New York City Department of Environmental Protection
Bureau of Water Supply

Schoharie Watershed Turbidity Reduction Report: Evaluation of Watershed Management Programs

September 1, 2007

Prepared in accordance with the 9/1/2006 SPDES Permit (NY-026 8151) for the Shandaken Tunnel Outlet

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Executive Summary

This report presents an evaluation of the potential for turbidity reduction from stream and terrestrial sources of fine sediment by the implementation of several existing watershed management programs established under the 1997 NYC Memorandum of Agreement (MOA) and the 1997 and 2002 Filtration Avoidance Determinations (FADs). It is prepared by NYCDEP in accordance with the schedule of compliance for the development of a "Turbidity Reduction Program" as detailed in SPDES permit number NY 026-8151 relating to the Shandaken Tunnel Outlet.

NYCDEP performed a combined quantitative and qualitative assessment for this evaluation. The SPDES permit language guiding this report does not dictate a specific evaluation approach. However, for the intended purpose of this report, we provide a quantified assessment of whether it is feasible to impact turbidity values at the Shandaken Tunnel Outlet, the point of discharge for the permit. The qualitative assessment is based on the experience of the past Filtration Avoidance Determination (FAD) activities and NYCDEP's understanding of the relative significance of these programs as estimated by the quantitative assessment.

The sources of the turbidity in the streams that feed Schoharie Reservoir are ice age deposits of silts and clays that mantle the valley walls and underlie the blanket of former stream sediment that covers the valley floor. Previous geologic mapping and mapping in support of stream management plans for the Schoharie Reservoir watershed show that these geologic sources are ubiquitous and variably exposed. Given that erosion into these deposits is going to occur as a natural process in landscape evolution, NYCDEP recognizes that it is unrealistic to remove or isolate all potential turbidity sources from runoff. This is especially so with the flood regime and steep mountain streams of the eastern Catskill Mountains.

The Watershed Management Programs included in the analysis 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-channel 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 are 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 quantitative analysis presented in this report estimates that roughly 76-91% of turbidity inputs at the outfall of the Shandaken Tunnel are derived from in-stream sources and only 9%-24% are generated from terrestrial sources. Since the total terrestrial input is 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. For purposes of this

report, in order to determine the maximum conceivable benefit associated with such terrestrial-based programs, we analyzed an obviously unrealistic best-case scenario using the optimum condition of a "pristine" (completely forested and undeveloped) watershed. The analysis confirmed that even under this scenario, the potential reduction of turbidity would be very small because most of the source is from the stream channel network.

The Stream Management Program has the greatest potential for reducing turbidity. Under the guidelines set forth in the SPDES permit, NYCDEP and GCSWCD will implement a Schoharie Basin Action Plan that includes a stream restoration program (at least 5,000 ft of treated stream) in the Schoharie Reservoir watershed. It will take many years to fully evaluate the effectiveness of stream restoration and other stream management practices. Moreover, for the reasons discussed in detail in this report, the impacts of improved stream management practices are likely to have, at best, only a marginal impact on turbidity levels in the diversions through the Shandaken Tunnel. These conclusions are based on a simplified analysis and the margin for error is high given the uncertainty of the conditions of entrainment and the effectiveness of programs in having a measurable reduction in turbidity at various flows. Still, it is apparent from this analysis that Watershed Management Programs can protect and improve water quality but may not be a useful action to improve achievement of parameters set forth in the SPDES permit.

Fundamentally, it is unlikely that the Watershed Management Programs will reduce the impact of extreme floods on prolonged turbidity levels in Schoharie Reservoir. These overwhelming events, in contact with a ubiquitous geologic turbidity source, control the quality of discharge 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 other flow conditions and hopefully reducing the prolonged impact of the big floods by creating a more resilient stream system and minimizing damaging post-flood activities that can do even more damage than floods to destabilize the stream system. Similarly, the protection programs contribute significantly, if not quantifiably, to avoiding new or expanded contributions of turbidity within the watershed.

1. Introduction

1.1. Purpose of this report

This report is prepared by NYCDEP in accordance with the schedule of compliance for the development of a "Turbidity Reduction Program" as detailed in SPDES permit number NY 026-8151 relating to the Shandaken Tunnel outlet. As the permittee, NYCDEP is specifically responsible for, among other action items 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 Watershed Memorandum of Agreement and the 2002 FAD. This report will include an evaluation of the potential benefits of increased or focused funding and implementation of whole farm, forestry, willing seller land acquisition, stream restoration, storm water retrofit, stream buffer and conservation easement programs. The report will include alternative proposals for a focused willing buyer-willing seller land acquisition and conservation easement program."*

The Shandaken Tunnel SPDES permit, in effect since September 1, 2006, established effluent limits for turbidity, temperature and phosphorus, as well as monitoring and reporting requirements (Attachment 1 – SPDES permit).

The Schoharie Reservoir and the Ashokan Reservoir comprise the New York City West-of-Hudson (WOH) Catskill District (Figure 1.1). Turbidity in the Catskill District has been a historical water quality issue (Joint Venture, 2006; CCEUC, 2007; NYCDEP, 2003). Turbidity in the Catskill District is largely episodic due to storm events that erode glacially-derived silt and clay from deposits exposed in the landscape or stream channel. These deposits are the source of suspended sediment that turns the streams and reservoirs a characteristic reddish-brown (Figure 1.2). Following these storm events the elevated turbidity in the Schoharie Reservoir impacts Esopus Creek through the inter-basin transfer of water via the Shandaken Tunnel (Figure 1.1; Figure 1.3). Elevated turbidity in Esopus Creek, the primary source of Ashokan Reservoir, is of concern primarily due to its potential impact on the overall water quality of NYC's unfiltered drinking water supply. Water quality sampling and modeling indicate that the turbidity delivered to Esopus Creek via the Shandaken Tunnel is not sufficient to impact the quality of the drinking water supply; however, sediment loading may impair aquatic ecosystems. (NYCDEP, 2006; CCEUC, 2007)

Figure 1.1. New York City Water Supply System

The ability to reduce turbidity to the reservoir system from the watershed depends on the ability to reduce suspended sediment loading from watershed sources. The programs described in this report are part of a comprehensive watershed protection and management strategy established as part of the MOA. While they were not specifically developed to be turbidity reduction programs, the SPDES permit requires evaluation of these programs for their potential to reduce turbidity.

This report is intended to address the following questions:

- What levels of suspended sediment loading reduction might be expected from applicable watershed management program implementation in the Schoharie Reservoir watershed?
- What levels of suspended sediment loading reduction may alter turbidity levels in the Shandaken Tunnel withdrawal?
- What is the appropriate combination of watershed management programs to help address suspended sediment loading such that reservoir water quality is effectively improved?

This report presents a quantitative and qualitative evaluation of the potential impact of watershed protection programs on reducing suspended sediment loading at the watershed scale.

There are a number of documents that contain important background information describing the history of the Catskill District of New York City's West-of-Hudson water supply system and the issue of turbidity in that water supply. This report will not recount those details that are adequately covered elsewhere. Specifically, extensive details on the Schoharie Reservoir watershed, the history of the Shandaken Tunnel, the geologic sources of turbidity, and watershed protection and management programs are discussed in readily available public documents. Only a brief description of those items is presented below as needed. A list of pertinent supporting documents is included in the references section of this report.

Figure 1.2. Turbid stream water in a tributary to Schoharie Creek

1.2. Catskill District and Shandaken Tunnel

The Catskill District includes the Schoharie Reservoir, Shandaken Tunnel, and Ashokan Reservoir (Figure 1.1). The Schoharie Reservoir drains a 314 square mile watershed, and delivers an average flow of 200 – 300 mgd to the Catskill System.

Figure 1.3. Shandaken Tunnel Outlet (Portal) discharging turbid water to a turbid Esopus Creek following the April 2-3, 2005 flooding.

Withdrawals from the Schoharie Reservoir are made via a rock-cut channel that carries water into the Schoharie Reservoir Intake Chamber, where it flows into the Shandaken Tunnel. The water flows naturally down the tunnel by means of gravity, with seven shafts that are open to the air along the way serving as a means to keep oxygen in the water throughout its 18 mile journey to Upper Esopus Creek. Once delivered, the Esopus carries the Schoharie Reservoir water an additional 12 miles southeast into Ashokan Reservoir. A summary of the regulatory controls on the Shandaken Tunnel (6 NYCRR PART 670 and the SPDES permit) can be found in the recently completed Esopus Creek Management Plan (CCEUC, 2007).

1.3. Catskill Turbidity Sources

Due to the geology of the watershed, the Catskill System is subject to periods of elevated turbidity from entrained suspended sediment. The turbid water that follows a storm event carries the fine silt and clay particles initially deposited as glacial till or pro-glacial lake sediment (Figure 1.4; Figure 1.5) (GCSWCD, 2007). Landscape and stream erosion of these fine sediment sources, along with re-suspension of fine sediment deposited in the stream bed, are the primary cause of the turbid water conditions that can impair the quality of Shandaken Tunnel discharge. The suspended sediment sources are lumped into two categories: landscape erosion source and in-channel erosion sources. The predominant location of sediment entrainment is within the channel network, rather than from overland flow across the landscape. The quantification of this division of loading is addressed in Section 3.

Recent mapping of these fine sediment sources along the Schoharie Creek channel reveals that these sources are exposed in the channel from headwaters to near the Schoharie Reservoir stem (Schoharie Creek SMP). Glacial till exposures dominate in the headwaters and hill slopes, while the larger valley bottoms tend to be uniformly underlain at varying depth by the thick inter-bedded layers of silt and clay lake deposits. Similar mapping efforts in Schoharie Creek sub-basins, as well as the adjacent Esopus Creek watershed, indicate that these clay-rich deposits represent a watershed scale non-point source of sediment delivery to Schoharie Creek. As streams reclaimed the glaciated landscape, they have interacted with these deposits for the past 15,000 years or so, and will continue to do so for the foreseeable future.

A more comprehensive accounting of the geologic conditions that influence turbidity in the Catskill District can be found in the stream management plans developed for the streams in the Schoharie Creek and Esopus Creek watersheds (GCSWCD, 2007; CCEUC, 2007). The 2003 Catskill Turbidity Control report prepared by NYCDEP in accordance with the 2002 FAD also includes additional detail on the geology (NYCDEP, 2003).

While the fine sediment sources exist throughout the watershed, their exposure to entrainment in runoff is quite heterogeneous and not easily characterized. First, the exposures in the stream channel network are generally temporally and spatially transient – variably scoured and exposed or covered depending on the movement and subsequent deposition of the coarser bedload that covers the fine sediment sources. Also, certain sub-basins are more likely to have a disproportionately larger sediment loading due to unique glacial conditions within the valleys or more degradation within the valleys attributable to poor stream management. Water quality sampling by NYCDEP, as reported in the Catskill Turbidity Control report (NYCDEP, 2003) provides evidence that the Batavia Kill and West Kill sub-basins are the major contributors of turbidity in the Schoharie basin.

Figure 1.4. Glacial lake silt and clay layers (varves) exposed in a streambank along Schoharie Creek.

Figure 1.5. Clay-rich glacial till exposed in a streambank along East Kill

2. Watershed Management and Protection Programs that May Address Turbidity in the Schoharie Basin

Several of the Watershed Management Programs, while not specifically designed to be "turbidity reduction" programs, have some turbidity reduction potential either from mitigating landscape sources or addressing stream channel sources. Table 2.1 is a simple matrix that categorizes the watershed programs into potential reduction or protection programs and as affecting landscape or stream channel erosion. Figure 2.1 is a map depicting the implementation of these programs within the Schoharie Reservoir watershed.

Table 2.1. Watershed Management Programs: Reduction vs. Protection

WATERSHED MANAGEMENT PROGRAMS	Landscape Erosion	Stream Channel
Reduction	Watershed Agricultural Program *Whole Farm Plans/BMPs* Watershed Forestry Program *Forest Management Plans/BMPs* Stormwater Retrofit Program *Urban stormwater management*	Stream Management Program *Stream Restoration* *Streamside Assistance*
Protection	Land Acquisition Program *Fee simple* *Easements*	Watershed Agricultural Program *CREP*

There are many reports that provide detail on the development and history of these programs. (NYCDEP, 2001; NYCDEP, 2006). Brief summaries of program scope and specific application in the Schoharie Reservoir watershed are provided below. Section 3 of this report provides details on how the effects of these programs are conceptualized and incorporated into the quantitative evaluation.

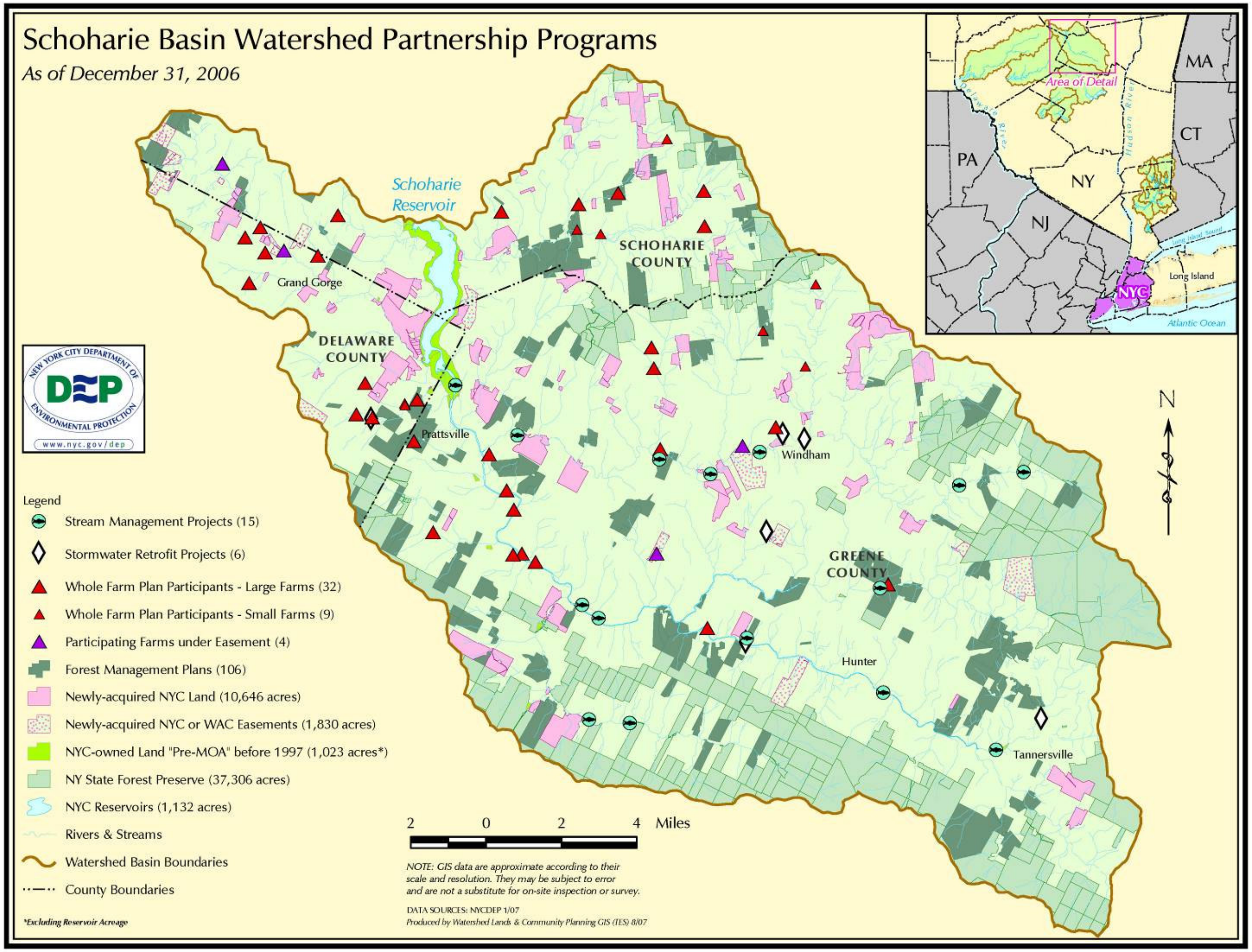

Figure 2.1. Schoharie Basin Watershed Management Programs status as of December 31, 2006

2.1. Watershed Agricultural Program

The Watershed Agricultural Program (WAP) has operated, in partnership with the Watershed Agricultural Council (WAC) since 1992 as a comprehensive effort to develop and implement pollution prevention plans on 85% of the commercial farms in the City's Catskill/Delaware watershed (NYCDEP, 2006). Since 1992, Watershed Agricultural Program has developed Whole Farm Plans (WFPs) on 43 farms (see Table 2.2 below for number of farms by subbasin and Figure 2.1 for location) in the Schoharie watershed. WFPs address potential water quality issues, including erosion and sedimentation, nutrients and pathogens, by recommending Best Management Practices (BMPs). Commonly used BMPs to address erosion and sedimentation are: riparian forest buffers, cover crops, crop rotations, diversions, fencing to exclude animals from watercourses and improved grazing systems. To date 36 of the 43 farms have begun implementing BMPs according to their WFP and 28 of those farms are considered substantially implemented. It should be noted that 11 of the 43 farms currently have no livestock and are considered inactive.

The agreement between New York City, New York State and USDA that created the NYC Watersheds Conservation Reserve Enhancement Program (CREP) in 1998 provided enhanced incentives for farmers to implement riparian forest buffers. To date, 12 farms in the Schoharie basin have agreed to implement approximately 145.5 acres of riparian forest buffers on their farms. Whole Farm Planners continue to encourage other eligible watershed farmers to enroll in CREP during annual plan status reviews and when plans are being revised. In addition, one farm in the Schoharie Basin has set aside 11 acres of riparian forest buffer through the USDA Debt to Nature Program.

Table 2.2. Number of farms in Schoharie subbasins with Whole Farm Plans (WFP) and those participating in CREP.

Subbasin	Farms with WFPs	Farms with CREP
Batavia Kill	4	0
Bear Kill	7	3
East Kill	1	1
Johnson Hollow Brook	6	0
Little West Kill	1	1
Manor Kill	8	3
Mitchell Hollow	3	1
Schoharie Creek	8	1
Schoharie Creek Headwaters	1	0
Schoharie Reservoir	1	0
Sutton Hollow	3	2
Total	43	12

2.2. Stormwater Retrofit Program

The Stormwater Retrofit Program funds the design, permitting, construction, implementation, and maintenance of stormwater BMPs to address existing stormwater runoff in concentrated areas of impervious surfaces in the WOH watershed to the extent such stormwater BMPs are necessary to correct or reduce existing erosion that may contribute turbidity to streams and/or pollutant loading. Catskill Watershed Corporation (CWC) manages the Stormwater Retrofit Program in consultation with DEP. CWC and DEP solicit program applications, conduct site inspections, complete project evaluations, and administer previously funded projects. Projects often address turbidity problems by creating detention basins for silt and clay laden stormwater from upland sources and also by attenuating the discharge of stormwater to streams which diminishes the erosive force on the stream channel.

To date, the Stormwater Retrofit Program has approved funding for nineteen projects within the Schoharie basin; three have been implemented (Figure 2.1). At this writing, a fifth round of projects is being solicited.

Two examples of how the Stormwater Retrofit Program in conjunction with other Watershed Management Programs can be useful in mitigating landscape sources of turbidity are the purchase and multi-year use of a hydroseeder and the replacement of a culvert.

With funding from the Stormwater Retrofit Program, the Greene County Soil and Water Conservation District (GCSWCD) acquired a hydroseeder in 1999 for use in seeding stream restoration projects. It is also used by watershed highway departments for critical seeding of earthen drainage ditches along town and county roads. To date, the hydroseeder has been used to seed hundreds of acres of riparian buffer area on GCSWCD/DEP stream restoration projects including the Big Hollow project on the Batavia Kill, the Farber Farm project on East Kill, the West Kill and Prattsville stream restoration projects.

The second project was partial funding of a culvert replacement under Johnson Hollow Road in connection with a Whole Farm Plan. The upgrading of the existing highway culvert provides needed hydraulic capacity in order to reduce the incidence of backwater surcharging and barnyard inundation, as well as overtopping of the roadway with resulting scour.

To date, the stormwater retrofit program in the Schoharie basin has committed a total of $1,131,315. Table 2.3 summarizes these projects.

Table 2.3. Stormwater Retrofit Program Projects in the Schoharie Basin.

Funding Year	Applicant	Project Area	Project Description	CWC Funding
1999	Greene Co. SWCD	Various Locations	Hydroseeder for Critical Area Seeding Program	$58,243
1999	Roxbury (T)	Johnson Hollow Road	Culvert Installation	$9,900
2000	Windham (T)	Mitchell Hollow Road	Roadside ditch stabilization and Stormwater treatment	$25,125
2000	Tannersville (V)	Various Locations	Sump Pump Connections	$107,162
2001	Windham (T)	Hickory Hill Road	Roadside ditch stabilization and Stormwater treatment	$73,950
2001	Hunter (T)	NYS Rt. 23A	Roadside ditch stabilization and Stormwater treatment	Completed by NYSDOT
2002	Windham (V)	Windham Ventures Parking Lot and Vets Road	Stormwater collection, conveyance and treatment	$20,500
2002	Greene Co. SWCD	Hunter (T) Highway Facility	Stormwater collection, conveyance and treatment	$56,100
2002	Jewett (T)	Carr Road	Feasibility Study	$10,000
2003	Roxbury (T)	Cronk Lane	Stormwater collection, conveyance and treatment	$36,575
2003	Greene Co.	Hunter Transfer Station	Stormwater Separation	$18,000
2003	Greene Co.	Street Sweeper	Sediment Collection	$170,120
2003	Hunter Mtn. Ski Bowl	Gravel Parking Lot	Stormwater collection, conveyance and treatment	$63,367
2003	Greene Co. SWCD	Windham Mtn.	Stormwater collection, conveyance and treatment	$279,630
2006	Windham (T)	Municipal Gravel Parking Lot	Stormwater collection, conveyance and treatment	$25,834.37
2007	Hunter (V)	Botti Drive	Flood By-Pass	$176,808.50

2.3. Watershed Forestry Program

The Watershed Forestry Program is a voluntary pollution prevention partnership that supports and maintains well-managed forests as a beneficial watershed land use. Among its core tasks, the Forestry Program offers cost-sharing, technical assistance and other incentives to loggers and landowners for implementing forestry BMPs, with a particular focus on promoting the use of portable bridges for stream crossings and utilizing erosion control technology during the construction of forest access systems. Although forests contribute the least amount of pollution per acre of any land cover, short-term water quality impacts may occur during poorly-managed timber harvest operations. Erosion and sedimentation from improperly designed timber harvest roads are the primary source of forest-based pollution. For this reason, the Watershed Forestry Program cost-shares the proper installation of new timber harvest roads and the remediation of existing forest roads having erosion problems. Through June 2007, more than 40 road BMP projects have been completed in the Schoharie basin, representing approximately 80 linear miles of properly constructed and stabilized forest access systems (Figure 2.1). In addition, more than 16,000 acres of private land in the Schoharie basin has been enrolled in watershed forest management plans. For additional information about project accomplishments, please refer to the Watershed Forestry Program semi-annual report submitted July 31, 2007.

2.4. Land Acquisition, Conservation Easements, and Management

The Land Acquisition Program (LAP) is a key component of New York City's comprehensive efforts to protect and enhance the quality of its water supply, ensuring clean and safe water for future generations. Land acquisition and proper stewardship can protect natural resources that filter pollutants (such as fine sediment) before they reach reservoirs. Acquisition of sensitive areas near watercourses, whether through outright purchase or through conservation easements, can prevent the introduction of new sources of pollution. The Program is further described in the MOA and FAD. Between 1997 and 2007, the City committed $250 million to acquire vacant land or conservation easements in the watershed that contain streams, wetlands, floodplains and other areas that are critical to maintaining high water quality.

As of 1997, NYC owned 1,044 acres of buffer land surrounding the Schoharie Reservoir, while approximately 36,000 acres were protected by NYS and other such entities (Figure 2.1). In a drainage basin which is roughly 201,000 acres in size, protected lands as of 1997 thus represented 18.4% of the basin. The Land Acquisition Program has been soliciting and acquiring lands in the Schoharie basin since 1999. To date 80,400 acres have been solicited in this basin, and DEP has secured 10,950 acres in fee simple, 843 acres under WAC conservation easement (CE), and 2,097 acres under NYCDEP CE. In all, 26.2% of the basin is now protected through public ownership.

Once land is purchased or a conservation easement has been obtained the City's Land Management Program has oversight in various areas that might affect turbidity. Impacts would largely be related to various land uses and would most likely be related to roads or other disturbances in the protected wetland, watercourse, or reservoir buffers.

2.5. Stream Management Program

The Stream Management Program (SMP) was established in the early 1990's and funded as a watershed protection program in the MOA and the 2002 FAD. The mission of the SMP is to protect and/or restore achievable levels of stream system stability and ecological integrity by providing for the long-term stewardship of streams and floodplains. Stream corridors were identified early on as a particularly important focus of the City's watershed protection and partnership effort because of the significant role that management of stream corridors plays in determining water quality by influencing the physical stability of streambanks and beds, and the processing of pollutants in surface and sub-surface flows to the streams. The SMP is working, through the development of stream management plans and their implementation with local and City program partnerships, to restore and preserve the functional integrity of stream corridors and floodplains. To date stream management plans have been developed for the Schoharie Creek mainstem, the Batavia Kill, the West Kill, and the East Kill (Figure 2.2)

A principle effort within the SMP that has a direct and potentially measurable reduction in suspended sediment loading from stream channels is the set of progressive stream restoration projects implemented by GCSWCD within the Schoharie Reservoir watershed. DEP and GCSWCD are promoting an applied geomorphic approach (after Rosgen 1996 and others) to streambank and streambed restoration in an attempt to reduce excessive rates of erosion and associated losses of sediment from within a river channel. This approach involves the application of the science of river morphology, providing much more than the traditional bank-hardening approach to stream management, including detailed consideration of sediment transport as well as water flow, and the influence of long-term river processes on stream channel maintenance. The underlying principle is that there is a direct relationship between a stream's morphology (its form or shape) and its function (how it behaves), with stream function directly impacting sediment losses from banks and bed. The approach that the City takes toward stream management is most recently described in the 2006 Watershed Protection Program Summary and Assessment Report (NYCDEP, 2006). To date there have been 8 restoration projects totaling ~22,500 feet funded or supported by NYCDEP (Table 2.4).

Table 2.4. NYCDEP Sponsored Stream Restoration in the Schoharie Basin

Restoration Project	**Year Completed**	**Stream**	**Length (ft)**
Maier Farm	1999	Batavia Kill	1,650
Brandywine	1999	Batavia Kill	3,600
Big Hollow	2002	Batavia Kill	5,130
Ashland Connector	2006	Batavia Kill	3,400
Conine	2007	Batavia Kill	1,650
Shoemaker	2005	West Kill	3,000
RAH Stables	2006	West Kill	1,200
Farber Farm	2000	East Kill	2,400
Lexington	1997	Schoharie Creek	500

The goal in applying a geomorphic approach to stream management and restoration is to achieve a more 'natural' (self-sustaining) stream function and stability, an important consequence of which may be a reduction of turbidity. In doing so, the SMP is applying watershed and reach assessment and classification systems, and creating regional databases for stable stream channel geometry for use as templates to guide stream restoration in appropriate settings. Restoration projects are designed with the entire stream system taken into account, including geologic, hydrologic, vegetative and management settings. Following restoration, projects are monitored to assess effectiveness with respect to the project objectives. It is important to note that project selection, to date, has not generally targeted reduction of sediment loading as a primary goal. For instance the Maier Farm and Brandywine reaches of the Batavia Kill were chosen as visible sites for education/outreach purposes and as training SWCD in natural channel design techniques.

With respect to turbidity source areas, project teams in priority Schoharie subbasins (the Batavia Kill, West Kill, East Kill and Schoharie Creeks) have undertaken a field-based, headwaters-to-mouth, stream assessment and data gathering process. The stream assessment data collected includes, among other things, stream reach stability (pattern, dimension and profile) and riparian vegetative conditions. Assessment and data analysis enables the project team members to prioritize stream management activities according to their potential benefit to water quality, private and public infrastructure, and ecological integrity. The main stem is mapped using GPS and the dimensions of significant areas of clay exposure or clay-related instabilities are identified. Stream reaches that are in or approaching an unstable form, combined with the presence of clay, are prioritized most highly for suspended sediment (turbidity) water quality purposes. Often, stream reaches that are significant contributors to suspended sediment are obvious from their strong visible contrast in clarity immediately above and below the source.

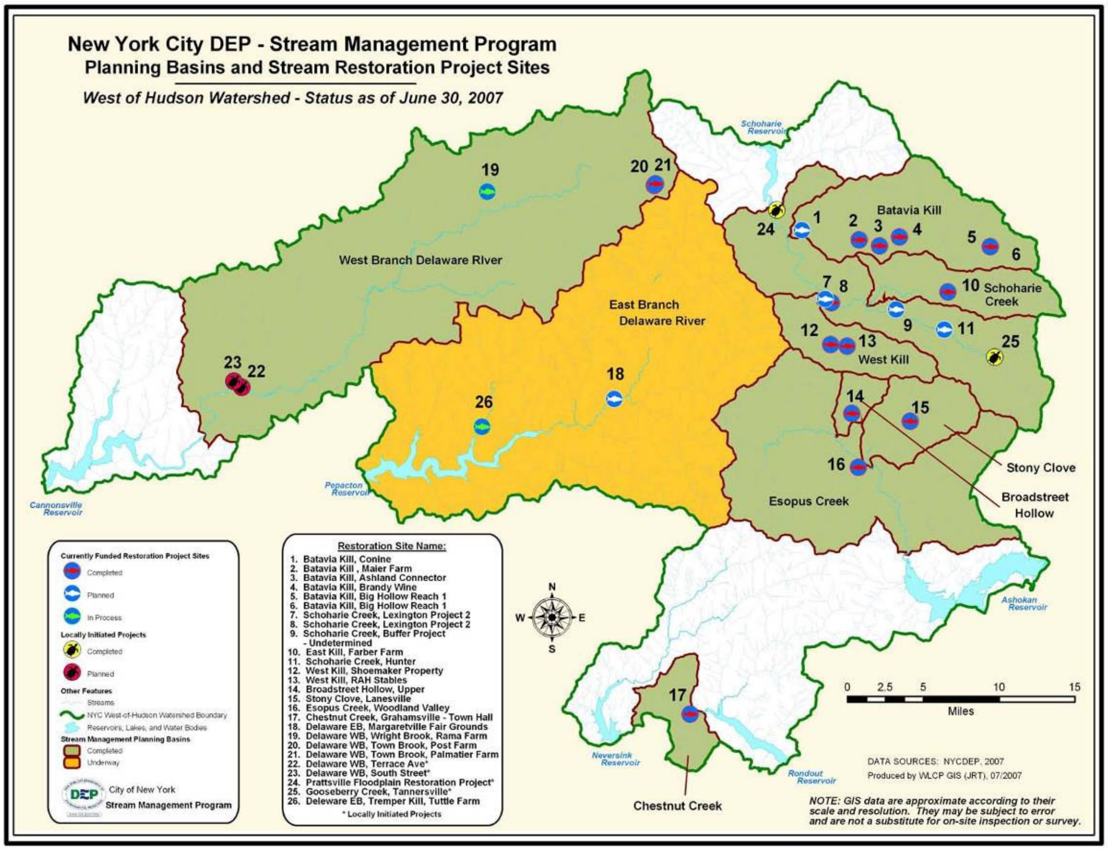

Figure 2.2. Stream Management Planning Basins and Restoration Project Locations

The SMP has been commonly perceived as a turbidity reduction program because it addresses eroding streambanks and the most visible pollutant from this source, suspended sediment. The City expects that the successful implementation of the SMP will address some of the impacts to water quality from some in-channel sediment sources. To date, visual improvements have been noted on stream restoration projects at low flows. At high flows, these streams still run turbid. The underlying geology of streams in the Catskill District, as described in Section 1.3, is predominated by glacial lake and glacial till soils, both clay-rich, in the stream valleys and surrounding mountainsides. For this reason, regardless of what stream restoration projects may be implemented, Schoharie watershed streams will experience turbidity, especially at high flows, because these flows naturally mobilize the boulders, cobbles, and gravels that make up the bed of the streams and which can have an erosive contact with the underlying clay-rich soils. The potential of this implementation to help achieve the SPDES Permit effluent limit is addressed in Section 3.

3. Analysis of Potential Effects of Watershed Partnership Programs

3.1. Introduction

This section presents analyses of turbidity within Schoharie watershed and potential benefits for reservoir turbidity levels associated with watershed protection and partnership programs. The analysis will attempt to answer the following: (1) what levels of suspended sediment loading reduction might be possible from the implementation watershed management programs; and (2) how might potential suspended sediment loading reductions alter reservoir turbidity levels related to the SPDES permit requirements.

Turbidity in the streams that feed Schoharie Reservoir is caused by the fine suspended sediments (silts and clays) that are entrained in streamflow during storm events. The generation and transport of suspended sediment through a watershed is a complex process. Sediment can be generated through erosion of upland areas such as farm fields, un-vegetated areas, steep slopes, and/or areas of highly erosive soils. Only a portion of this erosion will actually be transported to the stream, with the remainder being re-deposited in other locations within the watershed. The timing of the movement of these eroded particles is generally unknown and it can take many events to physically transport these particles from initial erosion to watershed outlet depending on the flow paths, event sizes and particle mobility.

In addition to upland, or landscape, erosion, sediment can also be generated from or deposited into stream channel itself. This makes the stream channel either a net source or sink of sediment. During any event, large quantities of sediment are transported. However, from the perspective of the entire stream channel system, sediment may be accumulated (along aggrading streams and floodplains) or exported via downstream transport of eroded in-stream particles. The difference between the accumulated and exported materials represents a net suspended sediment supply of the stream channel network.

This combination of landscape erosion and in-channel sediment movement is further complicated because it may take many years for sediment to be transported from any point in the watershed to the stream outlet. Any "reduction" in sediment generation, therefore, may take many years to be observed at the outlet. Given these complications related to the timing and movement of suspended sediment to the watershed outlet, we have focused on a long-term perspective for calculating potential sediment sources and suspended sediment transported to the Schoharie Reservoir.

The approach followed herein consists of five steps:

(1) Calculate the timing and the amount of sediment load from the Schoharie Watershed into the Schoharie Reservoir utilizing a suspended sediment rating curve (Section 3.2)

(2) Estimate the sources of sediment within the Schoharie Watershed (landscape erosion versus net in-channel sources), using erosion prediction models, sediment delivery and total long-term suspended sediment yield as derived from step 1 above. (Section 3.3)

(3) Model the maximum potential benefit of programs that target landscape erosion, by comparing estimates of erosion under both current condition and a scenario of "pristine" conditions. (Section 3.4)

(4) Estimate the potential benefits of in-channel reduction programs, based on distributions of stream characteristics as indicators of areas of sediment generation. (Section 3.4)

(5) Analyze the sensitivity of potential sediment reductions as estimated in steps 3 and 4 on turbidity in Shandaken Tunnel, by using a two-dimensional reservoir model. (Section 3.5)

3.2. Timing and Quantity of Suspended Sediment Loading to Schoharie Reservoir

To estimate the timing and amount of sediment load from the Schoharie watershed into the Schoharie Reservoir a sediment rating curve was used to estimate daily suspended sediment loading values for the outlet of the Schoharie Creek watershed at Prattsville (NYCDEP, 2006):

$$S_d = \begin{cases} 1.706 Q_d^{\,1.2} \text{ for } Q_d > 12.2 \text{ m}^3\text{/sec} \\ 0.019 Q_d^{\,3.0} \text{ for } Q_d \le 12.2 \text{ m}^3\text{/sec} \end{cases} \qquad (3.1)$$

where, S_{day} is the daily suspended sediment load (kg/day) and Q_d is the daily streamflow (m^3/sec). The numerical factors, exponents, and flow threshold in equation 3.1 were estimated by calibration, based on flow and stream monitoring data collected along the Schoharie Creek. Daily streamflow data was measured by USGS Stream Gage #1350000 located along Schoharie Creek at Prattsville (Figure 3.1). DEP stream monitoring data included both fixed frequency data (collected about every two weeks) and storm event sampling collected during a number of high flow events from October 1996 through December 2001. The storm event sampling included 21 high flow events, yielding 73 daily load values. Daily average suspended sediment concentrations during events was integrated from suspended sediment load calculated as the product of event sampled concentration and instantaneous (15 minute) flow data for USGS. The calibrated rating curve was tested and shown to be a good predictor of daily TSS for Schoharie Creek at Prattsville (Figure 3.2).

In the following sections, this suspended sediment rating curve will be used to derive inputs to support Schoharie Reservoir model runs (Section 3.5) and to estimate long-term total suspended sediment loads to the Schoharie Reservoir (Section 3.3).

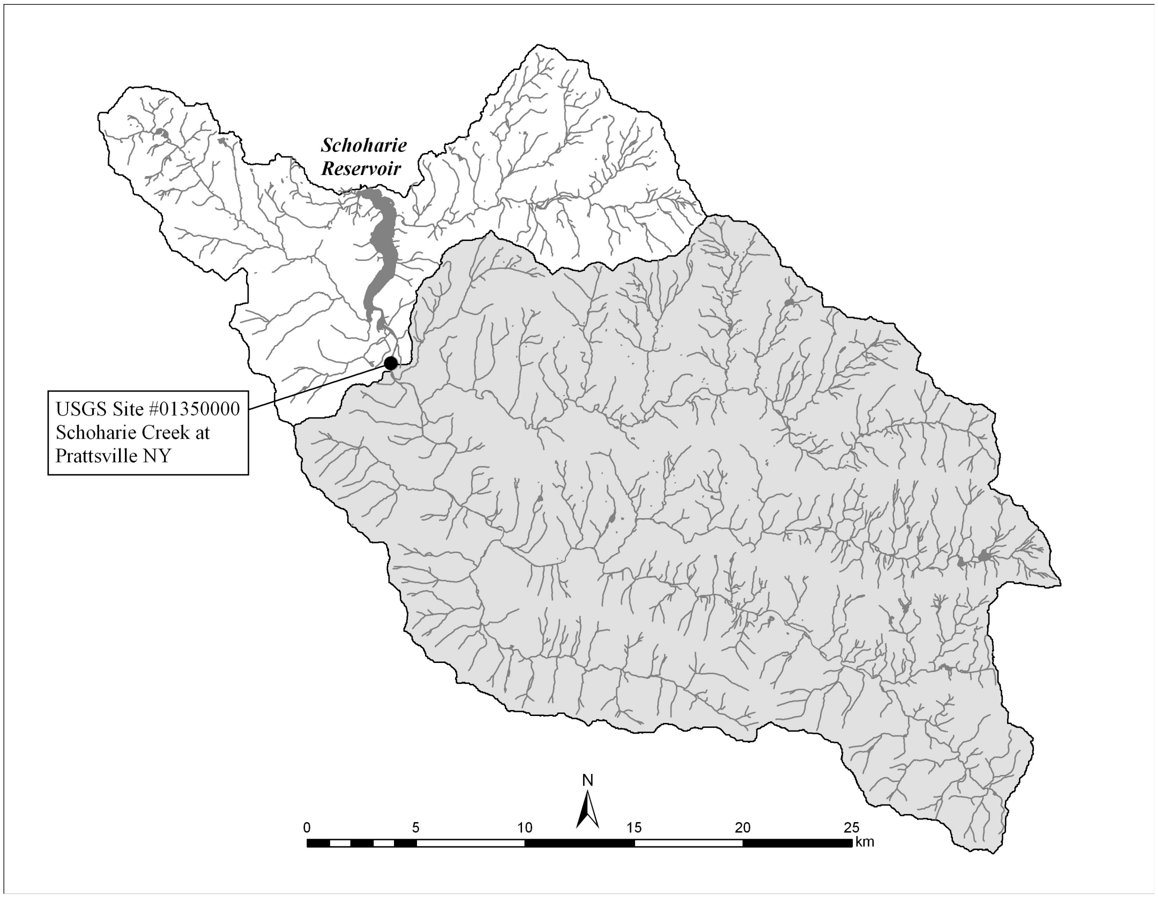

Figure 3.1. Location of USGS Streamflow gage along Schoharie Creek at Prattsville.

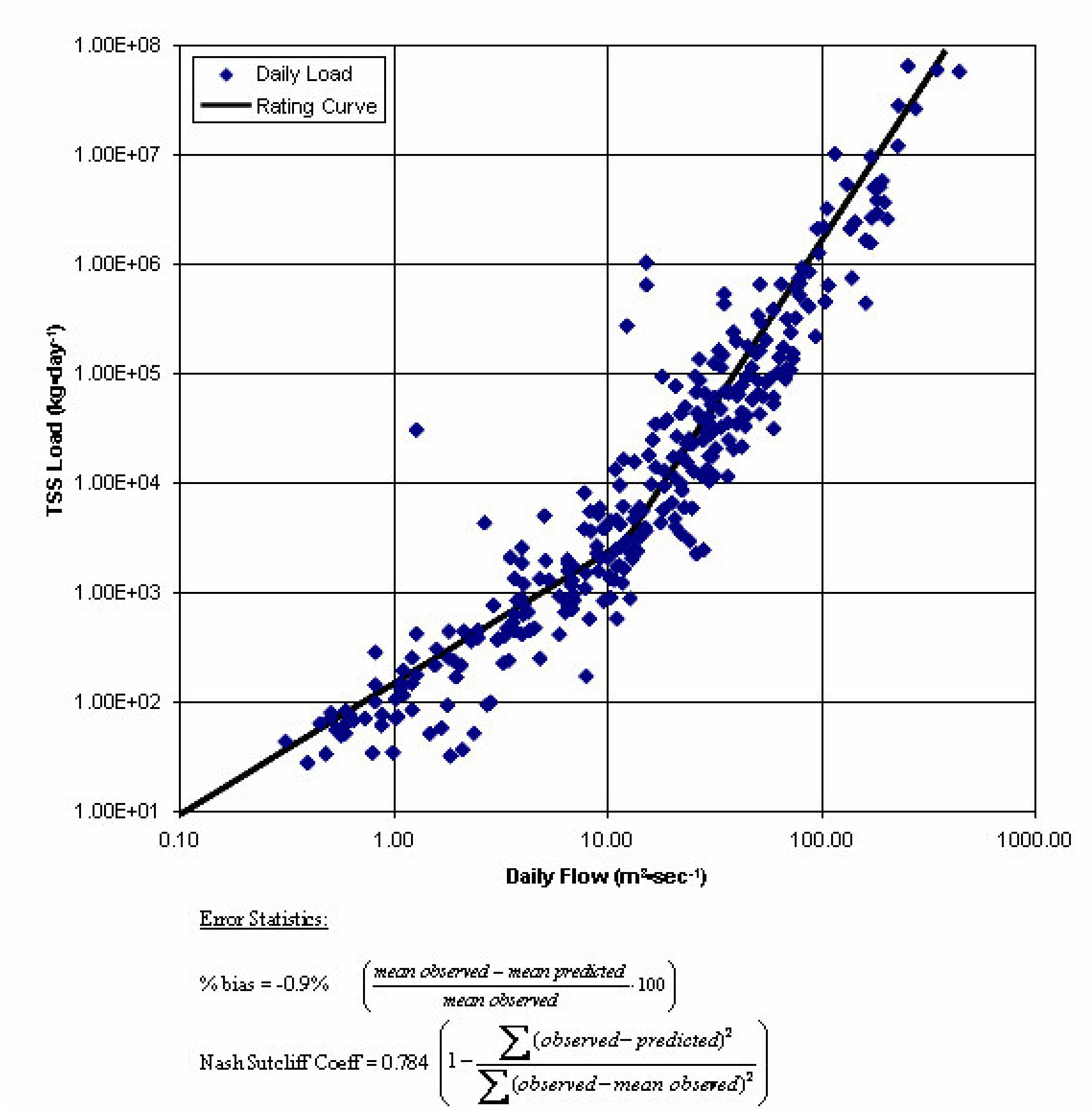

Figure 3.2. Rating curve showing relationship between suspended sediment load and daily flow for USGS streamflow gage located at Schoharie Creek at Prattsville. Error statistics show a good fit with % bias of -0.9% (Thomann, 1982) and Nash-Sutcliff coefficient of model efficiency of 0.784 (Nash and Sutcliff, 1970).

3.3. Sources of Suspended Sediment Load

For this analysis, the sources of suspended sediment are split into two major categories: landscape erosion and in-channel sediment sources. The total long-term sediment yield is:

$$S_{LT} = S_L + S_C \qquad (3.2)$$

where S_{LT} is the long-term total sediment yield, S_L is the landscape erosion portion of the sediment yield and S_C is the net in-channel sediment sources. All long-term values are calculated at annual averages (Mg•yr^{-1}).

To estimate the landscape erosion, we use the methods encapsulated in the Generalized Watershed Loading Functions (GWLF) model (Haith, 1992) which includes the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) for rural areas and a build up and wash off analysis for impervious surfaces. The USLE calculates erosion from source areas as a function of soil erodibility, topography, land cover, and management practices. These parameters are multiplied by the daily rainfall erosivity (Richardson, et al., 1983) and summed to obtain a long-term annual average estimate of upland erosion. For the impervious surfaces, build up and wash off functions are used (Haith, 1992) with sediment accumulating on impervious surfaces during dry weather and then washing off during wet weather based on an exponential function of daily rainfall.

The contribution of sediment supplied by landscape erosion is calculated with the application of a sediment delivery ratio that accounts for the fraction of the landscape erosion that actually is expected to reach the watershed outlet:

$$S_L = SDR * E_L \qquad (3.3)$$

where *SDR* is the sediment delivery ratio and E_L is the landscape erosion. A number of studies have empirically calibrated this value for other watersheds based on long-term estimates of sediment yield versus estimates of erosion. In general, the sediment delivery ratio decreases with increasing watershed area:

$$SDR = 0.38A^{-0.2} \quad \text{(USDA-SCS, 1983)} \qquad (3.4)$$

$$SDR = 0.463A^{-0.125} \quad \text{(Vanoni, 1975)} \qquad (3.5)$$

$$SDR = 0.622A^{-0.141} \quad \text{(Renfro, 1975)} \qquad (3.6)$$

Where *A* is the drainage area in km^2. Another method for estimating sediment delivery ratio based on GIS data is the Spatially Explicit Delivery Model (SEDMOD) (Fraser, 1999). With SEDMOD various factors based on water availability, soil texture, land cover, slope and surface roughness are used to calculate sediment delivery ratio on a cell-by-cell basis within a GIS framework (Figure 3.3). Averaging the delivery ratio values for all the cells within the watershed yields watershed sediment delivery ratio.

Given the wide range and empirical nature of possible methods for calculating the sediment delivery ratio, each of these methods is used to give a range of potential levels of contribution of landscape erosion toward total watershed sediment yield.

The total long-term sediment yield can be estimated based on the sediment yield measurements as estimated from the rating curve (See Section 3.2 above):

$$S_{LT} = \sum S_d \tag{3.7}$$

where S_d is the daily sediment yield as calculated using the rating curve (equations (1) and (2)). To obtain the long-term annual average sediment yield, daily streamflow data is used with equation 3.1.

Finally the in-channel sediment source is estimated by difference between total long-term yield and the landscape source:

$$S_C = S_{LT} - SDR * E_L \tag{3.8}$$

by rearranging and combining equations 3.2 and 3.3

Input Data

Streamflow, precipitation, land use, soils, physiography and geologic characteristics are necessary for implementation of the above landscape erosion calculations. Topographic information was derived in the GIS from a 30-meter Digital Elevation Model (DEM). (NYCDEP, 2005; 2006). Soils data is derived from the digital SSURGO database (USDA-NRCS, 2005).

Land cover and land use (LC/LU) data is derived from the DEP 2001 LC/LU classification. Modifications to the 2001 data set were made incorporating areas of rural roads and shoulders, built-up land covers and selected water and wetland features. Detailed descriptions of the LU/LC modification are described in NYCDEP, 2006. Sixteen land use classes are distinguished in the classification – deciduous forest, coniferous forest, mixed forest, brushland, non-agricultural grass, cropland, permanent hayland, pasture, barnyard, rural roads, residential pervious and impervious, commercial/industrial pervious and impervious, wetland and water. Forests and brushland are taken directly from the LC/LU coverage. Non-agricultural grass and farmland areas were derived based on grass and agricultural land uses in LC/LU coverage and split proportionally based on farm data collected by the New York City Watershed Agricultural Program. Barnyard areas are estimated based on the number of farms, as obtained New York City Watershed Agricultural Program. DEP GIS impervious surface coverage was used to divide residential and commercial/industrial pervious and impervious areas. Rural road surface area outside built-up areas is estimated from New York State Department of Transportation GIS road data.

To obtain the long-term annual average sediment yield, streamflow data is for Schoharie Creek, the streamflow time series from 1971-2000 for the Schoharie Creek USGS gage is used in equations 3.1and 3.7. The necessary daily precipitation data for calculating the rainfall erosivity is obtained from cooperator stations recognized by the National Climate Data Center and obtained from the Northeast Regional Climate Center. The precipitation station data is averaged using a Thiessen polygon method (Burrough, 1987; NYCDEP, 2004b).

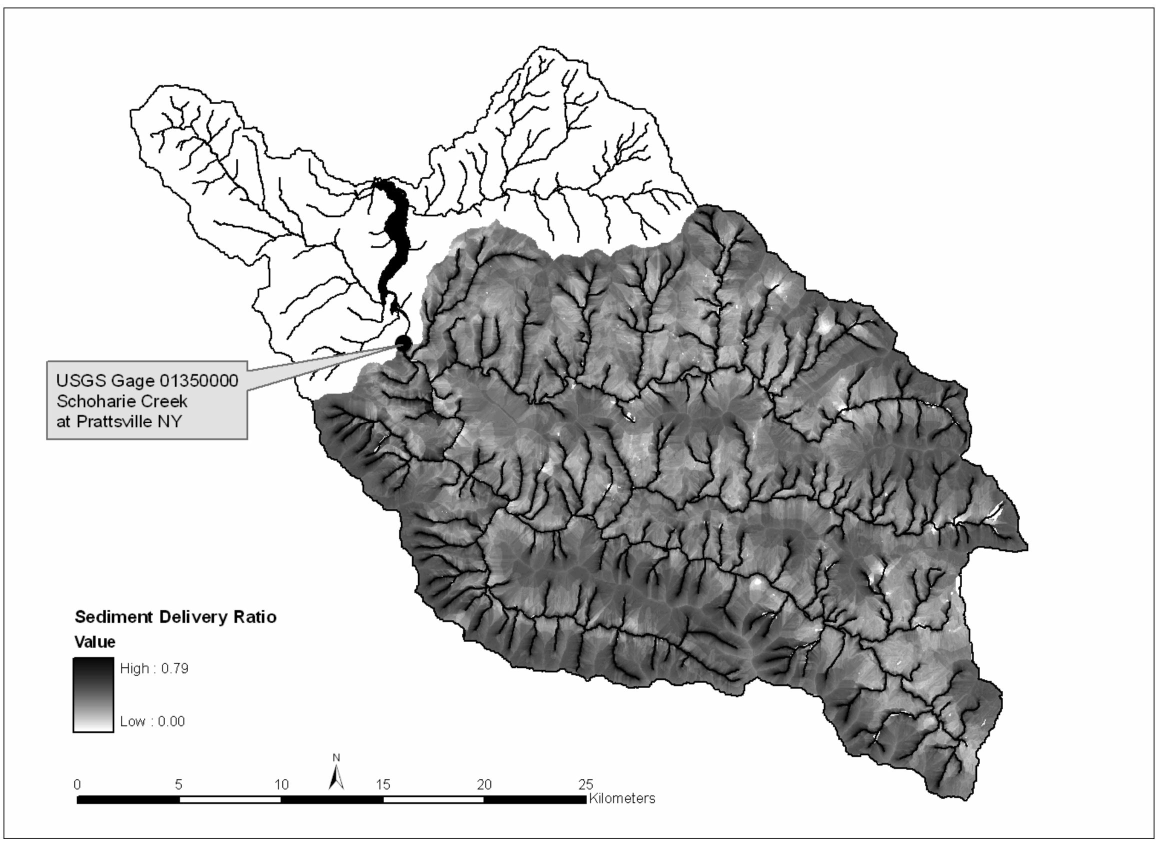

Figure 3.3. Map of sediment delivery ratio as calculated using SEDMOD (Fraser, 1999) for Schoharie Creek at Prattsville watershed.

Results

Using equation 3.7 with the daily streamflow data for Schoharie Creek at Prattsville, from 1971-2000 yields an average total long-term sediment yield of 102,758 Mg/yr. Landscape erosion rates using a combination of USLE (pervious surfaces) and build-up and wash-off rates (impervious surfaces) are shown in Table 3.1. Finally Table 3.2 shows the range of sediment delivery ratios using the four methods described above and the resulting proportion of sediment from landscape sources. The landscape sources range from 12 to 29% of total sediment yield, while the in-channel net sediment sources account for the other 88 to 71%.

Table 3.1. Mean annual erosion rates and land use areas for Schoharie Creek at Prattsville Watershed calculated for 1971-2000.

Land Use	**Area (km^2)**	**Mean Annual Erosion Rate ($Mg \cdot yr^{-1}$)**
Forest Deciduous	331.9	64,781
Forest Coniferous	165.2	24,183
Forest Mixed	39.9	5,835
Brushland	20.1	1,306
Non-Agricultural Grass	7.7	477
Pasture	6.9	1,457
Permanent Hay	7.2	1,515
Cropland	5.8	18,956
Barnyard	<0.1	88
Residential Impervious	2.3	270
Residential Pervious	10.8	113
Commercial/Industrial Impervious	0.7	35
Commercial/Industrial Pervious	1.2	9
Rural Roads	3.7	173
Wetlands	4.7	775
Water	4.4	0
Total	**612.5**	**119,973**

Table 3.2. Sediment Delivery Ratios and Sediment Supply Calculations

Sediment Delivery Ratio Method	**Sediment Delivery Ratio (SDR)**	**SDR * Erosion Rate ($Mg \cdot yr^{-1}$)**	**Total Sediment Yield ($Mg \cdot yr^{-1}$)**	**Fraction Sediment from Landscape Sources**
(USDA-SCS, 1983)	0.105	12,597	102,758	0.12
(Vanoni, 1975)	0.208	24,954	102,758	0.24
(Renfro, 1975)	0.252	30,233	102,758	0.29
SEDMOD (Fraser, 1999)	0.161	19,316	102,758	0.19
Range	**0.105-0.252**	**12,597 – 30,233**		**0.12-0.29**

3.4. Potential Reductions in Sediment Load to Reservoir

DEP's watershed management strategy includes programs that affect landscape erosion sources and those that affect in-channel sediment sources (Table 2.1). The separation of programs into these two categories (landscape erosion vs. in-channel processes) is based on the location of the implementation of the program. For example, the Stream Management Program works on stream channel areas and therefore may affect the in-channel sediment supply while the Watershed Agricultural Program tends to place most BMP's in farm fields, thereby potentially reducing landscape erosion.

Landscape Erosion Reduction

As shown in Section 3.3, landscape erosion represents approximately 12%-29% of the sediment supply for the Schoharie Watershed. Since this fraction is relatively small, we evaluated the maximum potential effects of all the programs combined by comparing the current watershed erosion rates to projected erosion rates of a "pristine" or fully restored watershed. The "pristine" watershed scenario bases the calculations on a completely forested and undeveloped basin. This is meant to represent the maximum potential reduction in erosion that could be obtained. This scenario, although unrealistic, represents an upper bound of the total reduction that could be gained from these programs.

Landscape erosion for the "pristine" watershed scenario was estimated by adjusting land use areas and re-applying the previously-described USLE and buildup/washoff analyses (table 3.3). The estimate total erosion rate for the "pristine" case was 99,463 $Mg \bullet yr^{-1}$, compared with 119,973 $Mg \bullet yr^{-1}$ for current conditions. The estimated total long-term annual average landscape erosion rate for current conditions is 119,973 $Mg \bullet yr^{-1}$, while for the "pristine" case the total erosion rate is 99,463 $Mg \bullet yr^{-1}$. This represents a 17% potential maximum reduction in landscape erosion from the current condition to the "pristine" scenario.

To estimate how this potential reduction affects the suspended sediment yield at the watershed outlet the 17% reduction (Table 3.3) is multiplied by the 12%-29% (Table 3.2) contribution of landscape erosion to total sediment yield. This results in a total maximum reduction of sediment yield of 2-5%.

Table 3.3. Mean annual erosion rates and land use areas for Schoharie Creek at Prattsville Watershed for current conditions and the "pristine scenario.

	Current Conditions		"Pristine" Scenario	
Land Use	**Area (km^2)**	**Mean Annual Erosion Rate ($Mg \cdot yr^{-1}$)**	**Area (km^2)**	**Mean Annual Erosion Rate ($Mg \cdot yr^{-1}$)**
Forest Deciduous	331.9	64,781	398.3	68,670
Forest Coniferous	165.2	24,183	165.2	24,183
Forest Mixed	39.9	5,835	39.9	5,835
Brushland	20.1	1,306	0.0	0
Non-Agricultural Grass	7.7	477	0.0	0
Pasture	6.9	1,457	0.0	0
Permanent Hay	7.2	1,515	0.0	0
Cropland	5.8	18,956	0.0	0
Barnyard	<0.1	88	0.0	0
Residential Impervious	2.3	270	0.0	0
Residential Pervious	10.8	113	0.0	0
Commercial/Industrial Impervious	0.7	35	0.0	0
Commercial/Industrial Pervious	1.2	9	0.0	0
Rural Roads	3.7	173	0.0	0
Wetlands	4.7	775	4.7	775
Water	4.4	0	4.4	0
Total	**612.5**	**119,973**	**612.5**	**99,463**

In-Channel Sediment Sources Reduction

In-channel sediment sources were estimated to account for about 71-88% in Section 3.3. Based on these estimates, the potential impact of channel management practices is of significant interest.

If we assume that stream management practices have a permanent and quantifiable effect for the reach over which they are applied, then the percent reduction of net loading from in-channel sources can be estimated by multiplying the efficiency of the management practices (e.g., stream channel restorations, bank bioengineering stabilizations, and other projects) by the percentage of net in-channel sediment supplied by the treated length of stream treated:

$$R_C = Eff * \frac{S_{treated}}{S_C} \qquad (3.9)$$

where R_C is the reduction in total net sediment loading from in-channel sources, *Eff* is the efficiency of the management practice in reducing sediment loading, $S_{treated}$ is the pre-treatment suspended sediment supplied by the portion of the stream network to be treated and S_C is the total net suspended sediment supplied by in-channel sources.

Applying equation 3.9 requires knowledge of the relative contribution of the treated stream length to the total net in-channel sediment supply. Unfortunately, a direct measure of this is not possible. To obtain some estimation of the relative importance of treated stream reaches we use statistical distributions of a number of potential indicators of net in-channel sediment loss including channel wetted perimeter, fraction of actively eroding banks and fraction of clay exposures. By using these indicator statistical distributions, and assuming that stream reaches making the largest contribution are treated first, cumulative distributions of the indicators versus stream length were constructed.

Figure 3.4 shows the histograms of possible indicators of in-channel sediment supply based on stream length. Figure 3.4(a) shows the distribution of wetted perimeter for the Schoharie stream network. The wetted perimeter values are derived using a GIS analysis of drainage area to each stream reach and applying these drainage areas into regional curves relating drainage area to wetted perimeter (Miller and Davis, 2003). Channel wetted area at bankfull discharge represents the potential source area in contact with flood flows. Greater wetted area means more surface area from which fine sediments can potentially be eroded per unit length.

Figure 3.4(a) treats all streams as potential sediment sources. Alternatively, Figure 3.4(b) limits the sediment sources to only 3rd order and higher streams. The difference between the entire stream network and the stream network only including 3rd order streams and above is shown in Figure 3.5. In Schoharie watershed, the glacial lake deposits generally associated with the sources of fine sediment tend to occur at lower elevations below historic glacial lake levels. For this reason, it is suspected that low order streams contribute relatively little of the total load and therefore are assumed to contribute effectively no net sediment to the system in the Figure 3.4(b) distribution.

Figure 3.4(c) represents the fraction of each reach with active bank erosion sites, while panel Figure 3.4(d) represents the fraction of each reach with clay exposures. The histograms show these values versus the fraction of total stream length attributed to the reaches in a given frequency class. Fractions of active bank erosion and fractions of clay exposures are based on stream survey data collected as part of Batavia Kill, Westkill, Eastkill and Schoharie Creek Stream Management Plans (GCSWCD, 2003, 2005, 2007, and 2007a). Fractions of active erosion and clay exposures are measures of potential sites for possible entrainment of suspended sediment. Figure 3.4(c) and (d) also only consider 3rd order streams and higher in the analysis.

Rearranging the axes on Figure 3.4 and ordering the stream lengths by highest to lowest indicator values yields a set of curves illustrated in Figure 3.6. For this set of curves, the length of stream is based on the cumulative distribution values derived from the Figure 3.4 histograms multiplied by the total length of stream in the Schoharie Reservoir Watershed (1245 km). These curves represent the fraction of in-channel sediment supply indicator value (wetted perimeter, fraction of erosion or fraction of clay exposure) that each additional incremental length of stream contributes. The separate curves represent the four indicators described above. For example, using the curve from the clay exposures indicator (curve (d)), the 5 km of stream having the greatest degree of clay exposures represents about 10% of the total clay exposures for the watershed. Similarly using the actively eroding bank indicator, the highest 5 km of stream length contributes about 5% of the actively eroding banks.

The fine sediment loading reduction efficiency of the Stream Management Program's restoration practices (*Eff* in equation 3.9) is not well-documented. These efficiencies can vary based on site- and project-specific factors including: accuracy and/or availability of targeted site selection for BMP implementation, appropriateness of BMP design to address problem; quality of BMP construction and longevity of installed BMP features; potential for de-stabilizing damages from storm flows prior to sufficient vegetative development; and new significant sources that develop subsequent to BMP implementation. One study of restoration work in the Batavia Kill (Chen et al., 2005) concluded that restored reaches on average 70% less erosion than untreated control reaches. However, it is not clear how this reduction in erosion translates to entrainment of fine sediment downstream. Further, a single study does not provide sufficient confidence of this efficiency value. Indeed, in the absence of additional supporting research, given the variables and unknowns identified in this report, it is reasonable to assume a much broader range of values for the stream restoration efficiency factor. This report brackets the range of efficiency between 20% and 80% to account for the probability of lower-than or possibility of higher than-than reported efficiencies.

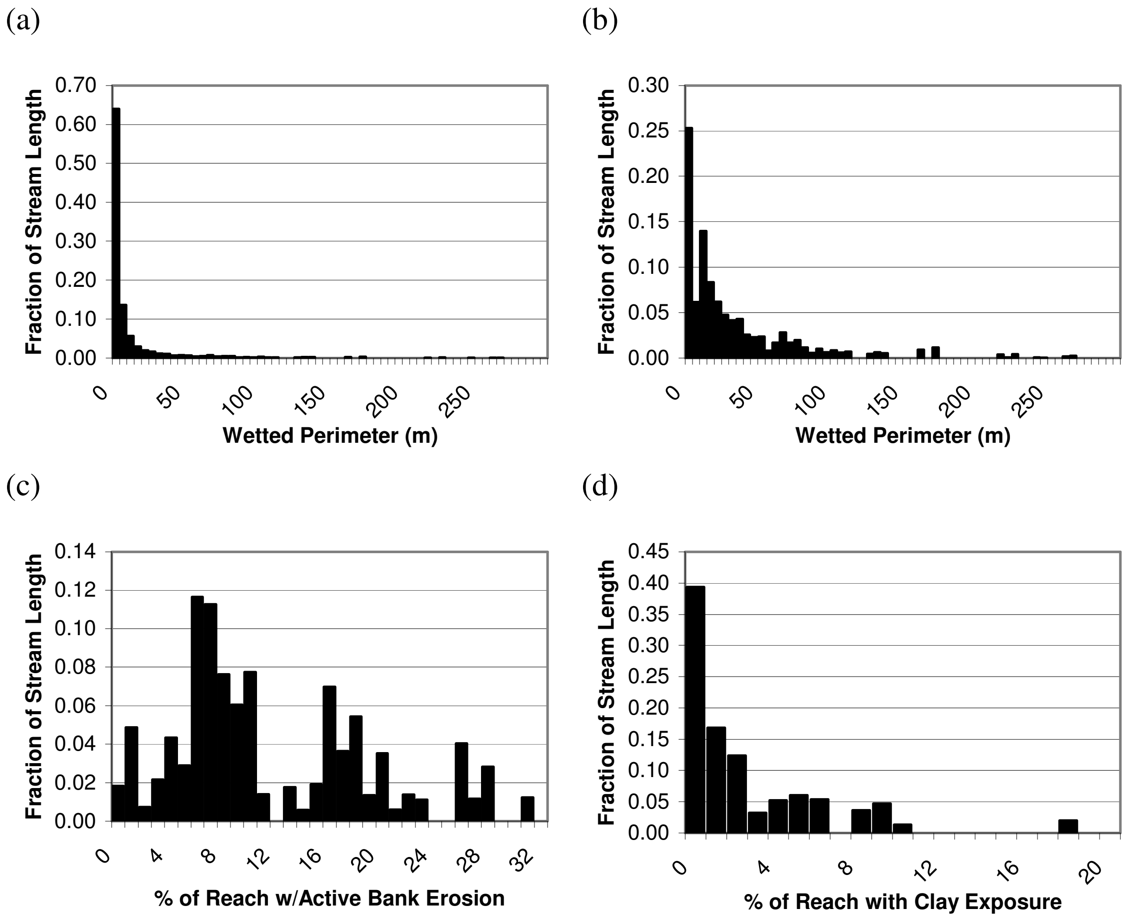

Figure 3.4. Histograms of indicators of sediment supply: (a) wetted perimeter including all streams; (b) wetted perimeter only including 3rd order and above streams; (c) percent of reach with active bank erosion and (d) percent of clay exposures.

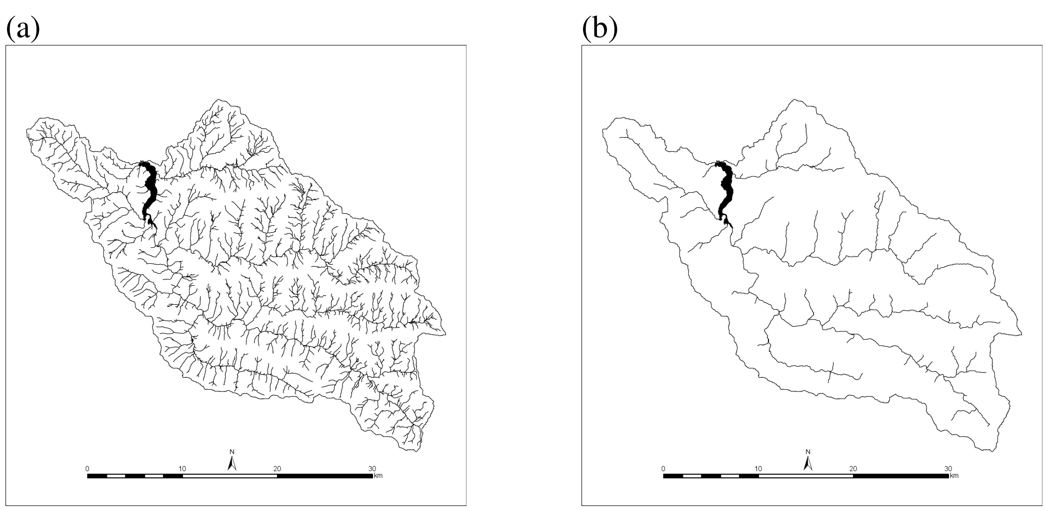

Figure 3.5. Schoharie watershed stream network: (a) all streams and (b) 3rd order and above streams.

Combining the statistically-based relationships between stream length and sediment supply indicators of Figure 3.6 with the 20-80% efficiency range yields an envelope of curves showing the reduction of the in-channel sediment indicator versus incremental stream length treated (Figure 3.7). These reductions inherently assume that the treatments will be carried out on the highest sediment contributing reaches first. Based on Figure 3.7, for example, treating the 5000 feet (~1.6 km) of stream (as planned under the SPDES permit) with the highest rates of clay exposures addresses potentially less than 5% of all clay exposures within the basin. If clay exposure percentage is a good representation of sediment entrainment potential then the level of reduction after applying the efficiency of any project (20-80%) and the fraction of sediment from in-channel sources (71-88%) the actual reduction achieved will be somewhat less than 5%. This is mainly due to the large total length of 3rd order and above streams (>300km) that exist within the watershed.

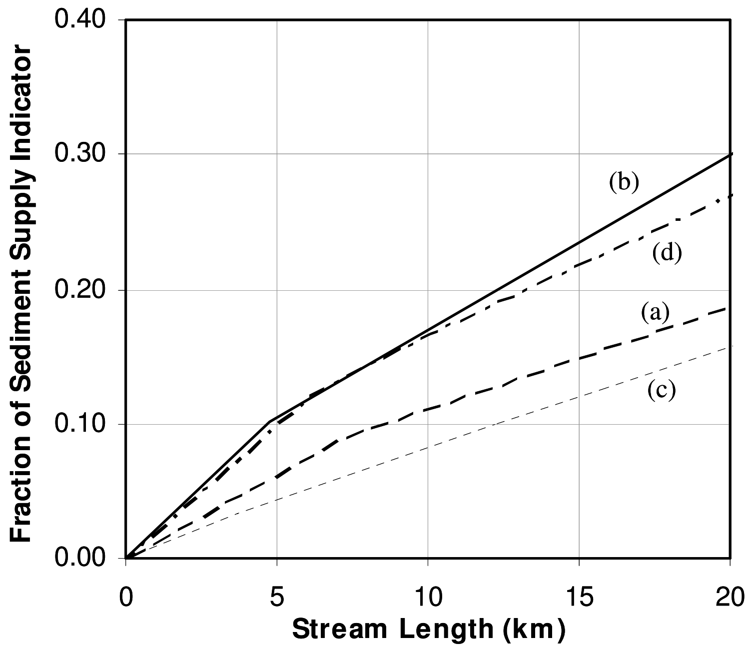

Figure 3.6. Cumulative distribution of indicators of sediment supply based on stream length: (a) wetted perimeter including all streams; (b) wetted perimeter only including 3rd order and above streams; (c) percent of reach with active bank erosion and (d) percent of clay exposure

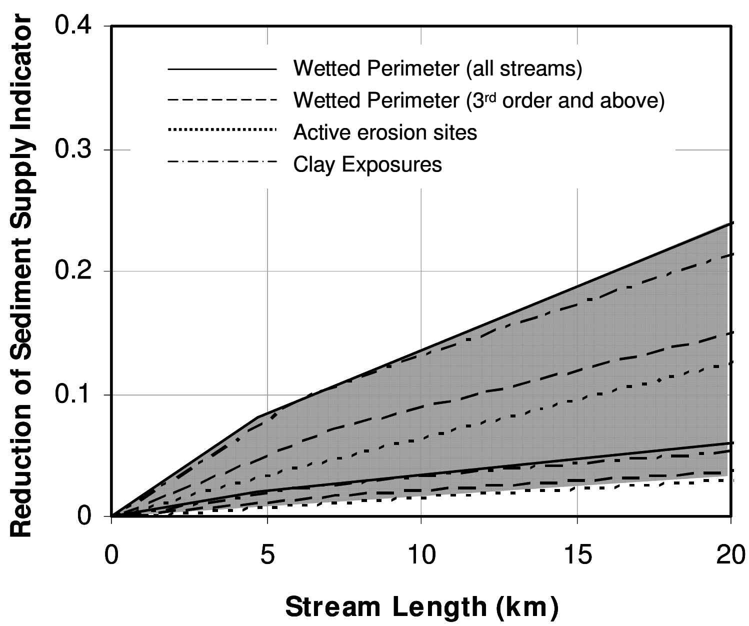

Figure 3.7. Envelope of reduction of in-channel sediment supply indicator versus length of stream based on the cumulative distributions of indicators from Figure 3.6 with 20-80% reduction efficiency.

3.5. Effects of Sediment Loading to Schoharie Reservoir on Shandaken Tunnel Turbidity

To analyze the effects of suspended sediment loading reductions on turbidity levels in the Shandaken Tunnel, we used the CE Qual-W2 reservoir model (NYCDEP, 2004a; Cole and Buchak, 1995). CE Qual W2 is a two-dimensional reservoir hydrodynamic and water quality model and has been developed and tested for used with the Schoharie Reservoir (Gelda and Effler, 2007). The model was set up to simulate beam attenuation coefficient (BAC) which is directly related to the turbidity, which in turn, has been related to input suspended sediment concentration (Figure 3.8).

Using the reservoir model, a sensitivity analysis was conducted, looking at Shandaken Tunnel turbidity levels versus constant percent reductions in reservoir loading from the watershed, without regard to the distinction between in-stream and landscape sources. By using the sensitivity analysis, the reduction ranges estimated in Section 3.4 can be put into context of possible reductions in the number of days that Shandaken Tunnel turbidity exceeds certain critical thresholds turbidity levels based on the SPDES permit requirements. Specifically, two turbidity requirements were investigated: (1) turbidity at the Shandaken Tunnel outlet should not exceed the turbidity in the Esopus Creek at the outlet by 15 NTU and (2) Shandaken Tunnel turbidity should not exceed 100 NTU. To accommodate the calculation of turbidity 15 NTU greater than Esopus Creek turbidity and turbidity versus flow relationship (Figure 3.9) for the Esopus Creek at Allaben USGS streamflow gage was used.

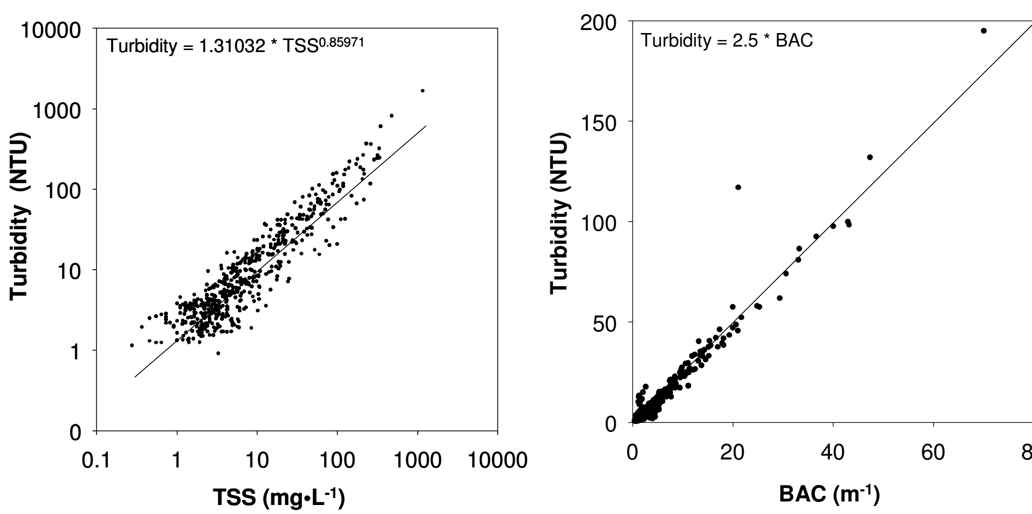

Figure 3.8. Relationships used to relate suspended sediment to turbidity (R. Gelda, personal communication, 2007) and beam attenuation coefficient (Effler et al., 2006).

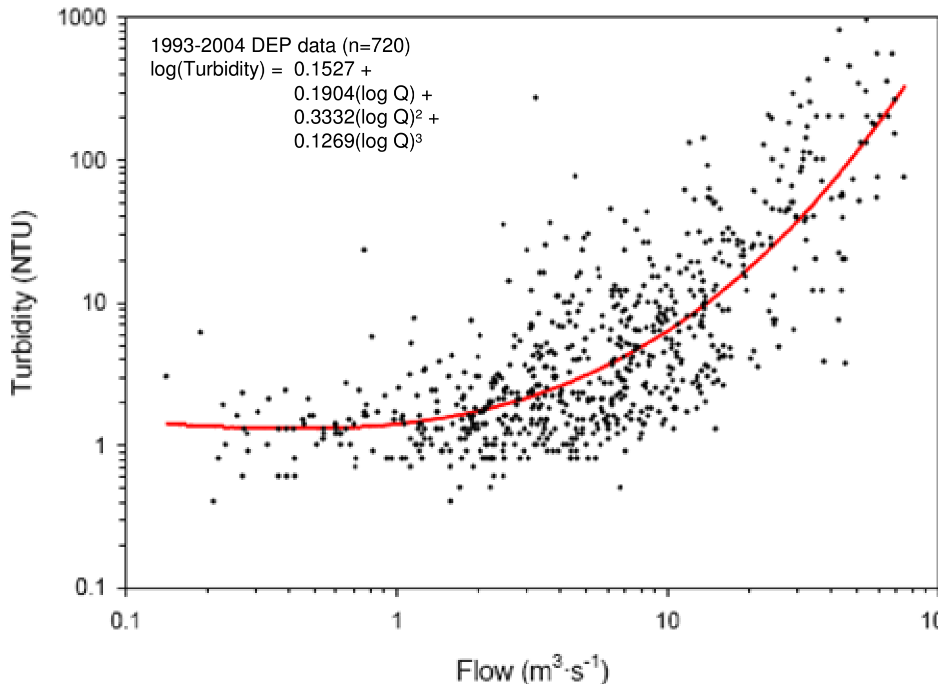

Figure 3.9. Relationship between streamflow and turbidity for Esopus Creek at Allaben. (R. Gelda, personal communication, 2007)

The model was run from 1987-2004, to incorporate climatic variability and a range of reservoir operating environments. A baseline scenario, representing current loading conditions was based on daily suspended sediment loading values estimated using daily streamflow data from the Schoharie Creek at Prattsville USGS gage and the suspended sediment rating curve discussed in Section 3.2. Nine loading reduction scenarios varying from 2.5% to 20% load reduction in increments of 2.5% were modeled. The Tunnel turbidity results were for days when the Tunnel actually operated during the model simulation period.

Figure 3.10 illustrates the results of the sensitivity analysis on the number of days per year that turbidity in Shandaken Tunnel exceeds the turbidity in the Esopus Creek at Allaben by at least 15 NTU versus the percent reduction in reservoir loading. For example, with a 5% reduction in turbidity loading which, given the potential reductions from watershed sources discussed above, may be an unrealistically optimistic reduction, there was a reduction from 58 days per year to 55.5 days per year that the Shandaken

Tunnel exceeded the Esopus Creek turbidity by greater than 15 NTU[1]. This was a reduction of about 2.5 days per year, or 4%, in the number of days exceeding the 15 NTU criteria.

For the 100 NTU criteria, a similar 5% reduction in turbidity loading reduced the number of days with Shandaken Tunnel turbidity greater than the threshold from 4.4 days per year to 4.2 days per year (Figure 3.11). This was a reduction of about 0.2 days per year or about 1 day for every five years of tunnel operation.

One reason for the small differences is that every year a number of events drive reservoir turbidity levels well above SPDES permit related thresholds. High turbidity events are associated with large streamflows and levels of suspended sediment load to the reservoir. Once in the reservoir this sediment leads to extended periods of high turbidity. Relatively small predicted reductions in watershed derived turbidity loads have little effect when reservoir turbidity levels greatly exceed the SPDES thresholds. For example Figure 3.12 shows a typical storm from September 1999. During this storm, modeled turbidity input peaked at 1009 NTU while modeled turbidity at the tunnel peaked at 215 NTU. It then took 16 days until reservoir tunnel turbidity returned to a level less than 15 NTU above Esopus Creek at Allaben turbidity and generally the amount of time difference between the baseline and the 5% reduction scenario that the turbidity was above the threshold was quite small – in this case less than one day.

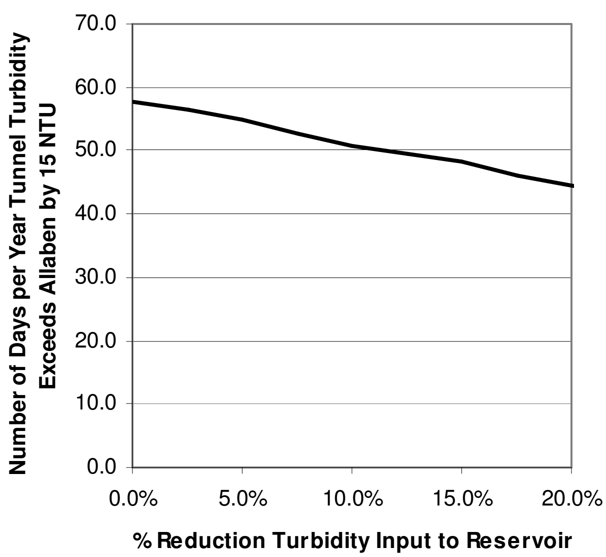

Figure 3.10. Sensitivity of the number of days that Shandaken Tunnel turbidity exceeds Esopus Creek at Allaben turbidity by at least 15 NTU versus the percent reduction in turbidity input from Schoharie watershed.

[1]We note that such exceedances do not necessarily reflect violations of the permit; diversions may be covered by one or more of the exemptions set forth in footnotes 1, 2, and 3 of the SPDES Permit.

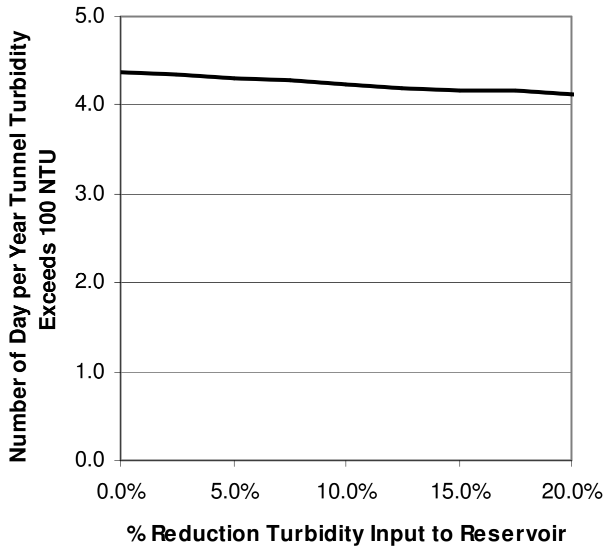

Figure 3.11. Sensitivity of the number of days that Shandaken Tunnel turbidity 100 NTU versus the percent reduction in turbidity input from Schoharie watershed.

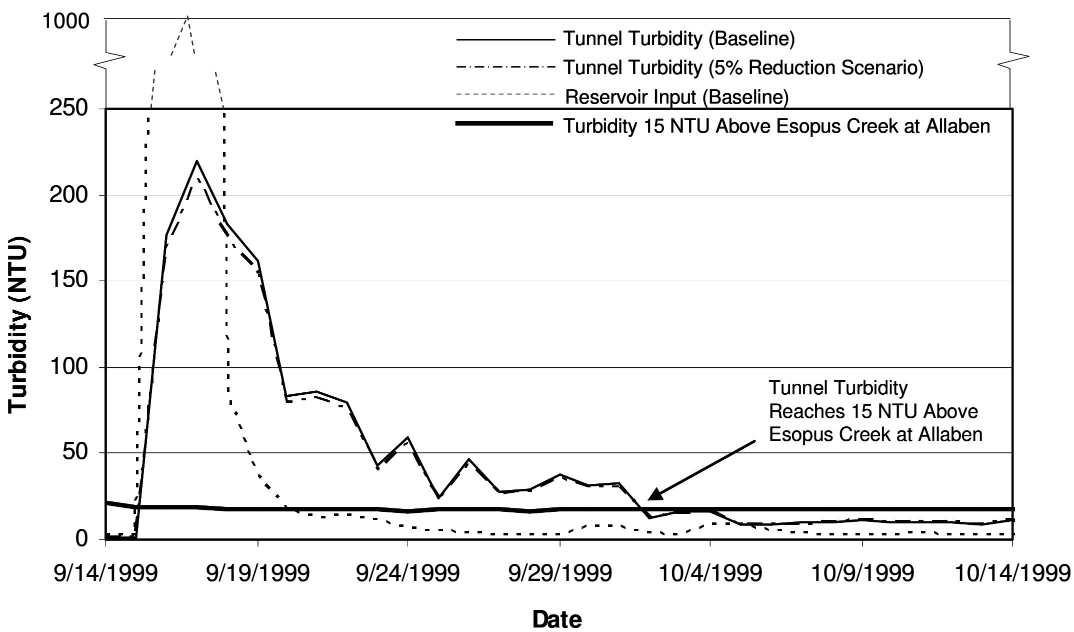

Figure 3.12. Example time series of model output showing storm input turbidity and resulting modeled tunnel turbidity for base case and 5% reduction scenario.

3.6. Summary

The analysis presented here is intended to give an overall framework for understanding potential reductions in Shandaken Tunnel turbidity through the use of watershed management programs in the Schoharie basin. Sources of fine sediment were split into two major sources: landscape or upland erosion and in-channel sediment sources. For landscape sources, models of landscape erosion were used to estimate the potential maximum benefits of programs addressing this source. For the in-channel sources, certain indicators of potential sediment sources along the streams were used to define the potential proportion of sediment that might be addressed by the Stream Management Program. Finally, a sensitivity analysis, utilizing a two-dimensional reservoir model, was used to place the potential watershed loading reductions into the context of turbidity in Shandaken Tunnel.

The watershed analysis presented herein relies on gross estimates and limited data to define the sediment sources and potential reductions due to watershed management programs. To account for uncertainty in these estimates, a number of empirical methods were used to bound the range in the source estimates. Additionally, the analysis of in-stream reductions relies on indicators of in-channel sediment sources and, therefore, the method assumes that the statistical distributions of these indicators are reflective of the distributions of the in-channel sediment sources. Finally, estimated reductions assume that Stream Management Program projects addressing sources of sediment will have a lasting effect, that these in-channel sources are clearly identifiable and that the source locations do not change over time.

The analysis indicates that a majority of suspended sediments are derived from in-channel sources. As such, watershed management programs that address landscape erosion are not anticipated to have a large impact on reducing suspended sediment loads to the reservoir. The Stream Management Program has multiple objectives including a commitment to cultivating long-term stakeholder (including riparian landowner) participation in protecting streams. While the Program as a whole provides a broad range of benefits, none of its components, including stream restoration, is likely to bring about significant reductions in suspended sediment load on the watershed scale, due to the basin size and the considerably large extent of sediment sources. Finally, the reservoir model sensitivity illustrates that reduction in sediment loads from the watershed have a limited effect on the number of days that Shandaken Tunnel turbidity is above SPDES permit thresholds, but high turbidity periods will still occur, especially during large streamflow events.

4. Watershed Management and Protection Program Recommendations

The 2007 FAD commits NYCDEP to a continued engagement with a set of programs that have a successful history of protecting the quality of the New York City West-of-Hudson water supply. These programs address a wide range of activities and potential sources of a number of pollutants including, but not generally focused primarily on, turbidity. These programs were not designed or intended to ensure compliance with the Shandaken Tunnel SPDES permit or to explicitly reduce turbidity levels in the Schoharie Reservoir. NYCDEP believes these programs, and particularly the Stream Management Program, can be effective in helping to minimize the entrainment of suspended sediment that leads to excessive turbidity conditions in the Schoharie Reservoir watershed. It is unlikely however that two key components of the turbidity problem – essentially the geology and hydrology of the watershed – can be effectively mitigated by an enhanced set of watershed management programs. These programs will however, help to reduce the human-induced contributions arising from poor landscape and stream channel management practices.

The mandate of this report is essentially an evaluation of the potential turbidity reduction benefits of increased or focused funding and implementation of terrestrial-based programs and projects (whole farm, forestry, willing seller land acquisition, conservation easement programs, storm water retrofit) and stream-based programs and projects (stream restoration, and stream buffer easement programs). Since the overwhelming majority, roughly 71-87%, of turbidity inputs at the outfall of the Shandaken Tunnel are derived from in-stream rather than terrestrial sources, the greatest opportunity for reducing such turbidity in the long-term is enhanced implementation of the Stream Management Program. On the other hand, the opportunity for turbidity reduction based on terrestrial-based programs is very limited. Indeed, as presented in the analysis within this report, even if one were able to apply BMPs in these terrestrial-based programs to all lands within the Schoharie watershed (which, for a variety of practical considerations, is hardly possible), the maximum theoretical turbidity reduction achievable would be less than 5%.

This final section of the report assesses the potential benefits of heightened or more expansive implementation of these programs, identifying and evaluating NYCDEP's commitments to these programs under the 2007 FAD.

4.1. Watershed Agricultural Program

Section 2.1 of this report summarizes the Watershed Agricultural Program and its activity to date in the Schoharie basin. The Program depends on voluntary participation by farm owners. Forty-three farms in the Schoharie basin already participate in the Program. Among the BMPs routinely included in the development of whole farm plans are BMPs to stabilize riparian buffers and prevent animal access to streams. These maximize the reduction of suspended solids into streams.

Per the analysis in this report, turbidity inputs from farms are relatively small. But potential inputs of pathogens and nutrients are a significant concern. As part of the 2007

FAD, DEP is committing to robust enhancements to the Watershed Agriculture Program. These include (excerpted from 2007 FAD):

- Support and monitor on-farm maintenance and operation of structural and non-structural BMPs on participating farms.
- Conduct status reviews on all farms with substantially implemented WFPs.
- Maintain "substantially implemented" status on 90% of all large farms in the west-of- Hudson Watershed.
- Develop a draft Programmatic Strategy for the replacement of aging/failing BMPs.
- Replace aging/failing BMPs on participating farms based on the Programmatic Strategy.
- Continue easement stewardship activities.
- Provide an additional $250,000 in funding to WAC for long-term stewardship of Watershed Agricultural Easements already acquired by WAC.
- Provide for payment of $8,000 per Easement, for each Watershed Agricultural Easement acquired by WAC from and after the date of this FAD, for long-term stewardship of such Easements.
- Continue to develop new and revise existing WFPs, including CREP enrollment, on farms in the west-of-Hudson Watershed.
- Pursue the development of new WFPs on approximately 12 existing "large" farms (farm income > $10,000) not currently participating in the program.
- Develop WFPs on 10 "small" farms (farm income > $1,000 and < $10,000) not currently enrolled in the program.
- Submit a Small Farms Assessment Report to determine the number, extent, and potential impact of small farms on water quality in the west-of -Hudson Watershed.
- Continue Farmer Education and Outreach initiatives.

The robust enhancements to the Watershed Agricultural Program reflect DEP's strong commitment to comprehensively addressing pollutants of concern at watershed farms while supporting the sustainability of this important industry. While principally directed at pathogen and nutrient management, many elements of the program also may reduce farm inputs of suspended solids to streams. Given the limited contributions from farms in the Schoharie watershed to turbidity levels in the reservoir, additional enhancements to this program, for purposes of achieving the turbidity reduction goals in the SPDES permit, are not proposed at this time.

4.2. Forestry Program

Approximately 85% of land within the Schoharie basin is forested land. In terms of drinking water quality, forested land is the preferred land use within a watershed. For over ten years, NYC has supported the management and use of forested lands through our Watershed Forestry Program. The program acts to sustain the economic viability of forestry as the predominate land use within the watershed, ensuring that forestry activities are as protective as possible of water quality. From the vantage point of water quality concerns, the Program is an anti-degradation or protection program rather than a remediation program. The Program offers a range of benefits beyond turbidity control, and in the 2007 FAD, DEP commits to the enhancements below.

Per the 2007 MOA, "The Watershed Forestry Program, administered by WAC, is a voluntary partnership between New York City and the forestry community to support and maintain well-managed forests in the watershed. The primary objective of the program is to maintain unfragmented forested land and promote the use of management practices to prevent non-point source pollution during timber harvests. Key elements of this program include development of forest management plans, logger training, support for model forests, and best management practices (BMP) implementation."

The 2007 FAD enhancements to the Program include (excerpted from the 2007 FAD):

- Continue enrolling eligible watershed landowners in WAC forestry program and develop new/additional forest management plans (which include specific riparian management recommendations)
- Continue evaluating the implementation status of 5-year old WAC forest management plans.
- Complete and evaluate the Management Assistance Program (MAP) pilot project during 2007-2008.
- Develop a MAP pilot project evaluation report.
- Expand and implement MAP on a watershed-wide basis (based on the results of the pilot evaluation) to eligible landowners having a WAC forest management plan.
- Complete road BMP projects, portable bridge projects, and other forestry BMP projects
- Conduct forester and logger training workshops
- Support/promote the NYS Trained Logger Certification Program throughout the watershed
- Continue research and demonstration projects
- Conduct forestry educational events
- Conduct/hold programs including: annual Watershed Forestry Institute for Teachers, Green Connections Education Program, and Watershed Forestry Bus Tour Program
- Conduct landowner education/outreach programs
- Support invasive species education/outreach programs

Again, while not expected to result in a quantifiable reduction of turbidity at the Shandaken Tunnel, DEP's enhancements to forestry programs are robust and can have only a positive effect on maintaining the viability of forests, the preferred (and predominate) land use within the Schoharie basin. Additional enhancements to this program are not warranted in connection with the turbidity reduction goals in the SPDES permit.

4.3. Stormwater Retrofit Program

As indicated in Section 2.2, the Stormwater Retrofit Program funds the design, permitting, construction, implementation, and maintenance of stormwater BMPs to address existing stormwater runoff in concentrated areas of impervious surfaces in the WOH watershed. The program addresses stormwater runoff from impervious surfaces. Within the Schoharie basin only approximately 3.26% of the area is impervious (more than 85% is forested). As a result, the opportunity presented by the Stormwater Retrofit Program for turbidity reduction in the Schoharie basin and at the Shandaken Tunnel is marginal. Section 2.2 identifies a number of Stormwater Retrofit projects that have been funded within the Schoharie basin since Program inception in 1997.

Notwithstanding the marginal turbidity-reduction opportunity of the Stormwater Retrofit Program, DEP continues its strong support for the Program with a continuation of funding in the 2007 FAD. Based on extensive discussions with other stakeholders in developing the terms of the 2007 FAD, we are confident that the Program has sufficient funding to meet demand.

Because the Stormwater Retrofit Program is voluntary and depends on land-owners to host sites, targeting projects in the Program depends on local recognition of stormwater needs and benefits. To address this issue, in 2007, DEP augmented the Program by working with CWC to add a stormwater planning and assessment component. Under the Planning and Assessment Program, municipalities receive funding to do comprehensive inventories of stormwater infrastructure and then, based on the inventories, can identify priority stormwater retrofits needs. Based on the assessments and planning, municipalities are able to work with landowners to apply for grant funding under the CWC's core Stormwater Retrofit Program. In May 2006, the Village of Hunter completed a Planning and Assessment project which then lead to a stormwater retrofit project at Botti Drive. In July 2007, CWC and DEP approved a Planning and Assessment project funding for the Town of Windham. The Windham project will provide a prioritized listing of stormwater mitigation projects.

Again, the urbanized portion of the Schoharie basin represents less than 4% of its area. Given this small share of land usage, the opportunity for turbidity reduction through the Stormwater Retrofit Program is marginal. DEP and CWC will continue to seek opportunities through the Stormwater Retrofit Program to work with Schoharie basin municipalities and property owners. However, given the voluntary nature of the Stormwater Retrofit Program, the sufficiency of program funding to meet anticipated demand, and the negligible potential for discernable turbidity reduction attributable to the Program at the basin scale, additional enhancements to this program are not proposed.

4.4. Land Acquisition Program

Section 2.4 provides basic information on protected land holdings in the Schoharie basin. The Land Acquisition Program is a pollution prevention program, not a pollution remediation program. DEP pursues land acquisition in the watershed not in order to reduce turbidity, but rather to prevent the type of development that may lead to increased pollution and turbidity in the future. The Land Acquisition Program benefits water quality in the long-term by averting land-use conversion to uses that might increase runoff and turbidity.

Pursuant to the 2007 FAD, DEP is committing to $300 million of land acquisitions between 2007 and 2017. While DEP will advance the program within the guidelines established in the 1997 MOA and Water Supply Permit, the additional funding allows DEP to significantly extend solicitations of interest to many more Schoharie basin landowners and this should lead to many new acquisitions in the basin over the next 10 years. In addition to the increased acreage represented by the enhanced funding during the next ten years, DEP is, pursuant to the 2007 FAD, examining the potential to augment land acquisition efforts by increased participation of land trusts. DEP will also consider enhancements to conservation easements. DEP will report to EPA and the State on findings on the possible enhancements presented by additional land trust involvement in November 2007. While the anticipated additional protected acres will not reduce turbidity at the outfall of the Shandaken Tunnel, the substantial funding enhancements to the Land Acquisition Program called for in the 2007 FAD will allow DEP to significantly increase solicitations in the Schoharie basin and will result in additional protected acreage which will prevent degradation of water quality that might otherwise occur.

4.5. Stream Management Program

DEP is committed to long-term engagement of restoring stream system integrity through multiple efforts including stream channel restoration, riparian buffer protection and/or enhancement (as identified in the SPDES permit schedule of compliance), increasing education and outreach efforts to encourage adoption of better management practices, and technical and material support to both public and private channel management efforts.

The analysis for this report indicates that the potential reduction impacts of stream restoration projects may be locally significant but are likely to have relatively limited impact on the watershed scale loading during large flood events given the multitude of source locations in the vast network of streams (i.e. the geologic sources are ubiquitous). However, we believe that there is potential to maximize the benefits of restoration projects by optimizing site selection based on a focused analysis of the relative turbidity contributions from different stream segments. As stated in Section 3, we know that the sources of fine sediment that cause turbidity are not homogenously distributed throughout the watershed. Further we know that the Batavia Kill and West Kill sub-basins are the largest contributors. Within those basins, further assessment of stream channel stability and sediment sources can be used to optimize the location for future DEP-funded stream restoration. However, restoration effectiveness is limited to (a) whether a “fix” is reasonably achievable for a given site; (b) whether there is landowner support; and (c) whether success can be sustained until mature riparian vegetation can help hold the channel together.

The “Conine” restoration project to be completed in 2007 on the Batavia Kill presents an opportunity to evaluate the reach and sub-basin scale impacts of stream restoration on turbidity reduction. Per the 2007 FAD, DEP will implement a special monitoring study on the Batavia Kill (at the Conine site) to evaluate whether water quality improvements can be quantified for this restoration project. The objective of this study is to quantify the effectiveness of stream BMPs at reducing turbidity and suspended sediment in the Batavia Kill stream. Observations and sampling have documented that the Batavia Kill delivers a significant amount of suspended sediment and turbid water to Schoharie Creek, the main inflow to Schoharie Reservoir. Major sediment source areas are known above and below Red Falls. Through a contract with DEP’s Stream Management Program, Greene County Soil and Water Conservation District will design and implement BMPs to reduce the sediment and turbidity originating in the Red Falls area. Originally, two areas (Red Falls and Conine) in the Red Falls region were proposed for remediation. Due to numerous project constraints, DEP determined the Red Falls project was not feasible and EPA concurred. The Conine site, immediately downstream of Red Falls, was approved as a substitute for monitoring the water quality benefits of a restoration project on the Batavia Kill. DEP has been monitoring turbidity at several sampling sites along the Batavia Kill prior to BMP implementation, and will continue to do so for several years after the BMPs are complete. By quantifying the turbidity and suspended sediment loads in the Batavia Kill before and after BMP implementation, DEP should be able to evaluate the long term effectiveness of the approach used, and that in turn will guide BMP design for other problem sites in the watershed. Ultimately, information gleaned from this project should help DEP be more effective and cost-efficient in reducing sediment and turbidity in watershed streams.

Particularly with respect to siting stream restoration projects, but also in connection with focusing implementation of the recommendations from Stream Management Plans through programs being implemented under the Shandaken Tunnel SPDES permit and the 2007 FAD, there is the clear need for further research in understanding the distributed character of sediment loading. Not all stream reaches yield the same amount of suspended sediment per unit length. Generally speaking, the lower reaches in the broad valley bottoms with larger drainage areas have orders of magnitude larger wetted areas unit length of stream than do the headwater reaches. Greater wetted area means more surface area from which fine sediments can be eroded. In addition, historical management practices create local variation in channel conditions, resulting in a linear patchwork of rip-rap, eroding banks, and well-vegetated, relatively resistant banks. Finally, the type of material comprising the banks and bed is heterogeneous; lake clays are found primarily in valley bottoms, and clay-rich tills in terrace walls. As a result of this heterogeneity of bed and bank area available for entrainment, of boundary cohesiveness and erosion resistance, of local stream power and of source material, it is possible that a relatively small percentage of stream length may be responsible for a disproportionately large percentage of the loading from in-stream sources.

The uncertainty associated with this heterogeneity translates into uncertainty regarding the potential effectiveness of enhanced implementation of stream management practices. Additional targeted, iterative suspended sediment sampling to develop more spatially focused sediment rating curves would be needed to quantitatively determine how reach level heterogeneity in geologic and morphologic variables impact reach-level loading. Ongoing research into the relationship between channel morphology, stream restoration practices and sediment transport should result in improved implementation of best management practices and a better understanding of the limits of these practices to mitigate loading at higher flows.

In addition to massive and expensive stream restoration projects, improved management practices advocated by DEP's SMP can provide significant reduction in suspended sediment loading. Rates of bed incision and lateral erosion into the floodplains and terraces have been shown to be significantly reduced through the use of "Natural Channel Design" restorations and maintenance of mature forested buffers (Chen et al., 2004; Allmendinger et al., 2005). DEP and our contract partners will continue to work with the many other stakeholders who manage streams throughout the watershed to ensure that these best management practices are adopted more widely, and that the least harm is done to the stream channel integrity. For example, DEP is committed to working with the various highway departments and private landowners to help improve the reduction of infrastructure stressors on the stream system integrity. Improperly sized bridges and road encroachment on stream channel dimensions are some of the biggest de-stabilizing stressors on the stream system. A major focus of new programming in the 2007 FAD is to make available technical and material assistance to leverage better stream management by this multitude of players.

The 2007 FAD includes the development and implementation of a Streamside Assistance Program (SAP) intended to assist streamside landowners with restoring channel stability through riparian buffer enhancement and bioengineering techniques. This program is intended to function as a means of restoring stream corridor integrity, which should, progressively, over time reduce erosion rates at a local and sub-basin scale.

Improved stream management practices advocated by DEP can provide significant reduction in suspended sediment loading. Common management practices employed by individuals and town highway departments include, for example, streambank stabilization and gravel removal. Such projects require Article 15 stream disturbance permits from the NYS Department of Environmental Conservation, Region 4. Where permit applications exceed the threshold for "minor" stream disturbances, the Region 4 routinely solicits and receives comments from NYCDEP Engineering and Regulatory Review. This permitting partnership has worked with increasing effectiveness over the period of the first and second FADs, in instances when permit applications are made outside of an emergency flood response situation and the project timetable allows for adequate review for its impact to adjacent stream reaches and their channel stability.

However, during emergency flood response, the demand for Article 15 permits is tremendous. Following the January 1996 flood, more than 1000 permits were issued, and following the June 2006 flood, more than 1500 permits were issued by Region 4. Following large floods, permit applicants often seek to move stream channels to pre-flood locations (planform and pattern) and pre-flood dimensions (width, depth and cross sectional area), and in most cases, pre-flood locations and channel dimensions are unmapped and decisions regarding the work are subjective. In many instances, poorly planned post-flood streamwork has set in motion channel instability processes such as headcuts that have undermined channel stability in nearby stable reaches. DEP documented the increase in Schoharie watershed turbidity following the 1996 flood, suggesting a correlation between emergency streamwork and turbidity in the Schoharie. The Schoharie watershed has missed the recent severe flooding experienced by Delaware County, but future severe flooding is certain. Improved coordination between DEP and DEC in the review of Article 15 stream disturbance permits and their impact on channel stability is one important piece of the watershed management strategy to reduce Schoharie Creek in-stream sources of turbidity. The FAD mandates a review and potential revision of Addendum A of the DEC-DEP Memorandum of Understanding to enable this closer coordination, due by June 2009.

An enhanced education and outreach program is also a key component to successful stream management and turbidity reduction. For example, research on the erodibility of glacial lake clays and glacial tills in the Esopus Creek watershed (Fischenich, et al., 2007) shows that once the clay-rich material is disturbed, either by natural hill slope failures, or by human-induced stress (such as excavation or development in sensitive areas), it is highly susceptible to erosion and entrainment. It is not possible to quantify the benefits of educating stream management practitioners and communities on how to avoid disturbing the integrity of the glacially-derived fine sediment, but we believe such work provides an important investment in watershed protection.

The 2007 FAD enhancements to the Program in the Schoharie Basin include (excerpted from the 2007 FAD):

- Meet annually with county contracting partners to re-evaluate stream management plan recommendations and priorities and establish a modified schedule for actions to be taken.
- Design and complete construction of five stream restoration projects on a basin priority basis, no later than 5/15/12. Two of these projects are to occur in the Schoharie watershed. These restoration projects and associated schedules shall be subject to review and approval by EPA, NYSDOH and NYSDEC.
- Establish and implement local funding program for enhanced implementation of recommendations from completed Stream Management Plans. For the Schoharie watershed this includes the $2 million mandated by the Shandaken Tunnel SPDES permit.
- Provide a coordinated program delivering technical assistance and conservation guidance to riparian landowners through a Streamside Assistance Program.
- Review and revise, as appropriate, Addendum A of the 1993 MOU between NYSDEC and NYCDEP as it pertains to the review of Article 15 Stream Disturbance Permits to reflect and enhance coordination between the agencies with the goal of ensuring consistency with the recommendations in Stream Management Plans.

- Submit an “Action Plan” for implementing stream management plan recommendations and establishing priorities, by reservoir basin. This provides the opportunity to re-evaluate restoration priorities.
- Submit the Conine Water Quality Report (due 12/31/12). This report will detail the findings on the effect that the restoration project had on improving water quality.

The uncertainties associated with both identifying high-loading reaches and determining the effectiveness of stream management practices and programs over time make it difficult to determine the level of turbidity reduction benefit that might be achieved by enhancing the Stream Management Program. Over the coming years, the results of ongoing research should reduce this uncertainty and inform the further development of programming. In the interim, SMP activities will be expanded under the 2007 FAD to provide funding for stream and riparian restoration and management work undertaken by private landowners and transportation infrastructure managers throughout the Schoharie watershed.

5. Summary

It is reasonably certain that the Watershed Management and Protection Programs in place in the Schoharie Reservoir watershed are valuable opportunities for helping to reduce turbidity by limiting contact with sources of fine sediment. The recently approved 2007 FAD includes a sustained and well-funded NYCDEP commitment to these Programs with the intention of maintaining and enhancing water quality.

Through the acquisition of property and conservation easements, NYCDEP can prevent new land uses that have the potential to exacerbate terrestrial contributions of turbidity in the Schoharie watershed.

The terrestrial-based programs have helped, and can continue to help, reduce runoff contact and delivery of sediment to the streams. A properly graded logging road, an improved cattle crossing, a properly lined roadside ditch or a sediment retention basin for storm water management can significantly reduce localized input of turbid water into the system. This is likely to have a measurable localized effect at the lower to moderate runoff events that can cause the streams to become turbid but do not tend to substantially impact the reservoir water quality.

The Stream Management Program is expected to have the most significant impact on reducing delivery of turbid water to Schoharie Reservoir by reducing erosive contact with clay and silt sources. In some instances, where there is room for proper alignment, implementing some grade control and the use of bank stabilizing measures with rock and vegetation, a stream segment may be effectively removed from the fine sediment source. In other cases, the stream erosion is into a massive hill slope that is mantled with clay-rich deposits that continually slide into the stream, and there is little room for realignment of the stream away from the unstable hill slope. The conditions are varied and the challenges numerous for addressing sediment loading in streams through stream restoration.

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