3.2.4 Geology

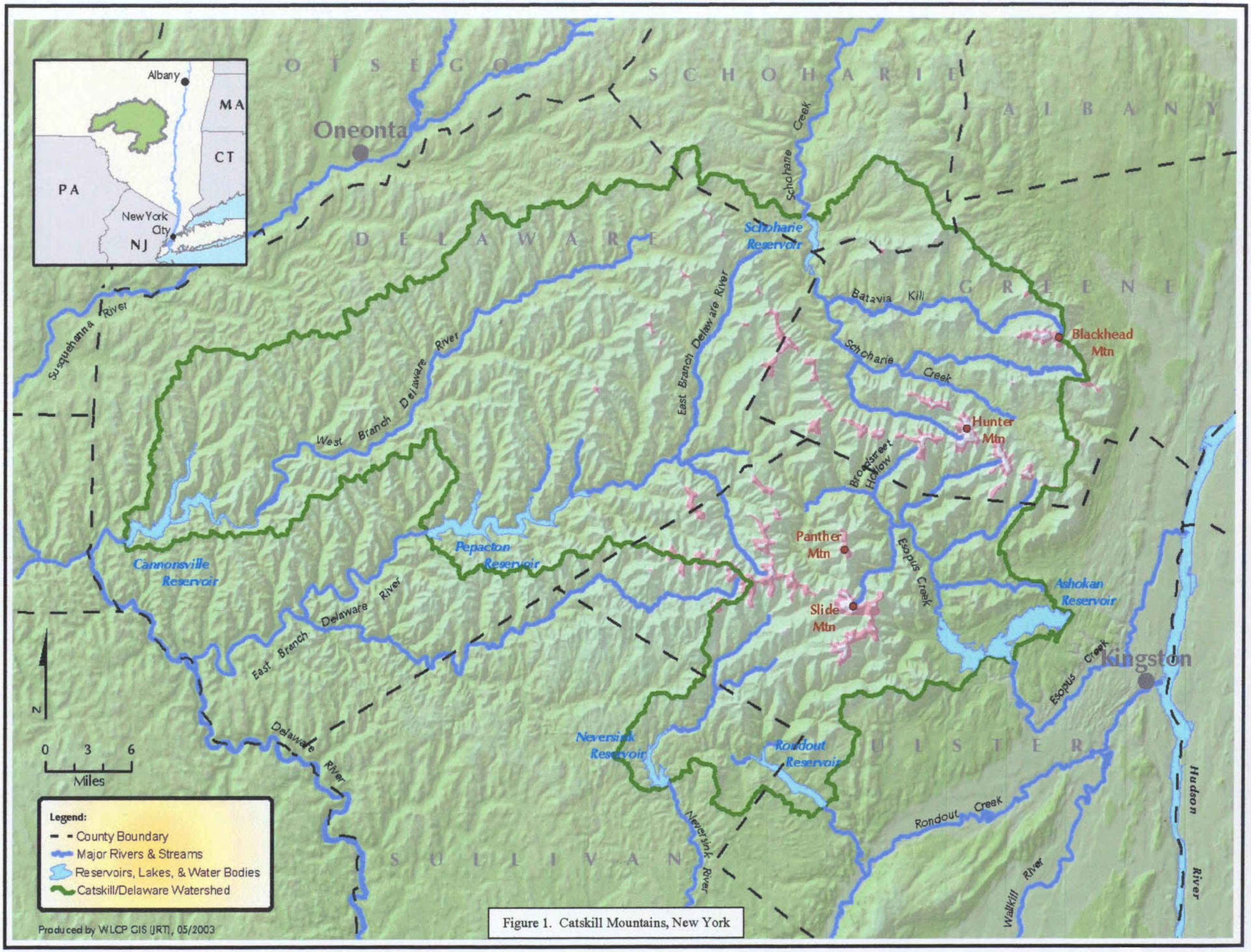
Introduction

In a landscape that has not been changed by human activities, the streams of a region reflect the climate, geology, and biology of that region. The Catskill high peak region has higher rain/snowfall amounts than the western and northern Catskills, and as a result, for a given watershed drainage area the streams are generally larger in the High Peaks than elsewhere in the Catskills (Miller and Davis, 2003). Likewise, the large amount of forest cover in the Catskills affects the amount of rain and snowfall that will run off the landscape to become streamflow, and therefore the shape and size (morphology) of the stream channel required to handle the amount of runoff (see Section 3.4 for more information about the role of riparian or streamside vegetation). Similarly, the geology of the Catskill Mountains exerts a clear influence on the landscape and stream valley and channel morphology. This section describes the basic geology of the Catskill Mountains, what is known about the geology of Broadstreet Hollow, and finally, how this affects the stream channel morphology, or fluvial geomorphology, of the basin.

3.2.4.1 Catskill Mountain Geology

The Catskill Mountains are a dissected plateau of mostly flat-lying sedimentary rocks cut into by streams and ice flow over millions of years. The mountains are at the northeastern extreme of the Alleghany plateau, a physiographic province (a land area with fairly uniform physical characteristics) that extends from Tennessee along the western border of the Appalachians (Rich, 1935).

There are many descriptions of the boundaries of the Catskills (Rich, 1935; Thaler, 1996; Isachson et al, 2000). A useful definition is Rich's description of the escarpments that comprise this mountainous region: Northeastern Escarpment (Blackhead Range); Eastern Escarpment (Wall of Manitou); the Central Escarpment (Indian Head to Utsayantha); and the Southern Escarpment (Slide Mountain to Ashokan High Point) (Figure 1). Broadstreet Hollow is located along the Central Escarpment, draining the south slope of West Kill Mountain and part of North Dome Mountain. The geologic discussion that follows pertains to the Central Escarpment.



Produced by WLCP GIS (JRT), 05/2003

Figure 1. Catskill Mountains, New York

Bedrock Geology

The bedrock of the central Catskill Mountains is comprised of conglomerate, sandstone, siltstone, mudstone and shale. 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 (Isachson et al, 2000). The sandstone and conglomerate are made up of river channel deposits, while the siltstones and shales are overbank and shallow fresh water deposits. The “red beds”, or mudstones, are often paleosols (ancient soils) that record the presence of Devonian forests. The repeating sequence of deposits shows continuous aggradation (building up) of the channels and floodplains of a complex meandering (many bends and turns) river system.

The “Catskill Delta” deposits were buried beneath other sediment, then uplifted as a plateau during the Alleghanian Orogeny (mountain building, 330 to 250 million years ago (mya)). When bedrock buried at great depth is subjected to stress (e.g. related to plate tectonics such as mountain building events) the rock can fold or fracture. In the case of the Catskill rock, intersecting sets of vertical fractures, called joints, formed during and after the Alleghanian Orogeny. The following eras eroded away the overlying rock, and streams cut multiple channels into the slowly rising plateau. The structure of the uplifted bedrock facilitated erosion and stream drainage development.

Surficial Geology

The cyclic ice ages of the last 1.6 m.y. (Pleistocene Epoch) have left the latest indelible mark on the already incised landscape of the Catskills. Vast continental ice sheets and smaller local alpine and valley glaciers scoured the mountains. The last ice sheet reached maximum thickness over the Catskills during the Wisconsinan Stage of the Pleistocene, about 21,750 years ago (Isachson, et al., 2000). This was a period of accelerated erosion from the abrasion (scraping of rock-on-rock) and bedrock quarrying by the flowing ice. Glacial erosion broke the rock down into an entrained mixture of fragments ranging in size from boulders to clay. This mixture of 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 drained the landscape before the glaciers advanced over the mountains.

As the ice thinned, the landscape was delgaciated – lobes of ice sheets melted back from the central Catskills, and from mountain glaciers formed on some of the newly exposed peaks (e.g. Hunter and West Kill Mountains). Meltwater along side the decaying ice left a complex array of meltwater and ice-contact deposits, along with lake clay where moraines (deposits at glacial margins) and ice impounded water, forming glacial lakes that filled the valley floors (Figure 2). As climate fluctuated during the period of deglaciation, temporary re-advances of ice 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. For more detail on the glacial geology of the Catskills the reader is referred to Rich (1935), Cadwell (1986), and Titus (1996).

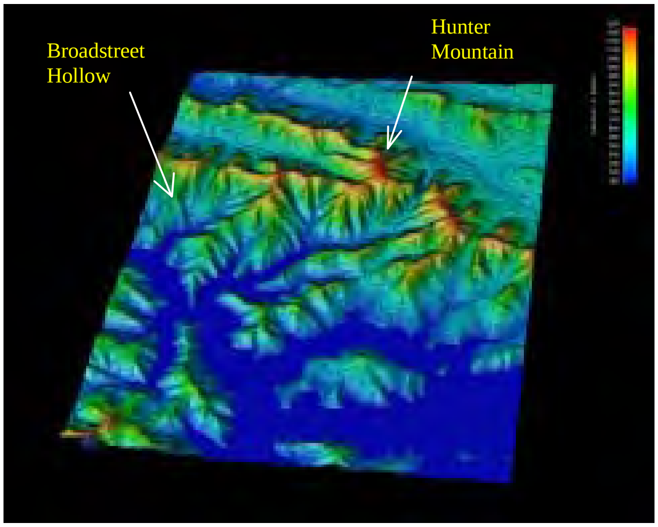


Figure 2. Model of glacial Lake Shandaken filling the Esopus Creek Valley. Water elevation is based on mapped lake deltas (created by Dominique Thongs, NYCDEP)

After the ice fully retreated north, rainfall-runoff returned as the predominant sculptor of the landscape. The Holocene (the last 12,000 years or so) has been a period of reclamation of the mountain landscape by forests and animals that together exert control on the stream valley and channel geomorphology. People then repopulated the landscape, and in the last 300 years humans have had the most dramatic effects on stream system morphology and stability.

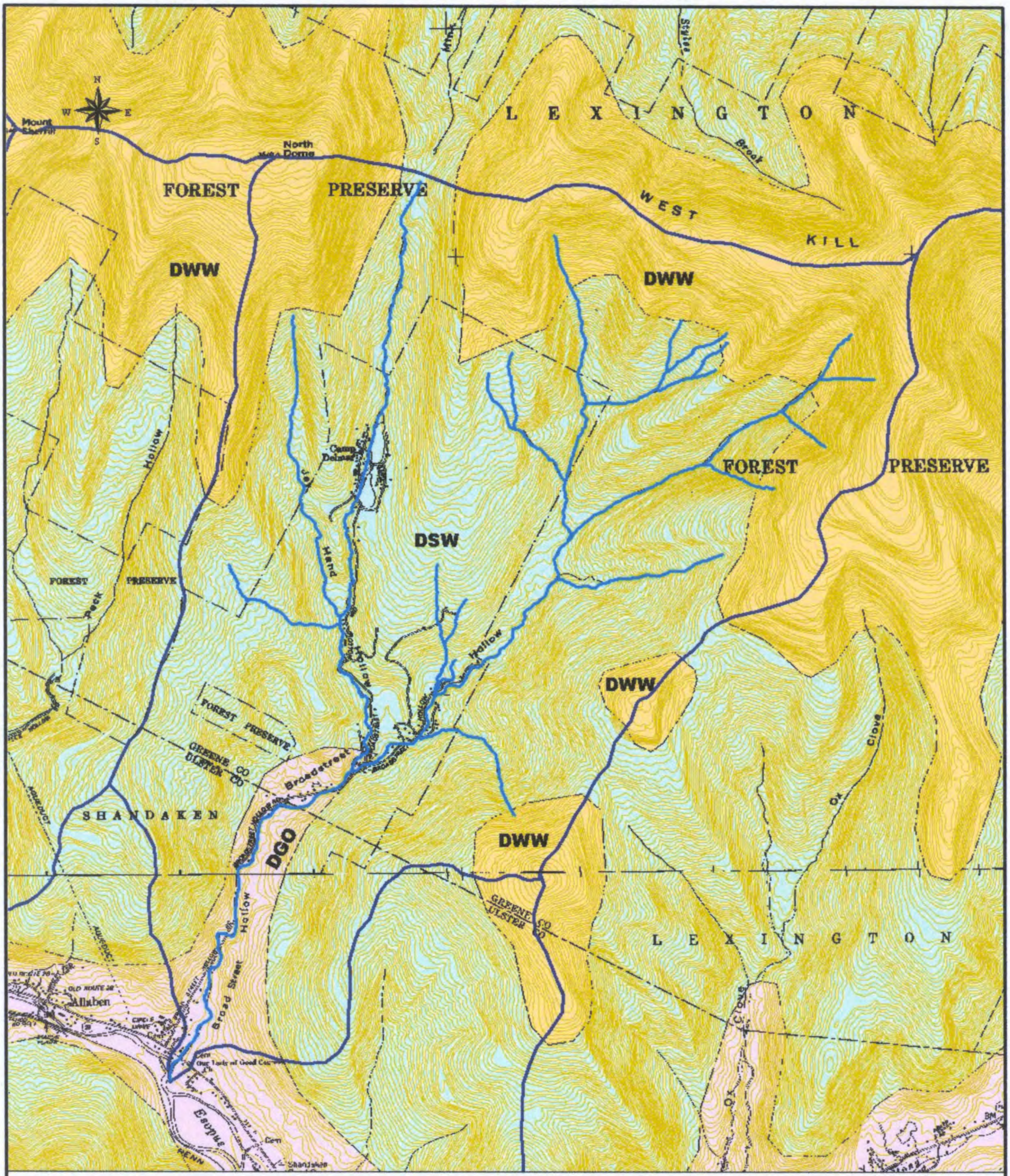
3.2.4.2 Broadstreet Hollow Geology

The geology of Broadstreet Hollow valley has been included in several comprehensive investigations of Catskill bedrock and glacial geology (Rich, 1935; Cadwell, 1986; Willis and Bridge, 1988) as well as the subject of smaller investigations by NYCDEP. Also, whenever a water supply well is drilled the driller records a log of the underlying material encountered, layer by layer, providing additional data for interpreting the local geologic history. The following discussion is an abbreviated account of Broadstreet Hollow geology based on available information.

Bedrock Geology

Rickard (1975) mapped the bedrock geology of the area as part of the New York State Geological Survey Map and Chart Series (Figure 3). The lower portion of the valley, below approximately 1400 ft, is mapped as the Oneonta Formation. This formation is expected to be around 900 ft thick in the Broadstreet valley. Most of the water supply wells in the valley are probably withdrawing water from the fractured sandstones and siltstones of the Oneonta Formation.

The overlying Lower Walton Formation makes up most of the valley floor and walls, while the ridges are capped with the Upper Walton Formation. The Walton Formations consist of greater than 1,000 ft of red beds (shales and mudstones), gray sandstones and small amounts of gray shale (Fletcher, 1967). The uppermost beds are conglomeratic sandstones that grade upward into the overlying Slide Mountain Formation that is comprised of a yellowish-gray conglomerate.



GIS Geologic bed and Planimetric coverages are edited and provided by NYC DEP, 2000, UTM NAD 27, Zone 18 North, meters. Aerial Photography provided by UCSWCD & NYC DEP November 2001. All other coverages were developed using GPS in the UTM, Zone 18 North projection, NADCON (Conus), datum. GPS data collected 2001, by UCSWCD & NYC DEP SMP.

Note: G.I.S. data are approximate according to their scale and resolution. Data may be subject to error and are not a substitute for on-site inspection or survey. Parcel coverages are based on Ulster County Real Property tax maps 2000 and may not reflect actual surveyed property boundaries.

Figure 3

Broadstreet Hollow Bedrock Geology

1: 40,000
Contour Interval 20 feet

2000 0 2000 4000 Feet

Legend

🟧 DWW - Upper Walton Formation
🟦 DSW - Lower Walton Formation
🟪 DGO - Oneonta Formation
Streams
▭ Broadstreet Hollow Watershed boundary

Surficial Geology

Rock outcrops are rare along Broadstreet Hollow Road and even in the stream itself. The only rock observed along the road is an outcrop of the Oneonta Formation about 0.8 miles from Route 28. Similarly, a walk along the mainstem of the stream within the Management Area (approximately 3.5 miles of the main stream extending up from the Esopus Creek) reveals no evidence of bedrock in the valley bottom. This is because the valley is thick with glacial sediment, masking the bedrock geology.

Surficial geology (deposits and landforms) has been mapped by Rich (1935) and Cadwell (1986) (Figure 4). Significant glacial landforms in the valley include the moraines and delta that form some of the steep topography of portions of Jay Hand Hollow (Timberlake). The Jay Hand Hollow issues from the U-shaped notch of Mink Hollow (between West Kill ridge and North Dome), interpreted by Rich to be an important conduit of ice flow into Broadstreet valley. Along the mainstem Broadstreet Hollow stream, probable kame terraces and moraine features locally extend out from the valley bedrock wall, confining the lateral extent (available width) of the stream valley floor. This confinement occurs most notably just below the confluence of the two main streams (see also MU4) and the section between the Ulster/Greene County line and the David Merwin bridge (see also MU 6-12). The distinctive meander bends near the bottom of the hollow (see also MU12, 13 and 15) appear to be controlled by similar glacial deposits.

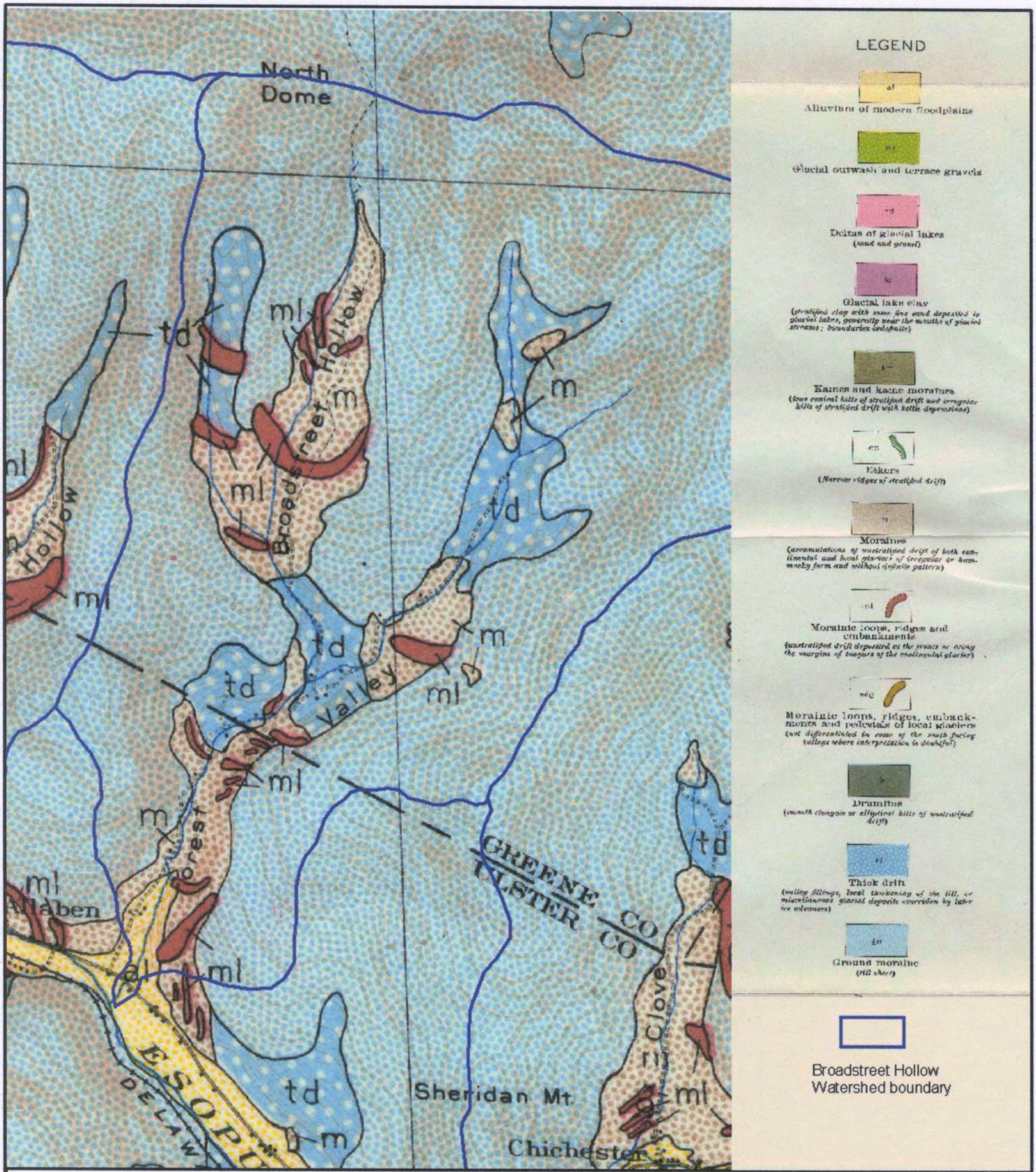


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Figure 4

Glacial Geology of the
Broadstreet Hollow Sub-basin
After John L. Rich, 1930

1:40,000

2000 0 2000 4000 Feet

Note: G.I.S. data are approximate according to their scale and resolution. Data may be subject to error and are not a substitute for on-site inspection or survey. Broadstreet Hollow Glacial Geology after Rich, 1930 Glacial Geology of the Catskill Mountains.

Along roadsides, hillsides and stream banks, the exposed geology is mostly glacial till, kame terrace (ice contact) deposits and Holocene alluvium (carried by post-glacial streams). In several places along the main stream, pure clay is observed in the stream channel and banks (Photo 1.). The layered clay is "glacial lake clay" from minor ice-contact impoundments within the valley during deglaciation, and from a glacial lake that filled the Esopus valley as the ice sheet melted back to the Hudson Valley (Rich, 1935; Cadwell, 1986; Dineen, 1986).

Photo 1. Eroding glacial lake clay along the stream bank and valley wall, across from the Fischzang property (see also MU17, monitoring cross-section 3).

Photo 2. Eroding kame terrace (ice contact deposit) composed of silts, sands, gravels and boulders along the stream bank across from the Foss property (see also MU8, monitoring cross-sections 11, 12 and 13).

Ice contact deposits (e.g. kame terraces), composed of variably stratified (layered) silts, sands, gravels and boulders are exposed in mass-wasted slopes of some steep, terraced valley walls (Photo 2.). Often, mass wasting is facilitated by the presence of localized clays within or underlying the more permeable ice contact deposits, forming water lubricated slip surfaces resulting in destabilized hillslopes. The glacial stratigraphy of the valley is complex, and the location and severity of stream network incision into it is influenced by this complexity.

Rich noted, back in 1935, exposures of lake clay veneered (covered in a thin layer) with till at the mouth of Jay Hand Hollow, which he interpreted as indicating considerable fluctuation of the ice margin (leading edge) in the valley while lake waters were present. He also noted slumping and land-sliding, attributable to the presence of "considerable" lake clay, along the entire portion of the valley below the confluence of Jay Hand Hollow and the main Broadstreet Hollow (see also MU4 through 19). Similarly, during the course of the watershed assessment in 2001, and recent observation of an excavated foundation, laterally discontinuous exposures of lake clay were revealed to be in abrupt lateral contact with coarse alluvium (gravels to boulders) and/or glacial till. A preliminary review of the available well logs and geotechnical borings (Volume I, Appendix Section 4.1) provides further evidence of both laterally extensive and highly localized clay deposits in a spatially complex arrangement. The laterally extensive clay deposits are probably attributable to glacial Lake Shandaken (Rich, 1935; Cadwell, 1987) while the localized clay deposits (lenses) resulted from isolated surface water impoundments within the valley during deglaciation. In some places, subsequent re-advance of glacial ice has deformed and rearranged the layered clays and surrounding deposits.

The soils of Broadstreet Hollow are formed from glacial deposits and bedrock. The Ulster County Soil Survey provides maps and detailed descriptions of the soil types observed in the valley. A brief summary of the soil types and a copy of the soil maps are available at the Ulster County Soil and Water Conservation District Office.

3.2.4.3 Applied Geology

How does geology relate to management of the stream? Bedrock and surficial geology of a drainage basin (watershed) influence all aspects of the stream system, though bedrock geology plays a limited role in the Broadstreet Hollow management area. Bedrock geology plays a more significant role in the upper headwater reaches, where less active stream management is required (i.e., primarily in NY State owned lands).

Glacial geology sets the framework for the Broadstreet Hollow stream valley, controlling such characteristics as depth of alluvium (water worked sediments), sediment supply and stream channel slope and geometry. Understanding the geology of the Broadstreet Hollow valley can help identify causes of stream erosion and water quality problems as well as assist in prioritizing where future stabilization/restoration actions will be most useful. The discussion below is separated into four general categories that pertain to the stream system: (1) *hillslope process* – slope stability and sediment supply; (2) *groundwater and surface water hydrology* – base flow conditions and runoff characteristics; (3) *valley and channel morphology* – valley type and orientation, channel shape and size, stream bed form, and bank material; and (4) *water quality* – base flow chemistry and temperature; suspended sediment, and contamination.

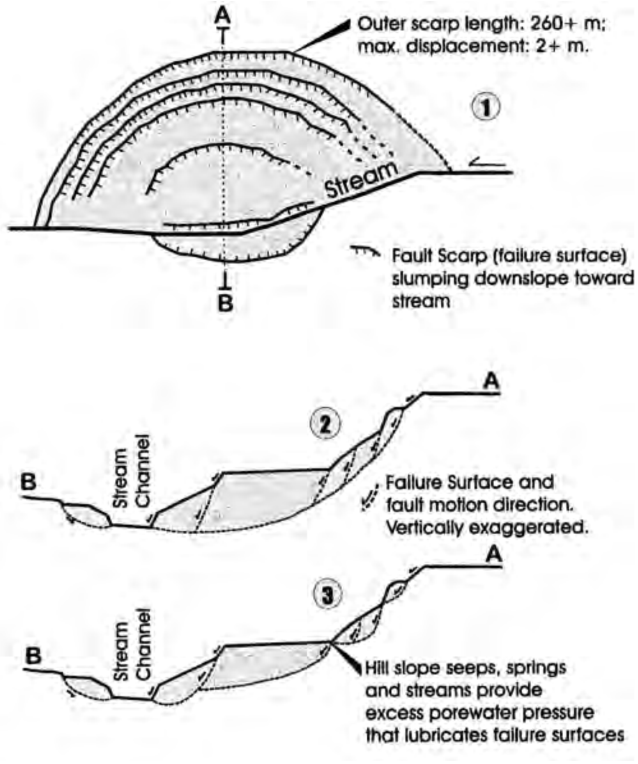

Figure 5. Sketch of fault scarps at the Broadstreet Hollow Demonstration Restoration project site (Rubin, 1997).

Hillslope process

The stream within the designated management area (primarily the main stream mapped in the watershed assessment in 2001) is entirely incised into glacial deposits overlying bedrock, and the adjacent hillslopes are formed in glacial deposits. Where layered clay is present in the hillslopes, clay-sourced slope instability adjacent to the stream can cause stream bank and bottom instability. A prime example of slope instability in response to presence of extensive lake clay deposits is the story of what has occurred at the stream stability restoration demonstration project site, located above the confluence with the Jay Hand Hollow tributary (see also Volume II, MU3, and Volume I, Section 4.1 for project descriptions). Appendix in Section 4.1 contains the geotechnical (slope stability) report for the project site as well as a detailed description of the site geology/hydrogeology (Rubin, 1997).

Geologic borings (vertically drilled samples) and well logs (Volume I, Appendix Section 4.1) reveal that clay is present and thick throughout the stream valley in multiple Management Units, and particularly so at the project site in MU3. The January 1996 flood event and subsequent emergency flood repair work removed the thin cobble and boulder stream bed armour overlying the soft, easily erodible clay – further aggravating a short, sharp drop, or headcut, in the stream bed. The stream swiftly incised (cut downward) into the clay, which lowered the stream bed, putting greater stress on an already failure-prone hillslope along the north side of the stream. The hillslope failure was characterized by slumping within an active, well-lubricated, gravity slide zone within and along the base of the thick glacial lake clays present in this location forming the valley wall (in places >30 ft thick). The resulting soil fault scarps (large, long cracks in the hillside) marked the progress of slumps of saturated clay toward and into the stream (Figure 5).

The clay also formed a confining layer causing artesian conditions (ground water under pressure, forced to the surface) in the underlying, more sandy material. This artesian condition extended under and into the stream bed, forming a “mud boil” in a zone where excess water pressure forced water and suspended clay out of the stream bed, resulting in a constant source of suspended sediment and turbidity, even at low flow conditions (Photo 3.).

Photo 3. Artesian "mud boil", early summer, 2000, showing clay hillslope on right bank, mid-MU3. Stream flow is from right to left.

Similar soil fault scarps and associated slumps of varying age observed elsewhere in the basin show that this complex hydrogeologic/hillslope condition is pervasive and has been going on for a very long time within the Broadstreet Hollow basin (see eroding banks and hillslopes at monitoring cross-sections in MU5, 8, 14, 15 and 17). In fact, this phenomenon is observed in many of the Esopus Creek drainages (Rubin, 1997).

Eroding ice contact deposits, and secondarily, till, are significant localized sources of sediment supply to the stream. The poorly consolidated, variably-sorted ice contact deposits that form steep embankments along the eastern valley wall can readily erode, especially if clay is present near the toe of the slope (as in Management Unit 8; Photo 4.). These deposits supply clay to boulder-sized material. Bar development (large stream sediment deposits) and boulder clusters often form associated with these sediment sources.

Groundwater

Where the stream flows through bedrock, base flow (the lowest stream flow, typically in summer or drought conditions, and primarily from ground water) is limited to discharge from the fracture network system (FNS). Base flow to streams throughout most of the Broadstreet Hollow valley is stored in the heterogeneous array of glacial deposits. The result is variable baseflow, water quality, and thermal ***refugia*** conditions for fish (i.e. protecting cold water locations necessary for fish survival in hot summer months).

Presence of clay near the surface, capped by coarse permeable deposits, causes groundwater to perch and flow near the surface with numerous springs, wetlands, and minor tributaries as a result. The presence of clay as a top confining layer also produces local artesian conditions (as noted above). When the clay has been breached (by fault formation or digging) groundwater can rise to, or near, the ground surface forming springs. There are many shallow "dug" wells in the valley that tap into these perched or shallow artesian "aquifers".

Photo 4. Glacial lake clay deposit at the toe of the slope across from the Foss property, monitoring cross-section 11 in MU8.

Valley and Channel Morphology

Valley orientation is based on pre-glacial erosion controlled by the fractured bedrock. Most of the stream valleys draining the Central Escarpment are oriented NE-SW, bisecting the two predominant fracture orientations. Glacial landforms, such as kame terraces and moraine features (Rich, 1935) determine the valley floor confinement and cross-sectional configuration.

Modern stream deposits in the Catskill Mountains are principally derived from erosion of well-bedded sedimentary bedrock of the Catskills. As a result, stream clasts (sediment particles and classes) have a low spherocity ("roundness"), typically forming platy or disk particle shapes, which strongly influence the imbrication of the stream substrate (stacking of stream deposited sediment, often forming a pattern like fish scales) and the magnitude of flows required for mobilization.

The complex Pleistocene glaciation of the Broadstreet Hollow valley has significantly modified the landscape and left varying deposits of clay-rich to bouldery till, silts, sands, gravels, and cobbles of meltwater streams and ice-contact deposits, and easily erodible glacial lake clays. The result is often a significant downstream variation in sediment supply (amount and size of material) and channel boundary resistance (the “roughness” of the channel, and sediment resistance to moving in high stream flows). The architecture of the stream channel (size, shape, bed form) is influenced to a large extent by the surficial (surface) deposit material size. Variable distribution of particle size in stream eroded and mass-wasted glacial deposits (i.e., the different character of bouldery melt-out till vs. clay rich lodgement till or cobble-gravel meltwater deposits) results in variably distributed bouldery step-pool channels interspersed with cobbly riffle-pool channels.

Water Quality

During much of the year, stream water chemistry is dominated by groundwater base flow. Water quality and temperature is expected to vary, as a function of the material the groundwater is flowing through and the retention time (amount of time water is in contact with underground material before flowing to the surface as springs or as stream flow). At this time there are no surface water or groundwater chemistry data available to characterize the system. Where lake clays cause groundwater to perch beneath very permeable deposits on top, there may be limited treatment of septic leachate from older septic systems adjacent to the stream.

Exposed clay deposits in the stream bed, banks and eroding hillslopes provide source areas that episodically contribute high suspended sediment loads to the stream. Preliminary sediment load estimates for four 1996 storms indicate that the Broadstreet Hollow stream contributed approximately 4%, 6%, 9%, and 1%, respectively of the total sediment load in the Esopus Creek measured at Coldbrook, while having less than 5% of the total contributing drainage area (Rubin, 1997). Small exposures of this easily entrained material can significantly increase storm and low flow turbidity. As noted before, an artesian, “mud boil” formed in the channel bottom at the downstream site, which literally pumped clay into the stream, even at low flow conditions. There were no known “mud boil” conditions found prior to 1997, when storm turbidity measurements were made. There are no known mud boils present in the stream at the time this document was prepared.

Recommendations

Given the importance of the geology on the stream morphology and water quality, a more detailed map of stream corridor geology is recommended for future planning and identification of potential stream instabilities. The map can be prepared by combining GPS recorded observations of geology along the stream corridor and available subsurface data.

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