

Aquifer Report
Mianus River
Upper Watershed Analysis

Towns of Bedford, North Castle, and Pound Ridge
Westchester County, New York
Town of Greenwich
Fairfield County, Connecticut



Engineers
Land Surveyors
Planners
Environmental & Safety Professionals
Landscape Architects

Prepared for:

Mianus River Gorge
167 Mianus River Road
Bedford, New York 10506

August 30, 2016

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1.0 INTRODUCTION

Mianus River Gorge retained The Chazen Companies to describe aquifers supporting the upper Mianus River based on readily-available data, and to offer observations and recommendations which might help preserve water quality and river baseflow through the Mianus River gorge. No field work was conducted to support this study although Chazen has spent some time driving through parts of the watershed for purposes of general familiarization.

Sections 2.0 through 4.0 of this report review the geography of the upper watershed, associated aquifer characteristics, and provide groundwater planning recommendations, respectively.

2.0 GEOGRAPHIC CHARACTER

Many geographic factors influence groundwater resources in the upper Mianus River watershed. The following sections summarize some of these.

2.1 Topography

For purposes of this study, the upper watershed of the Mianus River extends from the southern end of the Mianus River gorge in Greenwich, Connecticut, to headwaters of the watershed found primarily in the Westchester County Towns of Bedford, North Castle, and Pound Ridge. Figures 1-4 show the limits of the upper watershed, which covers approximately 13 square miles. Elevations lie primarily between 350 and 500 feet above mean sea level (amsl), with some ridgelines cresting over 650 feet amsl. The outlet of the Mianus River gorge at the head of the Mianus Reservoir lies at approximately 250 feet amsl.

The upper watershed is noted for the intersection of two dominant sub-valley alignments, such that Mianus River headwaters first flow northward toward of Bedford Village hamlet before the river then turns southward toward the Mianus River gorge. Topography of the north-flowing headwater section includes a valley floor approximately 1,000 feet wide generally parallel to and east of Route 22. Upper watershed areas adjoining the river valley consist of rolling hills and to the west some moderately-rugged ridgelines.

The upper watershed is also noted for three saddle valleys where precise watershed limits are somewhat indistinct. Saddle valleys are recognized where divergent streams lie within a common valley. The most prominent of these lies near Bedford Village where headwaters to a Stone Hill River tributary lie within approximately 2,000 feet of the Mianus River. The other saddle valleys lie in the Town of North Castle, with the more prominent found near Banksville and the Deercrest Country Club and associated commercial center. The third saddle valley is narrow and lies south of Long Pond. Saddle valley divides are noted on Figure 1.

2.2 Geology

Geologic formations in the upper watershed of the Mianus River include bedrock formations and overlying sediment formations.

Bedrock formations consist primarily of the Fordham Gneiss and the Bedford Gneiss, separated by a linear expression of Inwood Marble (Figure 2). Topography (Figure 1) and bedrock (Figure 2) suggests the following:

- Areas with Fordham Gneiss are notable for the highest topographic ridgelines and the most rugged geology in the upper Mianus River watershed, suggesting massive and hard-mineral composition on the basis of resistance to weathering and erosion.

-
- Areas with Bedford Gneiss similarly support higher-elevation highlands situated between the north-flowing and south-flowing Mianus River segments. Topographic expression suggests the Bedford gneiss may be marginally softer than the Fordham Gneiss but still highly resistant to mechanical and chemical weathering and to erosion. The north-south alignment of the Mianus River gorge conforms to a prominent linear feature mapped by the New York State Museum (Isachsen, 1977). From a topographic and hydrogeologic perspective, the Manhattan, Hartland, and Trap Falls formations are similar to the Bedford Gneiss each with smaller geographic coverages within the upper Mianus River watershed.
 - The Inwood Marble appears to define the flow of the north-flowing segment of the Mianus River and associated saddle valleys to the north and south. Carbonate formations (dolostones and limestones or their metamorphic marble equivalents) commonly underlie eastern New York valleys, such as this one, due to the greater vulnerability of carbonates to chemical weathering and mechanical erosion/weathering. The current alignment of the marble east of Mianus River may suggest where the marble was first exposed at grade as the Mianus River initially began inscribing its current valley.

Surficial geology (e.g. soils and associated sedimentary substrate) overlie all bedrock formations in the upper watershed of the Mianus River. Glaciation of the region left both water-sorted sediments in select lowlands and mixed clayey soils in upland areas.

- Near-bare rock and glacial till forms the dominant cover material on hillsides and hilltops (Figure 3). Glacial till consists of chaotically-sorted sediments which can include random boulders hosted in a glacial sediment mix dominated by compacted clay and silt. Till sediments were transported within and under the glaciers, either compressed under the ice or left as hillside drape deposits as ice melted away. Mullaney (2004) has identified till averaging 12 to 35 feet thick in nearby Fairfield County; similar thicknesses can be expected throughout the upper Mianus River watershed.
- Sediments sorted by moving water as the glaciers melted away lie dominantly in the northern section of the north-flowing Mianus River valley, and in the saddle valley near Banksville. The deposits have been characterized as Kame deposits by geologists (Figure 3) meaning they are interpreted to have been deposited in close proximity to the waning ice margins and thus were prone to significant variability from coarse sand and gravel to silty-clay horizons because of the rapidly changing water flow environment. Mullaney (2004) reports stratified sediments at least 35 feet thick in the Banksville area. Well records nearer to Bedford Village identify washed deposits up to 70 or more feet in thickness. Where saturated, the Towns of Bedford, North Castle, and Pound Ridge recognize these washed sediments as productive sand and gravel aquifers.

2.3 Water Consumption Patterns

Groundwater is the source of water supply for residents of the upper Mianus River watershed. Most water use in the upper watershed of the Mianus River is withdrawn by individual, private wells, but collective wells are used in community water systems supporting water districts near the Bedford Village hamlet center and elsewhere. Watershed runoff also supports the Mianus Reservoir in Connecticut, reportedly providing drinking water for approximately 130,000 people in Connecticut (Bedford, 2002). Thus, the upper Mianus River watershed is both used in-situ for domestic and public water system wells, and as a source watershed for the Mianus Reservoir.

Aside from swimming pool use, residents using private wells are estimated to withdraw approximately 113 gallons daily per person (interpreted from Mullaney, 2004). Applying typical occupancy rates of approximately 2.6 persons per household, this means daily well water withdrawals of approximately 294 gallons per home, aside from significant irrigation or pool usage. Water withdrawals in residential areas normally peak in summer due to increased seasonal general outdoor water uses.

Of these pumped gallons, residents only “consume” a portion of water, typically 20%. They pass the balance through as wastewater (Solley and others, 1998). Consumed gallons are dissipated by perspiration, steam from cooking, and evaporation from watering of plants, washing of cars, and use of dishwashers and clothes driers, among other activities. Consumption in this sense refers to water which is not available to return to the ground (e.g. via septic systems) or to streams or the ground (e.g. via local area wastewater treatment plants).

Aquifer modeling completed by Mullaney (2004) in Greenwich, CT, concluded that aside from heavy irrigation or pool filling uses, normal residential consumptive use of groundwater is small compared to total available recharge. Non-residential uses, heavy irrigation, or pool filling (as opposed to pool topping up) can nonetheless result in more significant localized reductions in available groundwater that is affected by otherwise day-to-day groundwater removal and water consumptive.

Water passed back to the environment from homes and facilities/businesses is typically discharged to septic systems or to wastewater treatment plants. Septic system returns often lie within a few hundred feet of points of well withdrawal, significantly off-setting local-area groundwater withdrawal impacts. During warm weather periods, some 30 to 50 percent of water released to septic leaching fields can in some instances be lost to transpiration depending on soil types. Wastewater treatment facilities generally experience lower evaporative losses than septic systems but also often discharge treated wastewater to streams or other surfacewater bodies distant from where groundwater was withdrawn, resulting in heavier groundwater withdrawal influences around the active well locations.

Land uses can influence rates of surface water runoff, evaporation, or plant transpiration (evapotranspiration). Forested lands and low-density residential land are dominant land uses in the upper Mianus River watershed. Concentrated residential and commercial use areas including those in Bedford Village and Banksville are generally clustered along transportation corridors. Heavy residential development is also found in select portions of the watershed.

3.0 GROUND WATER RESOURCES

Aquifers are defined technically as geologic formations providing economically-valuable volumes of water. All bedrock formations in the upper Mianus watershed are currently providing critical groundwater to residential homeowners and/or commercial entities, so are recognized here as bedrock aquifers. A sufficient share of the glacial kame deposits include saturated sand and gravel to suggest these deposits can be collectively referred to as overburden gravel aquifers.

Precipitation is the sole source of groundwater recharge to upper Mianus River aquifers. This water enters the subsurface through soils to replenish available aquifer storage in the fractures and the sediment pore spaces of the watershed's geologic formations.

Once such recharge reaches the saturated sediment or fractured rock zone, it then seeps through pore spaces and fractures toward lower elevation areas. Just as storm water flows downhill as overland flow, groundwater flow typically mimics directions of overland flow and can be considered "underland flow". Groundwater then re-emerges at grade at springs or in streambeds, providing base flow to streams and water to ponds and lakes. Wells installed along groundwater flow-paths tap the groundwater resource and reduce discharge to streams proportionally to consumed water volumes or to total pumped volumes depending on local wastewater return arrangements.

The natural flow of groundwater to streams provides aquatic baseflow that stabilizes stream flow between runoff events, typically sustaining better than fifty percent of overall stream flow.

3.1 Bedrock Aquifers

With limited areas of sand and gravel in the upper Mianus River watershed, bedrock aquifers are geographically dominant. Bedrock formations generally support well yields in the range of 5 to 15 gallons per minute, and sometimes less due the massive nature of the bedrock formations with only limited fractures. Bedrock aquifers store and transmit groundwater along fault surfaces and along other fractures and joints in the rock.

Linear feature analysis can suggest well drilling locations where intersecting or multiple fractures and faults may intersect, supporting higher-yield groundwater wells, sometimes in the range of 50 or more gallons per minute.

From a groundwater recharge and flow perspective, bedrock aquifers in the upper Mianus River watershed may be considered in the following general terms:

- The watershed's gneiss formations may be collectively recognized as valuable bedrock aquifer based on the current uses of wells to support widely-distributed individual wells exhibiting a wide range of yields.

-
- The marble formation extending through the upper Mianus River watershed likely provides statistically higher yields than well installed in the gneiss aquifer, based on the greater tendency of carbonate to fracture in response to tectonic stresses.
 - The upper tens of feet in both gneiss and marble aquifers may exhibit a greater density of weathering and erosion fractures and thus provide marginally higher well yields than deeper portions of any well column. However, in higher elevation locations, such shallow fractured zones may not always be saturated and so well yields may be dependent solely on fractures encountered deeper in the well column.
 - Groundwater flow in bedrock formations generally flows toward the nearest perennial stream where it emerges as baseflow discharge. Where a single bedrock formation extends over several tributaries, groundwater does not mix or risk contamination or over-use across tributary divides; rather each drainage remains a localized hydrogeologic regime dependent on recharge within each discrete drainage areas, with groundwater migration toward each localized tributary, and with hazards to aquifer depletion or quality defects limited to the individual tributary drainage. Thus, two adjacent drainages sharing a common bedrock aquifer can exhibit quite different quality and capacity based on land uses and water uses.
 - Generally modest rates of bedrock aquifer recharge and low bedrock permeability can lead to localized over-pumping of bedrock wells. This occurs most frequently where wells are closely clustered or where pumping rates exceed local area recharge rates. Such localized over pumping impacts however typically do not extend far beyond the locations of intensive withdrawal, and do not imply that entire bedrock aquifers in the watershed are being over-pumped or depleted.

3.2 Surficial Aquifers

Surficial aquifers consist of porous sediments such as sand and gravel and are normally found in valleys where pore-spaces can remain saturated with groundwater throughout the year. Sediments found above the watertable are not referred to or recognized as aquifers.

Glacial kame deposits provide a reserve of sediments including porous sand and gravel. Kame deposits are mapped along the Mianus River within North Castle and extending to the Bedford Village hamlet center, and also into the Banksville commercial center area.

Two wells drilled for the proposed Guard Hill Farms site slightly north of Bedford Village penetrated 70 feet of sediments. The upper 50 feet consist of fine silty sand and silty clay before the sediments coarsen at depth. Well screens are set in the coarser, deep sand and gravel and extend into the first 10 feet of underlying fractured bedrock. The overlying silt/clay confines the gravel and fractured rock to such a degree that the deeper groundwater is under pressure and

overflows the well casing at grade when the well is not being actively pumped. Pumping tests were conducted only at the rate needed to supply the particular project at 40 gpm rather than to define the maximum potential aquifer yield. The report suggests the wells could support considerably higher yields (Smiriglio, 1994).

Production and monitoring wells drilled to support the Rippowam Cisqua High School situated between Route 22 and the Mianus River identified similar sediments, up to 70 feet thick. Pumping tests were conducted above the approximate 8 gpm rate required for the school, at 71 and 200 gpm, in each case with only approximately 20 feet of stabilized drawdown in the test wells, suggestive of yet higher available flow capacity from these wells. As at the Guard Hill location, considerable sediment variability was encountered when advancing borings on the site, including encountering approximately 40 feet of silt overlying 11 feet of more productive fine-to-medium sand in test well PW-2 (Smiriglio, circa 1998), confirming both unconfined and confined aquifer horizons at this location. Several ponds without outlets lie on site, serving as reflections of watertable conditions in the unconfined sediment horizons in this vicinity. Ponds supported by pumped wells are described to meet irrigation requirements for school fields. Analysis by Leggette Brashears & Graham Inc. referenced in a project DEIS suggests that the Mianus River will experience a 30,000 gpd flow depletion as a result of irrigation uses of water (Kellard, 1999), characteristic of higher groundwater consumption rates associated with such non-domestic water uses. The proportional impact of such consumptive irrigation loss on flow of the nearby Mianus River will differ depending on the seasonal flow of this watercourse.

Four public water system wells tapping saturated sand and gravel for Windmill Farms have reported yields from 85 to 220 gallons per minute (gpm) from wells with a median depth of 57 feet (BBL, 1990). Such wells are likely be overburden wells but Chazen is unaware of any extensions of valley sediments into the vicinity of Windmill Farms. Monitoring wells installed east of the Hunting Ridge Mall tap sediments 38 to 60 feet thick (NYSDEC, 2002). Finally, Westchester County has mapped unconsolidated aquifers, including the upper Mianus Watershed study area, concurring with the approximate delineation of the kame deposits found along the Mianus River (Figure 3). The County map suggests the section nearer to Bedford Village is most likely to support average well yields exceeding 100 gpm (Westchester County, 2001) although no metadata available to Chazen supports this determination.

From a groundwater recharge and flow perspective, surficial aquifers in the upper Mianus River watershed may be considered in the following terms:

- The primary surficial aquifer in the upper Mianus River watershed consists of glacial kame deposits found along the Mianus River in the vicinity of, and upstream of, the Bedford Village hamlet. A secondary surficial aquifer lies near Banksville.
- The permeability of unconsolidated sand and gravel sediments tends to be higher than that of fractured bedrock so average well yields can be higher than those installed in bedrock aquifers.

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- Sediment variability is considerable in the surficial aquifers found along the Mianus River. Sediments range from silty-clay, to sand and gravel, warranting detailed soil borings to identify locations with higher-capacity sand and gravel and creating both watertable and partially-to-fully confined groundwater resources. Figure 4 reflects this sediment variability by identifying Hydrologic Soils Groups A through D across the valley bottoms. Confined groundwater does not have an immediately-overlying connection to grade either for recharge or discharge purposes, instead being reliant on typically nearby recharge and discharge locations within the watershed.
 - Valley saddle unconsolidated sediments near Bedford Village and Banksville represent locations where precise watershed dividing points defining shallow groundwater migration into or out of the Mianus River watershed may vary seasonally or on the basis of well pumping influences.
 - The geographic location of kame deposits in valley-center locations ensures enhanced groundwater capacity from the Mianus River's surficial aquifers since recharge from adjoining bedrock aquifers often migrates through the valley sediments before reaching streams. Stated another way, the recharge areas for surficial aquifers usually includes portions of adjoining bedrock aquifers. Inspection of Figure 3 can be used to consider how groundwater recharge into bedrock aquifers to the east and west of the Kame deposit migrates through the sediment formations before reaching the Mianus River. This relationship supplements the reliability of groundwater resources coming from valley sand and gravel formations, and also explains the source of the confined pressures found under some valley silt and clay sediments (e.g. as found at the Guard Hill location) where the adjacent higher-elevation bedrock aquifers drive groundwater into and below the confined valley sediments, where pressures can accumulate below confining silt and clay. (In the absence of wells, such pressures are normally relieved by groundwater migration around or over such horizons.)

3.3 Soils and Aquifer Recharge

A United States Geologic Survey report indicates that the mean annual precipitation near the Mianus River gorge is between 48 and 50 inches annually, and that typical evaporation and plant transpiration removes between 22 and 23 inches (Randall, 1996), leaving approximately 25 inches of precipitation available each year to recharge aquifers or to flow as overland runoff directly to streams. In reasonably close agreement, Mullaney (2004) similarly reports 48 to 50 inches of annual recharge in nearby Greenwich CT, with some 21 to 23 inches of rainfall reaching streams either directly or as groundwater baseflow although Randall (1996) suggests average annual rainfall near the Greenwich ocean shore falls to 44 inches.

Soils substantially control the rate of surface water recharge into groundwater. Soil mapping conducted by the Soil Conservation Service assigns Hydrologic Soil Group (HSG) ranks to every

soil. Recent investigations by Brandes et al (2005) suggest that the distribution of Hydrogeologic Soil Groups in watersheds correlates closely with recharge rates. The distribution of Hydrologic Soil Groups in the upper Mianus River watershed is shown on Figure 4.

Hydrologic Soil Group A and A/D soils allow high infiltration rates and consist chiefly of deep, well- to excessively-drained sand or gravel. HSG A soils in the upper Mianus River watershed are exposed at grade in less than 5 percent of the watershed, found primarily along the creek and exposed in reportedly-mined lands between mid-North Castle and the Bedford hamlet center (Figure 4). To prepare Figure 4, Chazen assigned soils attributed to mining to A or B HSGs based on adjoining undisturbed HSG determinations. Only limited acreages of HSG A soils are found on hillsides or hilltops. Most HSG A soils instead lie within short distances of streams or wetlands in valley settings.

Hydrologic Soil Group B soils are dominant in the upper Mianus River watershed, covering approximately 60 percent of the watershed (Figure 4). HSG B soils allow more moderate infiltration rates than do HSG A soils, consisting of moderately-fine to moderately-coarse textures. HSG B soils are somewhat uniformly distributed across the watershed, found both in valley areas with sediment soil cover and in upland hillside areas covered by glacial till.

Hydrologic Soil Group C and C/D soils have yet lower infiltration rates and consist of silty soils which substantially impede aquifer recharge. These soils have moderately-fine to fine textures and are found dominantly in areas with soils derived from glacial till although some HSG C soils are also found near the Bedford hamlet center. Approximately 30 percent of the watershed is covered by Hydrologic Soil Group C or C/D soils.

Hydrologic Soil Group D soils have the lowest infiltration rates of any natural soils, and consist primarily of clay and silty clay. Except for linear soils along riverbanks and upland wetlands there are few HSG D soils in the upper Mianus River watershed, consisting of only approximately 5 percent of the watershed. Most HSG D soils lie in valley settings coincident with current wetlands.

The balance of the upper watershed acreage consists of open water bodies, either flowing streams, instream ponds, or isolated ponds.

A Dutchess County study calibrated estimated aquifer recharge rates using Hydrologic Soil Groups (Chazen, 2006a). Calibrating recharge rates to the annual average rainfall rate of 48 inches in the upper Mianus River watershed, aquifer recharge rates near the Mianus River are estimated at:

- 22.1 inches/year through HSG A and A/D soils,
- 16.1 inches/year through HSG B soils,
- 8.3 inches/year through HSG C and C/D soils, and
- 4.6 inches/year through HSG D soils.

Using these aquifer recharge values, total estimated aquifer recharge entering the aquifers of the upper Mianus River watershed averages 8.2 million gallons per day.

This can be segmented as average daily recharge rates of:

- 1,647 gpd per acre through HSG A soils,
- 1,198 gpd per acre through HSG B soils,
- 620 gpd per acre through HSG C soils, and
- 342 gpd per acre through HSG D.

During drought years, average daily rates may decline by as much as 30 percent. A majority of aquifer recharge occurs between October and May when air temperatures minimize rates of evaporative loss and plant transpiration is reduced or absent.

Aquifer recharge modeling by Mullaney (2004) identified a unified groundwater recharge rate of 6.9 inches per year for glacial till in Greenwich. This value is at the low end of the recharge values suggested using the Dutchess County methodology. But rainfall along the Atlantic shoreline is lower than that in the upper Mianus River watershed, glacial till tends toward HSG soils B through D, and the ratio of HSG soils in Greenwich is not the subject of analysis examined by Mullaney. In general, the Mullaney and Dutchess County values are considered to be in acceptably agreement for purposes of this overview analysis.

Groundwater discharges support streams and riparian wetlands. Flow volumes come both from the aquifer recharge described above, and also from transient groundwater movement, or interflow, entering the subsurface only briefly and following root channels, clay seams, or buried bedrock surfaces rather than penetrating deeply enough to reach aquifer formations. Interflow contributions to streams generally dwindle within a few weeks after major rains but are estimated to add an additional 35 percent of baseflow to streams (Chazen, 2006b). Such “interflow” represents an important portion of stream flow for a week or two following rainfall events. Once this contribution drains, baseflow from the underlying surficial and bedrock aquifers then maintains continuing stream flow through longer droughts. The close proximity of most HSG A soils to major streams means that although significant quantities of water recharges aquifers and interflow through these soils, this recharge is likely to reach streams soon after precipitation events; it is recharge entering aquifer systems most distant from streams which supports stream flows for the longest periods after precipitation events. This is the recharge which is critical for the support of dry season stream flows and to the reliability of wells installed between near streams. The majority of areas most distant from streams are on hillsides or other upland areas covered by HSG B or C soils.

Considering both aquifer recharge and interflow recharge together, approximate total groundwater recharge through soils in the upper Mianus River watershed is estimated as follows

- 29.9 inches per year through HSG A and A/D soils,
- 21.7 inches per year through HSG B soils,

- 11.3 inches per year through HSG C and C/D soils, and
- 6.2 inches/year through HSG D soils.

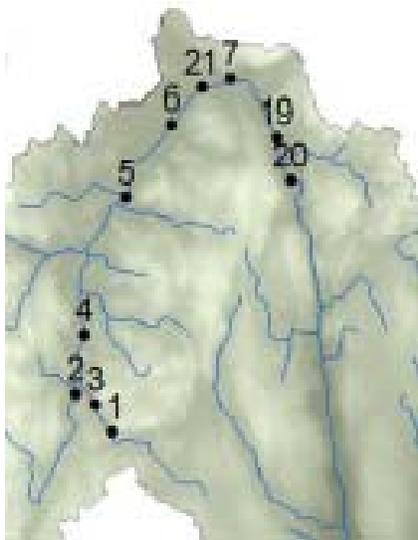
3.4 Groundwater Flow

Groundwater seeps toward lower elevations in the same manner as surface water, albeit far more slowly due to the intricacies of the pore and fracture pathways. Flow moves from points of higher elevation to points of lower elevation, generally mimicking surface topography. This occurs even where a common regional aquifer extends across adjacent drainages. Flow arrows shown on Figure 3 show such estimated general directions of groundwater flow in the upper Mianus River watershed.

3.5 Groundwater Quality

Groundwater quality varies by discrete well location but may also be considered in the aggregate by examining surfacewater quality as a reflection of regional aquifer discharge into streams. This text section examines the regional water quality record suggested by stream quality data, and then briefly reviews the significance of discrete remediation sites.

Water quality in the Mianus River was evaluated in 2011, 2012, and 2013 at ten locations in the upper Mianus River watershed (Saia, 2011, 2012, 2013).



The locations are shown to the left. Location 21 was introduced in 2012 when location 8 became inaccessible. Location 21 has tended to identify water quality different from most other stations for reasons unknown to Chazen. A record of data, organized from upstream to downstream, from these stations is provided on Table 1 (From Saia, 2013). Chazen's summary observations based on Table 1 are noted below:

- Water pH values in the watershed are typical for streams both with biological activity and overlying buffering carbonate bedrock horizons, tending to slightly basic pH values between 7.48 and 8.04. The most basic values are found at locations 19 and 20, potentially identifying where shallow groundwater otherwise migrating down valley within the sedimentary kame deposits in near proximity to underlying marble bedrock is forced to grade as the sediments thin. Stream gaging might demonstrate significant gain in flow between locations 7 and 19 across this zone of geologic and stream water quality change.
- In general, both nitrate (NO₃) and nitrite (NO₂) levels in the Mianus River sampling locations are quite low and very consistent, without evidence of increases nearer heavier

settlement area. Elevated nitrogen compounds in a watershed can come from various sources, including overly-dense concentrations of septic systems. Thus, with the exception of the sharply elevated nitrate recorded at location 21, the river's nitrogen data otherwise suggest septic system discharges are not a current significant quality stressor on the upper watershed. Uniform and healthy Dissolved Oxygen (DO) concentrations similarly suggest nitrate conversion is occurring without anoxic effect. Recommended minimum area septic densities is discussed elsewhere in this report.

- Salt use in the watershed, whether for road management or well softening, can lead to increased sodium and chloride in groundwater, often most notable during low-flow periods or spring “first flush” samples. Sodium (Na) and chloride (Cl) concentrations in stream water samples are quite consistent across all locations except for sharp increases as location 21, but apparently fully diluted once again before reaching location 7. The use of water softeners in the watershed is unknown to Chazen, but road salt typically better explains broadly distributed salt presence as demonstrated here. There is no bedrock salt formation in this area, so all salt must be considered to have been introduced by either road deicing and/or water softeners. Sodium concentrations in all locations vary at or around the human health NYSDOH guidance sodium threshold for individuals on most restrictive sodium diets.
- Soluble reactive phosphorous (SRP) values are somewhat elevated relative to EPA criteria for P levels in streams entering lakes. Sources of phosphorous in this watershed are unknown to Chazen and the uniform distribution at all locations suggests pervasive rather than point sources.
- Select quality parameters suggest some geologic distinction among stream reaches:
 - The stream segment evaluated by locations 1 and 3, originating from the direction of Banksville, exhibit higher concentrations of Total Organic Carbon (TOC), Sulfate (SO₄), Potassium (K), Iron (Fe), Magnesium (Mg), Manganese (Mn), Sulfur (S), Silica (Si) and Strontium (Sr) than other locales. This reach flows almost entirely across the Bedford Gneiss and may reflect the general nature of groundwater moving through this specific geologic formation.
 - The stream segment evaluated by location 2, originating from headwaters collected on the Fordham Gneiss is low in Sulfate, Iron, Magnesium, Manganese, Sulfur and Strontium, potentially reflecting also the general nature of groundwater moving through this geologic formation.
 - Total Suspended Solid (TSS) values vary throughout the upper Mianus River, suggestive either of shifts in substrate material such as locally-mobilized bottom silts, or changes between calm water versus riffle reaches.

Relative to potential commercial/industrial contaminant impacts, no heavy metals (As, Cd, Cr, Pb, Cu) were reportedly detected in 2011 at all sampling locations (Saia, 2011). The sampling regime did not include analysis for semi-volatile or volatile organic compounds (SVOCs or VOCs), but it would be unusual for VOCs (gasoline and solvents) or SVOCs (fuel oil and other heavier petroleum products) to be present in detectable concentrations except in close proximity to active spill areas, so the absence of such sampling data is not judged to be a data gap likely to be allowing overlook of significant undetected impacts.

Discrete locations with groundwater contamination are not the focus of this watershed hydrogeologic review, however, the following conditional notes are offered for purposes of representative planning or groundwater utilization purposes:

- Sampling data from stream location 21, between locations 6 and 7 is distinct from the other upper Mianus River watershed stream records for reasons unknown to Chazen (Table 1). The location demonstrates higher Dissolved Oxygen, Total suspended Solids, Chloride, Nitrate, Bromide, Potassium, Magnesium, Manganese, and Sodium than most other locations, and lower Silica. Discrete study of this location may be warranted, although we note that these anomalous conditions appear to dissipate shortly downstream by location 7 so the geographic influence of these quality parameters appears limited.
- In the late 1970s, private wells near active or former dry cleaners in Bedford Village were discovered to contain dissolved chlorinated solvents. By 2001, source removal and other measures had lowered contaminant concentrations at two source locations, the Shopping Arcade and Hunting Ridge Mall sites, to levels such that surface water samples met or only marginally exceeded surface water standards (NYSDEC Fact Sheet, November 2001) and no surfacewater samples from the Mianus River detected chlorinated solvents (NYSDEC, Proposed ROD Amendment, December 2001). Arrangements were being considered to provide a community water system (e.g. public water) to residents whose wells remained impacted by chlorinated solvents.

4.0 GROUNDWATER RESOURCE MANAGEMENT

4.1 Groundwater Summary

Precipitation represents the sole source of groundwater, surface water, and stream flow in the upper Mianus River watershed. The upper Mianus River watershed includes extensive bedrock formation, and more limited sedimentary formations southwest of and extending under the hamlet of Bedford Village with smaller sources of sand and gravel situated near Banksville. On an aerial basis, bedrock aquifers are more geographically extensive while the sand and gravel aquifers have supported higher capacity wells and provide higher porosity and thus stored groundwater volumes (on a per unit area basis) to support flows of discharging groundwater to the Mianus River during dry seasons.

Groundwater in the Town is recharged by precipitation infiltrating through overlying soils. A unique characteristic of aquifers in the upper Mianus River watershed is that segments of the sand and gravel groundwater resources are found in three valley saddle settings where the precise groundwater divide likely varies by season and water withdrawal conditions.

4.2 Available Yield

A functional approach to manage and preserve available well yields in the upper Mianus River watershed should involve strategies already engaged by some Towns in the watershed.

- Require preparation of water recharge budgets and analysis of off-site drawdown impacts for any proposed larger new wells. Pumping test protocols are discussed specifically in Section 4.5.
- When considering new projects, distinguish between water withdrawal and consumption. Withdrawals offset by wastewater returns impose less watershed stream capacity impact than water withdrawals supporting heavy irrigation with high rates of evapotranspiration losses, or for withdrawals associated with interbasin transfers either directly to sites outside the Mianus River watershed or in the form of fluid export businesses. Projects with large irrigation demands or water export typically result in gallon-for-gallon reductions in stream capacities. NYSDEC requires close analysis of interbasin transfers exceeding 1 million gallons daily (694 gpm) under 6 NYCRR Part 601.18 but lower threshold evaluations may be appropriate in tributary headwaters or along critical stream resources.
- Ensure that residential parcels which are developed with individual wells and septic systems meet minimum parcel size criteria to support wells and to adequately dilute septic system wastewater discharges (see section 4.3). This management approach also ensures that residential uses will intercept only a fraction of total groundwater recharge, preserving dry-season stream flows and quality in the Mianus River.

4.3 Minimum Parcel Sizes

Where individual wells and traditional septic systems are likely to be in long-term use, average parcel sizes should be large enough that on-site recharge can both sustain well use and provide adequate dilution for wastewater discharges. Nitrate loading analysis has been provided to predict where wastewater constituents may be overloading aquifers, either now or in the future.

There are various available nitrate loading models. A model developed by Chazen is based on a variation of New Jersey's septic system minimum density calculation (Chazen, 2006a). The approach identifies minimum average recommended parcel sizes suitable for settled areas with many adjacent parcels. The nitrate loading calculation formula is shown below.

$$A = (4.4186HM / CqR) + Isc$$

Where

A = recommended minimum acres per system, in acres (e.g. parcel size)

H = persons per system

M = pounds of nitrate-nitrogen per person per year

Cq = Nitrate-nitrogen target average groundwater concentration, in mg/L

R = Annual Recharge Rate, in inches

Isc = Impervious surface cover, in acres

This formula can allow flexibility for evaluating unique projects, but may also be used with default values for broad planning purposes. The recommended default values are:

H = 2.6 persons per household, representing regional typical occupancy levels

M = 10 pounds of nitrate-nitrogen.

Cq = 5 mg/l, equal to half the nitrate drinking water standard so that, as results average around this goal, most outcomes will remain below the standard.

Isc = 0.1 acres, to address driveways, roofs and other impervious surfaces.

R = use annual average recharge rates addressed elsewhere in this report for each of the four Hydrologic Soils Groups.

Using the recommended formula, and conservatively assuming aquifer recharge based on 44 inches of annual rainfall due to some suspected recharge rejection during peak storm events suggests the following:

For areas with Hydrologic Soil Group A:	1.2 acres per system
For areas with Hydrologic Soil Group B:	1.6 acres per system
For areas with Hydrologic Soil Group C:	3.0 acres per system
For areas with Hydrologic Soil Group D:	5.4 acres per system

Towns may wish to ensure that rural area average parcel sizes average at least 2.5 acres to ensure adequate bulk nitrate dilution for the areas with extensive coverage by Hydrologic Soil Groups B and C.

Additional sources of nitrate in aquifers do exist but are not included in this density model. For example, properly applied lawn fertilizers are fully utilized by site vegetation and will not contribute to elevated regional groundwater nitrate concentrations. Moreover, lawn fertilizer is not used at all homes, and is applied at ground surface rather than being released below ground level as are septic system discharges. Accordingly, nitrate from lawn fertilization can be readily addressed or mitigated by modified practices and community best management practice education and so need not be included in the calculations above.

4.4 Aquifer Protection

Many residents and businesses in the upper Mianus River watershed use wells which are individually owned and for which no routine sampling is required and for which no regulatory agency provides routine long-term quality or capacity management. In lieu of this, and since all geologic formations in the watershed are used for water supply purposes, this study recommends adoption of aquifer overlay protection ordinances to provide measures of groundwater quality protection in the communities and to enhance stream water quality.

Several upper Mianus River watershed Towns already possess aquifer protection programs. These should be examined to ensure they provide management and protection for bedrock aquifers as well as for the more limited acreages of surficial geologic aquifers. Aquifer ordinances often prioritize protection for sand and gravel aquifers and give little attention to bedrock aquifers supporting substantial domestic wells and where remedial efforts, if ever necessary, tend to be most costly.

4.5 Pumping Test Protocols

Where wells are installed for new community water supplies, testing of wells must conform to protocols required by the NYS Department of Environmental Conservation. Wells intended for such uses are normally required to undergo testing for at least 72 hours.

The 72-hour test protocol used for most community water systems is appropriately conservative since tests are normally conducted at twice the average proposed project daily water demand. Such tests are thus also likely to successfully identify groundwater shortages in a project area. During project scheduling and SEQRA scoping for such projects, Municipal boards should be encouraged to ensure that the following additional test and review components are also met to ensure reliability and persistence of stream flows:

1. Off-site monitoring in any adjacent existing wells, streams and/or wetlands.
2. Analysis and comparison of proposed water consumption (extraction less wastewater returns) to best estimates of local drought-flow level (e.g. 7Q10) in the nearest

watershed streams. If water consumption planned by a project exceeds stream drought flow, the project is likely to result in seasonal flow termination.

3. Flow tests may need to be extended if necessary until water levels in not only test wells, but also wells monitored on-site and off-site wells also stabilize or show 180 day drawdown projections consistent with those tracked in the pumping wells.

Where subdivisions of approximately 10 or more parcels are proposed using individual wells and septic systems and where average parcel sizes smaller than those recommended in Section 4.3 are allowed by zoning, some specific analysis may be warranted as part of project SEQRA reviews.

Bedrock wells or wells installed in confined aquifers may not directly influence water levels in a nearby wetland or stream. However, any aquifer withdrawals must still be considered to be a gallon-for-gallon removal of groundwater which would otherwise eventually reach nearby perennial stream flows, off-set only to the degree that project treated wastewater is returned on a project site. If a pumping test does not identify an immediate impact to adjoining wetlands, ponds, or streams, an applicant must still evaluate the impact of the project's consumptive loss on the nearest downstream perennial stream.

4.6 Road De-Icing

Salt is a regionally-recognized groundwater contaminant. Chloride contamination in wells has been documented in some towns and sodium levels in the upper Mianus River watershed is suggestive of regional salt loading. Road salt is a primary source of regional salt in groundwater while water softener salt discharges normally impact only local areas. Current economic factors and best management practices are beneficially reducing road salting practices in many communities.

4.7 Stream Gauge

The watershed management measures recommended above generally protect watershed groundwater quality and thus Mianus River baseflow quality. Some of these measures also contribute to management of stream flow by seeking to minimize consumptive water losses.

Capacity monitoring, or stream gauging, would add a component of confidence that measures were substantively contributing both to protection of upper Mianus River aquifers and to flow of the Mianus River through the Mianus River gorge. An existing dam or a naturally-existing point of constricted flow on the Mianus River near the gorge may be used advantageously to position a stream data stage datalogger, to initiate long-term stream flow gauging. Stage data would need to be translated into volume flows by sufficient manual stream gauging to develop a rating curve that transforms stage data (level) data into volume data (flow). Usually a rudimentary rating curve can be completed on the basis of 6 to 8 flow measurements over a range of typical low to high flow conditions.



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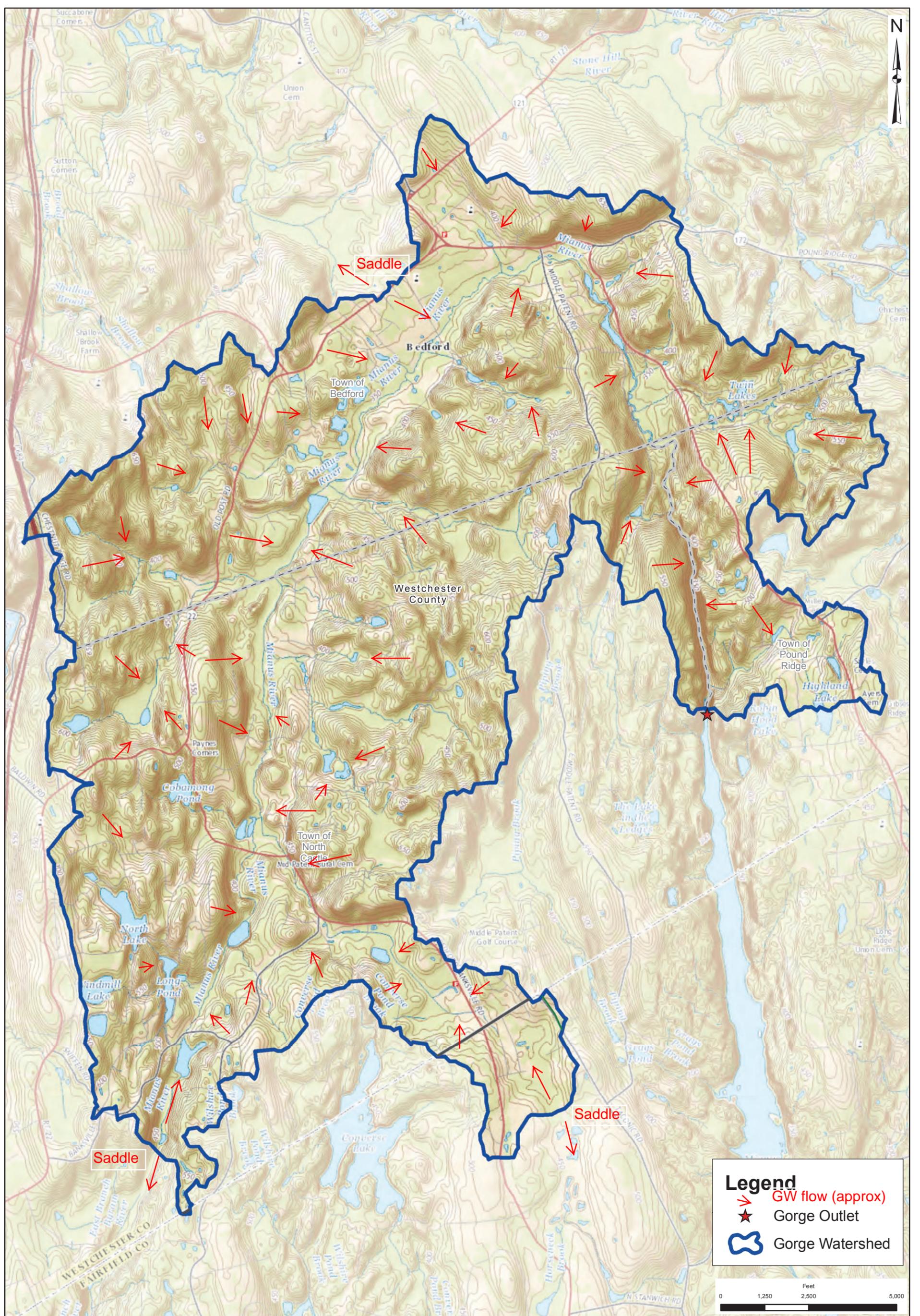
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Table 1. Average in-stream water quality data from 2011 to 2013 samples (n = 10).
sample point.

Site	pH	Temp (C)	DO	TSS	TOC	SRP	Cl	NO ₂ *	NO ₃ *	SO ₄	Br	Ca	Fe	K	Mg	Mn	Na	S	Si	Sr
1	7.48	16.94	7.88	12.20	7.48	0.04	71.50	0.32	1.79	5.31	8.79	34.31	0.26	7.53	9.03	0.16	22.83	6.05	5.35	0.17
2	7.94	17.27	8.33	2.03	4.04	0.02	66.63	0.31	1.58	3.17	8.18	34.22	0.04	3.70	7.23	0.03	22.54	3.58	4.12	0.10
3	7.92	15.82	8.34	1.73	6.12	0.04	72.75	0.21	1.63	5.25	8.65	42.63	0.59	14.83	9.30	0.08	20.24	7.25	4.88	0.15
4	7.79	16.20	7.93	14.23	4.20	0.03	57.87	0.31	1.49	3.84	7.64	35.14	0.07	4.52	8.09	0.07	19.85	4.27	5.09	0.12
5	7.76	17.36	8.57	4.53	4.83	0.02	59.49	0.24	1.57	3.61	8.03	32.80	0.07	3.84	8.04	0.04	19.91	4.11	4.27	0.11
6	7.73	16.97	8.43	20.65	4.59	0.03	62.01	0.32	1.49	3.67	8.29	33.90	0.10	3.93	8.75	0.07	20.42	4.16	4.44	0.11
21	7.81	17.83	10.53	149.67	5.82	0.03	133.20	0.25	5.72	4.76	11.68	41.88	0.04	5.73	12.47	0.17	55.95	4.98	3.42	0.18
7	7.56	16.41	8.10	7.12	4.84	0.03	63.08	0.21	1.48	3.65	8.28	33.58	0.10	4.00	8.70	0.07	21.32	4.18	4.42	0.11
19	8.04	17.48	8.94	3.40	4.57	0.03	64.17	0.12	1.52	3.70	8.21	33.47	0.09	3.89	8.55	0.06	21.02	4.10	4.58	0.11
20	8.01	17.94	9.21	7.40	4.76	0.03	72.44	0.23	1.46	3.70	8.10	32.25	0.10	3.94	8.33	0.05	21.00	4.12	4.18	0.11

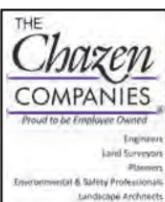
Abbreviations: dissolved oxygen (DO), total suspended solids (TSS), total organic carbon (TOC), soluble reactive phosphorus (SRP), chloride (Cl), nitrite (NO₂), nitrate (NO₃), sulfate (SO₄), bromide (Br), calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), sulfur (S), strontium (Sr), below detection limit (tr)

* NO₃ and NO₂ as NO₃-N and NO₂-N



Legend

- GW flow (approx)
- Gorge Outlet
- Gorge Watershed



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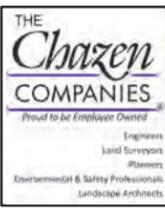
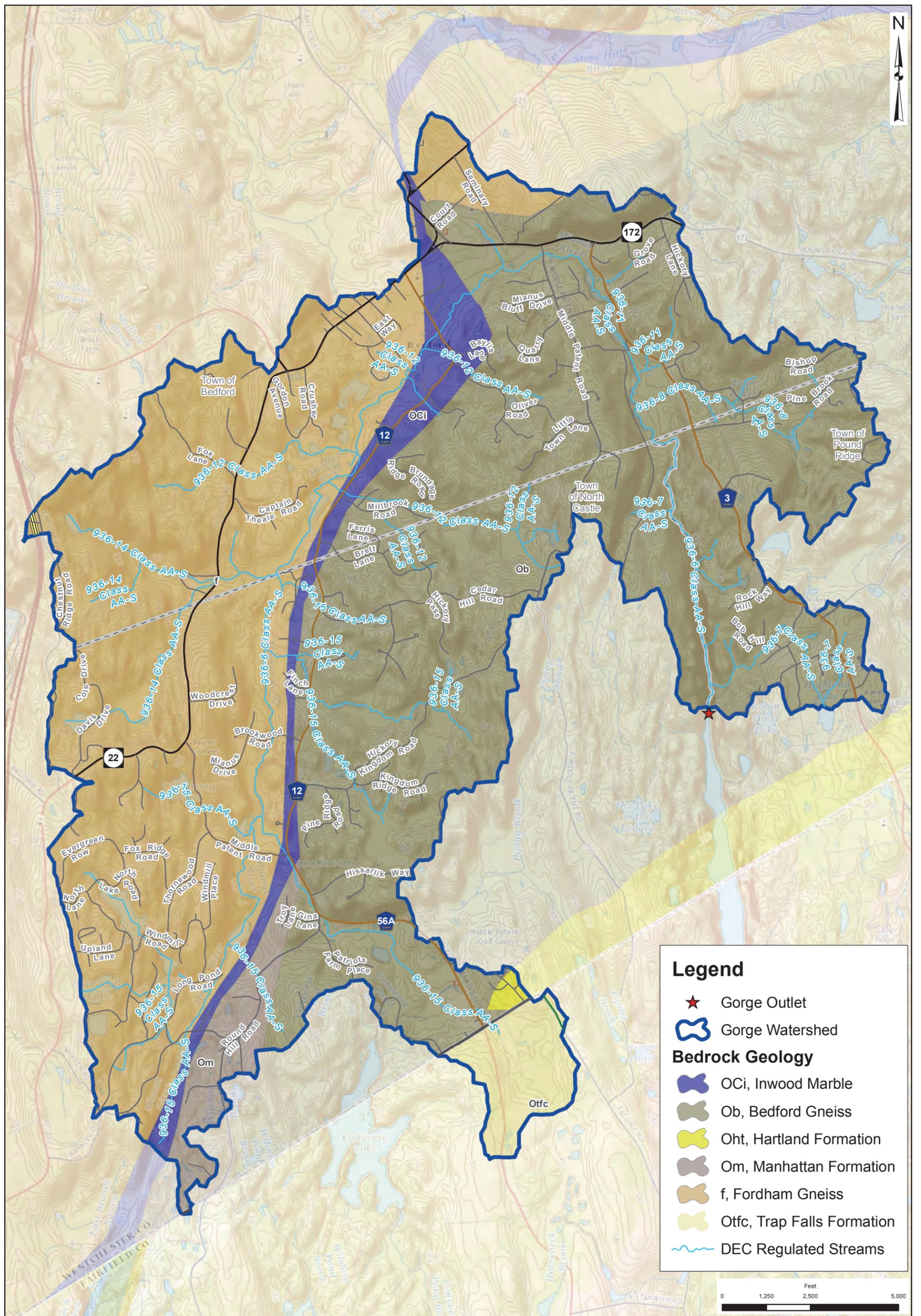
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Mianus River Upper Watershed Analysis

USGS Location Map

Towns of Bedford, North Castle & Pound Ridge - Westchester County, NY
Towns of Greenwich & Stamford - Fairfield County, CT

Drawn:	RL-B
Date:	06/30/2016
Scale:	1:30,000
Project:	41606.00
Figure:	1



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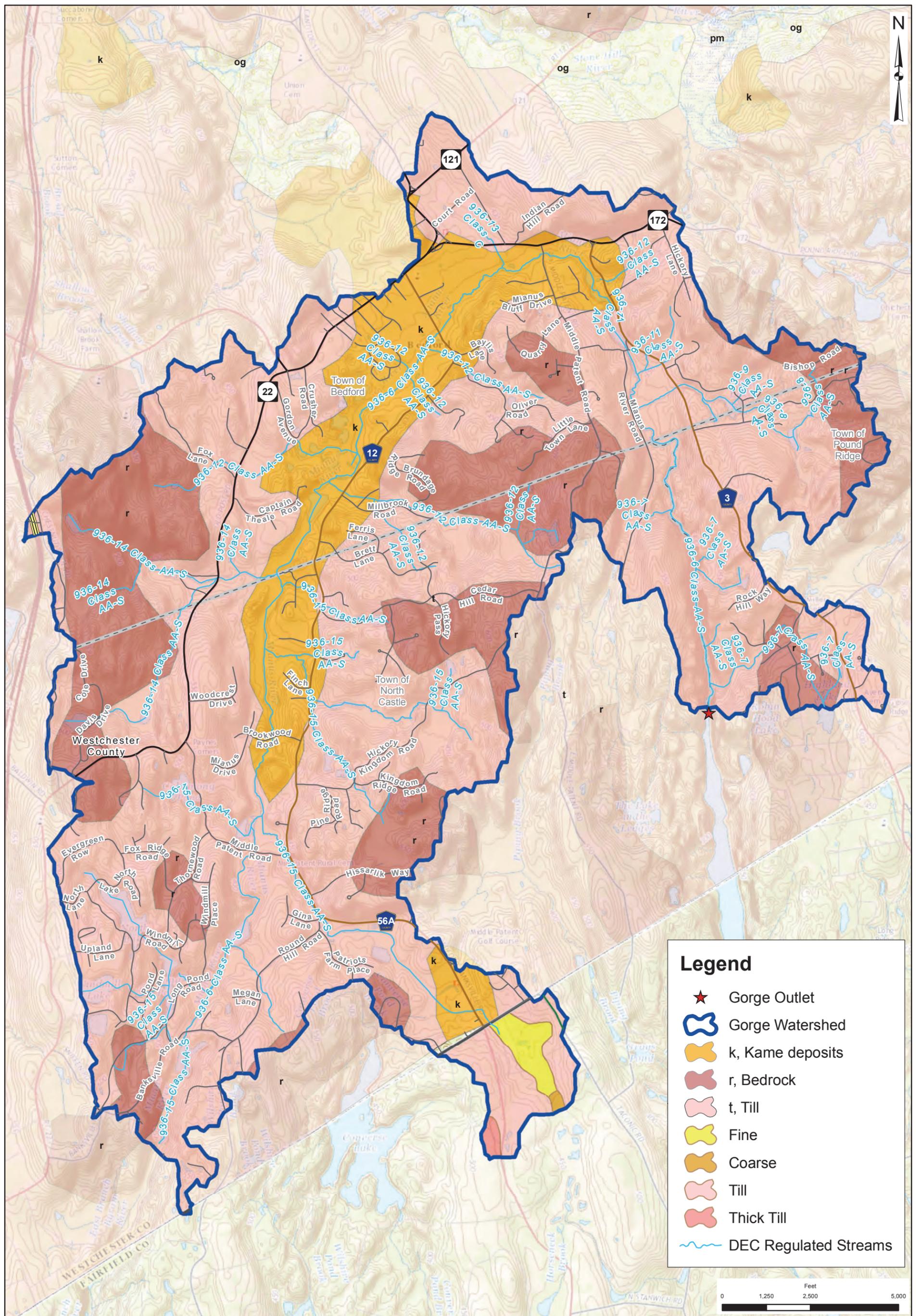
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Mianus River Upper Watershed Analysis

Bedrock Geology

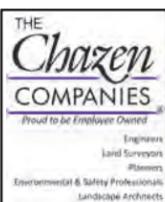
Towns of Bedford, North Castle & Pound Ridge - Westchester County, NY
Towns of Greenwich & Stamford - Fairfield County, CT

Drawn:	RL-B
Date:	06/30/2016
Scale:	1:30,000
Project:	41606.00
Figure:	2



Legend

- ★ Gorge Outlet
- 🔵 Gorge Watershed
- 🟡 k, Kame deposits
- 🟤 r, Bedrock
- 🟠 t, Till
- 🟢 Fine
- 🟠 Coarse
- 🟡 Till
- 🟤 Thick Till
- 🔵 DEC Regulated Streams



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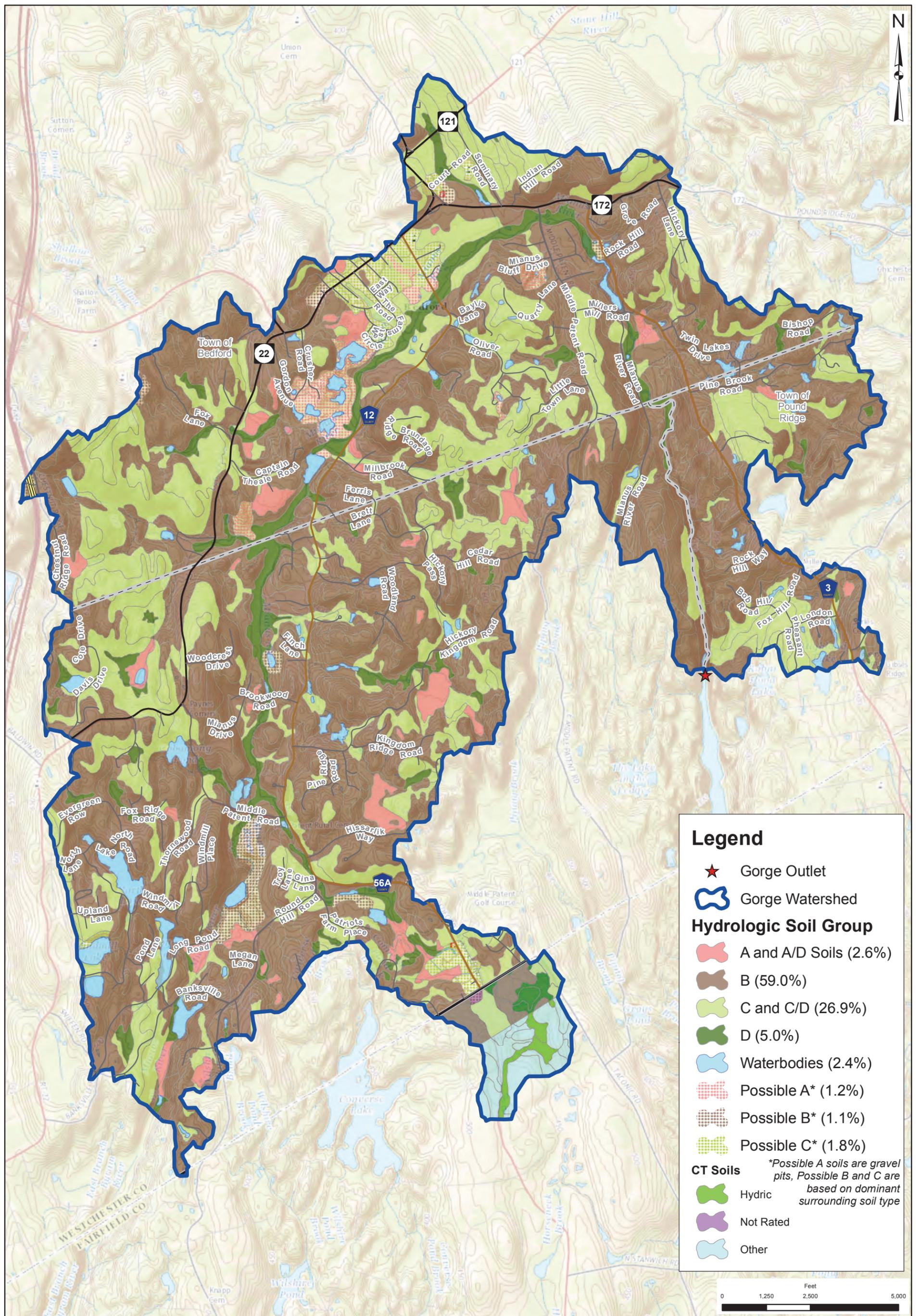
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Mianus River Upper Watershed Analysis

Surficial Geology

Towns of Bedford, North Castle & Pound Ridge - Westchester County, NY
Towns of Greenwich & Stamford - Fairfield County, CT

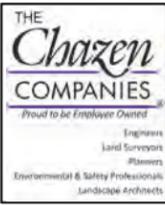
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Figure:	3



Legend

- ★ Gorge Outlet
- 🔵 Gorge Watershed
- Hydrologic Soil Group**
- 🔴 A and A/D Soils (2.6%)
- 🟤 B (59.0%)
- 🟢 C and C/D (26.9%)
- 🟩 D (5.0%)
- 🟦 Waterbodies (2.4%)
- 🔴 Possible A* (1.2%)
- 🟤 Possible B* (1.1%)
- 🟢 Possible C* (1.8%)
- CT Soils**
- 🟩 Hydric
- 🟪 Not Rated
- 🟦 Other

*Possible A soils are gravel pits, Possible B and C are based on dominant surrounding soil type



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Mianus River Upper Watershed Analysis

Hydrologic Soil Group Distribution

Towns of Bedford, North Castle & Pound Ridge - Westchester County, NY
Towns of Greenwich & Stamford - Fairfield County, CT

Drawn:	RL-B
Date:	06/30/2016
Scale:	1:30,000
Project:	41606.00
Figure:	4