New York City Department of Environmental Protection
Bureau of Water Supply

Evaluation of Turbidity Reduction Potential through Watershed Management in the Ashokan Basin

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Prepared in accordance with the 01/01/2007 SPDES Permit (NY-026 4652) for the Catskill Aqueduct Influent Chamber

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Executive Summary

This report describes what we know and can estimate about conditions resulting in elevated turbidity in the Ashokan Reservoir that leads to alum treatment and details what commitments DEP is making to develop and implement management strategies that aim to potentially reduce such turbidity. It is prepared by DEP in accordance with the schedule of compliance (e) "Turbidity Reduction Measures" as detailed in SPDES permit number NY 026-4652 relating to the Catskill Aqueduct Influent Chamber located at the Kensico Reservoir in Mount Pleasant, Westchester County, NY.

This evaluation of the potential for turbidity reduction from stream and upland landscape sources of fine sediment considers the historic and future implementation of several existing watershed management programs established under the 1997 NYC Memorandum of Agreement (MOA) and the 1997, 2002, and 2007 Filtration Avoidance Determinations (FADs).

Alum treatment is generally initiated in response to large stream runoff events in the Esopus Creek that transport large quantities of highly turbid water into the Ashokan Reservoir. The Esopus Creek watershed represents ~91% of the Ashokan Reservoir watershed. The other sub-basins that drain directly into the Ashokan do not seem to be significant sources of turbidity. The sources of turbidity are mainly from in-stream processes including erosion of layered glacial lake silt/clay and glacial till deposits in stream banks and beds, stream adjacent hill slope failures of these glacial deposits following high flow conditions, and re-suspension of fine-grained sediment in the stream bed material. Geologic and geomorphic mapping in support of stream management plans show that these geologic sources are ubiquitous and variably exposed by stream erosion and hill slope failure. Given that erosion into these deposits is going to occur as a natural process in landscape evolution, DEP 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.

Upland landscape erosion sources represent a smaller source for suspended sediment. The analysis based on application of the Universal Soil Loss Equation and a range of sediment delivery ratios presented in this report estimates that roughly 69-89% of potential suspended sediment inputs to the Ashokan reservoir are derived from in-stream sources and only 13%-31% are generated from terrestrial sources. The vast majority of land cover in the Esopus Creek watershed is forest; hence these potential upland landscape sources are already largely minimized. In addition, the Shandaken Tunnel also contributes a small percentage of turbidity to the Ashokan Reservoir, but this source is not a factor in the episodic need for alum treatment.

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.

Many of the watershed management and protection programs in place in the Ashokan Reservoir Watershed are valuable and may help to reduce localized turbidity conditions. These programs, in general, are not likely to significantly reduce turbidity on the watershed scale during the highest flow events that impact the use of alum.

The upland landscape-based programs have helped, and can continue to help, reduce runoff contact and delivery of sediment to the streams. A properly graded logging road, 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. However, these programs are unlikely to have a significant impact during the major storm events that substantially affect the reservoir water quality. Through the acquisition of property and conservation easements, DEP can prevent new land uses that have the potential to exacerbate terrestrial contributions of turbidity in the Ashokan watershed, but these programs will not reduce current turbidity levels.

The Stream Management Program has the greatest possibility of producing an impact on reducing delivery of turbid water to Ashokan Reservoir by potentially reducing in-stream 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 removed from the geologic fine sediment source, although fine-grain sediment in the stream bed material will persist. In other cases, the stream erosion is into a massive hill slope composed of 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. DEP believes that the Stream Management Program effectiveness can be enhanced by emphasizing coordinated response to flood events to minimize subsequent damage, investing in protecting and improving riparian buffers, and extending the current state of knowledge on best stream management practices to all who "manage" streams.

Fundamentally, it is unlikely that the Watershed Management Programs will reduce the impact of extreme floods on prolonged turbidity levels in Ashokan Reservoir. These overwhelming events, in contact with a ubiquitous geologic turbidity source, impact the quality of Ashokan Reservoir for extended periods of time. 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 DEP in accordance with the schedule of compliance for the identification and evaluation of "turbidity reduction measures" as detailed in SPDES permit number NY 026-4652 relating to the Catskill Aqueduct Influent Chamber located at the Kensico Reservoir in Mount Pleasant, Westchester County, NY. The CATIC SPDES permit, in effect since January 1, 2007, authorizes, subject to specified conditions, additions of aluminum sulfate ("alum") to the Catskill Aqueduct at the Influent Chamber, prior to discharge into the Kensico Reservoir.

The goal of this report is to satisfy the objectives described in the SPDES permit schedule of compliance. Essentially the permit requests that DEP evaluate the potential effectiveness of enhancing existing watershed management and protection programs as measures for reducing elevated turbidity in the Ashokan Reservoir. There is insufficient information to project actual reductions in turbidity in response to current or future use of watershed management strategies. There is sufficient information, however, to produce a preliminary characterization of turbidity causing conditions and a logical prioritization of pursuing watershed management strategies that may yield notable reductions. To meet the goal, this report describes what we know and can estimate about conditions resulting in elevated turbidity in the Ashokan reservoir and details what commitments DEP is making to develop and implement management strategies that aim to potentially reduce such turbidity.

The Schoharie Reservoir and the Ashokan Reservoir comprise the New York City West-of-Hudson (WOH) Catskill District (Figure 1.1). Water from these reservoirs is supplied to the Kensico Reservoir in Westchester County via the Catskill Aqueduct. Turbidity in the Catskill District watershed has been a historical water quality issue (Gannett Fleming and Hazen and Sawyer, 2006; CCEUC, 2007; DEP, 2003). Turbidity, an index of water clarity, is a water quality concern for water supply, ecologic, recreational and aesthetic use of the streams supplying the reservoirs. Suspended particles in the water are the source of turbidity in the Ashokan and Schoharie Basins streams. Specifically, the suspended particles (or solids) are predominantly fine-grained sediment in the silt to clay-size range. Section 2.2 of this report describes the sources of the suspended sediment that causes turbidity in the Ashokan Basin streams. A similar report submitted pursuant to the Shandaken Tunnel SPDES permit discusses the Schoharie Basin sediment sources (DEP, 2007). Watershed management is just one component of our overall strategy to reduce turbidity in the Ashokan Reservoir. A report on structural alternatives for turbidity reductions is also being prepared by DEP and is expected to be completed in July, 2008.

Water clarity is greatly affected by the presence of even small quantities of suspended sediment. At times, excessive suspended sediment loading results in elevated turbidity in Ashokan Reservoir. If the elevated turbidity enters the Catskill Aqueduct, DEP may use aluminum sulfate ("alum") as a last resort to flocculate the suspended sediment and reduce the turbidity thereby protecting the water quality of Kensico Reservoir. Section 2.1 of this report provides details on the conditions that lead to alum use.

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 periodically turn the streams and reservoirs a characteristic reddish-brown. The diversion of Schoharie Reservoir water to Esopus Creek via the Shandaken Tunnel is another source of turbidity to the Ashokan Reservoir. When the Schoharie Reservoir is turbid (following large flood events in the Schoharie Basin) the turbid diversions through the Shandaken Tunnel can also be a source of turbidity in the Ashokan Basin (See Section 2.2 for more detail).

Figure 1.1. New York City Water Supply System

The ability to reduce turbidity "loading" to the reservoir system from the watershed depends on the ability to reduce suspended sediment loading from watershed sources. The ability to evaluate turbidity reduction measures through watershed management strategies depends on the adequacy of available methods for characterizing the turbidity source conditions. Effective management to achieve measureable turbidity reduction in the Ashokan Reservoir should be founded in understanding the turbidity causing processes and associated sources (Simon, 2008). The existing watershed protection and management programs described in this report (Section 3) are part of a comprehensive watershed protection and management strategy established as part of the 1997 MOA. While these programs were not specifically developed to be turbidity reduction programs, the SPDES permit requires evaluation of these programs for their potential to reduce turbidity. Some of these programs may be useful in achieving measurable turbidity reduction. Before we can quantify any such reductions, however, we need to first improve our characterization of turbidity sources and processes in order to devise a set of watershed management strategies that can be successful. Further research may indicate that existing conditions beyond DEP's scope of control (i.e. geology, hydrology and existing development in the watershed) are the primary driving factors that lead to excessive turbidity. In this case, DEP will need to identify a realistic, science- based range of turbidity conditions that can be effectively modified through watershed management.

This report addresses the following questions:

- What types of events/situations create need for alum treatment? (Section 2.1)

- What do we know about the sources of turbidity? (Section 2.2)

- What are the current watershed management programs in the Ashokan Basin that may deal with turbidity sources and what potential do they have to measurably reduce turbidity in the Ashokan Reservoir through enhanced program activities? (Section 3)

- What are future watershed management activities which may help to reduce turbidity at a range of flows in the Ashokan Basin? (Section 4)

This report concludes with a summary of the potential impact of watershed protection and management programs on reducing suspended sediment loading at the watershed scale, the scale on which suspended sediment loading can lead to the use of alum at the Catskill Aqueduct Intake Chamber.

There are a number of documents that contain important background information describing the history of the Catskill 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 Ashokan and 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 (CCEUC, 2007; GCSWCD, 2007a, 2007b; DEP, 2006a). 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.

1.2. Catskill District Water Supply

The Catskill District includes the Schoharie Reservoir, Shandaken Tunnel, and Ashokan Reservoir (Figure 1.1) located in the eastern Catskill Mountains of New York State. The Catskill "System" is the water supply network that stores and conveys the water supplied by the "District".

The Schoharie Reservoir drains a 314 square mile watershed, and delivers an average flow of ~175 MGD to the Catskill System. The recently completed Schoharie Creek Management Plan includes extensive description of the watershed features (GCSWCD, 2007b). 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.

The Ashokan Reservoir drains a 255 square mile watershed, and delivers an average flow of ~485 MGD to the Catskill System. Figure 1.2 is a map of the landscape and sub-basins of the Ashokan Basin. The principal stream supplying water to the Ashokan Reservoir is Esopus Creek, which drains a 192 square mile watershed in the south-central Catskill Mountains (~91% of the Ashokan Basin). The Esopus Creek watershed includes nine tributary streams that contribute more than 10% of the drainage area to the creek where they enter, and numerous smaller tributary streams in the headwater reaches of Big Indian Hollow. The recently completed Upper Esopus Creek Management Plan includes extensive description of the watershed features (CCEUC, 2007). The Management Plan is available on-line at www.esopuscreek.org.

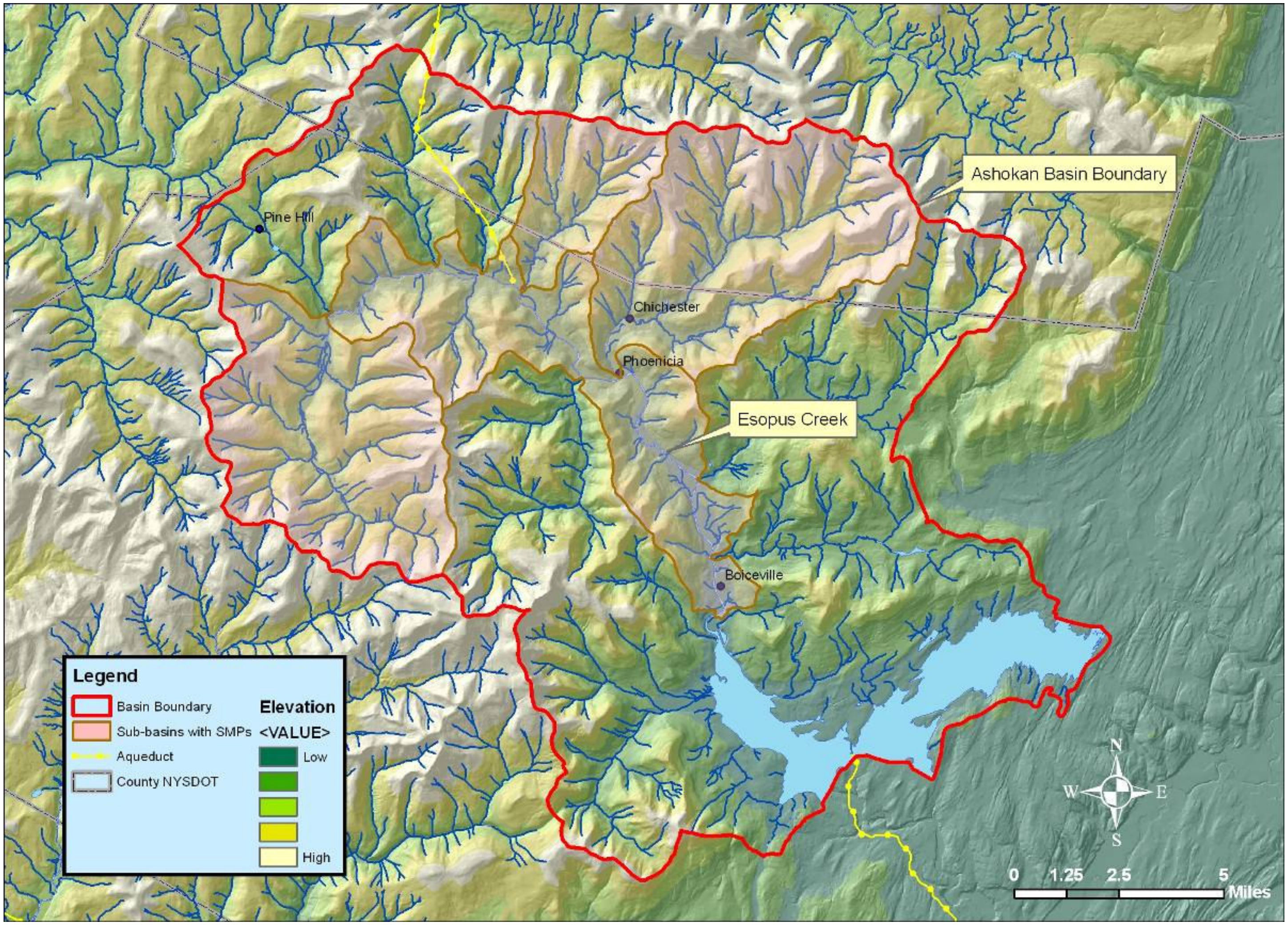


Figure 1.2. Map of Ashokan Basin landscape

2. Alum Use and Turbidity Sources in the Ashokan Basin

This section presents an analysis of the historic use of alum, a description of the geologic sources and geomorphic conditions in the Ashokan Basin that contribute to turbidity, a simple analysis of the partitioning of those geologic sources into landscape versus stream sources, and the role of the Shandaken Tunnel.

2.1. Characterization of Alum Use

For the twenty-one year period from 1987 through 2007, DEP has implemented alum treatment to reduce turbidity in the Catskill Water Supply during nine periods (Table 2.1) for a total of 524 days, or about 7% of the days for the twenty year period.

Analysis of Catskill Aqueduct flows conducted as part of an analysis of structural alternatives for Ashokan Reservoir found that initiation of alum treatment generally coincided with Catskill Aqueduct daily turbidity load exceeding 5000 NTU*MGD (Gannett Fleming and Hazen and Sawyer, 2007). The turbidity load is a representation of the quantity of turbidity causing particles (i.e. small light scattering particles) that flow into the Kensico Reservoir. Figure 2.1 (Gannett Fleming and Hazen and Sawyer, 2007) illustrates this relationship. Alum events, depicted by the gray shading only occur when a turbidity event causes the load in the Catskill Aqueduct to exceed the 5000 NTU*MGD threshold.

The turbidity loading in the Catskill Aqueduct is generally due to a combination of factors including the occurrence of a single or multiple consecutive extreme stream flow event(s) within the Esopus Creek watershed; a specific set of conditions in the Ashokan Reservoir prior to the onset of the event; and operational requirements due to special situations.

Of these factors, at least one high stream flow event is always present. Each of the twelve highest average daily flows for Esopus Creek led to, or influenced a period of alum treatment. The two alum treatment periods not caused by these highest flows were, nonetheless, triggered by other large flow events. These extreme events cause large quantities of highly turbid flow to enter the West Basin of the Ashokan Reservoir. After the West Basin quickly fills, the turbid water moves into the East Basin where water is normally drawn into the Catskill Aqueduct.

Sometimes, these extreme events occur during a period when the West Basin is already full, thereby allowing little available volume or time for settling to occur prior to turbid water reaching the aqueduct intake in the East Basin. On a number of occasions, the initial event may have caused elevated turbidity in the West Basin, but DEP was able to prevent or delay the use of alum by reducing flows in the Catskill Aqueduct. When water demands or operational conditions make continued low flow in the Catskill Aqueduct no longer possible, the probability of alum treatment being required is increased.

Table 2.1. Listing of alum treatment periods from 1987-2007.

Dates of Alum Treatment	Duration of Alum Treatment (days)	Avg. Daily Flow(s) at Coldbrook Causing Alum Treatment (cfs)	Date(s) of Daily Flow (mm/dd/yyyy)	Rank of Daily Flow for WY87-WY07
Apr. 6, 1987-May 19, 1987	43	17,400 10,000 9,460	04/04/1987 04/05/1987 03/31/1987	2 (tie) 8 11
Jan. 22, 1996-June 21, 1996	151	21,800 10,400	01/19/1996 01/27/1996	1 6
Jan. 14, 1997-Jan. 29, 1997	15	9,570	12/02/1996	10
Jan. 10, 2001-Feb. 2 2001	76	9,740	12/17/2000	9
Apr. 5, 2005-June 20, 2005	23	17,400 13,400	04/03/2005 04/02/2005	2 (tie) 4
Oct. 13, 2005-Nov. 23, 2005	41	6,520	10/13/2005	25
Dec. 1, 2005-Apr. 10, 2006	129	9,050	11/30/2005	12
May 15, 2006-May 24, 2006	10	5,950	05/12/2006	29
June 28, 2006-Aug. 2, 2006	36	11,400 10,300	06/28/2006 06/26/2006	5 7

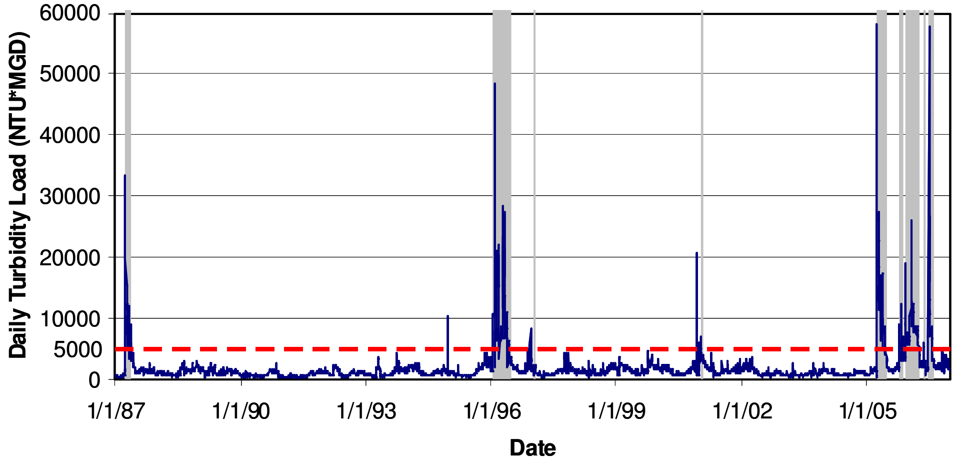


Figure 2.1. Time series of Catskill Aqueduct turbidity loads with alum treatment periods shaded in gray. Dashed red line shows 5000 NTU*MGD threshold that normally indicated that alum treatment may be required. (Gannett Fleming and Hazen and Sawyer, 2007)

2.2. Ashokan Basin Turbidity Source Characterization

Catskill Mountain streams are subject to periods of elevated turbidity from entrained suspended sediment, due in large part to the combination of the hydrology and geology of the watershed. As shown in the preceding section (Table 2.1), storm water runoff and snow melt events are major factors contributing high runoff and elevated turbidity to Ashokan Reservoir. Big floods cause muddy water. An additional primary factor is the geology of the watershed. The turbid water associated with high stream flows carries silt and clay particles eroded from the stream channel and landscape. Simon (2008) separates sources of fine-grained sediment that impair water clarity into three categories:

- Upland Landscape (slopes, fields, roads, etc)
- Urban Areas (developed land with impervious surfaces)
- Stream Channels (stream bed and banks)

For this report we are combining the upland landscape and urban sources. Urban sources in the Ashokan Basin are negligible. Previous analysis has shown the predominant source of suspended sediment in the Catskill District watersheds is within the channel network, rather than from overland flow across the landscape (DEP, 2007). An estimate of this primary division of loading for the Ashokan Basin is addressed in Section 2.2.2.

Historically, it has been the Esopus Creek watershed that has delivered the majority of the turbid discharge to the Ashokan Reservoir. Based on observed conditions during high runoff events the Bush Kill watershed in the Town of Olive does not seem to have the geologic source exposures of fine sediment that cause turbidity. DEP's water quality monitoring program supports that observation (DEP 1995). For the purpose of this report further discussion on turbidity sources is limited to the Esopus Creek watershed and the Shandaken Tunnel. Regardless of whether the source of suspended sediments is from the upland landscape or the stream channel, the geologic origin of the sediment is well known.

2.2.1. Catskill Geology

The Catskill Mountains are formed from a dissected plateau of sedimentary bedrock composed largely of repeating sequences of Devonian age sandstone, siltstone and shale. The repeated glaciation of these mountains during the last 1.6 million years abraded the bedrock, particularly the shale and siltstone, into clay and silt-sized particles. These fine particles along with coarser sized sediment were entrained into the base of the ice or along the ice margin to form glacial till, a mixed assemblage of sediment. When the glacial till was compressed by ice flow between the ice and terrain it is referred to as lodgment till. In the Catskills, the glacial till tends to be much enriched with clay and silt from the eroded bedrock. As the ice melted, the fine sediment would get entrained in glacial melt water that discharged into lakes impounded by the ice, recessional moraines and mountain topography. The sediment deposited in these *pro-glacial* lakes is referred to as lacustrine sediment. The silt and clay in these ice age deposits are the principal geologic sources that get entrained in the Catskill Mountain streams.

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, 2007b; CCEUC, 2007). The 2003 Catskill Turbidity Control report prepared by DEP in accordance with the 2002 FAD also includes additional detail on the geology (DEP, 2003).

2.2.2. Upland Landscape Turbidity Sources

Upland sources are generally derived from overland flow eroding and/or entraining fine-grained particles from exposures in the landscape. In the urban setting, storm water runoff across impervious surfaces may increase the erosive potential of the runoff to erode material from the landscape before getting into the stream channel. Roadside ditches intended to convey storm water runoff are assumed to be part of the stream channel network. Further, the delineation between channel network sources and upland sources can be arbitrary, in that steep hill slopes adjacent to streams can be eroded by a combination of stream channel process and mass failure of hill slope material.

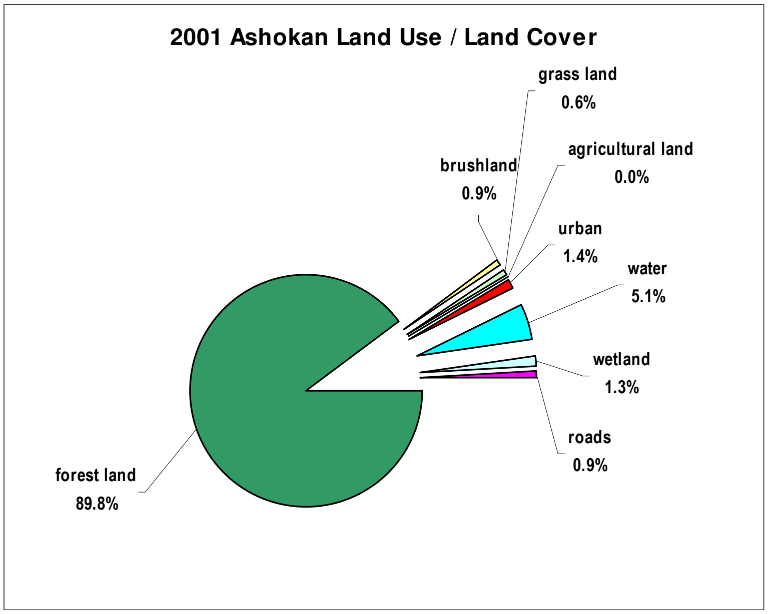


Figure 2.2. Land use/land cover breakdown for Ashokan Reservoir Watershed.

Figure 2.2 shows that based on 2001 land use / land cover data ~90% of the Ashokan Basin is forested and only ~2% is urban and roads. The extensively forested mountain landscape is the preferred land cover for minimizing entrainment of fine-grained sediment from upland sources. The remaining brush land, grass land and wetland covers (~3%) afford additional protection. The Esopus Creek watershed has an even higher percentage of forest cover (~95%) (DEP, 2005).

Clearly there are upland sources as can be seen in water delivered to roadside ditches following big storm events. Some of these sources may be due to natural landslide exposures of underlying glacial sediment or poor land management practices, such as poorly graded dirt roads/driveways or clear-cut logging.

DEP performed the analysis below to estimate the relative breakdown of sediment sources between erosion from the landscape (upland and urban lands) and stream channel sources. As noted in a similar analysis conducted on the Schoharie Reservoir Watershed (DEP, 2007), this approach has a large degree of unavoidable uncertainty related to the nature and distribution of sediment sources within the watershed, and the use of general empirical relationships describing erosion and sediment transport. The result provided here is a first order analysis which had the goal of determining the relative magnitude of channel versus landscape sediment sources in influencing the total sediment load in the Esopus Creek. The analysis is not however, capable of precisely specifying the level of either source contribution. To help account for this uncertainty, differing empirical estimates were used to bound the range in the source estimates, and results are reported as ranges of possible quantities.

Over long time periods the total sediment yield from landscape erosion sources can be calculated:

$$F_{s,l} = \frac{S_L}{S_Y} \qquad (2.1)$$

where $F_{s,l}$ is the fraction of sediment yield from upland landscape sources, S_Y is the long-term total sediment yield as estimated at the watershed outlet and S_L is the landscape erosion portion of the sediment yield. All long-term values are calculated as annual averages ($Mg \bullet yr^{-1}$).

Total Suspended Sediment Yield

The analysis first estimates the annual average suspended sediment yield from the Esopus Creek watershed into the Ashokan Reservoir using a sediment rating curve that estimates daily suspended sediment loading values for the outlet of the Esopus Creek watershed at Coldbrook:

$$S_d = 0.716 * Q_d^{\ 3.2} \qquad (2.2)$$

where, S_d is the daily suspended sediment load ($kg \cdot day^{-1}$) and Q_d is the mean daily streamflow ($m^3 \cdot sec^{-1}$). The numerical multiplier and exponent in equation 2.2 were estimated by calibration, based on flow and TSS monitoring data collected along the Esopus Creek and at the Shandaken Tunnel outlet.

Daily streamflow data was measured by USGS Stream Gage #1362500 located along Esopus Creek at Coldbrook (Figure 2.3). DEP TSS 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 December 1996 through September 2003. The storm event sampling included 23 high flow events, yielding 83 daily load values. Daily suspended sediment loads were calculated by summing 15 min loads that were estimated as the product of high frequency flow measurements (15 minute USGS) and TSS concentrations estimated by linear interpolation between less frequent measurements.

The loads and flows measured at Coldbrook include the contribution from the Shandaken Tunnel. To calculate the rating curve for the contribution of the Esopus Creek watershed to the total sediment yield, the Shandaken Tunnel flows and loads were subtracted from the loads and flows as measured in the Esopus Creek at Coldbrook. The resulting calibrated rating curve for daily TSS is shown in Figure 2.4.

Over the entire period of study, daily estimates of sediment yield were calculated as the product of rating curve derived TSS concentrations and daily USGS reported flows. The estimated long-term annual sediment yield, was calculated as the sum of daily sediment yield divided by the number of years in the period 1961-2000:

$$S_Y = \frac{\sum S_d}{40\,yr.} = 102{,}342 \text{ Mg/yr} \tag{2.3}$$

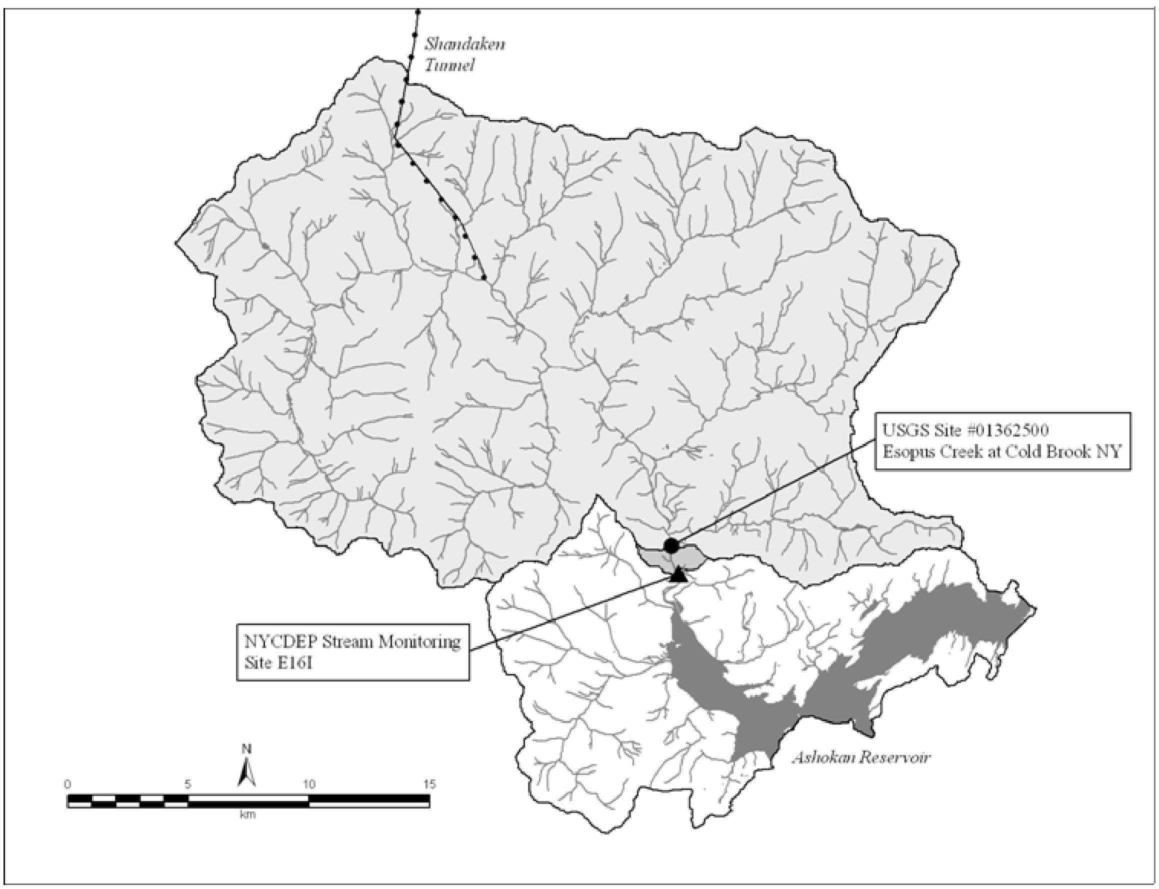
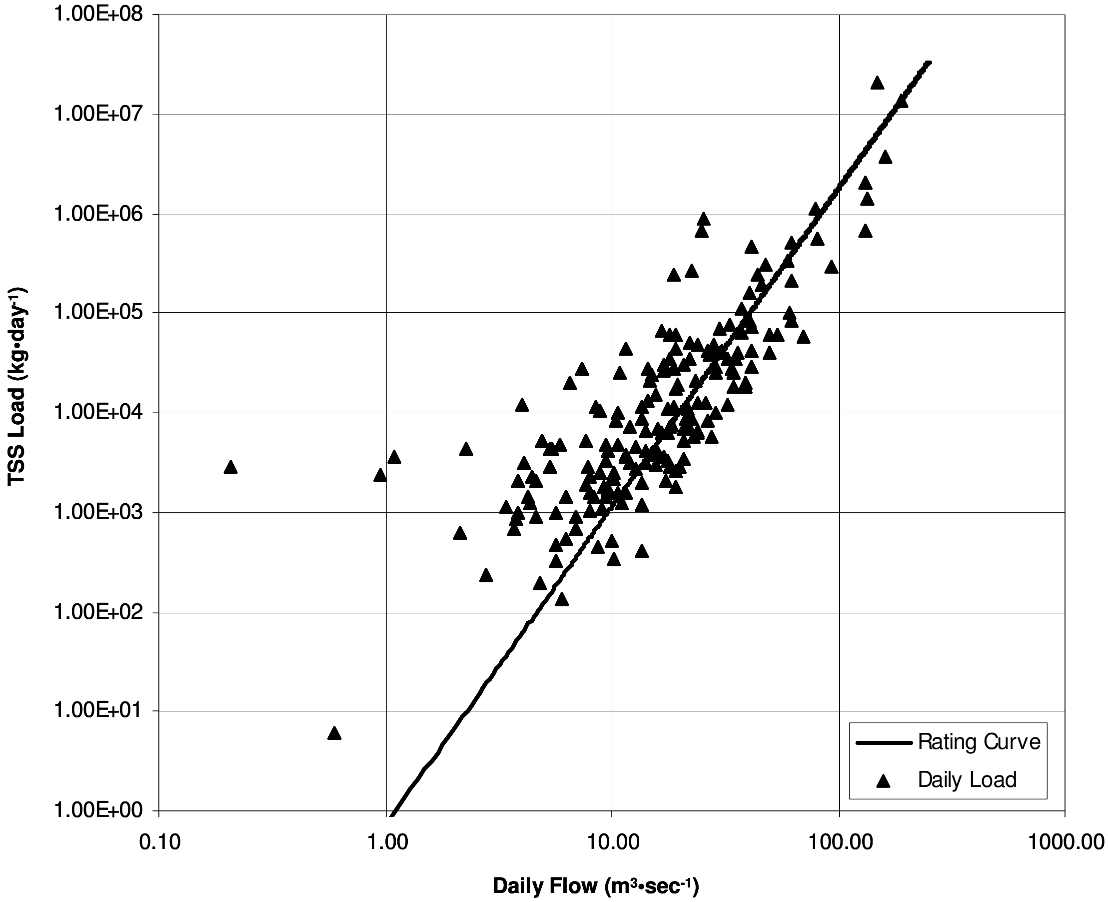


Figure 2.3. Watershed for USGS Streamflow gage (01362500) and DEP sampling site (E16I) along Esopus Creek at Coldbrook.



Error Statistics:

% avg.error = -0.2% $\left(\frac{mean\ observed - mean\ predicted}{mean\ observed} \cdot 100\right)$

Nash Sutcliff Coeff = 0.574 $\left(1 - \frac{\sum (observed - predicted)^2}{\sum (observed - mean\ observed)^2}\right)$

Figure 2.4. Rating curve showing relationship between suspended sediment load and daily flow for USGS streamflow gage located at Esopus Creek at Coldbrook. To account for Shandaken Tunnel contributions, the Tunnel flows and loads are subtracted from the measured flows and loads in Esopus Creek.
Error statistics show a good fit with % average error of -0.2% and Nash-Sutcliff coefficient of model efficiency (Nash and Sutcliff, 1970) of 0.574.

Landscape Erosion (Upland and Built-Up Areas)

The total landscape erosion from upland and built-up areas is estimated using 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 annual average erosion rates 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 et al., 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.

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). 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 used in this analysis are described in DEP (2006b). 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; DEP, 2006c).

The erosion results for the Esopus Creek watershed are shown in Table 2.2. The total mean annual erosion rate for the watershed is approximately 121,000 metric tons per year. The majority of this predicted erosion is from forested area which represents ~95% of the total land area.

Table 2.2. Land use areas and estimated mean annual erosion rates (calculated using precipitation from 1961-2000) for the Esopus Creek at Coldbrook watershed.

Land Use	**Area (km^2)**	**Mean Annual Erosion Rate ($Mg•yr^{-1}$)**
Forest Deciduous	352.2	91,945
Forest Coniferous	98.1	22,084
Forest Mixed	23.9	5,445
Brushland	2.9	221
Non-Agricultural Grass	4.9	428
Agricultural Lands (fields, barnyards)	0.1	95
Residential Impervious	1.4	150
Residential Pervious	4.3	49
Commercial/Industrial Impervious	0.3	14
Commercial/Industrial Pervious	0.3	3
Rural Roads	1.8	81
Wetlands	3.0	525
Water	2.1	0
Total	**495.5**	**121,039**

Only a fraction of the total erosion as shown in Table 2.2 is actually transported downstream to the watershed outlet. To account for this, a sediment delivery ratio is applied to obtain the sediment yield at the watershed outlet from upland landscape erosion sources:

$$S_L = SDR * E_L \quad (2.4)$$

where S_L is the sediment yield from upland landscape erosion sources, *SDR* is the sediment delivery ratio and E_L is the landscape erosion as described above and shown in Table 2.2. A number of studies have empirically calibrated the sediment delivery ratio 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:

$$SDR = 0.38A^{-0.2} \quad \text{(USDA-SCS, 1983)} \quad (2.5)$$

$$SDR = 0.463A^{-0.125} \quad \text{(Vanoni, 1975)} \quad (2.6)$$

$$SDR = 0.622A^{-0.141} \quad \text{(Renfro, 1975)} \quad (2.7)$$

where A is the drainage area in km^2.

Given the empirical nature of these methods for calculating the sediment delivery ratio, all three methods were used to provide a range of the estimated contribution of landscape erosion toward total watershed sediment yield.

Table 2.3. Sediment delivery ratios and calculations of the fraction of sediment from upland landscape sources

Sediment Delivery Ratio Method	Sediment Delivery Ratio*	Suspended Sediment from Upland Landscape Sources** ($Mg•yr^{-1}$)	Total Sediment Yield*** ($Mg•yr^{-1}$)	Fraction Sediment from Upland Landscape Sources
(USDA-SCS, 1983)	0.110	13,314	102,342	0.13
(Vanoni, 1975)	0.213	25,781	102,342	0.25
(Renfro, 1975)	0.259	31,349	102,342	0.31
Range	**0.110-0.259**	**13,314-31,349**		**0.13-0.31**

*See Equations 2.5, 2.6 and 2.7
**See Equation 2.4
***See Equation 2.3

Table 2.3 shows the range of sediment delivery ratios using the three methods described above and the resulting proportion of sediment from landscape sources. The upland landscape erosion sources range from 13 to 31% of total sediment yield. This analysis shows that (1) the majority of suspended sediment is not due to upland erosion and (2) to the extent that upland erosion contributes to suspended sediment, the majority of the upland erosion is generated from forested areas.

2.2.3. Stream Channel Sources

According to our observations, the estimate presented in Section 2.2.2 and previous analysis (DEP, 2007; CCEUC, 2007), the predominant source of suspended sediment induced turbidity in the Catskill watershed comes from erosion and resuspension within the stream channel network. For this source characterization the adjacent hill slopes where the channel is against the valley wall are lumped in with the active channel “corridor”. Erosion of the channel margin into the toe of a hill slope composed of glacial till and/or lacustrine sediment can induce hill slope mass wasting, with sediment transport directly to the stream. It can be argued that the stream adjacent hill slopes represent landscape sources; however the hydrologic mechanism for their contribution and ultimate entrainment is strongly linked to stream hydrology and riparian land management, and so from a management perspective we are including these sources in the stream channel category.

The DEP Stream Management Program and contract partners have conducted several assessments and studies that are useful in an initial characterization of the stream channel network sources. As of July 1, 2008 DEP and its partners have completed management plans for the Upper Esopus Creek corridor, Stony Clove and Broadstreet Hollow (CCEUC, 2007; GCSWCD, 2004; UCSWCD, 2003) (Figure 1.2). Each management plan includes an assessment methodology that identifies the distribution of stream bank erosion and exposures of fine-grained sediment sources in stream channels. Mapping of these fine-grained sediment sources along the Esopus Creek and all or parts of several tributary channels reveals that these sources are exposed in the channel from headwaters to the mainstem Esopus Creek. The two primary geologic sources of fine-grained sediment in the stream channel are discussed below (as adapted from the Upper Esopus Creek Management Plan).

Lacustrine silt/clay is a reddish brown, finely-layered, silty-clay deposit that floors significant portions of the Upper Esopus Creek and several tributaries (Figure 2.5). It was deposited subaqueously (from streams discharging into one or more pro-glacial lakes) as a sediment blanket draped over underlying till or bedrock. Locally, it was also deposited in smaller impoundments associated with alpine glaciers and moraine dams. It is commonly exposed along the toe of the stream bank, sometimes in the channel bottom (often beneath a thin cover of coarse alluvium), and less frequently as long and/or large banks.

The fine, uniform grain size results in a very cohesive deposit that exhibits unique hydraulic and mechanical erosion characteristics. The Upper Esopus Creek Management Plan includes a study on the erodibility of these deposits by the U.S. Army Engineer Research and Development Center (ERDC) (CCEUC, 2007). While the silts are easily entrained under high runoff events, many of the clay-rich deposits are resistant to hydraulic erosion. Susceptibility to erosion is largely dependent upon whether the layered silt/clay has been mechanically disturbed by geotechnical failures or human disturbance. The silt/clay unit tends to erode mechanically in the slope adjacent to the channel margin by slumping along rotational faults, subsequently losing its layered structure and cohesive strength. Within the silt and clay layers, strata of sand sometimes occur, creating the potential for piping and associated mechanical failures. When saturated, it tends to be extremely soft and in this physically- and chemically-weakened condition is susceptible to creep and erosion.

Figure 2.5. Esopus Creek stream bank exposure of lacustrine silt/clay layers deposited in a pro-glacial lake that once filled the Upper Esopus Creek valley.

Where vegetative cover is lost and large exposures of lacustrine silt/clays occur, revegetation is usually slow to due to the poor drainage and rooting characteristics of the soil. Elongate troughs, scour holes and even deep potholes in the stream bed reflect its entrainment potential during scouring flows. Clear stream water contacting lake clays often results in an entire stream becoming turbid within 50 feet (Figure 2.6). In the Upper Esopus Creek watershed the lacustrine silt/clay is a primary source for suspended sediment and turbidity problems.

Maximum elevations of the pro-glacial lakes have been interpreted to be around 1830 ft amsl (Rich, 1935). Figure 2.7 is a map that depicts what portion of the Esopus Creek watershed could have been inundated during the maximum stage of glacial Lake Peekamoose (1830 ft), and thus subject to lacustrine deposition of fine-grained sediment.

Figure 2.6. Broadstreet Hollow with exposed glacial lake deposits causing turbidity.

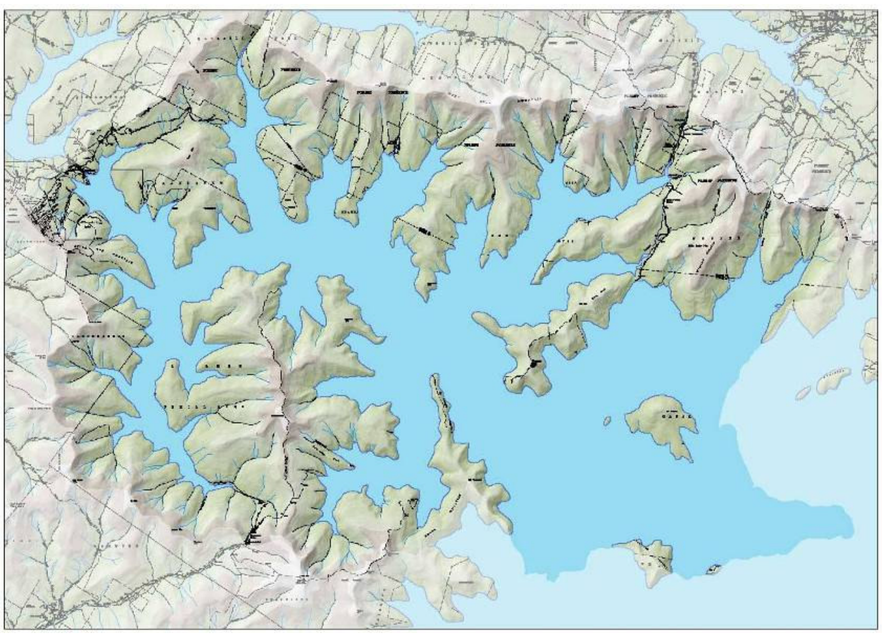


Figure 2.7. Map of hypothetical Lake Peekamoose based on Rich (1935)

Figure 2.8. Glacial till exposed in Fox Hollow stream bank. Turbid water is from contact with glacial till.

Glacial (Lodgment) Till is an over-consolidated (very dense), clay-rich, reddish brown deposit that is prevalent in the tributary valleys and valley margins of the Upper Esopus Creek watershed (Figure 2.8). This hard-packed silty clay with embedded pebbles, cobbles and boulders forms a number of steep banks in the drainage basin. Its dense, consolidated character is distinguished from the looser assemblage of mixed sediment sizes (silty sand-boulder) that comprises melt-out till found in moraines and along mountain sides. Lodgment till is typically exposed in stream channels where overlying lake clay deposits have been removed by erosion, where streams have scoured into valley wall deposits or where they have breached moraine ridges.

Its relatively competent nature, especially compared to disturbed lacustrine sediment, make lodgment till significantly more resistant to hydraulic erosion. It is however, susceptible to mechanical erosion by mass failure of fracture bound blocks during saturation/desaturation and freeze/thaw cycles. This failed material is subsequently eroded by stream flows (Figure 2.9). Under conditions of high stream velocities and discharges, lodgment till is a contributor of sediment. However, where the stream (particularly in tributary valleys) is against the valley wall and the hill slope composed of layers of lodgment till and lacustrine sediment is saturated, long-lasting exposures can be chronic sources of suspended sediment into the stream well after a storm event. Reaches in the lower Stony Clove valley below Warner Creek are subject to this phenomenon (Figure 2.10) Rain water and overland runoff contacting exposed banks can also readily entrain sediment from these units.

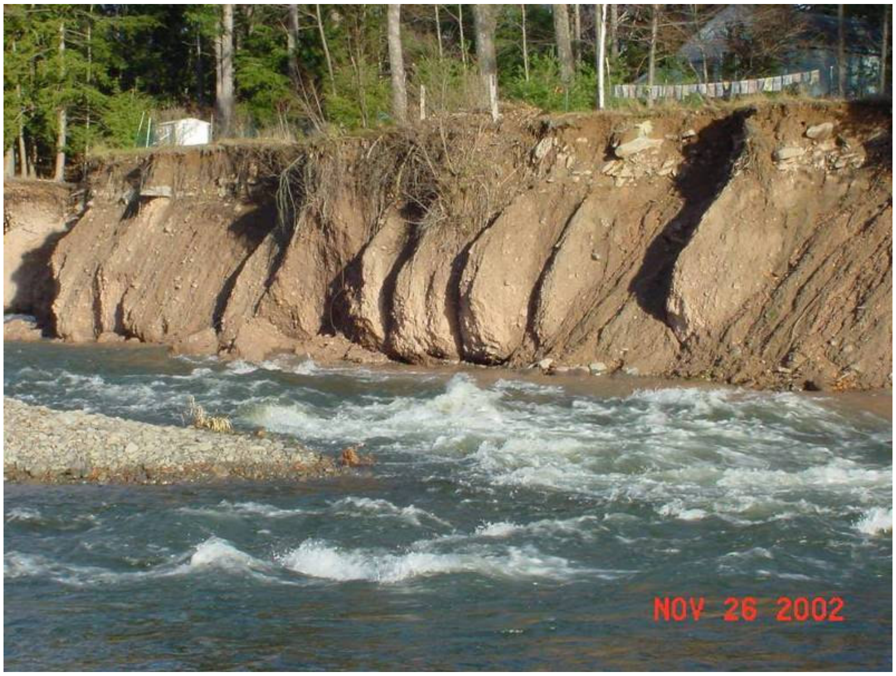


Figure 2.9. Erosion of glacial till by high velocity streamflow and mechanical failure


Figure 2.10. Stony Clove creek erosion of hill slope composed of glacial till and lacustrine sediment.

Field observations indicate that glacial till exposures dominate in many of the upper reaches of the tributary streams and adjacent hill slopes, while the valley bottoms tend to be uniformly underlain at varying depth by the thick inter-bedded layers of silt and clay lake deposits. Mapping efforts indicate that these clay-rich deposits represent a watershed scale, non-point source of sediment that is delivered to the Ashokan Reservoir. A photo-documentation of turbidity conditions along Esopus Creek following the April 2-3, 2005 flood event is presented in Figure 2.11. This set of photos shows that during the very large storm events that lead to alum use (Section 2.1), nearly the entire Esopus drainage network becomes a source of suspended sediment.

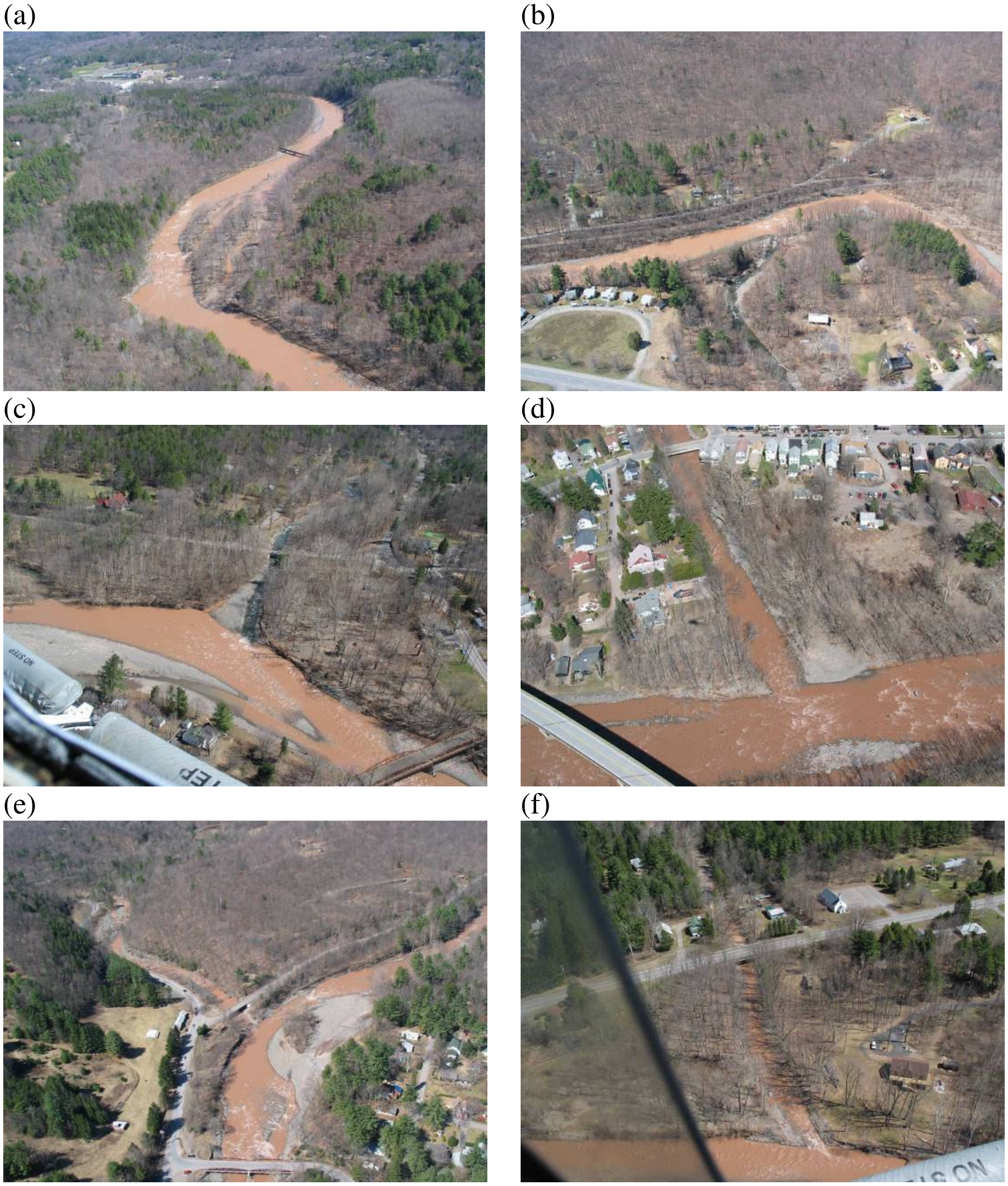


Figure 2.11. Photo-documentation following April 2-3, 2005 flood in the Esopus Creek watershed demonstrating watershed scale suspended sediment loading. All photos but one were taken on April 10, 2005. (a) Esopus Creek: reservoir stem below Boiceville; (b) Esopus Creek: Little Beaver Kill confluence (not turbid); (c) Esopus Creek: Beaver Kill confluence (not turbid); (d) Esopus Creek: Stony Clove Creek confluence; (e) Esopus Creek: Woodland Valley Creek confluence; (f) Esopus Creek: Broadstreet Hollow confluence.

(g)

(h)

(i)

(j)

(k)

(l)

Figure 2.11. Photo-documentation following April 2-3, 2005 flood in the Esopus Creek watershed demonstrating watershed scale suspended sediment loading. All photos but one were taken on April 10, 2005. (g) Esopus Creek: Shandaken Tunnel; (h) Esopus Creek: Fox Hollow confluence (April 5); (i) Esopus Creek: Bushnellsville Creek confluence; (j) Esopus Creek: Birch creek confluence; (k) Esopus Creek at Big Indian (just upstream of Birch Creek); (l) Esopus Creek at Full Moon resort in Oliverea. This near headwater reach was the upstream source of sediment in the Big Indian Hollow portion of the upper Esopus Creek on the flight date.

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 historic stream management. Water quality sampling by DEP, as reported in the BMP Strategy to Reduce Turbidity (DEP, 1995) and subsequent reports (GCSWCD, 2004) presents evidence that the Stony Clove sub-basin has been the major contributor of turbidity in the Ashokan basin. However, it should be noted that the sub-basin sediment loading conditions are temporally variable and depending upon the geology, scale and local dynamics of flood events some other sub-basins may contribute disproportionately more than others. For example, Bushnellsville Creek was a significant chronic source of turbidity to Esopus Creek for months following the April, 2005 flood after many pro-glacial lake deposits were exposed. Prior to that flood, the stream was generally clear or at most slightly turbid following a flood event. Over the course of the last three years many of the exposures have been covered by coarse alluvium deposited by subsequent smaller floods. The result is that the stream is not so readily turbid at this time. Similar conditions hold for Birch Creek, Broadstreet Hollow, Woodland Valley, and Beaver Kill.

An additional and unique mechanism of introducing suspended sediment into the Esopus Creek is via the Broadstreet Hollow stream "mudboil" present in the stream just upstream of Jay Hand Hollow (Figure 2.12). The artesian conditions associated with the groundwater hydrology of stream adjacent hill slope failure of lacustrine sediment causes a point source of turbidity to sporadically occur. The Broadstreet Hollow reach has been managed repeatedly through the years – first through traditional riprap revetment, then in 1999 by combined use of natural channel design (NCD) techniques and hill slope dewatering employed by Greene County Soil and Water Conservation District (UCSWCD, 2003). The April, 2005 flood that ravaged the Esopus Creek watershed caused significant erosion in this reach which helped reactivate the hill slope hydraulics leading to a reoccurrence of the artesian mud-boil and some damage to the project NCD features. DEP has provided additional funding to GCSWCD to remediate the project damages and hopefully reduce the hydraulic head that induces the mudboil. Work is planned for early summer 2008.

Figure 2.12. Photo of Broadstreet Hollow mud boil

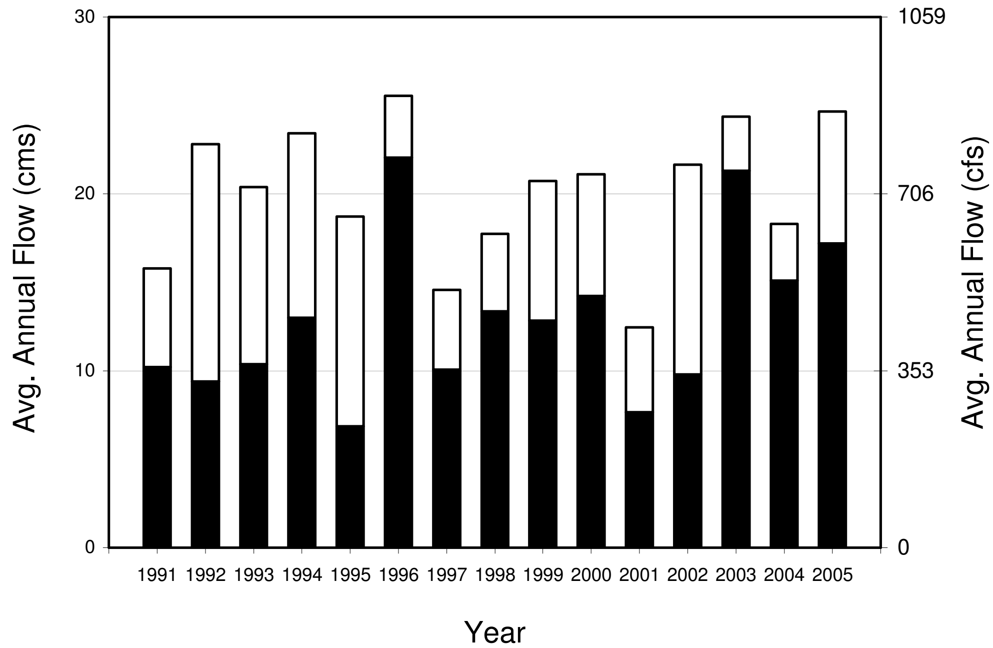
2.2.4. Shandaken Tunnel as a Turbidity Source

A "regulated" source of suspended sediment into the Ashokan Basin is the diversion of Schoharie Reservoir water into Esopus Creek via the Shandaken Tunnel. The Esopus Creek conveys this water (and the creek's natural flow) twelve miles downstream to the Ashokan Reservoir (Figure 1.1). On occasion, the Shandaken Tunnel carries highly turbid water, due to the turbidity issues that exist in the Schoharie Watershed and Reservoir. Even though the Shandaken Tunnel can contain high turbidity, the Tunnel turbidity contribution does not generally contribute to the initiation of alum treatment events because of dilution with natural Esopus flows and settling afforded at the Ashokan Reservoir. Additionally, following high flow events the Tunnel is shut down and no water is diverted into the Esopus Creek. Exceptions to this exist during emergency conditions at the Schoharie Reservoir, when the tunnel had to be operated at continuous high flow to help dewater the reservoir for repairs to the Gilboa dam.

Historically, initiation of alum treatments have been associated with large streamflow events within the Esopus Creek which are caused by either large rainfall or high precipitation combined with snowmelt within the Ashokan Watershed. UFI (2007) used a combination of DEP monitoring data and an empirical model of turbidity loading from the Esopus Watershed to determine the relative importance of Tunnel versus Esopus Watershed contributions to the total Ashokan Reservoir turbidity load. This study found that the vast majority of turbidity loading into Ashokan Reservoir is from the Esopus Watershed, not from the Shandaken Tunnel. Figure 2.13, which is based on this study, shows the yearly time series of turbidity contributions and flows from the Schoharie Tunnel and the Ashokan Reservoir. The percentage of turbidity from the Tunnel ranges from 0.5% during 1996 to 43% during 2001. Comparing the flows to the turbidity, shows that even though the Shandaken Tunnel flow contributes significantly to the water flowing into the Ashokan Reservoir, the turbidity contributions are relatively small.

DEP (2006b) used the LinkRes modeling system (UFI, 2002) to explicitly simulate the influence of Schoharie Tunnel turbidity on high turbidity values that occur in Ashokan Reservoir. The study tested two scenarios: one using turbidity loading as estimated from both the Esopus Creek Watershed and the Shandaken Tunnel and the other scenario assuming turbidity loads only from the Tunnel. Figure 2.14 shows time series of turbidity at the Ashokan outlet for the two scenarios. The peak turbidity levels in the upper graph, which are influenced by the Ashokan Watershed, are much greater than the peak turbidity levels in lower graph where only Schoharie sources are input to the reservoir. These results indicate that the large peak turbidity levels, that normally create the need to initiate alum use, are caused by turbidity from the Ashokan not Schoharie watershed sources.

(a)



(b)

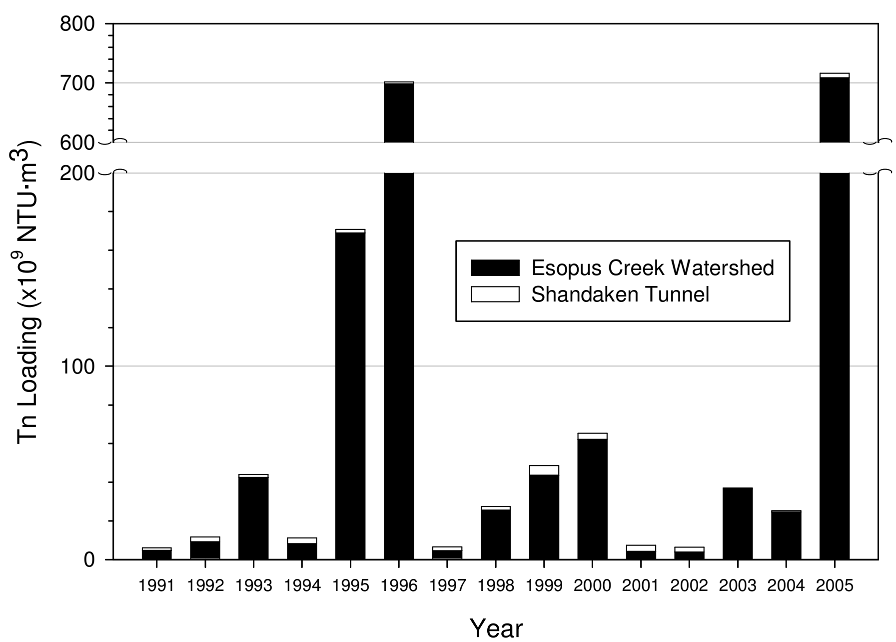


Figure 2.13. (a) Annual average flow contributions to Ashokan Reservoir and (b) annual turbidity load contributions from Shandaken Tunnel (white bars) and Esopus Creek Watershed (black bars). (Esopus Creek Flows based on USGS Gage #01362500; Shandaken Tunnel Flows based on USGS Gage #013622330 for 1996-2005 and DEP Strategic Services data for 1991-1996; turbidity estimates and graph from UFI(2007)).

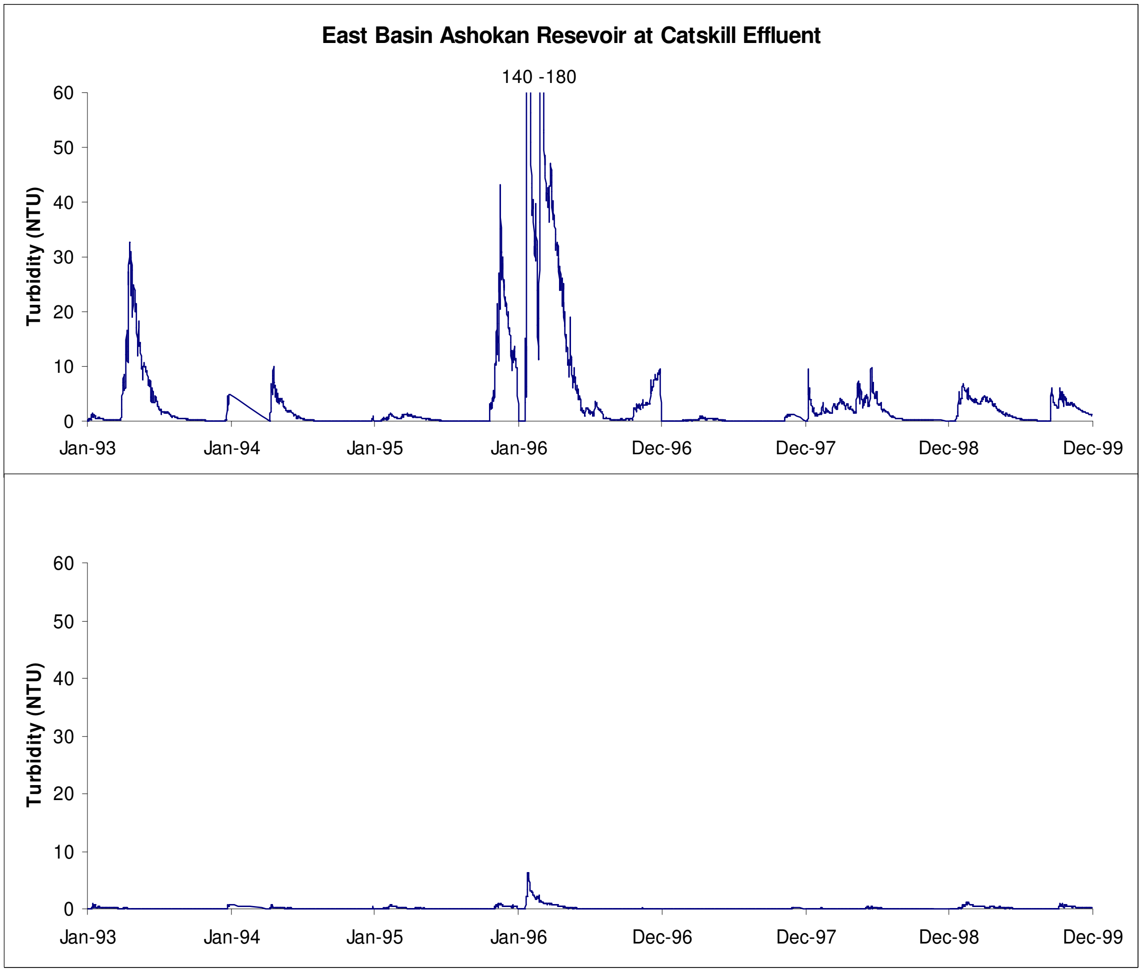


Figure 2.14**.** Turbidity levels simulated in the East Basin of the Ashokan Reservoir at the location of the Catskill aqueduct effluent chamber. Top panel shows the result for simulations where turbidity from Ashokan Reservoir watershed sources and the Shandaken Tunnel are input to the simulation. Bottom panel is the result when only the Shandaken tunnel sources are input to the simulation (DEP, 2006b)

2.2.5. Esopus Creek Sediment Budget: Preliminary Status

The Upper Esopus Creek Management Plan includes a preliminary fine sediment budget study conducted by Dr. Craig Fischenich of the U.S. Army ERDC (CCEUC, 2007). The study was conducted to assess the relative contribution of fine sediment sources in the Upper Esopus Creek watershed (excluding the effects of major floods) for the purpose of evaluating the efficacy of various management measures aimed at turbidity reduction. The study was considered an initial foray into whether such a complicated investigation could be pursued with extant data. The Upper Esopus Creek Management Plan details the limitations that preclude using the results for anything beyond general discussion purposes and information that can be used to construct a more rigorous investigation if necessary. The exclusion of the major flood events further limits its usefulness for this report, since
it is the major flood events that result in the use of alum. However, the study provided an "order-of-magnitude" assessment useful for evaluating the relative contributions of the various sources that comprise a computed total yield. The contributing sources were categorized as Shandaken Tunnel, mapped Esopus stream bank erosion, Esopus streambed re-suspension (Figure 2.15), mapped fine-grained sediment sources, and lumped tributary contribution.

According to this analysis on an average annual basis the Shandaken Tunnel contributed ~8%, while the mapped fine-grained sediment exposures could contribute up to ~24%. The remaining 68% is assumed to come from entrainment of fine sediment through stream channel erosion and re-suspension along Upper Esopus Creek and its tributary system

Figure 2.15**.** Streambed re-suspension in Birch Creek.

The erosion of fine-grained sediment sources (either by stream bank erosion and/or associated hill slope mass failure) is a major source of suspended sediment following floods. These sources are widely distributed across the watershed but are physically discrete. However, the preliminary sediment budget indicates that under bankfull and greater flow conditions the sediment that is re-suspended from the stream bed is the principal source of turbidity in Esopus Creek. The ERDC sediment budget sampling found that the percentage of fine-grained sediment in the sampled bed material ranged from 0.3 to 2.9 percent, with a mean value of 1.5 percent. A similar distribution of fine sediment was identified for most of the tributary streams as well. Considering the cumulative length of stream in the watershed and the potential volume of re-suspended sediment the stream bed material is a significant long-term source. This source cannot be effectively directly removed from the stream system. We do not yet understand the predominant source and mechanism for entrainment in the bed material. Fine-grained sediment in the bed material comes not only from eroding stream banks and landscape, but also from scour into the underlying glacial till and/or lacustrine silt/clay. Even if all potential landscape sources and eroding stream bank sources were effectively removed, this conveyer belt of sediment that comprises the stream bed is unlikely to "clean out" since the non-alluvial bed scour source will persist.

The relative contribution of the various sources to turbidity is dependent upon flows in the Esopus Creek watershed. According to the conclusions presented in the Upper Esopus Creek Management Plan, the Schoharie diversion through the Shandaken Tunnel (during and following highly turbid conditions in the Schoharie Reservoir) and disturbed clay deposits are the primary sources under low flow conditions, while fine sediments in the bed of the channel and tributaries coupled with runoff from roadside ditches are significant contributors during moderate runoff events, and bed and bank erosion predominate during flooding. The salient point is that many sources contribute to sediment loading and turbidity in Esopus Creek varying with a range in stream discharge; eliminating most of these sources is neither technically nor economically feasible.

3. Watershed Management and Protection Programs that May Address Turbidity in the Ashokan Basin

Several of the Watershed Management Programs established by the 1997 MOA and further developed in subsequent FADs, 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 3.1 is a simple matrix that categorizes the watershed programs into potential turbidity reduction or landscape protection programs and indicates if the programs are intended to address landscape or stream channel erosion. Figure 3.1 is a map depicting the implementation of these programs within the Ashokan Reservoir watershed.

There are many reports that provide detail on the development and history of these programs (DEP, 2001; DEP, 2006a). Brief summaries of program scope and specific application in the Ashokan Reservoir watershed are provided below.

Table 3.1. 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* Stormwater Retrofit Program
Protection	Land Acquisition Program *Fee simple* *Conservation easements*	Watershed Agricultural Program *CREP* *Land Acquisition* *Fee simple* *Conservation easements*

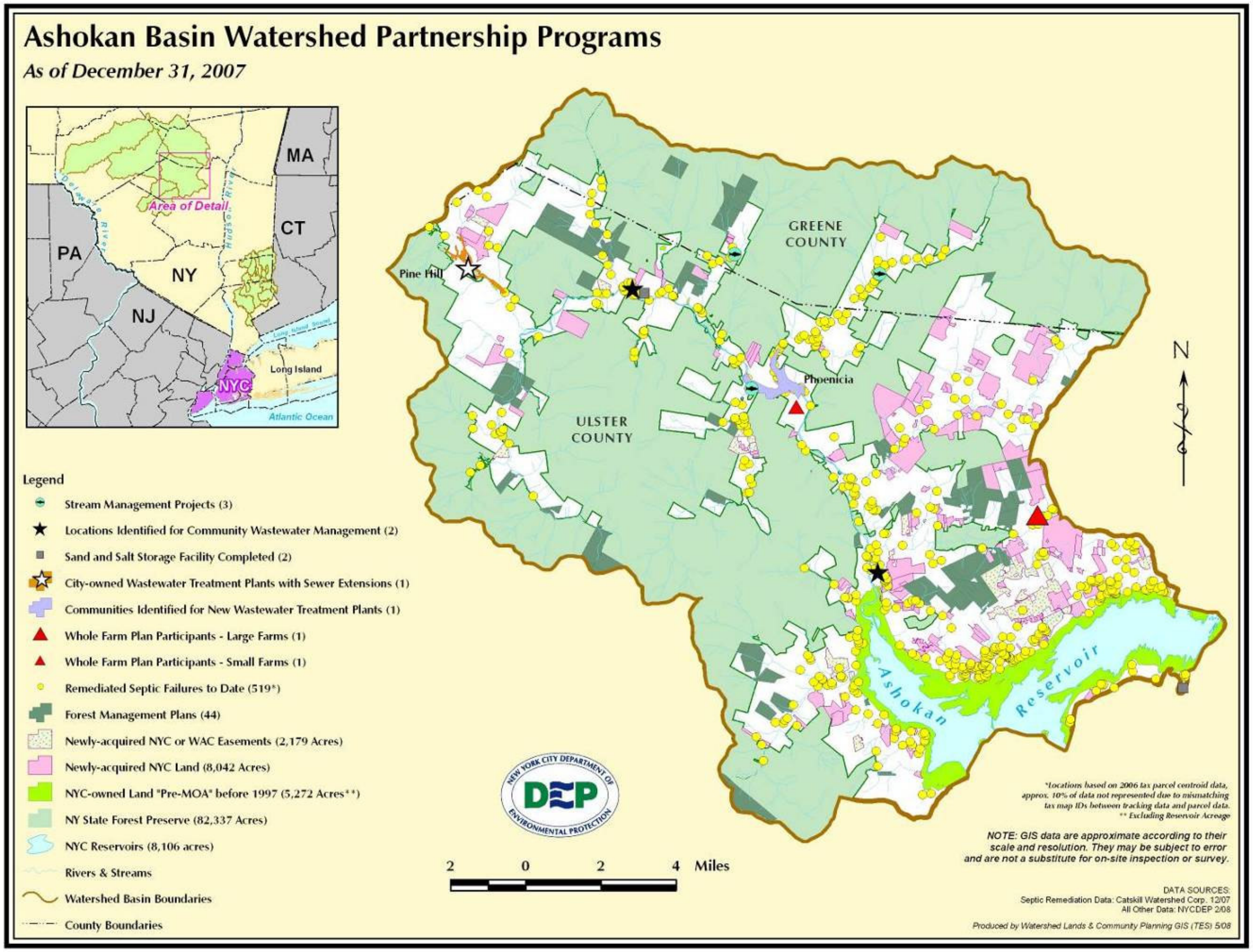


Figure 3.1. Ashokan Basin Watershed Management Programs status as of December 31, 2007

3.1. Watershed Agricultural Program

Since 1992, the Watershed Agricultural Council (WAC) has operated the Watershed Agricultural Program as a comprehensive effort to develop and implement pollution prevention plans on farms in the City's water supply watersheds. This program has the potential for reducing suspended sediment loading from upland landscape sources and is therefore considered here as potential turbidity reduction program. WAC is not aware of any large farms currently operating in the Ashokan Basin, and only one Whole Farm Plan has been developed (in 2002) for a small horse farm near Phoenicia. WAC has identified two other small livestock operations (one each in the Towns of Woodstock and Olive), but potential water quality issues of concern on these two farms rank relatively low compared to other small farms in the watershed based upon the results of an environmental assessment. As a result, these two small farms may not be actively planned for several years. In general, implementation of agricultural BMPs in the Ashokan Basin is expected to be minimal and will likely not contribute significantly to a reduction in suspended sediment loading. DEP does not believe that heightened or more expansive implementation of the Watershed Agricultural Program would provide a benefit in turbidity reduction to Ashokan reservoir given the minimal agricultural land use in the basin.

3.2. Watershed Forestry Program

Since 1997, the WAC has operated the Watershed Forestry Program as a voluntary pollution prevention partnership that supports and maintains well-managed forests as a beneficial watershed land use. With funding from the City and the US Forest Service, WAC offers technical assistance and cost-sharing incentives to promote the development of long-term forest management plans and the implementation forestry BMPs. This program has the potential for reducing suspended sediment loading from upland landscape sources, where land disturbance associated with forestry contributes to such loading and is therefore considered here as potential turbidity reduction program. In the Ashokan Basin, more than 40 landowners have completed forest management plans covering approximately 7,100 acres, and approximately two dozen forestry BMP projects have been completed (primarily road remediation projects). It is important to recognize that because forests contribute the least amount of pollution per acre of any land cover, the impacts of the Forestry Program on suspended sediment loading in the Ashokan Basin will generally be sporadic and minimal compared to stream channel sources and protection programs. However, improvement in logging road construction and maintenance is likely to be the most relevant component of this program to reducing suspended sediment from the landscape. Heightened or more expansive implementation of the Watershed Forestry Program may provide a benefit in turbidity reduction on a local scale but is unlikely to impact the need to initiate alum use.

3.3. 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. These stormwater BMPs are intended to correct or reduce existing erosion that may contribute turbidity to streams and/or pollutant loading. This program has the potential for reducing suspended sediment loading from upland landscape and stream channel sources (ditches and culverted stream flow) and is therefore considered here as a potential turbidity reduction program. 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 five projects within the Ashokan basin.

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 2002, 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 December 2005, the Ulster County Environmental Management Council (EMC) completed an Ulster County Watershed Storm Water Infrastructure Assessment Report funded through the CWC Planning and Assessment Program. The report highlighted the need for systematic planning and pro-active management of the county's stormwater infrastructure, and the acquisition of equipment by Ulster County for use in a shared resource program for maintenance of stormwater infrastructure. The Assessment Report also provided recommendations for stormwater management practices at Ulster County Highway substations. Ulster County received a CWC stormwater retrofit grant in 2006 for the purchase of a Hydro-Vacuum Truck for use in conjunction with the implementation of the Ulster County Stormwater System Maintenance Program to prioritize infrastructure maintenance based upon current sediment loads as detailed in the Assessment Report. The Assessment report also recommended a future investigation into sediment source characterization from upland areas.

In 2006, CWC stormwater retrofit projects were approved for the Town of Hurley Highway Facility/Transfer Station and for the Hamlet of Boiceville in the Town of Olive. In 2007, stormwater retrofit projects were approved in the Town of Hurley for Glenford-Wittenberg Road and the entrance road to the Bristol Hill subdivision.

To date, the Stormwater Retrofit Program has approved funding for the five proposed projects within the Ashokan Basin, committing a total of $1,427,389. Table 3.2 summarizes these projects. It should be noted that only the Boiceville project falls within the Esopus watershed and would have a potential impact on turbidity delivered to that stream. Heightened or more expansive implementation of the Stormwater Retrofit Program may provide a benefit in turbidity reduction but is unlikely to impact the need to initiate alum use.

Table 3.2. Stormwater Retrofit Program Projects in the Ashokan Basin.

Funding Year	Applicant	Project Area	Project Description	CWC Funding
2005-06	Hurley (T)	Hurley Landfill	Deep Sump Catch Basins	$235,321
2005-06	Ulster County	Ulster County	Purchase vacuum truck	$275,000
2005-06	Shandaken (T)	Hamlet of Boiceville	Deep sump catch basins/ Stormtech	$581,400
2007	Hurley (T)	Glenford-Wittenberg Rd	Catch basins and ditch stabilization	$224,782
2007	Hurley (T)	Bristol Hill Subdivision	Catch basins and ditch stabilization	$110,886

3.4. 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. LAP is further described in the MOA and the 2002 and 2007 FADs. This program has the potential for protecting the water quality by prevention of future additional sediment loading and is therefore considered here as a potential protection program. Between 1997 and 2007, the City committed over $250 million to acquire vacant land or conservation easements in the NYC water supply watershed that contain streams, wetlands, floodplains and other areas that are critical to maintaining high water quality.

As of 1997, NYC owned 5,272 acres of buffer land surrounding the Ashokan Reservoir, while approximately 83,891 acres were protected by NYS and other such entities (Figure

3.1). In a drainage basin (excluding the reservoir) which is roughly 155,299 acres in size, protected lands as of 1997 thus represented 57% of the basin. The Land Acquisition Program has been soliciting and acquiring lands in the Ashokan basin since 1999. To date DEP has secured 8,050 acres in fee simple and 2,179 acres under DEP conservation easements. The City's new acquisitions in Ashokan include 636 acres of stream buffer, the area within 300 feet either side of a stream. In all, 64% of the basin is now protected through public ownership, making the Ashokan Basin the most protected of all the basins in the Catskill-Delaware watershed. Heightened or more expansive implementation of the LAP (a protection program) is not expected to provide turbidity reduction but is likely to help minimize future development that can contribute to landscape turbidity sources.

3.5. 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 1997, 2002, and 2007 FADs. 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. This program has the potential for reducing suspended sediment loading from stream channel sources and is therefore considered here as a potential turbidity reduction program. 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 in the Ashokan Basin have been developed for the Upper Esopus Creek mainstem (CCEUC, 2007), the Stony Clove Creek (GCSWCD, 2004), and the Broadstreet Hollow Creek (UCSWCD, 2003) (Figure 3.2) representing 39% of the Ashokan watershed. These stream management plans present the assessment and findings of stream corridor conditions and propose recommendations to address flooding and erosion, water quality, aquatic and riparian ecosystem function, recreation, and management coordination. Recommended actions include further assessment if necessary, updating floodplain maps, improving riparian buffers, implementing small-to-large scale stream restoration projects, re-sizing bridges and culverts, and proactive education and outreach to inform stakeholders on how streams function in this landscape and what are the best approaches to "managing" them.

The SMP is a program that emphasizes engagement with multiple stakeholders (water supply managers, streamside property owners, anglers and other recreationists, local and state highway maintainers, and environmental/water quality advocates) involved with streams to address multiple management objectives. Quite often these multiple objectives are "overlapping" and certain management recommendations and/or actions address multiple issues. For instance, advocating an approach to stream bank stabilization that is based on natural channel design (NCD) principles, rather than just hardening the bank with rock rip rap, considers the needs of the aquatic ecosystem, the recreational use of a stream reach, and encourages diverting erosive force away from the channel margin and toward the channel thalweg. By working with natural stream process and recognizing the importance of flood plain connectivity this method can minimize erosion that can contribute to suspended sediment loading.

The NCD 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 (DEP, 2006a).

This approach has been extensively applied by DEP and the Greene County Soil and Water Conservation District (GCSWCD) in the Schoharie Basin (DEP, 2007). As of 2007, there have been three such stream restoration projects in the Ashokan Basin intended to address channel instability and water quality (Table 3.3).

Table 3.3. DEP Sponsored Stream Restoration in the Ashokan Basin

Restoration Project	**Year Completed**	**Stream**	**Length (ft)**
Broadstreet Hollow	2001	Broadstreet Hollow	1,100
Lanesville	2004	Stony Clove	1,700
Esopus at Woodland Valley	2003	Esopus Creek	1,000

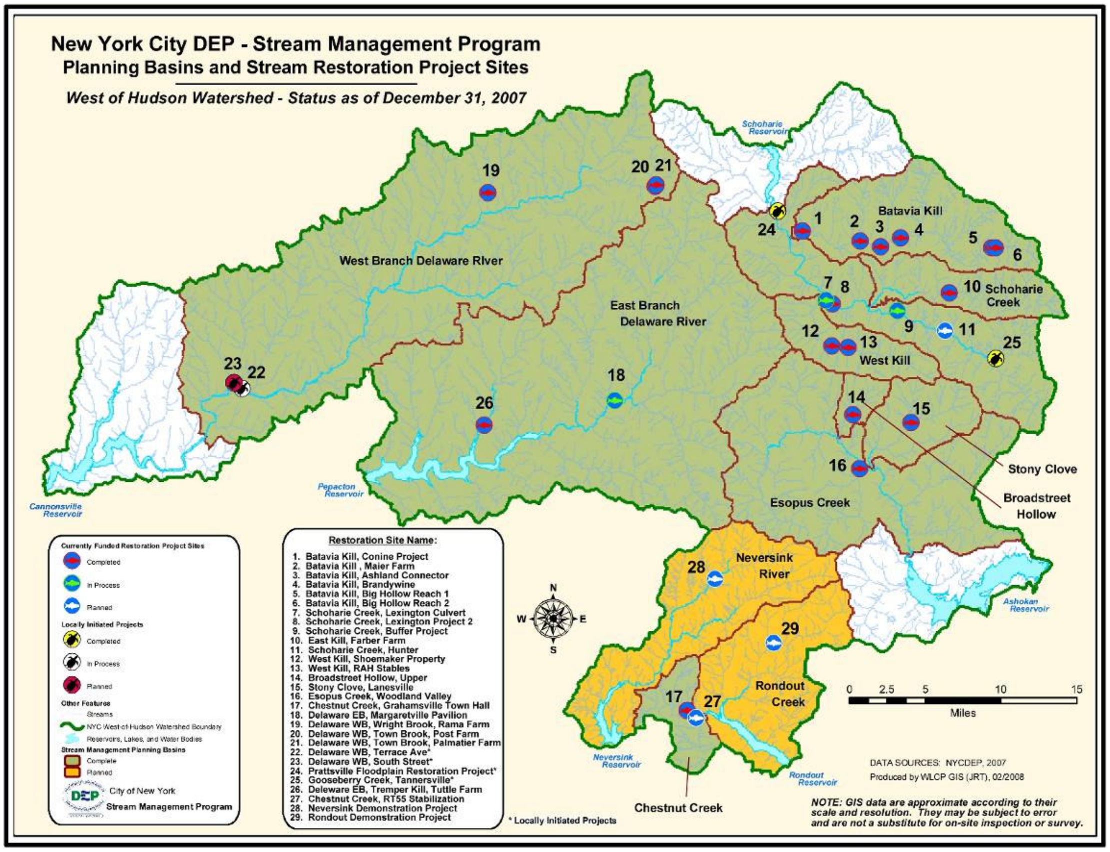


Figure 3.2. Stream Management Planning Basins and Restoration Project Locations

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.

With the exception of the Broadstreet Hollow restoration project, project selection has not specifically targeted reduction of sediment loading as a primary goal, though reduction of sediment loading has been included in each case as a reason for DEP support. For instance the Esopus Creek at Woodland Valley demonstration site was chosen because several residential properties were under imminent threat from excessive erosion into glacial till (Figure 2.9), as a visible site for education/outreach purposes and as training SWCD in natural channel design techniques (Figure 3.3). The project did include removing the channel from a large exposure of glacial till and lake clay that episodically contributed to turbidity. Similarly, the Stony Clove at Lanesville project and the Broadstreet Hollow project dealt with significant channel instabilities in addition to excessive sediment loading.

Uniquely, the Broadstreet Hollow project was designed to deal with a "mudboil" that was a continuous source of suspended sediment at low flow conditions. The Broadstreet Hollow stream management plan details the project history (UCSWCD, 2003). In each of these three projects DEP and our county partners have had to spend additional resources on extensive repairs following adjustments after floods. Ultimate success in this technique relies on the establishment of a protective riparian zone along the stream which can take many years to accomplish. In these mountain stream valleys, vulnerable channels are susceptible to adjustments in channel form and functioning condition.

With respect to turbidity source areas, project teams in assessed Ashokan sub-basins (the Esopus Creek, Stony Clove and Broadstreet Hollow) have undertaken a field-based, headwaters-to-mouth, stream assessment and data gathering process. The stream assessment data collected includes, among other things, fine sediment sources, 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 2.6).


Figure 3.3. Esopus Creek at Woodland Valley Restoration Demonstration Project. The photo was taken one year after completion.

4. Watershed Management Recommendations

The 2007 FAD commits DEP to a continued engagement with the set of programs described in Section 3. These programs have successfully addressed 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 reduce turbidity levels in the Ashokan Reservoir nor the need for alum additions to the Catskill Aqueduct. DEP believes some of 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 Ashokan Reservoir watershed, at least in low to moderate flow conditions. Two key components of the turbidity problem – essentially the geology and hydrology of the watershed – cannot 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 objective of this report is essentially an evaluation of the potential turbidity reduction benefits of increased or focused funding and implementation of upland landscape-based programs and projects (whole farm, forestry, willing seller land acquisition, conservation easement programs, storm water retrofit) and stream-based programs and projects (stream corridor management and storm water retrofit programs). Since the overwhelming majority of turbidity inputs into the Ashokan Reservoir are derived from in-stream rather than upland landscape sources, the greatest opportunity for reducing such turbidity in the long-term is enhanced implementation of the Stream Management Program, and secondarily the storm water retrofit program. On the other hand, the opportunity for turbidity reduction through upland landscape-based programs is very limited, as detailed in the similar study for the Schoharie Basin (DEP, 2007).

This section of the report assesses the potential benefits of heightened or more expansive implementation of those programs planned for the next 5 years that have a reasonable potential for achieving some reduction in turbidity in the Ashokan Reservoir watershed.

4.1. Management Strategies for Upland Landscape Turbidity Sources

Given that the landscape in the Esopus Creek watershed (principal source of suspended sediment) is at least 95% forested (DEP, 2005) and significantly protected by NYS and NYC ownership, enhancing the programs affecting upland areas beyond the 2007 FAD commitment will not achieve measureable turbidity reduction at the watershed scale or eliminate the episodic need for alum use.

<u>Watershed Agricultural Program</u>. The 2007 FAD includes continued commitment to the Watershed Agricultural Program, though application in the Ashokan Basin is expected to be limited given the minimal agricultural land use.

Watershed Forestry Program. The 2007 FAD commitment to enhancing the Watershed Forestry Program will have a positive impact on maintaining the viability of forests, the predominate land use in the Esopus Creek watershed and the entire Ashokan Basin.

Stormwater Retrofit Program. As indicated in Section 3, 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 Ashokan Basin only approximately 1% of the area is impervious (~90% is forested). As a result, the opportunity presented by the Stormwater Retrofit Program for turbidity reduction in the Ashokan Basin is marginal.

Notwithstanding the marginal upland-sourced 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

DEP encourages use of the CWC Planning and Assessment Program to follow through on additional assessment recommendations made in the Ulster County Watershed Storm Water Infrastructure Assessment Report (EMC, 2006).

DEP and CWC will continue to seek opportunities through the Stormwater Retrofit Program to work with Ashokan 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.

Land Acquisition Program. 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 land use 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 has committed to make $300 million in land acquisition funding available during the current FAD period. 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 Ashokan 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. The substantial funding enhancements to the Land Acquisition Program called for in the 2007 FAD will allow DEP to significantly increase solicitations in the Ashokan Basin. This will result in additional protected acreage which will prevent future land use changes that might otherwise impact water quality.

4.2. Management Strategies for Stream Channel Turbidity Sources

Potentially, the most effective management strategies for reducing turbidity in the Catskill watershed address in-stream sources of suspended sediment. The Stream Management Program is the principal program that can help reduce stream-sourced suspended sediment loading to the Ashokan Reservoir. The Stormwater Retrofit Program which deals with both landscape and stream-sourced sediment (by reducing runoff impacts to stream channels) can also have an incremental role in achieving some level of turbidity reduction by mitigating erosion potential of storm water runoff. Recommendations for implementation to the Stormwater Retrofit Program are discussed in the preceding section.

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, increasing education and outreach efforts to encourage adoption of better management practices and stream stewardship, and technical and material support to both public and private channel management efforts. Proposed components of the SMP and related efforts that may yield turbidity reduction benefits are discussed below.

<u>Stream Restoration Projects</u>
The potential turbidity 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 future restoration projects by optimizing site selection based on a focused analysis of the relative turbidity contributions from different stream segments. As stated in Section 2.2, we know that the sources of fine sediment that cause turbidity are not homogenously distributed throughout the watershed. We therefore suspect that certain sub-basins may be 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. At this time, it appears that the Stony Clove sub-basin remains the largest contributor to Esopus Creek following large runoff events. The creek continues to run turbid long after the runoff event has ended. We also know, that the reaches of the Stony Clove creek that contribute a disproportionately large amount of suspended sediment occur along a stretch that is less than a mile long in the vicinity of the hamlet of Chichester. This would be a likely first place to evaluate whether stream restoration is a feasible solution to reducing suspended sediment loading at low to moderate flows. 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. DEP has committed up to $2.1 million dollars in a contract with Ulster County Soil and Water Conservation District

(UCSWCD) dedicated to implementing best management practices in stream restoration/stabilization projects.

DEP is using the "Conine" restoration project on the Batavia Kill (in the Schoharie Basin) completed in 2007 as an opportunity to evaluate the reach and sub-basin scale impacts of stream restoration on turbidity reduction. Per the 2007 FAD, DEP will complete a special monitoring study in 2012 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. 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 entire Catskill watershed. Ultimately, information gleaned from this project should help DEP be more effective and cost-efficient in reducing sediment and turbidity in watershed streams.

An additional component in restoration projects that can potentially alleviate erosion-caused turbidity is to seek opportunities to reconnect the stream channel to a functioning floodplain. Ideally, a functioning flood plain serves to reduce in-channel excess shear stress that can erode stream banks and beds. This may help to reduce suspended sediment loading as a consequence of reduced erosion rates. DEP and the County partners will seek opportunities to demonstrate this restoration practice. The first step, however, is to get better information on the current state of the watershed floodplain.

<u>Improved Floodplain Protection</u>

DEP strongly supports promoting a revision to the existing and out-of-date floodplain flood insurance rate maps (FIRMs). These maps are used by communities to identify areas suitable, or not suitable for development. Significant geomorphic adjustments since the last flood maps were produced have significantly diminished their value. Keeping the stream channel hydraulically connected to the floodplain wherever this is achievable is a priority management strategy advocated in the existing stream management plans. As part of the 2007 FAD effort, DEP has earmarked ~$7 million dollars for revision of flood studies to produce new FIRMs within the NYC water supply watershed. The Esopus Creek watershed is a priority basin in this effort. In addition to helping to fund revised flood studies, DEP is also planning to procure new remote-sensed data that will improve characterizing the stream channel corridor's flood conveyance capacity. In particular, enhanced resolution of watershed topography through LiDAR and new digital orthophoto imagery will help identify changes in landscape and land use / land cover patterns since 2001.

Suspended Sediment Research

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 contribute more than do the headwater reaches. Their 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. As a result of this heterogeneity of bed and bank area available for entrainment, 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.

This heterogeneity translates into uncertainty regarding the potential effectiveness of enhanced implementation of stream management practices. Ongoing research into the relationship between channel geology and 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. The following planned efforts will help in reducing some of this uncertainty.

- DEP is pursuing an Agreement with the New York State Geological Survey (NYSGS) to remap the surficial geology of the Esopus Creek watershed. This collaborative project, funded by DEP, State and federal program funds will produce georeferenced data of the glacial geology that sources the fine-grained sediment causing turbidity. This work is expected to start in 2009 and continue through at least 2011. In addition to field mapping NYSGS will use borehole drilling and geophysical techniques to help map the three-dimensional distribution of these units. Such information can be very useful for modeling future contacts with the geologic units that yield suspended sediment.
- DEP will develop and implement enhanced water quality monitoring that will provide targeted sampling of suspended sediment and turbidity to assist in the development and evaluation of stream management plans addressing these issues.
- DEP is investigating the feasibility of using models to better understand sources and transport of suspended sediment in the Catskill watershed. To that end DEP is hosting a sediment transport modeling workshop in July to explore modeling options.

It should be noted that these research programs are not required by the 2007 FAD or the SPDES permit.

Ashokan Basin Stream Management Program

In addition to stream restoration projects, improved management practices advocated by DEP's SMP can provide additional reduction in suspended sediment loading. DEP and our contract partners in the Ashokan Basin 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. DEP has recently completed negotiating Agreements with Cornell Cooperative Extension of Ulster County (CCEUC) and UCSWCD to implement recommendations in existing stream management plans and expand stream management planning for the Ashokan Basin. The CCEUC Agreement was registered in June, 2008 and the UCSWCD Agreement is expected to be registered in the fall of 2008. The two contracts totaling ~$8 million to develop and implement an Ashokan Basin stream management program include:

- Staffing
- $2 million stream management plan implementation fund
- $2.5 million for stream BMPs and a riparian buffer enhancement program
- Progressive Education & Outreach program

It should be noted that of these commitments, only the $2 million for local implementation and the $2.5 million for stream restoration and the riparian buffer program are required under the 2007 FAD. The remaining ~$3.5 million represents additional commitments in the Ashokan basin for stream management programs, as part of a long-term investment in supporting stream stewardship.

Annual stream management action plans will be developed by the contract partners and an advisory council to help guide assessment and implementation. Aside from continued stream geomorphic condition assessment and targeted treatment, the Ashokan Basin program will use the following program components to help potentially reduce turbidity.

Highway Department Outreach

DEP is committed to working with the various highway departments and private landowners to help reduce 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 set of stakeholders.

Article 15 permit DEP/DEC Coordination

Emergency flood response is another situation that can lead to further destabilization of the stream system. The demand for Article 15 permits to respond to flood damage is tremendous. 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 stream work has set in motion channel instability processes such as headcuts that have undermined channel stability in nearby stable reaches. The destabilized streams increase the likelihood of incision or erosion into the geologic sources of fine-grained sediment. 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 Esopus Creek watershed 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.

Streamside Assistance Program

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 and fostering an improved streamside stewardship, which should, progressively, over time reduce erosion rates at a local and sub-basin scale. An additional $400,000 in the UCSWCD Agreement has been earmarked for this program to enhance/improve riparian buffer integrity along streams in the Ashokan watershed. In addition to the implementation funding level of $400,000, DEP funding will enable UCSWCD to hire a full time SAP Coordinator for the Ashokan Basin.

Public Education and Outreach

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 (CCEUC, 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 DEP believes such work provides an important investment in watershed protection.

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 all of these components of the DEP 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 expanded under the 2007 FAD anticipated the need to address turbidity in the Ashokan watershed. No additional expansion of the SMP beyond these commitments is proposed at this time.

5. Summary

This report describes what we know and can estimate about conditions resulting in elevated turbidity in the Ashokan Reservoir that leads to alum treatment and details what commitments DEP is making to develop and implement management strategies that aim to potentially reduce such turbidity.

Alum treatment is generally initiated in response to large stream runoff events in the Esopus Creek that transport large quantities of highly turbid water into the Ashokan Reservoir. The sources of this turbidity are mainly from in-stream processes including erosion of layered glacial lake silt/clay deposits in stream banks and beds, stream adjacent hill slope failures of glacial deposits following high flow conditions, and re-suspension of fine grained stream bed material. Upland landscape erosion sources represent a much smaller source for suspended sediment. Since the vast majority of land use in the Esopus Creek watershed is forested, these upland landscape sources are already largely minimized. In addition, the Shandaken Tunnel also contributes a small percentage of turbidity to the Ashokan Reservoir, but this source is not a factor in the episodic need for alum treatment.

Many of the watershed management and protection programs in place in the Ashokan Reservoir Watershed are valuable and may help to reduce localized turbidity conditions. These programs, in general, are not likely to significantly reduce turbidity on the watershed scale during the highest flow events that impact the use of alum.

The upland landscape-based programs have helped, and can continue to help, reduce runoff contact and delivery of sediment to the streams. A properly graded logging road, 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. However, these programs are unlikely to have a significant impact during the major storm events that substantially affect the reservoir water quality. Through the acquisition of property and conservation easements, DEP can prevent new land uses that have the potential to exacerbate terrestrial contributions of turbidity in the Ashokan watershed, but these programs will not reduce current turbidity levels.

The Stream Management Program has the greatest possibility of producing an impact on reducing delivery of turbid water to Ashokan Reservoir by potentially reducing in-stream 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 removed from the geologic fine sediment source, although fine-grain sediment in the stream bed material will persist. In other cases, the stream erosion is into a massive hill slope composed of 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. DEP believes that the Stream Management Program effectiveness can be enhanced by emphasizing coordinated response to flood events to minimize subsequent damage, investing in protecting and improving riparian buffers, and extending the current state of knowledge on best stream management practices to all who "manage" streams.

In the past decade, DEP has implemented and funded extensive activities in the Ashokan basin, including but not limited to:

- The Stormwater Retrofit Program has funded five projects within the Ashokan watershed for a total of ~$1.4 million dollars.
- The Watershed Forestry Program has facilitated more than 40 completed forest management plans covering ~7,100 acres and more than two dozen road BMPs projects.
- The Land Acquisition Program has purchased 8,050 acres and protected over 2,000 acres through DEP conservation easements – bringing the total protecting land thru public ownership up to 64%.
- Stream management plans have been developed for the Upper Esopus Creek, Stony Clove Creek and Broadstreet Hollow Creek – representing 39% of the Ashokan watershed. .
- Stream restoration projects have been completed on 3 stream reaches for a total of ~3,800 linear feet.

The recently issued 2007 FAD includes a sustained and well-funded commitment to the watershed management programs discussed in this report with the intention of maintaining and enhancing water quality. In addition to the continuation of many successful programs, the 2007 FAD also contains many new initiatives for watershed protection. Some of these programs, such as stream restoration projects, may occur in the Ashokan watershed but at this time that level of detail is not available.

However, specifically in the Ashokan basin, DEP is committing to the following activities and funding levels above and beyond the specific requirements in the 2007 FAD and CAT IC SPDES permit:

- DEP has committed an additional $1.647 million, above and beyond the $2 million for local implementation, in the CCE contract to support staffing, providing a local office in the watershed and stream management education and outreach activities in the Ashokan basin.
- DEP is contracting with the Ulster County Soil and Water Conservation District for a total of $4.4 million dollars for stream management planning and implementation in the Ashokan basin. The total contract includes investments of $250,000 for expert consultants, $47,000 for training and $1.4 million to provide adequate staffing and equipment to run a technical stream management program. DEP firmly believes that our investment toward building local capacity by providing this type of funding is important to the long term success of the stream management program.
- DEP is contributing $100,000 toward a collaborative project with the New York State Geological Survey to remap the surficial geology of the Esopus Creek watershed. This information may be very useful for identifying turbidity sources in the Ashokan Basin.

6. Implementation Schedule

Given the issues presented herein, DEP is proposing the following initiatives:

Activity	***Implementation Schedule***
Implement recommendations in the Stream Management Plans completed in the Ashokan Basin via contracts with CCEUC and UCSWCD.	Ongoing, based on annually updated Action Plans developed in concert with local county partners and a watershed advisory council. $2M implementation fund expected to be available for local grants by December 31, 2008. An additional $2.1M is specifically available for stream stabilization BMPs. These funds are expected to be available by December 31, 2009.
Provide technical and financial support to riparian landowners to enhance buffers	Ongoing per UCSWCD contract with DEP. Streamside Assistance Program guidelines expected to be fully in place by December 31, 2008 with implementation beginning in 2009. $400K has been provided for the first five years.
Use functional floodplain restoration as a feature of stream management project selection.	Ongoing per UCSWCD contract with DEP
Expand stream corridor assessment to key tributaries in Ashokan Basin	As per the current Action Plan, Woodland Valley watershed is to be assessed in 2008; Birch Creek and Beaver Kill in 2009; Additional tributary watersheds will be identified for assessment in subsequent Action Plans
Review and revise, as appropriate, Addendum A of the 1993 DEC/DEP MOU as it pertains to review of Article 15 Stream Disturbance Permits	June 30, 2009
Suspended sediment transport modeling workshop to explore feasibility of modeling as a tool for predicting sediment entrainment, transport and delivery to Ashokan Reservoir.	July 7-9, 2008
Suspended sediment geologic source characterization through mapping the surficial geology of the Esopus Creek watershed.	DEP and NYS Geological Survey are working to have a contract in place for work to commence in 2009.

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