UPPER ESOPUS CREEK MANAGEMENT PLAN

Volume III

Watershed and Stream Characterization

Looking east down the Upper Esopus Creek valley from the Hamlet of Shandaken, NY. December, 2005

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Acknowledgments

There are many contributors to this Volume. Dan Davis (DEP) and Craig Fischenich (ERDC) are the primary authors for Sections 1 – 3.2. Walt Keller (CCE) authored Section 3.3. The following individuals provided key contributions to the document.

DEP

- Stream management program staff
  - Beth Reichheld, participated in the development of this effort since its inception and helped compose and review each of the Volumes of the Management Plan
  - Sarah Miller and Mark Vian helped compose and review Sections 2.6 and 3.1. Mark also wrote the section on global climate change in Section 2.3.
  - Phil Eskeli helped write Section 3.2 and worked with Barry Vittor and Associates, Inc. (BVA) on verifying the riparian corridor composition assessment.
  - Jenn Grieser helped write Section 3.2 and reviewed much of Volume II
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  - Susannah Erwin, an SCA intern (now a graduate student in fluvial geomorphology at Utah State University) completed the Phase 1 geomorphic assessment documented in Section 3.1 and Appendix C for her internship with DEP.
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1.0 INTRODUCTION

Photo 1.1 Inventorying stream erosion, damage to infrastructure, and woody debris along Upper Esopus Creek. October, 2005

Volume III presents the assessment and a preliminary diagnosis of Upper Esopus Creek necessary to address the planning goals and lead to the recommendations presented in Volume I. Using available information and collecting new data, the Project Team characterized and inventoried features of the watershed setting, geology, hydrology, water quality, stream channel, riparian corridor, and aquatic ecology conditions (**Photo 1.1**). A tiered, or multi-phased approach was used for assessment, starting at the watershed scale and then refining focus to the corridor and stream channel scale in three successive phases. In conjunction with this natural resource assessment, we also assessed the community and water use aspects of the watershed as presented in Volume II.

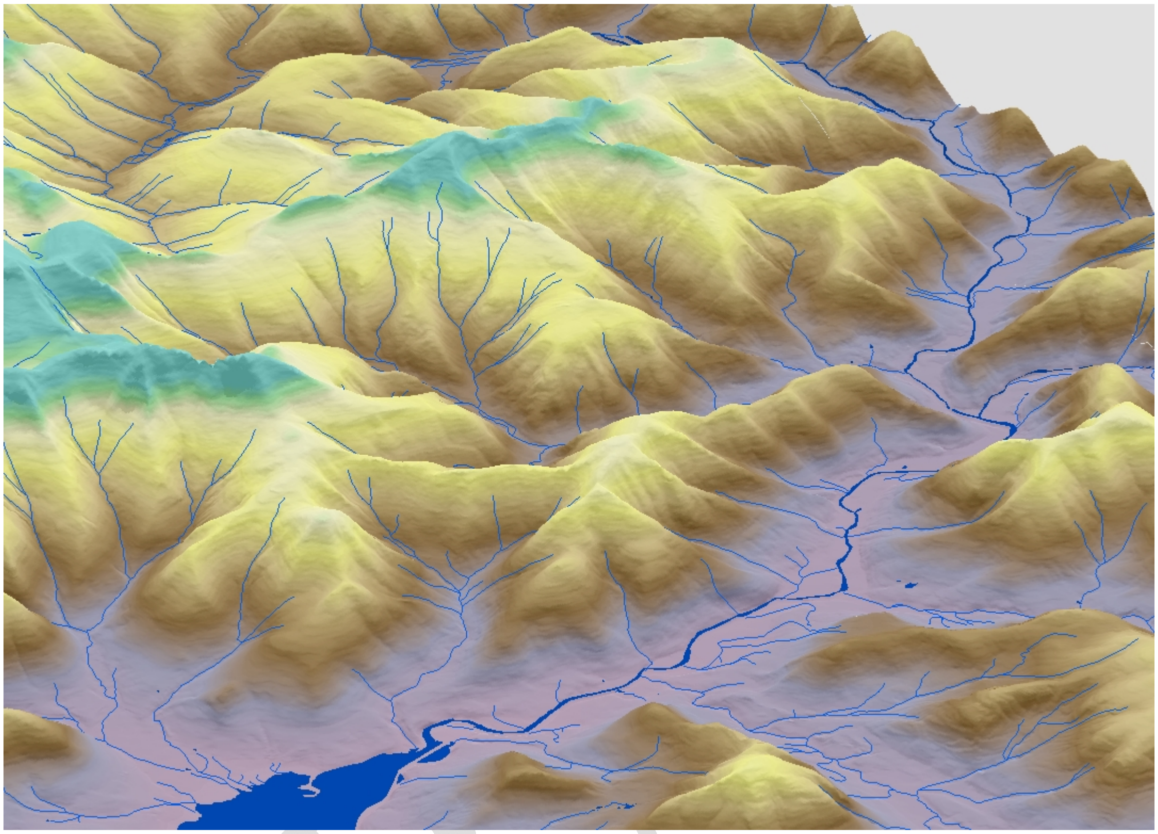
The Sections below will be reasonably detailed and assume basic knowledge of watershed and stream science. A “primer” on stream form and process (“fluvial geomorphology”) is attached in **Appendix A – Introduction to Stream Processes**. There is going to be a tedious amount of detail for some and an insufficient amount of detail for others. Additional resources are listed and briefly annotated in Section 4 for those seeking more detail. There are several appendices that contain additional information and other resources. All maps that are referenced in the text in bold (e.g. **Map 2.1**) are located in **Appendix B**.

As with any assessment of this scale in this timeframe, it is likely to be incomplete. There are the following limitations to consider:

- There is a lot more information available than could be included in this report. The bibliography is a good starting point for more information.
- The stream corridor assessments are limited primarily to Upper Esopus Creek, with some observations within the first few hundred feet of several of the tributaries. All the tributaries require further assessment to attain a more comprehensive assessment of the Upper Esopus Creek watershed.
- The stream flow conditions below the Shandaken Tunnel during the period of investigation often precluded safe (or even possible) wading for the stream reach and site scale assessments described in Section 3.1. A "float" in a kick-boat from Phoenicia to just above Boiceville was necessary to make in-stream observations. Helicopter flyovers and windshield surveys were also used to help with the reconnaissance of the lower reaches of the Creek. Still the detail for these reaches is considerably less than for the reaches above Phoenicia.
- Modeling developed for this assessment and presented in Section 3.1 is considered provisional.

We used the simplistic diagnostic premise that if there are multiple occurrences of a given condition over a broad area, it is reasonable to hypothesize that the condition is systemic rather than an isolated incidence. We applied this premise to both good and poor conditions. We did this because distinguishing systemic conditions from isolated conditions is necessary to guide appropriate management. If for example, stream bank erosion is a systemic problem caused by some watershed condition rather than a localized phenomenon, then localized stream bank stabilization is likely to fail. Likewise, if the cause for erosion is localized to a given reach then site-specific treatment is appropriate. This Volume presents a series of assessments that are a first step in developing a long-term assessment and monitoring program to guide management priorities of Upper Esopus Creek.

2.0 UPPER ESOPUS CREEK WATERSHED DESCRIPTION



Digital Elevation Model (DEM) of Upper Esopus Creek watershed (J. Tuscanes, DEP)

The purpose of this Section is to provide the reader with sufficient background information on the Upper Esopus Creek watershed physical setting, climate and how the landscape is covered and used by the people who live there. Detailed information on the watershed and stream corridor geology, hydrology, and water quality is also included. This information is necessary for setting the geographic context for the Creek and identifying important landscape scale conditions that influence it. The interested reader is referred to the bibliography in Section 4 for sources that go into more detail.

2.1 Regional Setting

The Upper Esopus Creek watershed covers a 192 mi^2 area in the South-central Catskill mountain region of southeast New York State (**Figure 2.1**). The entire 26 mile course of the creek flows "clockwise" in a sweeping arc from the headwaters at Winnisook Lake on Slide Mountain to the Ashokan Reservoir through the Ulster County Towns of Shandaken and Olive (**Figure 2.2**).

NYS Route 28 runs alongside ~13 miles of Esopus Creek from Boiceville to Big Indian as a major east/west artery connecting Kingston, NY with the Western Catskills. The Upper Esopus Creek valley is a popular tourist destination as discussed in Volume II.

The entire Upper Esopus Creek watershed falls within the Catskill Park with 58.5% of the land designated as state owned forest preserve. A detailed discussion on the history of the Catskill Park can be found in the recent book: **The Catskill Park: Inside the Blue Line, the forest preserve and mountain communities of America's first wilderness** (Van Valkenburgh and Olney, 2004).

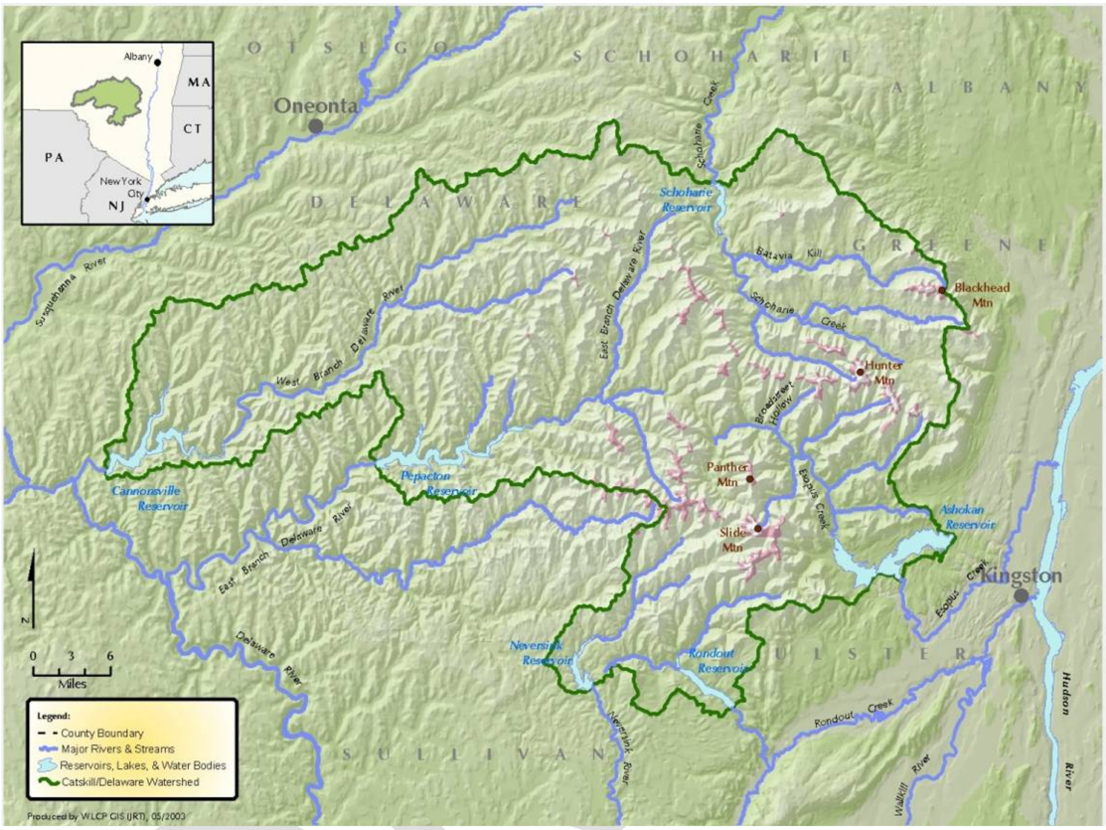


Figure 2.1 Catskill Mountains and NYC Water Supply West of Hudson Watershed

2.2 Physical Description

2.2.1 Physiography

Physiography refers to the natural features of the earth's surface – essentially the "look" of the land. Land is separated into different physiographic provinces based on similarity in geology, landscape structure, and climate that lead to a unified geomorphic history. The Upper Esopus Creek watershed is located in the eastern portion of the Alleghany Plateau physiographic province, which is the northern portion of the Appalachian Plateaus that extend from southern New York to central Alabama (Isachson, et al, 2000).

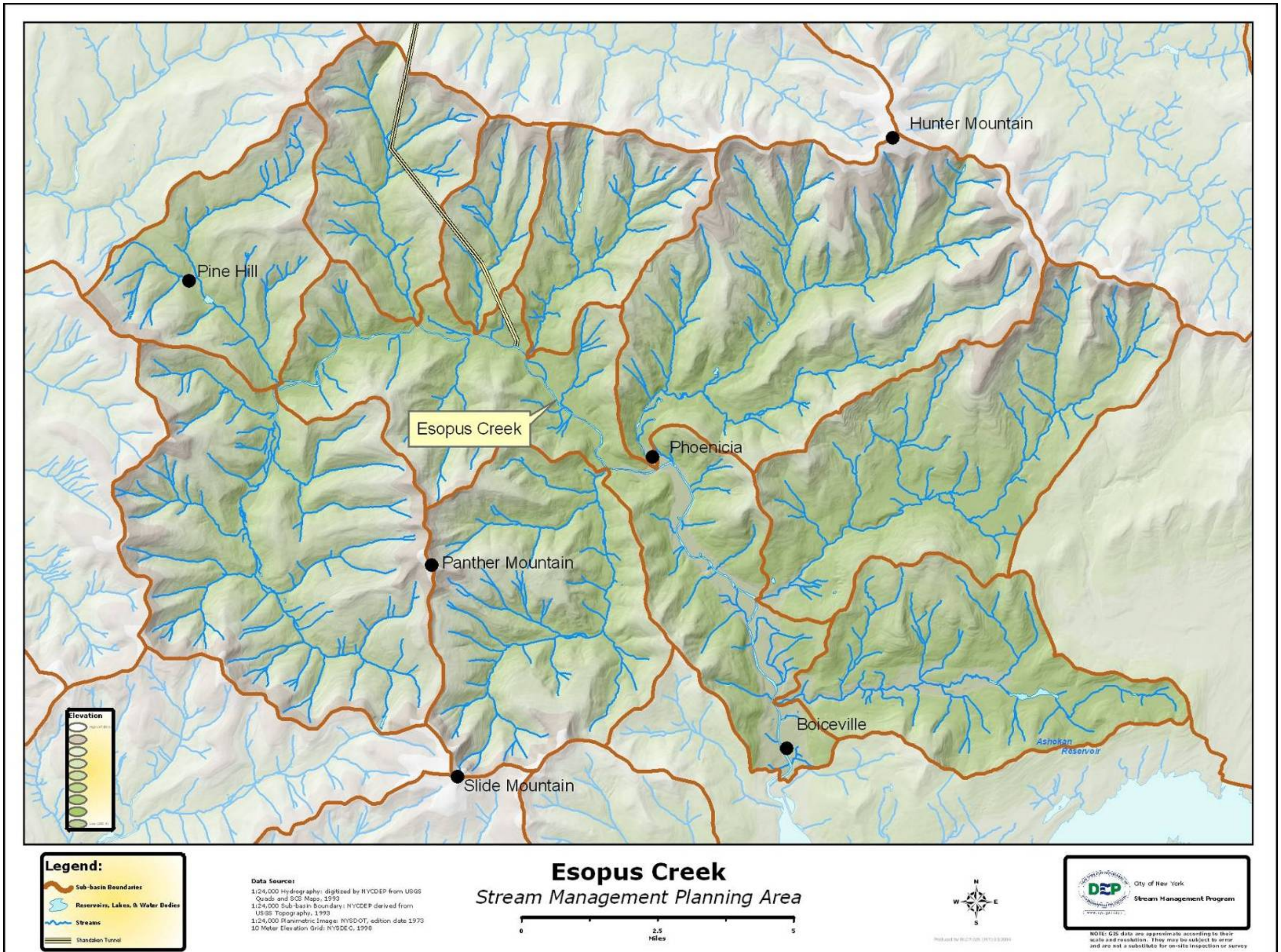


Figure 2.2 Upper Esopus Creek Stream Management Planning Area

The Catskills are only structurally a plateau, having been eroded by stream action over millions of years into what is today a region of high relief. Small, narrow valleys (or hollows) cut through the resulting mountains. The older, flat-lying surface is evident in the pattern of hilltops all tending to reach the same elevation. Such an eroded plateau is known as a dissected plateau. (**Photo 2.1**). The plateau was dissected by hundreds of millions of years of stream erosion and repeated glaciation in the last 1.6 million years.

Photo 2.1 Northwest view of Upper Esopus Creek watershed and central Catskill Mountain escarpment from Ashokan Reservoir

A unique physiographic feature of the Esopus Creek watershed is the circular drainage pattern that forms the base of Panther Mountain (**Figure 2.2**). This is discussed further in Section 2.5.

Upper Esopus Creek and its tributary network drain the most rugged terrain in the Catskill Mountains. There are 21 peaks greater than 3000' feet above sea level (ft asl) that are drained by this network (**Figure 2.2**). Among them is Slide Mountain, the highest peak in the Catskills at 4,120 ft asl. The base elevation in the watershed at Ashokan Reservoir is 633 ft asl. The resulting streams are steep erosive forces as water and sediment make the quick descent from mountain top to the base of the watershed at the reservoir.

2.2.2 Stream Network

There are 9 "main" perennial tributaries from Big Indian to Boiceville and many smaller perennial and intermittent streams that join the creek in a trellised pattern before it enters into the Ashokan Reservoir (**Figure 2.2**; **Table 2.1; Map 2.1**). The watershed includes at least 330 miles of stream, including the 26 miles of Esopus Creek.

Starting at the top of the watershed, Esopus Creek originates from Lake Winnisook at the divide between the Esopus and Neversink drainages. A similarly sized, unnamed tributary crosses CRT 47 about 0.5 miles below the NYSDEC Giant Ledge parking area and joins Esopus Creek, approximately doubling its watershed area. As the stream steeply descends this tight valley through a series of water falls and boulder steps it is joined by several "unnamed" tributaries. As Esopus Creek flows north through the broader valley of Big Indian Hollow, 5 larger tributaries draining the flanking mountains join the stream, such as McKenley Hollow creek and Hatchery Hollow creek. The stream turns to the northeast at the confluence with Birch Creek. At Shandaken, Bushnellsville Creek joins and the stream turns toward the southeast until it reaches the Ashokan Reservoir. Along the way seven tributaries draining the high peaks, and the Shandaken Tunnel diverting water from Schoharie Reservoir feed the enlarging Esopus Creek. In descending order and identified as from the north (N) or south (S) side of the Esopus valley: Fox Hollow (S), Peck Hollow (N), Shandaken Tunnel (N), Broadstreet Hollow (N), Woodland Valley (S), Stony Clove (N), Beaver Kill (N), and Little Beaver Kill (N).

Table 2. 1 Upper Esopus Creek Tributary Sub-basins

Sub-basin (from DS to US)	**Watershed Area**[1] (sq. mi.)	**Stream Miles**[2]
Little Beaver Kill	16.7	33.8
Beaver Kill	25.5	46.0
Stony Clove	32.3	62.5
Woodland Valley	20.5	40.4
Broadstreet Hollow	9.3	19.0
Peck Hollow	5.0	11.3
Fox Hollow	NA	NA
Bushnellsville Creek	11.1	21.8
Birch Creek	12.6	25.1
Esopus Creek Headwaters[3]	30	68

[1] Sub-basin area calculations derived from NYCDEP GIS coverage subbas24woh. Values for Fox Hollow were not available (NA) as of 1/19/07.
[2] Stream miles calculated from NYCDEP GIS coverages stream24woh and water24woh.
[3] Esopus Creek Headwaters includes all tributaries upstream of Birch Creek.

Valley and Stream Slope

Figure 2.3 graphs the stream's slope from Winnisook to Ashokan Reservoir. The slope along Esopus Creek ranges from 13% in the cascading headwater reaches down through 3% – 0.5% as the stream descends to Boiceville. (**Photo 2.2**). The average slope, or gradient, for Esopus Creek along this course is 1.5%. Any stream with an average slope greater than 0.2% is classified as a mountain river or stream. This is significant because management of mountain streams is considerably different than for lower gradient streams given differences in stream condition.

Photo 2.2 Varying stream slope from headwater reaches to just above Ashokan reservoir

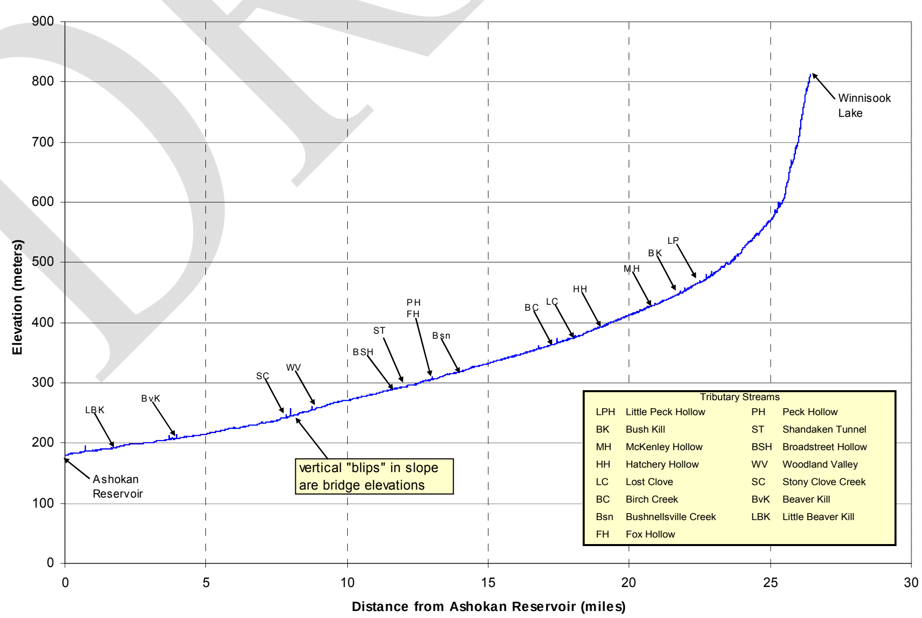


Figure 2.3 Longitudinal Profile (Slope) of Upper Esopus Creek using LiDAR and NYSDEC 10 meter DEM data

Valley Width

Figure 2.4 is a map that shows the Upper Esopus Creek valley's varying width and valley side slopes. All valley side slopes are steep to extremely steep. The valley bottom width varies but, as expected increases downstream, ranging averages of 44 meters in the headwaters up to around 740 meters in the lower reaches. With the exception of one unusual reach upstream of Bushnellsville Creek, the majority of the valley width ranges from 200 – 400 meters (**Photo 2.3**). Much of the variation corresponds to topographic features associated with the erosion and deposition of the last ice age (See Section 2.5.).

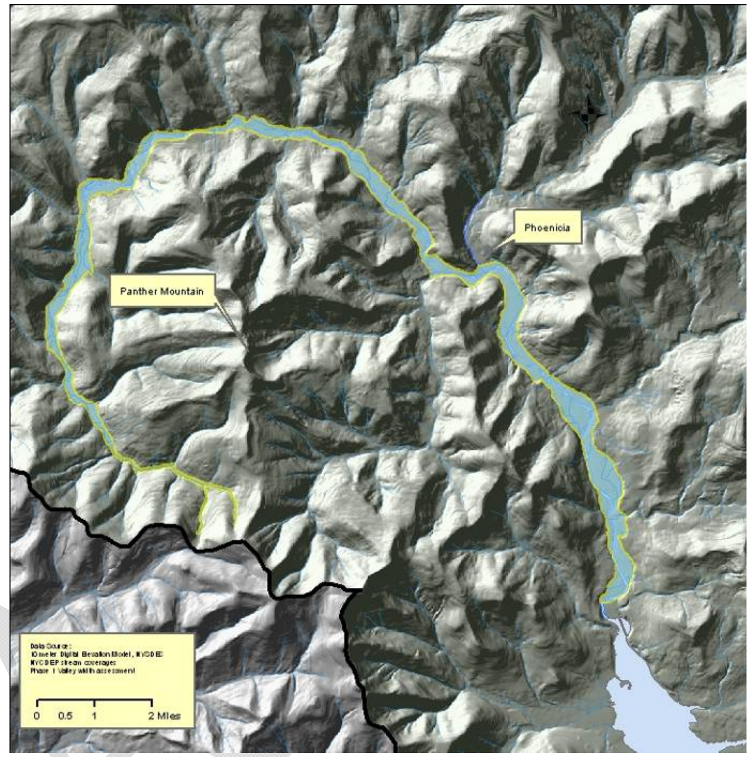


Figure 2.4 Upper Esopus Creek valley width

Photo 2.3 Valley width in the lower reaches of Upper Esopus Creek

2.3 Climate

Photo 2.4 View toward Belleayre Mountain from Mount Tremper, May, 2005

2.3.1 Catskill Mountain Climate

The climate, or the long-term weather pattern for a region delivers the water that the stream system conveys. The Southeast Catskill region, with its high relief/ high elevation stream-dissected landscape captures a lot of water (**Photo 2.4**). A map of precipitation prepared by Jerome Thaler for his book **Catskill Weather**, shows that there is a "bulls eye" of increasing precipitation amount around Slide Mountain (**Figure 2.5**). In fact the average rain fall measured at Slide Mountain is the highest for New York State. The amount, rate, and timing of water that the climate delivers to the landscape affect the size and type of streams that evolve to convey the range of water. This "bulls eye" of precipitation over Upper Esopus Creek watershed means the streams need to be larger than other streams with similar sized watersheds in adjacent areas to accommodate the larger volume of water.

Climatologists classify the Catskill region as humid continental. This means that cool, dry air masses move generally eastward throughout the year, and warm, humid maritime air masses from the south move northeastward during the summer (Lumia, 1991). The summers are cool, with relatively few hot days. Cold winter temperatures prevail whenever Arctic air masses flow southward from central Canada. Mean daily temperatures range from the low 20's (F) in winter to the upper 60's (F) in summer.

The climate delivers a lot of water to the Upper Esopus Creek watershed. Average precipitation increases from a regional 36 to 42 inches in the northwest to a high of 45 to 60 inches annually in the vicinity of the high peaks. This increase is largely due to orographic lifting. As air masses rise to higher elevations, they cool and their ability to hold moisture decreases causing more concentrated precipitation to fall in that area. Approximately 18% of the precipitation in the headwaters of the Esopus falls as snow (Murdoch 1991).

Mean annual precipitation for the Upper Esopus watershed ranges from 51.91 inches at Ashokan Reservoir to 63.61 inches at Slide Mountain. **Figure 2.5** shows the average annual rainfall distribution in the basin as presented in Thaler (1997). Average annual snowfall in the mountains (as recorded at the Slide Mountain weather station for 1971-2000) is ~100 inches. **Table 2.2** shows the monthly averages for precipitation for the period of 1971 through 2000. For comparison, the typical range of precipitation in the adjacent Delaware drainage basin is ~41 to 46 inches (DCSWCD, 2004)

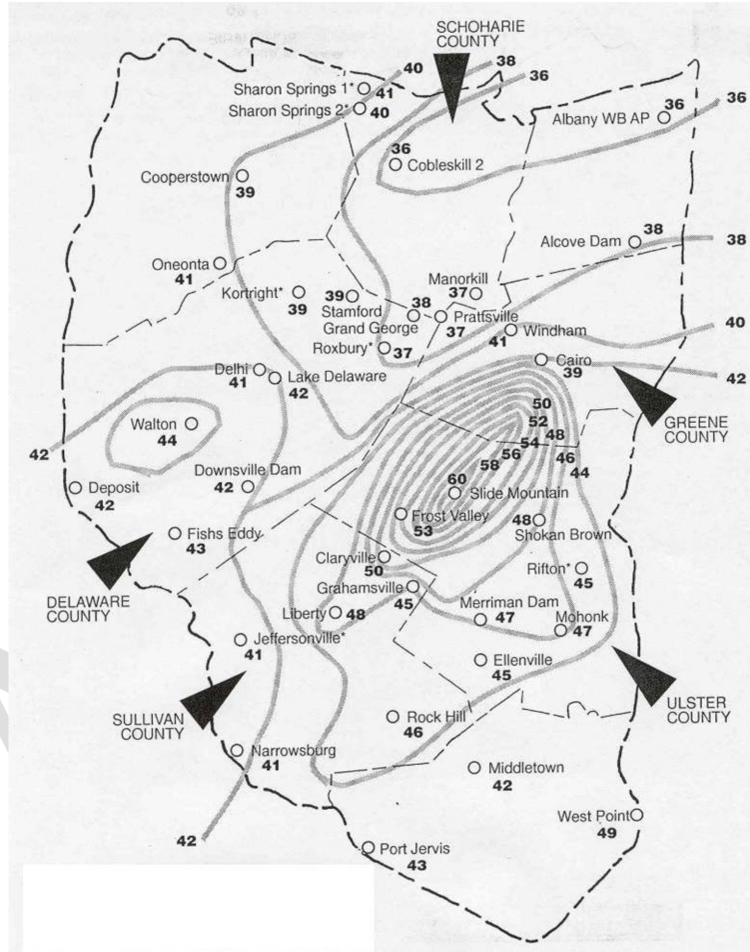


Figure 2.5 Average annual precipitation for the Catskill Mountain region (after Thaler, 1996)

Table 2. 2 Average Monthly and Annual Precipitation for Upper Esopus Creek Watershed

	Precipitation Normals (Inches)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
Slide Mtn*	5.30	4.24	5.52	5.25	6.03	5.55	5.10	4.86	5.40	5.32	5.90	5.14	63.61
Phoenicia	4.72	3.45	4.65	4.44	4.96	4.69	4.20	3.89	4.63	4.43	4.90	4.18	53.14
Shokan*	3.94	3.24	4.27	4.33	4.96	4.73	4.93	4.01	4.69	4.37	4.40	4.04	51.91
	* Data from Climatography of the United States No. 81, 1971-2000, National Oceanic & Atmospheric Administration National Climatic Data Center.												

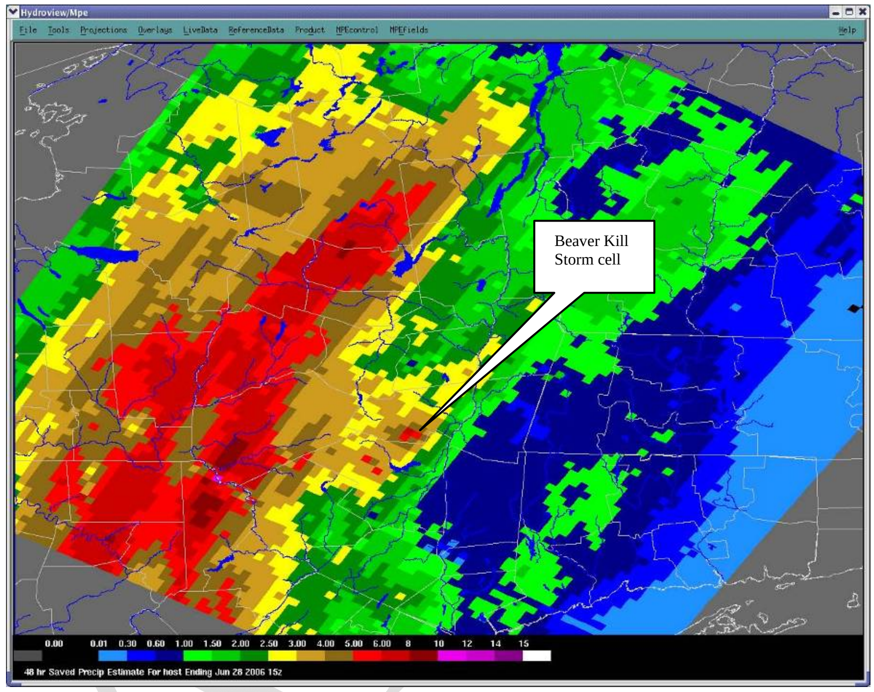


Figure 2.6 Radar image for June 26, 2006 rainfall that caused devastating flooding in the West Branch Delaware River basin and in the Beaver Kill sub-basin above Ashokan reservoir

The mountain landscape has its own "climate" within this larger one. Solar aspect, the orientation of a slope to the sun, affects the local microclimatic conditions. South facing slopes are warmer and drier than the cool, often moist north facing slopes of the valley. Summer thunder storms in the peak humid days deliver hammering rains that can be very isolated. A thunder storm cell over Stony Clove may drop a few inches of rain causing local flash flooding while the adjacent drainages don't get much rain at all. The recent flooding in late June, 2006 was an example of how larger regional storm events are unevenly distributed across the mountain landscape. The rainfall in the Beaver Kill tributary far exceeded the rain in the Esopus Creek valley and tributaries further to the west and thus the flooding was much more devastating (**Figure 2.6**).

2.3.2 Global Climate Change and Stream Management

The consensus in the scientific community is that human activities have increased the concentration of carbon dioxide in the atmosphere above recent historical levels, and that the "greenhouse effect" of this higher concentration is raising global temperatures (Frumhoff, et al., 2006). Atmospheric scientists have been modeling the impact of these higher average temperatures on weather patterns, in an attempt to predict how changes in climate might vary from region to region. While these local impacts are more difficult to predict, the models agree that, in the Catskills, increases in the frequency and magnitude of storm events with rainfalls greater than 2 inches in 48 hours is likely. The graphs in **Figure 2.7** are from **Climate Change in the U.S. Northeast: A Report of the Northeast Climate Impacts Assessment** (Frumhoff, et al., 2006)

The intensity of annual peak storms will also increase, as will the number of days with greater than 2" of rain. Paradoxically, drought periods are also likely to become more extreme (Frumhoff, et al., 2006).

These changes in precipitation are likely to result in more frequent flooding in our streams and rivers in the Catskills, and these higher flows could have significant implications for stream management, from the sizing of bridges and culverts, to planners' consideration of the land uses appropriate to floodplain areas, to how individual landowners maintain their streamside areas.

Figure 7. Projected increases in three indices of extreme precipitation: (1) precipitation intensity, (2) number of days per year with more than two inches of rain, and (3) maximum amount of precipitation to fall during a five-day period each year. Changes are shown for the lower- and higher-emissions scenarios. Model-simulated precipitation represents the average of the GFDL and PCM models (daily precipitation projections for the HadCM3 model were not available).

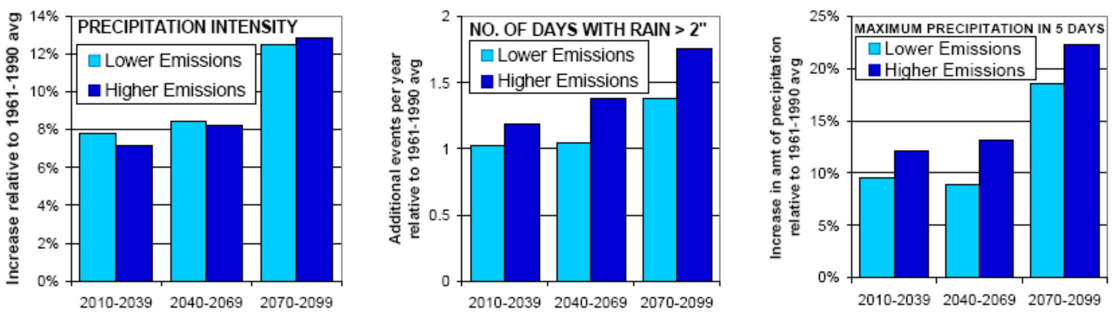


Figure 2.7 Predictions for precipitation increase attributable to global climate change

If, as expected, the frequency and magnitude of mid-sized storms increases, stream channels will likely enlarge to accommodate the larger flows until a new equilibrium is achieved. Channel enlargement would result in increased sediment loads –both suspended sediment and bedload. Catskills streams could also see increased introduction of large woody material into the stream as banks erode, and an accompanying increased risk of log jams at bridges, culverts and on bars. One result of additional sediment and woody debris loads could be more frequent shifts in channel alignments through the process of avulsion.

While it seems contradictory, drought periods are also predicted to increase. During droughts, vegetation can reestablish at channel margins and on mid-channel bars, also affecting channel morphology. During subsequent flood events, this additional vegetation could increase water surface levels and contribute to additional flooding. During droughts, both the structure and function of floodplain ecosystems will also be affected. Overall, we can expect changes in species composition toward species that are tolerant of both drought and inundation.

Stream managers –including streamside landowners-- will need a basic understanding of how streams are formed and evolve to effectively adapt to coming changes. They will need to anticipate and compare the consequences of different management options, and will need to act conservatively: oversizing culverts and bridge spans, leaving larger buffers of undisturbed streamside vegetation, and consider limiting new development of infrastructure or personal property in areas where conditions indicate a high risk of the stream channel shifting across the floodplain.

2.4 Land Use and Land Cover

Photo 2.5 The forested Upper Esopus Creek watershed looking toward Mount Tremper.

The land use and land cover of a watershed have a great influence on water quality and stream stability. The watershed's land cover directly impacts stream hydrology by influencing the amount of stormwater runoff. Forested and grassland areas produce significantly less runoff during a rain event than impervious (hardened surface) areas. A vegetated landscape also provides an effective filter for removing potential pollutants from runoff and preventing erosion into underlying sediment.

The Upper Esopus Creek drains a mostly forested watershed with residential and commercial development largely restricted to the stream valleys (**Photo 2.5**). As will be further explained in Section 3.1, Upper Esopus Creek has been divided into 23 reaches for assessment and planning purposes (see **Figure 3.4** and **Map 3.1**). Reach 1 starts at the Ashokan reservoir and reach 23 ends at Lake Winnisook. Using a stream and watershed assessment protocol published by the Vermont Agency of Natural Resources (VT-ANR, 2004) the dominant land cover/land use (LC/LU) for each reach's watershed and corridor was assessed. The analysis and results are presented in the Phase 1 Geomorphic Assessment of Upper Esopus Creek located in **Appendix C**.

2.4.1 Historic Land Use

The Esopus Basin has been altered by human influence. Settlement of the watershed took place between the late 1700s and the mid 1800s with the peak occurring around 1800. Agriculture associated with this settlement reached its climax by the 1850s. The completion of the railroad in 1870-1871 opened the door to several industries that altered the landscape. Tanneries, forestry (due to charcoal kilns, sawmills, and chair factories), bluestone quarries, and forest fires were the major agents of land alteration. Most of these influences had ceased by the early 1900s, however. Following this disturbance and the obvious degradation of the ecological health of the area, the state declared the Esopus watershed a part of the Catskill Park. The Catskill Park was established in 1904 to keep the area “forever wild.”

Tanneries were common in the Esopus Basin, and were centered in the Shandaken, Pine Hill, and Big Indian areas. The industry peaked in the mid 1800s and became virtually nonexistent by 1900. This industry had a major impact on the forest because tanning at the time required hemlock bark. The tanneries selectively cut hemlocks in the area. The tanning industry removed much of the first growth hemlock stands, but some remain.

Forestry in the Catskills was largely due to charcoal kilns and sawmill/chair factories. The charcoal industry was smaller than the sawmill industry, but the charcoal kilns had much greater impact on the land. The kiln operators clear cut portions of land in the Esopus basin. Kilns were most common at low elevations near railroad tracks, and were located around Winnisook Lake, Pine Hill, and Big Indian from 1870-1900. Sawmills were a much larger industry in the Catskills. Selective logging associated with this industry caused less impact than the clear cutting associated with charcoal. Large scale commercial logging was uncommon in the Catskill region, and most of the logging was done by private land owners.

Bluestone quarries in the Catskills were focused in the Esopus watershed from West Hurley to Shandaken and northeast of the Ashokan Reservoir (outside of the Management Plan reach). These quarries created a heavy localized disturbance of the forest, but only a small acreage was affected and bluestone quarries were a minor contributor to forestry issues in the Catskills. Reforestation of the quarries was swift due to their small size.

Kudish (2000) states, “By the late 1800s much of the accessible Catskill forest had been cut for settlement or industry. By 1885, an estimated 80 to 90% of the original first growth Catskill forest was no longer in existence.” The state began acquiring lands in 1887 and continues to purchase lands lot-by-lot. In 1885, the Forest Preserve was created for ecological preservation and to protect the valuable water supply in the Catskills. The state has purchased most of the higher elevation property in the region. The Catskill Park region was established in 1904 as an ecological preserve. Today this land is managed by the Department of Environmental Concern (DEC).

Reforestation efforts in the Catskills focused on agricultural lands, but these lands have long since become forest communities. Forest fire does occur in the Esopus Watershed, but on very small scale. Kudish claims fire to be "a minor player in determining what grows where." The major threat to the forest in the future is from invasive pests.

Going forward in time, by the 1980's, the USGS found that the most significant land-use change since their stream gage at Allaben was established in 1963 was an increase in residential population. The population of the Esopus Creek Basin upstream from the Ashokan Reservoir increased 147 percent between 1940 and 1980. During the same period, residential land use in the basin increased 230 percent, whereas commercial and agricultural land use decreased 80 percent (Freud, 1991). Second homes likely account for differences between the high increases in residential land use compared to the less marked increase in population.

2.4.2 Current Land Use Assessment

The analysis was conducted for current LC/LU only using NYCDEP's 2001 Land Cover/Land Use grid to produce statistics for each reach's watershed and corridor. The Anderson Level 2 classification categories are presented in Table 3.3. For a more complete description of these categories, refer to the Phase 1 Report in **Appendix C**.

Table 2.3. Land Use / Land Cover Classification Menu

Agricultural Land	Cropland, pastures, hay, orchards, groves, vineyard and nurseries
Brushland	Bushland, successional species, herbaceous species (grass, etc.) and shrubs (woody veg., saplings)
Built Up	Urban and commercial land. For example: shopping centers, office parks, sewage treatment plants, junkyards and landfills, industrial lands, airports and roads
Forested	Deciduous, coniferous and mixed forests, including those that have been burned or logged
Residential	Single or multi-family units, apartment complexes, residential hotels and mobile home parks
Turf	Managed turf, golf courses, parks, cemeteries
Water	Water
Wetland	Wetland

From the top of the watershed to the low point at Ashokan Reservoir, forested land exceeds 95% of the total watershed land cover, ranging from 95.5% to 99% (**Photo 2.5**). In the valley bottom, forest cover still tends to dominate the land cover along most of the stream's course, however along the Route 28 corridor, development associated with roads, residences, businesses, and town centers increases the percentage of impervious surfaces. The watershed contains several areas of relatively concentrated residential and commercial development, including the hamlets of Boiceville, Mount Tremper, Phoenicia, Shandaken, Big Indian, and Pine Hill (in the Birch creek drainage). There is no large-scale agricultural land use in the watershed. **Table 2.4** summarizes the

Anderson Level 2 classification for the 23 reaches. The Phase 1 Assessment Report in **Appendix C** contains a river corridor map of LU/LC.

Table 2.4 Land Cover and Land Use for Esopus Creek Corridor

Reach Number	River Corridor Land Cover / Use (%)							
	agricultural	brushland	built up	forested	residential	turf	water	wetland
1	0.70	2.57	16.05	53.79	5.47	2.34	8.57	10.51
2	1.07	4.37	7.51	53.40	5.01	3.51	5.16	19.98
3	2.09	4.46	9.06	35.65	5.04	1.99	9.60	32.12
4	3.15	4.77	10.62	39.39	8.61	2.98	5.90	24.59
5	1.02	9.08	10.20	54.56	3.38	2.71	3.81	15.23
6	0.70	0.86	16.83	49.37	9.35	1.93	4.94	16.02
7	0.88	5.08	8.79	56.76	7.53	2.76	3.03	15.16
8	0.88	4.01	3.77	57.85	3.77	3.15	0.43	26.14
9	0.31	3.45	5.70	60.07	6.57	4.16	1.73	18.02
10	0.15	5.78	12.19	35.27	3.62	0.00	1.86	41.13
11	1.20	2.57	23.24	41.18	9.17	1.32	2.71	18.60
12	0.70	8.66	11.64	57.22	9.97	2.32	1.12	8.37
13	2.06	3.16	12.17	48.00	7.36	1.59	2.00	23.67
14	0.25	1.14	6.01	81.68	6.91	4.01	0.00	0.00
15	2.65	5.34	7.33	51.85	3.27	1.81	0.98	26.77
16	0.00	3.48	3.87	57.78	7.16	1.54	0.00	26.17
17	0.00	13.52	1.10	53.62	2.64	1.90	0.24	26.98
18	0.49	11.60	3.71	48.71	6.23	3.29	0.45	25.52
19	0.43	6.24	1.86	57.45	8.58	5.00	1.15	19.30
20	0.50	6.63	2.07	72.22	9.87	4.79	0.95	2.97
21	0.51	4.71	1.69	66.71	6.76	3.71	1.46	14.45
22	0.64	0.19	1.40	94.55	1.04	0.65	0.00	1.52
23	0.00	0.00	3.22	95.19	1.05	0.00	0.00	0.54

2.5 Upper Esopus Creek Geology

Photo 2.6 Landslide next to Beaver Kill just upstream of Esopus Creek confluence. The hill slope failure exposes glacial deposits

2.5.1 Introduction

Water flows across the landscape and sculpts the watershed. The geology (the earth material) of the watershed helps determine the nature of the streams that form, influences the stream's water quality, and the way the landscape erodes (**Photo 2.6**). The waterfalls of the headwater reaches, the boulder rapids near Phoenicia, and the steep valley walls that frame the broad riffle-pool stream as it enters the Ashokan reservoir are controlled by geology. In the Catskill Mountains, geology is the primary control on water quality. Jill Schneiderman, a professor of geology at Vassar College, notes in her book **The Earth Around Us: Maintaining a Livable Planet** that the bedrock and glacial sediments of the Catskills provide excellent filtration for maintaining high water quality (Schneiderman, 2003). However the geology also periodically degrades the water quality. Where the stream erodes into very fine-grained (silt and clay) glacial deposits the water will become brown with the suspended sediment. This Section of Volume III presents basic background information on Catskill and Upper Esopus Creek geology and discusses some of the important implications of the geology with respect to stream management.

The intent is to provide just enough information to describe the geologic setting and history of the Upper Esopus Creek watershed. Specific recommendations pertaining to further characterization are presented at the end of this Section. References are provided for the reader interested in obtaining more detail on the geology of this region.

Streams and glaciers sculpted these mountains out of rock that formed from ancient rivers. That is essentially the geologic story of the Catskill Mountains. These mountains and their river valleys are the ongoing result of water interacting with landscape geology under the force of gravity over millions of years. Knowing the geology of the landscape and stream corridor will help stream managers understand important conditions that control the stream's work (moving water and sediment out of the watershed) as well as significantly influencing water quality.

The nature of the bedrock – its composition and structure – determines how the stream valleys will form and what the sediment will be like. Esopus Creek drains the highest and steepest parts of the Catskill Mountains on its course to the Hudson River (Rich, 1935). These mountains are composed of sedimentary rock. The broken bits of this rock, formed from layers of ancient river sediment, is the source of almost all of the stream sediment you see today - from clay to boulders. The reddish clays exposed in stream banks are ancient lake sediments eroded from the red siltstones and shales that often form the mountain slopes; the cobbles and boulders eroded from the thick-bedded sandstones that form the mountain cliffs (**Photo 2.7**). Much of this sediment that the stream is currently conveying was deposited during the most recent ice ages of 12,000 – 25,000 years ago, when the Catskills were mostly occupied by ice or the meltwater streams and lakes that followed the ice's retreat. The Esopus Creek and all the streams that feed it water and sediment have inherited this geologic framework.

Photo 2.7 Stream channel and stream bank sediment derived from Catskill bedrock

The geology of the Upper Esopus Creek valley is typical of the complex geologic conditions that prevail in the tributaries as previously documented in the Broadstreet Hollow and Stony Clove SMPs (UCSWCD, 2003; GCSWCD, 2004) and in the adjacent Schoharie Creek basin to the north as documented in the Batavia Kill and West Kill

SMPs (GCSWCD, 2003; 2005). The bedrock geology is straightforward, while the glacial geology provides the complexity that makes these basins unique in the Catskills.

2.5.2 Bedrock Geology

The bedrock geology of the Catskill Mountains and Upper Esopus Creek watershed exerts considerable control on the character of its valley slopes and streams (**Figure 2.8**). The sedimentary rock, primarily composed of alternating layers of sandstone and siltstone/shales, creates the characteristic Catskill stepped topography. The sandstones form the cliffs while the more easily erodible siltstones/shales tend to form the slopes. The mountain tops tend to be formed of conglomerate (a gravelly sandstone). The sediments that form the middle-to-late Devonian (390 to 360 million years ago) bedrock are interpreted to be deposits of a vast deltaic river system, often called the “Catskill Delta” deposits (Isachsen et al, 2000) that drained the ancient high peaks of the Taconic mountain range. Titus (1998) has compared it to the Bangladesh river complex draining the Himalayas. The sandstone and conglomerate are made up of river channel sand and gravel, while the siltstones and shales are overbank and shallow fresh water silts and clays.

The Catskill Delta deposits were buried beneath younger sediments, and then uplifted as a plateau. Prior to and during the uplift, intersecting sets of vertical fractures formed in the Catskill rock. The following eras eroded away the overlying rock, and streams incised multiple channels into the slowly rising plateau. The following two publications are recommended for further detail on the Catskill bedrock geology: Geology of New York: A simplified account (Isachsen, et al, 2000) and The Catskills: A Geological Guide (Titus, 1998)

Photo 2.8 Outcrop of Oneonta Fm sandstone along Woodland Valley Creek

Fisher, et al. (1970) mapped the bedrock of the area as part of the New York State Geological Survey Map and Chart Series (**Figure 2.8**). The mapped geologic formations that make up most of the watershed are the very similar Oneonta and Walton formations comprising sandstones, shales, and mudstones (**Photo 2.8**). The uppermost rocks in the sequence are conglomeratic sandstones of the Slide Mountain Formation.

Most of the stream valleys draining the Central Escarpment are oriented NE-SW, bisecting the two predominant bedrock fracture orientations. This orientation is principally based on pre-glacial erosion of the landscape, which was controlled by the fractured bedrock. The orientation of stream valleys is important, influencing the microclimate, average depth of snowpack and local hydrological regime in many ways. The Upper Esopus Creek and Woodland Valley drainages form a unique circular pattern. This distinctive circular pattern is striking when viewed from a high altitude (**Figure 2.8**). Isachsen, et al (1994) hypothesized that this is the result of preferential erosion along bedrock fractures associated with a buried meteor impact.

Modern stream deposits in the Catskill Mountains are principally derived from erosion of the well-bedded sedimentary Catskill bedrock. As a result, stream clasts (sediment particles and classes) have a low spherocity ("roundness"), typically forming platy or disk-like particle shapes. This platy shape affects the stability of the streambed in a number of ways. First, it allows the particles to *imbricate*, or stack up at an angle, forming an overlapping pattern like fish scales or roof shingles (**Photo 2.9**). Imbricated streambeds are thus generally more stable or "locked up", and all other things being equal, generally require a larger flow to mobilize the bed material than nonimbricated beds. However this same platy shape can also, under the right conditions, act like an airplane wing and be lifted by the streamflow more readily than would a spherical particle of similar weight. Once this occurs for even a few particles, the imbrication is compromised and significant portions of the streambed become mobile.

Photo 2.9 Example of imbricated Catskill stream sediment

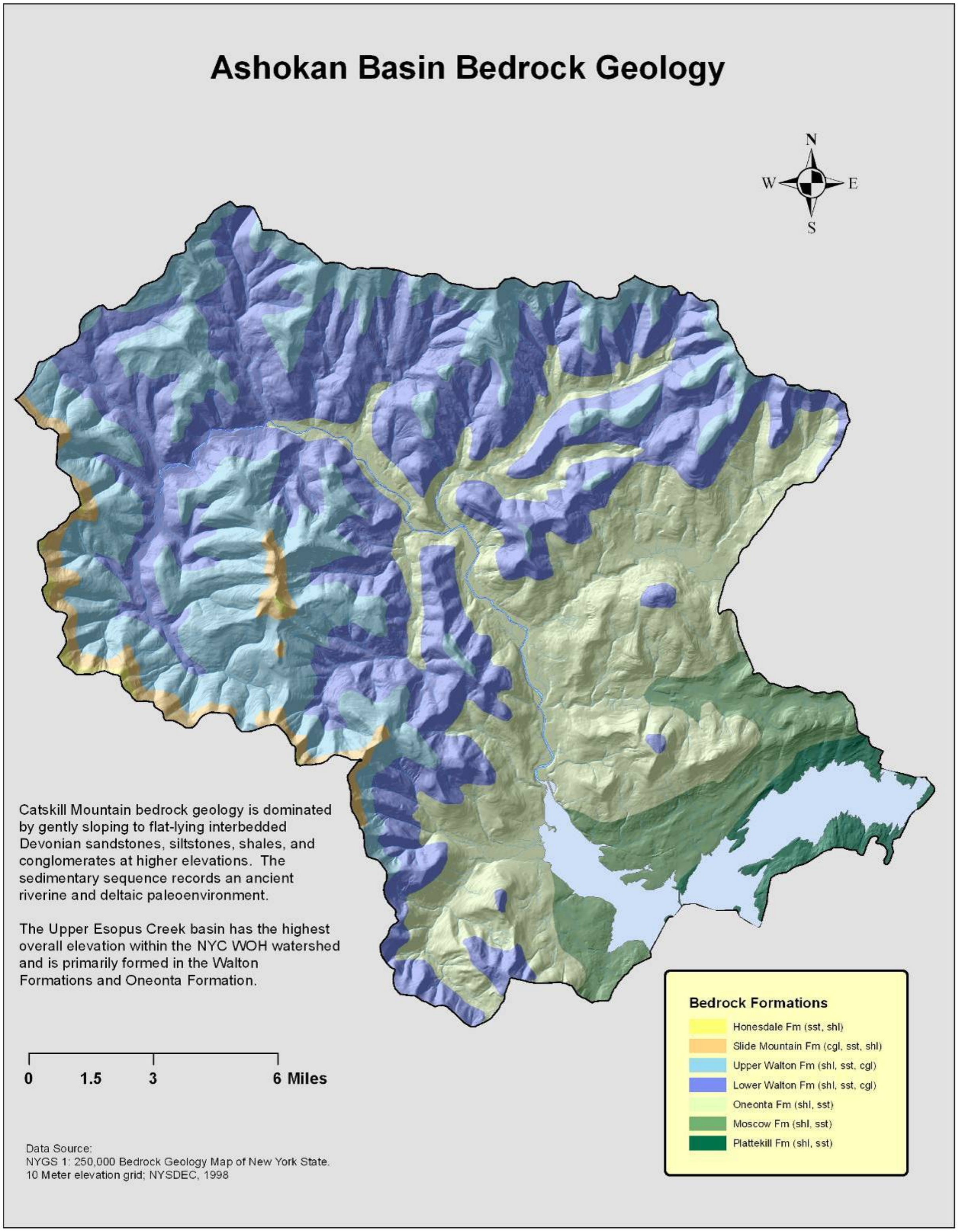


Figure 2.8. Bedrock Geology of the Ashokan (including Upper Esopus Creek) Watershed

2.5.3 Surficial Geology

Surficial geology is concerned with the material covering the bedrock. In the Catskills this surface material is principally soils and glacial deposits. The focus here is on a brief introduction to the glacial geology of the watershed and stream corridor. The Ulster County Soil Survey is an excellent source for examining the soils of the Upper Esopus Creek corridor (Tornes, 1979).

The ice ages of the last 1.6 million years (Pleistocene Epoch) have left the latest mark on the Catskill landscape. Vast continental ice sheets and smaller local mountain glaciers scoured the mountains and left thick deposits of scoured sediment in the valleys. The last ice sheet (the "Laurentide Ice Sheet") reached maximum thickness over the Catskills about 22,000 years ago (Isachsen, et al., 2000) and had fully retreated by 12,000 years ago (**Figure 2.9**). As measured on the scale of geologic time this was a very recent event.

Figure 2.9 (a) map of Laurentide ice sheet. (b) Photo of Greenland ice sheet in mountainous terrain.

The most recent ice ages – the time that spanned the last 30,000 years or so – had giant continental-sized ice sheets flowing across the northern landscape (**Figure 2.9a**). The ice sheet covering Greenland (**Figure 2.9b**) is a modern day analog to those Pleistocene conditions. The continental glaciers scoured and moved vast amounts of sediment across the landscape. Once the ice sheet started melting back into the Hudson River valley and to the north, smaller alpine glaciers formed in the mountains and further sculpted the landscape. The glaciers left a legacy that still profoundly influences hill slope and stream channel stability and water quality (**Photos 2.6** and **2.7**).

This was a period of accelerated erosion in the Catskills as the flowing ice sheet bulldozed sediment and "quarried" the bedrock. Glacial erosion broke the rock down into an entrained mixture of fragments ranging in size from boulders to clay. This mixture of saturated sediment was carried along by the ice and deposited as *till* (unsorted assemblage of glacial sediment) or as *stratified "drift"* if the sediment was subsequently sorted by melt-water streams. These glacial deposits filled in deep river ravines that once drained the landscape prior to the last glacier's advance over the mountains.

As the climate warmed and ice thinned, the landscape was deglaciated – lobes of the continental ice sheet melted back from the central Catskills in periodic stages (Dineen, 1986). As the ice sheet pulled back (and occasionally re-advanced as distinct "lobes" of flowing ice) alpine glaciers formed on some of the newly exposed peaks (e.g. Hunter and Panther Mountains). Meltwater from the decaying ice left a complex array of stream (outwash plain) and ice-contact (kame) sand and gravel deposits. Pro-glacial lakes formed where mountains, recessional moraines (deposits at former glacial margins) and ice impounded water and filled the valley floors with thick deposits of layered silt and clay (**Figure 2.10**). Up to 30 m of interbedded silt and clay layers are recorded in the valley bottom. "Fossil" deltas from meltwater streams pouring into large valley filling lakes occur at an elevation up to 564 m (Rich, 1935), exposing a large proportion of the catchment to the accumulation of layered fine sediment. As climate fluctuated during the period of deglaciation, temporary re-advances of ice from ice sheet lobes or alpine glaciers would leave till and other meltwater deposits on top of the earlier glacial material, resulting in the complex lateral and vertical distribution of glacial deposits observed today. After the ice fully retreated north, rainfall-runoff returned as the predominant sculptor of the landscape.

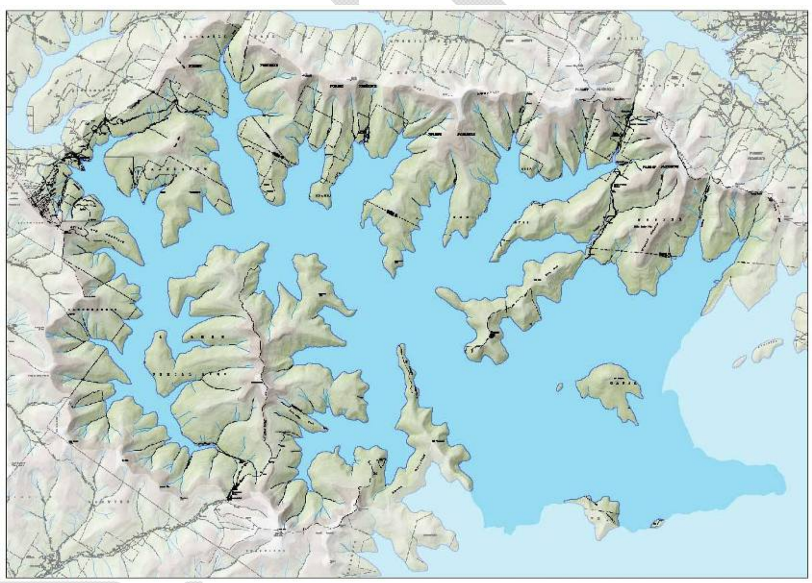


Figure 2.10. Map of hypothetical Lake Peekamoose based on Rich (1935)

Glacial geology sets the geologic framework for most of the Upper Esopus Creek stream system, controlling such characteristics as depth of *alluvium* (water worked sediments), presence of non-alluvial boundary conditions (till and glacial lake sediments), sediment supply and stream channel slope and geometry. For example, glacial depositional features that partially fill river valleys, such as recessional moraines or kame terraces along the valley wall, influence valley slope and cause valley constriction, both of which limit where the river channel can occur (insert future figure). Also, locally complex *stratigraphy* of glacial till, glacial lake deposits and unconsolidated *fluvial* deposits in the stream bank profile significantly influences erosional process. Understanding the glacial geology in detail beyond the general level can help identify causes of stream erosion and water quality problems as well as assist in prioritizing where future stream stabilization or restoration actions may be most useful.

For more detail on the glacial geology of the Catskills the reader is referred to Rich (1935), Cadwell (1986), Dineen (1986) and for a popularized account Titus (1996). **Figure 3.11** presents the glacial geology for the Ashokan basin and Esopus Creek as mapped by Cadwell (1987). **Appendix C** contains an excerpt of Rich's description of Esopus Creek glacial geology.

2.5.4 Hydrogeology

Though groundwater is not the subject of this Management Plan, its constructive role in maintaining base flow to the stream and cold water springs for thermal refugia, and its destructive role in hill slope failures should be addressed.

Photo 2.10 Hillslope failure and debris flow on Stony Clove

Given that much of the valley floor stratigraphy includes buried impermeable layers of glacial lake silt and clay and/or glacial till, groundwater circulating through the upper permeable coarse-grained alluvium is often perched and discharges as springs or base flow to the stream. Following periods of excess rainfall not only does the stream flow increase to or near flood stage, but the water table also increases and can flood basements. Much of the "flood" damage to basements in the Esopus corridor is due to excess groundwater in these shallow groundwater systems and not directly from stream flooding.

Groundwater flow through the complex glacial stratigraphy on the hill slopes is a major factor in the massive hill slope failures that impact stream channel conditions and water quality (**Photo 2.10)**. The combination of stream erosion at the toe of the hill slope, fluctuating groundwater levels, differential seepage from the slopes and saturated sediment can result in very long-lasting, deep-seated slope failures. Examples abound throughout the watershed. Every major rainfall-runoff event seems to generate new slope failures or reactivate older failures. Some of the chronic turbidity sources in the tributary streams are from these hill slope failure sources, such as in Stony Clove, and the unique artesian "mud boil" condition that is recurrent in a reach of Broadstreet Hollow (**Photo 2.11**). 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.

Photo 2.11 Artesian "mudboil" in Broadstreet Hollow stream bed. June, 2006

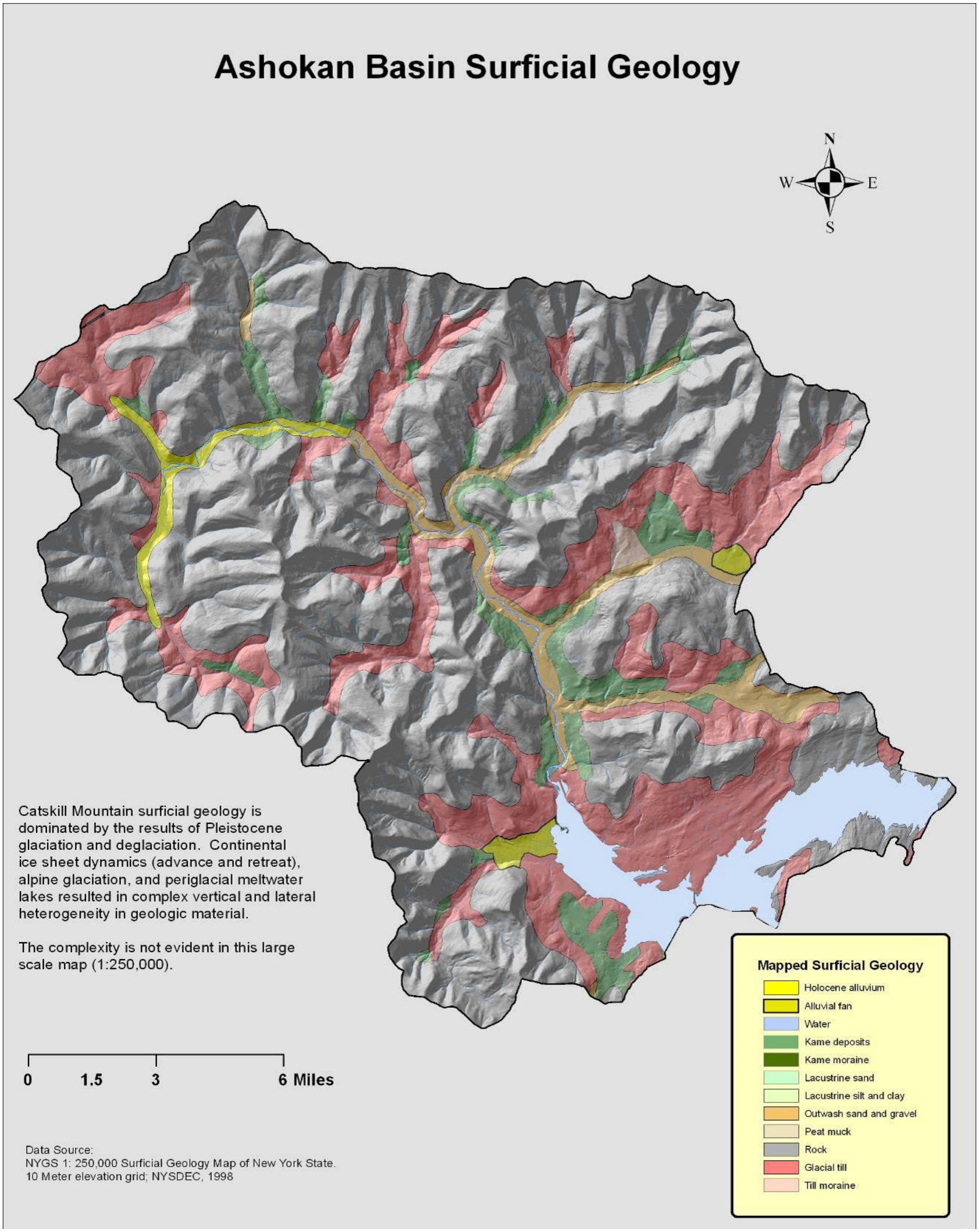


Figure 2.11. Surficial Geology of the Ashokan Basin (including Upper Esopus Creek) Watershed as mapped at 1:250,000 Scale

2.5.5 Stream Channel Geology

Developing an effective stream corridor management plan that incorporates geologic boundary conditions requires an additional step beyond describing the geologic setting. Additional analysis is needed to characterize the surficial geology that forms the stream channel boundary by some of its sedimentologic conditions, specifically grain size distribution, cohesiveness, and consolidation.

Upper Esopus Creek and its tributaries flow across a landscape characterized by *sedimentological heterogeneity* as a result of the complex distribution of glacial deposits and landforms. Stream channel stability and water quality vary in part as a function of this heterogeneity. By classifying the surficial geology along the stream corridor into mappable units that describe the potential for bed and bank erosion and entrainment of the stream channel material, recommendations for management of stream reaches can better reflect local geological considerations.

Rubin (1996) began this effort in the Stony Clove basin by classifying the glacial deposits into three sedimentologic units and mapping their distribution along the Stony Clove mainstem and tributary channels (GCSWCD, 2004). The following 3 key sedimentologic units that influence water quality and stream stability were proposed by Rubin (with some modification for this report).

Unconsolidated Deposits

This general term is applied to all unconsolidated deposits regardless of whether they were deposited directly as post-glacial stream deposits, glacial *outwash* (proglacial fluvial sediments), reworked outwash, *kame terrace* deposits, *melt-out till*, *moraine* deposits or reworked *lodgement till* (**Photo 2.12**). The unit is composed of sand, gravel, cobbles, boulders and a small clay/silt fraction. The unconsolidated deposits are present in valley centers, typically ranging from four to twelve feet in thickness (Rubin, 1996). With the exception of a thin, weathered mantle often capping it, this is the uppermost geologic unit most commonly forming stream banks. Boulders specific to this geologic unit naturally drop out as stream banks are eroded, providing some aquatic habitat and diversity.

Photo 2.12 Coarse fluvial sediment comprises most of Upper Esopus Creek stream banks

Lacustrine silt/clay

This reddish or pinkish brown, finely-layered, silty-clay deposit floors significant portions of the Upper Esopus Creek and several tributaries (**Photo 2.13**). It was deposited *subaqueously* (from streams discharging into one or more 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. **Appendix D** includes a study on the erodibility of these deposits by the U.S. Army Engineer Research and Development Center. 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 by slumping along rotational faults, subsequently losing its layered structure and cohesive strength (**Figure 2.12)**. Within the silt and clay layers, strata of

Photo 2.13 Esopus Creek streambank exposure of lacustrine silt/clay layers deposited in a pro-glacial lake that once filled the Upper Esopus Creek valley

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.

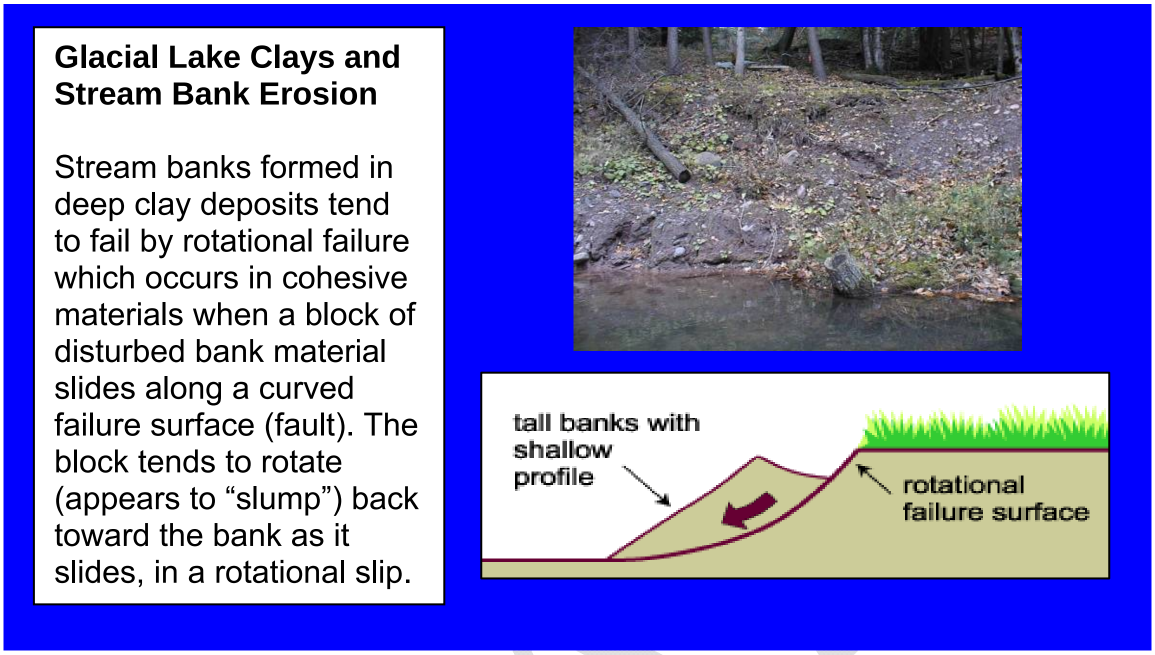


Figure 2.12 Glacial lake clays and stream bank erosion

Photo 2.14 Esopus Creek above Birch Creek with exposed glacial lake deposits causing turbidity

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. A metal probe or stick can often be sunk into this unit to depths of between three and five feet, thus enabling identification even when it is covered by a thin cobble layer. Elongate troughs, scour holes and even deep potholes reflect its entrainment potential during scouring flows. Clear stream water contacting lake clays often results in an entire stream becoming turbid within 50 feet (**Photo 2.14**). In the Upper Esopus Creek watershed this unit is a primary source for suspended sediment and turbidity problems.

Lodgement Till

This is an over-consolidated (very dense), clay-rich, reddish brown deposit that is prevalent in the Upper Esopus Creek watershed (**Photo 2.15**). 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. It 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 morainal ridges.

It's relatively competent nature, especially compared to disturbed lacustrine sediment; make it 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 streamflows. Under conditions of high stream velocities and discharges, lodgement 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 lodgment till is saturated, long-lasting exposures can be chronic sources of suspended sediment into the

Photo 2.15 Glacial till exposed in Fox Hollow stream bank. Turbid water is from contact with glacial till.

stream well-after a storm event. Reaches in the lower Stony Clove valley below Warner Creek are subjected to this phenomenon (**Photo 2.10**) Rain water and overland runoff contacting exposed banks can also readily entrain sediment from these units (**Photo 2.15)**. For field mapping, a metal probe or stick can rarely be pushed into this unit more than 0.2 feet.

Bedrock Control

The presence of bedrock sills and banks is an additional geologic unit equally important in characterizing geology for stream corridor management. These hydraulic controls can represent natural limits to changes in the stream channel system caused by incision or lateral migration. Examples include the falls in the headwater reaches above Oliverea (**Photo 2.16**), and occasional bedrock stream banks along the Upper Esopus Creek course.

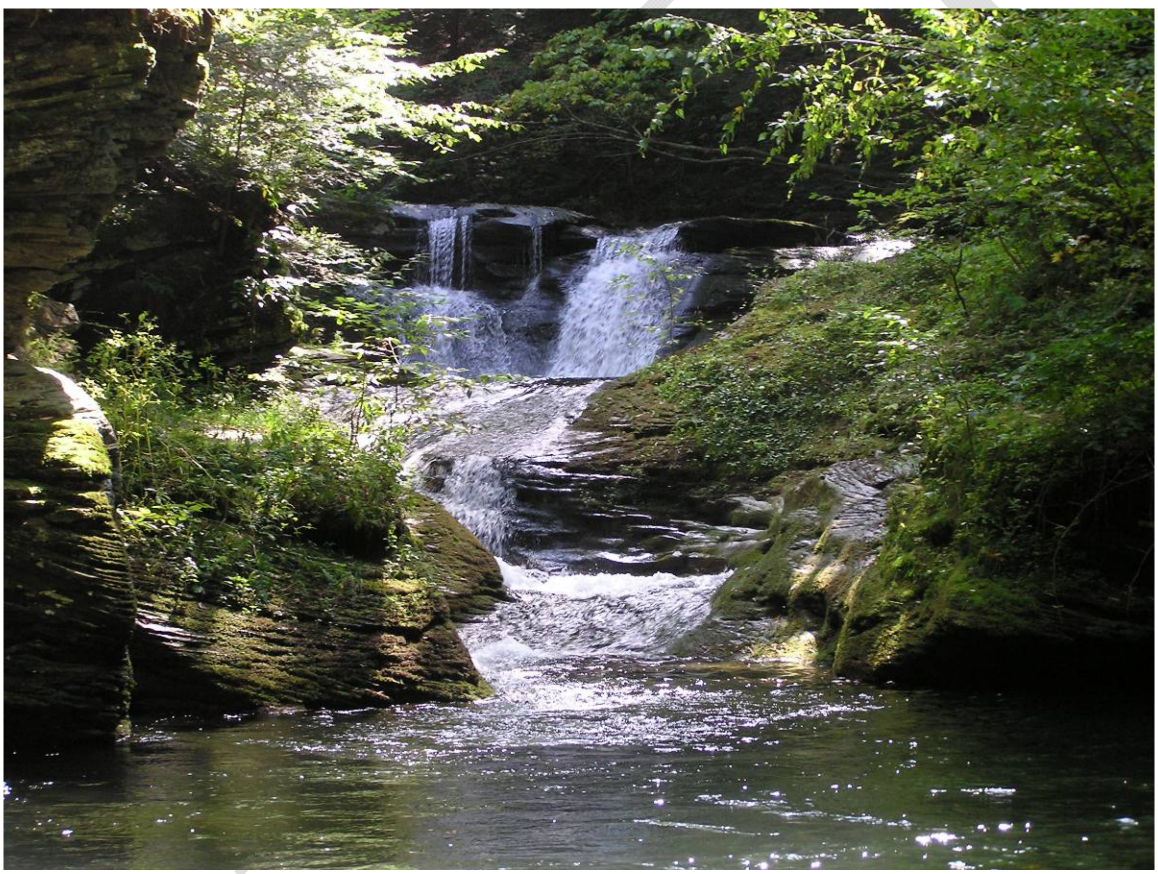


Photo 2.16 Otter Falls in the headwater reaches of Upper Esopus Creek

In summary, the variable character of the Upper Esopus Creek is largely a reflection of the geologic bedrock control and complex glacial history of the valley. These geologic influences are evident in the sedimentological variation characterizing the topography and geomorphology of the stream channel boundary. The nature of these deposits makes them variably susceptible to stream erosion. In particular, the lacustrine and till sediments are sensitive to natural or man made disturbances which can have a long lasting negative effect on channel stability, water quality and stream ecology.

2.5.6 Stream Management Implications

The inclusion of geology in stream management consideration for Upper Esopus Creek generally falls into four categories: fluvial erosion; hill slope erosion; water quality; and sediment supply.

Fluvial erosion

There are different types or "styles" of stream bank erosion associated with the different geologic units the stream encounters. The prediction, prevention and/or treatment of the eroding stream bank must factor in the stream bank material composition and the underlying mechanism of failure. **Photos 2.17a-f** depict typical stream bank erosion styles along Upper Esopus Creek for differing geologic boundary conditions. Observations made during this planning process and previous similar projects throughout the watershed indicate the following:

- The pro-glacial lake sediment erodes easily during storm events once exposed; however, if the "soft" silt and clay unit is overlain by coarser fluvial sediment (sand-boulder sized material) it is typically a short-lived exposure and the stream bank tends to get armored by the draping of the coarser sediment (**Photos 2.17a-b**).

- Pro-glacial lake deposits that are undisturbed are much more resistant to erosion than those that have had their physical and chemical bonds weakened by mechanical action (including abrasion and displacement from hill slope failures).

- The glacial till tends to erode either as (a) mass slumping from saturated conditions (**Photo 2.17c**) or (b) translational fracture-bound failures forming high steep banks (**Photo 2.17d**)

- The coarse-grained, non-cohesive fluvial sediment will erode easily if not protected by dense roots or revetment (**Photo 2.17 e-f**).

Photo 2.17a. Stream bank erosion into lacustrine silt/clay overlain by unconsolidated fluvial sediment. October, 2005

Photo 2.17b. Same location as 2.17a in April, 2006. Unconsolidated sediment has draped over lacustrine sediment removing exposure of fine sediment source.

Photo 2.17c. Slumping glacial till in headwater reach of Upper Esopus Creek

Photo 2.17d. Steep eroding bank of glacial till overlain by unconsolidated fluvial sediment.

Photo 2.17e. Stream bank erosion into unconsolidated fluvial sediment with limited riparian buffer protection. A very narrow strip of woody vegetation can exacerbate bank retreat as the individual trees are uprooted.

Photo 2.17d. Stream bank erosion into unconsolidated fluvial sediment with no riparian buffer. Boulders in stream are approaximate position of bank line before Tropical Storm Ivan flood significantly adjusted channel alignment. Non-keyed riprap was flanked and washed away.

Hill slope erosion

The mass wasting, or geotechnical failure of the valley hill sides when proximal to stream channels can result in chronic and excess fine and coarse sediment supply. This is a relatively common problem in the tributary valleys. Sediment entrainment occurs as a result of exposed glacial till or disturbed lake deposits to flood flows, or as in the unusual case of an artesian "mud-boil" observed in the Broadstreet Hollow stream at the restoration demonstration site (UCSWCD, 2003). In extreme situations, debris flows from these failures may block or cause the stream channel to adjust its planform. If the adjacent hill slope erosion is from a geotechnical failure in glacial till or pro-glacial lake sediment *and* the stream is actively eroding into the toe of the hill slope the problem is perpetuated by constantly activating the failure (**Photo 2.10**). Stream restoration or road construction/repair in these settings must first address whether the geotechnical failure can be resolved before dealing with the stream channel stabilization. Future construction or development activities in the Esopus Creek tributary valleys should include geotechnical investigations and slope stability analyses to ensure that the proposed actions do not contribute to new slope failures or exacerbate existing failures.

Water quality

The "muddy" or turbid water that follows a storm event or issues forth from the Shandaken tunnel (See **Volume II Section 2**) carries the fine silt and clay particles initially deposited as glacial till or pro-glacial lake sediment. Fluvial and hill slope erosion of these fine sediment sources, along with re-suspension of fine sediment deposited in the stream bed are the primary cause of the turbid water conditions (**Section 2.7** and **Section 3.1.2**). The fact that the glacial till and glacial lake sediment is widely distributed throughout most of the watershed suggests that effective removal of the stream from contacting this material is impractical to consider. High levels of suspended sediment and associated turbidity have been and will be an ongoing water quality condition in the Upper Esopus Creek watershed.

Sediment supply

The mantle of glacial deposits over the landscape is the primary source material for all the coarse and fine sediment that the stream system conveys. At any given time along any given reach of stream most of the sediment observed has been in the stream system for a "long time". However, it is important to determine where sediment recruitment takes place. Unanswered questions remain: Which tributary streams deliver a proportionally larger amount of bed load material that Esopus Creek has to process? Are there localized sources in the watershed that lead to localized aggradation?

2.5.8 Recommendations

The following recommendations are presented as an initial scope for further investigation and development of products to improve the Upper Esopus Creek Stream Management Plan.

- Work with research and/or academic institutions to better characterize the lateral and vertical distribution of glacial deposits that influence stream channel condition and water quality. Encourage academic interest in addressing this applied geology issue.
- Continue to monitor previously mapped fine sediment sources along Upper Esopus Creek, and implement a program to identify "new" exposures. The aim of this effort is to better characterize the temporal nature of fine sediment exposures and their contribution to water quality problems in the basin.
- Using (1) georeferenced data obtained during the Phase 2 geomorphic investigation (See Section 3.2.2), (2) available soils map and (3) further reconnaissance mapping develop a stream channel geologic map for Esopus creek.
- Extend stream channel geologic and fine sediment source mapping into all tributary valleys not previously assessed, and update the sediment budget described in Section 3.2.2 to include more detail on the tributaries so that the relative contribution of sediments from these sources can be determined and the potential benefits of management actions in the tributaries better elucidated.
- Support an investigation of the geotechnical and hydrogeologic processes controlling coupled hill slope and stream bank erosion in order to evaluate management feasibility.
- Develop a document that informs stream managers how to use this information when designing and implementing stream "stabilization" projects in the region.

2.6 Upper Esopus Creek Hydrology

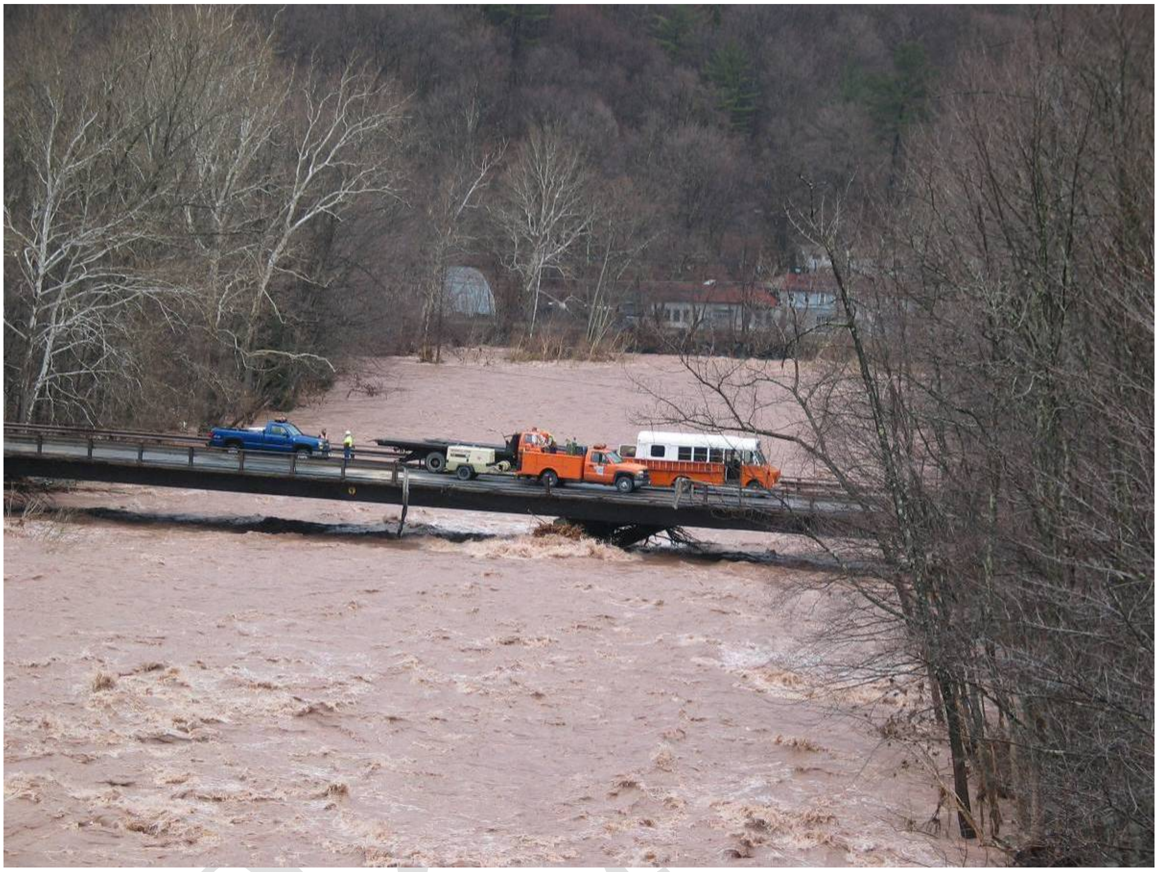


Photo 2.18 High Street Bridge over Esopus Creek at Phoenicia, April 3, 2005

2.6.1 Introduction

Hydrology is the study of how water cycles through the landscape (**Figure 2.13**). By characterizing how the dynamic Upper Esopus Creek watershed and stream system carry rain and snow melt over time as runoff and streamflow, we can gain some insight into how the landscape will likely react to future flood events. This can also help us predict changes in how Upper Esopus Creek will behave during floods (**Photo 2.18**) as a result of our management of the stream and the watershed.

Water flowing through Esopus Creek reflects the integrated net effect of all watershed characteristics that influence the *hydrologic cycle* (**Figure 2.13**). These characteristics include climate of the drainage basin (type and distribution patterns of precipitation and temperature regime), geology and land use/cover (permeable or impermeable surfaces and materials affecting timing and amount of infiltration and runoff, and human-built drainage systems), and vegetation (uptake of water by plants, protection against erosion, and influence on infiltration rates). These factors affect timing and amount of streamflow, referred to as the stream's *hydrologic regime*. Understanding the hydrology of a drainage basin is important to the stream manager because stream flow patterns affect aquatic habitat, flood behavior, recreational use, and water supply and quality.

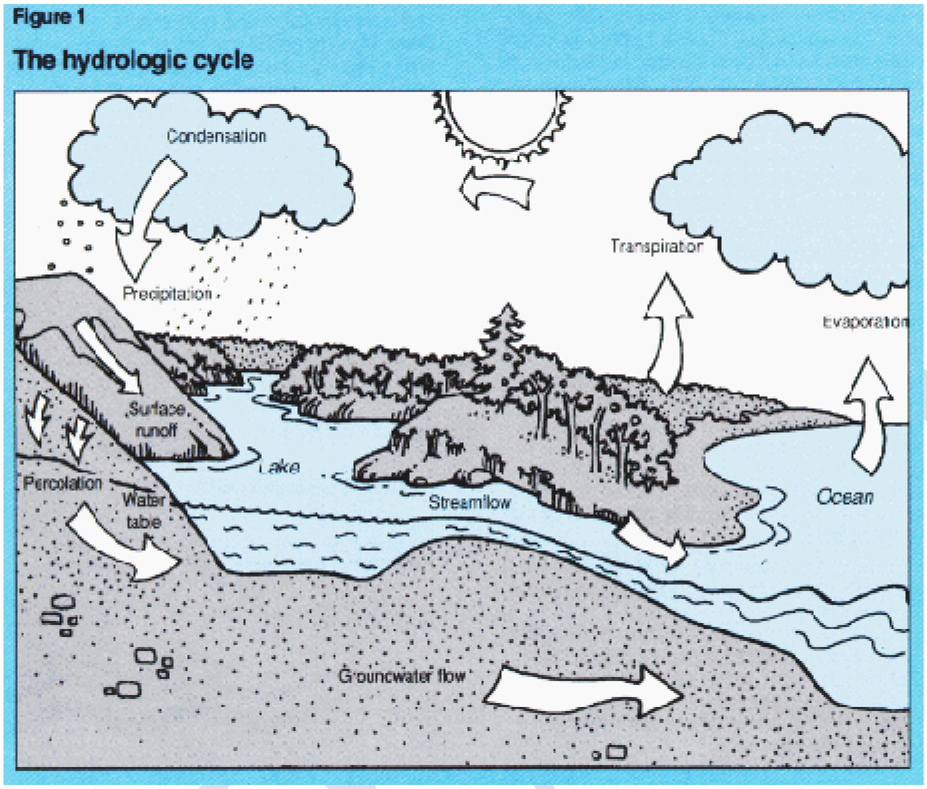


Figure 2.13 The Hydrologic Cycle

2.6.2 The Streamflow Record

Stream flow is simply the water flowing through a stream channel over a given time period. A graph of the magnitude of stream flow over time is called a *hydrograph* (**Figure 2.14**). We can use hydrographs to interpret the hydrologic regime of a watershed (e.g. identifying how the stream responds to storm events or droughts) and separate the two general categories of stream flow: *storm flow* and *base flow*. Storm flow appears in the channel in direct response to precipitation (rain or snow) and/or snowmelt, whereas base flow, originating from groundwater discharge, sustains stream flow between storms or during subfreezing or drought periods. There are many good resources for further detail on basic to advanced hydrology and stream flow partitioning (references). Also, the Stony Clove Stream Management Plan, developed for a sub-basin of Esopus Creek, includes a useful and detailed description on streamflow characteristics (GCSWCD, 2004). For the purposes of this Management Plan we will limit discussion to how and where stream flow is measured in the Upper Esopus Creek watershed, the use of the streamflow record to construct hydrographs, and finally statistical analysis that can be performed for Esopus Creek using the existing record.

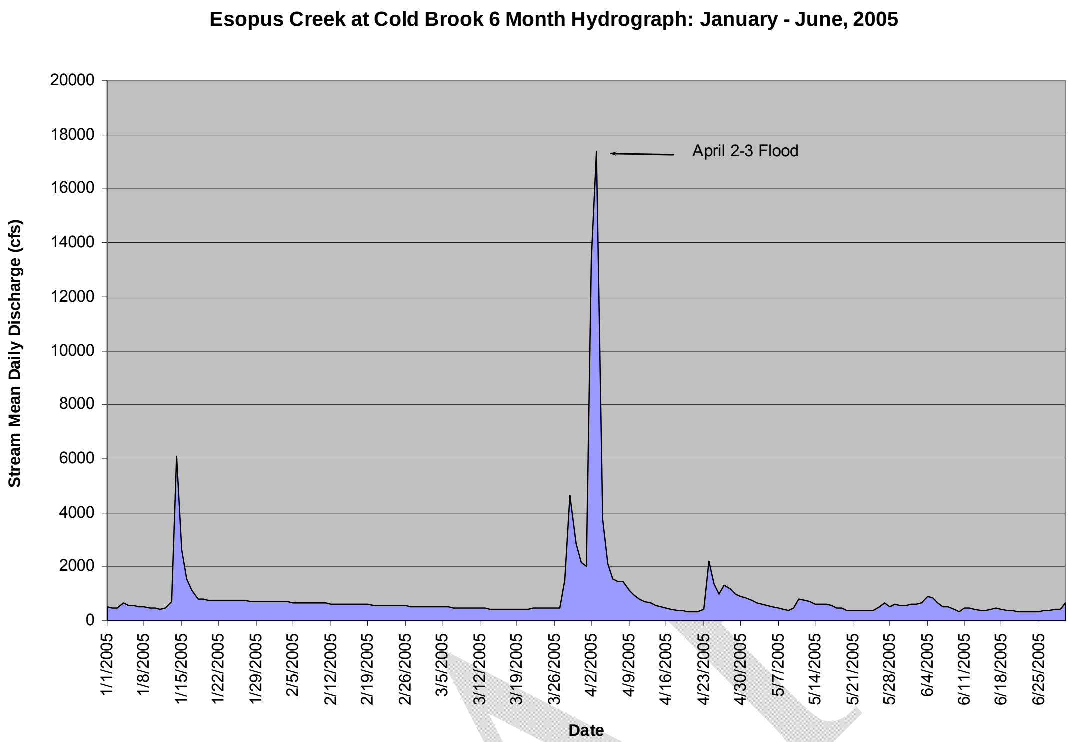


Figure 2.14 Hydrograph of streamflow measured at the USGS stream gage: Esopus Creek at Coldbrook, NY (01362500) for the period: January 1, 2005 – June 31, 2005

Stream flow is measured in units of volume of water passing a reference point for a unit of time (volume/time). We commonly use units of cubic feet per second (cfs). For example, 10 cfs means that for every second, 10 cubic feet of water is passing by an observer. Stream flow is directly measured by measuring the velocity (length/time) of water at several points along a cross section line. The velocity is multiplied by the area between measurements, resulting in units of volume/time. The discharge, or stream flow is the sum of all those measurements. This is a time consuming method and at high flows can be very dangerous. Hydrologists also measure and record the height of the water, or *stage*, for each discharge measurement. By recording both the stage and the discharge, the hydrologist forms a *stage-discharge* relationship that relates stream discharge to a corresponding stream stage (a much easier parameter to measure). The resulting *rating curve* is used to obtain stream flow estimates from recorded stages. A *stream gage* is necessary to monitor stream discharge) and stage at a particular location for a long period of time. These gages measure the *stage*, or height, of the water surface at a specific location, updating the measurement every 15 minutes. Using the rating curve developed for the gage based on many measurements over a range of discharges, the magnitude of flow in at the gage location can be determined at any time just by knowing current stage, or predicted for any other stage of interest.

The United States Geological Survey (USGS) through a contract with NYCDEP maintains ten continuously recording stream gages in the Upper Esopus Creek watershed (**Table 2.5; Figure 2.15; Photo 2.19**) and one crest stage gage on the Bushnellsville Creek. There are two gages on Esopus Creek: Esopus Creek at Allaben (established in 1963, drainage area 63.7 mi^2; USGS ID# 01362200) and Esopus Creek at Coldbrook (established in 1931, drainage area 192 mi^2; USGS ID# 1362500). **Figure 2.16** is a hydrograph for 25 years of the 75 years of record available for the Coldbrook gage. The real-time and historic data for these gages (and others in the watershed) is available online at the USGS website http://nwis.waterdata.usgs.gov/ny/nwis/rt.

Table 2.5 USGS Stream Gages in the Upper Esopus Creek Watershed

USGS ID	DEP Site Code	Station Name	DA (mi^2)	County	Start Date
01362200	E5	Esopus Creek @ Allaben, NY	63.7	Ulster	Sep 1988*
01362500	E16I	Esopus Creek at Coldbrook, NY	192	Ulster	Oct 1931
01362192	AEHG	Panther Mtn Trib To Esopus Cr Nr Oliverea NY	1.54	Ulster	Oct 2001
013621955	ABCG	Birch Cr at Big Indian	12.5	Ulster	Oct 1998
01362230	SRR2	Diversion From Schoharie Reservoir		Ulster	Dec 1996
0136230002	WDL	Woodland Creek above mouth at Phoenicia, NY	20.57	Ulster	Oct 2003
01362342	ASCHG	Hollow Tree Brook at Lanesville, NY	1.95	Greene	Oct 1997
01362380	SCL	Stony Clove Creek nr Phoenicia, NY	31.5	Ulster	Feb 1997
01362465	ABKHG	Beaver Kill Tributary above Lake Hill, NY	0.98	Ulster	Jul 2000
01362497	LBK	Little Beaver Kill @ Beechford nr Mt. Tremper, NY	16.5	Ulster	Oct 1997
01362197		Bushnellsville Creek at Shandaken, NY	11.4	Ulster	1971-'86, 1993 - P

*Prior to October 1988, published as "at Shandaken" (01362198)

Photo 2.19 USGS stream gage Esopus Creek at Coldbrook, NY (013262500)

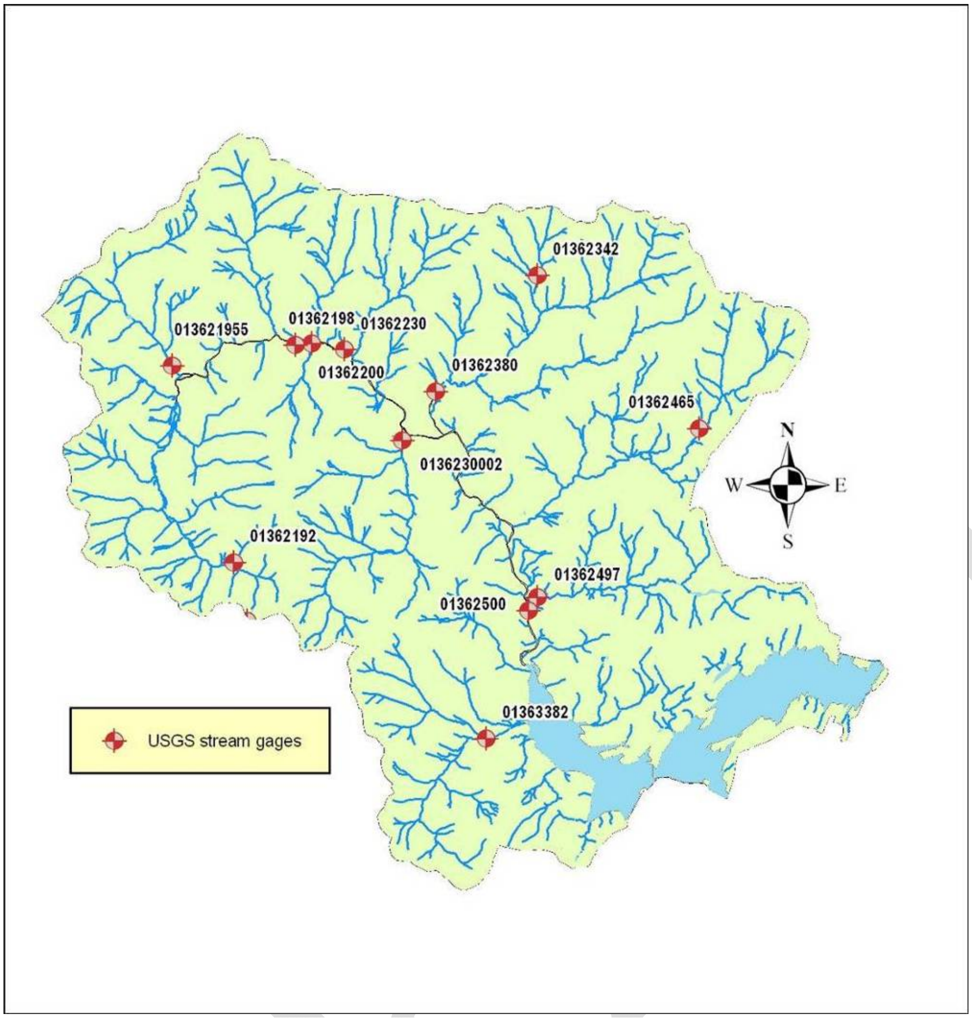


Figure 2.15 United States Geological Survey Stream Gaging Stations within the Esopus Creek watershed. The map includes the former gaging station at Shandaken (01362198) and does not include the crest stage gage located on Bushnellsville Creek (01362197)

The stream flow records for the two Esopus Creek gages are of sufficient length to perform several kinds of hydrologic analyses that take advantage of long-term records. The next section summarizes the hydrologic analyses completed by the US Army ERDC for this Management Plan.

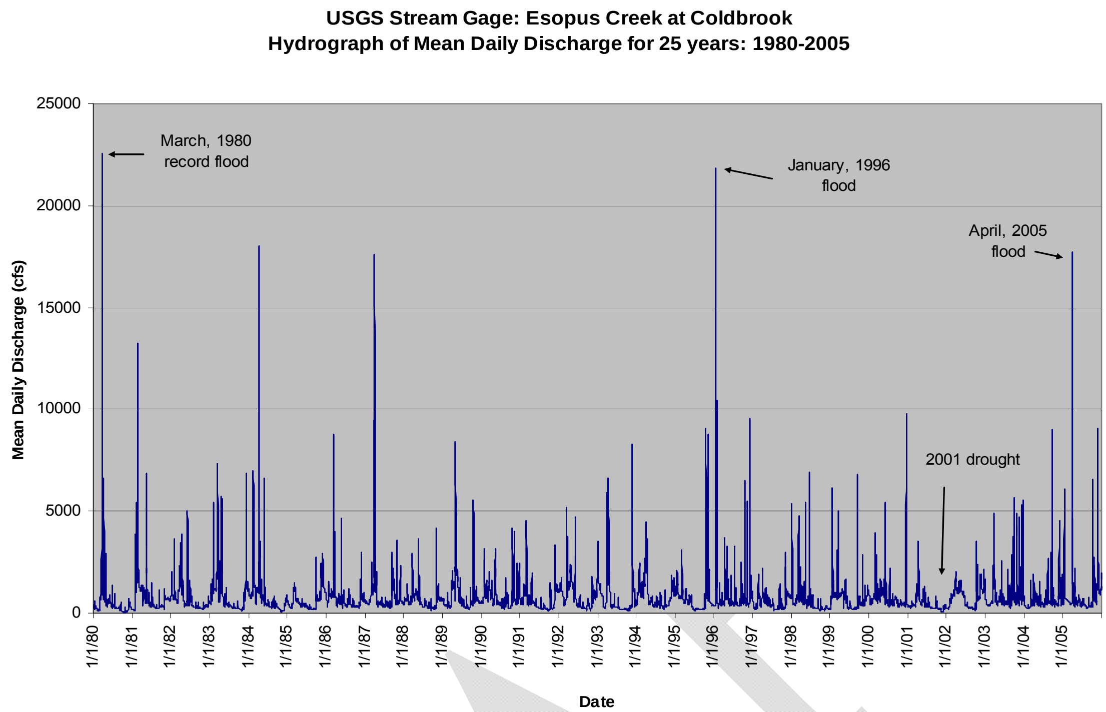


Figure 2.16 Mean Daily Discharge Hydrograph for Esopus Creek at Coldbrook (1980-2005)

2.6.3 Hydrologic Analyses

Hydrologic analyses were conducted to determine the flood frequency characteristics of the Upper Esopus Creek and its principal tributaries. This information was used in assessing flooding and erosion threats within the basin. Analyses were also conducted to assess trends that might be indicative of changing watershed or climate conditions. Flow duration analyses were developed at key locations to assist in formulating a sediment budget for the system. An analysis of low-flow conditions was conducted to support the environmental assessment for the system.

Flood Frequency Analyses

Flood frequency refers to the probability of a given flood magnitude to occur in any given year. The "*N*-yr" designation relates to the probability of occurrence of a discharge equal to or greater than the designated value in any one year, where *N* = 1/probability.

The 100-year flood, for example, is the stream flow rate, in cubic feet per second (cfs), that is exceeded by a flood peak in one year out of 100, on the long-run average, or, equivalently, exceeded with a probability of 1/100 (1 percent) in any one year. The 100-year terminology does not imply regular occurrence or that a given 100-year period will contain one and only one event. The 100-year flood also is called the 1-percent-chance flood, and this terminology calls attention to the fact that each year there is a chance that the 100-year flood will be exceeded.

Flood occurrence is a stochastic process, largely unpredictable over time spans longer than a few days or weeks. Thus, a rash of exceedances of the 100-year flood can occur in a short time by pure random chance (and bad luck). In addition, the true 100-year flood is never known with certainty, but must be estimated from a small sample using uncertain assumptions about the flood-generating processes, with the result that the estimated 100-year flood may be lower (or higher) than the true value.

Flood probabilities for the Esopus Creek mainstem and tributaries were determined using the guidelines in USGS Bulletin 17 B (1982) and instantaneous peak discharges from gage data for the period of record through the 2006 water year. Only three of the gages in the watershed (two on the mainstem) have a sufficient period of record to produce reliable estimates of flood probability using this method, so regional relations for ungaged watersheds were also applied to determine flood probabilities (Lumia, 1991).

Table 2.6 presents a summary of the computed discharges. Discharge-frequency estimates are presented as follows: top line (red) is computed from Lumia's regression equations; second line (blue) is computed from Bulletin 17B; third line (black) was used in the analyses for the Management Plan, and is an adjusted value based on professional judgment and site-specific knowledge compared with Lumia's regression and flood frequency analysis according to Bulletin 17B (where applicable) and rounded to three significant digits. **Appendix D** includes plots of the computed systematic-record flood frequency using an initial estimate of the Bulletin 17B frequency curve adjusted following the guidelines in 17B to account for historic data, high and low outliers, and regional (generalized) skew information (see USGS 1982 for more information on specific methods).

Flood frequency analyses were also conducted for the principal ungaged tributaries within the watershed using the regression relations developed by Lumia (1991). Estimates of the bankfull discharge were made using the Catskill regional regression relations developed by Miller and Davis (2003). Values of bankfull were assumed to fall in the range of a 1.3 to 1.7 year return frequency, with the 1.5 year return frequency displayed in report tables as an average. **Table 2.7** presents a summary of the computed discharges and relevant information for the tributaries.

For the purposes of the flood and erosion hazard analysis and the sediment budget discussed in **Section 3.1.2**, it was necessary to resolve these peak discharges at various points along the mainstem of the Esopus Creek. Adjustments to the peak discharges were made so that the flows were additive and representative of likely conditions at any point in the system. **Table 2.8** presents the discharges used for these analyses.

The Esopus Creek downstream of Allaben is a regulated stream**,** receiving releases from the Shandaken Tunnel, which provides an interbasin transfer from the Schoharie

Reservoir to the north in Greene County. Regulations under Part 670 specify that releases be provided to maintain minimum flows in the summer and not contribute to flooding (NYSDEC, 1977). Maximum discharge capacity from the Tunnel is about 1000 cfs, although the peak discharge recorded since the installation of a gage in December of 1996 is 913 cfs (USGS gage #01362230, Diversion from Schoharie Reservoir). Mean daily discharge at Allaben has exceeded bankfull (3000 cfs) three times during that period (12/96-11/06). On those dates, tunnel releases were 6.6, 5.5, and 65 cfs., respectively. On June 28, 2006, mean daily discharge at the Allaben Gage was 2940 cfs (bankfull is 3000 cfs). The USGS gage data for the diversion are absent for that day due to backwater effects at the tunnel, but discharge was 886 and 879 cfs, respectively, on the preceding and following days. [It is important to note that during flows greater than 2,000 cfs at the Allaben gage, the stage-discharge relationship at the Tunnel gage may be affected by backwater from Esopus Creek – as noted on the web-page for the gage.] **Figure 2.17** shows the mean daily portal discharges for the period of record for the USGS gage installed on the site. Also shown in the figure are the mean daily discharges at the Allaben gage on the Esopus Creek and the cumulative discharge. The figure demonstrates that, prior to 2006, high combined discharges are predominantly from Esopus Creek flows.

Table 2.6. Summary of flood frequencies for USGS gages in the Esopus Creek watershed.

Station name and number	Years of peak discharge record (N)	Recurrence interval (years)								
		1.25	1.5	2	5	10	25	50	100	500
		Peak-discharge (ft^3/s)								
Birch Creek (13621955)	7[1]		852	1015	1943	2784	4137	5376	6766	10762
			852	915	1550	2030	3000	3870	4840	7590
Bushnellsville (01362197)	27		772	897	1718	2463	3662	4761	5992	9533
		190	252	347	691	1,027	1,609	2,183	2,903	5328
			772	800	1370	1800	2650	3430	4290	6720
Esopus at Allaben (01362200)	42	2670	3410	4404	8157	11447	16626	21308	26516	41273
		1820	2493	3498	6961	10120	15240	19970	25580	42710
		2500	3000	3900	7500	10500	15500	20000	26000	43000
Woodland Valley (136230002)	3[1]		1242	1849	3651	5312	8037	10583	13487	22052
			1242	1665	2921	3878	5827	7620	9643	15547
Stony Clove (1362380)	9[1]		1769	2404	4523	6411	9415	12148	15202	23924
			1800	2500	5000	7000	10000	14000	17000	20000
Beaver Kill (1362465)	6[1]		1465	1976	3761	5365	7937	10290	12931	20524
			1470	1780	3010	3910	5750	7410	9250	14500
Little Beaver Kill (1362497)	8[1]		1055	1393	2697	3886	5813	7592	9601	15436
			1060	1250	2160	2840	4220	5470	6870	10900
Esopus Creek at Coldbrook (01362500)	74	6500	8160	11627	20881	28761	40906	51735	63675	96948
		7555	10090	13820	26390	37680	55850	72550	92270	152400
		7600	10100	13800	26000	37000	55000	70000	90000	150000

Top line (red) is computed from Lumia's regression equations; second line (blue) is computed from Bulletin 17B; third line (black) is an adjusted value

[1] Insufficient period of record for reliable 17B flood frequency analyses.

Table 2.7. Summary of flood frequencies for tributaries in the Esopus Creek watershed.

Reach	River Mile	Description	DA (mi^2)	Annual Precip (in)	Discharge (cfs) for the Indicated Return Frequency (years)						
					Bankfull[1]	2	5	10	25	50	100
20	22.4	Upper Esopus Creek	8.54	50.0	625	676	1178	1561	2339	3050	3845
20	22.4	Little Peck Hollow	2.67	50.0	252	243	437	591	906	1197	1528
19	21.75	Elk BuskKill	3.66	50.0	323	321	572	769	1172	1543	1962
18	20.75	McKinley Hollow	2.77	50.0	260	251	451	610	933	1233	1573
17	19.05	Hatchery Hollow	4.74	50.0	395	403	713	955	1447	1900	2409
16	18	Other Sources Upstream of Birch Creek	4.08	50.0	351	353	628	842	1280	1684	2139
16	18	Lost Clove	2.97	50.0	274	267	479	646	988	1304	1662
15	17.35	Birch	12.72	47.7	852	914	1554	2032	2999	3871	4837
12	14	Bushnellsville	11.20	47.2	772	807	1374	1798	2655	3428	4285
11	12.8	Peck Hollow	5.04	48.3	414	411	720	958	1442	1885	2381
11	12.95	Fox Hollow	4.01	51.0	346	355	634	854	1302	1717	2185
10	11.95	Shandaken Tunnel - "the portal"	N/A	N/A	940	940	940	940	940	940	940
9	11.7	Broadstreet Hollow	9.20	48.6	662	702	1211	1596	2378	3088	3880
6	8.75	Woodland Valley	20.60	56.8	1242	1665	2921	3878	5827	7620	9643
5	7.85	Stony Clove	32.45	49.4	1769	2163	3619	4680	6826	8747	10870
2	4	Beaver Kill	25.46	50.3	1465	1779	3009	3917	5754	7409	9245
1	1.8	Little Beaver Kill	16.71	51.3	1055	1254	2158	2837	4215	5467	6865
0	0	Bushkill	19.43	55.6	1186	1547	2705	3585	5375	7018	8868

[1]Bankfull discharge computed using Miller and Davis, 2003

Table 2.8. Discharges at key points along Esopus Creek used in Management Plan studies.

				Discharge (cfs) for the Indicated Return Frequency (years)							
Reach	River Mile	Description	DA (mi^2)	Bankfull[1]	2	5	10	25	50	100	500
20	22.40	Upstream of Little Peck	8.54	625	680	1200	1550	2350	3050	3850	6150
20	22.40	Little Peck - Hatchery Hollow	17.64	1400	1500	2650	3550	5350	7050	8900	14400
17	19.05	Hatchery Hollow - Birch Creek	29.43	2400	2500	4450	5950	9050	11900	15100	24500
15	17.35	Birch Creek - Bushnellsville	42.15	2600	3000	6000	8000	12050	15800	20000	32000
12	14.00	Bushnellville - Fox Hollow	53.35	2800	3600	7000	9800	14700	19200	24200	38800
11	12.8	Fox Hollow - Portal	62.5	3000	3900	7500	10500	15500	20000	26000	43000
10	11.95	Portal - Broadstreet	63.7	4000	4900	8500	11500	16500	21000	27000	44000
9	11.70	Broadstreet - Woodland Valley	71.61	5500	5700	9950	13200	19800	26840	32700	52300
6	8.75	Woodland Valley - Stony Clove	92.21	6800	7370	12900	17100	25700	33500	42300	67900
5	7.85	Stony Clove - Beaver Kill	124.66	8500	9530	16500	21800	32500	42300	54140	84700
2	4.00	Beaver Kill - Little Beaver Kill	150.12	10000	11300	20440	25700	38200	49700	62400	99200
1	1.80	Downstream of Little Beaver Kill	192	10100	13800	26000	37000	55000	70000	90000	150000

[1]Bankfull discharge computed using Miller and Davis, 2003

Analyses of flood frequency were conducted for several gages in the region and discharge values normalized on the basis of drainage area for translation to other sites (Table 2.9, from Fischenich 2001). The results show that discharge is highly variable in the region, but the discharges on the Esopus Creek are near the mean values for all the gages except at the highest discharges, where the flows on the Esopus are generally larger than the norm.

Table 2.9. Flood frequencies (determined by Gumbel analysis) of nearby gages normalized by drainage area.

				Q/DA by Frequency					
Gage	DA	1	1.5	2	5	10	25	50	100
Esopus Creek At Shandaken NY[1]	59.5	21.0	47.4	67.2	119.3	235.3	252.1	294.1	339.5
Esopus Creek At Allaben NY	63.7	23.5	35.5	42.4	90.3	188.4	235.5	282.6	329.7
Esopus Creek At Coldbrook NY	192.0	33.9	53.6	64.6	140.1	244.8	291.7	312.5	322.9
Esopus Creek At Mount Marion NY[2]	419.0	12.4	18.7	23.6	32.2	45.3	53.7	60.9	68.0
Beaver Kill Nr Turnwood NY	40.8	34.3	57.6	72.3	137.3	147.1	177.7	203.4	230.4
Batavia Kill At Ashland NY[2]	62.0	93.5	116.1	161.3	241.9	314.5	390.3	446.8	500.0
Shawangunk Kill At Ganahgote NY	147.0	17.0	20.4	33.7	71.4	88.4	107.5	123.8	140.1
Rondout Creek Nr Lackawack NY	100.0	1.7	18.0	27.7	75.0	120.0	156.0	188.0	215.0
Hannacrois Creek Nr New Baltimore NY	61.6	7.5	15.1	17.7	36.5	40.6	53.6	61.7	69.0
Mean	94.9	19.8	35.4	46.5	95.7	152.1	182.0	209.4	235.2
Median	63.7	21.0	35.5	42.4	90.3	147.1	177.7	203.4	230.4
Esopus Weighted Ave		26.1	40.0	47.9	102.7	202.4	249.5	290.0	328.0

1 Former site of present "Esopus Creek at Allaben" gage.
2 Not used in analyses because flows are regulated upstream of the gages, but displayed for information.

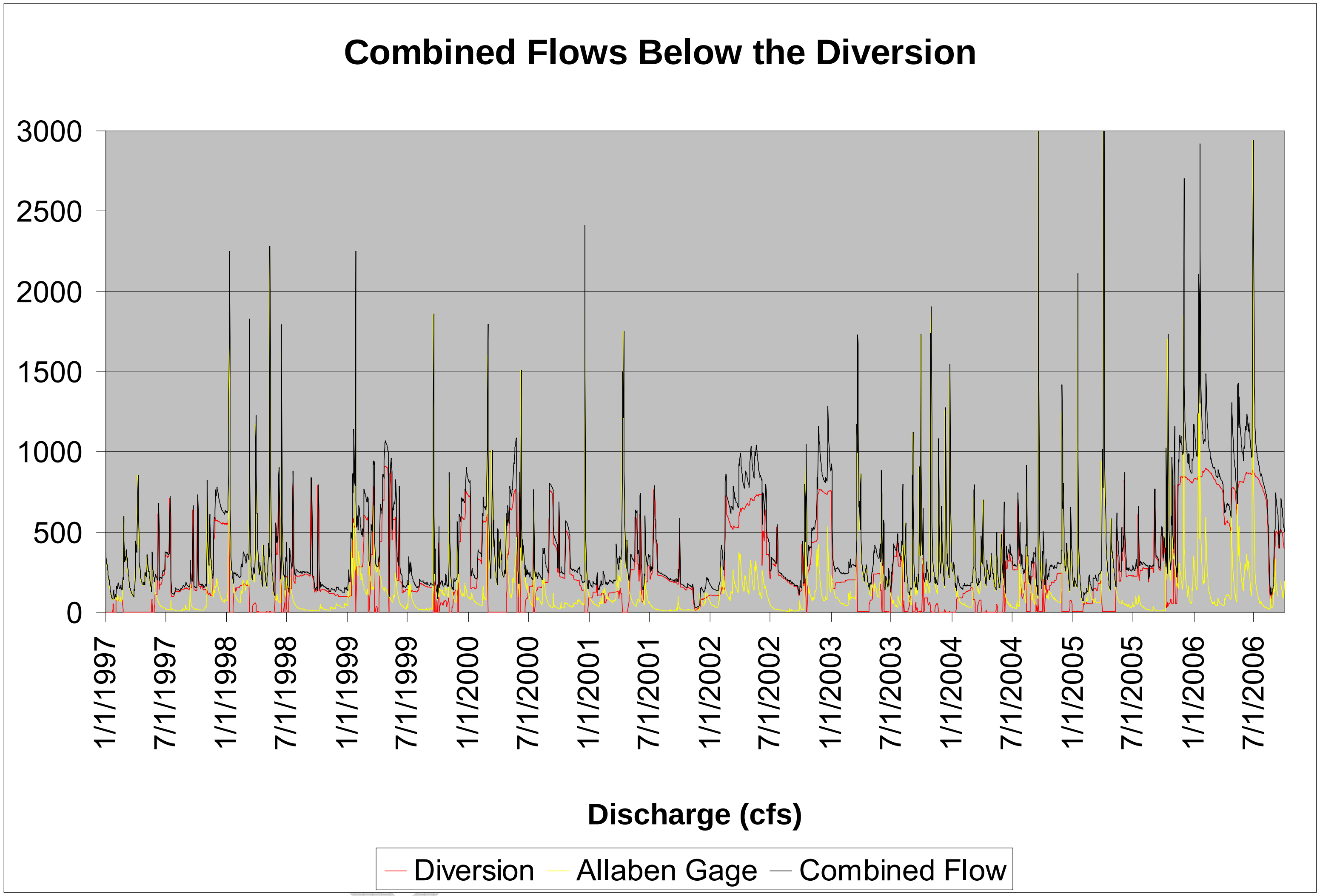


Figure 2.17. Portal discharges for the period of record shown in conjunction with flows on the Esopus Creek at Allaben.

Trends Analysis

Flood Frequency analysis shows that major floods have occurred sporadically throughout the last century with 1933, 1936, 1951, 1955, 1957, 1980, 1984, 1987, 1996, and 2005 being the 10 major floods of record. Among recent events, the 2005 flood ranks 3rd and the 1996 flood ranks 6th in this time period at the Coldbrook gage. Table 2.10 lists the top 10 flood events at the Coldbrook Gage since 1933. The mean daily discharge and stage are also shown in the table for information purposes.

Table 2.10. Ranking of the top ten floods on the Esopus Creek at Coldbrook.

Rank	Date	Peak Discharge (cfs)	Mean Daily Discharge (cfs)	Peak Stage (ft)	Adjusted Return Frequency (years)
1	21-Mar-80	65300	22100	21.94	40
2	30-Mar-51	59600	15800	20.7	
3	3-Apr-05	55200	17400	20.57	25
4	24-Aug-33	55000	24400	20.4	
5	15-Oct-55	54000	22900	20	
6	19-Jan-96	53600	21800	20.33	
7	4-Apr-87	51700	17400	20.06	
8	21-Dec-57	46900	15900	18.98	
9	12-Mar-36	38500	17200	17.9	
10	5-Apr-84	37400	17900	17.75	10

We can look at the annual peak flow record (the highest stream flow recorded for a year) and do two simple analyses (1) rank the flows and identify the flood of record; and (2) determine when these floods are most likely to occur. The flood of record was the March 21, 1980 flood. Figure 2.18 is a pie chart identifying when these peak floods are most likely to occur. Most flooding occurs associated with rainfall on snow events: December through early April accounts for 59% of the annual peak flows (and March has the most of any month). In fact, 8 of the top 10 floods were spring or winter floods associated with rain and/or melting snow.

If we look at the full record for the Coldbrook gage (**Figure 2.19**) we see that there are periods of more frequent flooding and periods of relatively dry conditions that roughly correspond to a decadal scale.

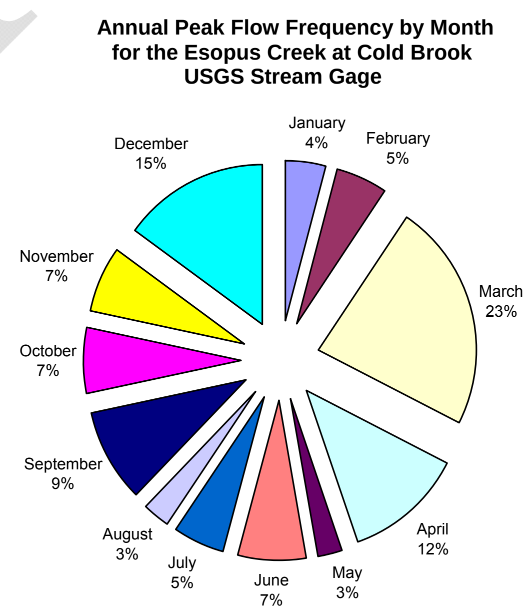


Figure 2.18 Seasonal distribution of annual peak floods for Esopus Creek at Coldbrook

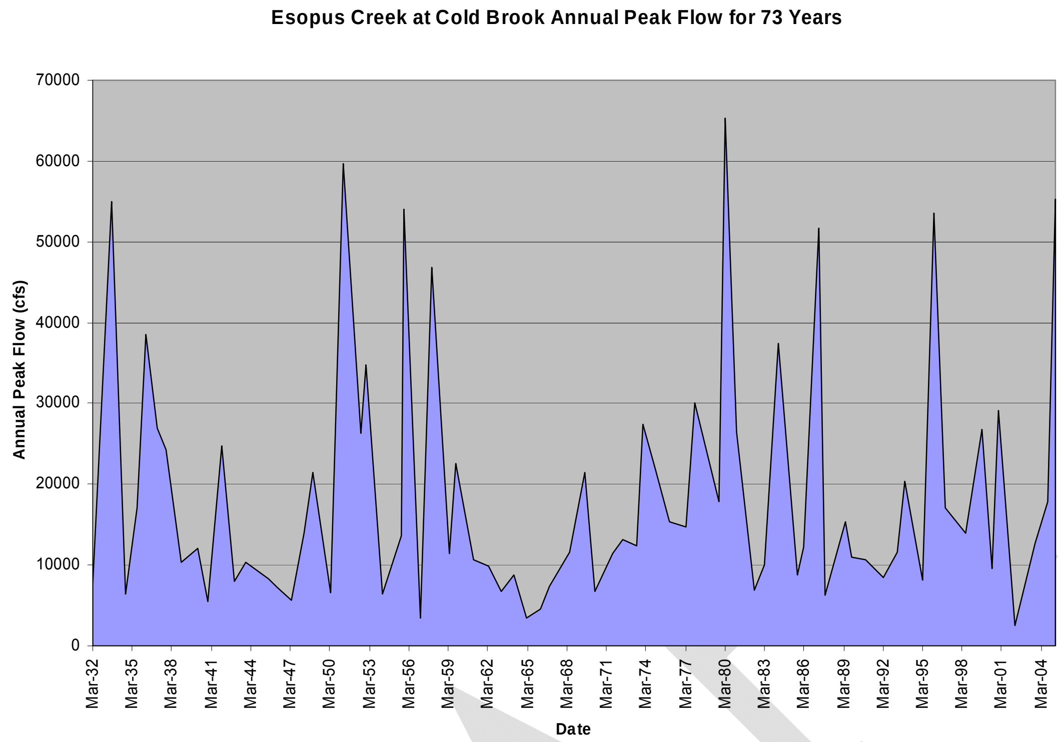


Figure 2.19 Esopus Creek at Coldbrook Annual Peak Flow Hydrograph

For instance the 50's and late 70's through the 80's had several big floods. The 60's was a notably dry period. There are of course important exceptions as there were years of drought during the generally wet periods. For example the record low peak flow occurred in 2002 and was followed by three relatively wet years.

Daily discharge data were evaluated for the Allaben and Coldbrook gages for the period of record to determine if any trends exist. Data from the Coldbrook gage for the annual maximum one day mean discharge (the highest mean daily discharge measured each year) show a slight decrease over the period of record, but the change is not statistically significant (**Figure 2.20**). The opposite trend is evident in data from the gage at Allaben (combined with data from the old gage site at Shandaken) but, again, the trend is not statistically significant (**Figure 2.21**). The role of the tunnel complicates this kind of "above/below" type trend analysis.

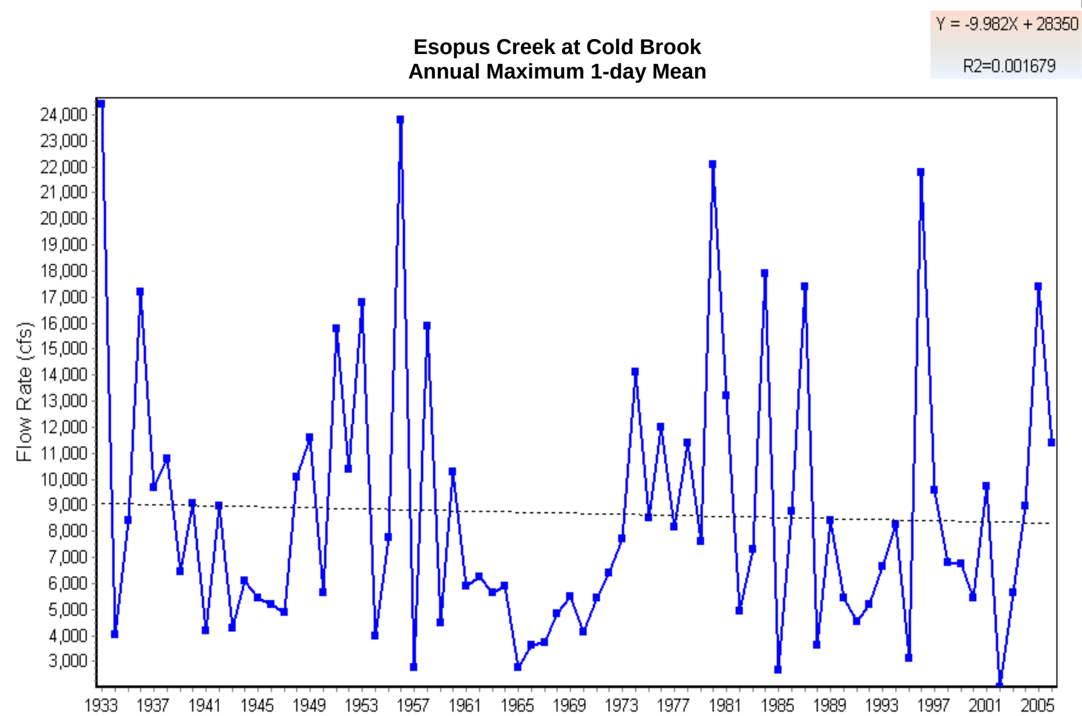


Figure 2.20. Trend in daily mean discharge for the period of record at Coldbrook.

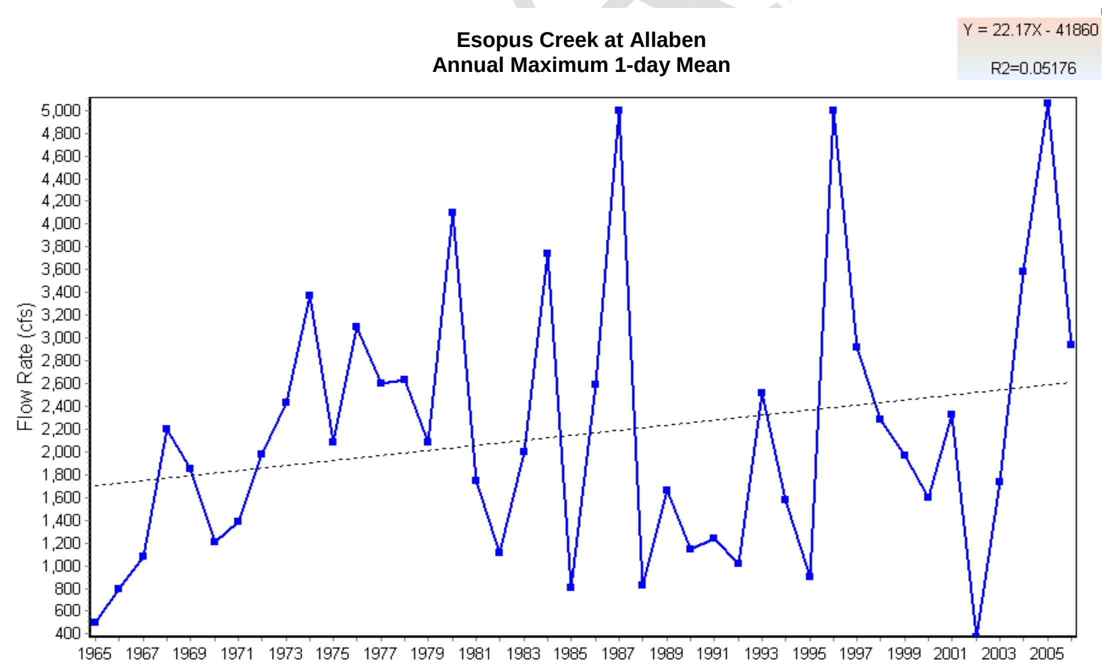


Figure 2.21. Trend in daily maximum discharge for the period of record at Allaben.

The upward trend in maximum daily discharge at Allaben is largely a function of the period of record. Roughly decadal climate cycles are often evident in precipitation records, and the Coldbrook data reflects the wet/dry periods experienced regionally in the past century. The 1930's, 1950's, late 1970's through the early 1980's, and late 1990's through present have been generally wet and the peak discharges in those years reflect this. The 1960's were among the driest on record, and this happens to correspond to the start of records for the Allaben/Shandaken gage. If either the first or last five years of the period are eliminated, no trends in the frequency of flood events are noted.

The number of times each year the discharge equals or exceeds bankfull, compared over a period of years, can be a useful metric in assessing stream stability. If, over the long run, bankfull and larger discharges begin to occur more or less frequently, or if the magnitude of these flows increases or decreases, stream channels may begin to adjust, affecting stream stability. **Figures 2.22** and **2.23** present plots of the annual frequency of small floods (defined as exceeding a 1.5 year return frequency based on daily mean discharge) for the Coldbrook and Allaben gages, respectively. While the trendline over the past seventy years indicate no statistically significant change in the frequency of bankfull or larger flows, over the past forty years, at least, a (roughly) decadal cycle is apparent. The impact of this cycling on stream system stability is not clear. Aside from the shorter term climactic cycling, over the long-term from the above analyses and other investigations we have concluded that there are no evident trends in the discharge characteristics of Esopus Creek as they relate to flood magnitude or frequency.

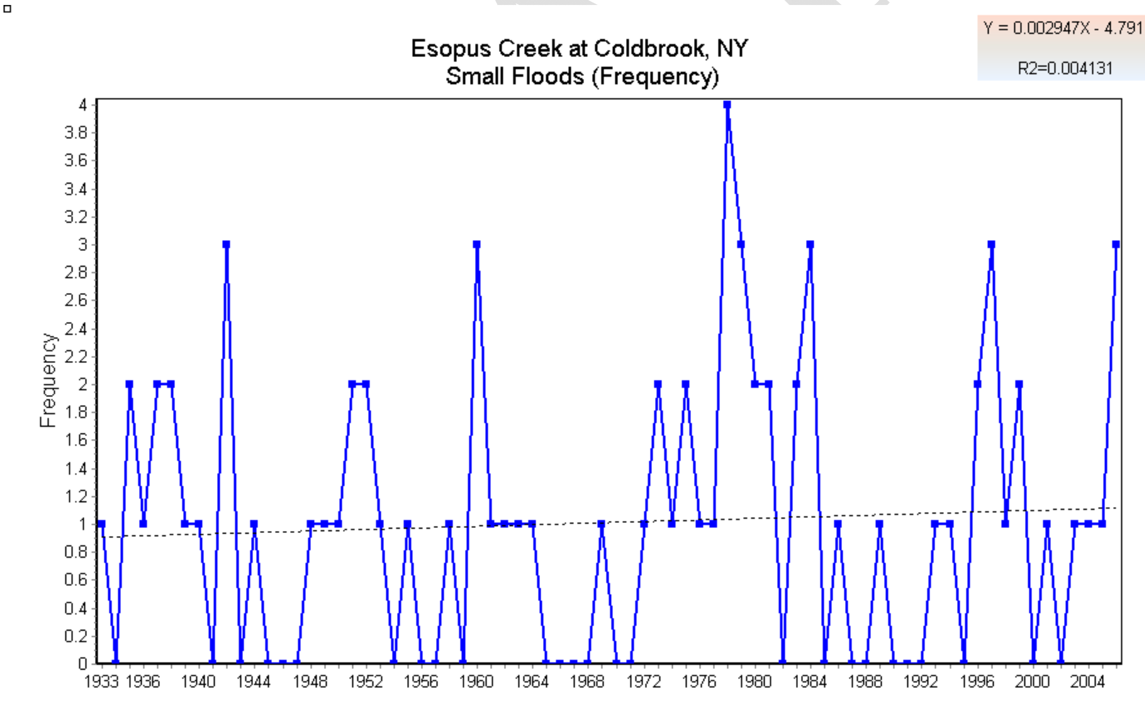


Figure 2.22. Frequency of bankfull or larger discharges at the Coldbrook gage.

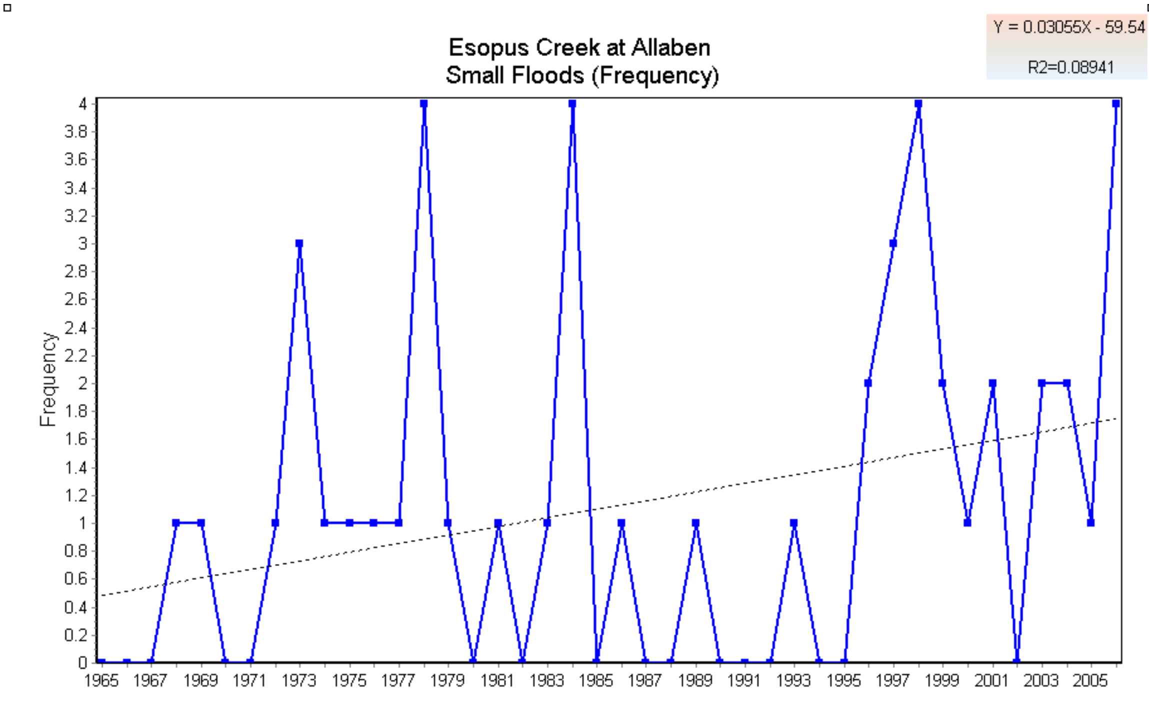


Figure 2.23. Frequency of bankfull or larger discharges at the Allaben gage.

Flow Duration Analyses

Flow duration analyses can be very helpful in assessing stream conditions. They are particularly useful when selecting elevations at which to establish erosion control measures that utilize plant materials, and for conducting erosion and sediment transport analyses. **Figures 2.24** and **2.25** present flow duration analyses for the Coldbrook and Allaben gages. **Figure 2.26** presents the flow duration analysis for 7 regional gages, where results are normalized by drainage area to permit comparison of relations among basins.

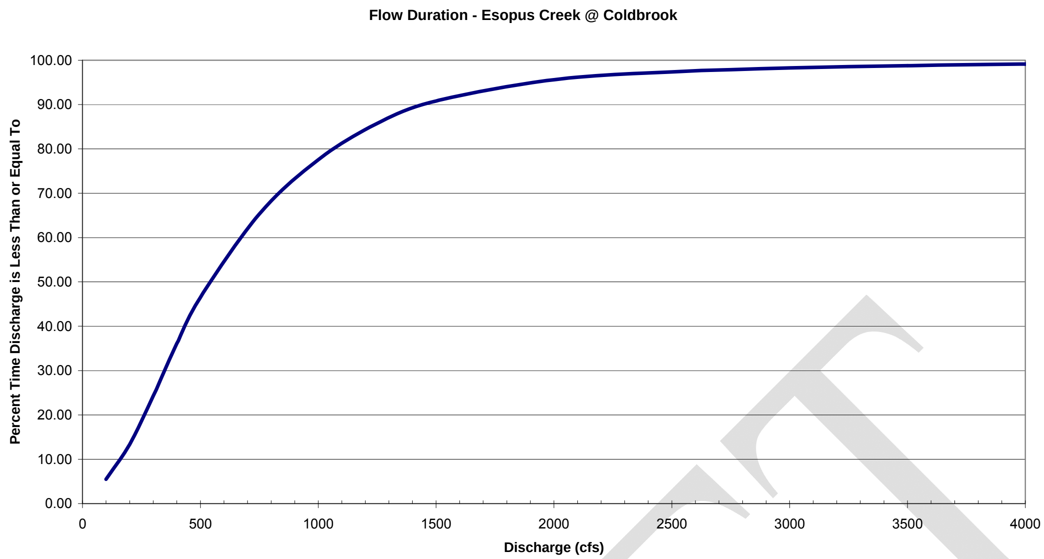


Figure 2.24. Flow duration analysis for Esopus Creek at Coldbrook. Percent Time is Exceedence probability (the probability that a selected flow will be exceeded) multiplied by 100.

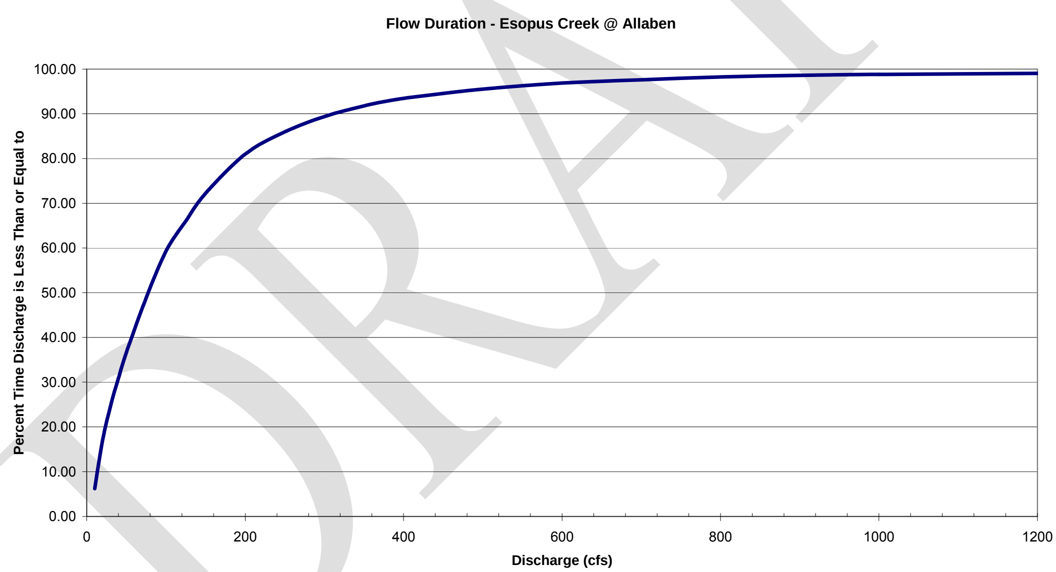


Figure 2.25. Flow duration analysis for Esopus Creek at Allaben. Percent Time is Exceedence probability multiplied by 100.

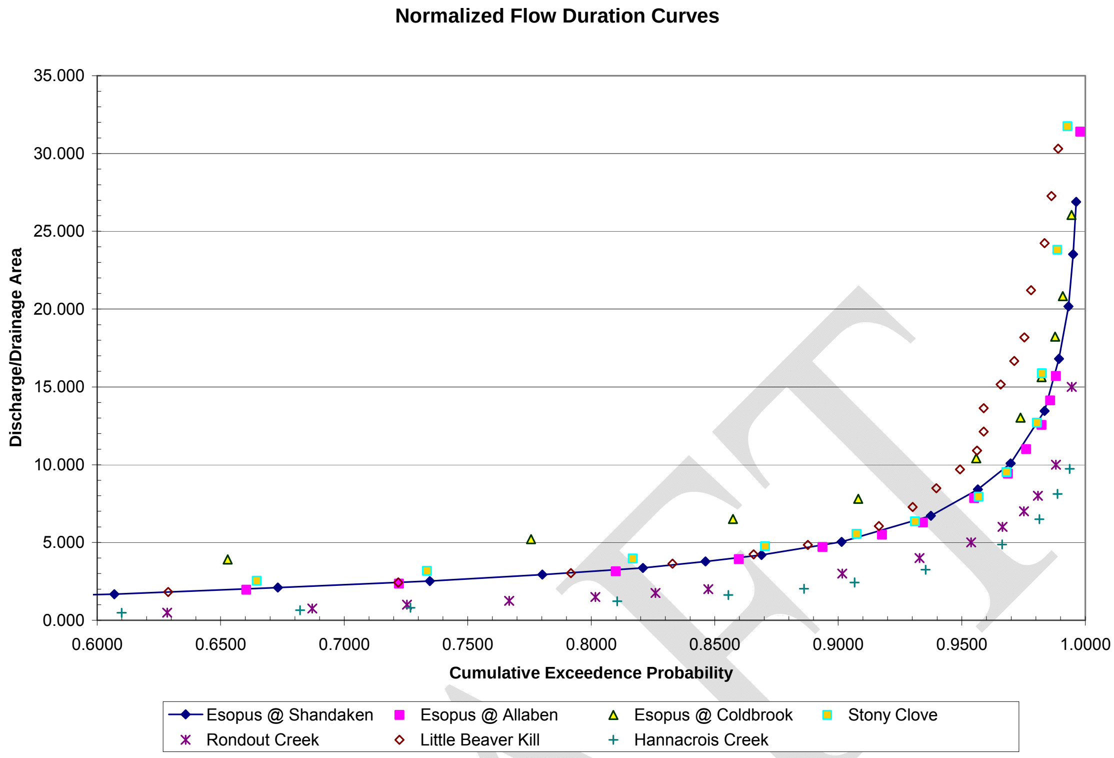


Figure 2.26. Normalized flow duration data for regional gages.

Environmental Flows

The timing, magnitude, frequency and duration of flow pulses and extreme flow events (high and low) play a significant role in defining the quality and character of aquatic and riparian ecosystems and wetlands. A statistical software package developed by the Nature Conservancy was used to assess the environmental flow components of Esopus Creek using 32 parameters organized into five groups (TNC 2005). All daily flows are partitioned into two initial event types, low flows and high flows. After this initial assignment of event types is complete, the low flows are divided between low flow and extreme low flow events, and the high flows are divided between high flow pulse, small flood, and large flood events. **Figures 2.27** and **2.28** show the flow conditions for the Coldbrook and Allaben gages.

The parameters evaluated for the gages displayed no significant trends or notable results, except that base flow conditions have increased at Coldbrook as demonstrated by the rise in seven-day low flow conditions (**Figure 2.29**). Further examination of the data suggests that much of the increase can be attributed to the diversion from the Shandaken Tunnel. **Figure 2.30** shows the change in the base flow index pre- and post-Part-670 regulation of the diversion flows.

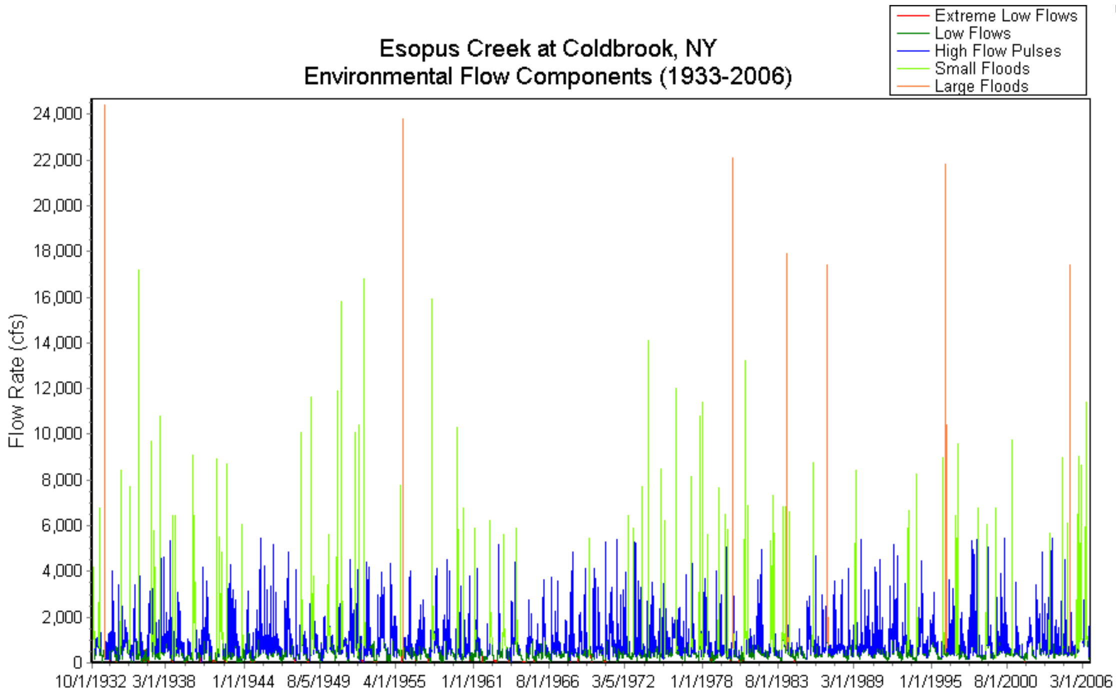


Figure 2.27. Environmental flow components for the Esopus Creek at Coldbrook.

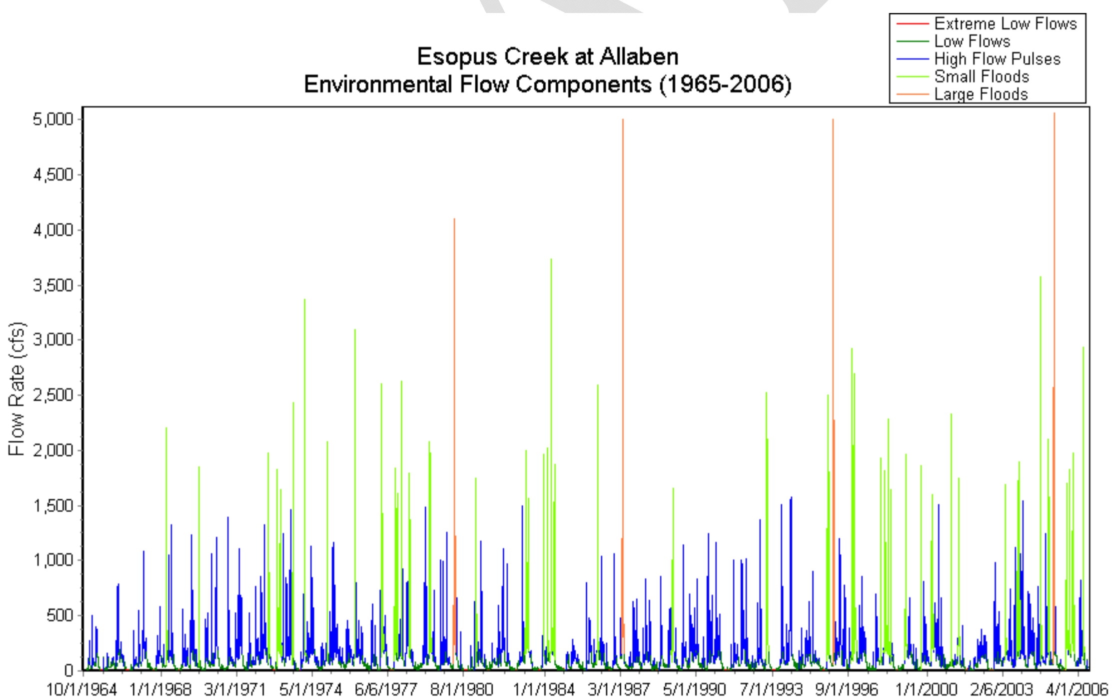


Figure 2.28. Environmental flow components for the Esopus Creek at Allaben.

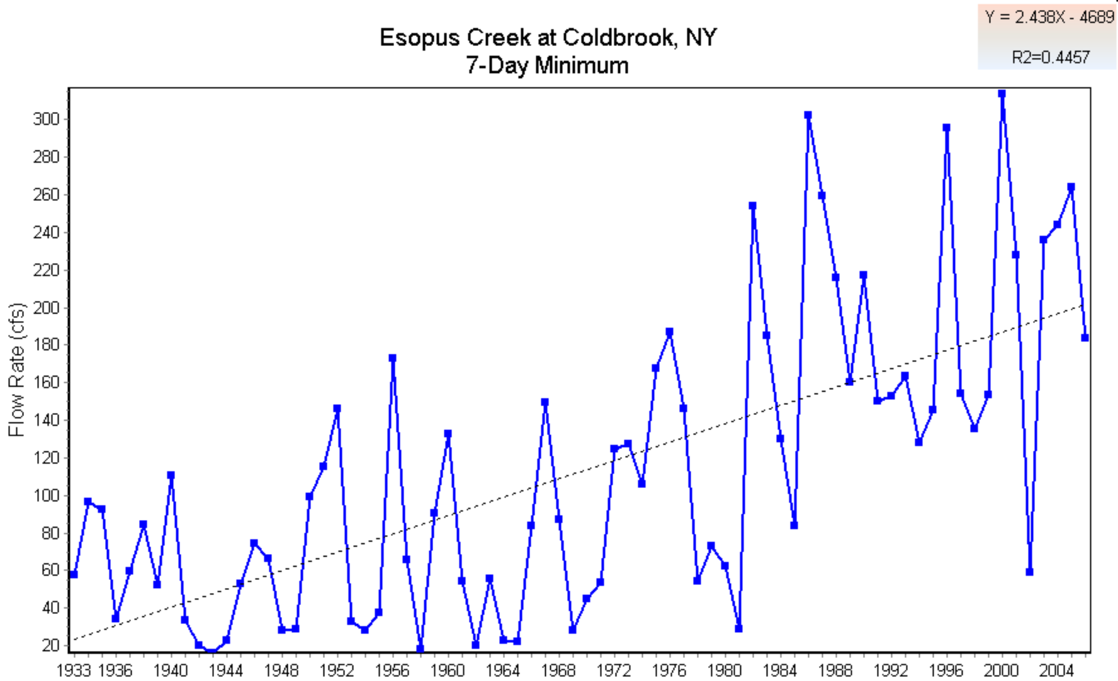


Figure 2.29. Seven-day low flow conditions for Esopus Creek at Coldbrook.

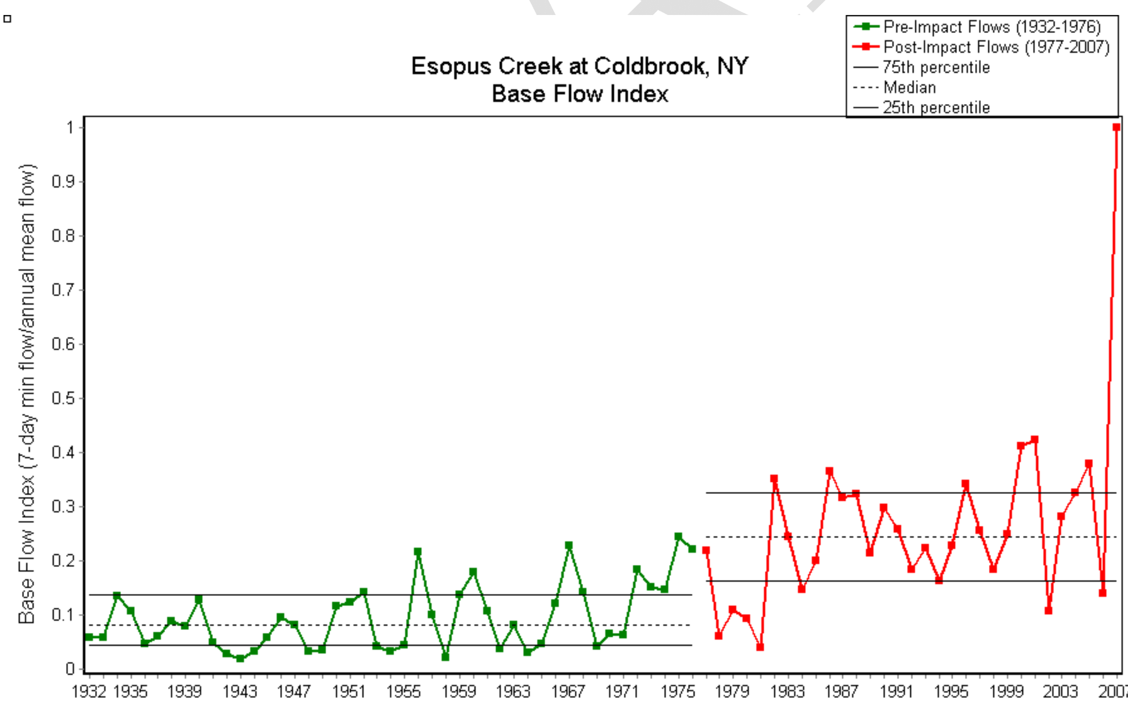


Figure 2.30. Baseflow index for Esopus Creek at Coldbrook comparing pre- and post-diversion conditions.

2.7 Upper Esopus Creek Water Quality

Photo 2.19 Confluence of Fox Hollow with Esopus Creek at Allaben, May 18, 2006

2.7.1 Introduction

The Purpose of this Section is to describe a general understanding of water quality issues in the Upper Esopus Creek watershed. Water quality is a broad topic and extends well beyond the focus of this Management Plan. The focus here is on water quality as it pertains to drinking water, ecologic, and aesthetic condition. What is the general quality of the water that flows through the Esopus? What is measured and who is monitoring the water quality? What are the most important water quality issues that need to be addressed in a Management Plan for Upper Esopus Creek? This Section addresses those questions.

First, and foremost, the Catskill Mountains yield good quality water. The water that flows through these creeks successfully sustains a healthy ecosystem and a substantial part of the water needs of over 9 million people. This is largely due to the “filter” that the forested land, bedrock and surface deposits provide the Esopus Creek watershed hydrologic system. However, the geology also throws a monkey wrench into the system. Silt and clay – buried in ice age deposits – are easily eroded into the stream and often, after a major storm, the streams run with a characteristic reddish brown color (**Photos 2.19** and **2.20**). As explained below, from all perspectives the resulting turbidity is considered the number one water quality concern in the watershed.

Photo 2.20 Esopus Creek just above Little Beaver Kill after the April 2-3, 2005 flood. During this time the Shandaken Tunnel was turned off.

Stream water quality is dynamic – it can change daily or with the season in response to what is going on in its watershed. This is obvious to anyone who has spent a few seasons watching a Catskill creek. We know that the water quality of Esopus Creek anywhere along its course is a function of the following factors:

- Geology: What is the earth material the water encounters while traveling in the landscape? Does the geology filter or contaminate the water?
- Land Cover and Land Use: Is there sufficient forest cover in the mountain landscape to minimize erosion and reduce flooding? Are there land uses along the stream that may potentially impair water quality or constrict the floodplain?

Is the amount of *impervious surface* in the watershed causing more contaminants to get in the stream?

- Hydrology/Climate: How do storm intensity, duration and magnitude affect water quality? Solar radiation and temperature can affect water quality in a number of ways. Storm events are a common cause of degraded water quality due to erosion and flooding.
- Precipitation quality: How clean is the water that is delivered to the watershed? There is some atmospheric deposition of mercury across the northeast. We know that throughout much of the last century acid deposition has impacted the region. How significantly has this affected the stream's water quality?

In addition to these natural watershed factors, Upper Esopus Creek has been augmented/regulated by the diversion of water from Schoharie Reservoir through the Shandaken Tunnel since the 1920's. Since its beginning, the Shandaken Tunnel has had an impact on water quality with respect to turbidity and temperature, as detailed in **Volume II Section 2**. Since 1977, the Shandaken Tunnel has been operated under the guidelines of Part 670 of the NYS DEC Rules and Regulations (http://www.dec.state.ny.us/website/regs/part670.html). A recent SPDES permit for the Shandaken Tunnel (September, 2006) further regulates the operation of the tunnel specifically with respect to turbidity and temperature (a pdf file of the SPDES permit is located in **Appendix C**). During the period of November, 2005 through December, 2006 the Shandaken Tunnel operated under emergency conditions while the Gilboa Dam (impounding the Schoharie Reservoir) underwent emergency repairs resulting in a year of sustained high flows.

2.7.2 NYSDEC Stream Classification and Impaired Water Body List

All waters in New York State are given a class and standard designation based on best usage for that water body (NYSDEC, 1998). The New York State DEC stream classification system includes the following designations:

Stream Classifications

Class	Best Use
AA	Drinking (after chlorination)
A	Drinking (after chlorination and filtration)
B	Bathing
C	Fishing
D	Secondary contact recreation

New York Codes, Rules, and Regulations ("NYCRR"), Title 6, Section 701.

Additional designations of "T" or "TS" can be added if a water body has sufficient amounts of dissolved oxygen to support trout and trout spawning. Water bodies that are designated as "C (T)" or higher (e.g., "C (TS)", "B", or "A") are collectively referred to as "protected streams," and are subject to additional regulations. Periodically, the DEC publishes the Priority Water bodies List (PWL), which includes a list of water bodies that do not meet their designated "best use" classification. A data sheet that describes the conditions, causes, and sources of water quality degradation for each of the respective listings is also included in the PWL. The PWL is used by the DEC and other agencies as a primary resource for water resources management and funding.

From the headwaters to the outlet of the Shandaken Tunnel, the Esopus is classified as C, C (TS). From the outlet of the portal to its confluence with Ashokan Reservoir it is designated as a Class A, A (TS) stream. Tributaries of the Esopus are Class B, C (T), and A (T).

The Upper Esopus Creek from the portal to Ashokan Reservoir and Ashokan Reservoir were first listed on the DEC 303(d) list of impaired water bodies in NY State as impaired by siltation in 1998 and more specifically by sediment/siltation in 2002 and 2004. The source for the sediment/siltation is identified as streambank erosion. The ID # is H-171-P848-.

2.7.3 Water Quality Record

There are many ways to measure water quality, from direct laboratory analysis of water samples for various *analytes* to indirect measures such as aquatic insect surveys as indicators of water quality. There is a relatively extensive set of data for both direct and indirect measures on Esopus Creek. This Management Plan does not contain the data; rather it presents a summary of available information and points to where more detail can be obtained. **Appendix C** is a set of CDs that provide supplemental information. **CD.2** contains adobe files of various reports and documents that provide some water quality data and further information.

Direct Water Quality Measurements

There are several sources for direct water quality measurements for Esopus Creek. The following sources that provide the bulk of available information are:

- The most extensive and comprehensive available is from NYCDEP as part of its long-term water quality monitoring of the NYC drinking water supply (NYCDEP, 2006; website). NYCDEP has been sampling and analyzing Esopus Creek stream water since the early 1900's.
- From 1963 – 1992 USGS maintained a water quality monitoring station at the former USGS stream gage located at Shandaken which was subsequently moved downstream 0.5 miles to the current gage location at the mouth of Fox Hollow. A summary of the results is presented in USGS circular 1173 (Mast and Turk, 1999; http://pubs.usgs.gov/circ/circ1173/circ1173a/chapter09.htm). A copy of the relevant chapter is included on **CD.2** in **Appendix C**.
- The USGS, under contract to NYC DEP, has collected water quality at 3 locations in the Esopus Creek Watershed: Hollow Tree Brook (1997 – present), Stony Clove Creek, near Phonecia (1999 – present), and a Little Beaver Kill tributary

above Lake Hill (1997 – 2006); http://nwis.waterdata.usgs.gov/ny/nwis/qwdata and http://ny.cf.er.usgs.gov/nyc/unoono.cfm.

- In 2000, Stroud Water Research Center located in Pennsylvania was awarded a Safe Drinking Water Act (SDWA) grant funded by the New York State Department of Environmental Conservation and the USEPA to conduct a six-year study to monitor and evaluate water quality and sources of pollution in the streams, rivers, and reservoirs that provide New York City's (NYC) drinking water. There are nine sites in the Esopus Creek watershed (3 on Esopus Creek) that have been variably sampled since 2000. Copies of the reports for the first five years can be found at (http://www.stroudcenter.org/research/newyorkproject.htm).
- Upstate Freshwater Institute: UFI is currently under contract to NYCDEP to develop "Integrated Programs of Monitoring, Process Studies, and Modeling in Support of Rehabilitation Initiatives for Turbidity Problems in Schoharie Reservoir and Esopus Creek". As a consequence, a vast amount of very detailed data for, for instance, temperature, conductivity, beam attenuation coefficient, turbidity has been collected for the Schoharie Creek and Reservoir and the Esopus Creek at Coldbrook. The data have been presented at numerous meetings with regulators and are being published in the peer-reviewed international literature.

There are other sources, primarily associated with bio-monitoring that add to the available data. This draft of the ECMP presents the pertinent findings of the available NYCDEP data. The interested reader or researcher is encouraged to consult the enclosed reports for more detail on the NYCDEP, USGS and Stroud Center data.

NYCDEP has a long-term water quality sampling program of streams in the NYC water supply watersheds. Water quality samples are collected at a fixed frequency from a network of sampling sites throughout the watershed. Grab samples are generally collected once a month (twice a month at selected sites). Storm event sampling is also performed at selected sites. While the analyses performed on samples from a specific site vary somewhat based on the objectives for the site, in general, samples are tested for temperature, pH, alkalinity, specific conductivity, dissolved oxygen, turbidity, nutrients, dissolved organic carbon, total organic carbon, silica, chloride, suspended solids (selected sites), major cations (Ca, Mg, Na, K, Fe, Mn, Al, Cu) (analyzed monthly), trace metals (Ag, As, Ba, Cd. Also included here are Cr, Hg, Pb, Se, Zn) (collected at selected sites quarterly), and total and fecal coliform (most sites). The current monitoring system was re-designed in 2002 and was based on multiple objectives. Details may be found in NYC DEP's Integrated Monitoring Report (NYC DEP, 2002). Results are presented in annual water quality monitoring reports (e.g. NYC DEP, 2006). **Map 2.2** shows the NYCDEP sampling locations.

The NYCDEP data reported here are annual medians for selected water quality variables, plotted against time for the main stem of the Esopus Creek and its major sub-basin tributaries (See **Appendix C – CD.2** for graphical presentation). The median is a statistic that expresses the "typical" condition of something. The median is simply the value in the center of a data set, i.e. half of the samples are higher, and half lower. One characteristic of the median is that it is not overly influenced by data from extreme events. Also, the results are based on routine grab samples, and do not specifically target extreme events. However, the median is a useful yardstick with which to compare data from different streams. In order to get a grasp on the variability of the data, as well as contrasting the Esopus with its tributaries, box plots of the raw data from 1987 to 2005 are also presented in **Appendix C**.

Turbidity and Total Suspended Solids

Turbidity, an index of water clarity, is a concern in this watershed for two regulatory reasons: Safe Drinking Water Act oversight of NYC water supply and a SPDES Permit for the Shandaken Tunnel. The Safe Drinking Water Act and associated regulations are concerned with turbidity levels entering the distribution systems for public water systems; accordingly, from a Safe Drinking Water Act perspective, DEP's primary concern is the level of turbidity in water leaving the Kensico reservoir. For purposes of drinking water, turbidity is of concern because it has the potential to mask pathogens and interfere with disinfection.

In contrast, the focus of the SPDES permit is on turbidity in water diverted through the Shandaken Tunnel at the point it enters Esopus Creek (**Appendix C – CD.2**). Turbidity is a concern for the ecologic, recreational and aesthetic use of the stream as well (See **Sections 3.3,** and **Volume II Section 2**). See the bibliography in **Section 4** for several simple to very detailed resources that are available for information on turbidity in Catskill Mountain streams.

Turbidity is an optical measurement of the light-scattering at 90^{o} caused by particles suspended in water (**Figure 2.31**). Turbidity is measured in arbitrary "nephelometric turbidity units" (NTUs) by a "nephelometer". The higher the NTU value, the lower the water clarity. Turbidity can be influenced not only by the amount of particles in suspension, but also by the shape and size of the particles. There is no single, fixed relationship between turbidity and total suspended solids. Total suspended solids are a measure of suspended solids concentration, expressed as a mass per volume (mg/L) obtained by physically separating the liquid and solid phases by filtration. Further, it is important to note that there is no universal, usable, fixed turbidity/clarity relationship. See the section on angling and water recreation (**Volume II Section 4**) for a discussion on this relationship.

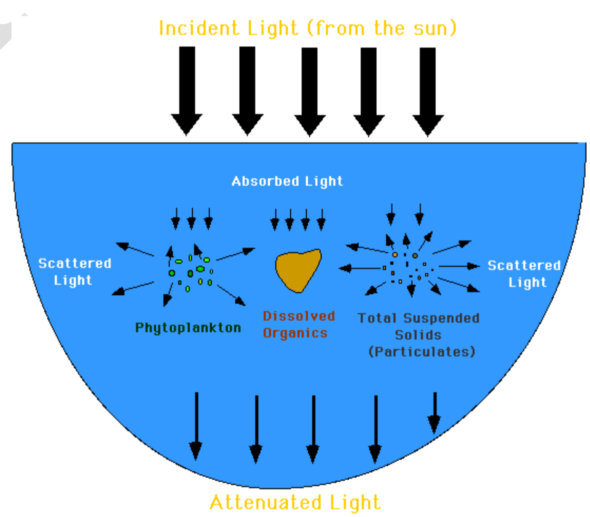


Figure 2.31 Illustration of light scattering caused by suspended particles in water.

Suspended solids in Catskill streams are predominantly fine sediment. It does not take much suspended sediment to reduce the clarity. The water clarity can range from clear to an opalescent red-brown following a significant high water event (**Photo 2.20**). Sediment gets in the stream from three sources: (1) runoff from the landscape carries fine sediment (silt and clay) into the stream through ditches and culverts (**Photo 2.21**); (2) from entrainment in the stream (**Photo 2.22**); and (3) from the Shandaken Tunnel (**Photo 2.23)**. We believe that it is the stream channel, and not the landscape, that is the primary source of sediments. The contribution of turbidity (as a surrogate for suspended sediment) from the Shandaken Tunnel relative to the Esopus Creek is known and shown in **Figure 2.32**.

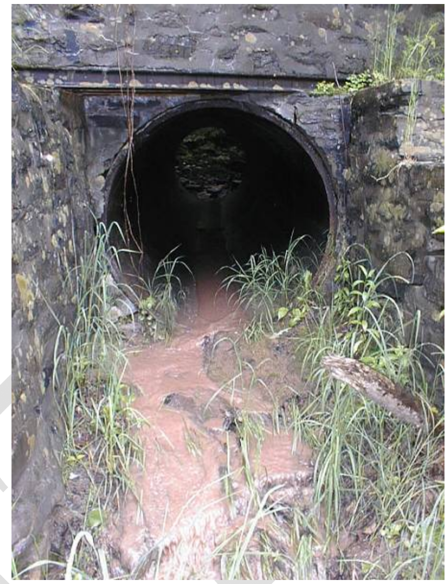


Photo 2.21 Turbid discharge from a culvert draining a road ditch

Photo 2.22 Stream flow entraining fine sediment along an eroding section of Stony Clove Creek. April, 2006

Photo 2.23 Turbid discharge from Shandaken Tunnel (March 28, 2006)

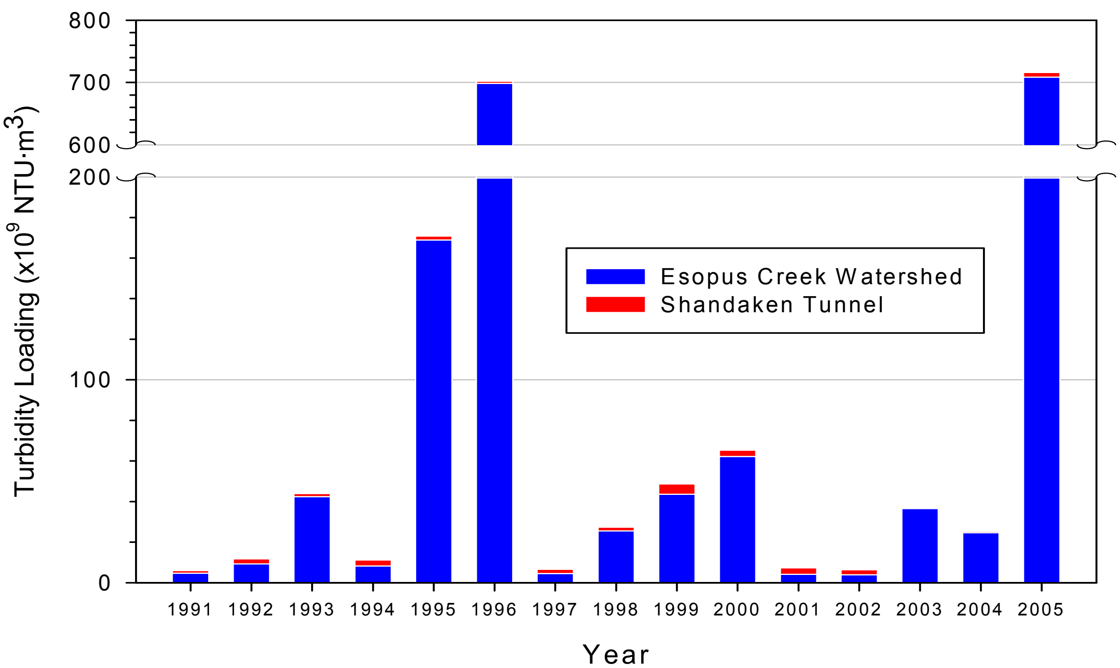


Figure 2.32– total annual turbidity loading to Ashokan Reservoir from the Esopus Creek Watershed and the Shandaken Tunnel, 1991-2005. (Figure courtesy of Upstate Freshwater Institute)

The regulatory water quality standard for turbidity in New York State is a narrative standard: "no increase that will cause a substantial visible contrast to natural conditions." NYCRR, Title 6, Section 703.2. There is also a narrative water quality standard for suspended, colloidal, and settleable solids: "None from sewage, industrial wastes or other wastes that will cause deposition or impair the waters for their best usages." *Id*.

Although there are no numerical standards for turbidity or suspended sediment, these constituents are of concern in streams because the presence of fine-grain sediments such as clay particles suspended in the water column can affect stream biota. These fine sediments can settle on substrates used by colonizing algae and invertebrates and can fill the small spaces between gravel where fish lay their eggs. Transmission of light through the water can be reduced, which can affect stream productivity. See **Section 3.4** for more information on the potential impact to the aquatic ecosystem.

Turbidity in Upper Esopus Creek is not a new phenomenon. The design of the Ashokan Reservoir itself reflects concern for turbidity on the part of the design engineers. Two basins separated by a dividing weir were created in order to allow time for suspended particles to drop out as the water flows from the mouth of the upper Esopus on the West basin to the spillway outlet on the East basin (**Photo 2.24**). In addition to the partitioned basins, the West basin includes a diverting "waste channel" that can release water into the

Photo 2.24 Dividing weir at Ashokan Basin (June, 2006)

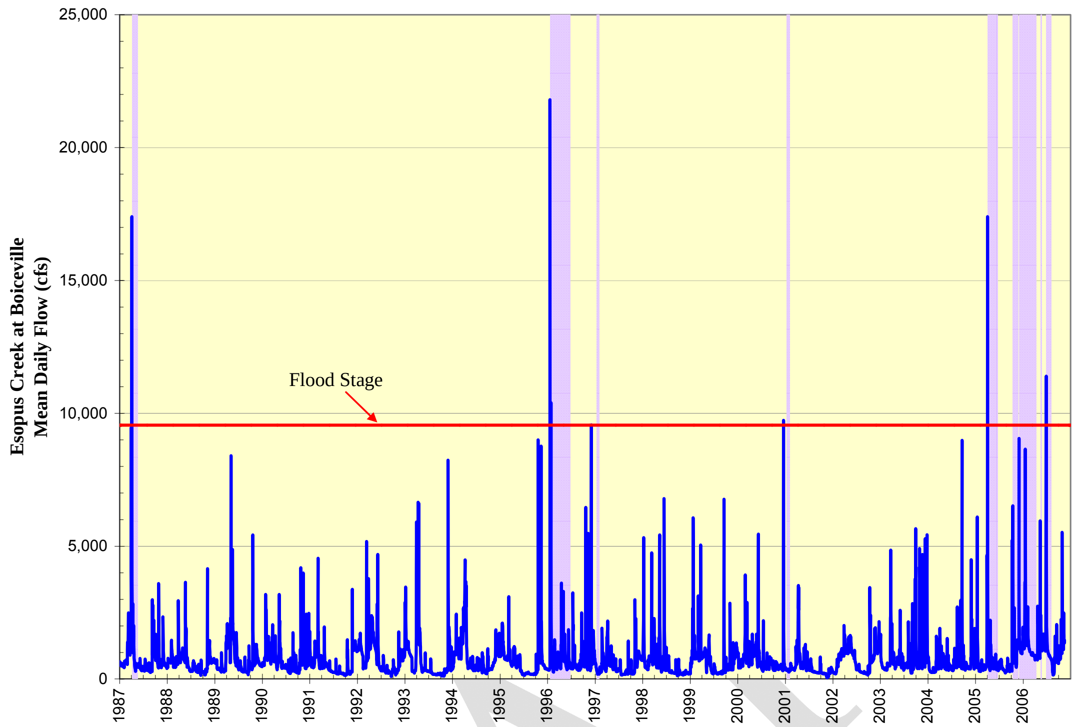


Figure 2.33 Esopus Creek flood events and alum treatment events (1987 - 2006). The alum treatment duration is shown in the purple stippled pattern.

former Esopus Creek channel below the reservoir. Photographs and documentation from the early 1900s confirm that facilities for adding coagulants to reduce turbidity levels in Catskill system water before it enters the Kensico reservoir were integral to the design of the Catskill system from the outset. Finally as further evidence of long-term turbidity conditions in the watershed, "muddy brook" was not an uncommon first name for a Catskill creek and there are still a few around, as in Woodland Valley.

Figure 2.33 is a hydrograph of mean daily flow for Esopus Creek at Coldbrook (Boiceville) showing a comparison of 20 years of Esopus flood events (greater than 9,000 cfs) and the periods during which turbid water leaving the Ashokan Reservoir reaches levels requiring treatment with alum, a coagulant. The hydrograph does not include the peak flows. Corresponding peak flows are shown in **Figure 2.19**. The "sustained" suspended sediment loading following the April, 2005 extreme flooding, evident in the increased usage of alum, shows that the watershed sources are sensitive to the high recurrence interval flooding and associated geomorphic change. It is likely that for the thousands of years since the ice age, major flood events such as the April, 2005 event cause periods of increased turbidity.

The two principal sources of turbidity in the Upper Esopus Creek watershed today are relatively well known. There is the obvious point source of the Shandaken Tunnel that has, since its beginning, delivered turbid water on occasion, especially following flooding in the Schoharie basin that causes the Schoharie Reservoir to become turbid. Water in the Schoharie Reservoir can remain turbid for extended periods after flood events due to characteristics of the reservoir and its watershed (Joint Venture, 2004 and 2006).

Table 2.11 Median turbidity values for Shandaken Tunnel from 1987-2005[2]

Year	Median Turbidity	Sample Size
1987	7.4	45
1988	4.95	48
1989	4.8	48
1990	4.3	47
1991	4.1	43
1992	5.05	44
1993	4.7	65
1994	5.35	74
1995	5.75	121
1996	25	56
1997	12	117
1998	12	119
1999	19	155
2000	14	122
2001	20	176
2002	5.25	247
2003	2.7	133
2004	6.2	143
2005	21	194
1987-2005	8.8	1997

There is a perception that the Shandaken Tunnel ("portal"), carrying water from the Schoharie Reservoir is the major source of turbidity in the Esopus. Indeed, based on data collected routinely at a fixed frequency (i.e., not specifically collected during storm events) for the period 1987-2005, the Tunnel has the highest median turbidity value of the basin at 8.8 NTU (**Table 2.11**). Analysis of available data and modeling has shown that for most years (not all), the Esopus watershed itself provides the vast majority of the overall mass of fines that contribute to turbidity in the Ashokan Reservoir (**Figure 2.32**). This is because most of the annual turbidity load comes during the most significant storm events of the year (UFI, 2007). While the bulk of the storm-related turbidity is flowing down the Esopus, during non-emergency operating conditions, the portal is shut off during major storm events. And, in fact, there are times when the water discharged from the tunnel has better clarity than that flowing in Esopus Creek. The perception that the portal is the dominant contributor to turbidity is likely due to visual observations made during periods of regional low flow, specifically during summer months when the portal water can be visibly more turbid in contrast to the above-portal Esopus Creek flow. It is the persistence of turbidity in the Tunnel flows, after storm events, which make the Tunnel such a noticeable source during normal flows.

There is also the combination of two non-point sources that turn almost every stream in the watershed brown after a big flood – the exposed "clays" that the stream has cut into (**Photo 2.25**) and the mobilization of fine sediment mixed in the stream bed deposits. A fine sediment budget study performed as part of this effort and described in **Section 3.1.2** found that, on average, 1.5 % of the stream bed material was composed of clays and fine silts that had settled into the spaces between the gravels and cobbles. Also, according to NYCDEP sampling and modeling analysis (NYCDEP, 2006) these non-point sources represent the major source of turbidity at times when turbidity reaches levels of concern for drinking water purposes.

[2] Three different turbidimeters were used during this period.

Photo 2.25 Layered glacial lake silt and clay exposed in streambank on Bushnellsville Creek

The exposed "clays" are actually ice age deposits from when the landscape was covered by glaciers and afterwards by their melt water lakes. The glaciers left *glacial till*, a dense mixed "hardpan" of clay and rocks. The legacy of the glacial lakes in the Esopus watershed is the thick blanket of layered silt and clay that settled out over the years the lakes were in place. The diversion of Schoharie Creek watershed water into the Esopus Creek, is delivering water from the same geologic condition – a landscape dominated by the legacy of glaciers. **Section 2.5** covers the geologic characterization of the conditions that impact turbidity. Some of the silt and clay entrained from the glacial sources (and the Shandaken Tunnel) settle out along the stream course and get incorporated into the stream bed material.

To get a sense of the significance of this condition, at any point along the Esopus Creek – above or below the portal – one can walk into the stream, and move his or her feet around to disturb the streambed. A plume of fine sediment will be released into the flow as the silts and clays in the voids of the gravel bed are exposed to the flow (**Photo 2.26**). During flood events that are sufficient to mobilize the stream bed the fine sediment is re-suspended. As described in the Sediment Budget Study in Section 3.1.2 the streambed source may be the most substantial source during the initial phase of a high magnitude flood event.

Photo 2 Photo 2.26 Clays and fine silts in the streambed are easily disturbed and contribute to turbidity throughout the basin.

An important aspect of the geologic fine sediment sources is that their exposure and potential entrainment vary in space and time as the stream process continues transporting sediment downstream. While there are many mapped exposures of fine sediment sources along Esopus Creek between Phoenicia and Oliverea (**Map 2.3 – Mapped Fine Sediment Sources**) many of these are transient. As explained in more detail in the geology section, floods that mobilize sediment scour new exposures and cover earlier exposures with new gravel and cobble. Some of the exposures mapped in the summer of 2005 were not present the following summer though new exposures were discovered in other locations.

Similarly the tributary streams are significant sources of turbidity/TSS that provide variable sediment loads depending upon geology/geomorphology, recent flood history, and storm conditions. Stony Clove Creek and Broadstreet Hollow Creek have, at least since 1996, been leading chronic turbidity contributors to Esopus Creek. Each of these tributary streams has a Stream Management Plan detailing the conditions of those streams (UCSWCD, 2003; GCSWCD, 2004). Flooding since 2004 has exacerbated the conditions in those streams and caused others to become significant chronic sources, specifically Birch Creek, Bushnellsville Creek, Fox Hollow Creek and Woodland Valley. The April 2005 flood ravaged parts of Bushnellsville Creek (**Photo 2.25**), Fox Hollow and Woodland Valley Creek such that there are many exposures of glacially-sourced fine sediment that cause these streams to become turbid at moderate floods. **Appendix C – CD.2** contains a memo documenting the turbidity conditions following that flood. The Beaver Kill and Little Beaver Kill did not become turbid following the April 2005 flood. However, the June 2006 extreme flooding in the Beaver Kill watershed has caused this stream to become a source at moderate floods.

Clearly the sources of fine sediment are systemic and difficult if not impossible to manage. There is hope though. The case of Birch Creek following an extreme localized thunderstorm over Pine Hill in May, 2004 is an excellent example of how these streams can “heal” (at least temporarily) without the help of active management. On May 14, 2004, 2.5 inches of rain fell in under 3 hours causing Birch Creek to swell from under 10 cfs to over 800 cfs. The flash flood scoured the streambed incising into the underlying glacial lake clays starting behind the Pine Hill WWTP and continuing down to within a half mile of the confluence with Esopus Creek. Seven extensive exposures of glacial lake clay were mapped following the flood. Those seven exposures turned the Esopus Creek red-brown all the way to the reservoir. **Figure 2.34** shows the impact of the flash flood on Esopus Creek and follows one of the source sites (Winding Mountain Road bridge) for a period of one year. At the depicted location, the scour was so severe that the stream abandoned its former bed and occupied a trench cut into the clay. There was a lot of concern raised by DEP, TU and others about the need to address the problem. Within a year, after a few more floods the trench filled in with coarse sediment and the stream reoccupied its former channel. The devastating April 2005 flood did not cause further damage to this site, as it was sufficiently “armored” by that time. However, other exposures developed elsewhere along the stream and throughout the watershed.

Birch Creek confluence May 15, 2004

Just below Birch Creek May 15, 2004

Esopus Creek along CRT 47 May 15, 2004

Esopus Creek at Shandaken Tunnel May 15, 2004

Birch Creek at WMR bridge May 19, 2004

Birch Creek at WMR June 13, 2005

Figure 2.34 Flash flood impact and recovery on Birch Creek and Esopus Creek

In the case of Catskill stream turbidity, both hydrology (storm events) and geology are important determining factors. The hydrology and geology cannot be effectively altered and so stream management has to adjust to accommodate the conditions.

Pathogens

NYCDEP monitors for pathogens, specifically giardia and cryptosporidium, in a large number of Catskill mountain streams. Specifically NYCDEP's Pathogen Program monitors eight sampling location sites within the Esopus Creek Watershed (**Map 2.2**) for, among other water quality parameters, protozoa; *Cryptosporidium spp.* oocysts and *Giardia spp*. cysts. While there are no regulatory thresholds for these protozoa in surface water NYC DEP maintains a monitoring program for them because they are a primary public health concern. These protozoa are of concern to public health for two reasons: 1) certain strains of these protozoa can cause disease in humans if consumed, and 2) the presence of these protozoa indicates that the water has been contaminated with fecal matter (animal or human) and; therefore, may be carrying other pathogens that have the potential to cause disease in humans. DEP's monitoring data has shown the presence of these (oo)cysts in ambient water, and during high flow conditions related to runoff events, however concentrations have been at low levels. In any event, since certain strains have the potential to cause disease in humans, determining their source, transport properties, and fate are of utmost importance to DEP. DEP maintains a surveillance program designed to narrow down source locations and trends of (oo)cysts in the Esopus Creek watershed and throughout New York City's water supply watersheds. Additional tools used by DEP to ultimately assess the public health risk associated with these protozoa in the watershed include: 1) PCR (polymerase chain reaction) source tracking to identify anthropogenic and autochthonous sources, 2) landuse / landcover which also indirectly identifies potential human sources such as failing septic systems and wildlife sources, 3) and watershed physiographic characteristics such as percent area of contribution to a site, slope and elevation which may affect transport and fate.

Temperature

Water temperature is one of the most important variables in aquatic ecology. Temperature affects movement of molecules, fluid dynamics, and metabolic rates of organisms as well as a host of other processes. In addition to having its own potential "toxic" effect (i.e. when temperature is too high), temperature affects the solubility and, in turn, the toxicity of many other parameters. Generally the solubility of solids increases with increasing temperature, while gases tend to be more soluble in cold water (i.e. available O_2 to fish).

Typically, the greatest source of heat in a watershed is solar radiation from the sun. In a densely wooded area, where the majority of a streambed is shaded, heat transferred from the air and from groundwater can dominate temperature dynamics. Annual fluctuation of temperature in a stream may drive many biological processes, for example, the emergence of aquatic insects and spawning of fish. Even at a given air temperature, stream temperature may be highly variable over short distances depending on plant cover, stream flow dynamics, stream depth and groundwater inflow. Sustained temperature values above 23 degrees C have negative consequences for brook trout because the availability of dissolved oxygen becomes limited.

The annual median values of Esopus water temperature from 1987 to 2005 vary from around 7 degree C at the headwaters site to about 8 degree C at Coldbrook, indicating a fair amount of shading and consequent moderation of incoming solar radiation. The lower temperature headwater sites reflect lower air temperatures at higher elevations, the inflow of groundwater as well as the predominance of shading. Individual yearly medians may vary significantly from year to year. The highest yearly median of the period at Coldbrook was just over 12 degree C recorded in 2005, with 1995 a close second. The effect on temperature due to the influx of normally cooler Schoharie Reservoir water can be seen in dry years like 2001-2002. The temperatures of the Esopus at Allaben, located above the portal, are some of the highest for the period, with values around 11 C. This is an effect of a very dry year, but downstream of the portal at Coldbrook the temperatures recorded are much lower than would be expected for the period with the median around 4 C.

Though the Shandaken Tunnel (ST) typically delivers colder water to Esopus Creek, in unusual conditions when the cold water reserve in the Schoharie reservoir is depleted the Tunnel can deliver water that is warmer than the ambient Esopus Creek water. The potential to have warmer water discharging from the ST than the normal Esopus Creek temperature is a concern for stakeholders that want to see a viable cold-water fishery. See **Section 3.3** for more detail. NYCDEP monitors for water temperature from above and below the Shandaken Tunnel as part of its monitoring program. Temperature is also continuously monitored by USGS at the Coldbrook gage and at the Shandaken Tunnel gage. Data is available on the USGS website. UFI has installed and monitored approximately two dozen thermistors along Esopus Creek from Allaben to the reservoir to assist in the development of a temperature model for the creek.

Phosphorus

Excess phosphorus in a watershed can cause excess nutrient and eutrophication conditions and is a concern to drinking water regulators. Phosphorus is a common biological nutrient found in natural waters. Primary sources of phosphorus include: human and animal waste, fertilizer runoff, atmospheric deposition, and internal recycling from reservoir sediments. Phosphorus is a constituent of potential concern in stream waters as an over abundance can lead to excessive growth of algae. Although there is no NYS numerical standard for phosphorus, it has been suggested that a value of 50 µg/L in streams is the limit under which there should be no problems with algal growth. The median annual values of total P show that for the Esopus and its tributaries, median levels were below 20 µg/L. Because phosphorus is fairly abundant in sediments, soil erosion may add considerable amounts of suspended phosphorus to a stream. However this is particulate phosphorus which is of far less concern than dissolved phosphorus. Considerable loading may occur during extreme storm events. This can be seen in a comparison of the plots of turbidity and total phosphorus where the highest values of TP correlate to the highest turbidity values (**Appendix C – CD.2**).

The analysis of sampling data NYCDEP has collected over the years concludes that phosphorus is not a problem in the Esopus Creek watershed at this time. Elevated spring and fall runoff in 2005 caused phosphorus concentrations to increase considerably in Ashokan's West Basin where the 2005 median total phosphorus was nearly 2.5 times the historic median. Most of the phosphorus load was confined to the West Basin as the 2005 median phosphorus in the adjoining East Basin was equivalent to the historic median. However, much of the phosphorus is not biologically available. In fact, in 2005, the median Trophic State Index (Trophic state indices are commonly used to describe the productivity of lakes and reservoirs.) for both Ashokan basins decreased substantially compared to past data, indicating decreased algal production. The decrease in production is attributed to reduced light transparency (light is an essential requirement for algal growth) resulting from the relatively turbid water conditions in 2005.

Fecal Coliform

Fecal coliform bacteria are a potential health hazard whose source can be traced back to either human or animal wastes, are measured to determine to what degree a stream may be contaminated by fecal matter. The New York State regulatory limit states: "The monthly geometric mean, from a minimum of five examinations, shall not exceed 200 CFU/100 mL". A review of annual median values from sampling of the Esopus stream for the period of record show that median fecal coliform values peaked around 20 CFU/100 mL in 1995 with lesser peaks of around 17 in 1999 and 16 in 2004 and for 2005 were around 9.

Specific Conductivity

Specific conductivity describes the ability of water to conduct an electric current, and is an index of the concentration of chemical ions in solution. An ion is an atom of an element that has gained or lost an electron which will create a negative or positive state. The natural conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Conductivity is often used to compare different streams because it is a cheap and easy measurement that can indicate when and where a site is being influenced from a source of contamination. Often when a wastewater treatment plant effluent provides the dominate flow in a stream, it can be seen in water quality data due to its higher conductivity signature. Road salting practices can also impact the conductivity values. The highest median conductivity values for the period of record for the Esopus watershed are consistently from Birch Creek and range from 60 to 110 μS/cm. In the case of the DEP treatment plant at Pine Hill, the effluent appears to have little or no effect on the conductivity. At Coldbrook the median value was around 65 μS/cm. That the chemistry of the Esopus Creek at Coldbrook is an averaged mixture of all the tributary inputs upstream is borne out by the specific conductivity data. In the plot of all the major tribs including the Esopus, it shows the Esopus at Coldbrook to be in near the middle of the conductivity values. The lowest, as expected, is in the headwaters area with median values around 15 μS/cm.

Dissolved Oxygen

Another water quality parameter of concern is dissolved oxygen (DO). Dissolved oxygen is vital for aquatic life. Adequate oxygen levels are necessary to provide for aerobic life forms which carry on natural stream purification processes. As dissolved oxygen levels in water drop below 5.0 mg/L, aquatic life is put under stress. The lower the concentration, the greater the stress. The New York State regulations regarding DO and a stream designated as trout spawning is that the DO should not be less than 7.0 mg/L from other than natural conditions. Data from 1987 to 2005 indicate that the median DO for the Esopus and its tributaries range from about 10 to 11 mg/L and may dip down into the 8 mg/L range during hot summer months.

Sulfur

Sulfur in natural waters is essential in the life processes of plants and animals. Although the largest Earth fraction of sulfur occurs in reduced form in igneous and metamorphic rock, there is significant sulfur in sedimentary rock as well. When sulfide minerals undergo weathering in contact with oxygenated water, the sulfur is oxidized to yield stable sulfate ions that become mobile in solution. Another major source of sulfate in the environment is the combustion of coal, petroleum and other industrial processes such as smelting of sulfide ores. Atmospheric deposition both as dry particulates and entrained in precipitation can cause acid rain that can alter stream chemistry. Sulfate is classified under the EPA secondary maximum contaminant level (SMCL) standards. The SMCL for sulfate in drinking water is 250 milligrams per liter (mg/l). The annual median values found in the Esopus Creek vary from 4 mg/l in the headwaters area to around 5.5 mg/l at Coldbrook. The high value of 6.6 mg/l was found in the tributary Little Beaver Kill. The period of record for NYC final Sulfate data was not established until 1994. The sulfate values basin wide have dropped since 1994, and despite a brief rise in 2002, have remained at a lower level.

pH

Knowing the hydrogen ion activity (pH) of water can give some idea as to the extent of chemical reactions in the liquid involving not only the dissolution of water, but also the myriad of other solute, solid and gaseous reactions involving hydrogen ions. This is because the activity (concentration) of the H^+ ion in water is the end result of those equilibrium and non-equilibrium reactions. The pH of pure water at 25 C is 7.00. Natural waters on Earth tend to have pH values ranging from 4 to 10.5 in extreme conditions. Annual median pH values for the period of record for the Esopus Creek range from a low of 6.3 in the headwaters to around 7.1 at Coldbrook indicate stream water not far from the neutral balance of around 7.0. The highest median value in the basin was found in Birch Creek at Pine Hill, above the WWTP. The slightly lower values found in the headwaters sites is likely due to groundwater leaching through acidic soils (average soil pH is 4.4, with low cation exchange capacities, Murdoch and Stoddard 1993) and acidic precipitation flowing through soils with low buffering capacity.

Chloride

EPA Secondary Drinking Water Standards require chloride levels not to exceed 250 mg/L. Criteria for protection of aquatic life require levels of less than 600 mg/L for chronic (long-term) exposure and 1200 mg/L for short-term exposure. Esopus Creek median chloride values range from 1-2 mg/L in the headwaters area to around 7 mg/L at Coldbrook. Basin wide chloride values vary from a 1 mg/L low to around 13 mg/L at Birch Creek. The higher values in the Birch Creek drainage may be a function higher elevations and lower winter temperatures tending to cause more road salt to be used, or may just be a factor of less dilution than occurs downstream.

Biomonitoring

As described in greater detail in **Section 3.3**, there is a lot of available biomonitoring data that can be used to evaluate water quality. The assemblage of macroinvertebrates, or “bugs”, can be used to infer water quality condition in an ecological context. Various indices (referred to as “metrics”) derived from the macroinvertebrate data can be used to assess whether water quality is impaired or not. Such assessments, however, do not identify cause. According to most of the biomonitoring assessments, Esopus Creek and its tributaries exhibit good water quality for optimal ecologic conditions. From the available NYCDEP and NYSDEC biomonitoring data there is no clear evidence of impact from sources of silt and clay along the Esopus Creek corridor. Section 3.3 discusses the relevance of these and other biomonitoring findings.

2.7.4 Stream Management Implications

There are factors influencing water quality that we can manage and there are factors we have to accommodate in our management. We do not have a direct influence over the precipitation water quality, geology and hydrology that exists. The Upper Esopus Creek watershed has had excess suspended sediment for thousands of years and will have a similar condition for thousands of years more until all the glacial lake sediment and glacial till have been effectively removed from the stream network. Floods are inevitable and continue to expose and entrain the silts and clays the glaciers left. It is the nature of this watershed.

There are obvious reaches where stream restoration may have a significant reach scale suspended sediment reduction at low and possibly moderate flows. The Broadstreet Hollow restoration project (UCSWCD, 2003) is an example. Sections of Stony Clove below the Warner Creek confluence are chronic contributors of suspended sediment from extensive hill slope failures that intersect the stream. If treatment is feasible in those conditions, a source of turbidity at moderate flows may be mitigated. However, it is important to remember that this is a watershed scale management issue. Stream restoration practices may help suppress sediment loading at low to moderate flows, but given the geology of the watershed, during extreme flood events both stable and unstable reaches contribute, and several new short and long-term sources will be exposed and continue to cause episodic excessive turbidity. The high flow periods are those that are linked with turbidity levels of serious concern from a drinking water perspective, and with overall loading of turbidity/TSS.

We do have direct influence over land use and to some degree land cover. Currently, the existing land use and land cover do not seem to impart deleterious impacts to Esopus Creek water quality at the watershed scale. Future development in the stream corridor with a resulting increase in impervious surface may increase runoff and impair water quality.

There are currently two WWTPs (Pine Hill and Onteora Jr. Sr High School) in the watershed, one community septic system (Chichester on Stony Clove) and one seasonal facility (Camp Timber Lake), which has been upgraded to intermittant stream standards. There are plans for two more WWTPs within the Esopus Creek corridor (Boiceville and Phoenicia WWTPs). The Boiceville WWTP will eliminate the Onteora school WWTP. The concentration of septic systems in Phoenicia and Boiceville are expected to be replaced by state-of-the-art WWTPs using tertiary treatment and additional filtration. The water quality of the WWTP effluent will meet the rigorous standards in the City's Watershed Regulations.

As an operated facility, the Shandaken Tunnel discharge may be the most significant source of turbidity that can be affected by human control. The turbidity levels in flows through the Shandaken Tunnel are based on turbidity levels in the Schoharie Reservoir, but releases to the Esopus can be managed through modifications/operations in the Schoharie Reservoir. The Catskill Turbidity Study Phases 1 and 2 have examined the management options to reduce the delivery of suspended sediment to the Upper Esopus Creek. Digital copies of the report are available upon request.

3.0 UPPER ESOPUS CREEK CORRIDOR ASSESSMENT

Photo 3.0 Using GPS technology to map large woody debris in Upper Esopus Creek. August, 2005

This Section describes the work done to develop additional analysis and information on Upper Esopus Creek in support of the Management Plan. There are some basic management recommendations that can be made without assessing a watershed in any greater detail than presented in the previous sections. We know we have to manage for a mountain stream. We know that turbidity is a problem and is a function of the geology and hydrology which are beyond our control. We know we have to manage for a regulated stream. We know the stream's watershed is over 90% forested and is in generally good shape. We know quite a lot but not enough to diagnose the actual current condition of the stream and the valley bottom corridor it flows through.

It is necessary to know where, how much, and what kind of stream bank erosion is occurring to understand whether or how the erosion can be managed. It is also necessary to know the composition, width and integrity of the streamside vegetation that protects the stream in order to know how best to augment it. Using the results of the 2004 Esopus Creek Focus Group meetings, NYCDEP and the US Army Engineer Research and Development Center – Environmental Laboratory ("ERDC") developed a work plan for assessing the watershed and stream channel condition that optimized the efficiency of getting enough of the right kinds of data to reasonably inform management recommendations. The Project Team used a multiple objective approach to characterizing and assessing the Creek corridor. Understanding that flooding and erosion along with drinking water quality and ecosystem integrity were priority concerns, emphasis was placed on collecting existing information and new data to address those concerns (**Photo 3.0**). This is a work in progress intended to generate a set of assessment and monitoring recommendations presented in Volume I.

There are three basic stream corridor component assessments presented in **Section 3**: stream corridor geomorphology, vegetation, and aquatic ecology. Each has been done using a “phased-approach” – starting at a broad scale and then through subsequent phases refining the scale as needed to adequately address a given concern. Mindful of the need to make this Section *reasonably* readable much of the data and analysis is either referenced or included as attachments that can be used by readers interested in the details. A glossary is also included in this volume (**Section 5**) and an introduction to fluvial geomorphology is provided in **Appendix A**.

3.1 Stream Corridor Geomorphic Assessments

Photo 3.1.1 Washed out Catskill Mountain Railroad Tracks and stream eroded exposure of slumping pro-glacial lake silts and clays about 1,000 feet upstream of Fox Hollow

A three-phased approach was used for the stream corridor geomorphic assessment of Upper Esopus Creek (excluding tributaries): starting at the watershed and corridor scale (Phase 1), followed by a stream reach scale reconnaissance, sediment studies, and hydraulic and erosion modeling (Phase 2), and concluding with a detailed site-scale data intensive assessment (Phase 3). **Figures 3.1.1 – 3.1.3** illustrate the application of the three-phased approach on the reach located between Lost Clove and Birch Creek. **Photo 3.1.1** shows a section of stream that was also examined during each phase because of its persistence as a hill slope/stream channel instability in lacustrine sediment.

Phase 1 relied upon readily available information to assess stream channel and corridor condition at the watershed to reach scale. **Figure 3.1.1** shows a general level of detail mapped from aerial photos. The limitations of this approach can be seen by observing the abandoned stream channels, now wet areas, bordering the stream to the northeast. The protocol used to develop the corridor for assessment did not account for the width of this active zone.

Phase 2 used a combination of methods to further assess the stream at the reach scale: a "rapid reconnaissance" approach to mapping features and conditions along the stream channel and corridor; sediment sampling to assess erodibility of glacial clays and to develop a sediment budget; hydraulic modeling to identify flood risk areas; and assessment of fluvial erosion hazard using a new model developed by ERDC for this project. **Figure 3.1.2** shows a sampling of the available *geo-referenced* data collected during the rapid reconnaissance.

Phase 3 was a very targeted investigation based on findings in Phase 2 and planning goals and objectives. Topographic and geomorphic surveys were performed along sections of stream with project-established grade control. The information was used for long-term monitoring and evaluation of alternative stream management practices. **Figure 3.1.3** shows cross section and longitudinal profile locations and sampling of survey results, pebble count locations, updated stream bank erosion and fine sediment source dimensions, and current stream channel alignment. The data will be used to assess management alternatives for this dynamic reach.

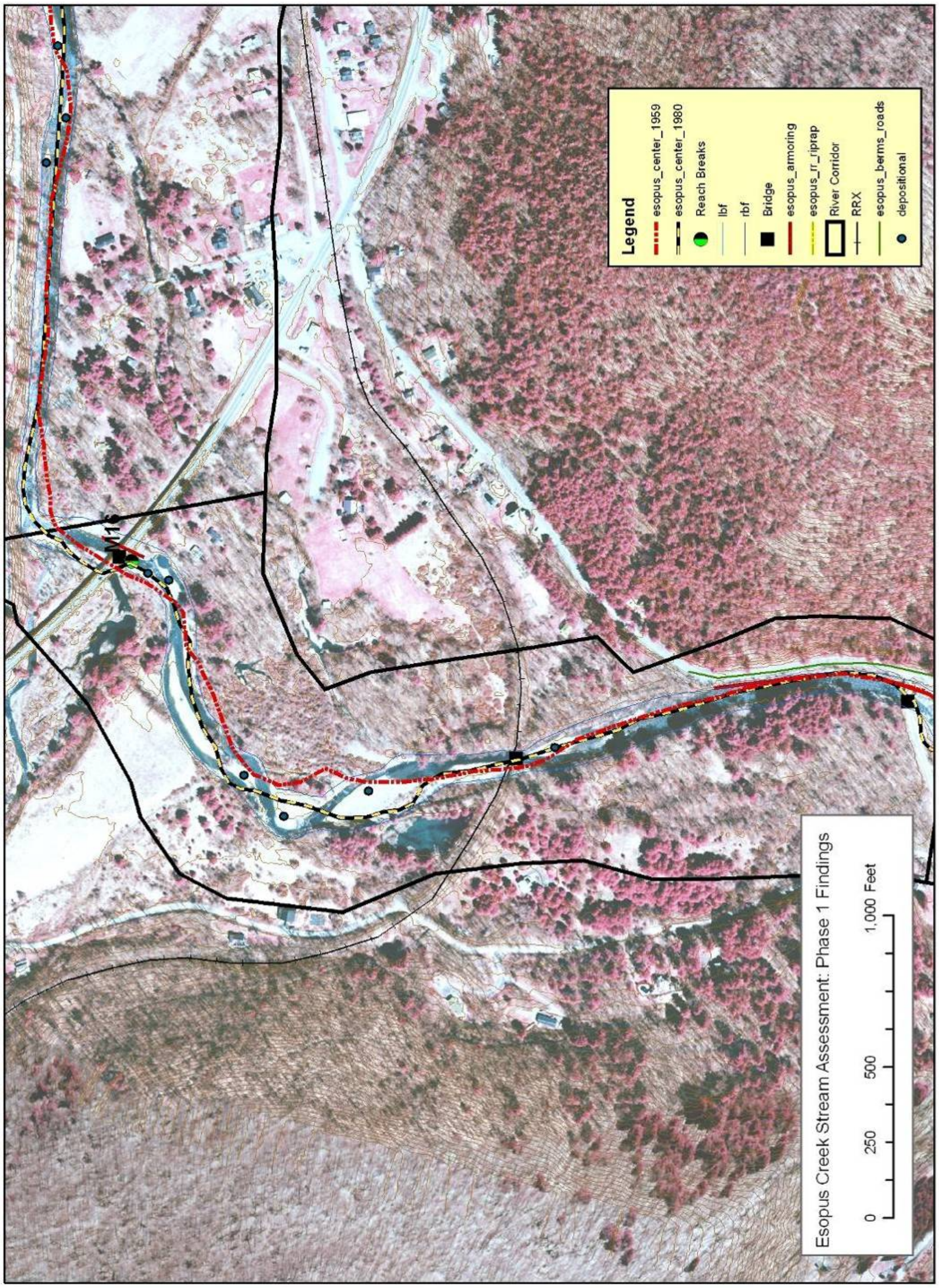


Figure 3.1.1 Example of Phase 1 Assessment Findings

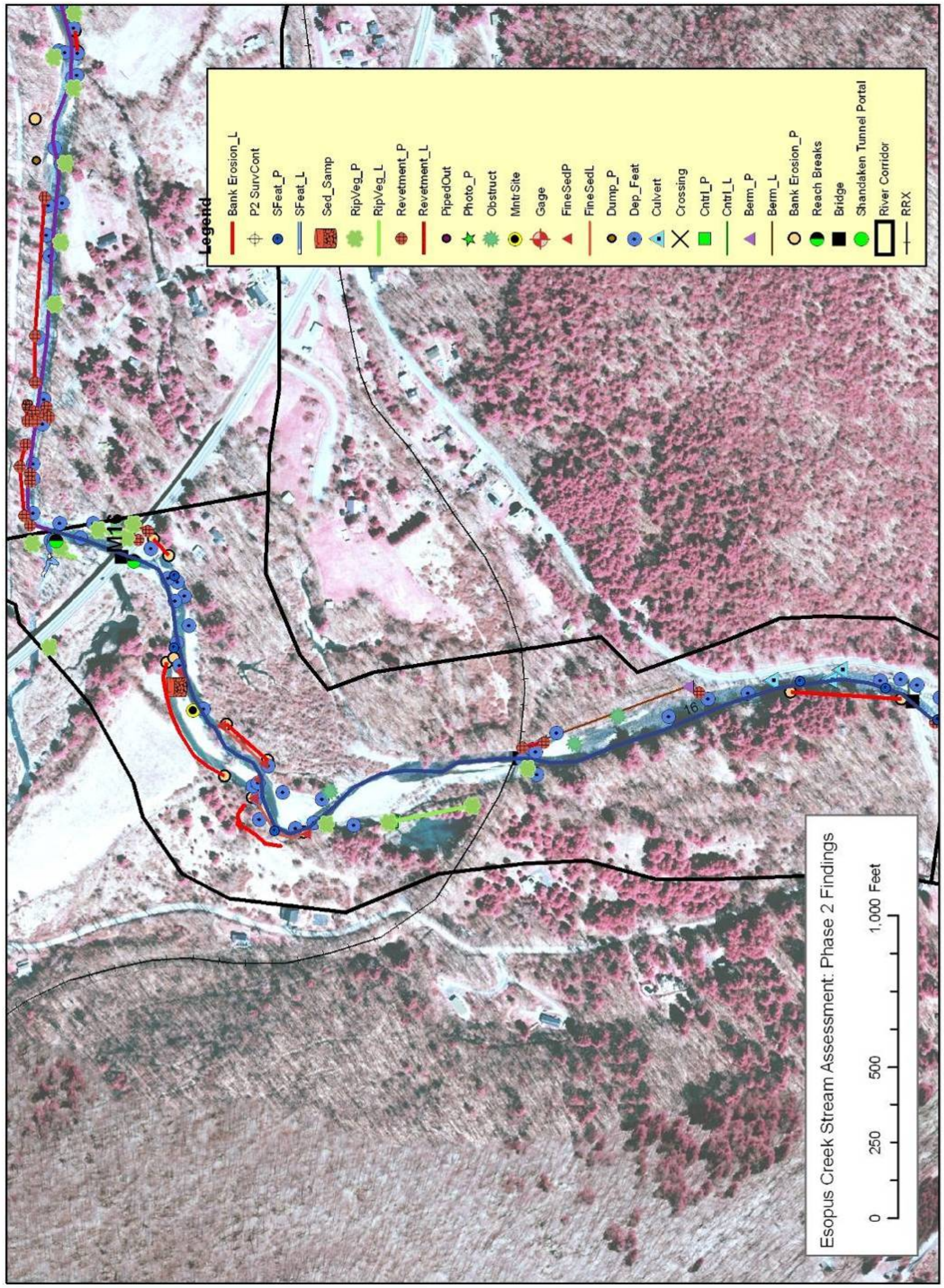


Figure 3.1.2 Example of Phase 2 Assessment Findings

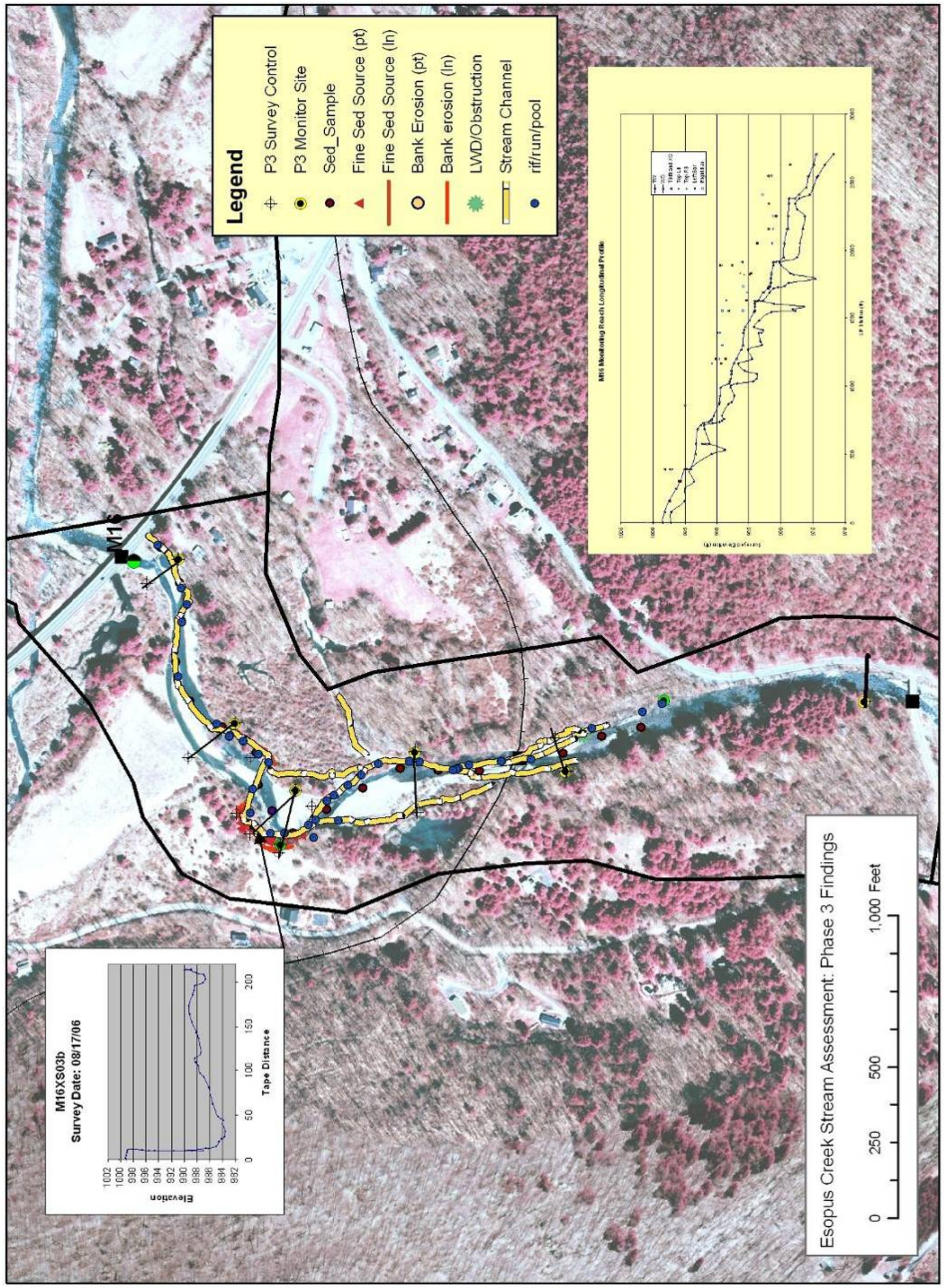


Figure 3.1.3 Example of Phase 3 Assessment Findings

NYCDEP provided use of a helicopter for repeated stream corridor reconnaissance. Starting in August, 2003 NYCDEP personnel flew all or portions of the Upper Esopus Creek corridor and watershed at least 12 times. Digital video and photos were obtained and are part of the visual database available for stream management of the Upper Esopus Creek watershed. **Table 3.1.1** lists the flight dates, area covered and whether videography and/or photography are available.

Table 3.1.1 Helicopter Reconnaissance Record for Upper Esopus Creek

Flight Date	Area covered	Photo	Video	Comments
08/13/03	EC1-EC10; principally EC6	Y	N	Photo-documentation for Esopus Creek restoration project at Woodland Valley confluence
09/11/03	EC1-EC10; principally EC6	Y	N	Photo-documentation for Esopus Creek restoration project at Woodland Valley confluence
10/16/03	EC1-EC10; principally EC6	Y	N	Photo-documentation for Esopus Creek restoration project at Woodland Valley confluence
04/21/04	EC1-EC19	Y	Y	Stream reconnaissance during spring leaf off; 1st continuous digital video from EC1-EC18
11/17/04	EC1-EC16	Y	N	Stream reconnaissance during fall leaf off; after Tropical Storm Ivan (9/17/04)
04/05/05	EC1-EC19	Y	Y	Stream reconnaissance during spring leaf off; immediately following April 2-3, 2005 flood; continuous digital video from EC1-EC18
04/10/05	EC1-EC20	Y	N	Continued photo-documentation of April 2-3, 2005 flood
04/20/05	EC1-EC18	Y	N	Stream reconnaissance during spring leaf off; continued photo-documentation of April 2-3, 2005 flood
12/08/05	EC1-EC19	Y	Y	Stream reconnaissance during early winter following fall flooding; video is poor quality
03/28/06	EC1-EC19	Y	Y	Stream reconnaissance during spring leaf off during unusually low flow conditions; continuous digital video from EC1-EC19
04/21/06	EC1-EC11	Y	N	Flight was focused on tributary assessment; video of tribs is poor quality
08/18/06	EC1-EC19	Y	Y	Stream reconnaissance during summer leaf on and low flow from Shandaken tunnel (~40 cfs).

3.1.1 Phase 1 Geomorphic Assessment

In 2004 DEP initiated the stream geomorphic assessments by piloting the use of assessment protocols developed by the Vermont Agency of Natural Resources (VT-ANR). The VT-ANR protocols are published in 3 handbooks and available online at http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_geoassesspro.htm. The VT-ANR approach is a three phased set of assessments that proceed from the watershed/corridor to the site scale. DEP used only the first phase assessment protocol as a starting point for the subsequent assessments performed with ERDC.

Phase 1 is a remote sensing investigation that involves collection and analysis of data from topographic maps or digital elevation models (DEM), aerial photography, soils and geology data, available existing studies, and limited field trips ("windshield surveys"). The stream channel is divided into geomorphic reaches and provisional reference stream types are established based on valley morphology and geology. Initial predictions of channel condition (departure from some reference condition), adjustment processes, and reach sensitivity are based on evaluations of watershed and river corridor land use and channel and floodplain modifications. Phase 1 is necessary for identifying reaches for further field-based study that address the overall assessment goals and issues.

The implementation of the protocol is documented in a report titled **Phase 1 Geomorphic Assessment of Upper Esopus Creek** ("Phase 1 Report") and is only summarily discussed in this section (Erwin et al, 2005). The Phase 1 Report is presented in **Appendix C** (**CD.1**).

The protocol uses a multi-step approach to collecting and analyzing data (Steps 1-7) and predicting condition (Steps 8-10). The details for each step outlined below are in the Phase 1 Report.

Step 1: Defining stream reaches
Step 2: Determining stream types
Step 3: Basin characteristics: geology and soils
Step 4: Land cover and reach hydrology
Step 5: Instream channel modifications
Step 6: Floodplain modifications
Step 7: Bed and bank windshield survey
Step 8: Stream impact ratings
Step 9: Stream geomorphic condition assessment
Step 10: Like reach evaluation

The Phase 1 assessment is primarily useful for familiarizing investigators with the comprehensive range and varying distribution of watershed and stream geomorphic characteristics. Segregating the stream into "reaches" based on similarity of basic geomorphic conditions allows the stream to be analyzed in sections (**Figure 3.1.4 and**

Map 3.1). The GIS-based assessment facilitates rapidity, repeatability, flexibility and power of assessment. The database of findings is very useful for organizing information and comparison between streams. The predictive findings are subject to significant limitations given the reliance on remote-sensed data and limited field observations, therefore they were not relied on for characterizing geomorphic condition but rather were used to help focus further assessment. It is also very important to note that the Phase 1 assessment was conducted prior to the extensive flooding in April and October of 2005.

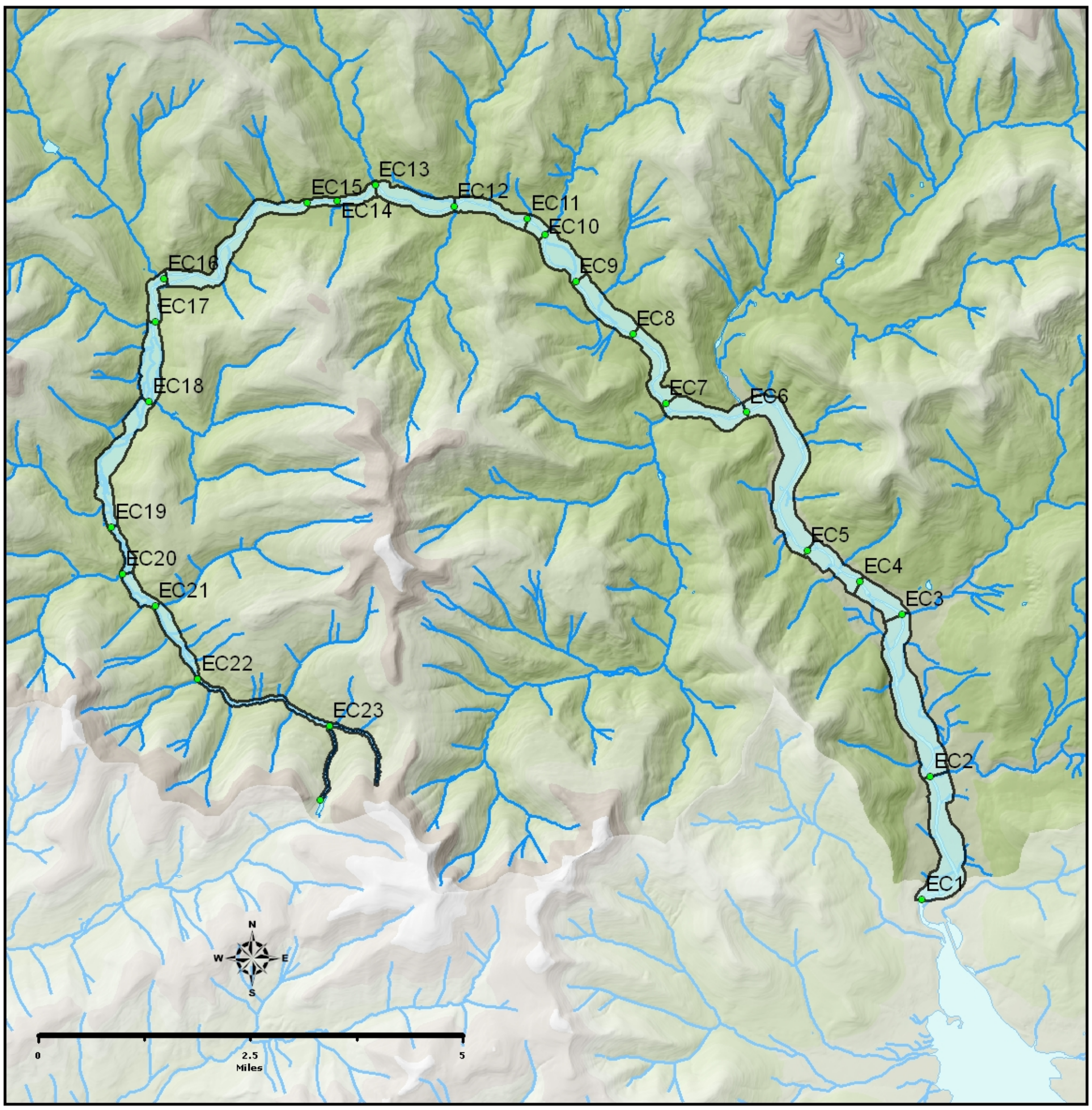


Figure 3.1.4 Phase 1 delineation of Upper Esopus Creek reaches and river corridor

An additional Phase 1 investigation that was completed but not included in the Phase 1 report is an historical channel alignment (HCA) analysis completed by Nicolas Miller for a Masters Thesis at SUNY Binghamton (Miller, 2006). Aerial photographs for 1959, 1968, 1980, 1996-99, 2001, and 2004 were obtained and the centerlines of the Upper Esopus Creek stream channel were digitized. An overlay analysis for comparison of channel alignment over time required use of georeferenced and rectified imagery. Georeferenced imagery uses a coordinate system based upon measurements of the earth, and rectification removes lens distortions from the image. The 1996-99, 2001, and 2004 images were digital orthophoto quarter quadrangles (DOQQ) and were already georeferenced. The 1959, 1968, and 1980 imagery had to be georeferenced (not orthorectified) by Miller. Maps of the HCA for 1959, 1980, and 2001 (21 year intervals) are presented in **Appendix E**.

Summary of Findings

There are several key products of Phase 1 that are deemed most useful for this effort:

Stream reach and river corridor identification

The first two steps of Phase 1 are intended to identify the stream reaches and their associated *reference stream type*. As described in the protocol, "the reference stream types are designated to describe stream channel forms and processes that would exist in the absence of human-related changes to the channel, floodplain, and/or watershed." Using an adaptation of the Rosgen stream classification system, remote-sensed data, regional relationships, and limited field observations potential reference stream types were identified. (Rosgen, 1996; Erwin, et al., 2005)

Upper Esopus Creek was divided into 23 distinct reaches based on the criteria prescribed in the Phase 1 VT-ANR protocol: valley slope, valley width, and tributary influence.

Table 3.1.2 summarizes the results of this exercise. **Figure 3.1.4** and **Map 3.1**shows the 23 reaches and the delineation of the river corridor used for further assessment. The river corridor is based on a multi-step process intended to capture the valley bottom and, where appropriate, the adjacent hill slopes that may directly influence the geomorphology of the stream channel. The Phase 1 Report uses the protocol prescribed naming convention for the stream reaches. The letter "M" (for main stem) prefaces the reach number, with number 1 at the downstream extent and number 23 at the upstream extent. For the purpose of this report and future reference the letter "M" has been replaced with "EC" for Esopus Creek.

Development of a fluvial geomorphic database

All of the data recorded for this investigation is stored in a Microsoft Access database developed by VT-ANR. Copies of the database reports are presented in the Phase 1 report. The database functions as a shared resource and can be used for comparison with adjacent and regional stream basins. Delaware County Soil and Water Conservation District (DCSWCD) are using the same geomorphic protocol for the East Branch Delaware River Stream Management Plan currently under development. There are differences in micro-climate, geology/geomorphology, and land use so there should be corresponding differences in stream type and condition. Much of the data is also available as ArcGIS shapefiles for mapping.

Initial riparian corridor analysis

Using the 2001 DOQQs a first phase riparian buffer assessment was completed reporting the presence or absence of riparian vegetation within the following categories: 0-25ft, 25ft – 50ft, 50ft-100ft, and >100ft. Section 4.2 provides further detail on this finding.

HCA and georeferenced aerial photography

The HCA along with the georeferenced aerial photography for the period covering 1959-2004 (45 years) provide excellent source of information to evaluate channel stability and changing river corridor conditions. For instance, the 1959 aerial photography and stream channel alignment is before the reconstruction of Route 28 which disconnected the stream from the floodplain in many places and in some cutoff meander bends with consequent changes in stream alignment and conditions.

Recommendations

We recommend the use of a protocol like the VT-ANR Phase 1 Stream Geomorphic protocol with supplementary analysis for all the tributary streams to the Upper Esopus Creek watershed. Recommendations for changes to the Phase 1 protocol are included in the CD containing the Phase 1 Report.

3.1.2 Phase 2 Geomorphic Assessment

The primary geomorphic concerns identified during the Focus Group sessions in 2004 and 2005 were (1) flooding and stream erosion hazards and (2) suspended sediment (source of turbidity). The Phase 2 geomorphic assessment was largely scoped so as to address these concerns. Using a combination of field reconnaissance and computer modeling methods, ERDC and DEP have completed an initial reach scale assessment including the following investigations:

- Stream feature inventory – a "walkover" with GPS technology using a standardized protocol to develop a geodatabase of key stream features (e.g. bank erosion, fine sediment sources, revetment, presence of Japanese knotweed, etc).
- Hydraulic modeling of Esopus Creek from EC1-EC21 using HEC-RAS to evaluate flooding hazards in the corridor.
- Preliminary stream erosion hazard modeling using the results of the hydraulic modeling and other assessment data with an algorithm developed by ERDC.
- Erodibility analysis on pro-glacial lake and glacial till deposits.
- Sediment sampling and budget analysis evaluating characteristics, transport, and fate of fine sediment in the Esopus Creek system.

This Section presents the basic methods and findings of the Phase 2 investigation.

Stream Feature Inventory

A stream feature inventory was performed for reaches 1 – 21 during 2005 and early 2006. Reaches 22-23 were not included in the inventory though reach 22 was assessed in 2004 as part of field verifying the Phase 1 findings (Erwin et al, 2005). Because the reach 22 data was collected with a different protocol, it was not used for this assessment. The reach 22 data is presented in the Phase 1 Report. Reaches 22 and 23 are both steep headwater reaches with significant amounts of vertical and lateral bedrock control. They are either bounded by state land, or are privately owned but away from developed property and/or infrastructure.

ERDC, NYCDEP and CCE staff walked or floated most of Upper Esopus Creek over the course of several weeks in late summer – early winter of 2005 and a few weeks in spring 2006. Reaches 1-5 were floated, rather than walked during early October 2005 because stream flow was too high for safe wading. Subsequent to that period the emergency operation of the Shandaken Tunnel that started in November, 2005 precluded further wading-based assessment due to sustained high flows. Therefore, the quality and quantity of observations downstream of Phoenicia are limited.

The GPS-recorded observations are stored in a "geodatabase" that is linked to GIS for spatial analysis. **Table 3.1.2** lists the feature categories used and the number of observations per category. A guide to the data dictionary that was used in the assessment is presented in **Appendix E – Phase 2 Geomorphic Assessment Data and Maps**. The reach maps included in **Appendix E** display some of the most pertinent data for stream management. **Table 3.1.3** summarizes the results in percentages per reach for eroding banks, revetment (any kind of hardening of the bank), berming in the floodplain, and fine sediment sources.

Table 3.1.2 Phase 2 stream feature inventory features and number of observations

Feature	Description	Observation	Feature	Description	Observation
Bank_L	Eroding streambank (line)	92	MntrPnt	Monitoring Point(point)	1
Bank_P	Eroding streambank (point)	192	MntrSite	Monitoring Site(point)	30
Berm_L	Berm(line)	18	Obstruct	Obstruction (point)	120
Berm_P	Berm(point)	36	Photo_P	Photo Point (point)	1
BMP_P	Best Management Practice(point)	4	PipedOut	Piped Outfall (point)	5
Bridge	Bridge(point)	21	Reach	Reach(line)	23
ClassM_B	Montgomery and Buffington Classification (point)	1	Revet_L	Revetment (line)	90
Cntrl_L	Control(line)	9	Revet_P	Revetment (point)	225
Cntrl_P	Control(line)	44	RipVeg_L	Riparian Vegetation (line)	133
Crossing	Crossing(point)	1	RipVeg_P	Riparian Vegetation (point)	269
Culvert	Culvert(point)	86	Road_P	Road(point)	16
Dep_Feat	Depositional Feature(point)	426	Sed_Samp	Sediment Sample location(point)	12
Dump_P	Dump(point)	8	SFeat_L	Stream Feature(line)	4
FineSedL	Fine Sediment Source(line)	94	SFeat_P	Stream Feature(point)	102
FineSedP	Fine Sediment Source(point)	160	Sgmt_Brk	Segment Break(point)	22
Fld_Ind	Floodplain Indicator(point)	1	SurvCont	Survey Control(point)	9
Gage	Gage(point)	6	Trib	Tributary(point)	161
MgtPract	Management Practice(point)	3	Utility	Utility(point)	12
Misc_P	Miscellaneous (point)	11			

Table 3.1.3 Phase 2 stream inventory: streambank conditions and fine sediment sources. Percentages are with respect to channel length.

Reach	% Eroding Bank	% Revetment	% Bermed	% Fine Sediment Sources
1	6.0	45.5	0	0
2	5.3	62.2	18.9	0
3	6.1	53.9	55.7	0
4	34.8	17.1	3.7	0
5	11	46	0	0
6	53.2	36.7	0	15.7
7	14	55.6	3.5	6.3
8	10.7	15.1	7	0
9	18.8	15	0.8	5.1
10	0	48.8	0	0
11	26.1	55.7	10.6	1.3
12	21.6	26.9	15.1	9.1
13	28.6	27.3	34.4	12.3
14	1.1	28.7	0	4.5
15	21.6	38.3	10.4	6.3
16	35.7	3	13.7	13
17	24.5	17.4	0.0	9.9
18	11	6.7	6.1	0
19	15.1	20.3	3.2	0.5
20	20.5	6.4	4.0	2.4
21	10.4	0	6	2.9

One of the features recorded using GPS technology in this inventory is actively eroding stream banks. Actively eroding stream banks for this investigation exclude those banks that are not subject to continued erosion in the near-term at discharges approximating bankfull. Many bank segments that experienced erosion from the April, 2005 flood were not classified as eroding because they are not expected to continue to erode under "normal" discharge (Photo 3.1.2). Feature categories recorded include (1) upstream and downstream extents of erosion; (2) bank height; (3) bank material; and (4) erosion mechanisms (hydraulic and/or geotechnical). Ninety actively eroding stream bank sites were recorded along the 21 miles of assessed stream. Approximately 17% of the total length of stream had at least one bank that is actively eroding. In terms of total bank length, about 9 percent of the Esopus Creek banks were actively eroding.

If we parse the data by reach, we find that some reaches are experiencing more stream bank erosion than others. According to the mapped data, the 5 reaches that are experiencing the most erosion as a percentage of bank length are:

- reach 6 (53.2% of the 1,654 meter long reach, or 26.6% of bankline)
- reach 16 (35.7% of the 1,143 meter long reach, or 17.9% of bankline)

- reach 4 (34.8% of the 1,270 meter long reach, or 17.4% of bankline)
- reach 13 (28.6% of the 851 meter reach, or 14.3% of bankline)
- reach 11 (26.1% of the 1,754 meter reach, or 13.1% of bankline)

The remainder of the reaches have mapped bank erosion ranging from 0% in reach 10 to 24.5% in reach 17. For the most part, the documented erosion occurs away from developed property and infrastructure. However, there are several sections of eroding stream bank that threaten developed property and infrastructure. Notable examples occur in reach 6 upstream of the Route 28 bridge at Phoenicia, reach 9 where at least 3 developed properties are experiencing rapid bank retreat, reach 18 where a Town road has been repeatedly washed out, and several locations where the abandoned railroad has been washed out. **Appendix E** includes reach scale maps of the eroding stream banks recorded during this investigation.

Photo 3.1.2 Non-persistent erosion caused by major flood events was excluded from classification as an eroding bank.

Flooding Hazard Assessment

Flooding was assessed by developing a Hydrologic Engineering Center's River Analysis System (HEC-RAS) model to simulate the water surface elevation on Esopus Creek associated with the bankfull, 2-yr, 5-yr, 25-yr, 50-yr, 100-yr, and 500-yr discharges, as discussed in the "Hydrology" section of this report (USACE 2006). **Appendix D** contains a more comprehensive report and associated maps.

Model Development

The HEC-RAS software was developed by the U.S. Army Corps of Engineers for assessing and designing flood management projects, although it is also used for many other purposes (USACE 2006). It is approved by the Federal Emergency Management Agency (FEMA) for use in developing Flood Insurance Rate Maps (FIRMs). It is capable of simulating steady and unsteady flow conditions as well as sub- and supercritical flows. For Esopus Creek, the model was run in a steady mode and flow conditions limited to the sub-critical state. The model was calibrated to known water surface elevations in those locations where such information was available (see discussion below) but has not been verified. The model is nonetheless useful for assessing conditions in the corridor and for alternative comparisons.

The model topography was generated using LIDAR data of the river corridor obtained in 2001, augmented with 2006 surveys collected by the Stream Management Team in the vicinity of Stony Clove, Woodland Valley, the Shandaken Town Hall, and immediately upstream of the Hwy. 28 Bridge near Big Indian. A digital elevation model (DEM) was generated from the LIDAR data and cross sections were developed from the DEM using HEC's GEO-RAS software (USACE 2006).

The 2006 ground survey data was integrated into the model by adding and adjusting cross sections where the ground data were collected. Bridges were simulated in the model using geometric data furnished by Ulster County Highways and Bridges Department, and the 1984 HEC-2 models from the Flood Insurance Mapping for Olive and Shandaken, furnished by the New York State Department of Transportation. Manning's resistance coefficients (roughness values) were set to 0.045 for the main channel and 0.09 for the overbank areas, based upon field observations and guidelines in Chow (1959), and expansion and contraction coefficients were set to 0.3 and 0.1, respectively. Tributary flows were modeled as discussed in the "Hydrology" section of Volume II of the Upper Esopus Creek Management Plan. Tributary geometries were not simulated, except at Stony Clove.

Although the model was not fully calibrated, adjustments were made to the resistance coefficients and ineffective flow areas (areas in the floodplains that are below the water surface but have no velocity) so that the bankfull water surface approximated points identified in the field; the 100-year water surface approximated that for the aforementioned flood insurance studies; and the 25-year water surface equaled that determined previously for the Woodland Valley Bridge. Ineffective flow areas were identified by overlaying computed water surfaces on the 2001 DOQQ imagery.

These model results should not be construed as a replacement for the existing Flood Insurance Studies in the watershed, and areas mapped as outside the 100-year flood zone in this analysis may, in fact, be subject to inundation from flow events of lesser magnitude. As described in the modeling goals listed above this analysis, in conjunction with field observations and interviews, is intended to assist planners in identifying areas that may be threatened by flooding or erosion, and to support other modeling efforts such as the sediment budget for the basin.

Model Results

Data were obtained from the model analysis for 160 cross sections on Esopus Creek mainstem, including 14 bridges, from reach 21 at river mile 23.1 to the mouth at the Ashokan Reservoir. At each section, hydraulic information such as the water surface elevation, channel velocities, cross sectional area, shear stress in overbank areas, etc., was computed for each of the simulated discharges. **Figure 3.1.5**, for example, shows the water surface elevations for each of the computed discharges at a section just upstream of the Highway 28 Bridge near Phoenicia. **Figure 3.1.6** shows a section that includes a bridge (Highway 28 upstream of Fox Hollow) and shows the velocity distribution associated with the 10-year flood event. The report in **Appendix D** presents a summary output table with some of the hydraulic information computed for each cross section.

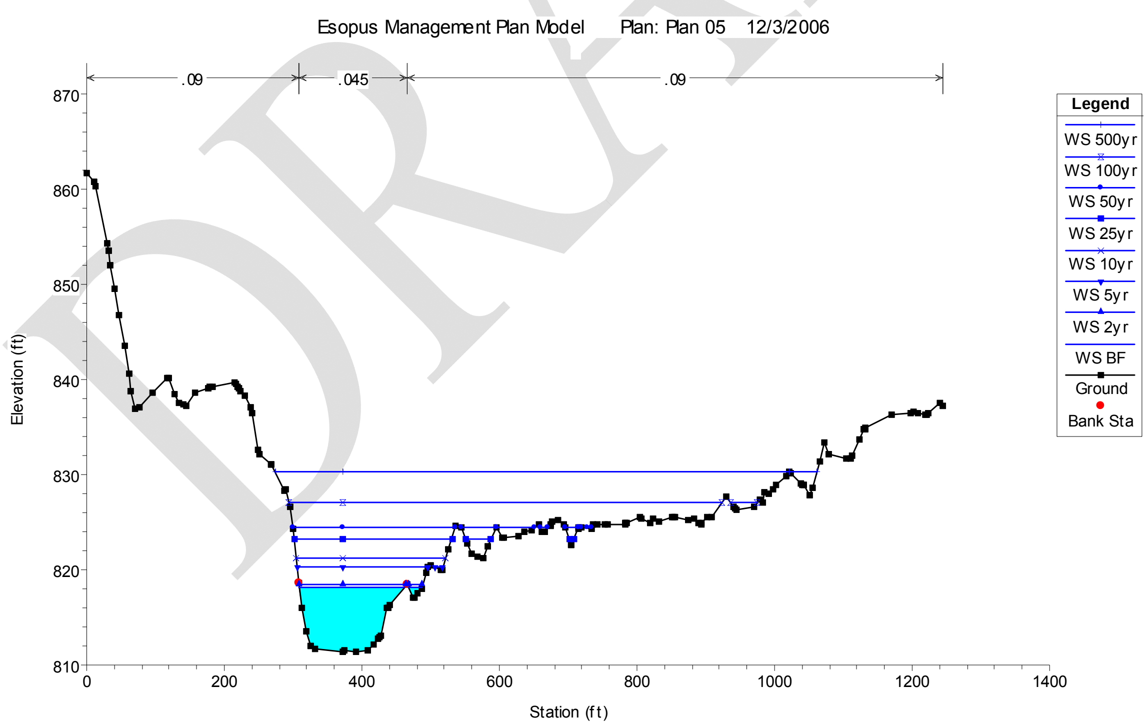


Figure 3.1.5. Example of HEC-RAS output showing water surface elevations (blue) and ground elevations (black). The example section is located just upstream of the Highway 28 Bridge at Phoenicia.

Appendix D presents plots of the water surface profiles for each of the modeled discharges. Flood inundation maps were generated by fitting these water surface profiles to the digital elevation model based upon the LIDAR data. The resulting flood depths are also shown on plots in **Appendix D**. The vertical accuracy of the DEM is 0.5 meters, so the displayed flood depths should be regarded as an indicator of potential flood depth only.

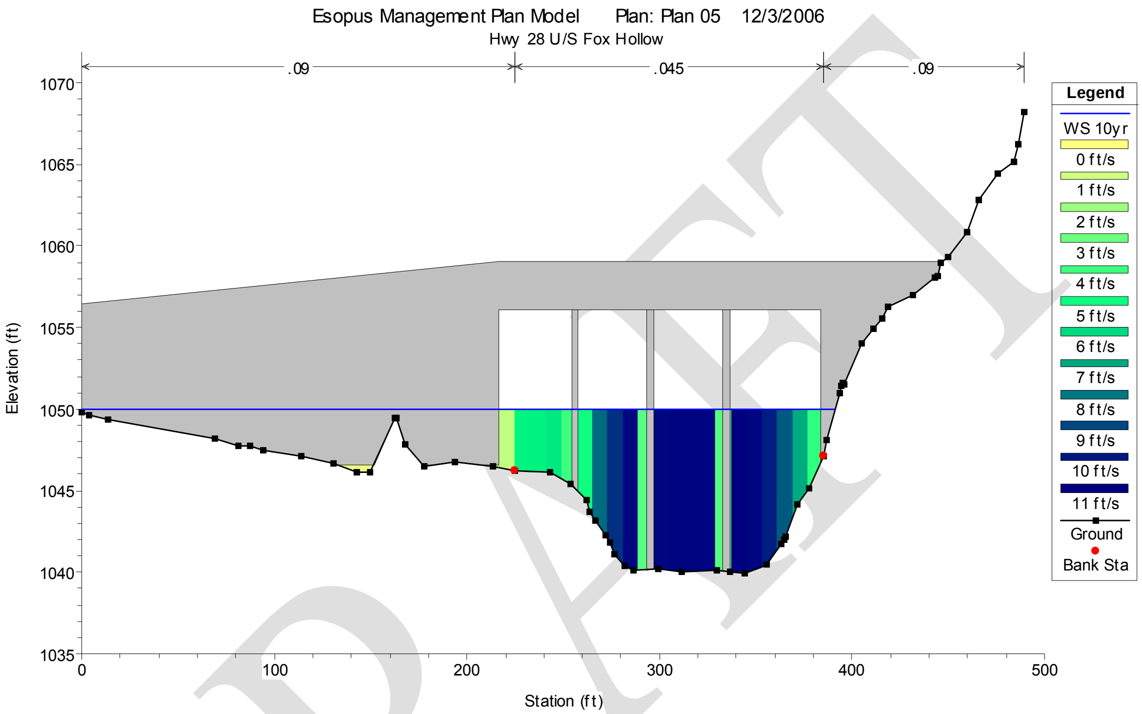


Figure 3.1.6. Example of HEC-RAS output showing bridge geometry, water surface elevation and velocity distribution for a 10-year flood event at the route 28 crossing just below Bushnellsville Creek.

An assessment of the impacts of discharges from the Shandaken diversion upon flooding potential in downstream reaches was made by superimposing a 900 cfs surcharge (equal to the approximate maximum operational flow from the Shandaken diversion) on the flows for the 10- 50- and 100-year flood events. Although this action is precluded by the requirements of Part 670 (NYSDEC, 1977), it represents a worst-case assessment of the potential influence of tunnel discharges. Maximizing tunnel releases was considered necessary given the emergency operations of the tunnel during the repair work on Gilboa Dam, so NYC applied for and received a waiver to operate outside the requirements of Part 670 on a temporary basis (NYSDEC, 1977). From November, 2005 through to December, 2006 the tunnel has been continuously operated at maximum capacity to help lower the Schoharie Reservoir water level during the work on the dam. Further dam rehabilitation work is anticipated starting in 2008 and the tunnel may be operated under emergency conditions again. The impacts of the tunnel releases in the mainstem Esopus Creek are to increase the water surface elevation about 3 inches in the first three miles downstream, on average (range 0 – 6 inches), and about 2 inches thereafter (**Figure**

3.1.7). The impacts diminish with increasing discharge and distance downstream. For example, while the average impact to the 10-year event water surface elevations is an increase of 2.67 inches, the 50-year event water surface elevation is raised by an average of 1.92 inches. Tunnel flows, even if operated at full capacity, have virtually no effect on downstream velocities, shear stress and stream power (< 1 percent increase) during flows in excess of the 10-year flood as analyzed above. Therefore the effect of the tunnel is negligible on stream bed erosion under these conditions, primarily due to the width over which the flow is spread at higher discharges (i.e., when the floodplain is in use as an overflow area).

Estimated 1.5 and 2 year return period flows for the mainstem Esopus Creek between the tunnel and Broadstreet Hollow are 4,000 cfs and 4,900 cfs, respectively (see **Table 2.8**, Hydrology Section). Adding 900 cfs to a 1.5 year event increases the discharge and the associated average depth (assuming a bankfull width of between 80 and 100 feet, from Miller and Davis, 2003) by 25%. We can therefore imagine that sustained high releases from the tunnel during flows that are marginally below bankfull may be sufficient to exceed bed erosion thresholds and add to minor stream bed erosion (though the bulk of stream bed movement occurs at the higher discharges which are not significantly impacted by tunnel flows). In many areas the Esopus Creek has sufficiently well-connected floodplain; in these areas small increases in overbank flows from tunnel contributions have much less increase in erosion impact because flows are spread over a larger area, and depth is not increased much. In sections of the stream that are confined and/or entrenched, however, the impact of even relatively small increases in discharge may increase stream bed or bank erosion, reminding us of the importance of floodplains to the resilience of streams in response to rapid and dramatic changes in flow magnitude.

Because the forces that cause bank erosion differ somewhat from those that cause bed mobility, small increases in flow stage that may not add to bed mobility may contribute to low-level bank loss in certain areas. Erosion thresholds would not generally be exceeded for natural, well-vegetated banks, but on some disturbed banks (such as those found in portions of Reach 9), the increased duration of erodible flows may contribute to bankline recession. These impacts were not specifically investigated during this study.

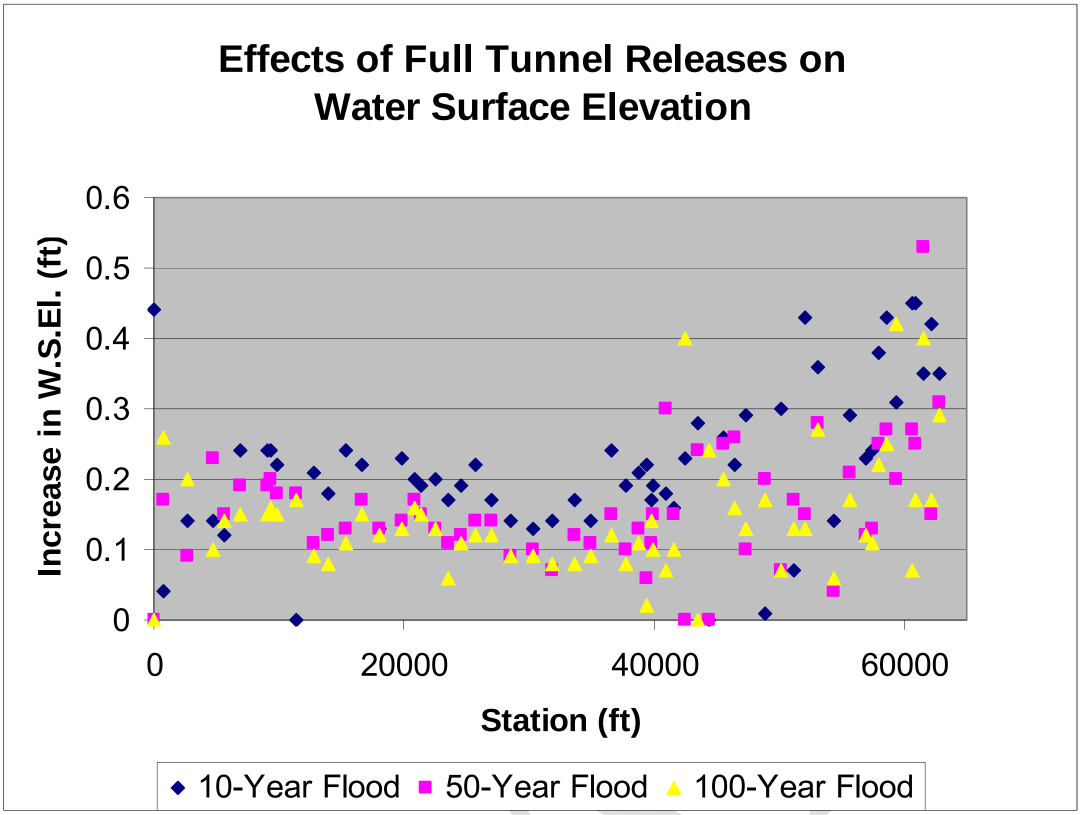


Figure 3.1.7. Effect of "Tunnel" discharges on water surface elevations of three floods on Esopus Creek mainstem; river station measured from 0.0 at the mouth of the Ashokan Reservoir upstream to the tunnel outlet.

Stream Erosion Hazard Assessment

Erosion is a naturally occurring phenomenon, and is common on even the healthiest of streams. It is necessary for many important ecological processes. Erosion recruits sediments needed for spawning and large woody debris that provides habitat and serves as both a substrate and a food source for lower trophic orders (primarily aquatic insects). Most importantly, erosion contributes to the shifting mosaic of habitats within a stream system that are exploited and required by many aquatic and riparian plant and animal species.

However, erosion can threaten infrastructure and, in cases where poor land management practices exist, become excessive and ecologically damaging. The Phase 2 field investigations revealed that about 10 percent of the banks along the mainstem of Esopus Creek are actively eroding. Most of these banks are retreating at rates of less than 1 foot per year, and are not presently threatening infrastructure, although they are resulting in the loss of valuable property. Major floods can induce widespread erosion, and the April 2005 flood eroded considerably more than 10 percent of the Esopus' banks, but most of this erosion is no longer active and is well on its way to healing.

Erosion is highly stochastic and is very difficult to predict, but mapping areas at high risk of erosion is technically feasible (Grimm, et al., 1999). On the basis of best professional judgment, a selection of potential factors that contribute to erosion risks, including both erosion and damage potential, were identified and a spatial model developed to evaluate relative risks for both banks of the Esopus Creek channel and for the channel avulsions within its floodplains. The model is a simplified risk rating system that evaluates several key variables representing processes that contribute to erosion and factor those along with the potential damages, which are largely a function of adjacent land uses. Data were not available for all variables and the algorithm used in the model process (described below) has not been peer-reviewed or field-verified. However, the rating system should help in identifying relative low, moderate, and high risk conditions that can then be further assessed to aid in determining the appropriate management steps. **Appendix D** contains a more comprehensive report on this first stage of model development. The discussion that follows is intended to outline the model methods and input. Upon peer review and field verification and subsequent model development final maps of erosion hazard ratings will be produced for future incorporation into the management plan.

Factors Important to Assessing Erosion Hazards

The algorithm for computing erosion hazards generates an index value ranging from 0 to 1.0 that can be roughly equated to a probability of erosion problems developing at a site in the foreseeable future (0 representing no probability of erosion). In reality, the index is most useful for relative comparisons of potential erosion problems. Although roughly 200 spatial data operations are necessary to compute the index, the basic equation can be reduced to the following:

EH = RC * A * BC * CC * TF * OF * DP

where EH is the Erosion Hazard Index, RC is a rating factor based on the riparian corridor conditions, A is an adjustment for channel avulsion potential, BC is a rating factor based upon the bank conditions, CC is a rating factor based on the channel characteristics, TF is an adjustment based upon proximity to a tributary confluence, OF is an adjustment based upon proximity to known obstructions and/or large woody debris, and DP is a factor that accounts for the potential damages should erosion occur at a site. These factors, as well as other important considerations that were not integrated into the model (generally because the data were unavailable or unreliable) are discussed below.

Although erosion is difficult to predict in time and space, factors that contribute to increased risk are relatively well known (**Figure 3.1.8**).

Figure 3.1.8. Factors included in the erosion hazards model include the lack of a healthy riparian corridor, high or over-steepened banks, areas located on the outer bank of meanders, and infrastructure located close to the stream corridor.

Chosen factors are discussed below, and their role in the computation of risk for the banks along Esopus Creek is presented. The algorithm used to compute erosion hazard first assigns a base value of 1.0 to all banks (a probability of 1.0 means certain erosion impacts), then adjusts this on the basis of the factors below with initial values and adjustment factor weightings based on best professional judgment.

In summary, with detailed description below, the above factors were assigned the following:

RC – erosion probability was reduced by a factor of 0.5 provided banks were located adjacent to healthy riparian buffer at least 30 feet wide;
A – channels that have flowing water at or less than bankfull conditions on the main channel were assigned a base value of 0.75, which was then adjusted on the basis of the other factors discussed in this section;
BC – base values of 1.0 for eroding banks with a height greater than 4 feet; 0.75 for eroding banks with a height of less than 4 feet; 0.5 for non-eroding banks, regardless of other conditions; and 0.25 for banks that were armored with bank protection materials;
CC – a factor of 0.5 was applied to areas not coincident to bars or meander bends with a ratio of radius of curvature to top width of less than 10;

OF – a factor of 1.25 was applied to banks within 100 feet of any obstructions or large woody debris jams;
TF – a factor of 1.25 was applied to banks within 200 feet of any tributary confluence;
DP – banks located within 50 feet of infrastructure were given a factor of 1.0; from 50 – 100 feet the factor was 0.75; and for 100 – 200 feet a factor of 0.5 was applied. For banks that have no infrastructure within 200 feet, a damage potential factor of 0.25 was utilized.

Riparian Corridor Conditions (RC)

Healthy riparian corridors, particularly those with dense stands of deeply rooted vegetation, buffer the effects of streambank erosion, encourage deposition of fine sediments and limit rates of bankline retreat. Conversely, the removal of woody and other vegetation from the streamside not only increases the likelihood of erosion, but the rates of erosion and bankline retreat will increase as well. For the hazard model, erosion probability was reduced by a factor of 0.5 provided the banks were located adjacent to a riparian buffer with a healthy stand of vegetation at least 30 feet wide. Areas lacking sufficient riparian buffer were first identified on aerial imagery, then field verified in Phase II of the assessment. The complete report in **Appendix D** presents a summary of the locations where the riparian corridor was determined to be insufficient. Note that this assessment was completed prior to the riparian corridor composition assessment performed by Barry Vittor Associates and documented in **Section 3.2**.

Channel Avulsion Potential (A)

Topographic relief in the floodplain can create zones of flood flow relief, storage areas for floodwaters, and increased resistance that slows velocities and reduces erosion potential. However, the potential for channel avulsions (abandonment of the existing channel and formation of a new channel on the floodplain) increases the risk of erosion in some areas. Most channel avulsions occur where an existing flood relief channel provides a steeper fall line than the existing channel, or where sediments and woody debris serve to or have increased probability to block all or part of the existing channel.

For the hazard model, potential channel avulsions were identified using the HEC-RAS model results in conjunction with a review of the digital elevation model and aerial photography to identify channels that have flowing water at or less than bankfull conditions on the main channel. These were assigned a base value of 0.75, which was then adjusted on the basis of the other factors (such as riparian corridor condition) discussed in this report section. Avulsions can be ephemeral features, and areas mapped as having an avulsion potential may change. The complete report in **Appendix D** lists the major avulsion areas identified in the study.

Bank Conditions (BC)

The condition of the banks can have a significant influence on erosion potential and the mechanisms by which the banks fail. **Figure 3.1.9** shows five factors identified in the

EPA's Watershed Assessment of Stream Stability and Sediment Supply (EPA 2004). Higher banks are more susceptible to erosion and geotechnical failures than are low banks. This is true both in an absolute sense and when considering the bank height relative to the bankfull water surface elevation as shown in **Figure 3.1.9**.

The more gradual the bank slope, the greater its resistance to erosion and failure. Vegetation roots greatly enhance the strength of bank soils, and the degree to which the roots are distributed in the bank horizon is a factor in erosion potential. Homogenous soils, all other factors being equal, are generally less susceptible to some bank failure processes than are banks with highly stratified soils. This is primarily due to the differential nature of soil drainage and the potential for piping in stratified soils. The size of the soil particles in the bank can be an even more significant factor. Coarse sediments are less susceptible to erosion than are smaller particles, unless the finer sediments have cohesive properties, as do the clays found in many of the Esopus Creek banks.

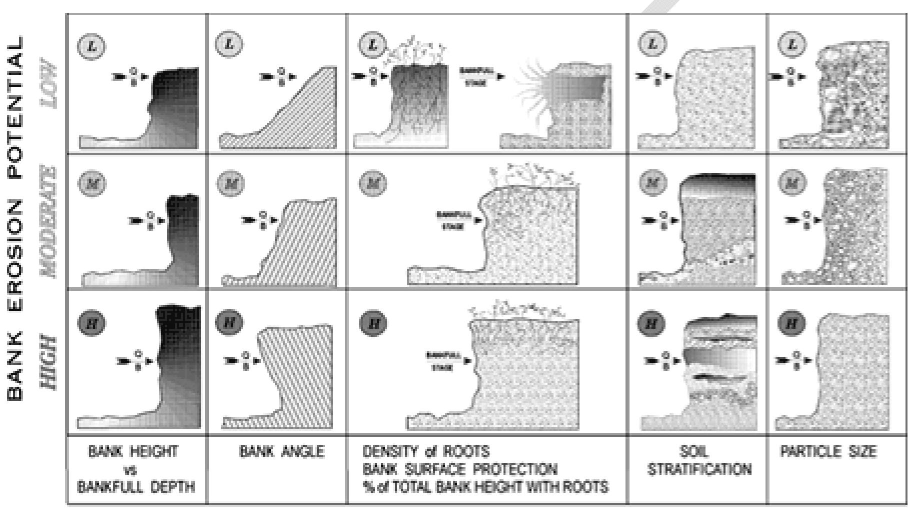


Figure 3.1.9. Bank factors influencing erosion potential.

For the hazard model, these factors were not directly utilized. The above information was collected during phase II only for eroding banks, while no specific information was collected for the non-eroding banks. Thus, a base value for the bank condition was determined on the following basis: 1.0 for eroding banks with a height greater than 4 feet; 0.75 for eroding banks with a height of less than 4 feet; 0.5 for non-eroding banks, regardless of other conditions; and 0.25 for banks that were armored with bank protection materials.

The bank protection factor was applied without regard to the quality of the protection measure employed at the site because existing bank protection measures were not critically evaluated during the investigations. During the Phase 2 investigations, however, it was noted that many of the existing protection measures were susceptible to failure from flanking or undermining by scour (**Photo 3.1.3**). Subsequent improvements to the model would likely include this factor.

Photo 3.1.3. Bank protection measures that are inappropriate for a site or are not properly keyed into the bed and banks of the channel and may be ineffective were nevertheless given a weighting factor of 0.25 in the Erosion Hazard Model.

Channel Conditions (CC)

Channel geometry and channel conditions play an important role in defining erosion potential. Meandering streams systematically erode the outer banks of a meander bend, while the inner bank is generally a zone of sediment deposition, for example. Areas adjacent to mid-channel bars and transverse bars often experience impinging flows and concentration of streamlines that result in increased erosive capacity of the flows. Areas in proximity to large woody debris and channel obstructions can experience local turbulence that increases erosion potential. Areas in the vicinity of tributary junctions are often unstable due to the differences in flood timing and sediment delivery.

For the hazard model, adjustment factors were applied to account for many of these conditions. A factor of 0.5 was applied to areas not coincident to mid-channel bars, transverse bars, or meander bendways with a ratio of the radius of curvature to the top width of less than 10. Locations of the above features were determined by inspection of the 2001 DOQQ's, and field conditions may have subsequently changed at some sites. A factor of 1.25 was applied to banks located within 200 feet of any tributary confluence, or if they were located within 100 feet of any obstructions or large woody debris jams mapped during the Phase II effort (OF in the above equation). The latter are often ephemeral features, so the increased erosion threat associated with LWD and obstructions may have changed since the conduct of the Phase II mapping effort.

Damage Potential (DP)

The impacts of erosion are most significant when they threaten life or expensive infrastructure. A "Damage Potential" factor was applied in the model to attempt to account for this variable. The factor is dependent upon the proximity of roads, structures (bridges, buildings), and utilities to the potentially eroding streambank. The infrastructure was identified in the field during the Phase 2 investigation, by review of the 2001 DOQQ's, and from GIS coverages of roads and homes. Banks located within 50 feet of infrastructure were given a factor of 1.0; from 50 – 100 feet the factor was 0.75; and for 100 – 200 feet a factor of 0.5 was applied. For banks that have no infrastructure within 200 feet, a damage potential factor of 0.25 was utilized.

Other Factors

Streambanks fail from a variety of causes, some of which are geotechnically related while others are induced by hydraulic forces. For the latter case, measures such as velocity, shear stress, and stream power can be good indicators of erosion potential. Although these measures were computed from the HEC-RAS analysis, their integration into the hazard model was not attempted because of complexities in formulating a suitable algorithm that accounts for the variation in these measures with discharge. It is recommended that future versions of the model directly include this important factor.

In-channel mining of gravels and other sediments can directly effect streambank erosion and stability by lowering local base flow level, causing headcuts, channel incision, changing channel dimensions and patterns. The EPA's assessment of risk for in-channel mining is based on the direct disturbance in relation to the percent of channel length impacted and is shown in Figure 3.1.10. The letters in the figure refer to different stream types according to the Rosgen Classification system (Rosgen 1996). Most reaches of Esopus Creek are associated with the blue and green lines. Although gravel mining has historically occurred on Esopus Creek, this factor was not included in the hazard model at this time. Locations of former mining activities have been indentified by interview with Keith Johnson, Shandaken Highway Superintendent. It is recommended that future improvements to the model seek to include this variable.

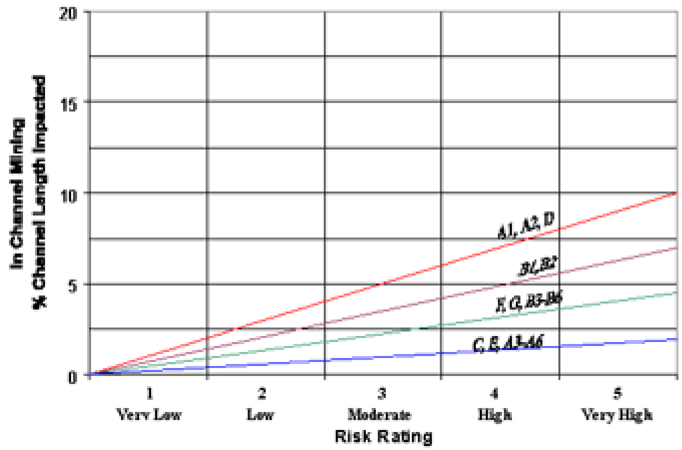


Figure 3.1.10. Risks for instability resulting from in-channel mining (EPA WARSSS 2004).

Fluvial Erosion Assessment Results

The model was run separately for the left and right banks of the Esopus Creek as well as for the channel avulsion zones. Probability/risk factors ranged from 0.0039 to 1.0 for the banks, with a median value of 0.125. Thirty-four channel avulsions totaling 9.2 miles were also mapped and evaluated; risk factors for 237 segments ranged from 0.004 to 0.141, with a mean value of 0.026. The banklines were separated into five classes of risk based upon a quantile distribution (values were ranked, divided into five equal groups based on number of occurrences, and assigned a class value).

Because of the construct of the algorithm, the areas of highest risk are near facilities or other infrastructure that could be threatened by erosion, and have at least two other risk factors (for example, the lack of a riparian corridor and proximity to a tributary). Conversely, areas without infrastructure and where an adequate riparian zone exists on the floodplain generally have low risk rankings. The distribution of the hazard rankings as a percentage of bank length for each reach is presented in Figure **3.1.11**.

Areas within the lower two quantiles are considered low risk, and no further action is recommended. Sixty-two percent of the banks (based upon length) were thus classified. The middle class (yellow in Figure 3.1.11) is regarded as moderate risk and worthy of periodic monitoring. Changes in the condition for any of the high risk factors could signal a shift into the high risk category. Twenty-six percent of the bank length on the Esopus Creek received this classification. The red and orange quantiles in Figure 3.1.11 represent areas of relative high erosion risk. Twelve percent of the banks received this classification. Assuming subsequent development of the model has similar results, these areas may warrant investigation to determine if action to reduce erosion risk is necessary, or if further monitoring is sufficient.

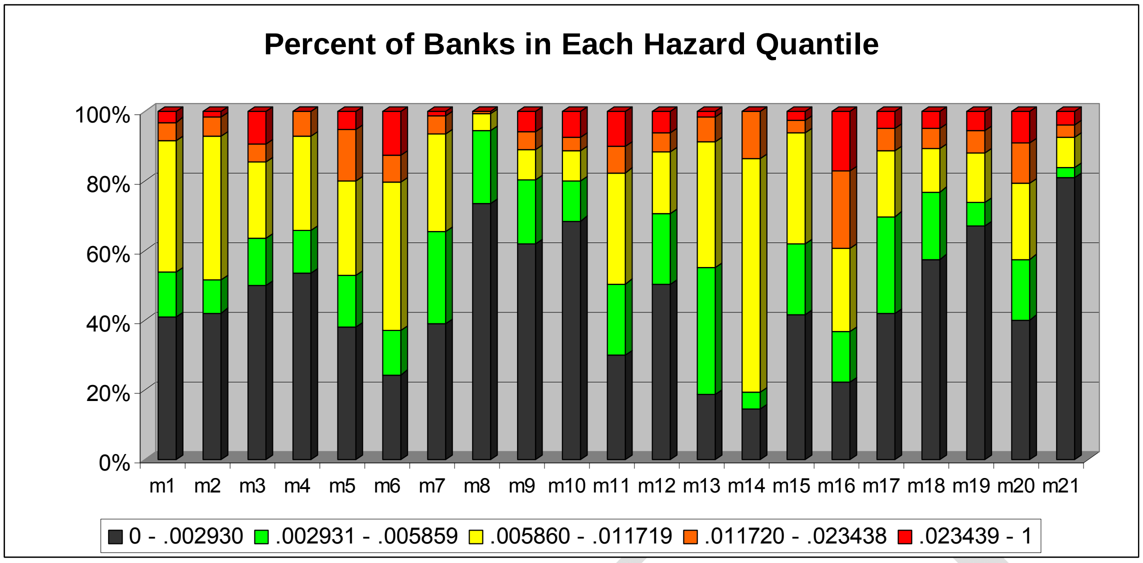


Figure 3.1.11. Percent of banks in each reach that fall within each fluvial erosion hazard quantile. Red and orange zones represent areas of greatest concern.

Recommendations

The Project Team proposes that this approach to identifying fluvial erosion hazard risk be further developed through the following activities:

1. Continue testing development of algorithm to include (a) stream flow velocity and shear stress; (b) stream bed and bank geologic composition; c) other factors discussed above. Review existing bank erosion dataset for possible use in model development.
2. Construct model to extent possible with adjusted topographic data based on updated LiDAR data (if available) and surveyed elevations.
3. Calibrate the model and develop program to field verify model, particularly to refine parameter values, ratios and weightings.
4. Develop program to ensure continued model development to adjust to changing channel conditions.
5. Multi-variate analyses to determine more accurate weightings for each chosen factor.

Stream Management Implications

Although a relatively small percentage of the banks on Esopus Creek fall into the highest risk category, addressing these areas requires a significant investment in resources. By definition, the areas of greatest concern are coincident with infrastructure that may be at risk from future erosion or channel avulsion. Reasonable actions to protect those facilities are generally site-focused, and offer only limited opportunities for meeting the broad range of objectives outlined for the Management Plan. Thus, the focus of the Management Plan will be on providing technical guidance aimed at improving performance and reducing impacts in support of the owners of jeopardized infrastructure, who must bear the majority of the responsibility for protecting those investments.

Conversely, many of the moderate-risk erosion areas can be addressed through management actions such as riparian buffer establishment that have a broad range of benefits that can individually and cumulatively extend well beyond the limits of the project. Biotechnical stabilization and riparian restoration actions are also generally more cost-effective than other stabilization measures, and can generally be implemented by local landowners with limited resources. During the course of future improvements to the Erosion Hazard Indexing Model and through the proposed monitoring program, the aim of the stream management effort will be to identify locations and actions that can potentially yield the greatest benefits per unit cost not only in terms of erosion reduction, but also for water quality, habitat, aesthetics, and the other management objectives. Developing a means of providing technical and potentially financial support for these efforts will be a future goal of the management program.

Glacial Sediment Erodibility Study

Where streams intersect clay-rich glacial till and/or glaciolacustrine silt and clay, fine sediment is entrained during high runoff giving the streams a characteristic red-brown turbidity (**Section 2.5** and **2.7**). After very large watershed scale flooding, NYC has had to flocculate reservoir water with alum to reduce the suspended sediment to levels that will allow for successful treatment without filtration (**Section 2.7**).

Exposures of fine sediment sources were mapped along the mainstem channel (**Figure 3.1.12** and **Map 2.3**). The fine sediment sources along Esopus Creek are typically glaciolacustrine layered silty clays and dense clay-rich glacial till. For the last 12,000 – 15,000 years, Esopus Creek and its tributaries have incised into the glacial and post-glacial stream deposits and continue to do so. When the stream exposes and erodes these non-alluvial sediments they can become a periodic source for turbidity. Further, when the stream bank and adjacent hill slope intersect in the presence of glacial till or glaciolacustrine silty clay, hill slope instabilities can occur and instigate a long-term exposure of fine sediment source.

Observation of exposures of these fine sediment sources over the past few years suggest that (1) glacial till and glaciolacustrine sediments erode differently; (2) they do not erode continuously, and the threshold of erosion may be quite high; and (3) the threshold of erosion is dependent upon the deposit characteristics and the amount of disturbance associated with adjacent hill slope failures. In order to facilitate decisions about stabilizing these exposures, a study was performed to assess the erodibility of fine sediment exposures and to determine if there are characteristics of the sediments that explain differences in erosion rates. **Appendix D** contains a draft paper documenting the study. The methods and results are briefly summarized below.

Method Summary

Six samples of clay-rich glaciogenic deposits were collected for this study (**Table 3.1.4** and **Figure 3.1.12**). The majority of the mapped fine sediment sources along Esopus Creek are glaciolacustrine (**Photo 3.1.4**). Five of the samples collected were glaciolacustrine sediments from the Esopus Creek channel and the sixth was a clay-rich glacial till from a tributary stream. Sediment cores were collected at each sampling location with a 16.6 cm diameter plexiglass tube driven into the in-situ sediment (**Photo 3.1.5**). Core depths of 13 to 22 cm were obtained for analysis. Because considerable variation exists in the glaciolacustrine sediment composition (varying degrees of silt and fine sand with clay) and degree of structural disturbance, sample sites were selected to represent the range of observed field conditions.

Critical shear stress and rates of erosion with variation in applied shear stress were evaluated by subjecting the sample cores to various flows in a straight flume, which has a test section with an open bottom through which the sediment coring tube can be inserted. The methods are detailed in the report in **Appendix D**.

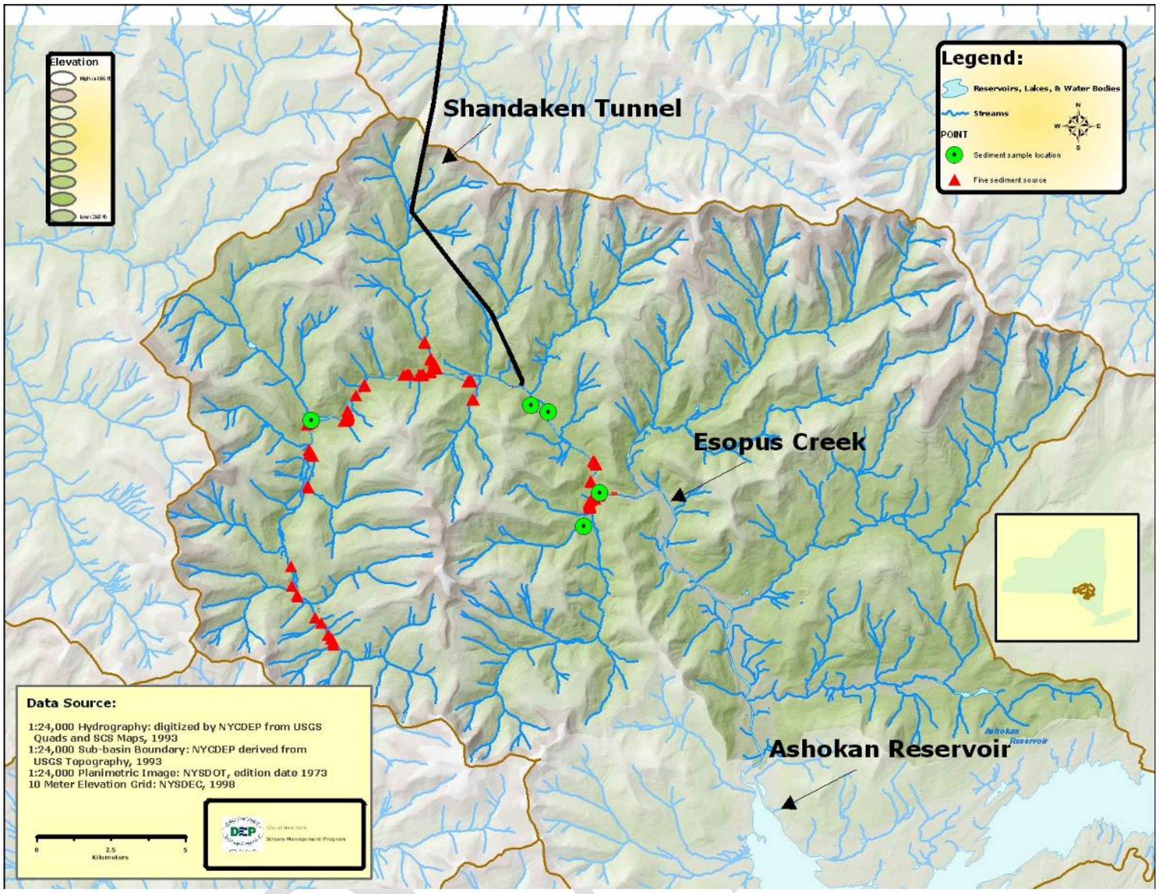


Figure 3.1.12 Map of the Esopus Creek study area with glaciogenic sediment exposures shown as red triangles. Sample sites for this study are shown in green.

Table 3.1.4. Summary of sample locations and conditions.

Sample ID	Sample Location	Orientation	Depth (cm)	In-Situ Condition
M6-S01	Reach 6	Perpendicular	20.6	Glaciolacustrine sample contains several fine sandy laminae with unit readily separating along sandy contact. Located in former restoration reach disturbed by equipment.
M9-S01	Reach 9 South channel	Perpendicular	17.5	Glaciolacustrine bedding is disturbed/deformed and adjacent hill slope has numerous slumps and scarps.
M9-S02	Reach 9 North channel	Perpendicular	20.5	Glaciolacustrine sediment exposed in toe of bank adjacent to fluvial terrace. Bedding of unit dipping ~20 deg into bank with a rotational failure scarp ~20 ft from stream edge. The unit is very ductile with micro-laminae bedding.
M16-S01	Reach 16	Perpendicular	18.5	Glaciolacustrine sediment exposed along channel margin is not evidently disturbed/deformed and site is away from hill slope. Unit is very dense and seems to be entirely interlayered silt/clay with little to no fine sand.
M16-S02	Reach 16	Angled	13.0	Same sampled unit as M16_S02 but sample collected at 45 degree angle to stream bed in downstream direction.
PK-S01	Panther Kill Woodland Valley	Perpendicular	21.8	Moderately deformed glacial till, composed of dense clay/silt with embedded granule to gravel sized clasts: representative of clay-dominated glacial deposits in head water tributaries.

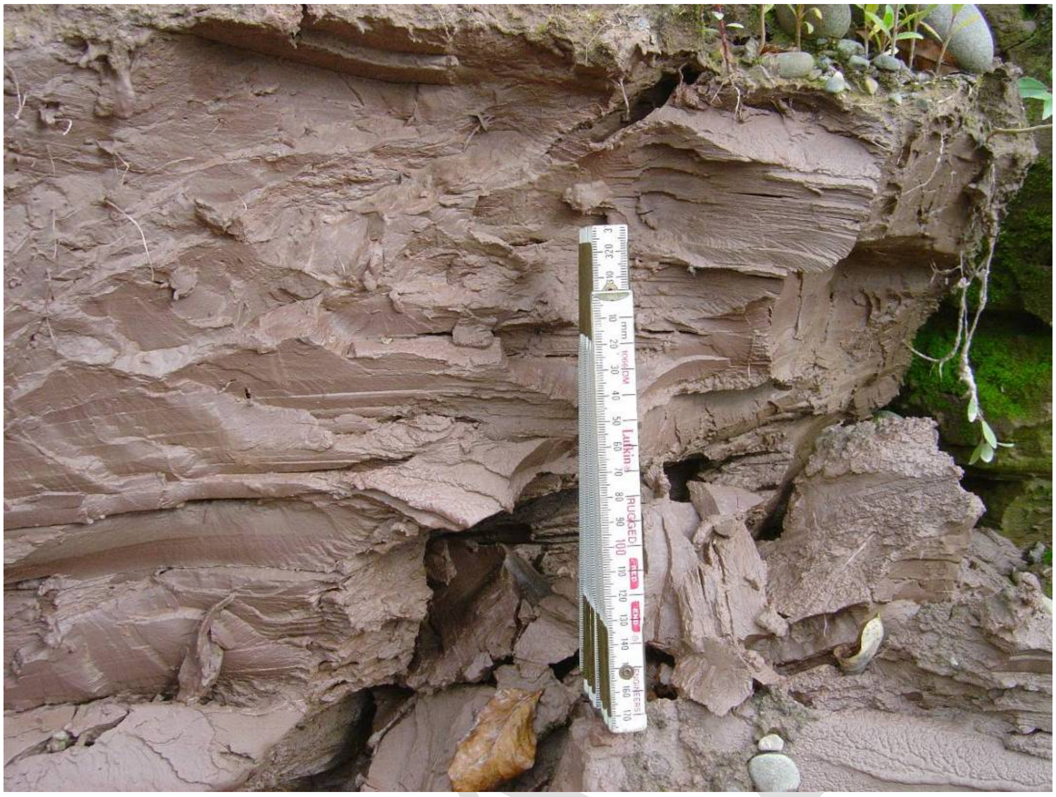


Photo 3.1.4 Typical clay exposure with the surface cleaved to expose bedding planes. Sample site M9-S02

Photo 3.1.5 Acquisition of a sample from the streambed. Sample M16-S01

Results Summary

A total of 185 measurements of erosion rate were obtained for the six samples, at shear stresses ranging from 0.1 to 12 Pa. In addition, thirty-nine sub-samples were obtained and evaluated to characterize the physical properties of the sediments. **Table 3.1.5** presents a summary of the findings. Roughly half of the runs resulted in erosion rates lower than the detection threshold ($1x10^{-4}$ cm/s). In five instances, 12 Pa was insufficient to erode the sample. The lowest shear at which measurable erosion occurred was 0.8 Pa.

Table 3.1.5. Summary of sample properties.

Sample ID	Mean Bulk Density	d50 (um)	d90 (um)	Coeficient of Uniformity	Mean Critical Shear (Pa)	Mean Erosion Rate (cm/s at 6.4 Pa)
M6-S01	1316	3.11	10.04	4.21	3.04	0.0277
M9-S01	1199	3.50	12.30	4.84	3.35	0.0014
M9-S02	1238	3.37	8.69	4.10	2.24	0.0395
M16-S01	1305	2.60	7.51	4.13	7.20	0.0005
M16-S02	1233	2.40	7.65	4.26	9.90	0.0001
PK-S01	1691	6.11	53.81	8.23	8.34	0.0001

The properties of the glaciolacustrine samples proved quite similar from sample to sample. Bulk density ranged from 1144 to 1398 gm/cm^3, and the standard deviation for the population was 62 gm/cm^3. The d_{50} and d_{90} of the sediments ranged from 2.0 to 4.3 µm and 6.4 to 17.4 µm, respectively. The till sample (PK-S01) had a bulk density range from 1640 to 1753 gm/cm^3, and the d_{50} and d_{90} ranged from 5.5 to 6.4 µm and 45.2 to 57.8 µm, respectively.

Erosion rates were not uniform over time for the glaciolacustrine samples. Rather, they were frequently observed to diminish and trend toward zero, particularly at values of shear stress less than 6.4 Pa. This result is consistent with field observations, where clay exposures have been known to erode for a short period of time and then “heal” such that they no longer contribute to visible turbidity. This process was simulated in the laboratory by rolling coarse sediment particles across the sample surface then evaluating erosion thresholds and rates. In general, the scuffed surface eroded briefly at 1.6 Pa, but flow rates had to be increased to the base critical shear stress to sustain erosion.

The samples were separated into two categories based upon apparent disturbance to determine if this factor contributed to erodibility. Core samples from M16-S01, M16-S02, and PK-S01 were extremely well consolidated with little variation in the grain size and bulk density, and were obtained from units believed to be largely undisturbed. Samples M6-S01, M9-S01, and M9-S02 showed more variation in grain size, and were obtained from units in close proximity to failed hillslopes or were otherwise disturbed.

Analysis of the samples indicated clear differences between the disturbed and undisturbed samples. The mean threshold of erosion was determined to be 2.9 Pa for disturbed samples and 8.5 Pa for undisturbed samples. It was noted that 43 percent of the disturbed sample runs resulted in measurable erosion at 1.6 Pa, and 52 percent of the runs for undisturbed samples eroded at 6.4 Pa, which may be a better indicator of the actual critical shear stress than the mean values shown in **Table 3.1.5**.

Erosion rates were higher for disturbed than undisturbed samples. A linear regression of the measured rates of erosion suggests that disturbed samples, on average, erode at six times the rate for undisturbed samples. Disturbed samples also "healed" more slowly when subjected to surface perturbation. Only five erosion rates in excess of 0.001 cm/s were measured for undisturbed samples, and none exceeded 0.0033 cm/s. Erosion rates exceeded 0.001 cm/s for disturbed samples 20 times, and were as high as 0.27 cm/s. All disturbed samples eroded at 3.2 Pa or higher, whereas this was the minimum shear at which undisturbed samples eroded, and many failed to erode at 12 Pa.

Discussion and Conclusion

The rate of erosion and critical shear stress were not found to be well correlated to the bulk density of the sediments, as has been suggested in previous studies. This may be due, in part, to the highly consolidated nature of these sediments. Difficulties in characterizing the sediment properties may be a factor as well. Bulk density and sediment size varied with depth in several of the samples due to differences in the sediment composition of bedding layers. However, the sampling strategy involved collecting a portion of the sediment core surface for analysis, and multiple bedding layers were invariably consolidated in this process.

Disturbed samples were found to be significantly more erodible than undisturbed samples. It appears that displacement of the clay units – such as occurs where hillslope failures intersect glaciolacustrine sediments - results in fracturing along planes that contain silts or sands, and may break some bonds between clay particles. The critical shear stress for these disturbed sediments is reduced by two-thirds, and the resulting erosion rates increase by a factor of six, on average.

Roughening the surface of the samples to simulate disturbance from gravels and cobbles saltating or sliding over the surface resulted in a lowered critical shear stress and an increase in erosion rate. However, while erosion was evident on rough surfaces, the erosion did not always persist or increase as the shear stress was increased. This indicated that once the disturbed material was eroded, the sample would smooth over and become more resistant to erosion.

There are several implications of the study results with respect to stream management. Given its geologic ubiquity and susceptibility to erosion during flooding, it may not be feasible to expect multi-objective stream management actions to substantively reduce total sediment loads derived from glacigenic sources in this system.

However, some actions may help reduce turbidity, particularly at lower discharges. Results of this study suggest that priority should be given to stabilizing those sites where the sediments have been disturbed, as these are the most likely to persistently erode at lower discharges, and generally contribute much higher volumes of sediment than comparable undisturbed sediment exposures. Conversely, care should be exercised before committing to stabilizing or armoring undisturbed glaciogenic sediments. Excavation and perhaps even equipment operation on or in the vicinity of these sediments may cause sufficient disturbance to increase their future susceptibility to erosion.

Sediment Budget

Photo 3.1.6. Exposed "glacial clay deposits" were one of several sources of fine sediment investigated in the study.

Objectives and Limitations

This study was conducted to assess the relative contribution of fine sediment sources (Photo 3.16) in the Esopus Creek watershed for the purpose of evaluating the efficacy of various management measures aimed at turbidity reduction. Sediment budgets require considerable data, and their accuracy is dependant upon the quality and completeness of that data, or the verity of assumptions when data are missing. Even with extensive data sets, sediment budgets are often regarded as order-of-magnitude assessments to evaluate general trends, and budgets for fine sediments (silts and clays) are particularly difficult. Nevertheless, this study was initiated with the purposes of identifying: 1) the primary sources of turbidity in the system, and 2) additional data collection needs and analyses to refine the budget, if warranted. This sediment budget follows the guidelines outlined by the U.S. Army Corps of Engineers for sediment investigations (USACE 1999).

Existing Conditions and Data

The study area includes the Upper Esopus Creek watershed upstream of Ashokan Reservoir, including the reservoir, Esopus Creek and its principal tributaries, surrounding uplands, and the Schoharie Diversion (Figure 3.1.13). NYCDEP has a long-term water quality sampling program of streams in the NYC water supply watersheds. Water quality samples are collected at a fixed frequency (systematic) from a network of sampling sites throughout the watershed. Grab samples are generally collected once a month (twice a month at selected sites). Storm event sampling is also performed at selected sites. In addition, the USGS and Stroud Research Center, among others, have conducted sampling and analysis of water quality at various locations and times in the watershed.

Figure 3.1.13. Overview of study area showing sediment and water quality sampling sites, USGS gages, and key watershed features.

Bulk sediment samples were collected at numerous locations on the bed of Esopus Creek and several of its tributaries as part of the Phase II investigations for the Management Plan (Photo 3.1.7). The percentage of fine material (silts and clays) in the bed was found to be roughly a function of distance upstream of Ashokan Reservoir ($r^2 = 0.43$), and ranged from 0.3 to 2.9 percent, with a mean value of about 1.5 percent. During Phase II, the locations and lengths of eroding banks along Esopus Creek were also documented (**Map 3.2** and **Appendix E**). Sediment samples to characterize the banks were not collected, although the general character (fill, alluvium, glacial till, etc.,) was noted during the site investigations. Samples of the pro-glacial deposits were collected and analyzed in the laboratory, and are discussed in a draft paper included in Appendix D.

Photo 3.1.7. Samples of the bed material were collected and evaluated to determine the volume of silts and clays present at various points along the channel.

The Upstate Freshwater Institute (UFI) investigated relationships between turbidity, total suspended solids, and the relative contributions to turbidity between the Schoharie Diversion and the Esopus Creek watershed (UFI 2007). They found a non-linear relationship ($r^2 = 0.62$) between flow and turbidity for data from 1991 - 2005 at sampling site E16i on Esopus Creek (Figure 3.1.14). Huge runoff events like those in January 1996 and April 2005, which erode substantial lengths of stream banks and supply continual sources of turbidity-causing particles, plot above the best-fit line in the figure, while data points below the line are generally associated with periods of relatively lesser flow and disturbance. The wide range of data values at lower discharges (more than an order of magnitude in variability) is common for supply-limited sediments.

Turbidity, while an optical property, behaves as an intensive property (like concentration of any other water quality constituent) due to the additive character of its sources and components. Though not commonly applied, this behavior permits mass balance calculations for turbidity and estimates of turbidity (quasi-) loads. Turbidity “loads” can then be converted to sediment loads using TSS/NTU relations. UFI used the NTU/discharge relationship to develop turbidity loads for 1991-2005 by multiplying hourly flows from gage records with the corresponding turbidity concentrations and integrating the results over the time period (UFI 2007).

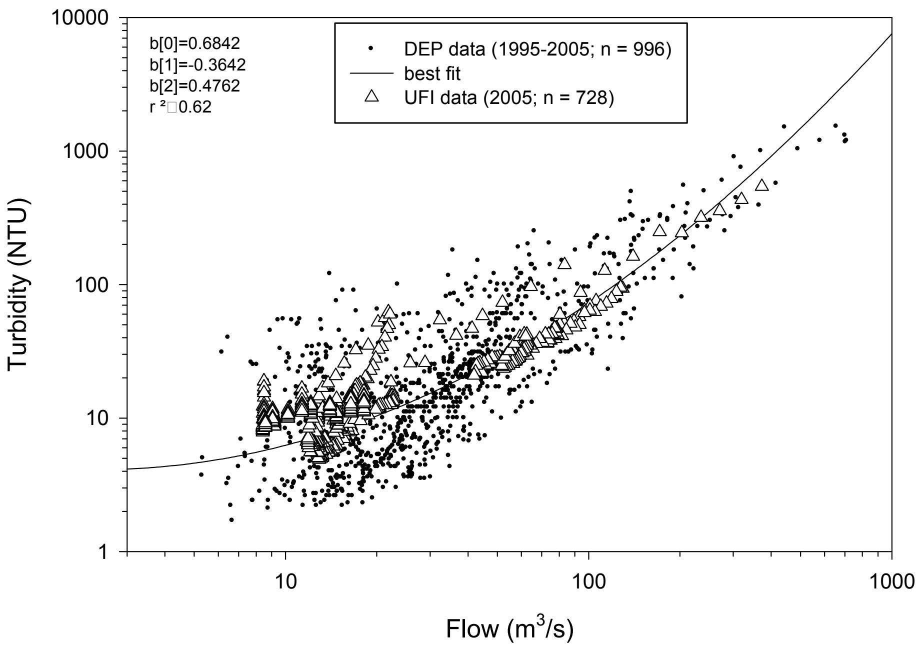


Figure 3.1.14. Flow-turbidity relationship for site E16i when the Schoharie diversion tunnel was not in use (source: UFI 2007).

Among the key findings of the UFI (2007) report:

- Shandaken Tunnel contributed 0.5% (3.4 B NTU·m^3) in 1996 (high flow year) to 43% (3.1 B NTU·m^3) in 2001 (low flow year) of total turbidity load to Ashokan Reservoir on an annual basis.
- Average turbidity loading for the study period from the Shandaken Tunnel was 2.1% of the total load.
- Turbidity loading from Esopus Creek ranged from 3.9 B NTU·m^3 in 2002 to 708 B NTU·m^3 in 2005. The rather large range in turbidity loading from the watershed is due to inter-annual variability in runoff events.
- Highest relative turbidity loading from Shandaken Tunnel most often occurred during low-flow months of February, July and August.

Sediment Budget Analysis

Sediment budgets can take many forms and serve a variety of purposes. In general, they involve quantifying one or more of the basic sedimentation processes: erosion, transport, deposition and consolidation. They can address the full range of sediments involved in these processes, or focus upon specific sediment classes of interest (e.g. fine sediments). For this study, we are primarily interested in identifying the sources of the silt and clay fraction of the sediment and their relative contribution to elevated turbidity levels in

Esopus Creek. The source and fate of coarse sediments as well as the deposition and consolidation of fines are of only passing interest.

Many methods have been developed for evaluating sedimentation processes, and each has limitations (Fischenich and Little 2006). Estimating fine sediment loss from source areas based upon measurements of sediment movement in streams and rivers faces several problems. Taking the measurements is time consuming and expensive; the accuracy of the measurements is likely to be poor; and even if there are good data on the movement in a stream it is not known where the soil (fines) came from and when they were eroded (Dickinson and Bolton 1992). Isotopic analyses can reveal the source of an individual sediment particle in some instances, but does little to quantify the volume of material derived from that source.

Total Yield

Two approaches were used to estimate total fine sediment yield: 1) an evaluation of reservoir deposits and 2) an assessment of turbidity loading. Sediment deposition in the Ashokan Reservoir was documented by Giblin et. al. (1999). Their study showed that 8078 acre-ft ($9.96X10^6$ m^3) of sediment had deposited in the reservoir between 1915 and 1997. Deposited sediments were 71% silts, 26% clays and 3% sands, generally in deposit thicknesses of less than 1 meter. Assuming the trap efficiency is 90% and the water content of the unconsolidated sediments averages 196% (see Appendix D), average annual dry sediment yield is about 70,000 m^3 based on this data.

The Upstate Freshwater Institute (UFI) investigated relationships between turbidity, total suspended solids, and the relative contributions to turbidity between the Schoharie Diversion and the Esopus Creek watershed (UFI 2007). The mean turbidity loading for the lower Esopus Creek in the period from 1991 through 2005 was 123 x 10^9 NTU * m^3/yr. After conversion to a sediment concentration, and division by the unit weight, the UFI analysis yields an average annual dry sediment yield of about 90,000 m^3.

The yield for 1991 – 2005 based on the UFI data compares favorably with the results of the analysis based upon reservoir sedimentation for the period 1915-1997. The range of yields can be considerable, and the vast majority of sediment is associated with large flood events. Based on the UFI (2007) study data, sediment yield ranged from 2,850 m^3 for 2002 to 518,000 m^3 for 1996 (2005 had similar levels). Excluding the 1996 and 2005 flood-related data, the mean loading from 1991 to 2005 was 24,700 m^3/yr.

The total sediment load is derived from a variety of sources, including the Schoharie Diversion, overland runoff (including ditch flows), point source erosion of glacial sediment deposits (especially when they are disturbed), and non-point source erosion of the banks and bed of the channels within the system. Estimates of each of these sources were attempted in the study.

Tunnel Contribution

Sediment yield from the Schoharie Diversion was assessed using 1991 – 2005 loading data presented by UFI (2007). The mean yield of sediment in that period is 1,890 m^3/yr, and varies from 290 m^3 (2003) to 5,520 m^3 (2005). Thus, Schoharie Diversion contributes about 2.5 percent of the total load to Esopus Creek over the long term. In the period since 1991, loadings ranged from 0.5 to 42.9 percent, and average 7.7 percent of the load in non-flood years. Estimates of sediment yield from this source are considered to be very reliable because they are based on direct measurements of NTU and discharge.

Clay Source Contribution

To assess the long-term sediment yield from mapped fine sediment sources (clays), a HEC_RAS model (discussed in the following section) was used to compute mean bed shear stress for a range of discharges along 146 sub-reaches of Esopus Creek. The discharges and associated shear stress were correlated to a duration. Equations relating erosion rates to shear stress were applied to each mapped fine sediment source, and the values summed over the annual flow duration series. Total sediment yield was determined to be 5930 m^3/yr on average, or 24 percent of the total load excluding floods (7.9 percent of long-term average). This estimate should be viewed with caution, however, as the equations for erosion rate required extrapolation well beyond the laboratory data upon which they were based.

Bank Erosion Contribution

Sediment contribution from bank erosion was computed by multiplying the dimensions of eroding banks documented in the 2005/2006 field season by an assumed average recession rate of 30 cm/yr (see Appendix D). The field data excluded erosion strictly associated with the 2005 flood, so is representative of non-extreme flood related erosion. The contribution as a function of sediment class (clay, silt, sand, etc.,) was determined by multiplying the total yield by the fraction in each size category found in the bank material. Computed average annual total yield was 5,780 m^3, and the contribution of silts, clays and fine sands was 2,370 m^3. Thus, the contribution of bank erosion to fine sediment yield is about 9.6 percent in years excluding major floods.

To evaluate the contribution including flood effects, field observations following the 2005 flood were used to estimate the total length of eroding bank and active channel avulsions. Approximately 30 percent of the banks had eroded an average of 30 cm following the event, and it is assumed that all of the 14,820 m of channel avulsions were active to the same degree. Assuming an average bank height of 2 m, the sediment contribution during this event would have been 19,950 m^3.

Stream Bed Contribution

Yield of fine sediments from disturbance of bed material in the mainstem creek channel was determined by computing the volume of material available in the active layer of the bed. The active channel width was set at bankfull, and the active bed depth was set at 1.5 times the d_{90} of the bed material, to account for armoring (Copeland 1989). The bed material d90 and the percent of silts and clays were determined from the bed material measurements and interpolated between actual field measurements. Volumes were computed for 146 reaches and summed for a total fine sediment yield of 4266 m^3/yr. This equates to 17.3 percent of the yield excluding major floods.

Assumptions regarding the depth of the active layer are keys to this assessment, and it is certain that the depth of disturbance during major floods exceeds 1.5 times the d_{90}, so the contribution from this source during major floods is likely to be much higher than the estimate presented herein. Scour analyses conducted as part of the Woodland Valley demonstration project showed that the 25-year flood could mobilize 2 – 3 feet of the bed material. The lower value of this range applied to the bed of the channel throughout the study area would result in a fine sediment yield of 17,340 m^3.

Tributary Contribution

Estimates of yields for tributaries at which measurements are available were determined by using the average annual turbidity values presented by NYCDEP (1993), adjusting these by a factor of 0.9 to convert to suspended sediment concentration (Giblin et al 1999) and assuming the dry unit weight of the sediments is 1230 kg/m^3. Where available, mean annual discharge was determined from USGS gage records and, in other instances, was determined from regional relations. Estimates for ungaged areas in the Esopus Creek basin were based on an average annual sediment yield for Esopus Creek of 0.079 m^3/ha/yr (Phillips and Hanchar 1996). These approaches yielded a fine sediment delivery estimate of 2490 m^3/yr, which equates to 10.1 percent of the flood-excluded yield for the watershed. Because of the non-linearity of the TSS/discharge relationship, extrapolating this method to account for sediment yield under conditions of flooding is not reliable. Sediment yields from tributary sources under flood conditions are expected to be much higher.

Summary

A summary of the computed sediment sources is presented in Table 3.1.6. The table includes coarse sediment yield, although it was not considered as contributing to the reservoir deposition. The total computed yield is 16,945 m^3/yr, which is about 70% of the annual yield determined from reservoir deposition and turbidity measurements if the major floods (e.g. 1996 and 2005) are excluded. The remaining 30% is distributed in an unknown fashion, but generally among the bed and bank erosion and tributary sources.

Table 3.1.6. Summary of computed sediment yield from various sources in the Esopus Creek watershed excluding the effects of major floods.

Source	Clay Yield (m^3/yr)	Silt Yield (m^3/yr)	Sand Yield (m^3/yr)	Coarse Yield (m^3/yr)	Total Fine Sediment Yield (m^3/yr)
Schoharie Diversion	1495	340	55	0	1890
Bank Erosion	1090	810	470	3410	2370
Bed Erosion	2950	1320	170000*	14500*	4270**
Clay Exposures	4980	920	30	0	5930
Watershed/Tributary	2090	395	Unknown	Unknown	2485
Total	**12605**	**3785**	**Unknown**	**Unknown**	**16945**

* - Represents transport capacity – actual transport is determined by supply.
** - Sand and coarse sediment loads omitted.

The contribution from the Schoharie Diversion is regarded as the most reliable estimate, as NTU and discharge measurements are made daily. The assumptions for contributions from bed and bank sources are regarded as conservative (underestimating actual contribution) because the assumed magnitude of bank and bed disturbance was at the low end of observed values. Yield is directly proportional to both bank recession and bed disturbance so, for example, an average bankline recession rate of 45 cm rather than the assumed 30 cm would result in a 50% increase in sediment yield. The extrapolation of the equation for the rate of erosion of disturbed clay exposures suggests that contribution from that source may have been over estimated.

Major floods like the April 2005 event have been shown to deliver 10 – 20 times the entire annual sediment load for non-flood years. Some of the primary sources of sediment during these extreme events were not accounted for in this study (new channel avulsions, hillslope failures, etc.). However, it was demonstrated that additional bank and bed erosion on Esopus Creek alone could account for more than 37,000 m^3 of sediment delivery from a single flood with a magnitude on the order of a 25-yr event.

Discussion and Recommendations

The implications to the Esopus Creek Management Plan of these study results coupled with field observations and other analyses presented in the appendices are several, and include the following:

- Many sources contribute to sediment loading and turbidity in the creek; eliminating all of these sources is neither technically nor economically feasible.

- The vast majority of sediment yield in the system is associated with major flood events (greater than a 10-yr return frequency) such as those that occurred in January, 1996 and April, 2005. The bank and channel erosion accompanying those events produced nearly 20 times the annual yield from a “normal” discharge year, and it is during these events that the City occasionally needs to treat the water to remove sediments. Alternatives that could reduce the frequency of alum treatments are not readily apparent, although the cumulative benefits of implementing a number of the recommended turbidity control and reduction measures proposed in this Stream Management Plan may be significant.

- The relative contribution of the various sources to turbidity is dependant upon the discharge. The Schoharie Diversion and disturbed clay deposits are the primary source under low flow conditions, fine sediments in the bed of the channel and tributaries coupled with runoff from ditches are significant contributors during moderate runoff events, and bed and bank erosion predominate during flooding. Strategies that address the more persistent sources in the watershed may yield ecological, recreational and aesthetic benefits although they may have little or no effect on downstream treatment requirements.

- Existing data and methods do not allow us to account for all the sediment sources in the system; a significant proportion of the assumed annual load is from unknown sources and uncertainty is high for the remaining computations.

Future data collection efforts and additional analyses should focus on the areas of greatest uncertainty. Of particular interest are assessments of the contributions from tributary sources and a more thorough assessment of bank and bed erosion in Esopus Creek, particularly during flood events. The proposed Phase III monitoring program should provide additional data to address many of these issues.

3.1.3 Phase 3 Geomorphic Assessment

Using the results of the Phase 2 investigations we scoped a Phase 3 investigation to include the following:

Stream Geomorphic Monitoring Program

- Develop a long-term monitoring protocol to monitor stream bank erosion, stream bed scour, presence and fate of glacial deposits through topographic survey and photo-monitoring techniques.
- Select candidate sites for establishing long-term monitoring locations along Upper Esopus Creek.

Stream Management BMP Assessment/Monitoring

- Select sites to monitor existing stream management practices
- Select sites for evaluating and possibly implementing stream management practices that utilize applied geomorphology practices, bio-engineering, and where needed, traditional practices

The Phase 3 geomorphic assessment was started in July 2006 but is by no means complete. This will be a long-term assessment and monitoring program established by the ECMP.

Long-term Stream Geomorphic Monitoring Program

ERDC and DEP have initiated the development of a long-tem monitoring program for the Upper Esopus Creek watershed. A draft (and incomplete) monitoring plan is presented in **Appendix F – Phase 3 Draft Monitoring Protocol, Data, and Maps**. For the Upper Esopus Creek Management Plan ("Plan"), monitoring may be undertaken for any of the following three purposes:

1. To collect data useful in analyses to better understand important physical, water quality or biological processes in the system,
2. To assess change in the system, particularly as it relates to candidate sites for the implementation of management practices, and
3. To evaluate the performance of management measures that have been implemented.

An efficient monitoring plan is one in which the needed information is obtained for the above purposes with the minimum effort. Efficiency is gained by combining purposes and selecting monitoring parameters and methods that provide the needed degree of accuracy with the least expenditure of resources.

The focus of this Section is on the physical (or geomorphic) parameters and processes of the stream system and the performance of stream management BMPs such as streambank stabilization or stream restoration projects. The existing NYCDEP water quality monitoring program and the efforts of other agencies and organizations is deemed sufficient for the purpose of the ECMP. NYSDEC and NYC DEP perform aquatic biomonitoring (fish and macroinvetebrates) that can be used to help satisfy the long-term monitoring needs for the ECMP. Additional assessment and monitoring is proposed in **Section 3.3**. Prior to this effort there was no established program for monitoring stream channel and riparian corridor conditions. **Section 3.2** includes recommendations for monitoring the riparian corridor.

The key stream geomorphic processes/parameters that should be included in a stream monitoring program for Upper Esopus Creek include:

- Channel morphology should be monitored sufficient to allow stream type classification using the Rosgen system (Rosgen, 1996) or other similar classification systems, such as Montgomery-Buffington (Montgomery and Buffington, 1997):
  - Cross-sectional hydraulic geometry (width, depth, area)
  - Longitudinal profile
  - Channel planform
  - Sediment characterization
  - Stream bed scour and stream bank erosion
- Exposures of fine sediment sources should be monitored at least annually in designated reaches to evaluate the fate of these exposures over time.
- Coupled streambank/hill slope erosion should be monitored at designated reaches to better understand this important system dynamic in the Esopus Creek watershed.
- The movement of large-scale sediment features over time should be monitored in key reaches to help determine the effects these processes have upon channel stability.

It is important to identify the geographic extent of monitoring needs. The longitudinal extent of monitoring is purpose and parameter specific. In most instances a study reach that is 20 to 50 channel widths in length should be sufficient for monitoring changes in channel form at project sites or baseline study sites. In some instances a single cross section and photo-monitoring will be sufficient.

Both the duration and frequency of monitoring are important components of a monitoring plan. A monitoring duration of three years should be considered a minimum for most process assessments and BMP project evaluations. A three-year monitoring period allows a process monitoring site or a project site to be exposed to a range of flows and gives project established vegetation time to pass from the critical establishment period to a more mature phase. However, changes in channel form may require a high flow or a series of high flows that have a low probability of occurrence during a three-year period. In other words, the geomorphic “stability” or success of a project may not be properly evaluated until such flows occur. It may be appropriate to extend monitoring activities following certain flow events, for example after any 10-year or greater flow. The primary determinants of a monitoring period should be project scope and risk.

Monitoring frequency refers to how often monitoring activities will occur during any monitoring year and what time of year they should occur. In many cases, a single, annual monitoring effort is sufficient, but some parameters should also be monitored following the occurrence of specific flood events. Monitoring may be systematic during certain times of year. For example, it may be appropriate to conduct habitat monitoring on one frequency interval that is tied to spawning schedules; while geomorphic conditions are monitored on another frequency that is tied to hydrologic sequences. An economical solution to limited monitoring budgets is to adjust the schedule of the monitoring plan so that more intensive, quantitative data is collected during the critical first three years. After this initial period, the scope of monitoring can be reduced. After a few years, the objectives, scope, and monitoring duration may change to reflect maintenance needs, rather than to achieve success criteria.

Given that Upper Esopus Creek is ~26 miles long and divided into 23 geomorphic reaches representative sites need to be selected that optimize the monitoring effort to include as many purposes and parameters as possible in a given study reach. **Table 3.1.7** lists the recommended monitoring locations with associated monitoring purposes and parameters. **Figure 3.1.15** shows the proposed monitoring locations. Where possible some of these sites have been chosen to coincide with the DEP biomonitoring program.

To date (December, 2006) the following Phase 3 monitoring activities have been completed:

Reach 22 (reference non-eroding headwater reach):

- a representative cross section was surveyed and monumented with capped rebar
- longitudinal profile surveyed for ~10 channel widths through cross section
- pebble count completed for section

Reach 20 (monitor bank erosion in upper reaches):

- two representative cross sections monumented (but not surveyed) to monitor eroding bank

Reach 16 (monitor bank erosion, fine sediment sources, avulsions, and BMP assessment):

- six representative cross sections surveyed and monumented
- 2,700 feet of longitudinal profile surveyed
- pebble count completed for longitudinal profile (200+)
- GPS mapping of channel thalweg for multiple threads and avulsions
- Photo-monitoring point established

Reach 13 (monitor bank erosion and fine sediment source):

- Two representative cross sections surveyed and monumented; one with two repeated surveys over a one year period
- Pebble count completed for reach

Reach 12 (monitor bank/hill slope erosion, fine sediment source):

- Four representative cross sections surveyed and monumented; one is a resurvey of cross-section established in 1999 for bankfull calibration survey at USGS stream gage at Allaben

Reach 11 (Proposed BMP assessment):

- One cross-section location monumented (not surveyed) for upstream control of proposed downstream project
- GPS 2006 thalweg of channel from Peck Hollow to below Town Hall
- Topopographic survey (with total station) with permanent survey control for proposed stream management BMP (see next sub-section for detail)

Reach 10-9 (monitor bank erosion and obtain data for proposed BMP assessment):

- Four cross-section locations monumented and three surveyed
- Capped rebar for survey control installed from Shandaken Tunnel to gravel bar separating north and south channel)

Reach 6: (BMP monitoring)

- Topographic and monumented cross-section surveys completed annually since 2003 as part of Esopus Creek restoration demonstration project. Data obtained by UCSWCD.

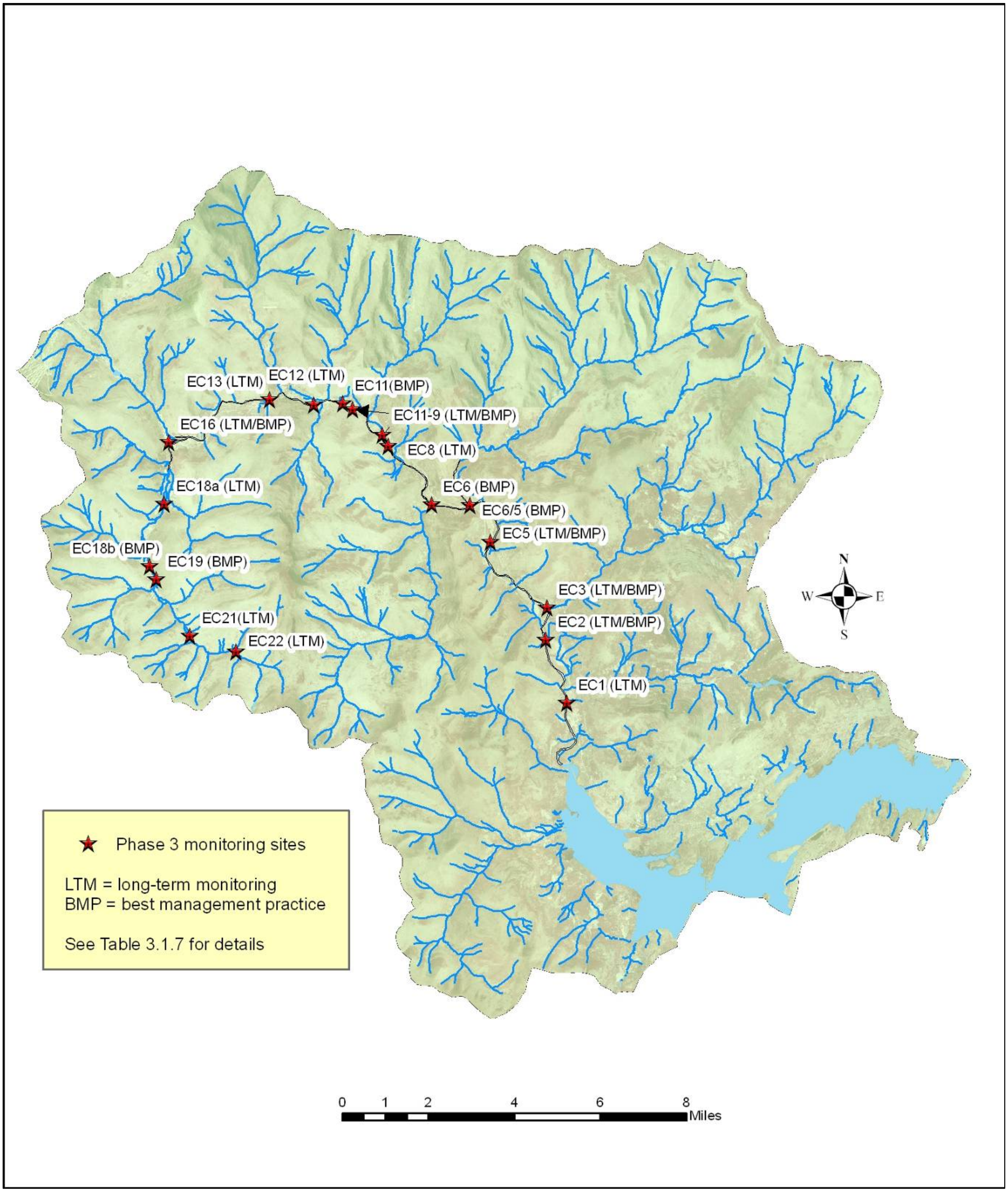


Figure 3.1.15 Proposed Phase 3 monitoring locations for Upper Esopus Creek Management Plan

Table 3.1.7 Proposed Monitoring Locations

Reach	River Mile	Section/ Segment	Monitoring Purpose	Parameter
EC22	24.75	Section	Reference Conditions	Physical: cross-sectional and longitudinal profile; bed/bank composition Biological: riparian vegetation and aquatic ecology
EC21	23.38 – 23.45	Segment	Channel instability (excessive bank erosion into glacial till overlain by terrace of coarse fluvial sediment); tree cantilever failure	Physical: cross-sectional and longitudinal profile; bed/bank composition;
EC19	21.61	Section	BMP monitoring (recent streambank revetment)	Physical: cross-sectional and longitudinal profile; revetment stability
EC18a	19.1 – 19.5	Segment	Reference conditions for multi-threaded channel	Physical: cross-sectional and longitudinal profile; bed/bank composition; channel braiding; LWD; deposition/erosion Biological: riparian vegetation and aquatic ecology
EC18b	21.0 – 21.25	Segment	BMP monitoring (proposed Brown Rd reach restoration designed by NRCS)	Physical: cross-sectional and longitudinal profile;
EC16	17.45 – 17.82	Segment	Channel instability (excessive bank erosion, headcuts and cobble bar formation) fine sediment source BMP monitoring (Proposed bioengineering demonstration project designed by ERDC)	Physical: cross-sectional and longitudinal profile; bed/bank composition; channel braiding; LWD; deposition/erosion Glaciolacustrine silt/clay; glacial till
EC13	14.45	Section	Channel instability (excessive bank erosion) Fine sediment source	Physical: cross-sectional and longitudinal profile; bed/bank composition; Glaciolacustrine silt/clay
EC12	13.0 – 13.3	Segment	Long-tem channel monitoring both stable and unstable conditions (USGS stream gage at downstream end) Fine sediment source and hill slope instability	Physical: cross-sectional and longitudinal profile; bed/bank composition; Glaciolacustrine silt/clay; glacial till; rotational failure Biological: riparian vegetation and aquatic ecology

EC11	12.34 – 12.8	Segment	BMP monitoring (proposed channel realignment in vicinity of Shandaken Town Hall)	Physical: topographic survey and cross-sectional profile
EC11-9	11.24 – 12.20	Segment	Excessive bank erosion BMP monitoring (proposed channel restoration from Shandaken Tunnel down to Allaben cemetery) Fine sediment source	Physical: cross-sectional and longitudinal profile
EC8	10.69 – 11.03	Segment	Reference conditions (below Shandaken Tunnel)	Physical: cross-sectional and longitudinal profile; bed/bank composition Biological: riparian vegetation and aquatic ecology
EC6	8.75 - 8.97	Segment	BMP monitoring (Esopus Creek at Woodland Valley restoration project – monitored by UCSWCD/NRCS)	Physical: topographic survey and cross-sectional profile
EC6/EC5	7.66 – 8.0	Segment	BMP monitoring (proposed “gravel removal” on Stony Clove just above confluence with Esopus Creek)	Physical: topographic survey and cross-sectional profile
EC5	6.4 – 6.6	Segment 2XS	Excessive bank erosion/revetment monitoring at Sleepy Hollow Campground	Physical: topographic survey and cross-sectional profile
EC3	4.0 - 4.3	Segment 3XS	Deposition at Beaver Kill confluence Riparian wetland (ZESI)	Physical: topographic survey and cross-sectional profile Biological: riparian vegetation
EC2	3.0 - 3.5	Segment	Excessive bank erosion; compromised riparian buffer and potential BMP monitoring	Physical: cross-sectional and longitudinal profile; bed/bank composition Biological: riparian vegetation and aquatic ecology
EC1	1.3 – 1.8	Segment 2XS	Channel monitoring in vicinity of USGS gage at Coldbrook (use bankfull study sites)	Physical: cross-sectional and longitudinal profile; bed/bank composition

Stream Management BMP Assessment and Monitoring

To help the streamside community and stakeholders address some high priority and/or representative erosion sites ERDC and DEP have (1) completed a preliminary assessment of alternative management options for five locations; and (2) incorporated the ongoing monitoring of the Esopus Creek Restoration Demonstration Project (ECRP) at the Woodland Valley confluence as a BMP monitoring site (NYCDEP, 2003).

Phase 3 Stream Management BMP Sites

Several sites were identified during the Phase 2 assessment that merited further evaluation with an emphasis on developing conceptual approaches to mitigating observed flooding, erosion or stability problems. Five sites were included in this first round of Phase 3 stream management BMP assessment. There are other sites that may merit further investigation, however resource constraints dictate staging these investigations. Additional data were collected at each site during the Phase 3 investigations, and recommendations were formulated. **Appendix F** includes the analyses and proposed actions at each site. The exception is the site in reach 18 as described below. Summaries for each site are presented below:

Reach 5/6 and Stony Clove Confluence

Flooding of Phoenicia has been a common problem and the community has historically removed gravel deposits from the lower reaches of Stony Clove in an effort to improve flood conveyance and reduce flooding risks. The Town of Shandaken plans to apply for a permit to remove 45,000 cubic feet of deposited sediments in the vicinity of the Rt. 214 Bridge. Ten alternatives were evaluated to determine the potential benefits of removing the material in different configurations and at different locations. **See the Case Study special feature at the end of this Section**.

The alternative yielding the greatest benefit was the excavation of a 50-ft wide, by 300-ft long trench with an average depth of 3 ft immediately downstream of the bridge. Assuming the bed of the channel does not change, this could lower the water surface immediately upstream of the bridge by about 2 feet when the discharge is 10,000 cfs (about a 25-year flood event), reducing the risks of flooding. A sediment study for this alternative demonstrated that the excavated sediments have the potential to be replaced by new deposits before any flood reduction benefits are realized, however. An 1,800 cfs discharge (1.5 year flood) for three hours or a 7000 cfs discharge (10-year flood) for 45 minutes could be sufficient to restore the channel to its pre-excavation dimensions.

Based on the study results, it is recommended that the community of Phoenicia pursue longer-term and more reliable alternatives to flood damage reduction in this area. If the gravel mining alternative is implemented, a 300’ by 50’ by 3’ (average) excavation from the bridge downstream is recommended to attain the greatest benefit. A monitoring program is recommended to assess the effectiveness and impacts of any gravel removal in this reach.

Reach 9 from Broadstreet Hollow to the Allaben Cemetery

Four homes and two businesses along the left bank of Esopus Creek in Reach 9 immediately downstream of Broadstreet Hollow have experienced persistent streambank erosion (**Photos 3.1.8 – 3.1.14**). Immediately upstream and along the right bank where the channel makes a sharp bend, erosion has entrained a number of large trees that present a hazard to recreation. The channel is bifurcated through this reach, with a portion of the flow occurring in the "Greeny Deep" segment (aka "south channel") – a reach with high aesthetic and ecological value.

Two management alternatives were identified for this reach. The first alternative consists of stabilizing the eroding streambanks using methods and materials that also afford aesthetic and aquatic habitat benefits. Approximately 750 linear feet of protection is required along the threatened homes and business, and modifications may be needed to 340 linear feet of existing protection. The threatened properties lack a suitable riparian buffer, and it is proposed that a buffer consisting primarily of herbaceous and shrub vegetation be installed and evaluated to determine the effectiveness of buffer configurations that preserve a view of the creek. This alternative would have a relatively low cost, but would do nothing to address the LWD problem or to restore more flows to the Greeny Deep stream segment.

The second alternative consists of channel modifications necessary to restore much of the flow to the Greeny Deep reach and, in so doing, relieve the areas experiencing erosion for all but the most extreme flood events. This would require some excavation across the "island" that separates the two channels, selection of the appropriate point at which to divert flows, installation of channel blocks in the existing channel of Esopus Creek, and potentially some alterations to segments of the Greeny Deep reach for erosion control or habitat enhancement. This alternative would address both the erosion and LWD problem areas on the Esopus Creek and provides opportunities for environmental enhancements to the Greeny Deep reach, though some impacts may occur as well. Disadvantages of this alternative include potential problems associated with fine sediment (plentiful sources in Greeny deep channel), LWD and Japanese knotweed entrainment along the Greeny Deep reach, and difficulties in keeping the current Esopus channel downstream of the diversion wetted. The only flows in the reach would be from Broadstreet Hollow and possibly the Portal, depending on the location of the diversion.

A third alternative maintains most of the below bankfull flow in the current main (north) channel and diverts greater flows into the Greeny Deep channel. This alternative consists of channel modifications necessary to restore a more stable planform and hydraulic geometry dimensions to the current channel and enhancement of an active avulsion separating the two channels so that high flows are diverted into the Greeny Deep channel. Benefits of this alternative include maintaining flows in the current channel and potentially diverting erosive and inundating flows into the Greeny Deep channel.

Disadvantages include potential for LWD jams to continue at meander bends and at the enhanced avulsion. A significant bed load mobilizing flood could plug the enhanced avulsion and all flow revert back to the current main channel.

Flows in this reach were high throughout the summer of 2006 due to the evacuation of Shandaken reservoir for repairs to Gilboa Dam. The high releases, coupled with periodic high runoff conditions on Esopus Creek, prevented the survey and data collection efforts needed to evaluate these alternatives. Consequently, the preferred alternative cannot be identified at present. It is recommended that the necessary data be obtained at the earliest possible date in 2007, and a full evaluation of the alternatives be conducted.

Photo 3.1.8 Reach 9/10 BMP Assessment Site: Looking west upstream through bifurcation. June, 2006

Photo 3.1.9 Reach 9/10 BMP Assessment Site: Looking east downstream through bifurcated channel. Broadstreet Hollow confluence in lower left corner. April, 2004

Photo 3.1.10 Reach 9/10 BMP Assessment Site: (1) hazardous-debris catching meander bend, (2) blue shed subsequently eroded away, (2) avulsion across bar connecting bifurcated channel. April, 2004

Photo 3.1.11. Reach 9/10 BMP Assessment Site: North channel following April, 2-3, 2005 flood. Note (1) alignment adjustment from 2004 condition ,(2) absence of blue shed, (3) line of trees in point bar is remnant of downstream end of meander bend shown in Photo 3.1.10.

Photo 3.1.12. Reach 9/10 BMP Assessment Site: Zone of active erosion adjacent to private property and businesses. June, 2006

Photo 3.1.13. Reach 9/10 BMP Assessment Site: Location of cobble bar separating north and south channels just below Broadstreet Hollow confluence. June, 2006

Photo 3.1.14. Reach 9/10 BMP Assessment Site: Looking upstream alongside Copperhood Inn. Note eroding bank and lack of woody riparian buffer on outside of adjusting meander bend. Previous riprap revetment failed in April, 2005 flood. June, 2006

Reach 11 at the Shandaken Town Hall

Erosion along the left bank of the Esopus Creek is threatening an existing stabilization project at the Shandaken Town Hall (**Photos 3.1.15 – 3.1.17**). Velocities at bankfull flows are about 7 feet per second, and exceed 12 feet per second under flood flow conditions. The condition is exacerbated because the bank is on the outside of a bend where secondary flows can increase scour at the toe of the revetment. The existing bank protection is for a berm that affords protection to the Town Hall for flows up to about the 25-year event. Failure of the berm would subject the Town Hall to flooding at less than the 10-year flow level. A channel avulsion is pending along the right bank at this location, and a large sediment lag is progressing into the reach from upstream. The floodplain is constrained by the railroad grade along the right bank, and this reach was adversely impacted by the realignment of NYS Route 28 in the early 1960's. The current road alignment cut off a meander bend just upstream of the Town Hall location.

Two alternatives were evaluated for the site. Both are predicated on the belief that the channel avulsion will occur, and are intended to capitalize on its further development to reduce erosion impacts on the left bank. The alternatives differ primarily in the means of implementation: Alternative 1 involves equipment mobilization one time and full construction would occur in a single season. Alternative 2 involves a phased construction effort wherein the creek's response to actions taken in the first phase are observed and the remaining phases adjusted accordingly. Costs for the two alternatives are roughly the same, the additional mobilization costs for Alternative 2 being offset by reductions in excavation and pollution prevention costs for Alternative 1.

Both alternatives consist of relocating approximately 500 feet of Esopus Creek into the area of the pending avulsion. Alternative 1 would accomplish this by excavating a channel with dimensions of 100 feet in width, 4.2 feet in depth below a bankfull bench, and 7.5 feet deep in total below the right bank. Alternative 2 would involve the excavation of a pilot channel only, with dimensions of 50 feet in width and a mean depth of half that for the full construction. Both alternatives would require a 300-ft downstream extension of the existing protection on the left bank prior to excavation of the channel through the avulsion.

A channel block approximately 100 feet long by 5 feet high (on average) would be constructed from the existing left bank of the channel to the remnant bridge abutment on the "island" in order to prevent sub-bankfull flows from accessing the channel. For Alternative 1, this block would be constructed immediately following excavation of the new channel and would serve to force the flows into the new channel. For Alternative 2, this block would be constructed only after high flows had eroded the remaining material from the pilot channel and the avulsion had taken place, permitting all construction (except the revetment extension) to occur "in the dry". Both alternatives may require some stabilization of the right bank for the new channel or compensation to the landowner for erosion that is likely to occur along the reach.

A third alternative not evaluated in this study is relocating the Town Hall and Highway Department buildings so that protection from inundation and erosion is not an issue.

Advantages and disadvantages of each alternative are discussed in **Appendix F**. Neither alternative is recommended at present. It is recommended that the Town of Shandaken work with adjacent landowners and resource agencies to select the preferred alternative and incorporate any needed adjustments or compensatory and mitigation requirements.

Photo 3.1.15 Reach 11 BMP Assessment Site: Looking downstream toward Shandaken Town Hall (12/08/05). Former meander bend is on left side of Route 28. Energy from cut-off meander increases shear against the bermed bank bordering the Town offices.

Photo 3.1.16 Reach 11 BMP Assessment Site: Channelized section with very erosive meander bends and a large depositional wedge above. The challenge will be to ...

Photo 3.1.17 Reach 11 BMP Assessment Site: April 3, 2005 - significant bank erosion nearly breached the berm protecting the Town Hall

Reach 16 upstream of Birch Creek confluence

A 1500-ft reach of the channel immediately upstream of the Highway 28 bridge near Big Indian is experiencing significant erosion and the reach contains numerous former, current, and pending channel avulsions (**Figure 3.1.3** and **Photos 3.1.18 – 3.1.21**). The erosion is not presently threatening infrastructure, although a home on the right floodplain near the bridge may become threatened with continued erosion in the reach. During and immediately following high flow events this reach is typically the upstream most significant source of fine sediment entrained from glacial deposits. There are many other exposures upstream of this location, however these other exposures are not nearly as persistent and extensive as the ones that occur in this reach. In addition, a scheduled replacement of the NYS Route 28 bridge needs to take into account the upstream channel instabilities.

Rapid bank retreat is occurring along the left bank in two locations. A 200-ft segment of the bank is experiencing erosion associated with both hillslope failures (along an old terrace) and has exposed a significant glaciolacusterine deposit that periodically contributes to turbidity. Just downstream, a 400-ft segment of bank with no riparian buffer has retreated from hydraulic erosion. The current channel alignment does not pose further hydraulic erosion potential, though a return to former conditions is very possible. Rapid bank retreat is also occurring along the right bank mid-way through the effected reach and has exposed a glaciolacustrine deposit in the stream bed and bank.

This reach was selected as a Phase 3 BMP site for three purposes: 1) to demonstrate the value of riparian corridor restoration and low-cost biotechnical stabilization measures that can be implemented by individual landowners, 2) to demonstrate the influence of large woody debris (LWD) on stream dynamics, and 3) to provide an opportunity to monitor large-scale channel changes and sediment movement on Esopus Creek. It is intended that information gained from the implementation and monitoring of BMPs in this reach will augment the guidance provided in the Management Plan and support future landowner management efforts elsewhere in the watershed.

Proposed actions in this reach are detailed in **Appendix F**. They consist of planting a 50-ft wide riparian corridor along a 400-ft segment of the bank that is experiencing erosion. The eroding bank would be partially stabilized using vertical willow bundles, willow fascines, and willow and dogwood stakes placed along the bank face and toe. Erosion of the bank would be further mitigated by relocating LWD into an area near the upstream end of the erosion to promote sediment deposition in the area that would reduce the effective bank height.

An existing LWD jam that is blocking a former channel would be removed and relocated to promote the reestablishment of that former channel, while reducing the hydraulic forces in the existing channel. The LWD is expected to promote sediment deposition in the existing channel as well, and this will be accelerated by felling one large sycamore tree on the left bank at the upstream end of the erosion.

It is recommended that the proposed plans be reviewed by the affected landowners, adjusted as necessary, and that funding be procured for implementation of the demonstration project. It is also proposed that a full monitoring effort be implemented in the study reach, including topographic surveys, photo documentation, vegetation plots, and sediment sampling. The reach should be resurveyed at least once annually, and preferably following any flow event in excess of bankfull.

Photo 3.1.18 Reach 16 BMP Assessment Site: Looking downstream toward Birch Creek valley. Esopus Creek water entrains fine sediment at the contact with exposed glacial deposits in this eroding terrace. April, 10, 2005

Photo 3.1.19 Reach 16 BMP Assessment Site: Looking downstream from the actively eroding channel margin composed of complex glacial stratigraphy. The small mid-channel gravel bar near the bottom of the picture is a thinly covered mound of deformed glacial lake clay.

Photo 3.1.20 Reach 16 BMP Assessment Site: Cobble-covered "push-up" structure of glacial lake clay formed from series of rotational failures in adjacent terrace.

Photo 3.1.21 Reach 16 BMP Assessment Site: scarps from rotational failures in left terrace adjacent to creek.

Reach 18 along Brown road

Flooding in the last two years has caused a section of Esopus Creek just upstream of the McKenley Hollow bridge to experience excessive deposition and channel avulsion (**Photos 3.1.22 – 3.1.24**). During the April, 2005 flood Brown road was "washed out" and several homes were inundated. Subsequent flooding has caused additional channel shifting. Adjacent landowners hired a local contractor to install a berm of stream bed material in the channel to serve as a temporary channel block, diverting stream flow toward CRT 47 and an alternative channel. This reach was not assessed for BMP alternatives as part of this study; however UCSWCD and NRCS have extensively surveyed the reach and have prepared a conceptual design employing natural channel design and traditional engineering. UCSWCD has approached NYC DEP to help provide local cost share for the further design and implementation of this project considered high priority by the Town of Shandaken.

Photo 3.1.22 Reach 18 BMP Assessment Site: Looking downstream along "Brown Rd Reach" with McKenley Hollow Rd bridge. April 5, 2005

Photo 3.1.23 Reach 18 BMP Assessment Site: wash-out of Brown Road following April 2-3, 2005 flood.

Photo 3.1.24 Reach 18 BMP Assessment Site: Flood damage on stream adjacent property. April 3, 2005

Phase 3 Stream Management BMP Monitoring Sites

As part of the Phase 3 monitoring program existing stream management BMPs should be selected for performance monitoring. Such BMPs should include the full range of practices from small revetment projects to full scale restoration and flood control projects.

Currently, the Esopus Creek restoration demonstration project (ECRP) at the Woodland Valley confluence is the sole site being monitored as part of this Management Plan (NYCDEP, 2003). This stream restoration demonstration project was an agency collaborative effort completed in 2003 as a 2002 FAD deliverable (NYCDEP, 2003). **Appendix C** contains several resources documenting the ECRP. **Figure 3.1.16** is a site map. In 2000 NYCDEP contracted with FIScH Engineering to complete a BMP assessment for this site that was experiencing excessive erosion and periodic water quality impairment from exposed glacial clays (**Photo 3.1.25**). In 2002 NYCDEP contracted with UCSWCD to oversee the construction of a restoration project that employed a combination of natural channel design techniques, traditional engineering (riprap revetment) and bioengineering (**Figure 3.1.17** and **Photos 3.1.26 – 3.1.30**). The project design used a bankfull flow of 3,400 cfs and 4,200 cfs upstream and downstream of the Woodland Valley confluence, respectively. A reconstructed flood plain filled in an active channel avulsion. Streambank protection through revetment was intended to account for up to 25 year recurrence interval flows.

Photo 3.1.25 Eroding streambank composed of glacial till overlain by stream deposits. May 2003

Since construction in 2003, UCSWCD and DEP have implemented a monitoring and maintenance program that has included annual topographic surveys and quarterly to biannual visual inspections using a standardized form and protocol (**Figures 3.1.18-3.1.19)**. The April, 2005 flood had an estimated peak flow through this reach of ~30,000 – 35,000 cfs, almost an order of magnitude greater than the design bankfull flow and close to the 50 year recurrence interval estimated for this reach (**Photo 3.1.31 – 3.1.32; Table 2.8** in **Section 2.6**). Significant channel adjustments below the confluence occurred when a vegetated bar along the right bank below the project was eroded. The primary objectives of the project (stabilizing the eroding bank and maintaining a habitat-rich single channel away from the formerly eroding bank) were unaffected by this change and the project continues to be regarded as successful.

UCSWCD has completed four topographic surveys since construction, has hired FIScH Engineering to complete two post-construction inspections, and has completed at least six visual monitoring inspections.

Figure 3.1.16 Location of Esopus Creek restoration demonstration project at Woodland Valley confluence. Digital aerial photo taken in April, 2001

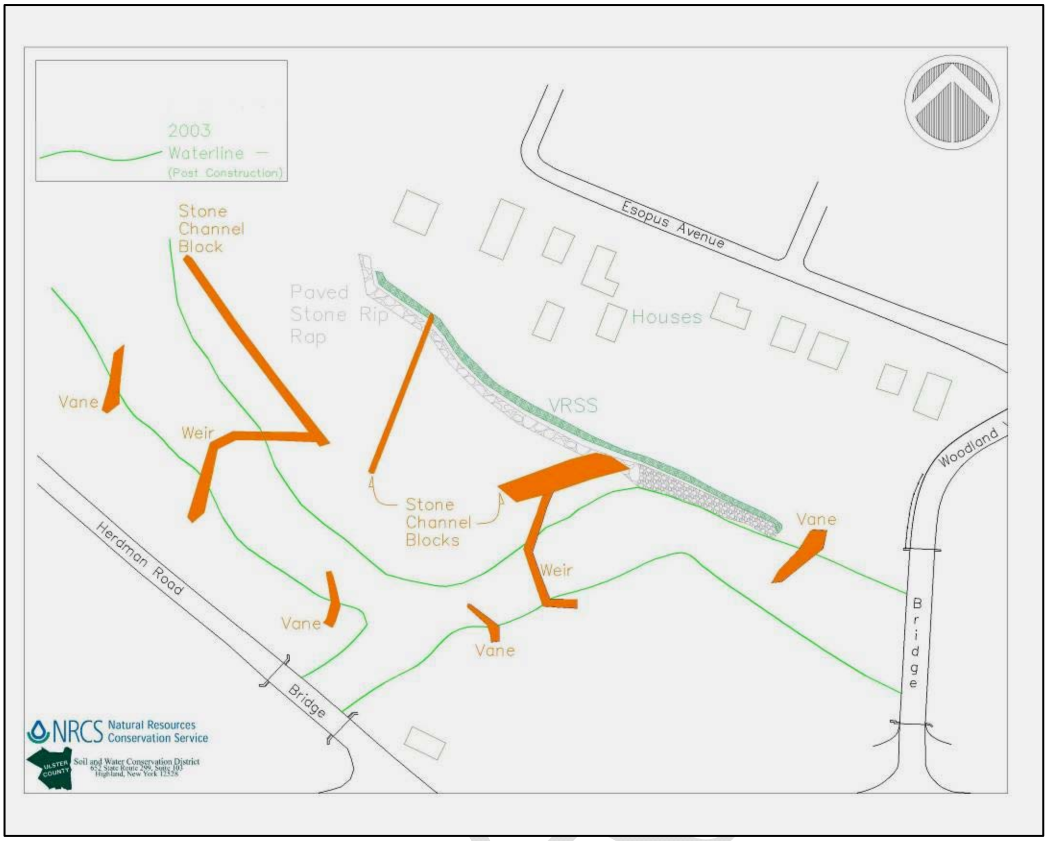


Figure 3.1.17 Conceptual design of Esopus Creek restoration demonstration project at Woodland Valley confluence.

Photo 3.1.26 ECRP site pre-construction. August 2003

Photo 3.1.27 ECRP site during construction. September 2003

Photo 3.1.28 Construction of rock vane arm of upper boulder weir. Glacial lake clay just below stream sediment.

Photo 3.1.29 Construction of VRSS: 7 layers of soil partially wrapped in geotextile fabric with ~25,000 willow whips.

Photo 3.1.30 ECRP site one year after construction. August 2004

Photo 3.1.31 ECRP site day after peak of April 2-3, 2005 flood. Flood stage was reportedly level with Woodland Valley bridge and above riprap along left descending bank.

Photo 3.1.32 ECRP site two days after April 2-3, 2005 flood. Note significant change below Woodland Valley and protection of left bank and reconstructed floodway with scour between channel blocks.

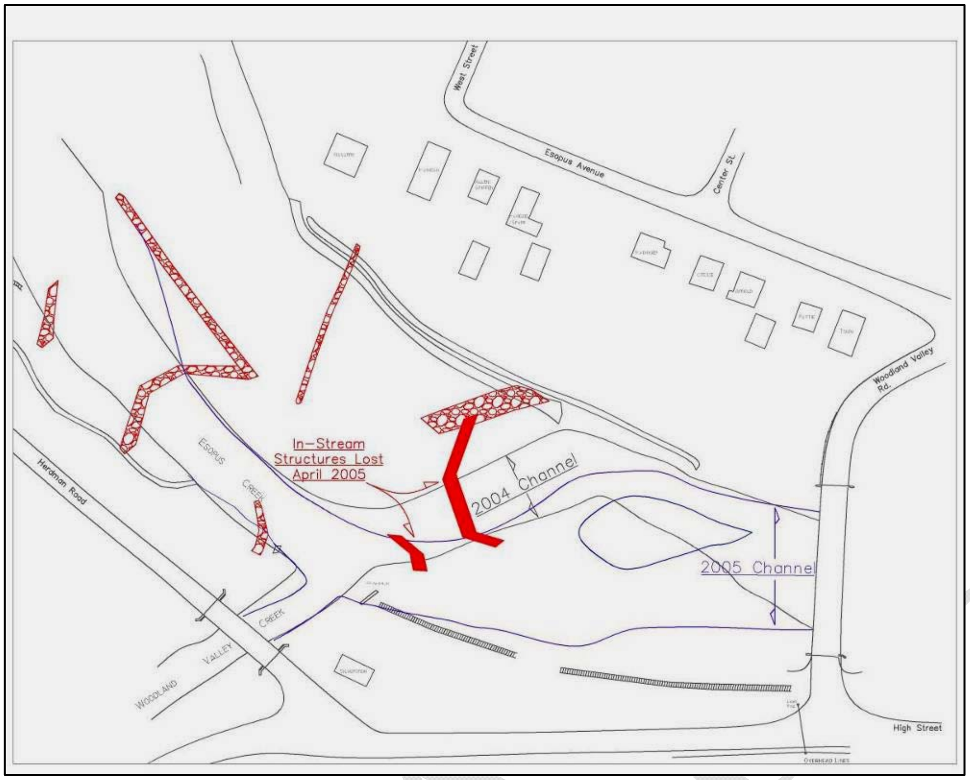


Figure 3.1.18 ECRP site features following April, 2005 flood. From UCSWCD/NRCS August, 2005 survey.

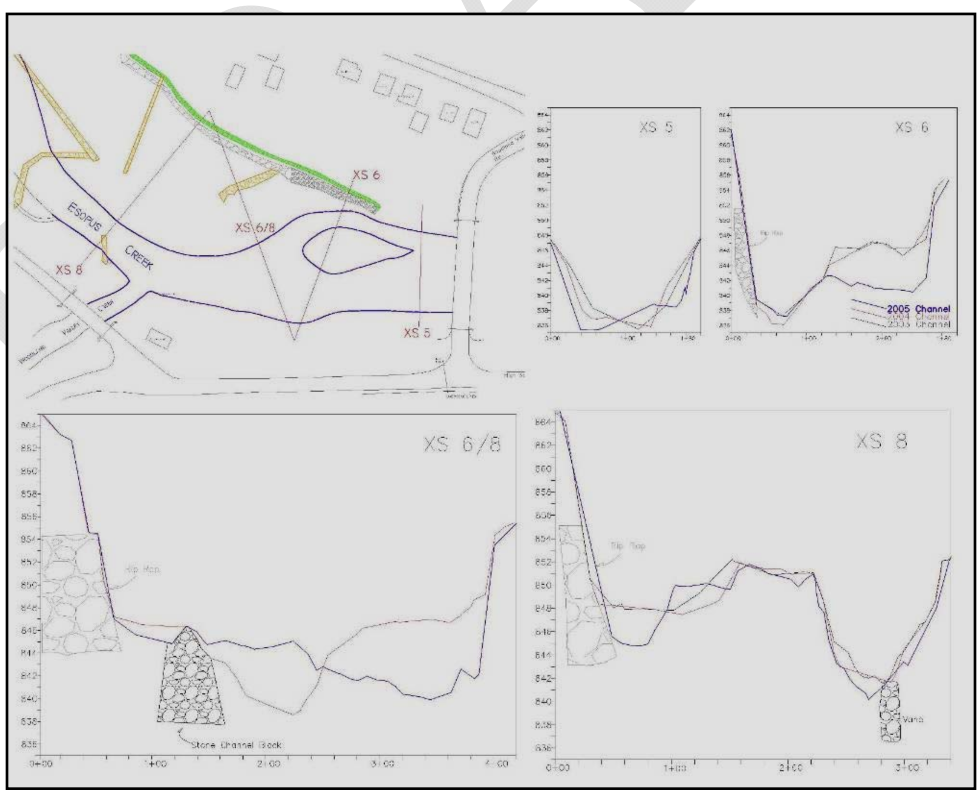


Figure 3.1.19 Example of post-construction monitoring results at ECRP site by UCSWCD and NRCS.

3.1.4 Phase 3 Stream Management Practice Assessment Case Study: Gravel Mining to Alleviate Flooding in Phoenicia

Background

Flooding of Phoenicia has been a common problem and the community has historically removed gravel deposits from the lower reaches of Stony Clove in an effort to improve flood conveyance and reduce flooding risks (**Figure 3.1.20**). The Town of Shandaken plans to apply for a permit to remove 45,000 cubic feet of deposited sediments in the vicinity of the Rt. 214 Bridge by excavating a trench 3-ft deep by 50-ft wide by 300-ft long into the existing deposits (approximately 2000 tons of material).

The removal of streambed deposits, whether for flood and erosion management purposes or for the purpose of obtaining the material for construction use, has come under broad criticism in the U.S. and in Europe because of the well-documented adverse effects often caused by these actions. In addition to the relative short-term impacts associated with the destruction of habitat for an array of aquatic organisms, the removal of sediment deposits can initiate significant erosion of the bed and banks of the channel in the vicinity of the removal and for some distance upstream. For these reasons and others, instream gravel mining is prohibited in many regions of the U.S., and highly regulated in others.

Questions abound regarding the benefits of gravel mining as well. Gravel removal is not a one-time fix to flooding problems; the deposits reform in the same place and to similar dimensions following any significant flow event, necessitating subsequent removal. There is little evidence that localized channel modifications such as that proposed provide any measurable reductions in water surface elevations, and no evidence of such actions having "prevented" any flood that would have otherwise occurred. The timing and rate at which the excavation is refilled with sediments during a flood event is a central question that remains unanswered because observations during a flood are not possible.

Given the uncertainties associated with the above issues, and the belief held by some that gravel extraction from Esopus Creek would improve flood conveyance, the proposed gravel removal at the Stony Clove confluence was selected as a Phase III study effort for the Esopus Creek Management Plan. The purpose of this study is to assess the potential benefits and impacts associated with the proposed gravel removal efforts, and if appropriate provide recommendations for adjustments to the proposed plan, necessary monitoring efforts, or alternative flood mitigation strategies.

Study Approach

The potential benefits and impacts to the proposed gravel removal activity were evaluated by constructing hydraulic and sediment transport models for the lower 1700 feet of Stony Clove and for the Esopus Creek downstream of Woodland Valley to the Ashokan Reservoir. The models were used to evaluate existing conditions, the proposed gravel excavation, and alternative gravel excavation scenarios.

Model output was evaluated with respect to flood conveyance, channel stability, sediment transport, and ecological issues. Sensitivity analyses were conducted to determine the influence of uncertainty in some of the model parameters. Alternatives and impacts were assessed on the basis of model outputs, information collected from site visits to the project area, and professional judgment.

Model Development

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) Version 3.1.3 software developed by the U.S. Army Corps of Engineers for assessing and designing flood management projects was used to assess flooding and sediment transport conditions on Stony Clove and Esopus Creek (USACE 2006). The model was run in a steady mode and flow conditions were limited to the sub-critical state.

Model Topography

The model topography was generated using LIDAR data of the river corridor obtained in 2004, augmented with 2006 surveys collected by the Town Supervisor, Green County Soil and Water Conservation District personnel, and the NYC DEP Stream Management Team. A digital elevation model (DEM) was generated for Esopus Creek from the LIDAR data and cross sections were developed from the DEM using HEC's GEO-RAS software (USACE 2006). Topography for the Stony Clove reach was generated by integrating the field survey data with the LIDAR Data and generating a separate DEM using Golden Software's Surfer V8.0 software. Fourteen cross sections were generated for Stony Clove, and 54 cross sections were used to model Esopus Creek.

Bridges were simulated in the model using geometric data furnished by Ulster County Highways and Bridges Department, and the 1984 HEC-2 models from the Flood Insurance Mapping for Olive and Shandaken, furnished by the New York State Department of Transportation. In addition to the Rt. 214 Bridge over Stony Clove, 7 bridges were simulated on Esopus Creek. The Highway 28 Bridge at Phoenicia was not included, as the geometric data for this bridge was not available and it was determined not to influence flood conditions in the reach given that it fully spans the creek and the bridge deck is located roughly 20 feet above even the 500-year water surface elevation.

Both SI and U.S. customary versions of the model were developed; the former for the purpose of permitting the background display of the 2001 Digital Orthophoto Quarter-Quadrangle (DOQQ) maps of the study area. Figure 1 shows the study area with the DOQQ backdrop. Cross sections employed in the analysis are shown in the figure as green lines, and the numbering refers to the distance upstream of the mouth in meters.

Hydrologic and Hydraulic Conditions

A water-stage recorder with a crest-stage gage exists on Stony Clove near the project site. The gage is located on the left bank, 0.5 mi south of Chichester on State Highway 214, and 1.3 mi upstream from mouth. This station has been cooperatively operated by the USGS and the NYC DEP Bureau Water Supply Quality & Protection since December, 1996, although only the annual maximum was collected in the first year. Elevation of gage is 900 ft above NGVD of 1929. Drainage area is 31.5 square miles at the gage, and 32.3 square miles at the project site.

Figure 3.1.20. Graphic showing study area (Stony Clove Creek entering Esopus Creek Mainstem) with 2001 DOQQ backdrop. Blue lines are stream centerlines; green lines are model cross sections; and numbers denote cross section distance (in meters) upstream from the confluence.

Flood probabilities for Stony Clove were determined using the guidelines in USGS Bulletin 17 B (1982) and instantaneous peak discharges from gage data for the period of record through the 2006 water year (**Figure 3.1.21**). The period of record for the gage is not sufficient to develop reliable flood frequency analyses using this approach alone, so regional relations for ungaged watersheds were also applied to determine flood probabilities (Lumia, 1991). These values were weighted to determine flood magnitudes to use in the analyses based on professional judgment and site-specific knowledge compared with Lumia’s regression and flood frequency analysis according to Bulletin 17B, and rounded to three significant digits (**Table 3.1.8**).

Table 3.1.8. Summary of flood frequency analysis. Red figures are from regression relations, blue from Bulletin 17 estimates; black figures are used in this analysis.

Peak Discharge (ft^3/s) for Specified Recurrence Interval (years)								
1.25	**1.5**	**2**	**5**	**10**	**25**	**50**	**100**	**500**
	1769	2404	4523	6411	9415	12148	15202	23924
3328	4074	5105	8267	10880	14830	18290	22230	33650
	1800	2500	5000	7000	10000	14000	17000	20000

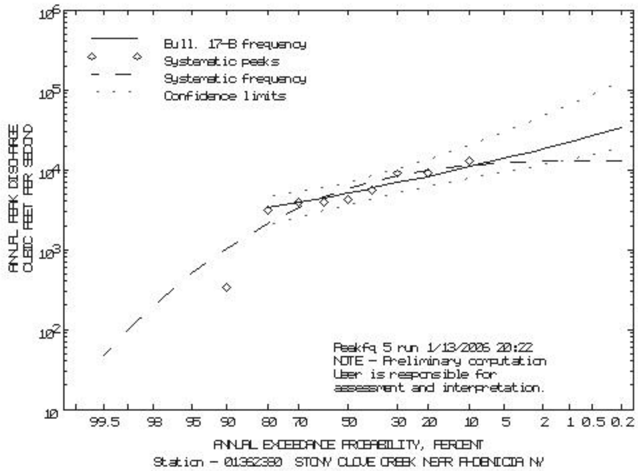


Figure 3.1.21. Bulletin 17B Flood frequency analysis for Stony Clove.

Manning's resistance coefficients were set to 0.045 for the main channel and 0.09 for the overbank areas for the Esopus Creek, based upon field observations. For Stony Clove, resistance for the main channel was varied from 0.047 for bankfull discharge to 0.042 for discharges in excess of a 5-year event, based upon the application of six different resistance predictors that utilize bed material size, channel slope, and hydraulic radius as predictive factors. Resistance for overbank areas were set at 0.070 upstream of the bridge and 0.09 downstream, based upon guidelines in Chow (1959). Expansion and contraction coefficients were set to 0.3 and 0.1, respectively.

Sediment Data

Two bulk sediment samples and two pebble counts were collected in the lower reaches of Stony Clove during the Phase II investigations for the Esopus Creek Management Plan. These were utilized to construct bed material gradations and inflowing sediment size distributions for the sediment studies. **Figure 3.1.22** shows the grain size distributions from the pebble counts. The bulk samples were sieved and weighed in the field, with the fraction larger than cobble sizes removed and weighed separately. **Table 3.1.9** shows the grain size distributions from those analyses, which were used for the Stony Clove assessment.

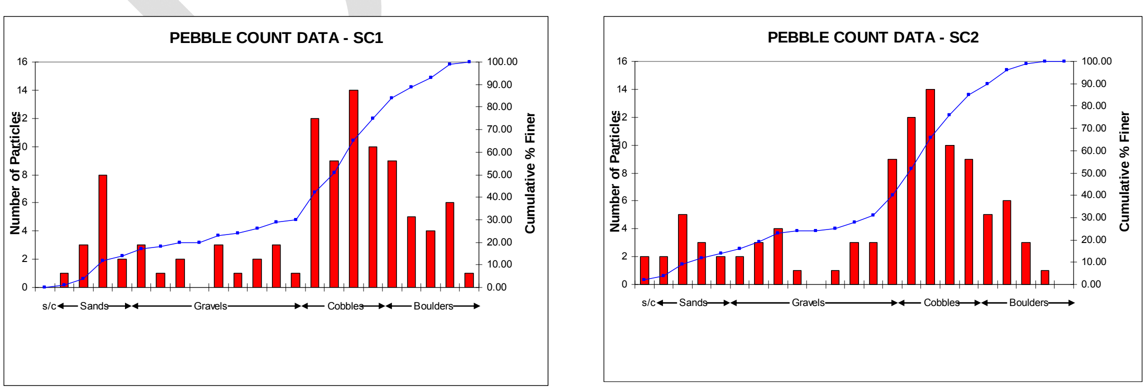


Figure 3.1.22 Stony Clove pebble count grain size distributions.

Table 3.1.9. Grain size distributions from bulk sediment analysis.

Sample	Percent in Each Fraction, by Weight					
	Boulder	Cobble	Gravel	Sand	Silt	Clay
SC-1	18	32	45	4	0	1
SC-2	15	35	40	8	1	1

Simulations

Model runs were made to simulate hydraulic and sediment transport for existing conditions and a variety of alternative dredging plans. Several runs were made to assess the effects of debris obstructions on the bridge pier, and a run was made with existing conditions for channel geometry, but with the bridge pier removed. Simulated channel excavations of 45,000 included a 300-ft long by 50-ft wide by 3-ft average deep channel (consistent with the proposed permit application), a 600 x 25 x 3-ft channel, a 600 x 50 x 1.5-ft channel, and a 1000 x 45 x 1-ft channel. For each of the first three dimensions, three alternative locations were evaluated: (1) downstream of the bridge, (2) centered at the bridge, and (3) upstream of the bridge. The fourth dimension was applied from the confluence with Esopus Creek to 350 feet upstream of the bridge. A constant slope of 0.011 was applied to all cuts, and the cut was assumed to be centered in the channel.

Results

The model demonstrates that the lower 1000 feet of Stony Clove is incised – incipient flooding for much of the channel occurs at slightly more than 10,000 cfs (roughly a 25-year return frequency) and the bridge, if unobstructed, is capable of conveying this discharge without overtopping. However, backwater from the bridge and a relatively low left bank immediately upstream of the bridge provide conditions for flooding to occur at lower discharges. Under existing conditions and assuming no bridge obstructions, incipient flooding occurs at about 9,000 cfs, which corresponds to about a 20-year return frequency. At this discharge, left bank flooding is likely in the 120 feet upstream of the bridge (**Figure 3.1.23**).

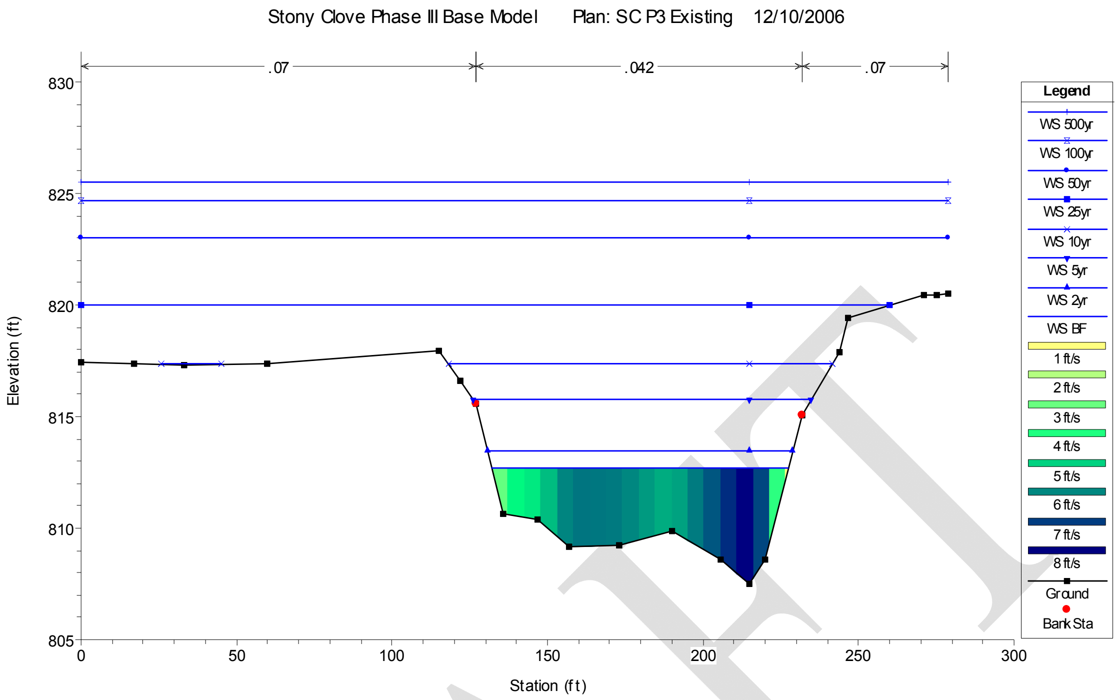


Figure 3.1.23 HEC-RAS model results for cross-section upstream of Route 214 bridge in Phoenicia for several discharges.

Obstructions on the bridge pier can have a profound effect on water surface elevations and flooding potential. **Table 3.1.10** lists the effects of various obstruction areas on water surface elevations. A 2-ft diameter tree trunk that is 50 feet long caught on the pier will raise the 10-year water surface elevation by more than three feet. Whereas a 9,000 cfs discharge (20-yr) is necessary to induce flooding under existing conditions, a 100 square foot obstruction will cause flooding at about 5,000 cfs (5-yr return frequency), as shown in **Figure 3.1.24**.

Table 3.1.10. Influence of debris blockages on water surface elevations 100 feet upstream of the Rt. 214 Bridge.

Blockage Area (sq. ft.)	Increase in Water Surface Elevation (ft) for Indicated Return Frequency			
	2-yr	10-yr	25-yr	50-yr
0	0	0	0	0
50	0.52	1.88	2.51	0.69
100	1.04	3.09	2.7	0.89
150	1.57	4.29	2.92	1.09
200	2.11	4.24	3.17	1.31

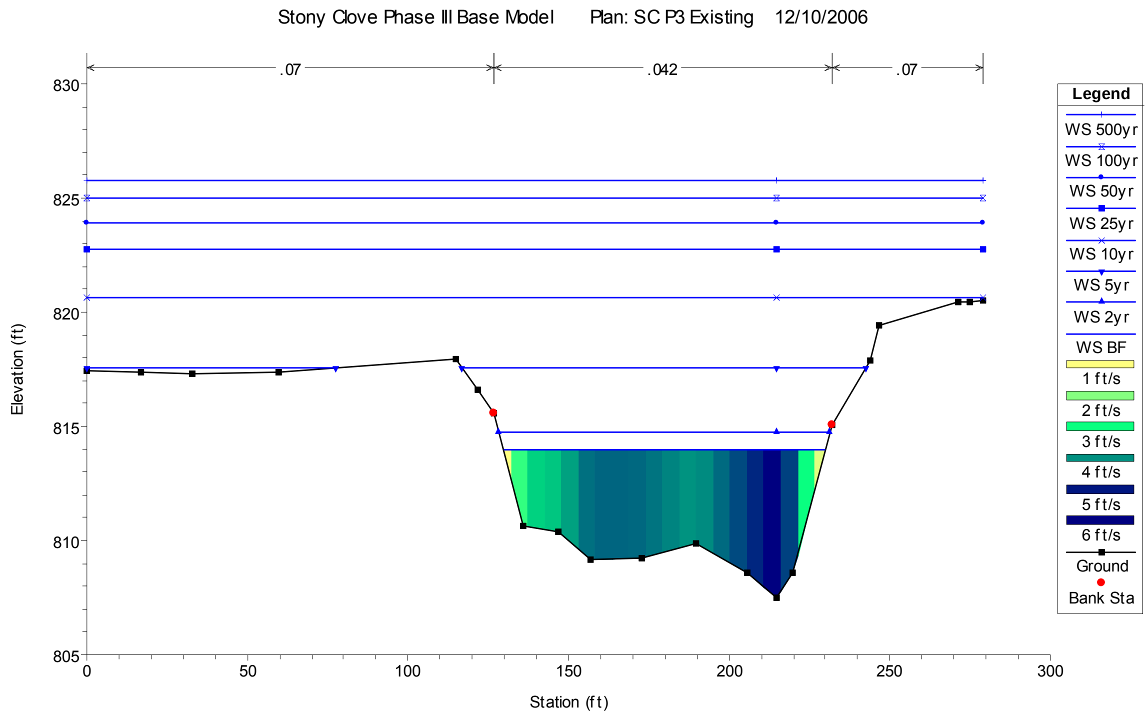


Figure 3.1.24 HEC-RAS model results showing impact of 100 sq. ft obstruction at Route 214 bridge on flood stage for same location as Figure 3.1.24.

Removal of the center bridge pier results in a lowering of the water surface elevation by a little more than 0.5 feet for about 100 feet upstream of the bridge. This increases the flood-free channel capacity by about 1000 cfs, and adds about 3 - 5 years to the frequency of an overtopping discharge.

Ten alternatives for the gravel removal proposal were evaluated to determine the reduction in water surface elevation with the assumption that gravel removed was not replaced (see sediment transport discussion below). The full report on this assessment located in **Appendix D** provides a summary of the model results for all the alternatives at all locations and for all flows. **Table 3.1.11** provides a summary of the benefits for the 10- and 25-year events in the critical area immediately upstream of the bridge. For all the alternatives, the benefits are greatest for excavation downstream of the bridge, and least for excavation upstream of the bridge. Alternatives with excavation extending equally up- and downstream of the bridge had intermediate benefits. The width of the cut had a greater effect on lowering water surface elevations than did the depth. Benefits were more broadly distributed for longer cuts, but the longer cuts provided less benefit in the critical 100-ft segment of the stream than did alternatives that maximized width. **Figure 3.1.25** shows the water surface elevations at the upstream face of the bridge for Alternative 1a, which had the greatest effect on elevations.

Table 3.1.11. Change in water surface elevation 100 feet upstream of the Rt. 214 Bridge for the 10, 25, and 50-year floods for each alternative.

	Dimensions (ft)				Effect on W.S. Elev. (ft)		
Alt.	**Length**	**Width**	**Ave. Depth**	**Location**	**10-yr**	**25-yr**	**50-yr**
1a	300	50	3	D/S of Bridge	-1.98	-2.67	-1.43
1b	300	50	3	U/S of Bridge	-1.54	-1.95	-1.42
1c	300	50	3	Centered on Bridge	-0.70	-0.50	-0.09
2a	600	25	3	D/S of Bridge	-1.40	-1.63	-0.80
2b	600	25	3	U/S of Bridge	-0.65	-0.86	-0.04
2c	600	25	3	Centered on Bridge	-0.60	-0.56	0.31
3a	600	50	1.5	D/S of Bridge	-1.54	-1.79	-0.41
3b	600	50	1.5	U/S of Bridge	-0.72	-0.93	0.08
3c	600	50	1.5	Centered on Bridge	-0.62	-0.58	-0.08
4	1000	45	1	From Confluence	-0.45	-0.62	0.58

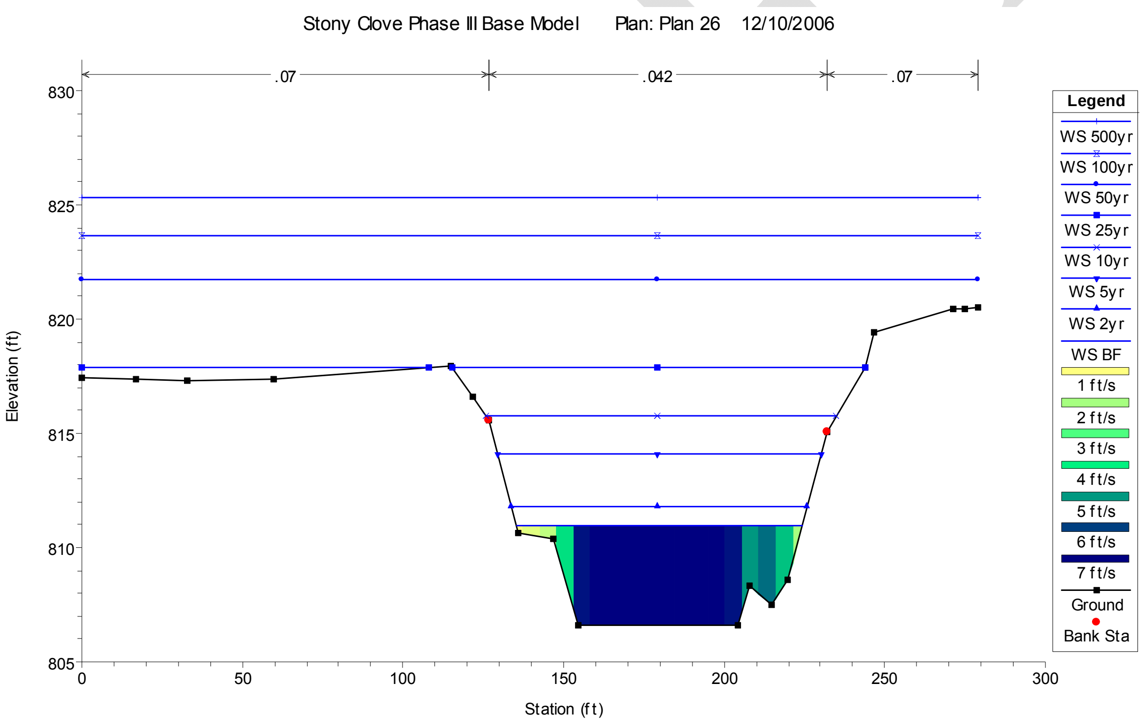


Figure 3.1.25. Water surface elevations at the upstream bridge face for Alternative 1a, a 300-ft long by 50-ft by 3-ft average cut from the bridge face downstream.

Sediment transport computations were made to assist in an assessment of the potential for the excavated channel region to refill with sediment. Alternative 1a was selected for the analysis because it provides the greatest flood damage reduction benefits. An average of the sediment gradations was applied to all cross sections, and the transport capacity for each of the modeled discharges was computed using the sediment transport functions by

Meyer-Peter and Muller (1948) and Yang (1984). The full report in **Appendix D** provides a summary of the analysis results.

Sediment transport capacity is very high in this reach due to the steep slope, low width/depth ratio, and high channel confinement. Even at bankfull flow (here assumed 1.5 year return frequency), median transport capacity is about 25,000 tons of sediment per day. At the 10-year discharge, this figure increases to about 80,000 tons/day (**Figure 3.1.26**). Actual transport is dependant upon sediment availability, and may be less than the capacities calculated by these relations. It is clear from the computations and can be seen in Figure 4, however, that the transport capacity diminishes significantly in the area where the sediments are to be excavated, and this is the critical point.

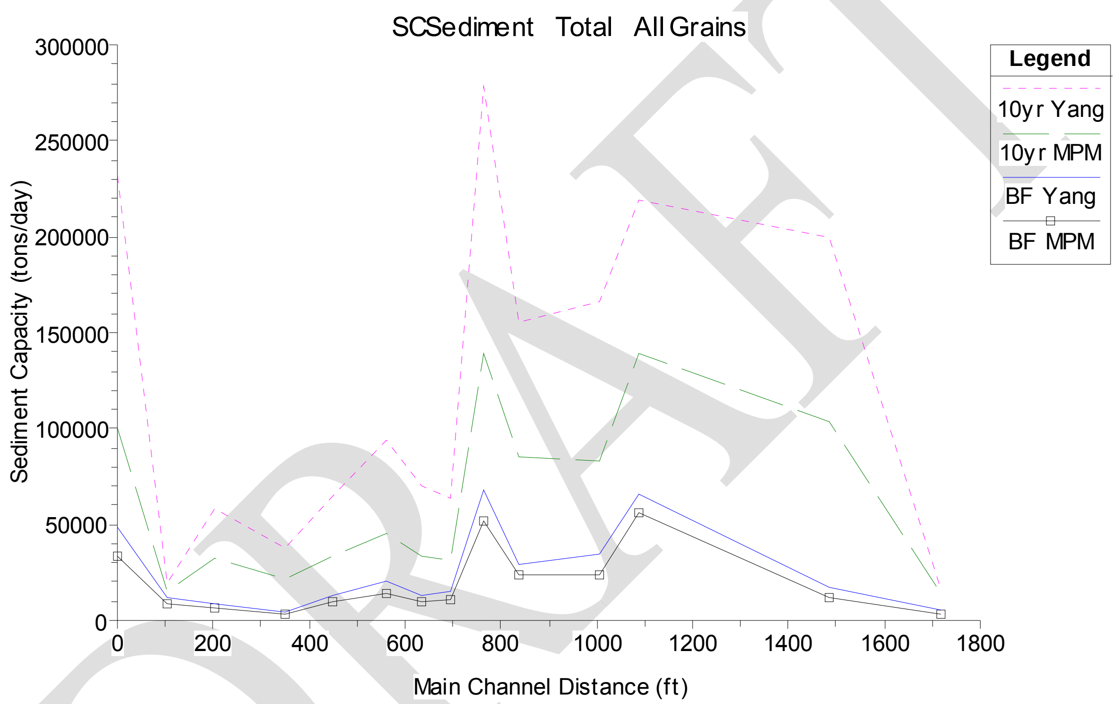


Figure 3.1.26. Sediment transport capacity in the study reach as computed using the transport functions by Meyer-Peter and Muller (1948) and Yang (1984). Rates shown are for total sediment load for the bankfull and 10-year discharges. Route 214 bridge is approximately at station 1050.

Sediment load delivered by an upstream reach with a higher transport capacity will deposit in a downstream reach with lower sediment transport capacity. **Figure 3.1.26** shows that the median transport capacity in the reach upstream of the bridge is about 30,000 tons/day. In the reach below the bridge where the excavation occurs, this drops to about 10,000 tons per day. Therefore, if Stony Clove is not supply limited and sediments are transported at full capacity, a bankfull discharge lasting 3 hours would be sufficient to replace the 2000 tons removed as part of the flood reduction effort. The differential at a 10-year event would replace the removed sediments in about 45 minutes. Although there is considerable uncertainty associated with estimates of the timing and magnitude of sediment conditions on rivers, it is a certainty that the excavated sediments from Stony

Clove will be replaced with new deposits. The question is, will this occur before a flood peaks and erase the benefits of the excavation?

The removal of gravel from the lower portion of Stony Clove is not expected to induce widespread instabilities in the system. A bedrock outcrop upstream of the project reach will effectively arrest any headcut that might develop as a consequence of the material removal. Locally, bank erosion potential will increase because of the "higher" banks, and this could compromise some local bank stabilization measures. We could not ascertain the extent to which these existing structures are embedded, so could not assess their resilience to undermining.

Ecological impacts are likely to be short term. Excavation should be scheduled to avoid major spawning periods, and macroinvertebrates will likely recolonize the disturbed areas in a matter of weeks. Construction-related turbidity controls will be required, but even if the channel is dewatered during excavation, groundwater seepage is likely to result in elevated turbidity levels in Esopus Creek from the disturbance. Capturing and filtering or settling this water may make the project cost-prohibitive.

Recommendations

- Maximum benefits are attained from excavation that occurs downstream of the bridge, and that maximizes the width of the excavation. The environmental impacts are related, in part, to the footprint of the project, and the smaller the disturbance area the better. For these reasons, Alternative 1a is the preferred gravel removal option – a 300' by 50' by 3' (ave) excavation from the bridge downstream.
- Benefits of the excavation are questionable. It is likely that the excavated area will fill with sediment before it has an opportunity to provide any real benefit. It is highly unlikely that benefits would span more than one minor flood event. Under the best of circumstances, the benefits are of the same order as removal of the pier or removing a single log obstructing the bridge. For these reasons, it is recommended that the community of Phoenicia pursue longer-term and more reliable alternatives to flood damage reduction.
- If the gravel mining alternative is implemented, a monitoring program is recommended to monitor the effectiveness of the practice. The proposed monitoring should, at a minimum, consist of periodic resurvey of monumented cross sections in the project reach and installation of scour chains.

3.2 Riparian Buffer and Corridor Assessment

Photo 3.2.1 Esopus Creek forested watershed and riparian corridor (Reach EC8)

The land within the active and historic flood prone area is often referred to as the *riparian* (streamside) zone (**Figure 3.2.1**). The vegetation growing alongside a stream within the riparian zone or corridor is referred to as the riparian buffer or riparian corridor (**Photo 3.2.1**). Riparian buffers are a linear band of vegetation adjacent to a stream or aquatic ecosystem that functions to maintain or improve water quality by trapping and removing various non-point source pollutants (e.g., contaminants from herbicides and pesticides; nutrients from fertilizers; sediment from upland soils) from both overland and shallow subsurface flow. Riparian buffers also can provide a dense network of roots that help stabilize stream banks. Riparian corridors are strips of vegetation along a water body that connect two or more larger patches of vegetation (i.e., habitat) and through which organisms will likely move through over time.

Characterizing the land cover within the riparian corridor and evaluating the condition and composition of the riparian buffer is a critical component of a stream condition assessment. This section serves two purposes in the ECMP: (1) it provides background information on the role and importance of the riparian zone, influences on the quality of the riparian buffer, and problems associated with invasive plants; and (2) a presentation on the Phase 1 and Phase 2 riparian corridor assessments.

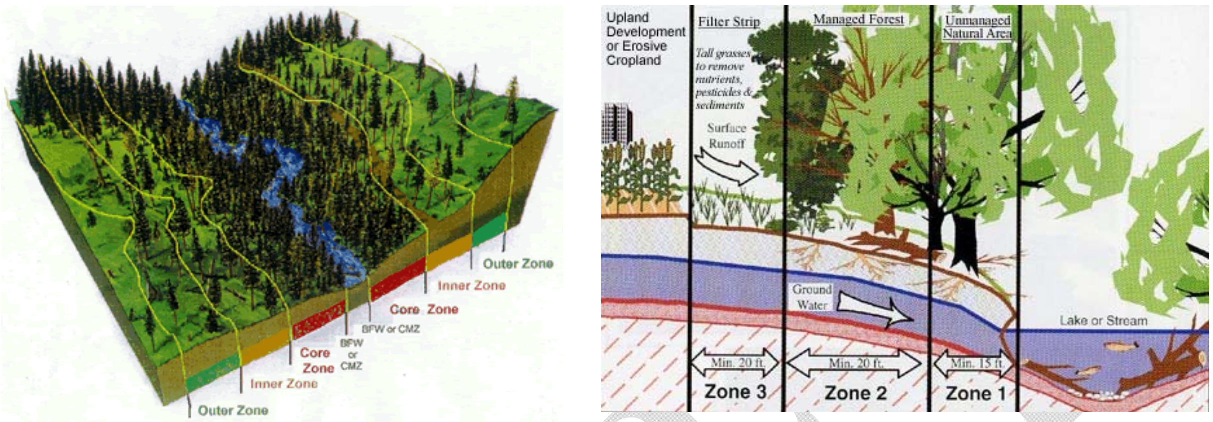


Figure 3.2.1 Illustrations of riparian zones within the stream corridor.

Specific riparian buffer management issues along Upper Esopus Creek and associated recommendations are presented in Volume 1.

3.2.1 Riparian Vegetation Function

Streamside vegetation provides numerous benefits to water quality, aquatic and terrestrial plants and animals, and local landowners. Riparian buffers facilitate stream stability and function by providing rooted structure to protect against bank erosion and flood damage. Riparian buffers offer protection against pollution and the adverse impacts of human activities. Streamside forests also reduce nutrient and sediment runoff, provide food and shelter for animals, and moderate fluctuations in stream temperature. Streamside vegetation also improves the aesthetic quality of the water course.

The extent of benefits is proportional to the width of the riparian buffer and its species diversity (Fischer and Fischenich, 2000). For example, a narrow 25 foot buffer zone may offer only bank stabilization and water quality benefits while a buffer 200 feet wide provides a more diverse range of ecological benefits. A buffer containing a variety of species and types (trees, shrubs, grasses and forbs) offers the best protection **(Photo 3.2.2)**. An area with a diverse mix of native species of different ages, including young plants, will provide more benefits than a less diverse community. The less diverse community is

Photo 3.2.2 mixed riparian vegetation along Esopus Creek

more at risk from disease, pests, and climatic events such as droughts. A greater variety of plant sizes and species will typically occupy more of the root zone helping to stabilize streambanks. Native plants in the riparian zone have the ability to resist or recover from disturbance, such as the repeated inundation and scour associated with floods.

The riparian forest community can be more extensive where a floodplain exists and valley walls are gently sloping. Where valley side slopes are steeper, the riparian community may occupy only a narrow corridor along a stream and transition to an upland forest community. Soils, ground water and solar aspect may create conditions allowing the riparian forest species to occupy steeper slopes along a stream, as in the case where Eastern hemlock (*Tsuga canadensis*) inhabits steep, north facing slopes along a watercourse. See the annotated bibliography in Section 5 for suggested further reading on this subject.

3.2.2 Conditions Affecting Riparian Corridor

Natural Disturbance and its Effects on Riparian Vegetation

Natural disturbances can greatly affect the vigor of streamside vegetation. These disturbances include floods, ice or debris floes, and to a lesser extent, high winds, pest and disease epidemics, drought and fire. Deer herds can also alter the composition and structure of vegetation due to their specific browse preferences. Riparian vegetation is generally well adapted to these disturbance regimes, and one of the distinctive characteristics of riparian zones is the "patchy" nature of the vegetation that is a reflection of previous disturbances.

Photo 3.2.3. Woody debris partially blocking a channel in Reach EC18

The effect of flooding on healthy streamside vegetation is generally short term and the recovery/ disturbance regime can be cyclical. Following a large flood, the channel and adjacent floodplains can be littered with everything from woody debris to downed live trees **(Photo 3.2.3)**. In following years, much of the vegetation recovers. Trees and shrubs flattened by floodwaters re-establish their form. In stable streams, gravel bars and sites disturbed in previous flood events become seedbeds for natural regeneration of grasses and forbs. However, if significant flood or ice floe events occur too frequently to allow adequate vegetation re-establishment, large trees do not have the opportunity to establish.

Springtime ice break-up, like floods, can damage established vegetation along streambanks and increase mortality of young tree and shrub regeneration. Ice floes can also cause channel blockages, which result in erosion and scour associated with high flow channels and over-bank flow. This type of disturbance generally has a relatively short recovery period.

Pests and diseases that attack vegetation also impact the riparian area. In portions of the eastern United States, the hemlock wooly adelgid (*Adelges tsugae*) attacks eastern hemlock and can affect entire stands[3]. The hemlock is an important riparian species. As described by the Olive Natural Heritage Society (ONHS) on their website (www.onhs.org):

“The Hemlock Forest is a "keystone community" is the Catskill Mountain region. The forested riparian zone in the deep, cool ravines where the rocky headwaters of Catskill streams arise is dominated by Hemlock stands. Vigorous, healthy Hemlock forests are essential to support the complex aquatic biotic assemblage characteristic of these richly-oxygenated waters. Hemlock Woolly Adelgid infestations in the Catskills are evident - and the threat to our hemlock forests is real. Because the woolly adelgid is no small threat, ONHS has established an Adelgid Monitoring and Verification Team. Team members are assigned sub-basins of the Esopus Creek to map the presence of hemlocks and monitor the spread of adelgid infestations.” A map of the 2002 ONHS hemlock wooly adelgid survey for the Esopus watershed is presented in **Figure 3.2.2**

[3] U.S. Forest Service, Morgantown office website: www.fs.fed.us/na/morgantown/fhp/hwa/hwasite.html (Verified 11-03-04)

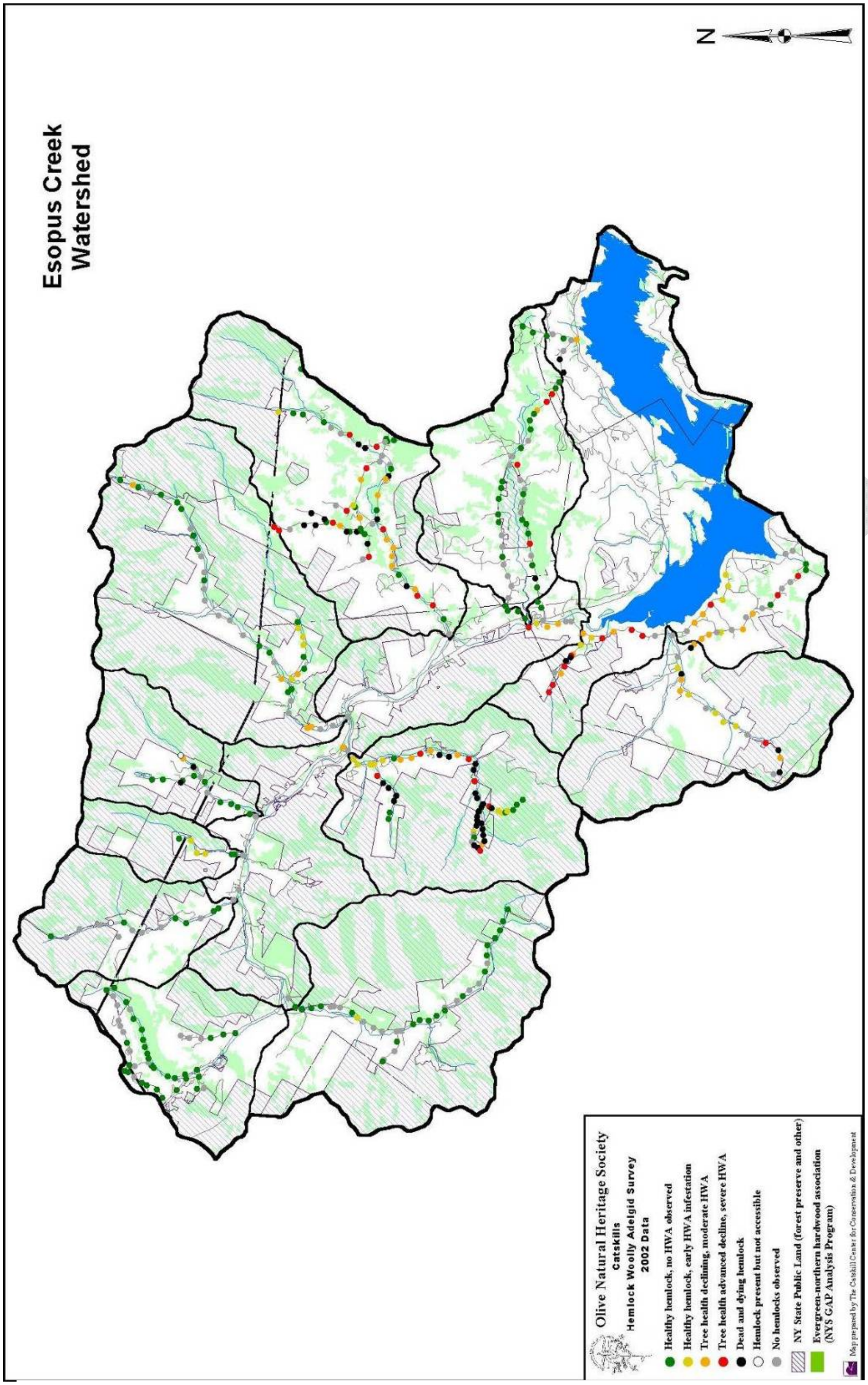


Figure 3.2.2 Distribution of Hemlock Wooly Adelgid in the Esopus Creek Watershed (from ONHS)

Human Disturbance and its Effects on Riparian Vegetation

The distinction between natural and human disturbances is important to understand. The effects of floods, ice floes, pests and disease can cause widespread damage to riparian vegetation but these effects are usually temporary. However, human activities often significantly alter natural conditions and can have a longer lasting impact on the capability of riparian vegetation to survive and function. In the Upper Esopus Creek watershed these disturbances can include residential lawn maintenance, construction and maintenance of highway infrastructure, real estate development and introduction of non-native species in the riparian zone. Agriculture and livestock grazing, previously more prevalent within the riparian corridor of the Upper Esopus watershed, it is not currently a significant factor disturbing riparian vegetation.

Photo 3.2.4 NYS Route 28 impact on riparian buffer (Reach 11)

Road/Railroad/Public Utility Infrastructure Influence

Use and maintenance of state and local highways also impacts the vigor of riparian vegetation where narrow buffers exist between roads and streams (**Photo 3.2.4**). These areas receive runoff containing sediment and road chemicals that stunt vegetative growth or increase stress and mortality. Accelerated storm runoff from these highways also contributes to increased streambank erosion, though revetment is often used to stabilize

Photo 3.2.5 Maintained railroad grade along reach M2 resulting in riparian buffer break.

the streambank in these locations. Highway maintenance activities that regularly disturb the soil along shoulders and cut banks can welcome undesirable *invasive plants*. The presence of the Catskill Mountain railroad line that approximately parallels the course of the Esopus for several miles has a significant influence on the continuity of riparian vegetation coverage between the Ashokan Reservoir and Birch Creek. Where the railroad is in active use and maintained (Esopus Creek reaches 1-5) it is a clear break in the riparian buffer (**Photo 3.2.5**). In areas where public utility lines parallel or cross streams, riparian areas are disturbed by the practice of keeping vegetation trimmed to near ground level. This practice of vegetation suppression is another contributor to accelerated runoff and increased streambank erosion.

Residential Development Influence

Photo 3.2.6 Streambank erosion and mowned lawn

Residential land use and development of new homes can have a significant impact on the hydrology and ecology of the riparian area. Houses require access roads and utility lines that often have to cross streams. Homeowners who enjoy their stream and desire to be close to it may clear all the trees and shrubs along it to provide access and views (**Photo 3.2.6**). They may replace natural conditions with a mowed lawn that provides little benefit to stream health or local wildlife. These practices can lead to new streambank erosion or increase existing erosion.

Many people live close to a stream and have access to the water without destabilizing the bank. By carefully selecting a route to the stream and locating access to the stream where the water's force on the bank is lower, a landowner can minimize disturbance to riparian vegetation and the streambank. Minimizing disturbance in the flood prone area and promoting a dense natural buffer provide property protection, aesthetic value and wildlife habitat. Riparian gardeners must know which riparian species are appropriate for planting. More information on re-establishing a riparian buffer can be obtained by contacting the Ulster County Soil & Water Conservation District, (845) 883-7162.

The following websites also offer information on riparian buffers:

USDA Natural Resources Conservation Service backyard tree planting - http://www.nrcs.usda.gov/feature/backyard/TreePtg.html (Verified 11-05-04)

USDA Natural Resources Conservation Service wildlife habitat - http://www.nrcs.usda.gov/feature/backyard/WildHab.html (Verified 11-05-04)

Fischer, R. A., and Fischenich, J.C. (2000). "Design recommendations for riparian buffer strips and corridors," EMRRP Technical Notes Collection (TN EMRRP-SR-24), U.S. Army Engineer Research and Development Center, Vicksburg, MS. – http://el.erdc.usace.army.mil/publications.cfm?Topic=technote&Code=emrrp (Verified 1-2-07)

Connecticut River Joint Commission, Inc. - http://www.crjc.org/riparianbuffers.htm (Verified 11-05-04)

The National Wildlife Federation - http://www.nwf.org/backyardwildlifehabitat/ (Verified 11-05-04)

The Long Island Sound Riparian Toolbox - http://www.hydroqual.com/projects/riparian/

Invasive Plants and Riparian Vegetation

Attempts to beautify a property with new and different plants will sometimes introduce a plant that spreads out of control and "invades" the native plant community. Invasive plants present a threat when they alter the interactions among organisms of a native plant community. This impact may extend to an alteration of the landscape should the invasive plant destabilize the geomorphology of the watershed (Malanson, 1993). *Japanese knotweed* (*Fallopia japonica*), an invasive plant gaining a foothold in the Esopus Creek basin, is an example of a plant capable of causing such a disruption.

Japanese knotweed

A plant whose presence within the Catskill region has become much more prevalent in the last few years, Japanese knotweed is an invasive plant often referred to by Catskill residents as bamboo or Japanese bamboo (**Photo 3.2.7**). Although bamboo and Japanese knotweed are two different plants, they do have a couple of similarities. Both have tall, hollow stems, but more importantly, neither belong in the United States. As implied by its name, Japanese knotweed originates from Asia. This categorizes knotweed as an *exotic* plant, one that evolved in another area of the world with different plants and animals.

Because exotic species are often transported without the associated plants and animals that normally keep them in check, exotic species can become *invasive* species. Invasive species earn this categorization by out-competing local, native species and may alter the ecosystem and its functions. Invasive plants can often survive under less than perfect conditions – from high and low soil pH levels to full or no shade to wet or dry conditions. The following section describes Japanese knotweed, its traits as an invasive species, what people can do about it and resources for additional information.

Photo 3.2.7 Japanese Knotweed colony along Upper Esopus Creek in Shandaken, NY

Characteristics of Japanese knotweed

Fortunately, Japanese knotweed is quite recognizable throughout the year. The series of photographs below illustrate different stages of Japanese knotweed's growth throughout each season. This herbaceous, or non-woody, perennial goes through these cycles every year.

In the spring (generally late April, early May), new red, asparagus-like shoots sprout from last year's crown or from underground roots (*rhizomes*). By July individual stems may reach as tall as 11 feet. Many thick, hollow stems are based at a crown. The upper areas of the stems form a few branches that reach out like an umbrella from the crown. Each main stem and branch holds several large, nearly-triangular leaves that shade out most of summer's sunlight. In August knotweed dons abundant clusters of small, white flowers that attract several pollinators, such as bees, wasps and Japanese beetles.

The numerous flowers turn into buckwheat-like seeds by late September, early October. Although some seeds may create small seedlings (Forman & Kesseli 2003), knotweed spreads more by their *rhizomes*.

Cold weather halts the growth of knotweed; once frost covers the land, knotweed drops its leaves and turns an auburn hue. These dead stems often remain standing for one or two years and then cover the ground, decaying slowly.

Problems associated with Japanese knotweed

As previously mentioned knotweed is an exotic, invasive species. Some texts explain that knotweed was brought to Great Britain as early as 1825 where it won accolades as an ornamental plant (Sieger 1991); now it is handled like a hazardous waste and people can be prosecuted for planting it (Environment Agency 2006). By the late 1800s immigrants to the U.S. brought their prized garden plant. Knotweed has escaped personal gardens and spread into lawns, farm fields, along roadsides and railroads, along streambanks and onto floodplains (**Photo 3.2.8**). It is now found in five Canadian provinces and all but ten states in the US (USDA 2004), becoming abundant in New York in recent decades (McVaugh 1958).

Photo 3.2.8 JKW growing amongst corn

Knotweed spreads vegetatively from portions of the roots or shoots. This vegetative propagation characteristic explains how it has expanded into such a wide variety of environments. The rhizomes begin new colonies of knotweed by spreading up to 20 feet from an existing plant. For this reason people may transport knotweed unknowingly by digging up rhizome-contaminated soils and dumping them elsewhere. Even a very small piece of this rhizome can sprout a new plant.

When kept moist, other plant parts, such as the stem, can also sprout new plants. Stems and rhizomes float downstream after breaking off from floods (knotweed is actually a very brittle plant and breaks easily) or from beaver damage. These fragments then come into contact with disturbed or eroded soils lacking vegetation and begin more new colonies. This is why streams host such dense stands of knotweed (**Photo 3.2.7**).

Knotweed can also be unwittingly introduced to new areas by highway departments and contractors through soil transported from gravel and sand pits contaminated with knotweed. *Stream assessment* teams have noted several instances where knotweed stands have developed in the new soil where a *culvert* or bridge has been renovated. Once established near the waterway, knotweed is able to spread downstream after disturbance associated with a storm event.

Figure 3.2.3 From left to right: knotweed flattened by high flow event in Greene County, a stream bank *slump* where only grass and knotweed bordered streambank, and the shade created by dense canopy of broad knotweed leaves.

Why is this rapid invasion such a concern? Knotweed's traits pose a broad array of concerns. Some of these concerns include:

- Knotweed appears to be less effective at stabilizing streambanks than deeper-rooted shrubs and trees, possibly resulting in more rapid bank erosion (**Figure 3.2.3**).
- The shade of its broad leaves and the cover by its dead litter limit the growth of native plants that provide food and shelter for associated native animals (**Figure 3.2.3**).
- Knotweed branches do not lean out over stream channels, providing little cooling from shade.
- Dead knotweed leaves (*detritus*) may alter food webs and impact the food supply for terrestrial and aquatic life.
- Large stands of knotweed impede access to waterways for fishing and streamside hiking.
- The presence of knotweed could reduce property value.
- Knotweed may alter the chemical make-up of the soil, altering soil microfauna and soil properties.

Despite these concerns, it is important to support research into the interactions of knotweed with surrounding flora and fauna and also with stream processes. One individual has observed over 200 different kinds of plants and animals associated with knotweed (Kiviat, et.al. 2006). Managers must continually weigh the risks associated with invasive species management and whether doing nothing or doing something will create the best results.

3.2.3 Esopus Creek Riparian Corridor Characterization

Riparian corridor characterization for the Upper Esopus Creek Management Plan was completed in two phases:

- The Phase 1 Stream and Watershed assessment included characterizing average riparian buffer widths for each of the 23 reaches and identifying dominant land cover types for each reach. The results are summarized below.
- The Phase 2 riparian corridor assessment included (1) mapping presence of Japanese knotweed during the Phase 2 stream reconnaissance performed in 2005 and 2006; and (2) a detailed Anderson Level 2 vegetation composition assessment using available aerial photography, helicopter flight videography, and limited ground-truthing. The results are summarized below.

Phase 1 Riparian Corridor and Buffer Condition Assessment

See **Appendix C** for the detailed Phase 1 assessment report covering methods and results. The dominant left and right bank riparian buffer widths for each reach were estimated using the 2001 DOQQs. Four buffer width categories (0-25 ft, 26-50 ft, 51-100 ft, and > 100 ft) were assigned a percent coverage value for each reach's left and right banks.

Determining the presence of herbaceous and shrub vegetation was challenging because the aerial photography was taken during leaf-off conditions. Where a road or railroad grade cut the riparian zone the effective buffer was presumed to end at the disrupting feature. Similarly, turf, lawn, and residential features terminated the effective riparian buffer width.

Lengths of riparian vegetation in each buffer width category were measured and divided by the channel length to determine percent in each category within the reach. The buffer width category with the highest percentage was recorded as the dominant width.

Table 3.2.1 Phase 1 Riparian Buffer Width Assessment

	Left Bank Buffer Information					**Right Bank Buffer Information**				
Reach Number	0-25 ft (%)	>25-50 ft (%)	>50-100 ft (%)	>100 ft (%)	**Dominant Width**	0-25 ft (%)	>25-50 ft (%)	>50-100 ft (%)	>100 ft (%)	**Dominant Width**
1**	16	19	1	64	>100'	32	22	6	40	>100'
2**	40	6	5	49	>100'	35	8	12	45	>100'
3	2	0	4	94	>100'	66	12	12	10	0-25'
4	0	0	0	100	>100'	37	7	12	44	>100'
5**	36	10	3	51	>100'	50	5	2	43	0-25'
6**	15	23	17	45	>100'	66	10	13	11	0-25'
7**	50	19	6	25	0-25'	26	16	16	42	>100'
8**	0	0	0	100	>100'	11	10	34	45	>100'
9**NC	33	0	1	66	>100'	10	0	0	90	>100'
9**SC	0	0	0	100	>100'	0	15	45	40	50-100'
10	65	20	0	15	0-25'	0	0	0	100	>100'
11**	38	20	8	34	0-25'	27	13	4	56	>100'
12**	24	11	7	58	>100'	60	7	2	31	0-25'
13	10	3	38	49	>100'	0	0	16	84	50-100'
14	28	54	17	1	25-50'	0	0	81	19	50-100'
15	21	18	28	33	>100'	12	5	4	79	>100'
16	9	5	6	80	>100'	23	4	1	72	>100'
17	6	6	0	88	>100'	18	6	5	71	>100'
18	8	4	4	84	>100'	18	5	8	69	>100'
19	0	0	0	100	>100'	21	3	14	62	>100'
20	5	3	12	80	>100'	17	0	0	83	>100'
21	0	3	0	97	>100'	1	0	11	88	>100'
22	0	0	0	100	>100'	0	0	0	100	>100'
23	0	0	0	100	>100'	10	2	4	84	>100'

Notes: ** indicates that the buffer condition/width is influenced by the presence of the railroad;
NC = north channel; SC = south channel

The approximately 26 mile channel corresponds to more than 52 miles of stream bank. According to the Phase 1 assessment a buffer width of >100 feet dominated in the majority of the reaches, with approximately 63% of the total stream bank length in this category (**Table 3.2.1**). Approximately 22% of the total stream bank length has an intact riparian buffer 25 feet or less. Six reaches contained a riparian buffer ranging from 0-25 feet along either bank for at least 50 percent of the reach. Based on the results of the Phase 1 approach, with just a few exceptions, the overall riparian buffer condition appears to be good.

Along some sections of stream that lack riparian vegetation there has been corresponding excessive stream bank erosion where channel dynamics are prone to causing stream bank erosion, such as on the outside of a meander bend or where the channel narrows.

The railroad track appears to be one of the foremost influences on the continuity of riparian vegetative coverage along the corridor between the Ashokan Reservoir and Birch Creek. Where the track is actively used (between EC1 and EC5) it is a clear break in the effective buffer (**Photo 3.2.5**). Where the track is inactive, some forest cover and shrub growth has locally reduced the impact of the railroad on the effective buffer width. For the purpose of this Phase 1 investigation, both the inactive and active track is assumed to be the lateral extent of the effective buffer width. The Phase 2 composition assessment will further characterize the actual impact of the inactive railroad.

Knotweed on the Upper Esopus Creek

As part of the stream assessment for this plan, the field team used GPS and field observation to map the location of Japanese knotweed colonies along the creek. This mapping effort began in 2005 and was completed in 2006. The stream flow (augmented by the Shandaken Tunnel flows) precluded safe wading for GPS mapping in the reaches below Phoenicia. These reaches were assessed by a combination of floating with a kickboat, observations from roadside access, and helicopter reconnaissance. The accuracy of the mapped knotweed in reaches 1-5 is less than that for reaches 6-23 given the difference in mapping methods. The Project Team mapped colonies that could be observed from within the stream channel, therefore the resulting mapping effort generally did not capture

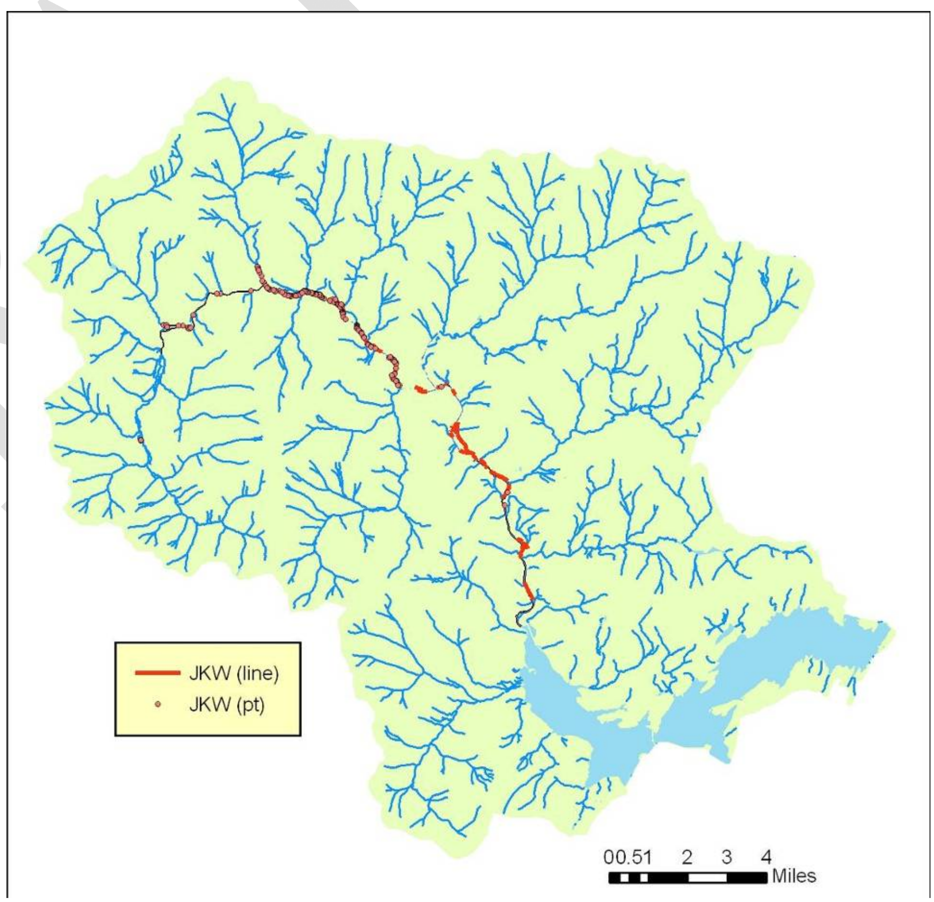


Figure 3.2.4 Distribution of Japanese knotweed (JKW) observed in 2005 along Upper Esopus Creek

colonies that are distant from the channel (but may be within the floodplain or flood fringe). Colonies were mapped as isolated points, or as a line with the beginning and end of a continuous stretch of colony identified along a bank.

The resulting map of colony locations (**Figure 3.2.4**) shows that the plant has extensively colonized the banks of the stream from the confluence with Birch Creek to the Ashokan Reservoir. Interestingly (and fortunately) there are very few colonies along Esopus Creek above Birch Creek, though there are several known colonies in some of the tributaries that drain into the Big Indian Hollow. These are evidently the results of road maintenance and stream repair activities that have brought in knotweed-contaminated fill.

Table 3.2.2 lists the number of mapped colonies per reach, cumulative lengths, and percent of reach colonized. Of the approximately 56 miles of Esopus Creek streambank assessed, Japanese knotweed had colonized approximately 9.5 miles (or 17% of the total length). However, below Birch Creek approximately 27% of the streambank is colonized by Japanese knotweed, with 9 reaches exceeding 50%. 125 colonies were identified ranging in length from 4 feet to 2,437 feet(EC5). The average size colony recorded is 400 feet long; the median is 120 feet long.

Table 3.2.2 Japanese knotweed colonies observed in 2005 on Upper Esopus Creek

Reach	# obs	length/reach (ft)	% channel length[1]
EC1	1	2635	28
EC2	8	7153	60
EC3	2	2982	86
EC4	6	4741	114
EC5	14	8974	70
EC6	4	2638	49
EC7	14	3379	59
EC8	14	4521	90
EC9	10	2339	30
EC10	6	2923	105
EC11	19	3973	69
EC12	22	3343	60
EC15	3	312	2
EC16	1	105	3
EC18	1	71	1
Totals	125	50090	

[1] If % exceeds 100 reflects colonies along side channels.

Japanese knotweed was observed in each of the tributaries from Little Peck Hollow to Little Beaver Kill. This is clearly a systemic problem in the entire Upper Esopus Creek watershed as it is elsewhere throughout the Catskills and the northeastern U.S. The fact that there are just a few small colonies in the watershed above Birch Creek presents an opportunity to try to eradicate it from the headwater reaches of the watershed in the near future. Further mapping of Japanese knotweed in the tributary valleys is needed to optimize an eradication program.

Riparian Corridor Land Cover Assessment

As part of the stream corridor assessment process, Cornell Cooperative Extension of Ulster County contracted with Barry Vittor & Associates, to create a digital map of land cover along the Esopus corridor from Reach 1 – 21 (BVA, inc. 2007; see **Appendix G - Riparian Land Cover Analysis and Maps**). The classification was based on a definition of land covers previously used in other stream management plans within the Catskills and contained two levels of definition. The classification, largely based on physiognomic characterization for the broadest level of definition (level 1) and a ecological community association for the more refined characterization (level 2). With respect to vegetation, level 1 land cover groups were based on the form and density, while level 2 groups added greater definition of species associations and ecological succession pattern.

The maps were created through a process of interpreting and on-screen digitizing the land cover unit boundaries from the 2001 color infrared digital orthophotographs for the corridor. This photoset was selected instead of the more recent 2004 black and white photoset for its clarity and utility in identifying distinct vegetation types. The office delineated maps were later field checked and adjusted based on a windshield survey of the entire corridor. Time constraints did not allow for a comprehensive verification of areas away from public access routes. Additionally, the definition of paved versus unpaved surfaces requires greater field verification. Therefore the analysis of the results with respect to impervious should be considered within the context of the limits of the data.

Reach maps of the corridor classification are found in Appendix G.

Analysis of the riparian corridor land cover presented below provides a comparison of land cover at the watershed and reach scales. **Table 3.2.3** presents the summary statistics for land cover along the creek for entire at corridor. The dominant land cover, floodplain forest, which occupies 28.3 percent of the corridor, indicates that much of the land along the creek is protected by forest. Overall, closed forest still covers 47 percent of the corridor. Retention of this forest cover will greatly assist in the long term maintenance of stream stability.

Table 3.2.3 Land Cover for the Esopus Creek Riparian Corridor

Land Cover Type	Total Acres	% of the Corridor
Backwater Slough	12.9	0.4%
Brushy Cleared Land	15.0	0.5%
Closed Deciduous Forested Wetland	4.7	0.2%
Closed Floodplain Forest	798.1	26.8%
Closed Hemlock Forest	18.5	0.6%
Closed Hemlock-Northern Hardwood	186.2	6.2%
Closed Northern Hardwood	156.6	5.3%
Closed Pine-Northern Hardwood	210.8	7.1%
Closed Successional Northern Hardwood	0.8	0.0%
Closed White Pine Forest	28.8	1.0%
Cobble	100.3	3.4%
Construction spoils	2.9	0.1%
Cropland	65.2	2.2%
Esopus Creek or Tributary	247.6	8.3%
Farm Pond/Artifical Pond	1.1	0.0%
Mowed Lawn	23.4	0.8%
Mowed Lawn w/ Trees	491.2	16.5%
Mowed Roadside	46.4	1.6%
Natural Pond	7.7	0.3%
Open Deciduous Forested Wetlands	1.2	0.0%
Open Floodplain Forest	45.0	1.5%
Open Northern Hardwood	12.7	0.4%
Open Pine-Northern Hardwood	72.4	2.4%
Open Successional Northern Hardwood	3.0	0.1%
Open White Pine Forest	0.8	0.0%
Other	1.8	0.1%
Pastureland	31.9	1.1%
Paved	159.7	5.4%
Pine Plantation	4.1	0.1%
Railroad	4.1	0.1%
Reservoir/Artificial Impoundment	1.8	0.1%
Riprap	1.0	0.0%
Rooftop	44.9	1.5%
Scrub/Shrub Wetland	55.2	1.9%
Sparse Vegetation	3.4	0.1%
Successional Old Field	45.5	1.5%
Successional Shrubland	22.7	0.8%
Tributary	3.3	0.1%
Unpaved Road	20.7	0.7%
Wet Meadow	25.7	0.9%
Grand Total	2,979.1	100.0%

The land covers, “mowed lawn” and “mowed lawn with trees”, which make up 17.3 percent of the corridor, are commonly associated with residential and light commercial land uses. Where these land covers make up a larger proportion of the overall landuse, it could be expected that the condition of the riparian buffer could be compromised. This is especially true where landowners have cleared the forest and now mow up to the stream bank. Instances were observed where landowners have recently cleared floodplain forest and have built residential structures in or very near the floodplain. Left unchecked, this desire to live near water will ultimately cost the community in terms of increased stream instability, greater flood damage and the need to spend scarce funds on revetment.

Roadways and parking areas make up about 6 percent of the corridor and when added to the area of rooftop (1.5 percent of the corridor) combine for an estimate of the surface potentially contributing to accelerated stormwater runoff. This percentage is greater than the extent of impervious surface typically found in rural areas (2 percent) and approaching the extent common to low density residential settings (10 percent). In reaches 1, 6, and 11 (Boiceville, Phoenicia, and Allaben) the area within the riparian corridor covered by roads or impervious surfaces exceeds 10 percent. Efforts to improve stormwater retention will benefit the community by helping to minimize flood peaks, reduce infrastructure damage in storm events, protect water quality and maintain a healthy aquatic ecosystem.

At the reach scale, it becomes apparent where the intensity of land use may be greatest within the riparian corridor. In reaches 3,6,7,9,10,and 11 (Mount Tremper, Phoenica to above Woodland Valley, and Fox Hollow to Allaben confluence areas) the percentage of “mowed lawn with trees” frequently exceeds 20 percent of the corridor. On the left bank of the river (the bank nearest Rt 28) access to the stream by residential properties has converted floodplain forest to mowed lawn with trees. At several points, this conversion has reduced the width of the riparian buffer. This finding is consistent with the Phase I riparian buffer width measurement (see **Table 3.2.1**) that found that the dominant left bank buffer width in reaches 7, 10, and 11is less than 25 feet. On the right bank, the same was true for reaches 3, 5, 6, and 12. While the strengthening of buffers in these reaches can be accomplished by tree planting and the reduction of mowing near the edge of the stream, the most cost effective method for protecting stream side properties is to prevent further conversion of the existing riparian forest to non-forest land covers.

3.2.4 Stream Management Implications

Riparian buffers in this mountain river setting are necessary for maintaining a stable channel form, water quality, and the ecologic integrity of the stream system. In general, channel stability and hence property protection increase as the riparian buffer increases. Based on the assessment findings, approximately 22% of the stream bank along Esopus Creek is in need of riparian buffer enhancement.

The composition of the buffer matters as well. A dominant riparian cover along Upper Esopus Creek is floodplain forest. This is an optimum riparian cover for this setting. Where possible, this forest should be encouraged and protected. Although trees along the stream's edge can fall into the stream during floods, the mobilization of woody debris during storm events is typical of a forested mountain stream and management needs to account for this process. When there are no trees present along this type of stream, the stream banks will erode often and wildly, mobilizing and redepositing substantially larger amounts of gravel debris downstream. Forested floodplains are both a source and sink for woody debris. Trees eroded from upstream banks are frequently caught in the wooded areas downstream. Constructing bridges with wide spans so as to minimize debris jams and preventing the construction of residential structures in the floodplain will reduce the damage and threat to property associated with woody debris. Flood hazard mitigation strategies should plan for removing debris where necessary following a flood event.

There is a systemic infestation of the exotic invasive Japanese knotweed on Esopus Creek. Though not mapped as part of this study, oriental bittersweet was observed in many locations from Reach 15 to 1. Japanese knotweed negatively impacts biodiversity and seems to increase the potential for stream bank erosion. Oriental bittersweet kills riparian trees by twining around tree trunks and branches, essentially choking them to death.

From the analysis to date these are the following priority riparian management issues for consideration in this Plan:

- Protecting and enhancing the existing riparian buffer along Upper Esopus Creek through Program development.
- Developing and Implementing a Japanese Knotweed (or other exotic invasive) Management Strategy
- Continued assessment is needed in the tributary valleys

3.2.5 Recommendations

- Develop a riparian enhancement program that assists landowners in (a) education on the role of riparian buffers in protecting their property and (b) establishing landowner riparian buffer management plans which include planting and monitoring support by UCSWCD.
- Work with UCSWCD and other agencies and organizations to continue mapping the presence of Japanese knotweed in the Upper Esopus Creek watershed. Encourage public participation.
- Work with UCSWCD to use the Esopus creek restoration Project Site as Japanese knotweed control demo site.
- Work with partners to develop a Japanese knotweed eradication program that emphasizes starting in the headwaters and main tributary streams, then working the mainstem below Birch Creek.

- Develop a Japanese knotweed monitoring program that optimizes available resources to monitor the expansion or reduction of the invasive species.
- Plan for stormwater retention and design stormwater delivery systems that mitigate flood and pollution impacts.
- Include consideration of woody debris management as part of infrastructure development and hazard mitigation planning.
- Emphasize the importance of protecting the existing floodplain forests from further development to planning boards, town officials, floodplain and building code enforcement officials and streamside landowners.

3.3 Aquatic Ecosystem Condition of Upper Esopus Creek

Fish eggs found in backwater channel along Upper Esopus Creek (Reach EC10)

Principal Investigator:

Walt T. Keller
DEC Region 4 Fisheries Manager (Retired)
Cornell Cooperative Extension of Ulster County

DEDICATION

This work is dedicated to the memory of my grandfather, David Thomas Lamond, who drowned with his friends and business associates, Robert D. Burns and E. Lionel Parrot, during a squall while fishing in Ashokan Reservoir on September 18th, 1948. Also to Ray Smith, their guide, who was haunted by the accident and Walter, my father, invited but unable to go.

3.3.1 Introduction

This inquiry was initiated to understand the connections between stream management practices and aquatic ecosystem conditions in the upper Esopus Creek (upstream of Ashokan Reservoir). The findings complement the results from the geomorphic and riparian buffer assessments, and social surveys of streamside landowners, whitewater recreationists, anglers and other stakeholders towards developing a multi-objective management plan for the upper Esopus Creek.

For the geomorphic and riparian buffer studies of the Esopus Creek Management Plan, the primary study area boundaries encompass the main-stem of the Esopus Creek from Winnisook Lake in Frost Valley to the inlet of Ashokan Reservoir in Boiceville. The tributary mouths and some upland sediment supply areas are also included. A supplementary aquatic ecosystem assessment as part of the Phase 2 geomorphic assessment (Section 3.1.2) was performed by ERDC using a procedure based upon the EPA's Rapid Bioassessment Protocols (RBP) to qualitatively assess the environmental condition in each reach. The approach was accomplished by visual assessments at a reach scale made during the Phase 2 stream feature inventory. **Appendix H** includes documentation of the assessment.

For this aquatic ecosystem condition analysis, the study boundaries have been expanded to include the entire watershed upstream of the dividing weir in the Ashokan Reservoir. The discharge outlet of the Shandaken Tunnel (or Portal) to Esopus Creek is thereby included in the boundaries of this analysis, and is considered reflective of watershed conditions and management actions in the Schoharie Reservoir basin. The portion upstream of the Portal is essentially a hydrologically natural river with the exception of the diversion in Birch Creek to provide water for snowmaking at the Belleayre Mountain Ski Area. Downstream of the Portal the creek is regulated subject to discharges from Schoharie Reservoir at the other end of the aqueduct. These portions of the creek are referenced accordingly in this document.

The ecosystem, as defined for this plan, includes all things living in the above described Esopus Creek watershed or using the watershed, human and non-human, and their respective habitats. However, the primary focus is on non-human biota as human elements are addressed elsewhere in this management plan, and especially on the fishery. Historical and ongoing Esopus Creek ecosystem reports, data sources and other resources are used as the basis of this inquiry. The intended audience of this discussion is the general public. Supporting documentation can be found in **Appendix H** on the attached bullet point summary and appended listing of those resources, certainly not exhaustive but thought to include the majority of available data.

3.3.2 Discussion

Major Habitat Zones

This study considers the Upper Esopus Creek watershed as composed of four basic habitat zones. They include:

1) West Basin of Ashokan Reservoir,
2) Main stem of Esopus Creek from Ashokan Reservoir upstream to the Portal at Allaben,
3) Main stem of Esopus Creek from the Portal upstream to its source at Winnisook Lake; and finally,
4) Tributaries to the main stem Esopus Creek and the West Basin of Ashokan Reservoir.

The main stem of the creek upstream of the Portal and all Ashokan Reservoir tributaries are generally similar in function and in ways that they are used by biota. However, they are considered separately because the respective fisheries are managed separately and the water classifications and standards are different. Below is a discussion on the aquatic ecosystem organized according to these four habitat zones.

<u>*West Basin of Ashokan Reservoir*</u>

Ashokan Reservoir view from High Point Mtn, 8/05 (note Dividing Weir, West Basin in foreground). Photo Courtesy Aaron Bennett, Catskill Center for Conservation & Development

The water of Ashokan Reservoir is afforded the highest level of protection of any water in the watershed because it is drinking water and its classification and standards reflect that fact. Its fish fauna is typical of waters that support populations of both warmwater fishes (the black basses and other sunfishes for example) and coldwater fishes including trout and cisco (a member of the whitefish family). Most of the fish species are introduced and some have been maintained by stocking at different times. Their take by anglers is governed by fishing regulations specific to the reservoir.

The public is allowed controlled access to the fishery by permits issued by the New York City Department of Environmental Protection (DEP) but anglers must first be licensed to fish in New York State. Boat fishing is also permitted by DEP but the boats must be inspected, steam cleaned to prevent the introduction of zebra mussels, and left at the reservoir once they have been inspected. Boat owners must have their permits with them when on the water to fish. Wildlife in the Ashokan watershed that make use of the reservoir are typical of the Catskills and afforded the necessary legal protection there as in the remainder of the Catskills.

There are health warnings about human consumption of certain sizes and species of fish for certain human age and gender groups due to the fishes' contamination from atmospheric mercury.[4] There have been no indications of anomalies in fish or wildlife in the reservoir that would indicate the action of endocrine disrupters, but that has not been investigated.

In 2006, anglers observed Ashokan Reservoir-caught brown trout as skinny or slender, suggesting starvation. Such a condition is indicative of either an impaired feeding due to an inability to see prey fishes or to a low abundance of prey fishes. Alewives have replaced emerald shiners as the principal forage species for reservoir brown trout and other predator species within the past 30 - 40 or so years - most likely through competition for food and perhaps predation on young shiners. Alewives are also subject to extreme fluctuations in the size of their populations. Two habitat variables that cause alewife population fluctuations are severe changes in water temperature and turbidity. Turbidity causes alewives to starve for the same reason brown trout starve. Turbidity could also impair the ability of alewives to respire because they are mostly filter feeders and their gills have more filaments than most of the other fishes in the reservoir.

Habitat management is limited to impacts associated with releases from the Portal and some logging on the City property surrounding the reservoir. There is no human habitation on the banks of the Ashokan. The City has added alum to the reservoir to precipitate clays causing turbidity subsequent to four flood events. Additionally, the reservoir may have to be dredged in the future to remove accumulated sediment to increase storage capacity.

Main Stem Esopus from the West Basin of Ashokan Reservoir upstream to the Portal

[4] New York State Department of Health. 2005

Esopus Creek Downstream of Portal (Reach EC1)
Photo Courtesy of Ed Ostapczuk, Trout Unlimited

The aquatic habitat of the main stem of the Esopus Creek downstream of the Portal is regulated by releases of water via the Shandaken Tunnel. New York City utilizes the Schoharie Reservoir as a drinking water diversion reservoir – and thus sends out collected waters at the Portal, into Esopus Creek and downstream to Ashokan Reservoir. Those releases are subject to 6 NYCRR Part 670 Rules and Regulations promulgated by the New York State Department of Environmental Conservation and more recently to a SPDES permit (see Section 2.2 for more detail on these regulations), which together provide for flows, temperatures, and turbidity thresholds to protect aquatic biota. Part 670 also allows for up to four water releases of a specific magnitude each summer for whitewater recreation.

This habitat area is among the most densely populated by the human community, has easy public access, and has more human activity of all types than does the rest of the watershed area. Fishing is regulated by season, size and bag limits and is open to licensed anglers. Hunting is allowed along this part of the habitat with proper licensing and according to seasons, and bag limits. Wildlife, including mammals, birds, reptiles, amphibians, fish and invertebrates are typical of similar Catskill settings.

Water diversions from the Schoharie Reservoir through the Shandaken Tunnel vary by temperature, turbidity, velocity, and volume, and very likely have a greater impact on the biota in this part of the watershed than any other watershed factor but flooding. The portal carries cold water from Schoharie Reservoir, which is critical to sustain the trout populations downstream of the Portal, and especially critical when normal flows of water from within the Esopus watershed are too warm. Reservoir managers actively manage the water diversions to avoid depleting the cold water from Schoharie Reservoir and jeopardizing the trout population being managed in both Schoharie Reservoir and Esopus Creek.

Turbidity in the Schoharie Reservoir water flowing into Esopus Creek is an issue that water supply and resource protection agencies have devoted considerable time addressing. With the exception of impacts to Ashokan Reservoir alewives, trout, emerald shiners and walleye, turbidity has not been shown to be a problem to the non-human biota in the Esopus or the Ashokan Reservoir downstream of the Portal. It is at least aesthetically problematic and it does impact fishing however, and has been the subject of litigation over violations of water quality standards as referenced in Volume II Section 2.

Some residents of the watershed believe that turbidity has killed fish downstream of the Portal or that it has affected reproduction of fishes. Embeddedness and siltation - impacts of sedimentation and turbidity - may be a problem for some macroinvertebrates and interstitial-dwelling fishes such as sculpin because it limits available habitat. Embeddedness may also make it difficult for trout to dig their redds (nests), and may reduce oxygen supply to deposited eggs. Fish reproduction, trout reproduction at least, does not seem to be an issue as there is no lack of trout in this part of the watershed. There have been no studies to determine the impacts of Esopus turbidity on the fish population, if any.

The response of biota to the habitat in this section of the watershed is reflected in the organisms that inhabit it.

- Zooplankton are four times as abundant immediately downstream of the portal than they are immediately upstream, but only when the Portal is releasing. Those animals are entrained from the water column at the Shandakan Intake in Schoharie Reservoir and are transported to Esopus Creek by the Shandaken Tunnel.

Portal – delivering Schoharie Reservoir water to Esopus Creek

- The characteristics of the aquatic insect population around the Portal vary from year to year and by season, and are thought to be a reflection of the releases. During years with higher flows there appears to be an abundance of net building caddis flies below the Portal, compared to a much lesser representation a short distance upstream of the Portal. Those caddis flies are probably feeding on the zooplankton coming out of the Portal.
- Trout, especially rainbow trout, are more abundant in the downstream section of the Esopus and they grow faster than their siblings in the upstream section (probably resulting from cooler water and or more food.)
- The substrate of the Esopus is more embedded (the spaces between the larger material making up the stream bottom is filled in with smaller material)

downstream of the Portal than upstream, and during normal periods of surface runoff the main stem Esopus may be more turbid than main stem Esopus upstream, depending upon water clarity of the diverted water and condition of tributary inflows (especially Stony Clove, Woodland Valley and Broadstreet Hollow). Reasons for the differences in embeddedness are unknown.

Opportunities for habitat management in this part of the Esopus are clearly evident in management of releases to optimize flows to accommodate biota. The chance to refine releases could come with construction of a newly located or similarly located new multi–level intake structure in Schoharie Reservoir or by modifying the existing system.

Esopus Creek upstream of Portal to Winnisook Lake

Upper Esopus Creek Headwaters reach
Photo Courtesy of Ed Ostapczuk, Trout Unlimited

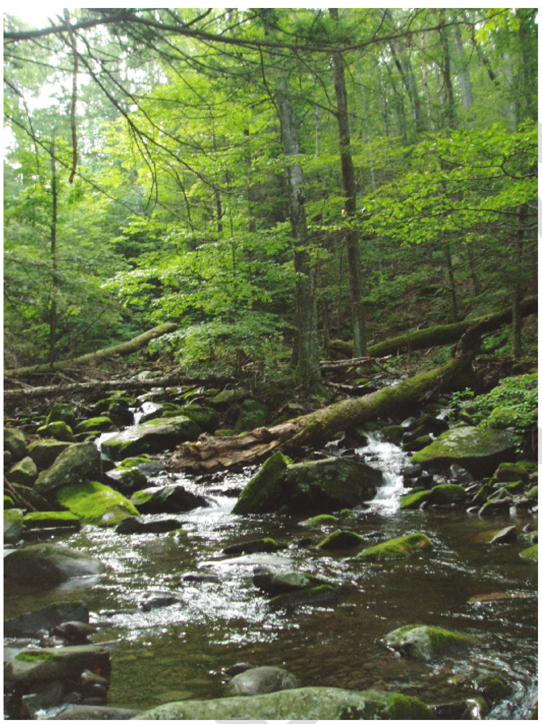
Except for water withdrawals from Birch Creek for snowmaking and the discharge from a waste water treatment plant to the main stem at Pine Hill, the flows of Esopus Creek are unregulated from the Portal upstream to the source at Winnosook Lake. Flows are not augmented by any releases of significance and flows are largely made up of surface runoff and ground water.

The habitat in that section of the river is however impacted by road encroachment, crossings and runoff, and disruption of riparian vegetation, similar to the same perturbations downstream. There are areas accessible to the public, although perhaps not as accessible as the downstream main stem. Boating and tubing are not issues for this reach or the tributaries, although there is a clear run on the main stem from the source at private Winnosook Lake to the Ashokan Reservoir.

Some comparisons of instream biota relative to the Portal were made in the previous section. The fish fauna gets very sparse in the headwaters of the main stem Esopus, as it does in the tributary headwaters and way upstream is limited to brook trout, the only native salmonid in the system. During the summer, flows get low and warm, and trout are dependent on cool ground water emerging as spring seeps for survival. Water from those seeps exits the ground year round at a temperature that is close to the average annual air temperature of the watershed, generally somewhere between 50 and 60 degrees Fahrenheit (F). Wetlands along the stream and within the stream floodplain are important habitat for unique biota in their own right and are also probably very important in maintaining cool water inflow to the Esopus. Wetlands in this reach especially need further inventory and characterization.

Trout are more likely to spawn in the upper main stem of the creek than downstream since the stream bed is not as embedded and it is easier for trout to dig their redds. Additionally the flows are more moderate. Macroinvertebrate samples have generally indicated good water quality in this section of the stream, as they did downstream of the Portal. Upstream of the Portal the Esopus runs through a relatively wide valley, often in a braided channel. The lower water velocities associated with braided channels may provide favorable habitat for macroinvertebrates and may be used by trout for spawning.

The Esopus Tributaries



Tributary in Upper Esopus Creek Watershed.
Photo Courtesy of Ed Ostapczuk

Except for Birch Creek, mentioned previously, the tributaries of Esopus Creek, and other watershed tributaries that drain directly to Ashokan Reservoir are unregulated. They are certainly not all similar, nor as publicly accessible as the rest of the watershed. However, they do generally support biota that are representative of the watershed and reflect good water quality. Birch Creek, Fox Hollow, Broadstreet Hollow, Woodland Valley and Stony Clove have been identified as being turbid at times and contributing to the turbidity of the main stem Esopus. Stream restoration including habitat improvement has been done on Broadstreet Hollow and Stony Clove, with mixed results in increasing numbers of fish and pounds of fish biomass.

By the presence of fingerlings, trout have been shown to spawn in the majority of the tributaries to Esopus Creek. Spring seeps are extremely critical for trout survival in the tributaries during the Summer and early Fall. Those same seeps may be important for trout spawning as the water temperatures there are warmer than the flowing stream during the winter (about 50-60 degrees F compared to about 32 or 33 degrees F).

Public use for recreation is least in the tributaries among the four habitat zones. The tributaries to the Ashokan Reservoir, partly on City property, may provide good controls for future studies in that they can be made inaccessible to the public and therefore undisturbed.

3.3.3 Conclusions

Aquatic ecosystem variability in the Esopus Creek system is thought to be largely a function of the water flow (velocity and volume), water temperature and turbidity. Except for trout, walleye, emerald shiner and alewives, the non-human natural resources of the watershed appear to be doing well with conditions as they have existed from as far back as the supporting documentation goes. Despite frequent extreme changes in flows, either natural or the result of changes in the amount and quality of water released from the Portal, the populations of animals that were the subjects of the reported studies appear to be doing well. That is not to say that extreme changes in environmental conditions do not wreak havoc on populations of animals that are restricted to the aquatic environment. It may be that the subjects of most of the studies are generally short lived to begin with and their populations are able to rebound quickly after catastrophic changes in their respective habitats. Some fish sampling showed losses of year classes of one species due to flooding and it is expected that cold water fish populations in the Esopus upstream of the portal and in the tributaries were greatly diminished during the drought of the 1960’s for which there does not seem to be many (or any) references.

Esopus Creek brown trout
Photo Courtesy Ed Ostapczuk

The poor condition of reservoir trout has been previously discussed as it relates to forage of alewives and other species. The same problems effecting trout are impacting the alewife population. Walleye young have been decimated by predation from alewives. Alewives are also thought to have caused the loss of the large emerald shiner population, probably shortly after they became established in the reservoir, either through competition for food or predation of young shiners by alewives.

Key Management Issues

The following key management issues regarding the aquatic ecosystem condition of the upper Esopus Creek watershed, including the four habitat zones described above, have been identified:

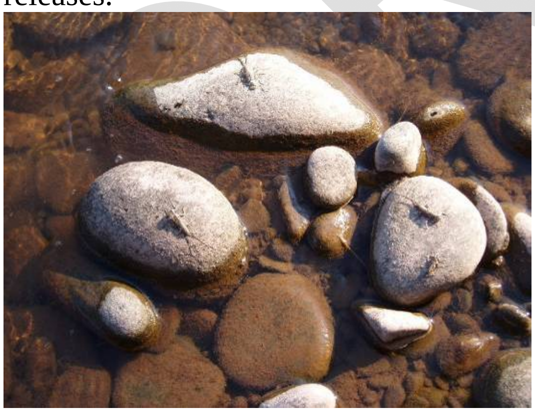
- Turbidity in Ashokan Reservoir

As reflected or suggested by the biota of the four habitat zones described above, only the West Basin of the Ashokan Reservoir has serious habitat problems. The emaciated condition of larger, fish eating trout caught by anglers suggests that the trout are unable to feed efficiently. It follows that either trout prey is scarce or the trout can't capture prey because they can't see the prey fish. Whatever the status of the alewife population, turbidity is blamed for the poor condition of reservoir trout. Turbidity also likely surpressed the alewife numbers since alewives are mostly filter feeders and derive their nourishment from zooplankton (which in-turn feeds on suspended algae which requires light to photosynthesize). Turbidity seriously limits light penetration in the water column and will stop the food chain at its source if it persists long enough and seriously prohibits light penetration.

Any turbidity reductions in the reservoir would be expected to improve the growth of trout in the reservoir. Options being investigated by DEP to improve water quality at the Schoharie Reservoir intake may help to minimize turbidity although there is evidence that it is the large storm events that seriously contribute to the turbidity load in Ashokan Reservoir and that require the addition of alum by the City. Those same options, structural or operational or both, are designed to deliver clearer cold water when it is needed for trout during the warm months of the year and should help maintain the large population of young, wild trout in the main stem Esopus downstream of the Portal.

- <u>Cold water discharge from the Shandaken Tunnel</u>

Structural and operational alternatives currently being considered by New York City and the U.S. EPA may allow for the fine tuning of releases helping to optimize habitat for aquatic biota, particularly water temperature as it relates to the needs of trout. The gates at the Shandaken Tunnel intake on Schoharie Reservoir could be operated so as to mimic the natural temperature variation in the stream both daily and seasonally. Such operation could extend the cold water reserves to protect the trout in Schoharie Reservoir. In any circumstances, target water temperatures must be determined and used to help in operating the system. Those target temperatures would then have to be related to temperature and volume of flow in the stream at the Portal and releases made accordingly, obviously taking into account travel time of water in the aqueduct. The habits of trout and other fish, during the day and seasonally during the hot months of the summer and early fall, will need to be known for Esopus Creek to effectively refine the releases.



Stoneflies in Esopus Creek. Photo Courtesy of Ed Ostapczuk.

Additionally, habitat suitability curves for certain target species, particularly trout, will have to be factored into the formula to refine release operation. Fortunately, habitat suitability curves have been developed for some key Esopus creek species but they can certainly be refined as more is learned of the needs and habits of the Esopus Creek biota.

As humans are the biggest users of the ecosystem services provided by the Esopus, human needs must be considered in modeling releases, both the operation of releases and any structural modifications made to provide those releases. The aspects of releases to be considered are temperature, turbidity, velocity and volume. Those variables must be considered in the light of transfer of water between reservoirs by the City, recreational use of the creek, habitat for the biota of the Esopus and the Ashokan Reservoir and impacts on the floodplain as they regard streamside property owners and infrastructure.

- Cold water sources upstream of the Shandaken Tunnel and in tributaries

Cold water in the main stem of Esopus Creek and in the tributaries must be protected to maintain the trout in those parts of the watershed. During the warm months of the summer there is no relief to those trout provided by any releases and the spring seeps must be identified and protected. Brook trout, the only native salmonid in the system exist primarily in the extreme upper headwaters of the main stem Esopus and in the headwaters of the tributaries, sometimes as the only fish species. They need cooler water than either of the other trout species and again, that cold water only comes from spring seeps.

- Wetlands and other habitats

Wetlands along the stream and within the stream floodplain are important habitat for a unique biota in their own right and are also probably very important in maintaining cool water inflow to the Esopus. Only aerial inventory and no field inventory have been conducted to date. Thus wetlands that may eligible for additional regulatory protections have not been identified.

Upper Esopus Creek Backwater flood channel, floodplain, and wetland complex proximate the Zen Environmental Studies Institute, November, 2006.

3.3.4 Recommendations

Potential studies or activities that would enhance understanding of the system and future management actions are outlined below.

Aspects of the following principal habitat management options serve as a basis for the need to know more:

- Protection of Habitat and Biota through application of laws.
- Regulation of quantity and quality of water flow.

- Alteration of stream bed and banks.
- Introduction or removal of biota.

Habitat Management

The key study to the enhancement of the Esopus Creek ecosystem is the modeling of releases from Schoharie Reservoir through the Shandaken Tunnel. Modeling must accommodate New York City water delivery needs, the habitat needs of trout and other biota, and flow needs or tolerances for fishermen, canoers, kayakers and tubers. It must also take into account temperature, turbidity, velocity and volume as they relate to property owners in the flood plain and the other biota in the stream. Modeling results may be applied to discharge criteria and inform future iterations of current operating regulations (Part 670 and SPDES), and might be considered relative to design and placement of intake and release structures. Application of a release model would affect the ecosystem downstream of the portal directly and the remainder of the watershed indirectly.

Paul Rush of NYCDEP
Presentation to PAC on Shandaken Tunnel operations 12/3/05.

The recent development of the OASIS model and Operational Support Tool has expanded the ability to optimize water quality and quantity delivery throughout the West-of-Hudson watershed. These models may further improve the capability to deliver water relative to biota and stakeholder needs.

The location and protection of spring seeps is essential for trout. Ground water provides thermal refugia for trout in the summer and may also provide trout spawning habitat. Any activity along the banks or in the main stem Esopus or its tributaries, for example placement of stormwater culverts, could compromise those refugia. Spring seeps need to be inventoried and characterized (mapped and described by discharge, pH and oxygen content). Spring seep thermal refugia are most important for trout in the main stem Esopus upstream of the portal and the tributaries, but are also critical in the main stem downstream of the portal when the temperature of water releases approach trout tolerance for warm water.

Wetlands along the main stem of the Esopus have not been adequately inventoried and studied to date. Wetlands are especially critical, in their own right, for specific plants and animals and are also very important in their relationship to spring seeps. Some wetlands along Esopus Creek tributaries have been studied.

Biomonitoring

Monitoring of biota, plant and animal, is key to determining the success of habitat management actions. Monitoring strategies must be standardized and monitoring must be representative of the ecosystem in time and space. Biomonitoring will initially require an assimilation of standardized base line data.

Electrofishing on Stony Clove Creek, Summer 2006

Collaboration

Collaboration of governmental, non-governmental scientists with private contracts, and citizen scientists is mandatory for the effective, efficient and standardized collection and analysis of meaningful ecosystem data. Ongoing collaboration is needed to develop and standardize strategies for collecting and analyzing data. Data collection and analysis will be needed to establish baselines and to ultimately monitor the success of habitat management actions. Findings from analysis of biomonitoring data must be shared, as must the data.

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5.0 GLOSSARY

[Taken from the Stony Clove Stream Management Plan. There may be terms in here that are not used in this document.]

Aggradation - The process by which streambed elevation is raised by the deposition of material (sediment) eroded and transported from other areas. The opposite of degradation.

Alluvial Channel - A channel developed in sediment transported and deposited by a stream.

Alluvial Fan - A fan-shaped deposit of alluvium found where a stream flows out of a mountain stream onto flat terrain at the base of a mountain. The sudden decrease in stream velocity causes deposition. Alluvial fans are often found at the confluence of a steep stream with a flatter one.

Alluvial Features – Landforms and stream bed forms created by rivers, such as floodplains and gravel bars.

Alluvium - Sediment transported and deposited by streams, often rounded by the action of rolling and bouncing, especially against other grains (abrasion).

Angle of Repose - The maximum slope at which unconsolidated material remains stable.

Anthropogenic - Human caused or influenced.

Aquatic Habitat - The physical aquatic environment (and immediately surrounding terrestrial environment) that meet the necessary biological and physical requirements of fish species during various life stages. Physical attributes of the stream channel and riparian area that are important to the health of all or some life stages of fish, aquatic insects and other stream organisms. Attributes include water quality (temperature, pH), riparian vegetation characteristics (shade, cover, density, species), stream bed sediment characteristics, and pool/riffle spacing**.**

Armoring - Natural armoring is the formation of a resistant layer of relatively large particles resulting from removal of finer particles by erosion. Also, this term is used for anthropogenic placement of large rock or other materials (e.g.., rip-rap, sheetpiling) to protect a stream bank from erosion by hardening.

Artesian Spring – An artesian spring is created when groundwater in a confined aquifer is pushed out through faults or cracks in the overlying impervious layer on to the surface under pressure. Water from an artesian well or spring is usually cold and free of organic contaminants, making it desirable for drinking. Artesian conditions can be associated with sand or other layers within glacial lake (lacustrine) clay deposits.

Avulsion - A rapid change in channel location, when a stream suddenly breaks through its banks and creates a new channel. Typically, an avulsing stream bisects an overextended meander arc creating an “oxbow cutoff” in the old channel.

Backeddy Scour - Erosive action of water in streams by excavating and transporting bed and bank materials downstream (scour) specifically caused by the swirling of water and the reverse current created when water flows past an obstacle (backeddy). This type of scour is most commonly seen downstream from bridges, though can be seen upstream as well.

Backwater - Condition in which the water surface elevation is raised by downstream flow impediments or constriction.

Backwater Effect - The effect that a dam, bridge or other obstruction has in raising the surface of the water upstream from it.

Bank - The elevated ground bordering a lake or river, or forming the edge of a cut or hollow. Most often banks are left elevated following erosive formation of stream channels or lakes.

Bank Erodibility Hazard Index (BEHI) - An index for predicting erosion potential on selected stream banks, usually associated with a monitoring cross-section for measurement of actual erosion rates over time (Rosgen, 1996).

Bank Height Ratio - The ratio of height of bank to bankfull height, used in stream assessment to determine whether a stream is stable – bank height and bankfull height will be the same in a stable stream (BHR = 1.0).

Bankfull (Bankfull Discharge, flow) - Commonly equated with the channel-forming flow or effective flow; that flow which over time maintains the form of the channel by transporting the majority of the sediment load. In certain types of streams, this discharge is most easily identified as associated with the condition of incipient flooding which occurs when water just begins to leave the channel and spread onto the floodplain (FIWG, 1998). Typically recurs every 1-3 years.

Bankfull Stage - The elevation of the water surface at bankfull discharge.

Bar (mid-channel, point, side, lateral, etc.) - A location within the stream channel in which sediment accumulates occupying a significant portion of the channel and composed of more of the larger sediment available for transport (i.e., a gravel-bedded stream typically has gravel bars rather than sand bars, though fine sediments can comprise other localized depositional features).

Base Flow - The sustained low flow of a stream, usually resulting from groundwater inflow to the stream channel between surface water runoff from storm events or snow melt. Summer base flow is typically lower than winter base flow due to increased demand for water by growing vegetation.

Bed Material - The composite mixture of substrate of which a stream bed is composed.

Bed Roughness - A measure of the irregularity of the streambed as it contributes to flow resistance, commonly expressed as a Manning's "n" value.

Bedload - The amount (volume, weight and/or rate) and size distribution of stream bed material or substrate that is mobilized by tractive and force measured or calculated at a specified discharge and is transported by bouncing, rolling or sliding on the bed layer of the stream. Contrast to Suspended Load.

Bedrock - the solid rock or geologic surface underlying unconsolidated surface materials (e.g., water, soil, alluvium).

Belt Width - The distance between lines drawn tangential to the extreme limits of fully developed meanders, typically in a down-valley direction. That width to which meanders would extend if allowed to develop.

Berm - A mound of earth or other materials, usually linear, constructed along streams, roads, embankments or other areas. Berms are often constructed to protect land from flooding or eroding, or to control water drainage (as along a road-side ditch). Some berms are constructed as a byproduct of a stream management practice whereby stream bed sediment is pushed out of the channel and mounded on (and along the length of) the stream bank - these berms may or may not be constructed for flood control purposes; some are simply piles of excess material (sidecast). Berms often interfere with other stream processes such as floodplain function, and can exacerbate flood-related erosion or stream instability.

Bioengineering - The use of live vegetation, either alone or in combination with harder materials such as rock or (dead) wood, to stabilize soils associated with stream banks or hillslopes. Roots stabilize the soil, while stems, branches and foliage slow high velocity water, reducing erosion and encourage deposition of fine sediment.

Boulder - A large substrate particle that is larger than cobble, with b-axis diameter between 256 - 4096 mm.

Bridge Scour - (also bridge pier scour, bridge abutment scour) Excessive erosion of stream banks and bed under a bridge as a result of the concentration and direction of stream flow.

Bridge Scour Depth - The calculated depth at which the streambed and substrate will mobilize and be transported during channel forming flows (or larger modeled flows or floods). Used to determine safe design depth at which to place footings and stable keyways in streambeds that are not expected to erode or be undermined.

Buffer Zone/Strip/Area - (also Riparian zone etc.) An area of permanent vegetation between waterways and adjoining land uses that functions to intercept and filter out pollution before it reaches the surface water resource, slow flood waters allowing groundwater recharge and flood peak attenuation and fine sediment deposition, and provides bank stability from root strength. Typically, activities such as agriculture or other development are restricted in these areas to protect water quality and stream stability and sometimes for ecology.

Cascade – A relatively short, steep drop in streambed elevation often marked by boulders and agitated white water. Typically a cascade is formed by a series of steps in rapid succession without fully formed pools in-between.

Central Bar - A bar found in the mid-channel zone, not extending completely across the channel or touching either bank.

Channel - An area containing continuously or periodically flowing water that is confined by banks and a bed.

Channel Cross-section - The physical measurements (width X depth) across the channel and floodplain perpendicular to flow direction, typically measured or estimated for a selected stage or flood size or recurrence interval.

Channel Forming Flow - See Bankfull.

Channel Migration - Lateral or longitudinal (down-valley) migration of the stream channel within the valley by the process of erosion and deposition.

Channel Pattern - The meander geometry of the channel within its active floodplain, readily visible from a top-down view of the channel.

Channel Profile (or longitudinal profile) - The plot of the stream bottom elevation (and often the water surface, bankfull and valley elevations) longitudinally along the stream. The change in bottom elevation over distance is called Channel Gradient.

Channel Scour - The erosive action of water and sediment that removes and carries away bed and bank material.

Channel Slope (or Channel Gradient) - The inclination of the channel bottom, measured as the elevation drop per unit length of channel.

Channelization – The modification of a natural river channel; may include deepening, widening, straightening, or altering of the slope, to accelerate conveyance or increase drainage of wet areas. Often referred to as hydromodification.

Cobble – Substrate particle that are smaller than boulders and larger than gravels, and are generally 64 - 256 mm. in diameter.

Colluvial features – Landforms that are not well developed by the river. Sediments are typically angular and jagged.

Confluence - The meeting or junction of two or more streams, each with its own watershed.

Convergence – The downstream end of a split channel, where the stream merges back to one channel; the two channels having the same watershed.

Conveyance - Continuous transport of water.

Corridor - The area of land along a stream between the valley walls including floodplains, riparian areas, and terraces.

Critical Shear Stress - The minimum amount of shear stress required to initiate substrate particle motion along the stream bed or banks.

Cross-section (see also monitoring cross-section) – In the context of stream assessment surveys, a cross-section is a location on a stream channel where stream morphology is measured perpendicular to the stream flow direction (as if taking a slice through the stream), including width, depth, height of banks and/or terraces, and area of flow.

Cross-sectional Area - The area of cross-section below the water surface perpendicular to the direction of flow.

Cross vane – A type of rock vane used to provide grade control, to keep the thalweg in the center of the channel, and to protect the bank. A cross vane consists of two rock vanes and one center structure perpendicular to the flow. This center structure sets the invert grade of the streambed. Therefore, this structure can be used to raise the bed and is often used at the head of a riffle to set the elevation of the upstream pool.

Culvert – A closed conduit for the free passage of surface drainage water. Culverts are typically used to control water running along and under the road, and to provide a crossing point for water from road side drainage ditches to the stream, as well as for routing tributary streams under the road to join the Stony Clove Creek. Culverts are also used by landowners to route roadside drainage ditch water under their driveways to reduce or prevent erosion.

Degradation (see also downcutting) - The process by which streambeds and floodplains are lowered in elevation by eroding downward into the stream bed over time. Often an indicator that the stream's discharge or sediment load is changing, by periodic episodes of bed scouring without filling, or by longer term transport of sediment out of a reach without replacement. A degrading stream will typically show a bank height ratio greater than 1.0. The opposite of Aggradation.

Demonstration Stream Restoration Project (demonstration project) – A stream (stability) restoration project that is designed and located to maximize opportunities for monitoring of project success, public and agency education about different stream restoration techniques, and interagency partnerships funding and cooperation.

Deposition - Accumulation of sediment on the channel bed or banks.

Destabilized (see also instability, unstable) – Describing a section of stream that has been made unstable, by natural or human activity.

Discharge (stream flow) – The amount of water flowing in a stream, measured as a volume per unit time, usually cubic feet per second (cfs).

Discontinuous floodplains (see also floodplain) – A series of small floodplains, formed as a series of small benches along stream banks. These floodplain features, typically seen in steeper mountain streams, are not connected sequentially following the valley floor, but still provide the critical floodplain functions of reducing water velocity and enhancing sediment deposition and infiltration (water sinking into the ground rather than running straight to the stream).

Dominant Channel Materials – A selected particle size index value, the D50, representing the most prevalent of one of six channel material types or size categories, as determined from a channel material size distribution analysis.

Dominant Discharge - A channel forming discharge that, if maintained indefinitely, would produce the same channel geometry as the natural long-term hydrograph. The dominant discharge concept is applicable to stable, alluvial streams (i.e., streams that have the ability to change their shape but are neither aggrading nor degrading).

Downcutting – See degradation

Drainage Area/Drainage Basin – See watershed

Dry Ravel - The downhill movement of soil and debris during dry periods, caused by gravitational forces.

Dynamic Equilibrium - The state at which the channel exhibits patterns of erosion and deposition but there is not net change in the input and output of materials. Considered stable, but over time the features and location of the channel within the valley will change.

Eddy - A circular current or a current of water running contrary to the main current, usually resulting from an obstruction.

Effective Discharge - The discharge that transports the largest fraction of the annual sediment load. The effective discharge results in the average morphologic characteristics of a channel and at which channel maintenance is the most effective.

Embankment – A linear structure, usually of earth or gravel, constructed so as to extend above the natural ground surface. Similar to a berm, but usually associated with road fill areas, and extending up the hillside from the road, or from the stream up to the road surface.

Embeddedness - The degree to which the coarse channel bed materials (boulders, cobble, gravel, sand) are surrounded or covered by fine sediments, usually measured as percent coverage by finer sediments.

Entrainment - One of three distinct processes involved in erosion. The process of lifting or mobilization of a sediment particle by stream flow.

Entrenchment – A vertical description of the stream that has eroded downward or was constructed such that it no longer has access to its original floodplain during moderate flow events. Flood flows in an entrenched stream are contained within the stream banks or adjacent terraces. Flood flows in a stream that is not entrenched are spread out over a floodplain.

Entrenchment Ratio - The ratio between the flood-prone width and the bankfull width. This ratio is used as a part of Rosgen stream classification system to determine stream type. For example, if this number is less than 1.4, the stream is said to be highly entrenched, if between 1.4 and 2.2 it is mildly entrenched, and greater than 2.2 it is not entrenched. Entrenchment ratio is used with other stream shape data to determine stream type, and define baseline data for future monitoring (Rosgen, 1996).

Ephemeral Stream - A water course that is usually dry but sporadically contains stream flow, typically during significant rain or snowmelt events.

Equilibrium (see also stable) – The degree to which a stream has achieved a balance in transporting its water and sediment loads over time without aggrading (building up), degrading (cutting down), or migrating laterally (eroding its banks and changing course).

Erosion – The wearing away of the land surface by detachment and movement of soil and rock fragments during a flood or storm or over a period of years through the action of water, wind, or other geologic process. In streams, erosion is a natural process, but can be accelerated by poor stream management practices.

Erosion Potential – The amount of erosion that may be expected under given climatic, topographic, soil, and cultural conditions.

Fascines – A bioengineering method using bundles of small branches of willow or other riparian tree/shrub species, tied together and laid into shallow trenches along a stream to stabilize and revegetate stream bank areas.

Fill - Soil or other material placed as part of a construction activity. Often used to raise the ground level of a floodplain or wetland to make it suitable for construction or other human activities.

Flood - The temporary inundation of normally dry land areas resulting from the overflowing of the natural or artificial confines of the stream channel.

Flood Attenuation - To lessen the amount, force or severity of high flows.

Flood Peak - The highest value of stage or discharge achieved by a flood. Flood crest is equivalent to peak stage.

Flood Stage - The gage height at which the stream begins to overflow its banks.

Floodplain – A relatively flat alluvial feature adjacent to the stream channel that is formed during the present climate and receives flood flows. The floodplain usually consists of sediment deposited by the stream, in addition to riparian vegetation. The floodplain acts to reduce the velocity of floodwaters, increase infiltration (water sinking into the ground rather than running straight to the stream - this reduces the height of the flood for downstream areas), reduce stream bank erosion and encourage deposition of sediment. Vegetation on floodplains greatly improves their functions.

Floodplain Bench - A small level area that forms at the effective discharge stage within an over-wide, entrenched channel.

Floodplain Connection - The stream's ability to access the land area adjacent to its active channel during higher flows in order for the stream system to function properly and dissipate energy or velocity.

Floodplain Drainage – The use of culvers under bridge approaches to allow overbank flows to pass from the upstream floodplain to the downstream floodplain.

Flood-Prone Area - A term coined by Rosgen (1996) to describe the area flooded at flows twice the maximum depth of flow at the effective discharge.

Floodway - The stream channel and those parts of the floodplain adjoining the channel that are required to carry and discharge the floodwaters or flood flow of the stream.

Fluvial - Relating to a stream or river; produced by stream action.

Fluvial geomorphology - The study of the formation of landforms by the action of flowing water.

Function - The physical, chemical and biological processes, services and values that occur in an ecosystem (e.g., floodplain, stream, wetland) as a result of their structure and composition.

Gabions – Large wire-mesh baskets filled with rock material used to harden or stabilize road embankments and sometimes stream banks.

Gaging Station - A particular point on a stream of known cross-section where systematic observations of water depth or discharge are obtained.

Geographic Information System (GIS) - Desktop software with a graphical user interface that allows loading and querying, analysis and presentation of spatial and tabular data that can be displayed as maps, tables and charts. The maps in the Stony Clove Creek stream management plan were produced with a GIS, and can be updated as new information becomes available.

Geologic Control - A local rock formation or clay layer that limits the vertical or lateral movement of a stream at a particular point.

Geomorphology - The branch of geology that studies the nature and origin of land forms. The natural forces that shape landforms include water, ice, wind, gravity and time.

Geotechnical Failure - Stream bank failure collapse or slippage of a large mass of bank material into the channel caused by stream bank soil and rock properties, including seepage and piping.

Glide - Shallow, low gradient stream sections with slow current and fine substrate.

Global Positioning System (GPS) - A satellite based positioning system operated by the U.S. Department of Defense (DOD). When fully deployed, GPS will provide all-weather, worldwide, 24-hour position and time information. The stream feature inventory completed for the Stony Clove Creek stream management plan used a GPS unit to document the locations of all mapped stream features. This information was added to the GIS to produce the maps.

Gradient - The rate of change in (vertical) elevation per unit of horizontal distance.

Grading - Term used to denote the variability and distribution of sediments and bed materials. A well-graded material will be sorted by size. A poorly-graded material will consist of a single sediment size or all size materials uniformly mixed.

Gravel – Substrate particle that are smaller than cobbles and larger than sands, that and generally measures between 2 - 64 mm. in diameter.

Hardening – Any structural revetment that fixes in place an eroding stream bank, embankment or hillside by using hard materials, such as rock, sheet piling or concrete, that does not allow for revegetation or enhancement of aquatic habitat. Rip-rap and stacked rock walls are typically considered to be hardening measures, though some revegetation of these areas is possible.

Headcut – A marked change in stream bed slope, as in a step or waterfall, that is unprotected or of greater height than the stream can maintain.

Headcutting - The process by which the stream is actively eroding the streambed downward (degrading, incising, downcutting) to a new base level. Because of the resultant high gradient change, this erosional action progresses upstream. Often suggests adjustment to changing stream hydrology or sediment load.

Headwater– the uppermost portion or beginnings of a stream**.**

Hydraulic - Relating to the flow or conveyance of water through a channel; movement or action caused by water**.**

Hydraulic Gradient - The change in hydraulic head over some specified distance.

Hydraulic Jump - Abrupt, turbulent, noisy transition from super-critical flow to sub-critical flow. Entrains air into the stream.

Hydraulic Radius - Cross-sectional area divided by the wetted perimeter.

Hydrograph - A graph showing flow, stage, velocity or discharge with respect to time, for a given point in the stream.

Hydrology - The study of the properties, movement and behavior of water on the land surface and under ground.

Hydro-morphological Units (HMUs) – The physical character of a stream shaped by the movement of water through the channel (riffle, rapid, cascade, run, fast run, pool, plunge pool, glide, side arm, ruffle, backwater).

Hydrostatic Pressure - Force caused by water under pressure

Impairment - Impact that damages the biological integrity of a water body such that attainment of the designated use is prevented.

Impervious Surface - Surfaces, such as roads, parking lots and roofs, whose properties prevent the infiltration of water and increase the amount of stormwater runoff in a watershed.

Impoundment - A body of water, such as a pond, lake or reservoir, formed by confining a stream or other surface flow.

Inboard – Referring to a roadside ditch that is between the road and adjacent hillside, on the higher or uphill side of the road.

Incised Channel (Incision) - A stream that, through degradation, has cut its channel into the bed of the stream valley. See entrenchment and degradation.

Infiltration - The downward movement of water through soil or porous rock.

Instability (see also unstable) - An imbalance in a streams capacity to transport sediment and maintain its channel shape, pattern and profile.

Intermittent Stream - A stream that flows periodically or seasonally, and is dry part of the year.

Invasive Plants – Species that aggressively compete with and replace native species in natural habitats.

Japanese Knotweed (*Polygonum cuspidatum*), (see also invasive plants) – An invasive plant, not native to the Catskill region, that colonizes disturbed or wet areas, especially stream banks, road-side ditches and floodplains. This plant out-competes natives and other beneficial plants, and may contribute to unstable stream conditions.

Joint Planting – The insertion of live stakes into the soil, in the spaces or joints, between previously placed rip-rap rocks. When placed properly, the cuttings are capable of rooting and growing.

Keyed-in – Refers to tying the ends of a structure into the bank to prevent water from going behind it.

Knick-point – A usually less erosive material, such as bedrock or a fallen log that creates an abrupt change in the longitudinal profile of a stream and controls the streambed elevation, slowing downstream erosion of the stream channel and the upstream migration of a headcut.

Lateral Migration - The movement of a channel across its floodplain by bank erosion. The outside banks of meanders move laterally across the valley floor and down the valley.

Laterally unstable channel – a channel which prone to short-term, side-to-side migration across a floodplain; symptomatic of undeveloped or depleted riparian vegetation.

Leaching – The process by which chemical or mineral materials are removed from a physical matrix (such as soil, or mixed sediment materials) by water running through and creating a solution of those chemicals.

Left Bank – The left stream bank as looking or navigating downstream. This is a standard used in stream assessment surveys.

Live Stake – Live branch cuttings that are tamped or inserted into the earth to take root and produce vegetative growth

Macroinvertebrates - Stream-dwelling arthropods (insects, crustaceans) without a backbone that can be viewed without magnification. Examples include crayfish, leeches, water beetles and the larva of dragonflies, caddisflies, and mayflies. Macroinvertebrates are an important food source for many species of fish.

Mainstem - The common outlet or stream, into which all of the tributaries within a watershed feed.

Manning's "n" - Manning's n-value is a coefficient used to describe boundary roughness of a channel or pipe. "n" incorporates the roughness of the bed material, vegetation, bends, junctions and other irregularities.

Mass Wasting - Large slope failures associated with downcutting stream channels and undermined support of steep slopes. Contrast to Rotational Failure (global) or Bank Erosion.

Meander - Bend or curve in a stream channel.

Meander Belt - The area between lines drawn tangential to the extreme limits of fully developed meanders. The meander belt width is the distance between the tangential lines marking the extremes of successive meanders, measured normal to the downvalley progression of the stream. Meander length is the distance between corresponding points in two successive meanders, or twice the distance between crossover or inflection points.

Meander Width Ratio - The quantitative expression of confinement (lateral containment of rivers) and is determined by the ratio of belt width/bankfull width.

Meandering Stream - A stream characterized by a clearly repeated pattern of meanders as seen from above.

Mitigation - To alleviate, or compensate for, the impact of environmental degradation, often through replacement of lost ecological functions or values at a nearby location.

Monumented – Refers to a location, usually a cross-section, that is marked with a permanent or semi-permanent marker, or “monument”, to enable future monitoring at the same place.

Morphology - The form (dimension, pattern and profile) and structure of the stream channel.

Multiflora Rose (Rosa multifora), (see also invasive plants) – An *invasive plant*, not native to the Catskill region, that colonizes disturbed or wet areas such as fields, forest edges, stream banks, and roadsides. This plant spreads quickly and forms impenetrable thickets that exclude native species. It impedes succession and out competes other plants for soil nutrients.

Native Vegetation - Vegetation indigenous to an area and adapted to local conditions.

Non-Point Source - Extensive or disperse source of pollution. Examples include agriculture, lawns, parking lots and septic systems.

Nutrient – The term "nutrients" refers broadly to those chemical elements essential to life on earth, but more specifically to nitrogen and phosphorus in a water pollution context. In a water quality sense nutrients really deal with those elements that are necessary for plant growth, but are likely to be limiting -- that is, where used up or absent, plant growth stops.

Old Fields - Cultivated lands that have been abandoned, and are in the process of gradual succession to a forested ecosystem.

Oxbow - A cut off and abandoned meander of a river.

Particle Size Distribution - See Substrate Analysis.

Pathogen – Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Peak Flow - The highest discharge achieved during a storm event.

Pebble Count - Method for determination of the size distribution of channel bed materials.

Perched - To stand, sit, or rest on an elevated place or position. If a tributary is perched at its confluence with the mainstem, it may suggest incisement, or a drop in the stream bed elevation, of the mainstem

Perennial Stream - A stream that normally contains flowing water at all times regardless of precipitation patterns.

Pinch Point - A narrowing can be caused by valley form or infrastructure encroachment.

Piping - is caused by groundwater seeping out of the bank face. Grains are detached and entrained by the seepage flow (also termed sapping) and may be transported away from the bank face by surface run-off generated by the seepage, if there is sufficient volume of flow. Piping is especially likely in high banks or banks backed by the valley side, a terrace, or some other high ground. In these locations the high head of water can cause large seepage pressures to occur. Evidence includes: pronounced seep lines, especially along sand layers or lenses in the bank; pipe shaped cavities in the bank; notches in the bank associated with seepage zones and layers; run-out deposits of eroded material on the lower bank. Note that the effects of piping erosion can easily be mistaken for those of wave and vessel force erosion (Hagerty, 1991a,b).

Planform - Horizontal stream pattern, including, sinuosity, meander radius, and belt width, as viewed from above. Stream planform can be developed from aerial photographs.

Point Bar – A depositional feature with coarse material - usually sand or gravel - caused by a decrease in sediment transport capacity usually located on the inside of a meander bend.

Point Source - Source of pollution from a single, well-defined outlet. Examples include wastewater treatment outfalls, combined sewer overflows, and industrial discharge pipes.

Pool - Deep, flat, areas in the stream created by scour, with slow currents at low flow. Usually pools occur on the outside of a meander bend between two riffles or the bottom of a step. Pools generally contain fine-grained bed materials, such as sand and silt. Natural streams often consist of a succession of pools and riffles.

Radius of Curvature - The radius of curvature (r) is the radius of the circle defining the curvature of an individual bend measured between adjacent inflection points. The arc angle is the angle swept out by the radius of curvature between adjacent inflection points. The radius of curvature to width ratio (r/w) is a very useful parameter that is often used in the description and comparison of meander behavior, and in particular, bank erosion rates. The radius of curvature is dependent on the same factors as the meander wavelength and width. Meander bends generally develop a radius of curvature to width ratio (r/w) of 1.5 to 4.5, with the majority of bends falling in the 2 to 3 range. The tractive force is also greater in tight bends than in longer radius bends. This was confirmed by Nanson and Hickin (1986) who studied the migration rates in a variety of streams, and found that the erosion rate of meanders increases as the radius of curvature to width ratio (r/w) decreased below a value of about 6, and reached a maximum in the r/w range of 2 to 3.

Rapids – A reach of stream that is characterized by small falls and turbulent, high-velocity water.

Rating Curve - See stage-discharge relationship.

Reach - A section of stream with consistent or distinctive morphological characteristics

Recurrence Interval - The interval of time, on average, between occurrences of a hydrologic event of a certain magnitude.

Reference Site/Reach - A stable portion of a stream that is used to model restoration on an unstable portion of stream. Stream morphology in the reference reach is documented in detail, and that morphology is used as a blueprint for design of a stream stability restoration project.

Restoration - Bring back to a former, natural condition. Alternately, the recovery of biological and hydraulic function such that the biological integrity and health of an ecosystem can be self-sustained over time.

Return interval – The expected frequency of occurrence for a given discharge, i.e. 1.5 years.

Revetment - A facing of stone, rootwads, cut trees, or other durable material used to protect a stream bank or hillside against erosion.

Riffle – A reach of stream that is characterized by shallow, fast-moving water broken by the presence of rocks. Riffles typically occur in areas of increased channel gradient where hydraulic conditions sort transported sediments. Most invertebrates will be found in riffles.

Right Bank – The right stream bank as looking or navigating downstream. This is a standard used in stream assessment surveys.

Riparian - The area of land along stream channels, within the valley walls, where vegetation and other landuses directly influence stream processes, including flooding behavior, erosion, aquatic habitat condition, and certain water quality parameters.

Riparian Buffer - An undisturbed, vegetated strip of land adjacent to a water course.

Riparian Corridor/Zone - Area adjacent to a river or stream. "Those areas that are saturated by ground water or intermittently inundated by surface water at a frequency and duration sufficient to support the prevalence of vegetation typically adapted for life in saturated soils." (Beschta 1991)

Rip-rap – Broken rock cobbles, or bounders placed on earth surfaces, such as a road embankment or the bank of a stream, for protection against the action of water; materials used for soil erosion control.

Riverine - Relating to rivers or streams.

Road Fill - (see also embankment) – Typically gravel and sand sized material used to elevate the level of the road, control the road grade, or provide a buffer for the road grade from stream erosion.

Rock Vanes - The two most common types of vanes are the single vanes and cross vanes. Rock vanes protect the stream bank by redirecting the thalweg away from the stream bank and towards the center of the channel, and improve in-stream habitat through scour, oxygenation, and cover. Single rock vanes are constructed with large boulders which are oriented upstream with angles off the bank from 20 to 30 degrees, just downstream of the point where the stream flow encounters the stream bank at acute angles. Before installing rock vanes, the designer must first complete a thorough morphological assessment of the stream reach and watershed.

Rotational Failure - A form of bank erosion caused by a slip along a curved surface that usually passes above the toe of the bank. Rotational slips can be caused by a variety of factors. The most common mechanism reason for them to occur is erosion at the base of the slope which reduces the support for overlying sediments. Erosion at the base of a slope can be caused by the presence of a stream channel

Run - A reach of stream that is characterized by swift flowing water with little surface agitation and no major flow obstructions.

Runoff - That portion of rainfall or snowmelt that moves across the land surface into streams and lakes.

Sand - Substrate particle that area smaller than gravel and larger than silts, and are generally 0.062 - 2 mm. in diameter.

Scour – Erosive action of water in streams by excavating and transporting bed and bank materials downstream.

Scour Pool - An area of deeper water created by the scouring action of water. These generally occur downstream of obstructions or along the outside of a meander bend.

Sediment - Material such as clay, sand, gravel and cobble that is transported by water from the place of origin (stream banks or hillsides) to the place of deposition (in the stream bed or on the floodplain).

Sediment Transport Discontinuity - Any interruption in sedimentation, whatever its cause or length, usually a manifestation of non-deposition and accompanying erosion. A stable stream must be able to consistently transport its sediment load, both in size and type, associated with local deposition and scour.

Sediment Yield (Sediment Discharge) - The total sediment (i.e., bed load and suspended sediment load) outflow from a drainage basin in a specific period of time.

Sedimentation (Siltation) - The deposition of sediment.

Shear stress (Shear Velocity/Shear Force) – The force exerted parallel to (rather than normal to) by flowing water on the bed or banks of a stream. The tractive force that removes material from a stream bank as flow moves over the surface. Shear stress may be estimated as the product of mean flow depth or hydraulic radius, channel slope, and the density of water.

Side Castings - Stream bed sediment pushed out of the channel, usually by heavy machinery, and mounded on the stream bank.

Side Channel - a secondary channel of the stream.

Silt – Substrate particle that area smaller than sand, and are generally measured between 0.0039 - 0.062 mm.

Sinuosity - The relative curviness of a stream channel. Quantified as the total stream length divided by valley length, or the ratio of valley slope to channel slope.

Sluiceway – chute; an open channel inside a dam designed to collect and divert logs in the stream.

Slump – The product or process of mass-wasting when a portion of hillslope slips or collapses downslope, with a backward rotation (also a rotational failure).

Sorting/Bed Sorting - Natural separation of stream bed substrate into different size classes due to variability in flow velocities and the differential depositional characteristics of those bed materials.

Stable Channel (see also equilibrium) - State in which a stream develops a stable dimension, pattern and profile such that, over time, channel features are maintained and the stream system neither aggrades nor degrades (Rosgen, 1996)

Stacked Rock Wall – A boulder revetment used to line stream banks for stabilization. Stacked rock walls can be constructed on a steeper angle than rip-rap, so they take up less of the stream cross-section, provide a wider road surface, and provide less surface area for solar heating, allowing stream temperature to remain cooler relative to banks lined with rip-rap. These features can be augmented with bioengineering to enhance aquatic habitat and stability functions.

Stage - In streams, stage refers to the level or height of the water surface, either at the current condition (i.e., current stage), or referring to another specific water level (i.e., flood stage).

Stage-Discharge Relationship/Curve - A graph showing the relation between gage height (or stage) and the amount of water flowing in the channel.

Step – A vertical drop formed by boulders, bedrock, or downed trees. Serves as grade control in high gradient streams.

Step/Pool Morphology - Steps are vertical drops often formed by large boulders, bedrock knickpoints, downed trees, etc. Deep pools are found at the bottom of each step. Step/pool sequences are found in high gradient streams. The step provides grade control and the pool dissipates energy. The spacing of step pools gets closer as the channel slope increases.

Stream Bank - The side slopes of a channel between which the streamflow is normally confined.

Stream Power - Measure of energy available to move sediment, or any other particle in a stream channel. It is affected by discharge and slope.

Stream Profile (or Longitudinal Profile) - A graph of elevation vs. distance along a stream channel. At a minimum, should include channel invert and water surface. Can also include bankfull, floodplain or terrace elevations.

Stream Stability (Source: Rosgen, 1996) - A stream is stable when it maintains its dimension, pattern and profile such that, over time, channel features are maintained and the stream system neither aggrades nor degrades.

Stream Type - As defined by Rosgen (1996), one of several categories defined in a stream classification system, based on a set of delineative criteria in which measurements of channel parameters are used to group similar *reaches*.

Substrate - Channel bed materials (silt, sand, gravel, cobble, boulders, organic debris,)

Substrate Analysis - Any test utilized to determine the size or size distribution of substrate, e.g., core analysis, sieve analysis or pebble count. A Particle Size Distribution is a plot showing the cumulative percent of substrate smaller than a given particle diameter. The percent smaller than a given diameter is denoted by a "D". For example, the median particle diameter, or D50, is larger than 50 percent of channel material as determined by a substrate analysis. Other substrate size indices, such as the D84 (i.e., the particle diameter larger than 84 percent of channel material as determined by a substrate analysis) are often used as indicators of stream power and the ability of the stream to mobilize that particle size during a given discharge event.

Summer Base-flow – Stream discharge primarily from groundwater (not from surface runoff). Typically this is the lowest flow of the year, occurring in late summer, or following extended periods of drought.

Suspended Sediment/Suspended Sediment Load - The soil particles lifted into and transported within the streamflow for a considerable period of time at the velocity of the flow, free from contact with the stream bed. These materials contribute to turbidity. Contrast to Bedload.

Target Fish Community – The desirable composition of fish species in a stream, developed to establish what native fish species were in a stream and at what proportions. This is determined through a comprehensive literature search followed by an assessment by a regional biologist to determine which of the native species would be most common in the stream under natural conditions.

Terrace (or Floodplain Terrace or Low Terrace) - A level area in a stream valley, above the active *floodplain*, that was deposited by the stream but has been abandoned as the stream has cut downward into the landscape. These areas may be inundated (submerged) in higher floods, but are typically not at risk in more common floods.

Thalweg – Literally means "valley way" and is the deepest point of a cross section. It is the low flow channel of the stream. In stream assessment, this location is used as a reference location for surveys and other measurements, and is most often associated with the deepest point in the stream cross-section.

Toe – The break in slope at the fool of a stream bank where it meets the stream bed.

Tractive Force - The drag or shear stress on a stream bank or stream bed caused by passing water which tends to pull soil particles along with the stream flow.

Transport Capacity - The ability of a stream, for a given flow condition, to transport a volume (or weight) of sediment material of a specific size per unit time.

Tributary - A stream that feeds into another stream; usually the tributary is smaller in size than the main stream (also called "*mainstem*"). The location of the joining of the two streams is the confluence.

Truncated Meander Bend - A shortened or cut off of a bend in the stream channel usually caused by valley form or infrastructure encroachment.

Turbidity - A measure of opacity of a substance; the degree to which light is scattered or absorbed by a fluid. Streams with high turbidity are often referred to as being "turbid".

Undercutting - The process by which the lower portion or "toe" of the stream bank is eaten away by erosion leaving a concave, overhanging section of stream bank. Often occurs on banks at the outside of stream bends.

Unstable (see also instability) – Describing a stream that is out of balance in its capacity to transport sediment and maintain its channel shape, pattern and profile over time.

Velocity – In streams, the speed at which water is flowing, usually measured in feet per second.

Vertically unstable channel – a channel with tends to downcut and abandon its flooplain; symptomatic in a channel where erosion is progressing faster than deposition.

Wash Load - The sediment load that because of its fine size has such a small settling velocity it would be held in suspension. It is essentially synonymous with suspended load.

Water Quality - A term used to describe the physical, chemical and biological characteristics of water with respect to its suitability for a particular use.

Watershed - Area that drains to a common outlet. For a stream, it is all the land that drains to it or its tributaries. Also commonly called Basin, Drainage Basin or Catchment. A Sub-basin or Sub-watershed is a discriminate drainage basin within a larger watershed, typically defined for planning or modeling purposes. The size of a watershed is termed its Drainage Area.

Weir - An artificial structure to construct water levels in a stream.

Wet Ravel - The downhill movement of soil and debris during wet periods, caused by hydrologic processes of rainsplash and overland flow.

Wetland – An area that is saturated by surface water or ground water with vegetation adapted for life under those soil conditions, as in swamps, bogs, fens, and marshes.

Wetted Area - The total area submerged by the flow of a stream

Wetted Perimeter - The boundary of wetted contact between a stream of flowing water and its containing channel at a given discharge, measured in a direction perpendicular to the flow.

Winter Base Flow - Stream discharge primarily from groundwater (not from surface runoff) -see summer base flow- Winter base flow is generally higher due to lower rates of evapo-transpiration during vegetative dormancy.

Woody Debris - Any large, relatively stable woody material that intrudes into the stream channel.

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