Section 2.4

Upper Neversink Watershed Geology

Geology is the study of the Earth, its composition, structure and the dynamic processes that affect change over the duration of Earth history. Over the passage of millions of years, the interaction of the climate and geology of the upper Neversink watershed has created the high relief southern front of the Catskill Mountains. The streams that carry the water and sediment out of these mountains reflect the geologic composition, structure and process (Figure 1).

Figure 1. Bedrock reach along the West Branch Neversink River

The Catskill Mountains are unlike many other mountains often formed from the uplifting of folded and faulted rocks during continental collisions. The Catskills are a gentler sort of mountains crafted from eons of scouring stream water and carving glacial ice as the terrain slowly uplifted as a plateau over millions of years. This stream dissected plateau in the southern and eastern Catskills is characterized by steep mountain valleys carved in sedimentary bedrock from the mid to late-Devonian period (390 – 360 million years ago). These valleys are also filled with the deposits left behind from the last Ice Age that ended ~10 thousand years ago. Following the retreat of the continental ice sheet out of the Catskills, streams got back to work in shaping the valley bottoms. The sedimentary bedrock framework and Ice Age glacial legacy deposits are largely what control valley bottom characteristics such as slope, valley and stream confinement; in streams, the geology influences channel morphology such as bedform, planform, and alluvial versus non-alluvial boundary conditions. Water quality is directly and indirectly influenced by geology. For example, the potential for acidic stream waters stems from acidic deposition on a terrain with poor buffering capacity. Wise stream management requires a good foundation in understanding the regional and local geologic controls on stream geomorphic, ecologic, and water quality condition.

This section of the plan briefly covers the general geologic history of the watershed region, and highlights the key geologic features with implications for stream management (lithology or composition, valley and stream morphology, and water quality. We encourage the interested reader/researcher to check out the more detailed sources of information on the regional geology and related issues included in the bibliography at the end of this section. The section also includes a list of research topics that if pursued would be beneficial to stream management

General Geologic History

The Catskill Mountains that comprise the NYC Catskill and Delaware water supply watersheds are a noted example of cyclic patterns in geology. In the mid to late Devonian period of earth's history the towering Acadian mountains to the east eroded into vast deltaic plains of meandering and braided rivers sloping into an inland sea (about where Binghamton is now). Robert Titus compares it to the modern Bangladesh river complex draining the Himalayan Mountains in geologic setting (Titus, 1998). Those vast ancient river deltas laid down layer upon layer of sediment: stream gravels and sand, and floodplain silt and clay, creating the Catskill Delta (Isachsen et al, 2000). These were not barren deltas; there were fern tree forests and fish in the waters. Over time, these deposits were buried and turned to rock only to be upthrust again to the surface encountering the force of eroding water and inexorable return to stream sediment: a cycle of mountains to rivers to mountains to rivers.

The high peaks of the Catskill Mountains all have a similar range in elevation from 3,000 – 4,000 ft in elevation above sea level. The common interpretation of this relatively unique condition is that the Catskills are an example of an eroded *peneplain*. That means the mountain tops were once part of a flat plain that probably had additional rock layers above the Devonian rocks. The plain was then uplifted as part of the Alleghany plateau (Isachsen, et al, 2000). The streams that meandered across that ancient plain were steepened and eroded away the rock above the Devonian strata and carved valleys out of the uplifting terrain. The more erosion resistant sandstone and conglomerate caps of the current mountain tops yielded a mountain range with very similar heights.

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 in some of the high peaks, 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). As measured on the scale of geologic time this was a very recent event. The ice sheet covering Greenland is a modern day analog to those Pleistocene conditions. 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 possibly 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 throughout the Catskills.

Figure 2. Maximum extent of Laurentide ice sheet.

Since the Ice Ages, the return of streams and a forested landscape are the latest development influencing the current geologic processes (streams eroding and depositing sediment).

Bedrock Geology and Implications for Stream Management

Bedrock Geology Composition

The bedrock composition of the upper Neversink watershed is entirely sedimentary rocks: shales, siltstones, sandstones, and at higher elevations conglomerate. Figure 3 is a bedrock geology map for the watershed based on the NYS Museum's state series geologic maps and charts (Fischer, et al, 1970). The mapped geologic formations that make up most of the watershed are the Upper Walton formation comprising sandstone, shale, and siltstone and at higher elevations the Slide Mountain and Honesdale formations comprising mostly sandstone and conglomerate with some shale (Figure 3). These geologic map formations are just variations on a theme of alternating layers of fine grained rocks (siltstones and shales) and coarse grained rocks (sandstones and conglomerates). The coarse grain rocks are stream channel deposits, and you can often observe old channel features, such as cross-bedded troughs, gravel bars, and in some rare places fossilized log jams in outcrops. The fine grain rocks are typically the floodplain deposits. Often the red shales show old soil horizons with fossilized root holes and in places Devonian tree parts. Each package of coarse and fine grain rocks equals one story of a prehistoric stream channel's meander across the Devonian delta plain.

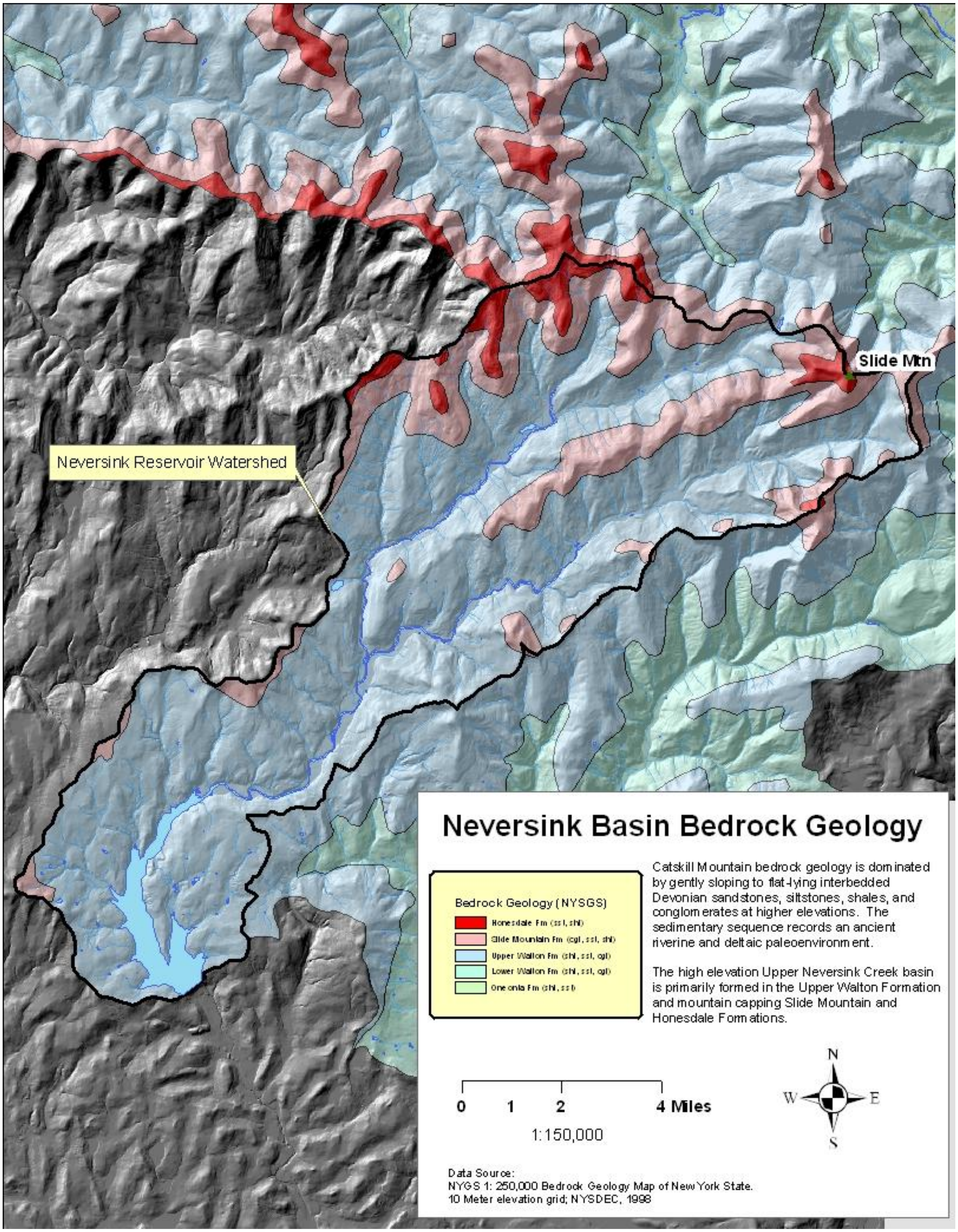

Figure 3. Bedrock Geology of the Upper Neverskink Watershed

Valley Morphology

The sedimentary bedrock composed of the nearly flat-lying, alternating thick layers of sandstone, shale, and at higher elevations conglomerate are responsible for the characteristic stair-step pattern observed in the mountain valley walls, and to some degree in the changes of valley scale slope in the valley bottom. In the headwaters, the more resistant sandstone and conglomerate layers form the steeper valley walls and valley grade control, while the more erodible shales tend to form the gentler slopes of the valley walls.

Most of the stream valleys draining the Southern 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, very gently southwest dipping bedrock. The orientation of stream valleys is important, influencing the microclimate, average depth of snowpack and local hydrological regime in many ways.

Stream Morphology

While there are many grade and planform controls on stream morphology at a range of scales, from large woody debris to bridges, bedrock is the fundamental valley scale control for grade and channel planform. Where the stream flows against a bedrock valley wall or across a bedrock valley bottom the stream's erosional process is effectively arrested in a timescale that matters for stream management. There are several bedrock grade and planform controls throughout the upper Neversink stream network, more so in the West Branch (Figure 4). Figure 5 shows the mapped bedrock grade and planform control identified in the stream feature inventory.

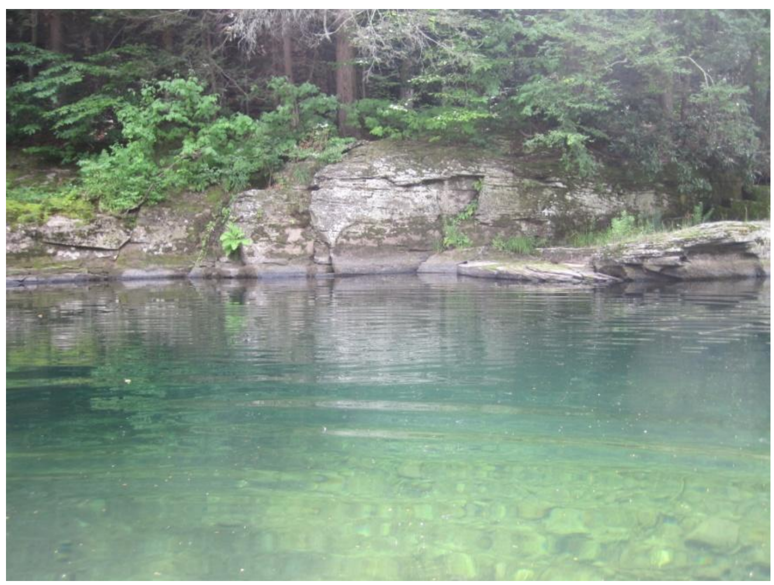

Figure 4. Bedrock planform control along the West Branch Neversink River

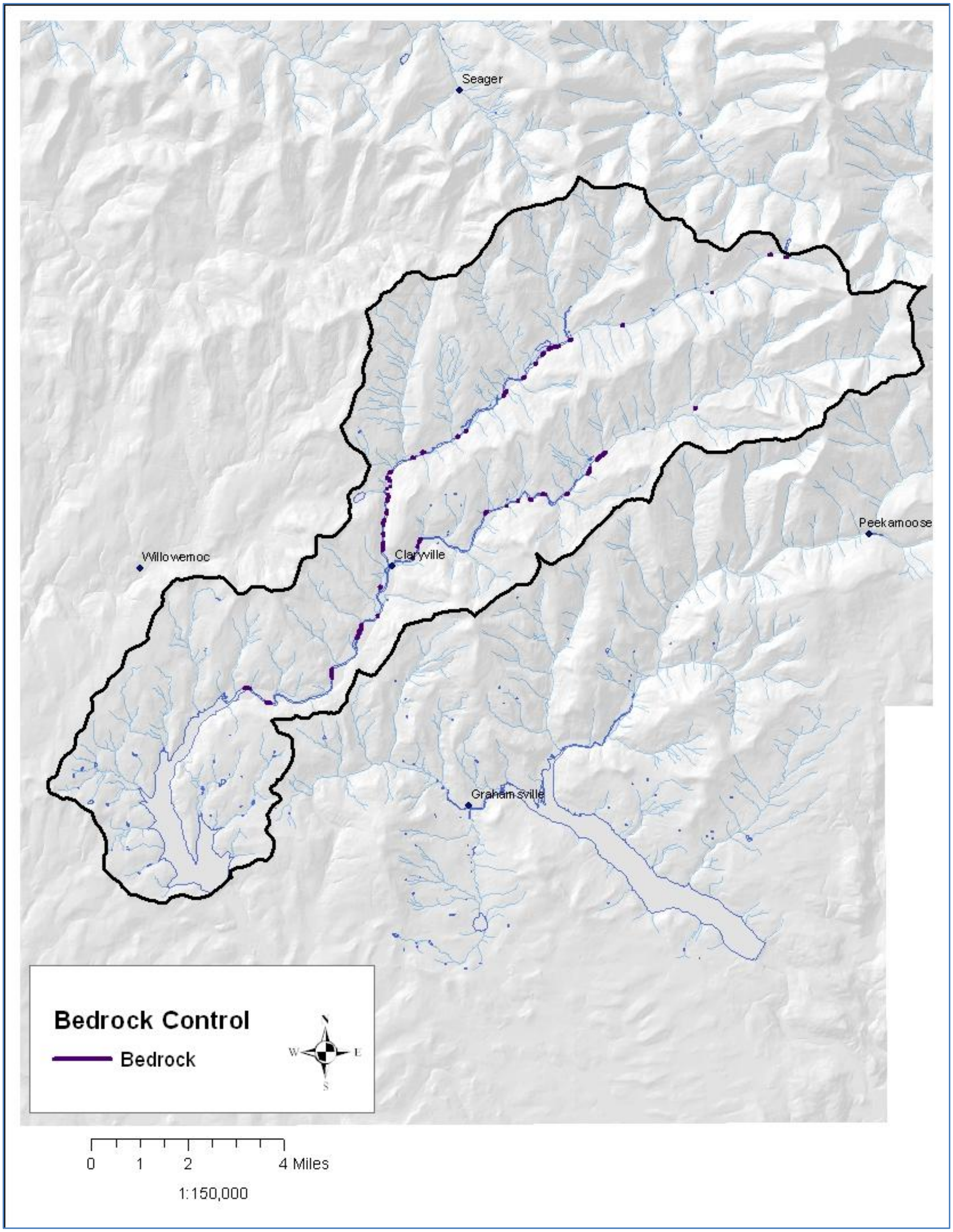

Figure 5. Mapped bedrock grade and planform control along the Upper Neversink River

Modern stream deposits in the Catskill Mountains are principally derived from erosion of the layered 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 (Figure 6 – photo of imbricated stream deposits).

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.

Figure 6. Example of imbricated Catskill stream sediment

Surficial Geology and Implications for Stream Management

Surficial Geology Composition

Surficial geology is concerned with the material covering bedrock. In the Catskills this surface material is principally soils and glacial deposits. The focus here is on the glacial geology of the watershed and stream corridor. The Ulster County and Sullivan County Soil Surveys are excellent sources for examining the soils of the Upper Neversink watershed (Tornes, 1979; Seifried, 1989).

The Pleistocene was a period of accelerated erosion in the Catskills as the flowing ice sheet bulldozed sediment and "quarried" 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 ice and deposited as *till* (unsorted assemblage of glacial sediment; Figure 7) or as *stratified "drift"* (Figure 8) 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. Figure 9 presents the surficial geology of the Upper Neversink watershed as mapped by Cadwell (1987). Note that this map is a t 1:250,000 scale and significantly oversimplifies the distribution of varied glacial deposits.

As the climate warmed and ice thinned, the landscape was deglaciated – lobes of the continental ice sheet melted back from the Catskills in periodic stages. Meltwater from the decaying ice left a complex array of stream (outwash plain) and ice-contact (kame) sand and gravel deposits. Pro-glacial lakes would have formed where mountains, recessional moraines (deposits at former glacial margins) and ice impounded water and left deposits of layered silt and clay.

Figure 7. Glacial till exposure along the stream

Figure 8. Stratified drift exposed in an eroding kame terrace

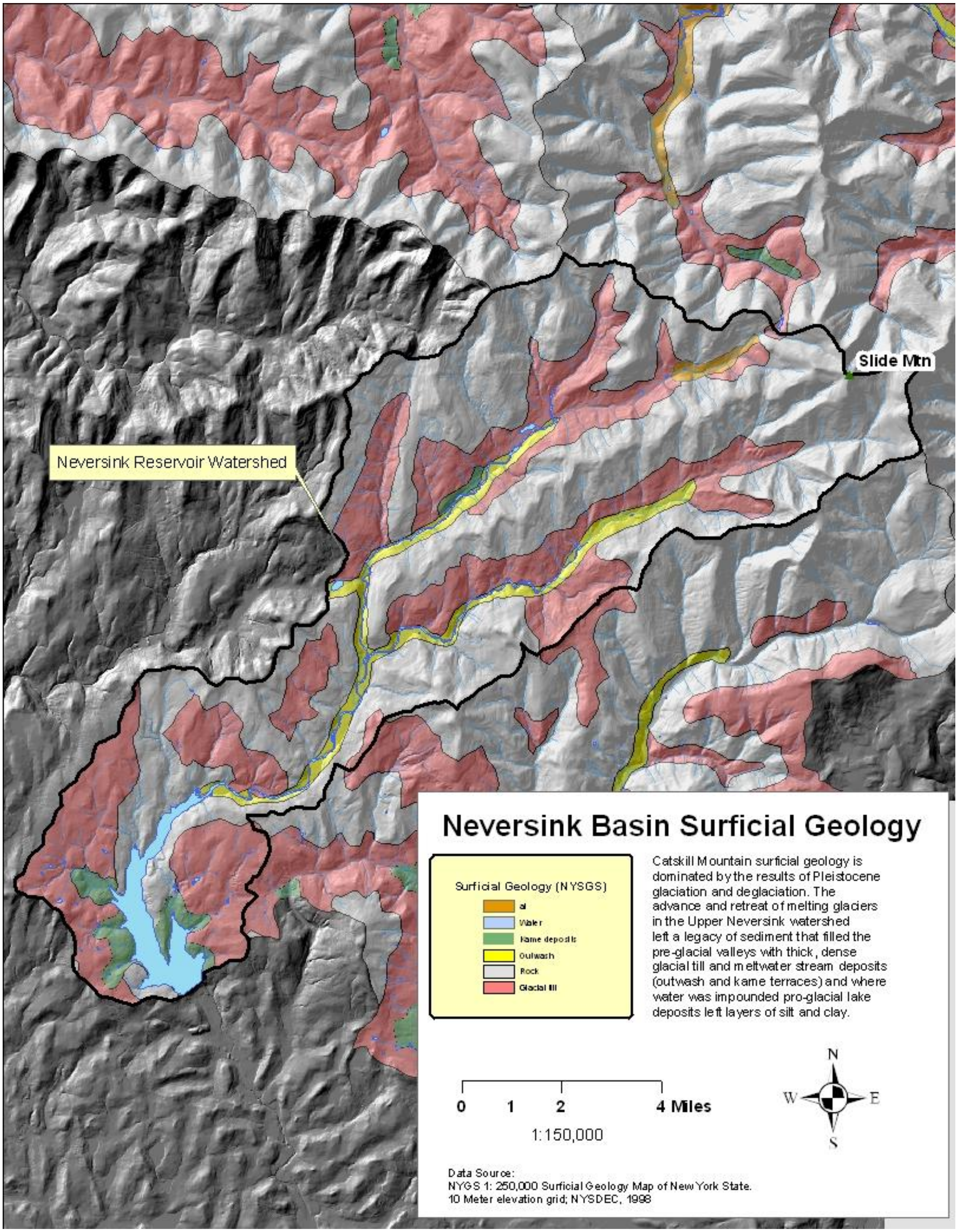

Figure 9. Surficial geology of the Upper Neversink watershed

The glacial geology of the Catskills can be quite complex given a very complex and poorly understood deglaciation, or melting of the retreating ice. Previous research by Rich (1934) and Ozvath and Coates (1986) indicate that the drainages of the southern escarpment of the Catskills (Beaver Kill, Neversink, and Rondout) were subjected to a chaotic retreat of ice with massive blocks of ice stagnating and melting in place. Rich also hypothesized that local alpine glaciers may have descended down each of the Branches from the Southern Escarpment. Subsequent work has disputed this hyposthesis but there has been little research in this area to conclude the debate.

The ice age deposits typically found in the upper Neversink watershed are generally directly from ice contact - glacial till (Figure 7); or from melt water deposits along the ice margin and the valley walls – kame terraces, or in meltwater streams discharging from the melting ice - outwash (Figure 8). There is not much evidence at the surface for large pro-glacial lakes that would have received the meltwater. Previous surficial geologic mapping efforts have not noted much presence of the layered silt and clay glacial lake deposits that make the adjacent Esopus Creek watershed very prone to muddy water. Observations from a streamside landowner of "chunks" of layered lake deposits in post-flood bar deposits show that they are present but not all that exposed.

Following deglaciation, streams became the acting geomorphic agent in the valley bottoms, re-working much of the glacial sediment into Holocene alluvium. Much of the active stream corridor is floored with this alluvial material typically ranging in sediment size from sand to boulders (Figure 10).

Figure 10. Alluvial (stream-deposited) sediment exposed in an eroding streambank

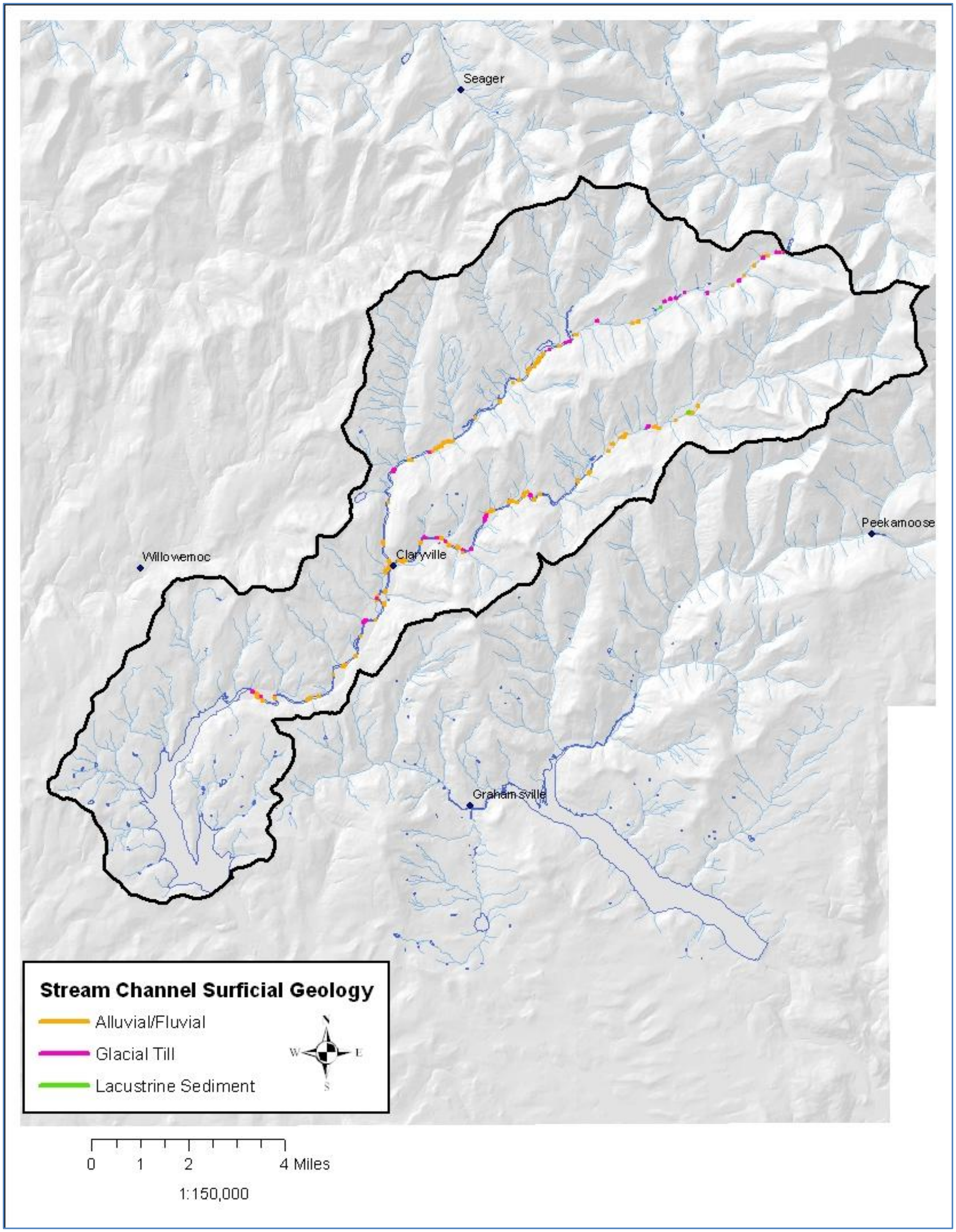

Figure 11. Stream channel surficial geology map derived from the Stream Feature Inventory

The stream feature inventory completed for the Stream Management Plan includes mapping active streambank and adjacent hill slope erosion. The geologic material exposed in the banks and hill slopes is recorded and can be used to show the distribution of stream channel geology as presented in Figure 11.

Valley Morphology

Glacial geology sets the geologic framework for most of the Upper Neversink stream system, controlling such characteristics as depth of *alluvium* (water worked sediments), presence of non-alluvial boundary conditions (bedrock, 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 the lateral extension of the river channel in its floodplain.

Glacial landscape features, such as moraines and glacial terraces influence valley cross sectional morphology. Glacial till is more resistant to erosion than former stream deposits and it can locally influence planform and grade control. Rich (1934) notes several locations in both branches where glacial moraines force the current stream channel to one side of the valley and often in contact with bedrock. Also, these morainal valley obstructions tend to induce the development of wide valley alluvial plains upstream of the obstruction (e.g. valley floor between Fall Brook and Biscuit Brook). Outwash terraces along the valley margins are mapped by Rich along portions of both Branches. These features can further confine the active channel corridor and be a source of bedload material supply.

Stream Morphology

Alluvial channels are stream channels with stream-deposited sediment on all boundaries. Non-alluvial channels are stream channels are with a direct contact with material not supplied by the stream, such as bedrock, glacial till or glacial lake silty clay. Erosional processes and recovery to stream channel equilibrium will vary as a function of this alluvial/non-alluvial condition. There are many places in the upper Neversink stream network that have non-alluvial or mixed-boundary conditions (Figures 5 and 11).   Eroding "bank run" banks (sand, gravel, cobble from glacial meltwater streams or alluvial sediment from more historic streams) tend to experience higher lateral adjustments because the material, if not protected by roots, is easily entrained and mobilized (Figure 10).   These banks, if not exposed to lots of recurrent shear stress can recover to a stable slope and vegetate quickly. Non-alluvial stream boundary material tends to erode geotechnically rather than hydraulically. Dense glacial till banks will tend to form steep high banks from mass failures and take a long time to recover (Figure 7). Stream banks with glacial lake deposits tend to be the result of slumping and easy toe erosion and consequently can be active for along period of time. The stream feature inventory did not reveal the presence of this condition that is so common in the central Catskill stream corridors.

Bibliography of Relevant Geology Publications

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Figures