2.5 Upper Schoharie Watershed Geology (including East Kill)

(Note: this is an adaptation of the Upper Esopus Creek Management Plan geology section)

Introduction

Photo 2.5.1. Streambank erosion into glacial lodgement till along East Kill, tributary to Schoharie Creek.

Water flows across the landscape and sculpts the watershed. The geology (the earth material) of the watershed helps determine the nature of the streams, influences the stream's water quality and the way the landscape erodes (Photo 2.5.1). In the Catskill Mountains, geology is the primary influence 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 presents basic background information on Catskill and Upper Schoharie watershed geology, and discusses some of the important implications of geology on stream management. The intent is to provide just enough information to describe the geologic setting and history of the Upper Schoharie 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 a plateau of rock that formed from ancient rivers. That is essentially the geologic story of the Northeastern 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 helps 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 form and what the sediment will be like. Upper Schoharie Creek and its tributaries drain much of the northeast Catskill Mountains. 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 layered reddish clays exposed in stream banks are the legacy of ancient lake sediments eroded from the red siltstones and shales that often form the mountain slopes and the cobbles and boulders eroded from the thick-bedded sandstones that form the mountain cliffs (Photo 2.5.2). 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 melt-water streams and lakes that followed the ice's retreat. The Schoharie Creek and all the streams that feed it water and sediment have inherited this geologic framework.

Photo 2.5.2. Streambank/bed with alluvial and non-alluvial sediment

The geology of the Upper Schoharie Creek valley is typical of the complex geologic conditions that prevail in the tributaries as previously documented in the Batavia Kill (GCSWCD, 2003) and West Kill (GCSWCD, 2005) Stream Management Plans and in the adjacent Esopus Creek basin to the south, as documented in the Upper Esopus Creek Stream Management Plan (CCE, 2007). The bedrock geology is straightforward, while the glacial geology provides the complexity that makes these basins unique in the Catskills.

Bedrock Geology

The bedrock geology of the Catskill Mountains and Upper Schoharie watershed exerts considerable control on the character of its valley slopes and streams (Figure 2.5.1; Photo 2.5.3). The gently sloping 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 that drained the ancient high peaks of the Taconic mountain range (Isachsen et al., 2000). Titus (1998) 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.

Photo 2.5.3. Bedrock exposed along Schoharie Creek

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).

Fisher, et al. (1970) mapped the bedrock of the area as part of the New York State Geological Survey Map and Chart Series. The mapped geologic formations that make up most of the watershed are the Oneonta and Walton formations comprising sandstones, shales, and mudstones (Photo 2.5.3). Around the Schoharie Reservoir a similar sequence of rocks comprise the Genesee Group and the Moscow formation. The Moscow formation is the rock that hosts the famous Gilboa forest fossils (VanAller Hernick, 1996).

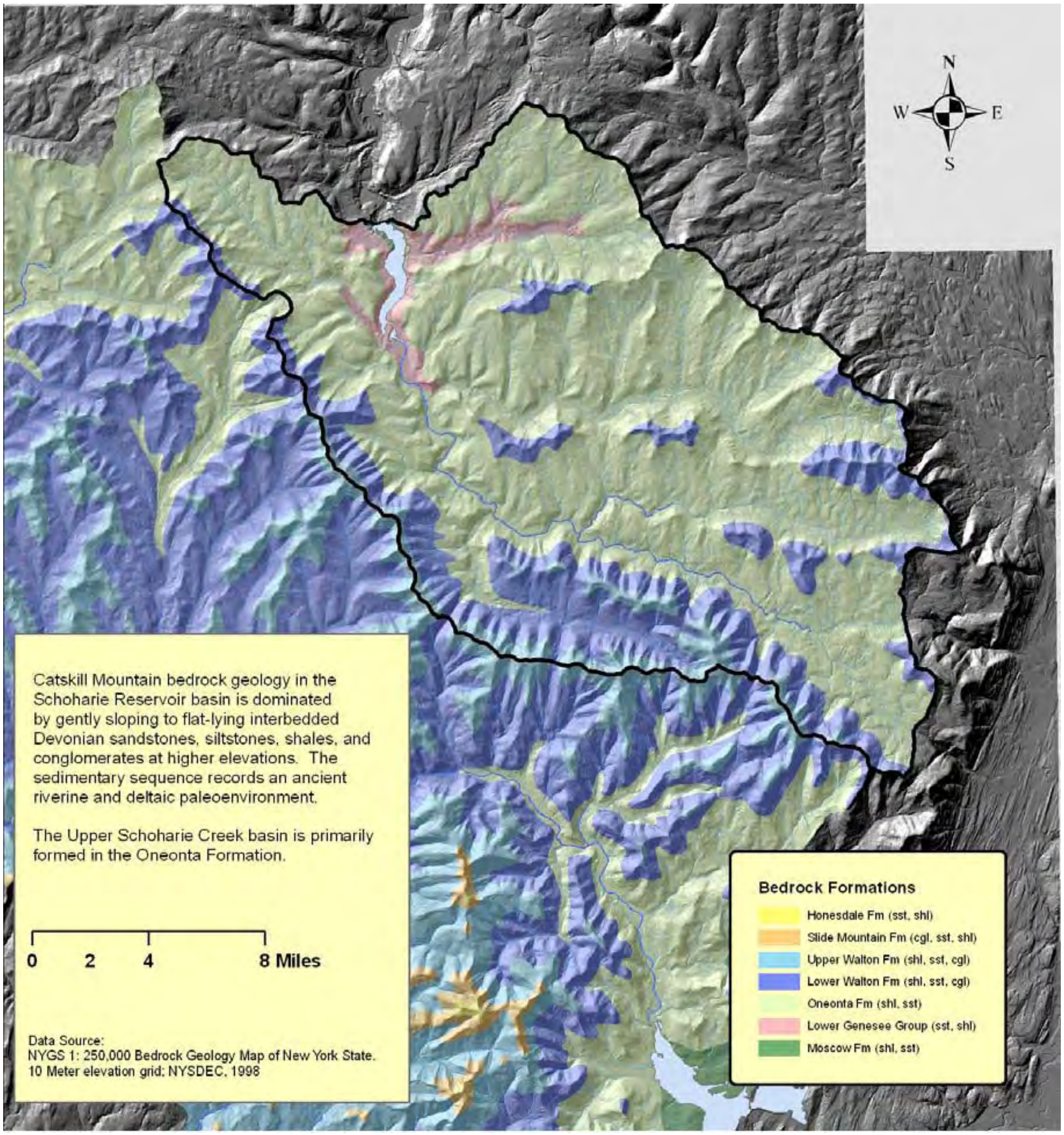

Figure 2.5.1. Bedrock geology of the Schoharie Basin.

The orientation of the stream valley is important, influencing the microclimate, average depth of snowpack and local hydrological regime in many ways. The Schoharie Creek watershed is uniquely oriented for Catskill drainage basins, with drainage to the west and north rather than to the southeast or southwest typical of the other principal watersheds.

Bedrock fracture orientations in the area are generally consistent with the overall trend of two sets for the central to northeastern Catskill Mountains. The dominant high-angle (near vertical) fracture sets are oriented NE and NW, influencing drainage pattern development.

Photo 2.5.4. Example of imbricated Catskill stream sediment

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 2.5.4). 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.

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 Schoharie watershed and stream corridor. The Greene County Soil Survey is an excellent source for examining the soils of the Upper Schoharie Creek corridor (USDA, 1993).

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 2.5.2). As measured on the scale of geologic time this was a very recent event.

Figure 2.5.2. (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 2.5.2a). The ice sheet covering Greenland (Figure 2.5.2b) 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-Mohawk River valleys to the north, smaller alpine glaciers formed in some of the higher mountains and further sculpted the landscape. The glaciers left a legacy that still profoundly influences hill slope and stream channel stability and water quality.

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 Mountain). 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 2.5.3). The extent of the pro-glacial lakes in the Catskills are inferred from elevations of "fossil" deltas from meltwater streams pouring into valley–filling. One long-standing lake during this time filled the ice-free parts of the Schoharie valley at an elevation up to 1600 ft (Rich, 1935) corresponding to the elevation of the notch at Grand Gorge. The notch was a spillway for Glacial Lake Grand Gorge, discharging water into the Delaware basin. The extent of the glacial lakes during the prolonged melting of stagnant continental ice exposed a large proportion of the catchment to the accumulation of layered fine sediment. As climate fluctuated during the period of deglaciation, temporary re-

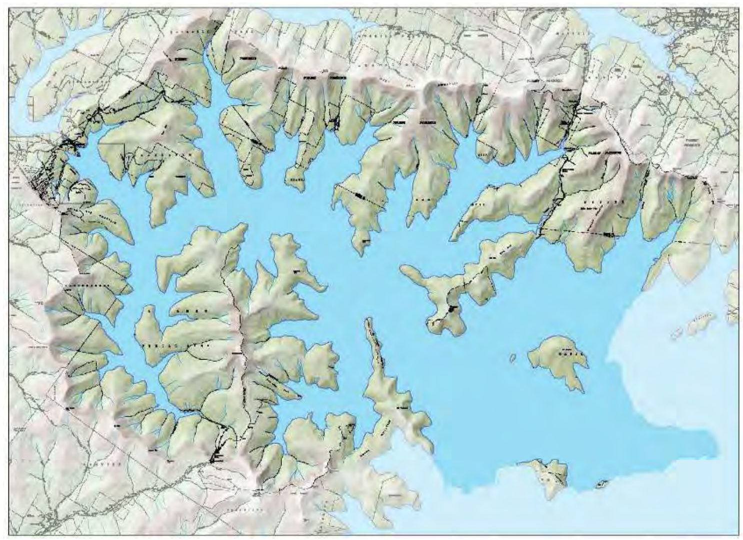

Figure 2.5.3. Example of extent of pro-glacial lake in adjacent Esopus Creek watershed

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.

Glacial geology sets the geologic framework for most of the Upper Schoharie 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. Also, locally complex stratigraphy of glacial till, glacial lake deposits and unconsolidated *fluvial* deposits in the stream bank profile significantly influence erosional processes. Understanding detailed glacial geology 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 2.5.4 presents a map of the surficial geology for the Schoharie basin as mapped by Cadwell (1987). It is safe to say that the actual geology is significantly more complicated than depicted on such a small scale map.

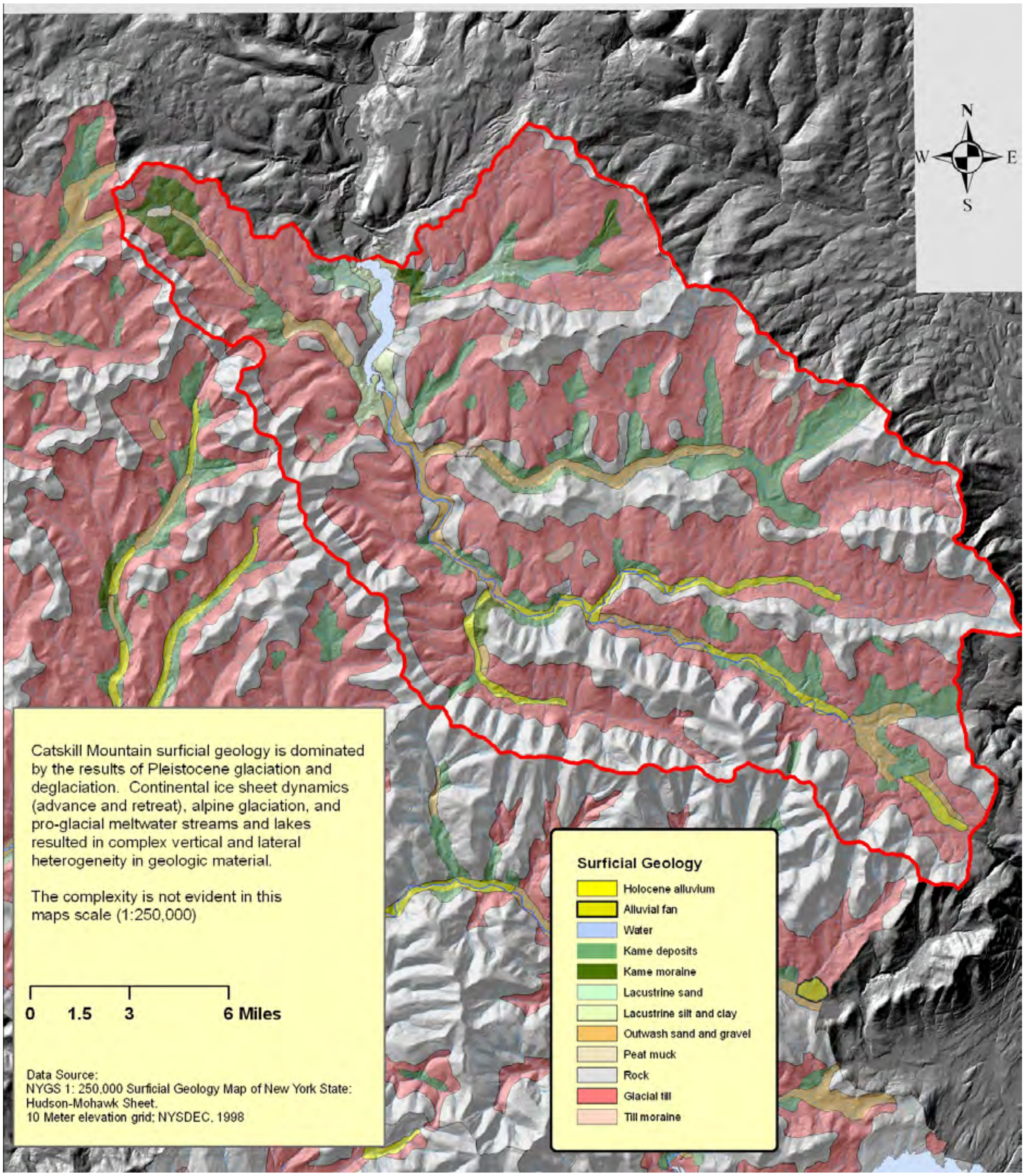

Figure 2.5.4. Surficial Geology of the Schoharie Creek Basin as mapped at 1:250,000

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.

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 Catskills is due to excess groundwater in these shallow groundwater systems and not directly from stream flooding.


Photo 2.5.5. Hillskope failure in the Schoharie basin

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 2.5.5). 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 failures, such as in Batavia Kill and West Kill (GCSWCD, 2003; GCSWCD, 2005).

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 Schoharie 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 main stem and tributary channels (GCSWCD, 2004). The following are the three key sedimentologic units that influence water quality and stream stability. They were first proposed by Rubin (1996), and have been subsequently adapted for the development of stream management plans (GCSWCD, 2004; GCSWCD, 2005; CCE, 2007).

Unconsolidated Deposits

Photo 2.5.6. Coarse fluvial sediment comprises most of the Schoharie Creek and East Kill stream banks

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 2.5.6). 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.

Lacustrine silt/clay

Photo 2.5.7. Clay deposit along the Schoharie Creek

Reddish or pinkish brown, finely-layered, silty-clay deposits are present in significant portions of the Upper Schoharie Watershed (Photo 2.5.7). 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. 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 2.5.5). Within the silt and clay layers, strata of sand sometimes occur, creating the potential for piping and associated mechanical failures. When saturated, it tends to be extremely soft and in this physically- and chemically-weakened condition is susceptible to creep and erosion. Research in the Esopus Creek also demonstrated that erodibility was a function of the degree of disturbance of the exposure surface, and tended to diminish over time as the exposed surface smoothed through erosion Fischenich et al., 2007).

Glacial Lake Clays and Stream Bank Erosion

Stream banks formed in deep clay deposits tend to fail by rotational failure which occurs in cohesive materials when a block of disturbed bank material slides along a curved failure surface (fault). The block tends to rotate (appears to "slump") back toward the bank as it slides, in a rotational slip.

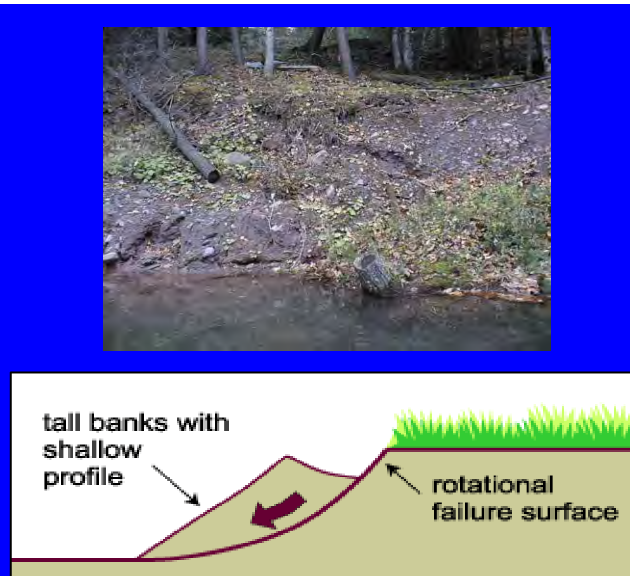

Figure 2.5.5. Glacial lake clays and stream bank erosion

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. In the Upper Schoharie Creek watershed this lacustrine silt/clay, along with lodgement till, are the primary sources for suspended sediment and turbidity problems.

Lodgement Till

Lodgement till is an over-consolidated (very dense), clay-rich, reddish brown deposit that is prevalent in the Upper Schoharie Creek and East Kill watersheds (Photo 2.5.8). This hard-packed silty clay with embedded pebbles, cobbles and boulders forms a number of steep banks in the drainage

Photo 2.5.8. Lodgement till in the East Kill

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. Lodgement till is typically exposed in stream channels where overlying lake clay deposits have been removed by erosion, where streams have scoured into valley wall deposits or where they have breached morainal ridges.

Its 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 stream well-after a storm event. Reaches in many of the Schoharie tributaries are subjected to this phenomenon. Rain water and overland runoff contacting exposed banks can also readily entrain sediment from these units. 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, and occasional bedrock stream banks and sills along the Upper Schoharie Creek/East Kill (Photo 2.5.9).

Photo 2.5.9. Lateral bedrock control in the East Kill

In summary, the variable character of the Upper Schoharie watershed 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.

Stream Management Implications

The inclusion of geology in stream management consideration for Upper Schoharie Creek and East Kill 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. Observations made during this planning process and previous similar projects throughout the watershed indicate the following:

- 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.
- 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).
- Glacial till tends to erode either as (a) mass slumping from saturated conditions or (b) translational fracture-bound failures forming high steep banks.

- Coarse-grained, non-cohesive fluvial sediment will erode easily if not protected by dense roots or revetment.

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. 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. 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 Schoharie 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

Photo 2.5.10. Turbid tributary entering the Schoharie Creek during a summer storm.

The "muddy" or turbid water that follows a storm event carries the fine silt and clay particles initially deposited as glacial till or pro-glacial lake sediment (Photo 2.5.10). 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. 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 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 Schoharie Creek has to process? Are there localized sources in the watershed that lead to localized aggradation?

Recommendations

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

- 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 Schoharie Creek and East Kill, 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 geomorphic investigation, (2) available soils map and (3) further reconnaissance mapping develop a stream channel geologic map for Upper Schoharie Creek and East Kill.
- Extend stream channel geologic and fine sediment source mapping into all tributary valleys not previously assessed, and develop a sediment budget 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.

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