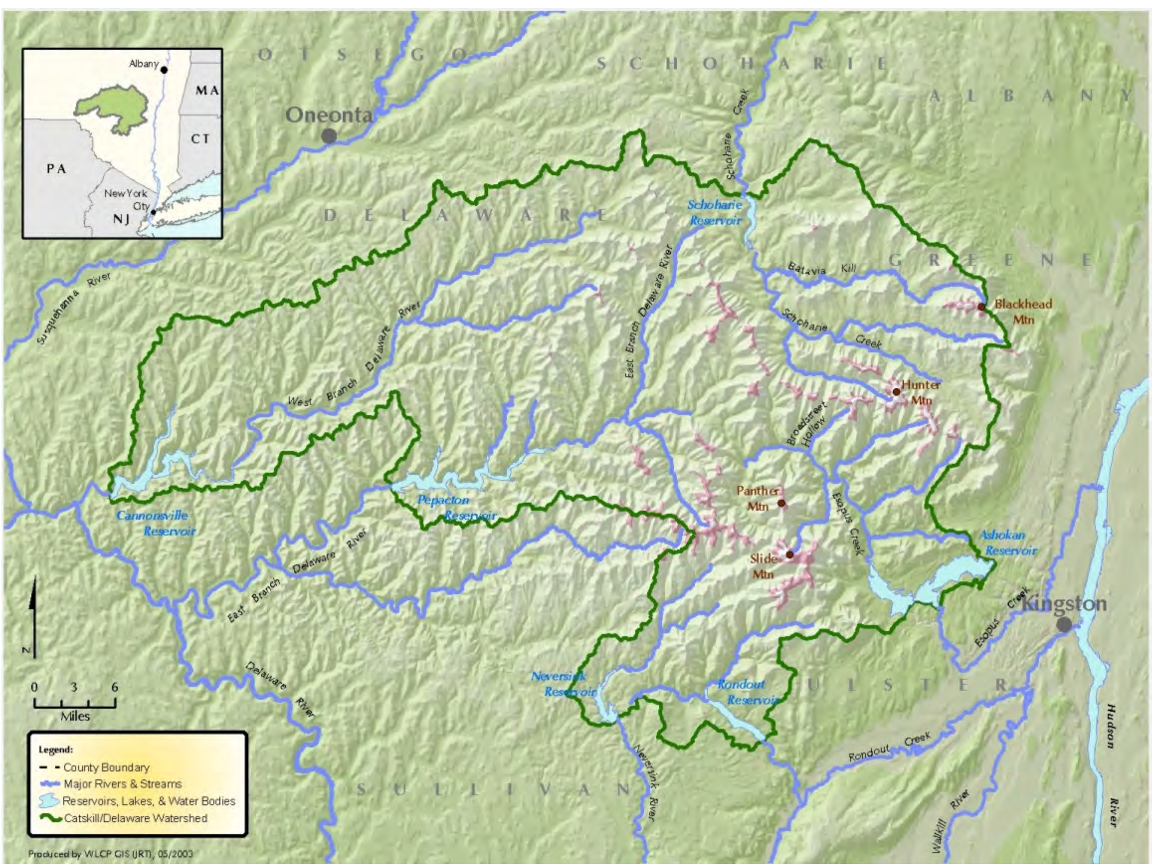
2.4 Geology of the West Kill watershed

Introduction
Catskill Mountain geology provides the framework for valley and stream channel morphology as well as exerting considerable influence on stream water quality. This section briefly describes the basic geology of the Catskill Mountains, an overview of the West Kill watershed geology and how this affects stream channel form and water quality of the basin.

Catskill Mountain Geology
The Catskill Mountains are a dissected plateau of sedimentary rocks carved 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). Rich (1935) provides a useful 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 2.4.1). West Kill is located along the northern side of the Central Escarpment, draining the slopes of Hunter, Rusk, and West Kill Mountains. The geologic discussion that follows is for the Central Escarpment.



igure 2.4.1. Catskill Mountain Region and the West of Hudson NYC Water Supply Watershed

Figure 2.4.2 Bedrock geology of the upper Schoharie Watershed

Bedrock Geology

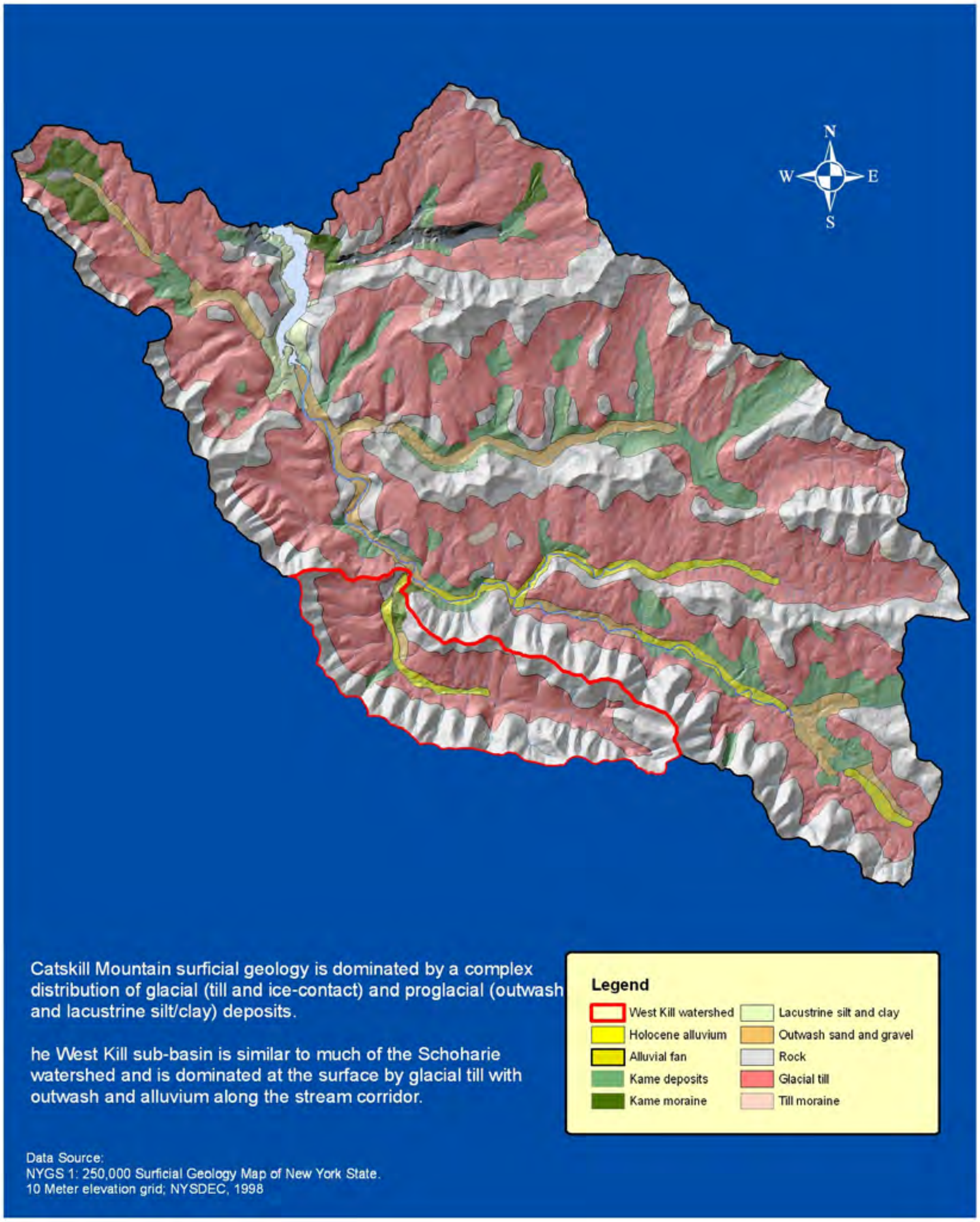
The bedrock of the central Catskill Mountains is sedimentary and composed of interbedded sandstone, siltstone, mudstone, shale, and conglomerate at higher elevations (Figure 2.4.2). The sediments that form the middle-to-late Devonian (390 to 360 million years ago) bedrock are interpreted to be deposits of a vast deltaic river system, often called the "Catskill Delta" deposits (Isachsen et al, 2000). 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 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 following two publications are recommended for further detail on the Catskill bedrock geology: Geology of New York: A simplied account (Isachsen, et al, 2000) and The Catskills: A Geological Guide (Titus, 1998).

The Catskill Delta deposits were buried beneath other sediment, 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 cut multiple channels into the slowly rising plateau. The structure of the uplifted bedrock facilitated erosion and stream drainage development.

Surficial Geology
The ice ages of the last 1.6 million years (Pleistocene Epoch) have left the latest mark on the already incised landscape of the Catskills. Vast continental ice sheets and smaller local alpine and valley glaciers scoured the mountains and left thick deposits in the valleys. The last 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. As measured on the scale of geologic time this was a very recent event.

This was a period of accelerated erosion in the Catskills as the flowing ice sheet bulldozed the past 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 drained the landscape before these most recent glaciers advanced 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. As the ice sheet pulled back (and occasionally readvanced as distinct “lobes” of flowing ice) alpine 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 fluvial and ice-contact deposits, along with thick deposits of layered silt and clay where moraines (deposits at glacial margins) and ice impounded water, forming glacial lakes that filled the valley floors. 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. For more detail on the glacial geology of the Catskills the reader is referred to Rich (1935), Cadwell (1986), and for a popularized account Titus (1996). Figures 2.4.3 and 2.4.4 present the glacial geology for the Schoharie basin and West Kill as mapped by Cadwell and Rich, respectively.



2.4.3 Surficial Geology of upper Schoharie Watershed

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.

2.4.5 Scanned copy of John Rich's 1935 glacial geology of the Catskills map, centered on West Kill

West Kill Geology

The following discussion is an abbreviated account of West Kill geology focusing on its relevance to stream channel condition and water quality.

Bedrock Geology

The bedrock geology of West Kill exerts considerable control on the character of its surrounding mountains and streams. The sedimentary rock, composed of alternating layers of sandstone and siltstone/shales, creates the characteristic Catskill stepped topography. Rickard (1975) mapped the bedrock of the area as part of the New York State Geological Survey Map and Chart Series. According to the geologic mapping, the Walton Formations comprise most of the West Kill watershed bedrock from valley floor to mountain top (Figure 2.4.2). The Oneonta Formation forms the valley floor in the lower half of the watershed. This sequence of rock consists of alternating layers of red beds (shale and mudstones), gray sandstones and small amounts of gray shale (Fletcher, 1967).

Stream deposits in the Catskill Mountains are principally derived from erosion of the layered sedimentary Catskill bedrock. As a result, the sediment particles (typically gravel through boulders) typically form 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 2.4.5). Imbricated streambeds are thus generally more "locked up", and all other things being equal, generally require a larger flow to mobilize the bed material than non-imbricated beds. However this same platy shape can also, under the right conditions, act like an airplane wing and be lifted by the stream flow across it more readily than would a spherical particle of similar weight.

2.4.5 Imbricated stream sediment

Bedrock also forms lateral and vertical grade control throughout the valley. This occurs most spectacularly at Diamond Notch Falls (Figure 2.4.6). These hydraulic controls can represent natural limits to changes in the stream channel system caused by incision or lateral migration. The Management Unit descriptions map the locations of these bedrock exposures along the West Kill.

Insert Figure 2.4.6 as photo of Diamond Notch falls.

An additional and important aspect of the bedrock geology of the West Kill valley as well as all of Schoharie is the presence of the red beds and shale. These rock layers that often form the more gentle slopes of the Catskill Mountain stepped topography were easily eroded during glaciation and ground into the red silts and clay that form the ubiquitous lake deposits. When entrained by stream flow they impart the red-brown turbidity that characterize the streams during storm water runoff conditions.

Glacial Geology
Glacial and associated deposits control such characteristics as depth and nature of *alluvium* (water worked sediments), sediment supply, suspended sediment and stream channel slope and geometry. Awareness of the West Kill watershed glacial geology can help explain some of the stream erosion, hill slope mass wasting, and subsequent water quality problems. This knowledge can assist the stream managers in prioritizing where future stabilization/restoration actions will be most useful.

Rich (1935) and Cadwell (1986) are the primary published sources of information on the glacial geology (deposits and landforms) of the West Kill watershed. During the first quarter of the twentieth century John Rich examined the glacial geology of the Catskill Mountains in great detail (Rich, 1935). His detailed information and interpretation on glacial landforms and distribution of glacial deposits in the West Kill watershed is included in Appendix _ and Figure 2.4.4. The published work by Cadwell is less detailed and at a scale that is not useful for stream corridor assessment (Figure 2.4.3) though it is useful for a watershed scale assessment. The 2004 and 2005 stream reconnaissance (Section _) provides additional detail that can be used to interpret the geology that the stream flows through. As mentioned above the glacial geology story is complex and the detail is not necessary here. What is important to know is the type and distribution of the glacial deposits that influence valley and stream morphology and process.

The West Kill stream and its tributaries flow across a landscape characterized by geologic and geomorphic heterogeneity as a result of the complex distribution of glacial deposits and landforms. Stream channel stability varies in part as a function of this heterogeneity. By classifying the geology along the stream corridor into mappable units that describe the potential bed and bank erosion and entrainment of the stream channel material, recommendations for management of stream reaches can better reflect local geological considerations. For now we can describe the mappable units, though a map of these geologic units has not been created yet for the West Kill. A recommendation for the next phase of West Kill stream management planning is to take the observations made during the various stream reconnaissance walkovers and, in combination with Rich's 1935 map and the USDA Soil Survey maps, create a stream corridor geology map that can be used to assist in identifying fluvial erosion hazard areas, fine sediment sources, and hill slope problem areas.

The following 3 key geologic units that influence water quality and stream stability were used in the Stony Clove Stream Management Plan (reference) and are propose for use here.

Unconsolidated Deposits. (Figure 2.4.7; hillslope or streambank exposure of loose coarse fluvial or ice-contact deposits). This general term is applied to all water-sorted, unsorted and unconsolidated deposits regardless of whether they were deposited directly as recent stream alluvium, glacial outwash (proglacial fluvial sediments), reworked outwash, kame terrace deposits, melt-out till, moraine deposits or reworked lodgement till. For mapping purposes, this unit incorporates finely stratified glaciolacustrine sand

and pebble horizons sometimes interbedded with thin clay beds. The unit is composed of sand, pebbles, 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. 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 fish habitat and limited channel armoring.

2.4.7 Examples of unconsolidated deposits: (a) kame terrace or outwash exposed in bank failure; (b) coarse alluvium in stream bank

Lacustrine silt/clay. (Figure 2.4.8). This reddish or pinkish brown, finely-layered, silty-clay deposit floors significant portions of the mainstem West Kill and lower reaches of several tributaries. It was deposited *subaqueously* (from streams discharging onto the floor of one or two glacial lakes) as a sediment blanket draped over underlying till. Locally, it was also deposited in smaller impoundments associated with alpine glaciers and moraine dams. It is commonly exposed along the toe of a stream bank, sometimes in the channel *invert* (often beneath a poor armor), 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 and clays are easily entrained under high runoff events it is somewhat resistant to hydraulic erosion. The silt/clay unit tends to erode mechanically by slumping along rotational faults, subsequently losing its layered structure and cohesive strength. Within the silt and clay layers, strata of sand sometimes occur, creating the potential for piping and associated mechanical failures. It is extremely soft and, when saturated, physically weak character result in few large bank exposures. Where large exposures of lacustrine silt/clays are exposed and vegetative cover lost, revegetation is usually slow to occur due to the poor drainage 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 armor. Elongate troughs, scour holes and even deep potholes reflect its entrainment potential. Clear stream water contacting lake clays often results in an entire stream becoming turbid within 50 feet. In the West Kill watershed, as in other nearby drainages once occupied by glacial lakes, this unit is a primary source for suspended sediment and turbidity problems.

2.4.8 Glaciolacustrine silt/clay deposits in (a) stream bank and (b) hill slope failure on West Kill

Lodgement Till. (Figure 2.4.9; lodgement till exposure in hillside or streambank) This is an over-consolidated, clay-rich (pink to reddish-brown silty clay loam) till that underlies much of the West Kill valley and its tributaries. It is also plastered against valley sidewalls as a result of extreme glacier ice pressure atop and against pre-existing clay-rich soils. This hard-packed silty clay loam 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 erosionally removed, where streams have scoured into valley wall deposits or where they have breached morainal ridges. It's relatively competent nature, especially as compared to lake clay deposits, 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 cycles. A metal probe or stick can rarely be pushed into this unit more than 0.2 feet. Under conditions of high stream velocities and discharges, lodgement till is a contributor of sediment. Also, rain water and overland runoff contacting exposed banks readily entrains clay and silt-sized sediment fractions, resulting in wet ravel.

2.4.9 Examples of glacial till: (a) lodgment till and (b) melt-out till over lodgment till

Stratification of these geologic units in the stream adjacent hill slope or streambank can facilitate rapid erosion by undercutting inducing cantilever failure. A common problem associated with stratification of these deposits for homeowners along the valley floor is the poor condition for septic leachate absorption and filtration. Septic leachate can "short circuit" to the stream if there is a thin veneer of coarse fluvial deposits overlying dense, impermeable lacustrine or till deposits, resulting in water quality impairment.

The variable character of the West Kill valley streams reflects the complex glacial history of the West Kill valley. The footprint of these glacial processes – the glacially modified landscape with its varying deposits of clay-rich or bouldery till, the silts, sands, gravels, and cobbles of meltwater streams and ice-contact deposits, and the glacial lake clays— can be tracked in the significant variation in floodplain topography, sediment supply (amount and size of material), channel boundary resistance (the "roughness" of the channel, and sediment resistance to moving in high stream flows) and rate of vegetative recovery of streambanks and hillslopes following catastrophic disturbance. In this way, the current architecture of the stream channel (its size, shape, bed form) is influenced to a large extent by the glacially and post-glacially deposited soils through which the stream runs, and in the adjacent hillslopes. Section 3 below provides an overview of stream processes, including more detail on the role of bed material in stream channel morphology. The detailed management unit descriptions in Section 4 describe channel material characteristics reach by reach.