked model simulations: use of different flow-turbidity relationships resulted in significant differences in the number of days in which Schoharie diversions exceed the 15 NTU turbidity threshold. However, while absolute performance varied, the relative performance of all alternatives was nearly identical under six different Schoharie Creek turbidity loading scenarios, including three alternative flow-turbidity relations and three representations of uncorrelated variability. Therefore, the results of the both the Phase II performance evaluation and the Supplemental Studies analysis were regarded as robust and indicative of the relative performance capabilities of the different turbidity control alternatives under a range of turbidity loading scenarios that reflect the inherent uncertainty and dynamic nature of the Schoharie Creek flow-turbidity relationship.

6. Catskill Turbidity Control Phase III

The goal of the Phase III study was to identify and evaluate feasible, effective, and cost-effective measures for reliably reducing peak turbidity levels turbidity entering the Catskill Aqueduct, thereby reducing the frequency and duration of alum addition events. The Phase III study included conceptual design and performance evaluation of the following six alternatives:

- West Basin Outlet – to release water from the West Basin of Ashokan Reservoir during peak events and reduce transfer of turbid water to the East Basin, effectively reducing turbidity in Catskill Aqueduct diversions;
- Dividing Weir Crest Gates – to provide temporary detention storage in the West Basin to retain peak inflows and reduce transfer of turbid water to the East Basin;
- East Basin Diversion Wall Improvements – to reduce short-circuiting between the Dividing Weir and the Upper Gate Chamber, increase travel time, and improve settling;
- Upper Gate Chamber Modifications – to improve selective withdrawal capability so that intake elevations can be readily adjusted to draw from strata with the lowest turbidity levels;
- East Basin Intake – to allow withdrawal of water from a zone of the reservoir less susceptible to elevated turbidity conditions;
- Catskill Aqueduct Improvements – to reduce turbidity transport to Kensico by allowing the Catskill Aqueduct to be readily operated at low flow rates while still maintaining water service to upstate communities; and
- Ashokan Modified Operations – to modify Ashokan Reservoir operating rules to optimize operation of existing facilities.

The performance of each alternative was evaluated based on predicted daily turbidity levels in Catskill Aqueduct diversions from Ashokan Reservoir, as well as the number and duration of alum addition events at Kensico Reservoir. Predictions were developed using an advanced state-of-the-art modeling framework that linked mechanistic reservoir water quality models of Schoharie, Ashokan and Kensico Reservoirs with the operations model of the NYC Reservoir System. This modeling framework allowed each alternative to be evaluated on a dynamic and long-term basis under realistic operating conditions and a wide range of environmental forcing conditions.

6.1 Methodology

Major design, capacity, or construction method options were identified for each alternative, and conceptual designs and associated planning-level cost estimates were developed for each of these options. Each of the alternatives was evaluated with respect to constructability, environmental and permitting considerations, reliability, operations and maintenance requirements, water supply reliability, water quality performance, and cost. Water quality performance for each alternative was evaluated using an expanded version of the linked water supply-water quality modeling framework that was developed and applied in Phase II. The linked model had several features that allow it to provide a robust evaluation of alternatives:

- Long simulation period (57 years), which encompassed a wide range of environmental forcing conditions that could be expected to occur in the future, and allowed for probabilistic interpretation of results;
- Dynamic linkage between water quality and water supply models, which allowed daily simulation of water quality-based diversion decisions and accounted for feedback between diversion/release decisions and reservoir water quality;
- Mechanistic two-dimensional water quality (turbidity) models of Schoharie, Ashokan, and Kensico Reservoirs, supported by detailed monitoring and process studies; and
- Robust operating rules to provide realistic simulation of reservoir system operations under a wide range of conditions, subject to contemporary system physical constraints, regulatory requirements, water supply needs, and water quality objectives.

6.2 Description of Alternatives

6.2.1 West Basin Outlet

An expanded Outlet Structure in the West Basin could reduce the number and magnitude of events during which there is uncontrolled transfer, as opposed to a controlled release, of turbid waters from the West Basin over the Dividing Weir to the East Basin. During peak storm events, turbid inflows pass quickly into the East Basin without the full benefit of dilution and settling that the West Basin provides under normal flow conditions. The only means available to release water from the West Basin and prevent spill to the East Basin was (and remains) through the Ashokan Release Channel, with a capacity of 600 mgd. A new Outlet Structure would allow water to be released from the West Basin during large storm events, thereby reducing spill to the East Basin. Conceptual designs were developed for single weir and multi-level outlet structures, with capacities ranging from 2,000 mgd to 6,000 mgd.

All West Basin Outlet alternatives represented conventional structures that are physically feasible and would be expected to provide long-term, reliable service. Although the structure could be constructed without major impacts on operation of the Ashokan Reservoir facilities or surrounding areas, operation of the outlet at the rates being considered would have potential flooding impacts on the lower Esopus Creek.

6.2.2 Dividing Weir Crest Gates

Gates could be installed on the Dividing Weir crest and could be operated to temporarily increase the West Basin overflow elevation by four feet to increase detention storage in the West Basin and reduce uncontrolled turbidity transfer to the East Basin. Based on a review of alternative types of gates, Obermeyer inflatable gates were selected for conceptual design purposes. The construction-related impacts on Ashokan Reservoir operations were projected to be minimal, provided that construction was scheduled during one or more periods when the level of both basins was below their respective overflow elevations. It was estimated that approximately 240 acres of DEP property would have to be cleared above the present shoreline of the West Basin for water quality and vegetation purposes. Affected areas also would include an estimated 33 acres of jurisdictional wetlands. Existing points of public access, parking areas, and related facilities in these areas would have to be relocated upland to maintain recreational usage of the reservoir.

6.2.3 East Basin Diversion Wall Improvements

The existing Diversion Wall in the East Basin is submerged by 20 feet or more and is not a fully effective barrier to flow that short-circuits over the Dividing Weir towards the Upper Gate Chamber. Extending the height and length of the Diversion Wall would direct flows from the West Basin farther out into the East Basin and would reduce short-circuiting to the Upper Gate Chamber and increase the travel time and dilution of flows prior to withdrawal. Conceptual designs and cost-benefit analyses were developed for three alternative wall lengths (750 feet, 1,700 feet and 2,400 feet) using jetty wall and closed-cell coffercell construction methods. Potential improvements to the adjacent spillway channel, either in conjunction with or in lieu of the wall improvements, were also considered. Issues that would be encountered during construction include accessibility (e.g., access road widths and weight limits), substantial truck traffic, and temporary impacts on reservoir operations and the reservoir environment. Any improvements to the spillway channel would permanently alter the area northeast of the Dividing Weir used for fishing and rowboat storage and launching. Permitting for any East Diversion Wall improvement alternative could be a major undertaking.

6.2.4 Upper Gate Chamber Modification

Multi-level withdrawal capability at the Upper Gate Chamber is currently provided by an arrangement of fixed stop shutters and open ports in the four bays on the east and west sides of the intake. Adjustment of intake elevation in response to water quality conditions was feasible at the time but involved a labor-intensive and time-consuming stop shutter removal process. The study concluded that installation of operable gates within the existing stop shutter frames, or at some or all of the ungated openings on the exterior walls of the intake while blanking off any unused ports would allow operators to readily adjust intake levels. Other than potential interference with the operation of the Upper Gate Chamber facilities, this alternative presented minor construction-related interferences confined largely to traffic disturbances on Reservoir Road and minor land disturbances above and below water.

6.2.5 East Basin Intake

Construction of a new intake towards the center of the East Basin would provide an alternative withdrawal location to the existing Upper Gate Chamber, where water quality is less susceptible to elevated turbidity conditions. Conceptual designs were developed for a variety of single and multi-level intakes employing various construction methods (microtunneling, underwater pipelines and regular tunneling) to connect to the Upper or Lower Gate Chamber or Catskill Aqueduct. Construction of a new East Basin Intake would be a major undertaking and would entail several construction-related impacts (e.g., suspension of withdrawals from the East Basin and Ashokan Reservoir, traffic, etc.) and environmental issues (such as impacts to land above and below water).

6.2.6 Catskill Aqueduct Improvements – Shaft 4 Interconnection

The Shaft 4 Interconnection would be a new engineered connection between the Catskill and Delaware Aqueducts near Shaft 4 of the Delaware Aqueduct where the two aqueducts cross. This connection would allow DEP to divert Delaware system water into the Catskill Aqueduct, thereby reducing the flow of Catskill water when turbidity is elevated but still maintaining sufficient flow to provide service to outside communities and meet overall demand. This would increase operational flexibility, reduce turbidity levels entering Kensico (by blending Catskill diversions with low turbidity Delaware water), and improve water quality for outside communities.

6.2.7 Catskill Aqueduct Improvements – Aqueduct Stop Shutters

Improvements to stop shutter facilities or outside community connections along the Catskill Aqueduct between Ashokan and Kensico would provide DEP with greater flexibility to reduce or eliminate diversions from the Catskill system during turbidity events. Ability to readily cut back flows in the Catskill Aqueduct and operate it at the minimum flowrate needed to satisfy demand would reduce turbidity loads entering the Kensico Reservoir, and reduce the need for alum addition.

The original Catskill Aqueduct configuration required a minimum flow of roughly 275 mgd to maintain supply to the 14 outside community connections along the Catskill Aqueduct, even though these utilities typically draw less than 15 mgd from the Aqueduct. At flow rates below 275 mgd, supply to these outside communities would be maintained only by installing (and later removing) stop shutters at up to six locations. This was a time-consuming and labor-intensive procedure that is implemented only under emergency conditions. DEP could not readily reduce diversions from the Catskill system in response to elevated turbidity conditions.

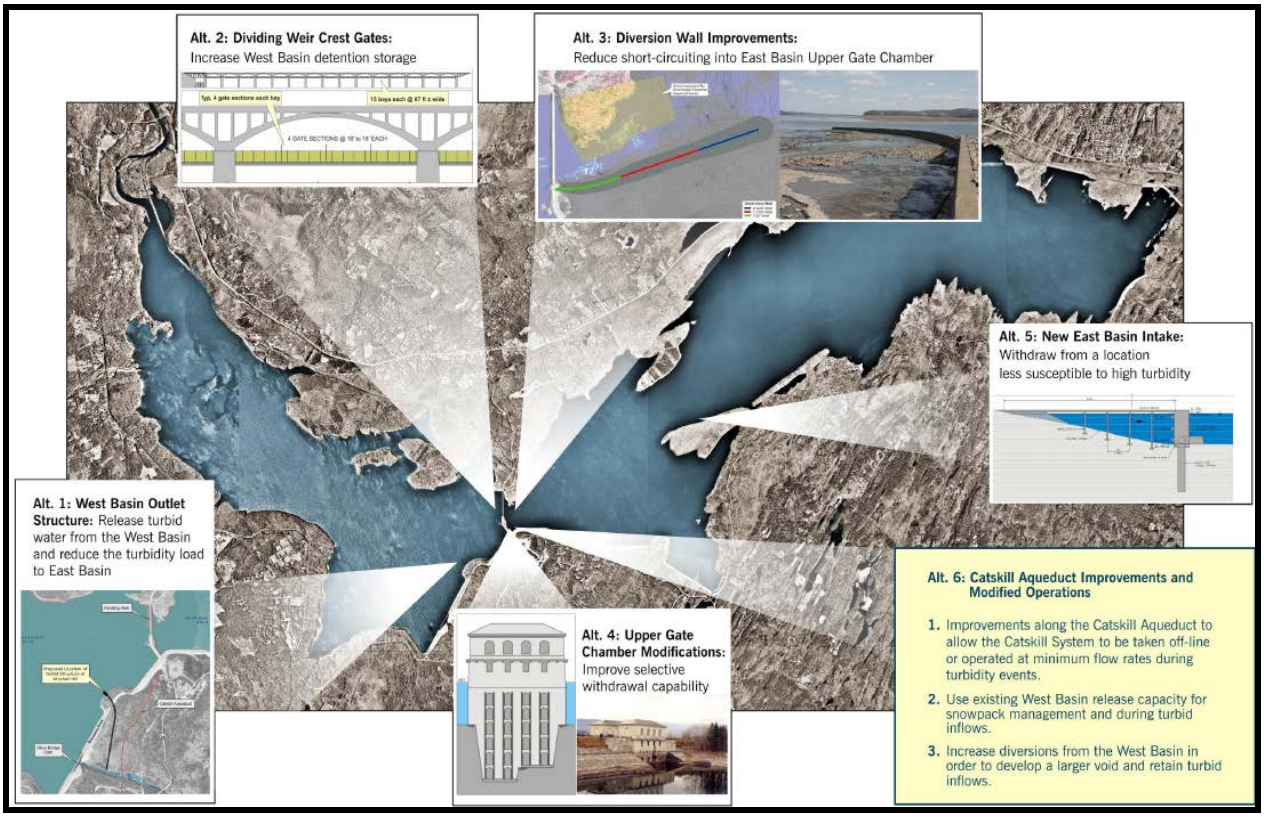
Extended periods of reduced diversions from the Catskill system would require associated modifications to baseline system operating rules, since the reduced Catskill diversion must be compensated by increased diversions from the Delaware and Croton systems. DEP's ability to reduce diversions from the Catskill system will increase substantially when the Croton Water Treatment Plant (WTP) is fully operational. The Croton WTP will effectively increase the transmission capacity from the Croton system to NYC by roughly 130 mgd compared to existing conditions.

Whereas in the past DEP was required to operate the Catskill system at relatively high flow rates during turbidity events in order to meet demand, DEP will have increased flexibility to reduce Catskill diversions once the Croton WTP comes on-line. Lower diversion rates will decrease turbidity loads entering Kensico Reservoir and are expected to provide associated reductions in the need for alum addition.

6.2.8 Modified Operations

In addition to Catskill Aqueduct Improvements and associated modifications to system operations, two modifications to baseline Ashokan operating rules were also evaluated: (i) West Basin Drawdown - increasing Catskill diversions from the West Basin whenever turbidity levels were acceptable to create a void in the West Basin to capture turbid inflows and (ii) Optimize Use of Ashokan Release Channel - operating the existing Ashokan Release Channel to release water from the West Basin, both for snowpack management and to prevent turbid spill to the East Basin prior to or during a storm event.

Figure 2. Phase III Ashokan Alternatives



6.3 Summary of Findings

For all alternatives except the East Basin Diversion Wall Improvements, water quality performance was evaluated using the linked OASIS-W2 model run on a daily time-step over a 57-year simulation period (1/1/1948 to 9/30/2004). Performance of the East Basin Diversion Wall Improvements was evaluated using the 3-D model of the Ashokan East Basin for several discrete storm events. This modeling framework allowed each alternative to be evaluated on a dynamic and long-term basis under realistic operating conditions and a wide range of environmental forcing conditions.

Turbidity control alternatives were evaluated under two different scenarios. The Current Conditions Scenario was used to evaluate the Catskill Aqueduct improvements, and reflected the status of the system through completion of the Croton Water Treatment Plant (WTP). The Post-Croton Filtration Scenario was a long-term planning scenario used to evaluate performance of all turbidity control alternatives. This scenario reflected the status of the system after completion of major ongoing or planned system improvements, including completion of the Croton WTP, planned upgrades at Croton Falls and Cross River Pump Stations, and repair of the Rondout-West Branch Tunnel. This long-term scenario also included an increase in system demand to reflect future population growth. An annual average NYC demand level of 1,250 mgd was used for this scenario, corresponding to demands that were then projected to be reached in roughly 2030 to 2035. A long-term planning horizon was selected in order to provide a conservative assessment of the potential turbidity control benefits of the alternatives under consideration.

Overall, the model simulations indicated that operating the Catskill Aqueduct at minimum flow rates when turbidity levels were elevated was the most effective way to reduce the turbidity load transferred from Ashokan to Kensico. Releasing water from the West Basin prior to and during a storm event (either through the existing Ashokan Release Channel or through a new Outlet Structure) also provided significant reductions in turbidity loading to the East Basin, and hence to Kensico. Both alternatives were predicted to substantially reduce the number of daily diversions of turbid water and the duration of alum addition events. In addition, when alum addition would be required, the amount of alum to be added would be reduced, due to the lower turbidity loading rates associated with these alternatives.

6.3.1 West Basin Outlet Structure

The West Basin Outlet Structure would provide additional capacity to release water from the West Basin during storm events, beyond the capacity provided by the existing Ashokan Release Channel. Outlet Structures with 2,000-, 4,000-, and 6,000-mgd release capacities were evaluated, along with a 4,000-mgd Outlet Structure with multi-level withdrawal capability. In all cases, the Outlet Structure was evaluated in combination with the existing Ashokan Release Channel to examine the potential incremental benefits of the additional release capacity compared to the existing release capacity.

Simulations indicated that in combination with optimization of the existing Ashokan Release Channel, a 6,000-mgd Outlet Structure could be operated to provide a roughly 35% reduction in the number of days with high (>10,000 mgd*NTU) turbidity loads transferred to the East Basin, relative to Baseline Operations. These reductions in turbid spill protected East Basin water quality and resulted in 25% and 35% reductions in days with Catskill diversion turbidity and turbidity load over their respective thresholds. The frequency of alum addition was predicted to decrease by 30%.

Additional simulations of outlet structures in combination with Catskill Aqueduct Improvements and West Basin Drawdown indicated that overall performance generally increased with the release capacity, but that improvements showed diminishing returns above a capacity of 4,000 mgd. Similarly, a 4,000-mgd Outlet Structure with multi-level release capability provided only slight additional improvement, compared to a 4,000-mgd outlet weir structure.

6.3.2 Dividing Weir Crest Gates

The linked model simulations predicted no overall benefit for the Crest Gates as a stand-alone alternative relative to Baseline Operations, since the roughly 4 billion gallons (BG) of temporary detention storage provided by the gates was insufficient to substantially reduce spill to the East Basin during the high inflow events that gave rise to elevated turbidities. Performance of the Crest Gates was improved slightly by operating them in conjunction with modified operating rules, since drawdown of the West Basin and operation of the Ashokan Release Channel effectively increased the size of the event that the Crest Gates could mitigate.

6.3.3 East Basin Diversion Wall Improvements

Improvements to the East Basin Diversion Wall would reduce short-circuiting of flow from the Dividing Weir to the Upper Gate Chamber. Due to the need for lateral (i.e., north-south) resolution of flow and turbidity patterns, this alternative was evaluated using the 3-D model of the East Basin. Short-term simulations were conducted for eight storm events using historical Ashokan diversion rates, and for four of these events using diversion rates from the linked model simulations. Diversion Wall Improvements were generally effective in reducing short-circuiting

and delaying the time it takes for peak turbidity levels to reach the Upper Gate Chamber. Diversion turbidity levels during the onset and peak of the event were lower than the base case (i.e., no Diversion Wall Improvements), usually for a period of roughly one week, after which the diversion wall provided negligible benefit. Despite substantial reductions in peak turbidity levels, diversions were still well above 8 NTU during large events. Based on these results the Diversion Wall could be expected to improve turbidity control during small events and at the onset of large events. Benefits were projected to be minimal during major events that could require extended periods of alum addition. The Diversion Wall in combination with Catskill Aqueduct Improvements and Modified Operations reduced the number of days above the turbidity and turbidity load thresholds by one or two days for each of the four events simulated.

6.3.4 Upper Gate Chamber Modifications

Modifications to the Upper Gate Chamber (either on the East side or on both sides) to allow daily adjustment of withdrawal elevations were predicted to provide relatively minor (~5 – 10%) reductions in the number of days over turbidity and turbidity load thresholds. Selective withdrawal structures could provide some benefit during stratified conditions, but no benefit during storm events in fall, winter, and spring, thus limiting overall performance potential.

6.3.5 East Basin Intake

A new intake facility near the center of the East Basin was predicted to provide modest (~10%) improvements in Catskill Aqueduct performance measures compared to Baseline Operations. A MLI performed slightly better than a Single-Level Intake (SLI). Though turbidity at the proposed intake location was typically lower than at the Upper Gate Chamber, predicted turbidity levels during large storm events were still high enough to trigger alum addition. An East Basin MLI in conjunction with Catskill Aqueduct Improvements and Modified Operations was predicted to provide roughly 15% and 30% reductions in turbidity load and alum addition.

6.3.6 Catskill Aqueduct Improvements and Modified Operations

Under the Current Conditions Scenario, improvements to the Catskill Aqueduct to facilitate operation at flow rates less than 275 mgd provided substantial (~40%) reductions in turbidity loads transferred to Kensico compared to Baseline Operations. Use of the Ashokan Release Channel to implement a snowpack management program and to release water from the West Basin prior to or during peak inflow events provided a roughly 30% reduction in the number of days with high (>10,000 mgd*NTU) turbidity loads transferred to the East Basin, and resulted in 15% and 20% reductions in the number of days with Catskill diversion turbidity and turbidity load over their respective thresholds. Drawdown of the West Basin by increasing diversions from the West Basin provided modest benefits (~5%) with respect to turbidity loads to the East Basin and to Kensico. When combined, the performance of the three components of Catskill Aqueduct Improvements and Modified Operations was roughly additive.

Performance of the Catskill Aqueduct Improvements as a stand-alone alternative was significantly enhanced under the Post-Croton Filtration Scenario due to reductions in the minimum flow necessary to meet demand – the turbidity load transferred to Kensico and the number of alum addition days were both reduced by more than 50%. The Croton WTP will effectively increase the transmission capacity from the Croton system to NYC by roughly 130 mgd compared to current conditions, and will allow DEP to reduce its minimum Catskill diversion during turbidity events by the same amount. While the Croton WTP was not constructed to help minimize the impacts of Catskill turbidity on the overall water supply system, the benefits of this additional supply were found to be significant. Overall, the

combination of Catskill Aqueduct Improvements and Modified Operations was predicted to reduce the turbidity load transferred to Kensico and the number of alum addition days by 75 to 80% percent. DEP's ability to implement and refine the modified operating rules developed and to minimize the need for alum addition in general would be greatly enhanced subsequent to implementation of OST.

6.4 Value Engineering

6.4.1 Summary

Subsequent to submission of the Phase III Final Report, a Value Engineering (VE) session organized by the NYC Office of Management and Budget (OMB) was conducted during the week of January 28, 2008. During this session, a panel of ten consultants reviewed Phase III findings and cost estimates, and offered recommendations for further evaluation. It should be noted that the focus of this analysis was on cost and it did not necessarily address other implementation issues.

The VE panel identified 26 recommendations related to the design, implementation, or performance evaluation of alternatives. Each of these recommendations was evaluated by DEP and assigned one of four categories prescribed by OMB (Accept, Partially Accept, Reject, or Further Study).

Nineteen of the VE recommendations were related to alternative designs for the six turbidity control alternatives identified in the Phase III report. Eleven of these were design modifications that would not substantially alter the functionality, cost, or water quality performance of their respective base alternative, but which were found to merit further study during the design phase if the base alternative was selected for implementation. The remaining eight design recommendations were rejected based on one or more factors affecting feasibility, including environmental impacts, ease of implementation, reliability, water quality impacts, cost, and maintenance requirements. Three of the VE recommendations were related to various aspects of DEP's overall turbidity control efforts. These included improving Catskill inflow predictions (included in OST; accepted); supporting Lower Esopus stream management efforts (ongoing; partially accepted), and promoting regulatory acceptance for alum treatment (inconsistent with applicable law; rejected).

The VE recommendations and City responses are described below by topic. The identification number refers to VE categories: M = Miscellaneous; MF = Manage Flows; RC = Reduce Concentration; and RL = Reduce Load.

6.4.2 Recommendations for West Basin Outlet Structure

- (MF-10) Lower weir box to +/- elevation 575 and add 4 feet to dividing weir crest gates.

  The VE team recommended that DEP evaluate a West Basin Outlet Structure in the same location and with the same horizontal and vertical configuration as the 6,000 mgd option proposed in the Phase III Final Report but lower the elevation of the top of the weir box to El. 575 instead of the El. 585, as proposed. They also recommended that DEP install the Dividing Weir crest gates (or other alternative if indicated), as proposed to increase the depth of the West Basin by four feet.

  Long-term simulations of the performance of this alternative were conducted using the OASIS-W2 linked model. These simulations indicated that this alternative would provide a marginal performance benefit compared to the original alternative (West

Basin Outlet Structure). However, the benefit provided by the VE proposal would be substantially less than that provided by the Catskill Aqueduct Improvements and Modified Operations, which could be implemented at much lower cost than either the West Basin Outlet Structure or the VE proposal. The VE proposal was recommended for further study only if the West Basin Outlet Structure was selected for implementation.

- (MF-11) Convert Olive Bridge Dam to a gated overflow spillway.

  The VE team recommended consideration of five sluice gates in the concrete section of the Olive Bridge Dam to allow overflow through the dam directly into Esopus Creek, thus avoiding the need for turbid water entering the West Basin from having to flow into the East Basin to be released.

  This alternative would involve major modifications to the 252-foot high dam structure which was placed into service more than 100 years ago. Such an undertaking was judged to be inherently too risky to warrant consideration for implementation. Major technical and project cost issues not addressed in the VE design concept include: the likely need for tiedown anchors to provide required stability along the section of the dam impacted by the proposed gate construction; and modifications required to address the fact that the proposed gates would interfere with the upper inspection gallery. Further, to prevent erosion along the downstream face of the dam, a substantially higher degree of protection than the proposed 9 feet of concrete armoring would probably be required. Project construction would also require that the level of the West Basin be maintained at or below Elevation 575 feet over an extended period. This VE recommendation was rejected.

- (MF-19) Use passive weir as well as Dividing Weir crest gates, guarded with 1 foot flash board for West Basin spillway.

  The VE team recommended evaluating a long passive weir in the West Basin outlet by using 1,100 feet of weir at elevation 588 along the natural knoll at the north end of Olive Bridge Dam constructed at the shoreline with 3 feet of Obermeyer inflatable weir along the concrete weir and 1 foot Obermeyer weir on the Dividing Weir Crest between the West and East Basins.

  During evaluations of alternative weir configurations for the West Basin Outlet DEP concluded that a weir of the length proposed by the VE team would not be a practical option. The proposed “passive” weir concept was mechanically complex in that it involved the installation of two sets of Obermeyer inflatable gates: 1-foot high gates on the Dividing Weir and 3-foot high gates on the proposed passive weir. The 3-foot gates (crest elevation of 591 feet in raised position) would not protect the Old Esopus Creek valley during extreme flood events. An inflated gate height of 17 feet would be required to provide required downstream protection during passage the Probable Maximum Flood (Maximum West Basin El 605 feet). This change would greatly increase the complexity and cost of the project design. This VE recommendation was rejected.

- (RC-8) Locate the West Basin outlet structure at Olive Bridge Dam and make a low level outlet.

  The VE team recommended that DEP consider relocating the West Basin outlet structure to the west side of Olive Bridge Dam. In addition, the design would include a low level outlet that could continue to release water even as the West Basin water surface is lowered.

  During the conceptual design of the West Basin Outlet Structure, a location east of Olive Bridge Dam was selected based on a preliminary review of potential sites for the outlet structure on either side of the dam. If this alternative were to be selected for implementation, detailed design-level evaluations would be conducted of alternative outlet sites, alignments, and design concepts including a multi-level outlet rather than the single-level conceptual design presented in the Phase III report. A multi-level structure could potentially optimize turbidity removal and could also incorporate a low level outlet, as may be required to address dam safety issues. This VE proposal was recommended for further study only if the West Basin Outlet Structure was selected for implementation.

- (RC-23) Provide a diversion channel along the north bank of the West Basin and tunnel across the basin to Old Esopus Creek.

  The VE team recommended consideration of a bypass conduit to directly release turbid water from the Esopus Creek directly into the Old Esopus Creek to limit turbid material mixing in the West Basin. This proposal would involve the construction of several miles of large scale culvert, open channel, tunnel and shaft construction in order to bypass turbid storm flows from Esopus Creek near the headwaters of the West Basin to Old Esopus Creek below Olive Bridge Dam. This would be a project of major scale and would involve significant environmental and permitting challenges. More importantly, based on hydraulic constraints, the concept as proposed would be limited to an estimated capacity of about 2,000 mgd, which would be insufficient to provide effective turbidity control. This VE recommendation was rejected.

6.4.3 Recommendations for Catskill Aqueduct Improvements

- (RL-1) Modify existing water service siphons to reduce the amount of required submergence by constructing a sump pit at customer taps.

  The VE team recommended that DEP evaluate modifying the configuration of community service connections to the Catskill Aqueduct to construct a sump pit at all community taps so that less flow depth would be required in the aqueduct during withdrawals.

  This modification would be required at up to 11 individual community connections and the 10-ft. by 10-ft. in area by 6 ft. in depth, would involve a much higher level of demolition and construction within the aqueduct at each of the affected 13 community connections than the boring and jacking modifications proposed under Phase III. This VE recommendation was rejected.

- (RL-3) Tap the side of the Aqueduct for customers at invert.

  The VE team recommended that DEP evaluate modifying the configuration of community service connections to the Catskill Aqueduct to construct a side connection to the aqueduct at all community taps so that less flow depth would be required in the aqueduct during withdrawals.

  This recommendation was a variation of the proposed alternative to modify outside connections but it omitted the cored sump which would be required for proper diversion of flow to each of the 11 individual connections under low aqueduct flow conditions. During the Phase III analysis a side connection concept similar to RL-3 was evaluated but rejected. This VE recommendation was rejected.

- (RL-5) Use shaft 4 on the Delaware Aqueduct to either dilute the Catskill turbidity or substitute the supply required.

  The VE team recommended an evaluation of a connection between Shaft 4 of the Delaware Aqueduct and the Catskill Aqueduct instead of upgrades at the stop shutter locations. This connection could be used during high turbidity events and the 275 mgd of required flow would be made by a combination of Catskill and Delaware water, thus diluting the turbidity in the Catskill Aqueduct to reduce the need for alum addition at Kensico.

  This VE recommendation was included in the Phase III Implementation Plan.

- (RL-10) Replace the stop shutters with inflatable crest gates.

  The VE team recommended using inflatable gates in place of the removable shutters to increase the water depth at each pump. The inflatable gates could have the advantage of being operated remotely and could be adjusted easily to meet changing conditions.

  This VE proposal was recommended for further study if stop shutters improvements were selected for implementation.

- (RL-14) Combine Alternatives 1 and 6.

  The VE team recommended combining the Catskill Aqueduct Improvements with construction of a new West Basin outlet structure.

  The results of the Phase III analysis and subsequent analyses indicated that while this combined alterative could be effective, it would provide only marginal improvement over Catskill Aqueduct Improvements as a stand-alone alternative, though at much higher cost. This VE recommendation was rejected.

- (RL-16) Divert 275 mgd of local supply water into New Croton Lake.

  The VE team recommended evaluating an existing 72-inch connection and the existing Harlem River Siphon stop shutters to divert the water needed for Catskill community intakes to the New Croton Aqueduct near New Croton Lake. The turbid water would be treated at the Croton WTP.

  The Croton WTP is a dissolved air flotation plant designed to treat low turbidity water. In particular, the maximum turbidity level that could be handled in the

residuals treatment process is on the order of 20 NTU. Sustained treatment of turbidity levels in excess of 100 NTU, while operating the WTP at the design maximum capacity of 290 mgd, would not be feasible. This VE recommendation was rejected.

6.4.4 Recommendations for System Modeling

- (MF-2) Improve in-flow prediction outcome through meteorological and hydrological information from Upper Esopus watershed.

  The VE team recommended developing and implementing hydro-meteorological forecasting capability for the Catskill watershed to improve information for DEP reservoir operations.

  This VE recommendation was accepted and included in the design of OST.

- (MF-17) Conduct uncertainty and sensitivity analysis for the modeling.

  The VE team recommended a formal uncertainty analysis of the integrated W2-OASIS model. This analysis would help to characterize the uncertainty in the frequency of higher turbidity events entering Catskill Aqueduct as a function of estimated input parameters, input data errors, boundary and initial conditions.

  This VE recommendation was accepted and the results presented in the Phase III Implementation Plan (specifically Sections 2.2, 2.3, and Appendix A).

- (RC-42) Improve flow-turbidity relationship used in modeling for Upper Esopus Creek with better measurement and modeling techniques.

  The VE team recommended a dynamic turbidity-flow relationship to the extent that the coefficients could adjust to accommodate the effects of seasonality, magnitude of storm, hydrologic responses from different land uses in the watershed.

  This VE recommendation was accepted and the results are included in the Phase III Implementation Plan.

- (RL-21) Use the 3-D model for alternatives considered using the last eight alum events.

  In the Phase III analysis, five of the six alternatives were evaluated using 2-D modeling only. The VE team recommended using the 3-D model for all alternatives if feasible.

  The linked OASIS-W2 (2-D) model was selected as the primary tool for evaluation of all alternatives that could reasonably be simulated within a 2-D framework because it offers two key advantages over a 3-D model: (1) it provided a dynamic linkage between reservoir operations and reservoir water quality which captures the feedback that exists between how a reservoir is operated and the water quality in the reservoir (e.g. today's diversion or release decision is affected by today's water quality, and in turn affects tomorrow's water quality); and (2), it could be run over a long (57-year) simulation period, thus capturing a wide range of hydrologic and meteorologic forcing conditions. The 3-D model cannot be used for long-term simulations, and dynamic linkage with OASIS was not feasible within project constraints, thus limiting its application to alternatives that cannot be simulated within 2-D framework.

The East Basin Diversion Wall Improvement was the only alternative that was required to be modeled within a 3-D framework. In the Phase III report, performance of this alternative was demonstrated for eight storm events under historical operations, and four events under OASIS-derived operations. These simulations were useful in characterizing the performance of this alternative, and generally indicated that the turbidity control benefit would be limited to several days at the beginning of storm events. However, quantitative comparisons with other alternatives evaluated using the long -term OASIS-W2 model were difficult to make, due to the limited number of events simulated with the 3-D model. This VE recommendation was partially accepted and additional modeling was conducted for the Phase III Implementation report.

6.4.5 Recommendations for East Basin Diversion Wall

- (M-11) Install a diversion wall equal to 7/8 the length of the East Basin (approx. 5 miles).

The VE team recommended that DEP evaluate installing a long diversion wall (5 miles long) across the East Basin so that turbid water overflowing the dividing weir would be more thoroughly mixed with the clear East Basin water before flowing into the Catskill Aqueduct.

Head losses associated with the conveyance of flow in a confined 5-mile channel extending eastward along the northern shore of the East Basin would effectively decrease the capacity of the Dividing Weir and impair its ability to pass the Probable Maximum Flood. This head loss would back water up at the Dividing Weir, effectively reducing its hydraulic capacity. The proposed sheetpile wall could potentially be designed to be overtopped during very high flow events. However, the hydraulic losses associated with flow overtopping the wall would impair the Dividing Weir hydraulic capacity. Furthermore, in this case, the wall would not provide the desired water quality protection during high flow, high turbidity events.

Structural analyses completed in connection with this alternative concluded that a single-row sheet-pile wall would not be a feasible construction approach for this application because ice loadings would be excessive and there would be a high level of difficulty and cost associated with keying the sheeting into the bedrock foundation. As a result, a sheetpile coffercell approach was selected as a possible construction approach. This approach involved the installation of sheeting in closed cells that are backfilled with suitable granular material. However, as a result of ice and other loadings, DEP concluded that this type of construction would not be suitable for a wall length in excess of about 1,700 feet. A jetty wall or similar type of construction would be required over the deeper sections of the proposed wall.

In-reservoir operations required to construct the proposed 5-mile wall would have major impacts on the environment and operation of the East Basin. The wall section, modified to a combination of sheetpile coffercell and jetty wall construction as discussed above, would have a construction footprint on the order of 100 acres. This VE recommendation was rejected.

- (RC-10) Construct a new diversion from West to East Basin to send turbid water further into East Basin.

  The VE team recommended evaluation of a diversion structure to transfer water north of the existing diversion weir to send turbid water from the West Basin further to the north and east than would occur if water flowed over the diversion weir. The diversion structure would consist of twin 10-foot by 15-foot box culverts with a sluice gate for each box culvert at one end.

  With a length of approximately 2,500 feet, as estimated by the VE team, hydraulic losses for this alternative would be higher than those for the existing Dividing Weir gates by themselves or in combination with any of the proposed Diversion Wall improvements. As a result of these hydraulic considerations, DEP concluded that, while the diversion structure proposed by the VE team could improve East Basin water quality at relatively low West-East transfer flows, it would not result in significant water quality improvements during turbidity upsets, which are driven by high rates of runoff into the West Basin. This VE recommendation was rejected.

6.4.6 Recommendations for Upper Gate Chamber Improvements

- (M-14) Improve existing shutter arrangement at Ashokan Upper Gate Chamber.

  The VE team suggested replacing the existing stop shutters with a new complement of light weight panels. A second complement of new heavy-duty stop shutters would be acquired and stored for use when forebay dewatering is required.

  DEP concluded that this VE recommendation would be studied further if Upper Gate Chamber Improvements were selected for implementation.

- (RC-27) Convert inlet channels to buried perforated pipe/slow sand filters at the upper gate chamber.

  The VE team recommended that DEP evaluate converting the Upper Gate Chamber inlet channels to underwater slow sand filters by filling them with a graded gravel-to-sand filter media and providing a perforated pipe under drain system. The under drain system would be connected to the east and west faces of the Upper Gate Chamber at the lowest ports. In order to provide sufficient head to operate the filter it would be necessary to seal and/or provide sluice gates for the upper ports to enable drawing down the water column inside the gate chamber. A small, bar-mounted dredge would possibly be necessary to clean the top of the sand and replace media.

  The proposed slow sand filter concept was an unproven technology in an application of this scale and configuration. Filling the east and west inlet channels with the proposed filter media would have major, irreversible implications on Upper Gate Chamber operation. Access to deep water would be available solely through the proposed filter media, which has a stated design capacity of 275 mgd. Access to higher flows would be available only at the upper intake levels at the east and west sides, greatly restricting the operational functionality of this facility. This VE recommendation was rejected.

- (RC-40) Provide induced infiltration to intake chamber.

  The VE team recommended that DEP evaluate filling the east and west Upper Gate Chamber inlet channels with a graded gravel-to-sand filter media. This would require sealing and/or providing sluice gates in the upper ports of the gate chamber to enable drawing down the water column inside the gate chamber to provide sufficient head to induce flow through the sand/gravel pack to the lowest inlet ports.

  The proposed graded gravel-to-sand filter concept was an unproven technology in an application of this scale and configuration. Filling the east and west inlet channels with the proposed filter media would have major, irreversible implications on operation of the Upper Gate Chamber. Access to deep water would be available solely through the proposed filter media, which has a stated design capacity of 275 mgd. Access to higher flows would be available only at the upper intake levels at the east and west sides, greatly restricting the operational functionality of this facility. This VE recommendation was rejected.

6.4.7 Recommendations for New East Basin Intake

- (RC-7) Relocate intake to eastern end of the east basin and install conduit to lower gate chamber.

  The VE team recommended that DEP evaluate a new bi-level intake structure at the upper reaches of the East Basin which is rarely inundated by turbidity. The 12 foot diameter pipe line would be approximately 5 miles long tunneled to the existing Lower Gate Chamber.

  OASIS-W2 simulations indicated that Catskill Aqueduct/Modified Operations could provide near complete turbidity control at substantially lower cost than this VE alternative. Further, it should be noted that the bottom elevation of the reservoir at the proposed location is higher than the intake location identified in the Phase III Report, thus limiting any reliability–related benefits that this suggestion could provide. This VE recommendation was rejected on the basis of cost:benefit relative to the Catskill Aqueduct/Modified Operations alternative.

- (RC-24) Construct a low cost East Basin intake structure using submerged passive screens and pipeline on the reservoir floor

  The VE team recommended that DEP evaluate a subaqueous pipeline reaching to the east end of the deep portion < El. 510.0 of the East Basin. This could provide full 600 mgd capacity and use end of the pipe passive screens to maintain low turbidity inflow to Catskill Aqueduct during times when the West Basin has a turbidity spike. An air backwash system would be installed to flush the screens periodically.

  This VE proposal is a modification of sub-alternative 2C investigated in Phase III but would involve the extension of dual subaqueous pipelines (rather than a single pipeline) 5,000 feet farther east in the East Basin and the furnishing of fine screens at the intake inlet. This VE recommendation would have been studied further if the East Basin Intake alternative had been selected for implementation.

- (RL-22) Provide new East Basin intake with gated cutoff wall west of new intake plus relocation of reservoir road over cutoff wall.

  The VE team recommended that DEP evaluate an earth berm with a gate structure across the Narrows to form a third basin at the eastern end of the East Basin. This would also require construction of a new intake structure east of the new berm and pipeline as per the original design in Phase III.

  The VE team estimated the cost of this alternative to be $943M but it did not include the costs for construction of a gate structure within the new berm to regulate flows nor were any costs included for relocation of Reservoir Road. The cost estimate would be closer to $2,784M. This VE recommendation was rejected as cost prohibitive.

6.4.8 Miscellaneous Recommendations

- (M-4) Submit convincing evidence to regulators regarding use of alum.

  The VE suggested DEP provide supporting evidence from other locations/jurisdictions that use alum treatment processes with little or no adverse environmental impacts.

  This VE recommendation did not address relevant state regulatory requirements. The NYSDEC narrative water quality standard for suspended, colloidal and settleable solids prohibits discharges from "sewage, industrial wastes or other wastes that will cause deposition or impair the waters for their best usages" (NYSDEC §703.2). Of the four examples cited by the VE team (Massachusetts, Michigan, South Dakota, and Washington), none of these states has a water quality standard that overtly conflicts with intentionally settling out solids. This VE recommendation was rejected.

- (MF-6) Create win-win solutions with Lower Esopus communities.

  The VE team recommended aggressive funding and a consultation/design program to clean, widen and straighten the streambed of the Lower Esopus Creek, through Hurley-Kinston-Ulster-Glenerie to Diamond Mill Dam in Saugerties.

  The VE suggestion was focused on mitigating flooding concerns downstream of Ashokan, and would not improve turbidity control. DEP supports improved stream management planning for the lower Esopus Creek and has provided funding and technical support on these issues. This VE recommendation was partially accepted.

- (RL-18) Add new performance metrics per alternative.

  The VE team recommended three new metrics to better communicate DEP's concern about alum events, as follows: total number of alum events; total turbidity load into Kensico Reservoir; and volume of alum added at Kensico Reservoir.

  The total number of alum events was adopted but as a qualitative metric only, because it doesn't provide information on the duration of events. Because the relative performance findings using total turbidity load were consistent with findings based on the primary measures (days over 8 NTU, and alum treatment days), this metric was not adopted as a formal performance measure. Overall, this VE recommendation was partially accepted.

6.5 Implementation Plan

In the Phase III Implementation Plan, each of the Phase III alternatives was evaluated with respect to water quality performance, water supply reliability, cost, constructability, environmental and permitting issues, and operations and maintenance requirements (Table 3). The evaluation of alternatives with respect to constructability, environmental and permitting issues, and operations and maintenance requirements was based on the findings presented in the Phase III Final Report. The water quality, water supply, and cost evaluations were updated in the Phase III Implementation Plan to reflect VE recommendations and requests from regulatory agencies. The overall intent of the supplemental modeling was to evaluate the sensitivity of model predictions to various model parameters and drivers, and to provide additional support for comparisons among the turbidity control alternatives.

The water quality performance of the alternatives was evaluated based on analysis of long-term OASIS-W2 simulation results according to the following primary water quality performance measures:

- Percent of days with predicted Catskill Aqueduct diversion turbidity above 8 NTU.

  This threshold turbidity level was selected based on a review of historical water quality data. While a turbidity of 8 NTU in the Catskill Aqueduct does not necessarily trigger alum addition, this threshold represents a level of concern above which some action may be needed to minimize turbidity impacts at Kensico Reservoir. In the linked model simulations, turbidity levels above 8 NTU were used as a trigger for reducing diversions from Ashokan.

- Percent of days in which alum addition at Kensico could be required.

  Conditions that may require alum addition were estimated using simple triggers based on turbidity load. Alum addition in the OASIS-W2 model was triggered when the turbidity load entering Kensico Reservoir via the Catskill Aqueduct exceeded 5,000 mgd*NTU. The 5,000 mgd*NTU threshold is based on DEP data from 1987 through 2007, and is a reasonably good indicator of conditions that have historically required alum treatment at Kensico. Alum addition in the model continues on a daily basis until the five-day average turbidity load falls below 4,000 mgd*NTU. This latter threshold was intended to identify downward trends in Catskill turbidity levels and prevent “toggling” of the alum trigger when the load hovers around the threshold.

  As explained in the report, the decision to add alum is complex, and cannot be fully simulated with available mathematical modeling tools. In addition to turbidity levels in the Catskill System, other important factors considered in DEP's decision-making process include turbidity levels in the Delaware System, time of year, temperature, extent of stratification in the Kensico Reservoir, and predicted future Kensico turbidity levels. Therefore, the alum trigger applied under this evaluation should be thought of as a surrogate indicator for conditions that could require alum addition in practice.

- Total mass of alum applied over the simulation period.

  The mass of alum added on a given day was calculated by multiplying the predicted alum dose by the daily Catskill Aqueduct diversion and converting to pounds of alum. Daily data for mass of alum were then summed over the full simulation period, normalized to

the total number of days in the simulation period (20,728 days), and expressed in units of pounds of alum per day.

6.5.1 West Basin Drawdown

Simulations conducted using a surrogate threshold level of 3 NTU indicated this practice would provide a slight reduction in the expected frequency of alum treatment. Development of formal operating rules for and full implementation of this practice requires the monitoring and forecasting capabilities provided by OST. DEP currently draws down the West Basin in accordance with the Interim Release Protocol.

6.5.2 Ashokan Release Channel Operation

Simulations conducted using a conservative set of rules indicate that this practice will provide a modest reduction in the expected frequency of alum treatment. As above, development of formal operating policies for this practice requires OST. DEP currently operates the Ashokan Release Channel in accordance with the Interim Release Protocol.

To fully utilize the Ashokan Release Channel, several improvements were required to the area downstream of the reservoir, specifically acquisition of the low-lying portions of the Ashokan Field Campus and demolition of buildings located in the floodplain. In August 2008, DEP purchased a portion of the property and entered into a License Agreement with Open Space Institute (later transferred to the Ashokan Foundation) to allow DEP use of the Ashokan Release Channel. This agreement includes a provision to demolish the Ashokan Center buildings located in the floodplain once the Center constructs new structures out of the floodplain which is complete. Demolition is likely to commence in 2014.

6.5.3 Catskill Aqueduct Improvements

DEP is implementing Catskill Aqueduct Improvements as a long-term turbidity control measure. This alternative will allow DEP to reduce Catskill diversions during turbidity events to the minimum level necessary to meet NYC and outside community water demands, without compromising water supply reliability for outside communities. DEP's current ability to minimize Catskill diversions during turbidity events is limited primarily by outside community demands on the Catskill Aqueduct. There are a total of 14 community connections tapped into the Catskill Aqueduct: 8 located west-of-Hudson and 6 east-of- Hudson. Many of these connections begin to experience service interruptions as the flow rate, and therefore water level, in the aqueduct is reduced. Though the total outside community demand is less than 15 mgd, DEP must maintain the minimum aqueduct flow at 275 mgd to avoid service interruptions, or it must install stop shutters along the aqueduct. Installation and removal of the existing stop shutters is time-consuming, labor-intensive, and cumbersome, and has therefore only been implemented under emergency conditions.

The goal of the Catskill Aqueduct Improvement Option is to reduce diversions from the Ashokan Reservoir during turbidity events while still avoiding service interruptions to outside communities. The Implementation Plan identified two engineering alternatives to achieve this: improvements to the stop shutter locations and redesign of the water supply community taps. Both alternatives would allow for a reduction in diversions from Ashokan Reservoir to the minimum amount needed for the communities that tap in. The modeling used to support the implementation plan did not distinguish between these two options.

DEP chose the stop shutter option for several reasons. First, the stop shutter improvements pose less inherent risk to the Catskill Aqueduct, as they do not affect the aqueduct structure itself.

Similarly, the construction will be less disruptive to water supply operations. The stop shutter infrastructure is already in place and the modifications mainly consist of a dedicated hoist superstructure at the surface and site improvements. Second, modification of the stop shutter locations could be implemented more quickly and easily since DEP owns the stop shutters and can perform the work under one contract with limited shut-down of the Catskill Aqueduct. Finally, longer Catskill Aqueduct shut-downs would likely be necessary with the community tap installations, which would also have to be coordinated with other water supply needs. Thus, the stop shutter option can be constructed sooner and more efficiently.

Independent of these two options for reducing Catskill flows, DEP is also pursuing a new connection between the Catskill and Delaware aqueducts at Shaft 4 which will allow water from the Delaware System to enter the Catskill Aqueduct. This will provide additional water supply benefit by allowing for water to be diverted from Rondout Reservoir and a corresponding reduction in flows from Ashokan Reservoir during periods of elevated turbidity. This provides even greater flexibility to meet overall demand with the highest quality water while ensuring adequate flows to outside communities. In addition to the turbidity control benefits of this alternative, it has several important additional benefits: decreases risk associated with operating the RWB tunnel at maximum capacity during turbidity events; reduces turbidity levels entering Kensico by blending Catskill diversions with lower turbidity Delaware water; increases overall operational flexibility; and improves water quality for outside communities.

In conclusion, the alternatives ultimately chosen for implementation were Modified Operations and Catskill Aqueduct Improvements. In addition to the development of OST, DEP decided to proceed with the construction of an interconnection at Shaft 4, to improve overall system dependability, and to improve stop shutter facilities.

The Phase III Implementation Plan was approved by NYSDOH, pursuant to the 2007 Filtration Avoidance Determination, on November 26, 2010 and the components are currently being implemented. DEP currently operates the Ashokan Release Channel in accordance with the Interim Release Protocol in the Catalum SPDES consent order and OST was completed in 2013. Design and construction for the Catskill Stop-Shutter improvements and Shaft 4 connection are underway.

Table 3. Summary of CTC Phase III Evaluation

ALTERNATIVE/OPTION	CAPITAL COST[1,2] ($M)	O&M COST ($M/YR)	LIFE-CYCLE COST ($M)	SCREENING RESULT
West Basin Outlet Structure				
2000 mgd Outlet Capacity	$213	$0.6	$235	Rejected on the basis of cost compared to selected alternatives
4000 mgd Outlet Capacity	$228	$0.7	$251	
600 mgd Outlet Capacity	$248	$0.8	$272	
Dividing Weir Crest Gates				
Inflatable Crest Gates	$88	$2.0	$140	Rejected on the basis of cost compared to selected alternatives
East Basin Diversion Wall Improvements				
Jetty Wall Construction (750 ft wall)	$79	$0.0	$80	Rejected on the basis of cost compared to selected alternatives
Closed Cell Coffercell Construction (750 ft)	$57	$0.0	$58	
Jetty Wall Construction (1,700 ft wall)	$287	$0.1	$289	
Closed Cell Coffercell Construction (1,700 ft)	$130	$0.1	$132	
Jetty Wall Construction (2,400 ft wall)	$489	$0.1	$492	
Spillway Channel Improvements	$415	$0.0	$415	
Channel & Jetty Wall Improvements (2,400 ft wall)	$695	$0.1	$699	
Upper Gate Chamber Modifications				
Stop Shutter Guides (East side)	$55	$0.3	$64	Rejected on the basis of cost compared to selected alternatives
Stop Shutter Guides (East and West sides)	$106	$0.7	$125	
Exterior Wall (East side)	$86	$0.5	$99	
Exterior Wall (East and West side)	$160	$0.9	$185	
East Basin Intake				
Offshore MLI w/Tunnel to Lower Gate Chamber	$460	$1.2	$493	Rejected on the basis of cost compared to selected alternatives
Offshore MLI w/Tunnel to Catskill Aqueduct	$456	$1.2	$489	
Offshore MLI w/Subaqueous Pipe to Upper Gate Chamber	$789	$1.1	$821	
Offshore SLI w/Subaqueous Pipe to Upper Gate Chamber	$556	$0.6	$579	

ALTERNATIVE/OPTION	CAPITAL COST[1,2] ($M)	O&M COST ($M/YR)	LIFE-CYCLE COST ($M)	SCREENING RESULT
On-Shore MLI w/Tunnel to Lower Gate Chamber	$407	$0.9	$434	
On-Shore MLI w/Tunnel to Catskill Aqueduct	$412	$0.9	$439	
On-Shore SLI w/Tunnel to Lower Gate Chamber	$306	$0.7	$328	
Catskill Aqueduct Improvements and Modified Operations				
West Basin Drawdown (Operations Support Tool)	$6.4	$0.9	$32	Selected for Implementation
Ashokan Release Channel Operation	$ 17	$0.2	$24	Selected for Implementation
Stop Shutter Improvements	$14	$0.1	$17	Selected for Implementation
Modified Community Connections	$14	$0.03	$15	Rejected compared to Stop Shutter Improvements
Shaft 4 Connection	$27	$0.2	$32	Selected for Implementation
Notes: All costs are conceptual design-level planning costs, in 2007 dollars. Cost differences between alternatives/options of 10 to 15 percent are considered to be within estimating error.				

6.6 Turbidity Control Alternatives Analysis

6.6.1 Summary

The Turbidity Control Alternatives Analysis completed in 2011 built upon the previous analyses and further evaluated the alternatives that were selected for implementation based on the results of the Catskill Turbidity Control Study. These include:

- Drawdown of the West Basin in anticipation of a potential storm event (considered to be part of baseline operations for Ashokan and therefore included in all model simulations).
- Use of the Ashokan Release Channel in advance of and during a turbidity event. For this study, operations were modified to include updated maximum flow rates as well as restrictions to prevent operations that could potentially contribute to downstream flooding.
- Catskill Aqueduct Stop Shutter improvements, modified to more accurately simulate the current operational and hydraulic constraints associated with installation of Stop Shutters.
- Proposed Shaft 4 connection between the Catskill and Delaware Aqueducts to allow transfers of Delaware water to meet outside community demands.

Water quality performance for each turbidity control alternative was evaluated using an updated version of the linked water supply-water quality modeling framework that was developed and applied in Phase III of the Catskill Turbidity Control Study. The linked model had several features that allow it to provide a robust evaluation of alternatives:

- Long simulation period (~61 years) that encompassed a wide range of environmental forcing conditions that could be expected to occur in the future (planning horizon through 2017), and allowed for probabilistic interpretation of results;
- Dynamic linkage between water quality and water supply models, which allowed daily simulation of water quality-based diversion decisions and accounted for feedback between diversion/release decisions and reservoir water quality;
- Mechanistic two-dimensional water quality (turbidity) models of Schoharie, Ashokan, and Kensico Reservoirs, supported by detailed monitoring and process studies; and
- Robust operating rules that provided realistic simulation of reservoir system operations under a wide range of conditions, subject to contemporary system physical constraints, regulatory requirements, water supply needs, and water quality objectives.

Turbidity control alternatives were evaluated under two different water supply demand scenarios: under current demands and under projections for 2012 – 2017 demand. The current demand scenario was based on an annual average in-city demand level of 1,010 mgd and an annual average outside community demand level of 110 mgd. The 2012 – 2017 demand scenario reflected an increased demand for both NYC (annual average of 1,100 mgd) and the outside communities (annual average of 125 mgd).

The water quality performance of alternatives was evaluated based on analysis of long-term OASIS-W2 simulation results according to the following primary water quality performance measures:

- Total number of alum addition days at Kensico Reservoir over the 61-year simulation period;
- Total mass of alum applied at Kensico Reservoir over the simulation period;
- Turbidity levels (and loads) entering Kensico Reservoir at the Catskill Aqueduct Influent Chamber (CATIC); and
- Turbidity levels leaving Kensico Reservoir through the Catskill Aqueduct Lower Effluent Chamber (CATLEFF)

Alum addition in the OASIS-W2 model was based on simple turbidity load-based triggers. As noted above, these triggers do not fully describe the complexity of the actual decision-making process for alum addition. Therefore the alum-days performance measure should be interpreted as days on which alum addition could possibly be required. The mass of alum applied in OASIS-W2 was computed based on a simple empirical relationship between historical CATIC turbidity levels and alum doses.

6.6.2 Results

Major findings are summarized below with respect to the water quality performance of the turbidity control alternatives as well as model sensitivity testing.

Operation of the Ashokan Release Channel could be an important component of an overall turbidity control program by reducing turbidity transfer from Ashokan West Basin to East Basin and thus allowing East Basin turbidity levels to return to normal levels faster following a storm event. A maximum release rate of 800 mgd was found to provide substantially more benefit than a 250 maximum release rate.

Consistent with previous analyses, alternatives that allow DEP to reduce diversions from the Catskill system during turbidity events are critical to controlling turbidity loads entering Kensico, reducing the frequency of alum treatment, and reducing the amount of alum applied when alum addition is required. The Stop Shutters and Shaft 4 connection were predicted to fully or nearly control almost all of the major turbidity events in the 61-year model simulation period.

Routine deployment of Stop Shutters under elevated (greater than ~18 NTU) turbidity conditions was predicted to provide a reduction in the overall number of alum treatment days that is less than but roughly comparable to that of the Shaft 4 connection. With Stop Shutters a number of relatively short duration (i.e., 2 – 10 day) alum addition events were predicted to occur, associated in large part with the installation lag time and minimum flow assumptions in the model. It should be noted that the simulation results do not account for the actual operational effort or complexity associated with installing and removing stop shutters.

Transfer of Delaware water to the Catskill Aqueduct via a Shaft 4 connection was predicted to control all but one turbidity event in the 61-year hydrologic record, a spring storm event in 1980 that was projected to impact turbidity levels into the higher-demand summer drawdown period. When the Shaft 4 connection was operated in conjunction with the Stop Shutters and the Ashokan Release Channel (at rates up to 800 mgd), the model predicted that the need for alum addition for all turbidity events in the 61-year model simulation period was eliminated.

Model sensitivity testing was conducted to examine the sensitivity of model performance predictions to changes in key turbidity input specifications for the Ashokan and Kensico W2 models. As was the case with sensitivity testing under the Catskill Turbidity Control Study (Phases I – III), testing indicated significant sensitivity of performance measures to the input turbidity levels, but little difference in the relative performance of turbidity control alternatives.

7. Watershed Management Alternatives

7.1 Schoharie Watershed Analysis

The Shandaken Tunnel SPDES permit required DEP to "*Submit an approvable turbidity reduction report evaluating the potential benefits of the heightened or more expansive implementation, within the Schoharie Reservoir basin, of program activities established under the 1997 New York City Memorandum of Agreement (MOA) and the 2002 FAD.*" The report, entitled Schoharie Watershed Turbidity Reduction Report: Evaluation of Watershed Management Programs (2008), contained a comprehensive evaluation of the sources of turbidity in the basin and the potential impacts of the watershed programs specified. The watershed programs were divided into four categories based on whether the programs act as protection or reduction programs and whether they affect landscape erosion sources or in-stream sediment

sources. Protection programs, such as the Land Acquisition Program, are designed to protect water quality in the future and thus, analyses of reductions from these programs were not possible. Nonetheless, these programs provide an important, if unquantifiable, benefit by protecting against new potential sources of turbidity. Reduction programs, such as the Stream Management Program, were designed in part to improve water quality, and therefore an analysis of potential reduction from these programs was attempted.

The primary conclusion of the analysis was that terrestrial sources contribute little to the turbidity at the Shandaken Tunnel (the permitted location). The quantitative analysis estimated that roughly 76-91% of turbidity inputs at the outfall of the Shandaken Tunnel were derived from in-stream sources and only 9%-24% were generated from terrestrial sources. Since the total terrestrial input was significantly less than the in-stream sources, the potential for reductions in overall turbidity loading associated with terrestrial-based watershed management and protection programs is extremely limited. Even if the terrestrial-based programs were expanded to every acre of land in the basin, the maximum theoretical turbidity reduction achievable would be less than 5%.

The report concluded that while in-stream sources account for 71-87% of the turbidity, stream management programs would not significantly affect turbidity levels at very high flows – the critical circumstances when turbidity levels most impact the Shandaken Tunnel. These overwhelming events, in contact with a ubiquitous geologic turbidity source, control the quality of releases from the Tunnel for long periods of time. Yet, cumulatively and over time, these programs are expected to have a measurable impact on reducing turbidity for low flow conditions. Similarly, the protection programs contribute significantly, if not quantifiably, to avoiding new or expanded contributions of turbidity within the watershed.

7.2 Ashokan Watershed Analysis

The Catalum SPDES Permit required DEP to submit a report to "*identify and evaluate the potential benefits of the heightened or more expansive implementation, within the Ashokan Reservoir basin, of program activities established under the 1997 New York City Watershed Memorandum of Agreement, the 2002 FAD and subsequently issued FAD's. …submit an approvable report detailing the actions to be taken with respect to each of the measures above as well as any other avenues to be investigated that will achieve the goals of turbidity reduction and reduced alum usage within the Ashokan Reservoir basin*." The report, entitled Evaluation of Turbidity Reduction Potential through Watershed Management in the Ashokan Basin (2008), contained a comprehensive evaluation of the sources of turbidity in the basin and the potential impacts of the watershed programs. As with the Schoharie basin analysis, the watershed programs were divided into four categories based on whether the programs act as protection or reduction programs and whether they affect landscape erosion sources or in-stream sediment sources.

The Esopus Creek watershed represents ~91% of the Ashokan Reservoir watershed. The other sub-basins that drain directly into the Ashokan do not seem to be significant sources of turbidity. The sources of turbidity are mainly from in-stream processes including erosion of layered glacial lake silt/clay and glacial till deposits in stream banks and beds, stream adjacent hill slope failures of these glacial deposits following high flow conditions, and re-suspension of fine-grained sediment in the stream bed material. Geologic and geomorphic mapping in support of stream management plans show that these geologic sources are ubiquitous and variably exposed by

stream erosion and hill slope failure. Given that erosion into these deposits is going to occur as a natural process in landscape evolution, it is unrealistic to remove or isolate all potential turbidity sources from runoff.

A regulated source of suspended sediment into the Ashokan Basin is the diversion of Schoharie Reservoir water into Esopus Creek via the Shandaken Tunnel. On occasion, the Shandaken Tunnel carries highly turbid water, due to the turbidity issues that exist in the Schoharie watershed and reservoir. Even though the Shandaken Tunnel can contain high turbidity, the Tunnel turbidity contribution does not generally contribute to the initiation of alum addition because of dilution with natural Esopus flows and settling at the Ashokan Reservoir. Moreover, following high flow events, the Tunnel is shut down and no water is diverted into the Esopus Creek. During high flow events – the critical events that can lead to alum addition – the total quantity of water, and at times turbidity, delivered to the Ashokan Reservoir from in-basin sources overwhelms any contribution from the Shandaken Tunnel. (A one-time exception to this existed during emergency conditions at the Schoharie Reservoir, when the tunnel had to be operated at continuous high flow to help dewater the reservoir for repairs to the Gilboa dam.)

The primary conclusion of the analysis was that terrestrial sources contributed little to the turbidity at the Catskill Influent Chamber (the permitted location) and that in-stream sources account for 69-89% of the turbidity. The report also found that stream management programs do not significantly affect turbidity levels at very high flows – the critical period when turbidity levels most impact the Ashokan reservoir withdrawals and alum addition may be necessary. DEP concluded that it is unlikely that the watershed management programs will reduce the impact of extreme floods on prolonged turbidity levels in Ashokan Reservoir. These overwhelming events, in contact with a ubiquitous geologic turbidity source, impact the quality of Ashokan Reservoir for extended periods of time.

8. Kensico Alum Alternatives

The Catalum SPDES Permit included a requirement for DEP to develop a report to analyze alternatives to minimize the area of floc deposition resulting from the addition of alum and sodium hydroxide. The report, entitled Feasibility of Minimizing the Area of Alum Floc Deposition in Kensico Reservoir (2007), includes a mixing zone analysis that identifies the spatial and temporal pattern of floc deposition, a discussion of how the various alternatives for minimization of floc deposition would be implemented, the area and depth of floc that would result from each alternative, and identification of the chosen alternative.

8.1 Methodology

In order to analyze the present deposition patterns and the potential benefits of structural alternatives, a numerical computer model of the portion of Kensico Reservoir near the Catskill Influent Chamber (CATIC) was developed. The model was used to:

- assess reservoir flow patterns by comparing model performance with field measurements;
- evaluate existing flow circulation and alum floc deposition patterns; and
- assess the effectiveness of potential alternatives to limit the areal extent of alum floc deposition.

Two types of models could be used to simulate particle movements in a water body: conventional sediment transport models and Computational Fluid Dynamics (CFD) models. Conventional sediment transport models, used previously by DEP for Kensico Reservoir, are generally accepted models to study sediment transport including deposition, erosion and re-suspension processes. However, these models are not capable of modeling baffling geometries, which is the main focus of the analysis. The CFD model could simulate the reservoir bathymetry and the influent infrastructure (CATIC Influent Weir and Drain Gate) to a greater level of detail. This is advantageous since these features dictate the flow pattern inside the cove. In addition, the CFD model could incorporate proposed baffles, silt curtains, submerged weirs, and other flow control structures more accurately and efficiently than other models. The CFD model assumed isothermal conditions and therefore does not take into account the effects of stratification on the deposition of particles; however, the large amount of flow entering Kensico Reservoir through the CATIC weir would likely disrupt any existing stratification near the cove. Overall, the advantages offered by this CFD model outweighed any limitations it might have had and it was deemed adequate to perform a mixing zone analysis to identify the spatial and temporal patterns of floc depositions.

8.2 Description of Alternatives

8.2.1 Non-Structural Alternatives

The following non-structural alternatives could be implemented outside the reservoir itself:

- Minimize Catskill Aqueduct suspended solids concentration. This alternative was investigated separately in CTC Phase III.
- Reduce aqueduct flow rate during times of alum addition. This could proportionately decrease the area of the reservoir needed for settling. DEP already practices this approach within the constraints of overall system operating requirements. Because of other improvements DEP believes that the maximum flow rate could be kept below 300 mgd for any future alum addition events.
- Improve the alum mixing and flocculation process. A review of these processes indicates that the existing aqueduct configuration creates conditions that are not ideal, but that are reasonably close to normal water treatment design criteria. The rapid mixing intensity is less than ideal and the meter where it occurs is located a bit downstream of the application point. The flocculation time is on the order of 40 minutes, which is ideal. The flocculation mixing intensity (velocity gradient created by turbulence in the flowing aqueduct) is constant throughout the flocculation zone and on the order of 10 to 15 sec-1. Any improvements to these processes would be difficult to implement and would probably only achieve a marginal difference in reservoir settling area.
- Use alternative coagulants. Alum is a proven coagulant for Catskill system water. Other coagulants, however, could be considered. An iron-based coagulant, such as ferric chloride, would produce a ferric hydroxide floc. However, the floc characteristics and settling rate would be very similar. Use of polyaluminum chloride, if successful, would reduce the concentration of aluminum hydroxide in the floc and thus slightly reduce the total pounds of floc created. Introduction of a polymer as a settling aid after the alum addition might increase the floc particle settleability. Consideration of these alternatives would require treatability testing and assessment that the alternative chemicals would not

adversely affect the reservoir environment and drinking water quality. Based on experience and prevalent use of alum in the water treatment industry, any performance improvements would probably be only marginal.

Two of the non-structural alternatives have been evaluated elsewhere. The other two alternatives, improving the process parameters and use of alternative coagulants, were not considered for further evaluation based on limited expected benefits.

8.2.2 Structural Alternatives

An evaluation of structural alternatives that could be installed within the reservoir to improve the efficiency of the existing settling process and thus reduce the areal extent of the floc depositions was performed. Six alternatives were identified and each has the objective of improving the influent or the effluent flow conditions of the study area to minimize the areal extent of alum floc deposition.

- Perforated Target Baffle – Installation of a perforated vertical baffle wall to dissipate the energy of water as it enters the CATIC cove would make the flow leaving the cove uniform, thereby reducing the area of floc deposition.
- Sedimentation Basin – Installation of two baffles on the east bank and one baffle on the west bank of the cove would interrupt the high velocity current and increase particle residence time in the area near the CATIC inlet.
- Perforated Baffle Wall – Installation of a perforated baffle wall perpendicular to the general flow direction would make the flow uniform before it leaves the cove as opposed to allowing the more narrow higher velocity current to project the alum floc into the open area.
- Submerged Weir – A submerged weir could act as a baffle to make flow uniform and trap large particles that settle quickly. The submerged weir creates more uniform flow from the cove into the open area of Kensico Reservoir.
- Boom and Silt Curtains – An oil boom and two silt curtains could create a large settling basin within the reservoir. The boom would float on the water surface and be 4 feet deep, allowing water to pass underneath. The silt curtains would be full-depth and assumed impermeable. The oil boom would partially break the high velocity current along the east bank of the CATIC Cove, creating a more uniform outgoing flow pattern from the cove. In this manner, the boom and silt curtains would form a large and enclosed settling basin.
- Large Settling Basin – This alternative represents a combination of concepts. For this alternative, a perforated wall would be placed upstream to homogenize inflow, and an effluent weir would be placed in the open area of the cove to control outflow, making the cove and part of the open area a large settling basin. The arrangement would be designed to mimic a formal water treatment plant settling basin.

8.3 Summary of Findings

None of the six alternatives would produce major changes to the area of floc deposition. However, the most advantageous in terms of process performance would be the Target Baffle. That alternative would involve constructing a permanent perforated baffle wall in the reservoir approximately 50-100 feet from and parallel to the existing weir. The wall would extend for the full length of the weir, about 200 feet.

Because of its location within the reservoir, implementing the Target Baffle alternative would be very difficult and involve significant engineering, environmental and construction issues. These would need to be investigated in detail before a decision could be made on whether to proceed with implementing the Target Baffle.

A flow rate of 300 mgd would not typically be exceeded during future alum addition events. Under this flow rate, the Target Baffle would increase the amount of deposition in the cove area from about 60 percent of the total alum floc deposited to about 90 percent. However, with or without the Target Baffle, all of the floc would be deposited in the general study area near the Catskill Aqueduct Influent Chamber. Given this relatively modest benefit, it does not appear that the Target Baffle warrants further investigation.

9. Modification of the Catalum SPDES Permit EIS

As discussed above, NYSDEC issued the Draft Scope for the Modification of the Catalum SPDES Permit EIS on April 9, 2014. The proposed permit modification includes the incorporation of certain turbidity control measures and the delaying of dredging of alum at Kensico Reservoir until after the completion of certain infrastructure projects. DEP's turbidity control measures are intended to minimize the need for chemical addition through the use of operational, engineering, and other non-treatment measures, while also minimizing the potential for significant adverse impacts to the environment. DEP has already implemented certain measures; while others are under design and/or construction, and are planned to be operational in the next few years. The use of the Ashokan Release Channel per the Interim Ashokan Release Protocol is part of the Proposed Action of the EIS. In addition the following alternatives at Ashokan Reservoir, along the Catskill Aqueduct and at Kensico Reservoir, will also be considered (Table 4).

9.1 Ashokan Reservoir Alternatives

As described above, Phase III of the Catskill Turbidity Control Study completed in December 2007 focused on alternatives at Ashokan Reservoir that could reduce turbidity levels entering Kensico Reservoir. Six potential turbidity control alternatives were evaluated in the "Phase III Final Report - Catskill Turbidity Control Study" dated December 31, 2007. Alternative 6 (Catskill Aqueduct Improvements and Modified Operations) was predicted to have substantial reductions in turbidity levels and resultant alum addition and is part of the Proposed Action. The other five alternatives that have been described previously above will be included in the EIS alternatives analyses.

- Ashokan Reservoir Alternative 1 – West Basin Outlet.
- Ashokan Reservoir Alternative 2 – Dividing Weir Crest Gates.
- Ashokan Reservoir Alternative 3 – East Basin Diversion Wall and Channel Improvements.
- Ashokan Reservoir Alternative 4 – Upper Gate Chamber Modifications.
- Ashokan Reservoir Alternative 5 – East Basin Intake.

In addition to the alternative previously evaluated as part of Phase III of the Catskill Turbidity Control Study, the following additional alternatives would be evaluated as part of the EIS.

- Ashokan Reservoir Alternative 6 – Changed Release Channel Operation. This alternative will evaluate potential effects of different operation scenarios under the Interim Ashokan Release Protocol that may increase community release flows downstream of Ashokan Reservoir, further enhance spill mitigation, and/or increase the capacity of and flows through the Ashokan Release Channel.
- Ashokan Reservoir Alternative 7 – Bypass of Low Turbidity Upper Esopus Creek Water directly to the Ashokan East Basin. Alternative 7 would include construction of a bypass tunnel or other structural improvement to enable routing Ashokan reservoir inflow from the upper Esopus Creek directly to the East Basin.
- Ashokan Reservoir Alternative 8 – Bypass of Upper Esopus directly to the lower Esopus Creek. Alternative 8 would include construction of a bypass tunnel or other structural improvement to enable routing Ashokan reservoir inflow from the upper Esopus Creek around or through the reservoir, discharging to the lower Esopus Creek below the reservoir.

9.2 Alternatives along the Catskill Aqueduct

In addition to alternatives at Ashokan Reservoir, the following alternatives for operation of the Catskill Aqueduct that include options to discharge water from the Catskill Aqueduct prior to its reaching the Kensico Reservoir will be evaluated in the EIS.

- Catskill Aqueduct Alternative 1 – Use of the Hudson River Drainage Chamber. This alternative would involve reconstruction and modifications to the existing Moodna/ Hudson River Tunnel drainage chamber to allow for discharges of turbid water from the Catskill Aqueduct directly into the Hudson River on the east side of the Hudson River near the borders of Putnam and Dutchess Counties. The existing Moodna/Hudson River Tunnel drainage chamber was designed to drain water on an occasional basis from the Catskill Aqueduct for purposes of inspecting the Catskill Aqueduct, and has never been used. Modification to the drainage chamber to accommodate up to 600 MGD of flow from the Catskill Aqueduct on a regular basis will be evaluated.
- Catskill Aqueduct Alternative 2 – Use of the Croton Lake Siphon. This alternative would involve use of the blow-off at the downtake shaft of the Croton Lake Siphon to allow for discharges of turbid water from the Catskill Aqueduct directly into the Croton Reservoir.
- Catskill Aqueduct Alternative 3 – Use of the Rondout Pressure Tunnel. This alternative would involve modification of the Rondout Pressure Tunnel Siphon Drain in order to allow for discharges of turbid water from the Catskill Aqueduct to Rondout Creek that leads to the Hudson River after its confluence with the Wallkill River.
- Catskill Aqueduct Alternative 4 – Use of the Wallkill Pressure Tunnel Siphon Drain or the Wallkill Blow-off Chamber. This alternative would involve use of either the Wallkill Pressure Tunnel Siphon Drain, with modification, or the Wallkill Blow-off Chamber to allow for discharges of turbid water from the Catskill Aqueduct to the Wallkill River that leads to the Hudson River after its confluence with Rondout Creek.

9.3 Alternatives at Kensico Reservoir

The six alternatives referenced in Section 7 above as described in the "Feasibility of Minimizing the Area of Alum Floc Deposition in Kensico Reservoir," dated October 2007, will be included in the EIS alternatives analyses.

- Kensico Reservoir Alternative 1 – Perforated Target Baffle.
- Kensico Reservoir Alternative 2 – Sedimentation Basin.
- Kensico Reservoir Alternative 3 – Perforated Baffle Wall.
- Kensico Reservoir Alternative 4 – Submerged Weir.
- Kensico Reservoir Alternative 5 – Boom and Silt Curtains.
- Kensico Reservoir Alternative 6 – Large Settling Basin.

10. Conclusion

The Catskill water supply system is naturally prone to high levels of turbidity due to the geologic history of the region. Over the past decade DEP has evaluated a wide range of structural and non-structural approaches using a combination of engineering analyses and sophisticated mathematical models. Managing turbidity in the water supply has been an evolving process that continues today with the development of tools such as OST and the upcoming environmental review.

Table 4. Catskill Turbidity Control Alternatives

Alternatives	Phase I	Phase II	Phase II Implementation Plan	Phase III	Phase III VE	Ph III Implementation Plan	Turbidity Control Alternatives Analysis	Kensico Feasibility of Min Alum	Catalum EIS[1]
Multi-level Intake in Schoharie Reservoir (MLI)	✓	✓	✓						
Turbidity Curtain	✓								
In-Reservoir Baffle	✓	✓	✓						
Schoharie Modified Reservoir Operations	✓	✓	★						
Engineered Treatment Facilities	✓								
Ashokan Modified Operations (combined into OST)	✓								
High-Rate Sedimentation Basin	(2)								
West Basin Outlet				✓	✓	✓	✓		✓
Dividing Weir Crest Gates				✓	✓	✓			✓
East Basin Diversion Wall Improvements				✓	✓	✓			✓
Upper Gate Chamber Modification				✓	✓	✓			✓
East Basin Intake				✓	✓	✓			✓
Catskill Aqueduct Improvements - Shaft 4 Connection				✓	✓	★	✓		✓
Catskill Aqueduct Improvements - Stop Shutters						★	✓		✓
Modified Operations (Operations Support Tool (OST))						★	✓		✓

Alternatives	Phase I	Phase II	Phase II Implementation Plan	Phase III	Phase III VE	Ph III Implementation Plan	Turbidity Control Alternatives Analysis	Kensico Feasibility of Min Alum	Catalum EIS[1]
Perforated Target Baffle								✓	✓
Sedimentation Basin								✓	✓
Perforated Baffle Wall								✓	✓
Submerged Weir								✓	✓
Boom and Silt Curtains								✓	✓
Large Settling Basin								✓	✓
Bypass of Low Turbidity upper Esopus Creek Water									✓
Bypass of upper Esopus directly to the lower Esopus Creek									✓
Hudson River Drainage Chamber									✓
Croton Lake Siphon					✓				✓
Rondout Pressure Tunnel									✓
Wallkill Pressure Tunnel Siphon Drain or the Wallkill Blow-off Chamber									✓

Notes:

1. The Catalum EIS alternatives are based on the draft scope and may not reflect the final list of alternatives analyzed in the EIS.
2. Evaluated in a separate Technical Memorandum as a follow-up to the Phase I analysis.
3. Check marks indicate where alternatives were analyzed.
4. Stars indicate alternatives selected for implementation.