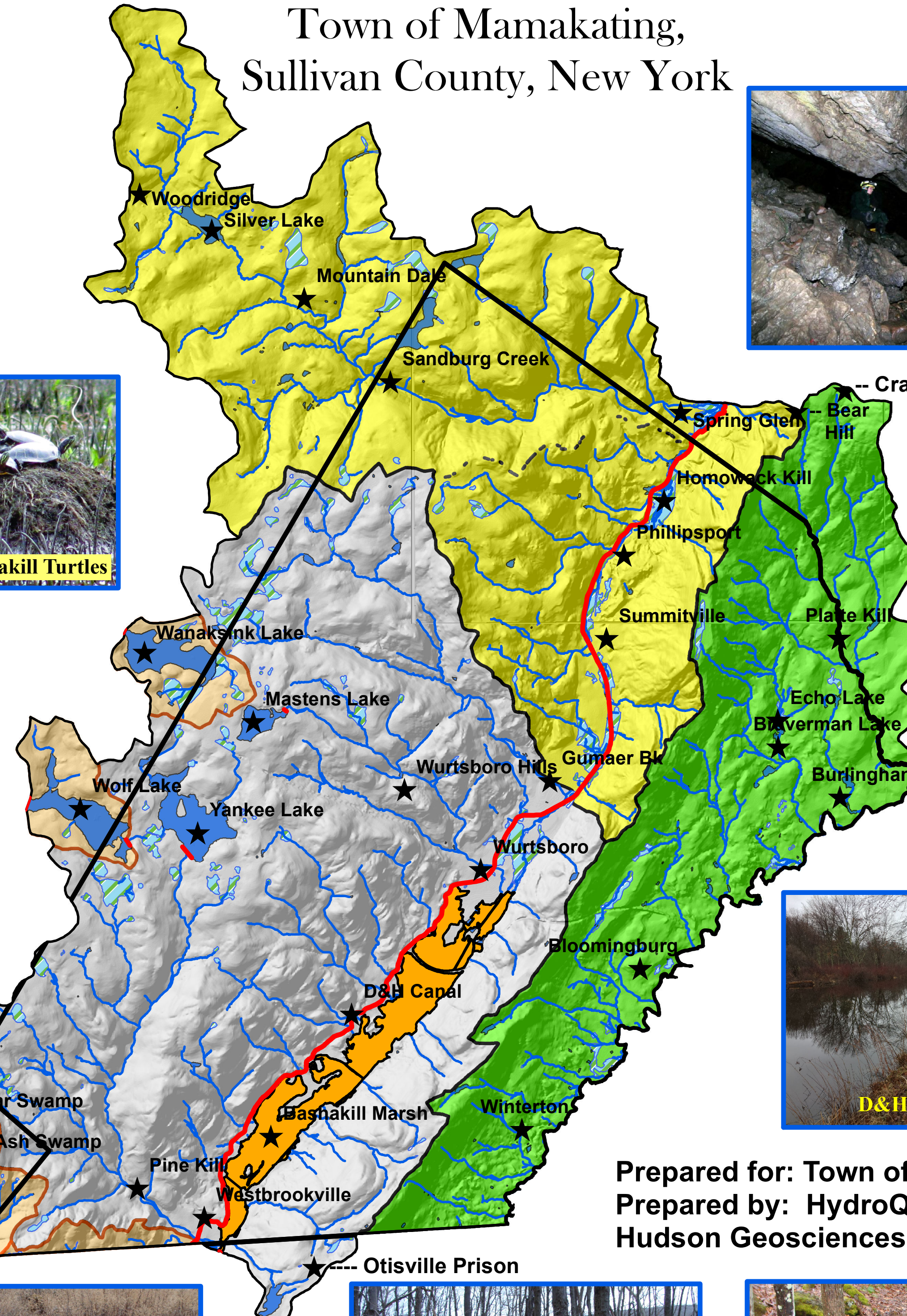
Hydrogeologic Study of the Town of Mamakating, Sullivan County, New York




Surprise Cave


Bashakill Turtles


D&H Canal Linear Park

Prepared for: Town of Mamakating
Prepared by: HydroQuest and Mid-Hudson Geosciences April 2017


Pine Kill and Permeable Sediments


D&H Canal and Towpath Trail


Karst Spring

EXECUTIVE SUMMARY, page 1 of 2

The hydrogeologic features of the Town of Mamakating were examined with the purpose of identifying actions designed to maintain and improve surface and groundwater quality, wetland ecosystem health, and ecotourism.

Areas of highly permeable soils were identified beneath the Mamakating Valley which extends northward from Westbrookville to Phillipsport and beyond. This valley is underlain by an unconsolidated principal aquifer with well yields of up to 400 gallons per minute.

Field reconnaissance indicated that previous delineation of the hydrologic divide between the Delaware and Hudson rivers in the Wurtsboro area required revision. It is miles further south than previously assessed and includes about 50 percent of the D&H Canal Linear Park. This location of the divide reduces the watershed area and tributaries to the Bashakill Marsh, but does not negate the significance of the "*Mamakating Aquifer*," which is comprised of groundwater flowing through unconsolidated sediments under the southwest flowing Bashakill Marsh.

It is likely that this Mamakating Aquifer is far from being fully exploited. Protection of this unconsolidated aquifer is recommended. An interim measure may be to classify the aquifer area as a special zone while conducting the hydrologic characterization required to request NYSDEC classification of the aquifer as a State Primary Aquifer.

A second key study recommendation is to establish a USGS stream gaging station at the NYSDEC dam at the outlet of the Bashakill Marsh. Water discharge is a parameter needed to calculate and evaluate chemical loading and water quality. Water quality directly correlates with the health of wetland ecosystems, species diversity, and ecotourism. Also, the gage will provide important measurements of discharge during flooding, fluctuations, and baseflow related to climate change in the Catskill Mountains.

Given the observation that the surface water divide in the valley is farther south than previously mapped, this finding reduces flow to the southwest through the Bashakill Marsh while increasing flow to the northeast in the Homowack Kill flowing to Sandburg Creek to Rondout Creek, and eventually to the Hudson River at Kingston.

Heavy metal-laced surface water, groundwater and sediments are being discharged directly into the D&H Canal within the Linear Park and the Homowack Kill from the Wurtsboro Lead Mine. High lead concentrations from the waste site have not been removed or remediated. The lead mine is or was a NYSDEC Superfund Site. Additional investigation of the level of contamination in sediments and water of the Canal and stream should be conducted and if appropriate DEC should be required to conduct an effective remedial action.

Another contaminant threat to water quality in the Town of Mamakating includes the ongoing incompletely treated sewage effluent stemming from the Otisville Prison that may be endangering bats in Surprise Cave and ultimately discharging into Bashakill Marsh. Other possible contaminant sources may include the Mamakating Landfill superfund site, Sullivan County Landfill, Mamakating Town Dump, and other point and non-point source contributions.

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Much water quality protection is now afforded by protective buffers in the Town (e.g., NYSDEC lands around the Bashakill Marsh). We recommend a number of additional measures to maintain and improve and assess water quality. These include:

- Further investigate the Wurtsboro Lead Mine and Otisville Prison effluent and initiate actions to remove these water quality threats;
- Establish multi-acre lots and a 300-foot development buffer distance from streams and State wetlands;
- Allow no further development west of South Road;
- Establish a Karst Protection Area proximal to Surprise Cave to protect Bashakill Marsh water quality and the bat population severely impacted by White-Nose Syndrome (WNS);
- Establish a USGS stream gaging station at the outlet dam of the Bashakill Marsh;
- Review housing density adjacent to Town lakes (e.g., Yankee and Mastens) with respect to potential eutrophication;
- Incorporate use of our watershed and subbasin delineations as integral parts of zoning boundary assessment, especially as related to water quality protection;
- Review existing land-use and zoning within the Pine Kill subbasin, recognizing that any contaminant inputs will enter the Bashakill Marsh;
- Work with adjacent towns to protect Town of Mamakating water quality. Water quality protection requires input into and control over land use practices throughout entire watersheds. In places, as depicted on GIS maps, Town of Mamakating watersheds extend beyond Town boundaries; and
- Analyze and examine existing and future potential water demand from the Mamakating Aquifer.

Additional recommendations include:

- Encourage the use of prime agricultural land and expand Agricultural District 4;
- Avoid Oil and Gas Development, especially Hydraulic Fracturing; and
- Drill wells and conduct pumping tests for all proposed home sites on the Shawangunk Ridge to demonstrate adequate water supply prior to construction.

Groundwater and Surface Water Protection:
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List of Maps (in PDF File)

1.0 INTRODUCTION

HydroQuest and Mid-Hudson GeoSciences conducted a hydrogeological study for the Town of Mamakating to provide scientific information and evaluation pertaining to geologic and hydrogeologic conditions in the town. Key tasks conducted as part of the study included:

- Data compilation and analysis. Digital maps and spatial data from various sources were used to define and characterize surface and subsurface hydrologic features including: topography, soils, wetlands and surface waters, floodplains, surficial geology, bedrock geology, drillers' water well logs, unconsolidated aquifers, bedrock aquifers, environmental contamination sites, and watersheds and subbasins;

- Field examination of bedrock geology, karst features, segments of the Delaware & Hudson (D&H) Canal, select watershed boundaries (e.g., Wolf Lake), the Bashakill Marsh, and the confluence of the Pine Kill with the Bashakill Marsh;

- Detailed photogrammetric analysis of 1990s Color Infrared (CIR) imagery of the entire Town and beyond, with emphasis on enhancing the quality of existing wetland, stream, and lake database. Numerous GIS shapefiles were created using ESRI ArcGIS software;

- Watershed and subbasin delineation were conducted that brought together the CIR-based data base generated, field reconnaissance findings, Digital Elevational Model (DEM) data, and Digital Raster Graphic (DRG) data bases;

- Construction of numerous GIS maps to emphasize the findings of this study. They are presented as a project map set and are discussed within the text of this report. In addition, many new GIS shapefiles generated during this project are available if desired (i.e., ponds and lakes, streams, wetlands, watershed boundaries, numerous subbasin boundaries, karst features, hypothesized karstic flow routes, spring locations, resurgence zone, sinkholes, stream sink point, cave locations, carbonate band, mixed carbonate and shale, proposed karst protection area, beaver dam locations, Bashakill Marsh boundary, relict dam, numerous bedrock and unconsolidated well yield shapefiles, D&H Canal, contaminant threat locations (e.g., Wurtsboro Lead Mine), gravel, sand and gravel, severe building soils, high permeability soils); and

- Hydrologic assessment of the data and study findings presented in a format useful to Town planners for consideration in Town zoning and comprehensive planning.

2. 0 STUDY DETAILS

Data compilation and analysis comprised the initial phase of this project. Data was obtained from a number sources including the Town of Mamakating, NYSDEC databases, the NYS GIS Clearing House, the NYS Museum, the Soil Conservation Service, and the Cornell University Geospatial Information Repository (CUGIR). This compilation required far less time than other project phases that built upon this base information through a combination of geologic and hydrologic field work, detailed photogrammetric analysis of CIR imagery, and hydrologic delineation of watershed and subbasin boundaries.

Watershed and subbasin delineation are important because they provide planners with a comprehensive tool to evaluate potential impact on water quality and quantity when reviewing proposed development plans in specific basins and subbasins. From field observations, this study has refined the northern boundary of the Bashakill Marsh watershed (i.e., the watershed tributary to the outlet of the Bashakill Marsh) from hydrologic modeling work conducted by others. Modeling of low gradient topography can lead to erroneous watershed boundary delineation, which in turn can lead to unintended land use and water quality impacts. For example, the actual watershed boundary along the Delaware & Hudson Canal Linear Park is some 12,190 feet (~2.3 miles; 5.7mi^2) further south than a modeled boundary provided. A second important field study finding was that all low and moderate flow of the Pine Kill directly enters the Bashakill Marsh, not at an overflow point downstream of the Marsh outlet dam. Thus, the value of field reconnaissance cannot be overemphasized.

The soil maps for Sullivan County were available in digital format, so they were incorporated into our GIS database. A number of important soil characteristics were extracted from this database to highlight particular soil properties (e.g., high permeability soils, soils well-suited for road construction material). Some of these features were defined by more than one source, such as "unconsolidated aquifers" which are a combination of information on maps of soil permeability, surficial geology, and published maps that delineate "unconsolidated aquifers."

Well data provided the most definitive information available to define the actual location of saturated unconsolidated aquifers because the well record gives us specific yield in gallons per minute, depth of the well, and type of materials penetrated by the well. For bedrock aquifers, wells are the only information to provide definitive information because there is very little published information on the permeability and saturation of bedrock units in the scientific literature.

With respect to obtaining a listing of contaminated sites, we reviewed a number of available state and federal resources that contained information for the County of Sullivan and the Town of Mamakating. We provide a description of these sites below and identify their locations on GIS maps provided as part of this report. Additionally, we reviewed the NYSDEC spill database. Dozens of spills are reported within the greater Wurtsboro area. However, these cases were closed after examination, testing and corrective action. As such, they do not present current contaminant threats and their locations are not plotted in our GIS map set.

Project completion included building upon available GIS databases using ArcGIS software to construct shapefiles of various physical features, many of which were created through hydrologic interpretation of existing, field and mapped databases. The advantage to using a GIS database compared to a stack of paper maps is that various layers or features can be overlain and maps can be constructed, upgraded and modified at any scale to show and emphasize important comparisons and results.

3. 0 LAND-USE & ZONING CONSIDERATIONS

Resource sustainability is directly linked to water quality protection. This is particularly important in the Town of Mamakating because protection of water quality in the Bashakill Marsh and water-bearing portions of the D&H Canal are vital to sustaining vital natural ecosystems, recreational opportunities, ecotourism, and the Town's economy.

Protection of the Town's surface and groundwater quality can best be achieved through a combination of measures. These include land protection via conservation easements, public ownership, and zoning. With respect to providing meaningful hydrogeologic input into the zoning process, there was discussion between the authors of this report and the town's planning consultants to define the intersection of our respective disciplines. Since the zoning process divides the land into areas of similar landscape and sustainability, some hydrogeologic characteristics provide good predictors of sustainability or desirable housing density on land exhibiting certain physical, geologic and hydrologic characteristics. Some of the features and related actions which contribute to resource sustainability are:

- Minimize septic system installations in highly permeable soils proximal to streams;
- Avoid dense housing on steep slopes;
- Avoid overly dense housing proximal to lakes with no community septic systems to avoid lake eutrophication;
- Remove or remediate major existing contaminant sources (i.e., Wurtsboro Lead Mine, Otisville Prison effluent input to the Bashakill Marsh);
- Establish protection zones for areas determined to be particularly vulnerable to water quality degradation (e.g., proposed Karst Protection Area); and
- Refine existing hydrogeologic data specific to the principal aquifer underlying the Port Jervis Trough (aka Mamakating Valley), with an eye toward potential expanded use.

In order to make the process of zoning work, the first requirement is knowledge of what features are present in the area to be zoned. Our GIS database and map set provide important information relative to the physical characteristics of the land surface and subsurface. This information is essential in determining appropriate land-use and zoning.

4. 0 MAPS OF HYDROGEOLOGICAL LANDSCAPE CHARACTERISTICS

The following sections describe mapped features of concern and their relevance to zoning. After the treatment of individual physical characteristics of the landscape, recommendations are provided to protect or preserve specific land areas. Selection for protection and preservation is based on many factors including vulnerability to degradation by contamination, sustainability for future use, species protection, and preservation and enhancement of historic land use.

4.1 Topographic and Slope Degree Maps (Maps 1 and 2)

The most significant landscape feature shown on the topographic map (Map 1) and Slope Degree Map (Map 2) is what civil engineer John B. Jervis referred to as the Mamakating Valley. [Jervis staked out the route of the D&H Canal and superintended its construction.] Its trace roughly follows the US Route 209 corridor from Spring Glen, southward to Phillipsport, Summitville, Wurtsboro, Haven, Westbrookville, and Orange County at the southern boundary of Mamakating. As seen in the central portion of the Town on Map 1, highlighted by the dark green shading (~512 to 768 ft) proximal to the major watershed divide (orange line), this portion of the Town is the hydrologic divide between the Hudson and Delaware River drainages. Note the lower elevation yellow areas further northeast and southwest of the hydrologic divide (Map 1). North of the watershed divide, the waters of the Homowack Kill form the headwaters of Sandburg and Rondout creeks as they descend to the Hudson River. South of the watershed divide, the Basher Kill augments the flow of the Neversink River which joins the Delaware River. Hydrologically, the valley is the low point where all tributaries discharge their flow.

The Mamakating Valley is bounded on the east by the steep northwest-facing flank of the Shawangunk Ridge and on the west by the sharp rise of the eastern face of the Catskill Plateau. The expression we see as the valley is just the top of a deeper bedrock-bounded valley filled with glacial sediments. The buried deep valley is known as the Port Jervis Trough and extends from Port Jervis through Orange County, Town of Mamakating in Sullivan County, and through Ulster County to Kerhonkson. The original deep valley was formed by erosion and degradation bands of carbonate rocks. During Pleistocene glaciation, sediments were deposited in and around the deep valley. Some of the beds in the trough are very porous and permeable and are capable of producing water up to 300 gallons per minute from drilled wells (Reynolds, 2007).

The eastern boundary of the Town is the thalweg of the Shawangunk Kill flowing northeast to the junction of Sullivan, Ulster and Orange counties, then continuing north-northwest along the Platte Kill to the Sullivan/Ulster County border. The Shawangunk Kill flows northeast and enters the Wallkill River at Gardiner and continues north to Rifton where it enters the Rondout. [In hydrological and fluvial landforms, the thalweg is a line drawn to join the lowest points along the entire length of a stream bed or valley in its downward slope, defining its deepest channel.]

The steepest slopes portrayed on the Slope Degree Map are to the northwest of the 209 corridor along the eastern slope of the Catskills and on both sides and top of the Shawangunk Ridge to the southeast of the corridor. Another area of steep slopes is along NY Route 55, where Sandburg Creek cuts across the northwest corner of the town flowing east into Ulster County and continues north to the Rondout Creek, eventually flowing into the Hudson River on the south side of the City of Kingston.

Looking at the topographic map (Map 1), the various zones of similar elevation are shown as bands trending northeast to southwest parallel to the major drainage systems described above. The brown color areas along the northwestern side of the Town are some of the highest terrain. Two other brown high elevation areas are also present at the crest of the Shawangunk Ridge near the northern Town boundary (south-southwest of Bear Hill).

On both sides of the Route 209 corridor, the red and white pointed areas are streambeds with the thin end pointing uphill (Map 1). In other words the stream valley widens as the stream flows downhill and gathers more water. On both sides of the Route 209 corridor, the stream patterns show parallel drainage toward the Homowack Kill and Basher Kill drainage.

4.2 Wetland Map: New York State and Federal (Map 3)

Map 3 depicts NYS and Federal wetlands available through State and Federal GIS databases. Two sizes of wetlands are shown on Map 3, NYS protected wetlands larger than 12.4 acres and smaller Federal wetlands. Hydrologically, whether the wetlands are classified as State or Federal wetlands based on an arbitrary size limit (12.4 acres), is of little importance. It is their hydrologic and ecologic functioning that matters. NYSDEC is responsible for State wetlands and the US Army Corps of Engineers is responsible for Federal wetlands. In places, NYSDEC and Federal wetlands overlap. In other locations, wetland boundaries vary. The quality of these data sets is suspect.

Wetlands and streams, including the Bashakill Marsh, that are portrayed on all other maps presented in this project (e.g., Maps 2, 4-8, 10-16) were mapped using high resolution color infrared imagery (CIR). Aerial mapping was based on vegetative health, wetland tonal hues, and water presence. Wetlands were not differentiated based on size. During detailed photogrammetric mapping, visual comparison with State and Federal wetlands depicted on Map 3 was conducted. **Our new CIR mapping provides higher quality wetland and stream mapping throughout the Town**. Again, because of the higher resolution of our wetland mapping, it provides a better map base. As always, development proposals require site-specific wetland delineation.

The town has three major areas of wetlands (e.g., see Maps 2 and 4), one along the Route 209 valley-bottom corridor including the Bashakill Marsh and Homowack Kill lowlands, one in gently sloping to flat-lying areas in elevated northwestern portions of the Town underlain by shales and sandstones of the Oneonta Formation, and one along the valley-bottom setting of the Shawangunk Kill.

Along the Route 209 corridor, wetlands are associated with the Homowack Kill to the north and the Basher Kill to the south. These wetlands are most significant because they are associated with a trough of permeable water-bearing sediments which form an aquifer right through the center of the Town. In 1972 the NYSDEC purchased much of the Bashakill Marsh area and classified it as a Wildlife Management Area. NYSDEC constructed a dam to maintain a constant water level just upstream of the Pine Kill floodwater overflow entrant near Westbrookville. Currently there are 3,107 acres in the Management Area. The wetlands with the D&H Canal trail are an enticing focal point for recreation and tourism in the Town. In addition to the scenic value of this geographic band of wetlands, it is also likely a very prolific unconsolidated aquifer. More specific information will be presented below with respect to aquifer types characterization, regulation, and protection.

Without question, the Bashakill Marsh that is central to the Basha Kill Wildlife Management Area is the crowning jewel in the Town of Mamakating. Its wildlife and trail system serve as lure to ecotourists which has potential for enhanced visitation. Key factors that can promote enhanced ecotourism are efforts to maintain excellent water quality and limiting new development to outside of roads that border the wetland.

4.3 Watershed Maps (Maps 4 to 11)

The Town of Mamakating is drained by four watersheds (Maps 4 and 5). These are the Homowack Kill and Sandburg Creek that flow northward from the northwestern portion of the Town, the Shawangunk Kill which receives drainage off the eastern side of the Shawangunk Ridge and flows to the northeast, the Basher Kill which drains the Catskill Plateau and south-central portion of the Town, and four small areas the drain to the Neversink River. Two of these small areas are watersheds of Wolf and Wanaksink lakes.

The first three watersheds are then subdivided into subbasins as shown on additional maps (Maps 6, 7, 8, 10 and 11). These maps reveal that about 56 percent of the drainage from the town goes to the Delaware River, with most of the northern and eastern portions of the town draining to the Hudson River via Sandburg Creek and the Shawangunk Kill. The surface hydrology that drains the Town of Mamakating does not conform to town boundaries. Because surface flow and anthropogenic activities that may impact the town may originate outside town boundaries, hydrologic/watershed boundaries were delineated, mapped and portrayed (e.g., Maps 4 and 5). The dam at the outlet of the Bashakill Marsh was selected as downstream limit of Basher Kill watershed delineation.

4.3.1 Watershed and Subbasin Boundary Delineation

Watershed and subbasin delineation were determined using a combination of USGS topographic maps, detailed mapping of streams and wetlands on 1990s color infrared (CIR) photography, Digital Elevational Model (DEM) data for twelve 7.5 minute quadrangles, GIS hydrologic modeling technology and field verification at select site locations. To ensure complete coverage of the Town of Mamakating and surrounding areas, this analysis required creating a mosaic of Digital Elevational Model (DEM) data from the following USGS quadrangles: Monticello, Woodridge, Ellenville, Napanoch, Hartwood, Yankee Lake, Wurtsboro, Pine Bush, Port Jervis North, Otisville, Middletown and Goshen. This task involved a multi-step process, in which individual USGS quadrangle DEMs were converted to a grid format and then mosaicked together into a single grid file in preparation for additional analyses. Finally, the mosaicked supergrid file was used in the hydrologic modeling process to create a terrain model consisting of a grid of estimated topographic elevations. While watershed and basin divides were initially examined from digital elevation model results, basin delineation was best accomplished using a combination of topographic maps, photogrammetric interpretation of CIR imagery, and field reconnaissance. Hydrologic model results were significantly flawed in low gradient areas, especially along the northern portion of D&H Canal corridor.

4.3.1.1 Pine Kill (Maps 8 and 9)

Significantly, field reconnaissance documented that under low and moderate flow conditions, all of the Pine Kill drains into the Bashakill Marsh (29 percent contribution), thus emphasizing the need for water quality protection measures in its mapped subbasin as part of comprehensive planning. Review of multiple years of historic aerial photography documents the presence of stream channel changes over time in the field immediately north of the Bashakill Marsh (see Map 8 and red circled area and Map 9). This stream diversion significantly alters the inflow to the marsh because the Pine Kill watershed is quite large (approximately 10,656 acres vs. 36,981 acres of the entire Bashakill Marsh watershed; Map 6).

Overflow from the Pine Kill to its former outlet just downstream of the steel sheet piling dam that impounds the Bashakill Marsh occurs only during high flow runoff events. From a hydrologic standpoint, diversion into the marsh within the Bashakill Wildlife Management Area is good for aquifer recharge, water quality, boating, wildlife and ecotourism. Recognition of this diversion is important because land-use activities in the Pine Kill subbasin have the potential to adversely impact the water quality of the Bashakill Marsh. As a result, we recommend that planning and zoning permitted land-use activities in the Pine Kill subbasin be reviewed relative to water quality protection.

4.3.1.2 The Delaware & Hudson Canal (Map 32)

The 108-mile Delaware & Hudson Canal (15.0 miles in the Town of Mamakating), constructed in 1825-1827, is in many ways the centerpiece of the Town of Mamakating. It is an historic treasure worthy of preservation and enhancement for ecotourism. Surface water flow north of Gumaer Brook and south of Summitville Road occurs at the highest elevation in the Mamakating Valley bottom because it is close to the watershed divide between the Delaware and Hudson River drainages (see Maps 2, 4, 10 and 13). Here, along the D&H Canal Linear Park, the level of northward flowing canal water is the hydrologic base level because all streams and adjacent wetlands flow to this canal level. North of Summitville Road surface water continues to flow in the canal. However, the berm that forms the towpath along the D&H Canal Linear Park separates outflow from the wetland east of the towpath which then descends to a lower hydrologic base level of the Homowack Kill. The change in hydrologic base level from the D&H Canal to the headwaters of the Homowack Kill occurs some 2.3 miles north of the northern Bashakill Marsh watershed boundary.

Canal engineering and functioning required unnatural alteration of pre-canal drainage networks so that adequate water was available to float barges, yet not so much that canal banks would wash out. While review of engineering documents is necessary to verify the physical relationship between major Mamakating streams that intersected the canal (e.g., Pine Kill in Westbrookville; Willsey Brook in Wurtsboro), it is likely that all streams flowing downslope to the valley bottom were diverted into the canal. Lowenthal (1997) mentions times when water was "*let*" into the canal, thus the engineering design appears to have had water control mechanisms both at and between locks. This control requires further verification. It seems likely that all flow incident to the canal from upslope tributaries would either have needed to be captured so as to not breach the canal or be diverted beneath the canal. The existing elevation of the canal invert proximal to the Pine Kill is only about two feet higher than the recently altered stream bottom and stone-laid retaining walls, thus the diversion beneath the canal interpretation seems unlikely.

Historic accounts of early canal water-related problems include difficulty in keeping the canal bottom and sides sealed from water loss, flood washouts of canal walls, and muskrat canal wall holes (Lowenthal, 1997). Problems with porous canal soils is not surprising because much of the waterway was constructed as a trough on the sides of hills (Lowenthal, 1997; see bottom center title page photo). Canal engineers also took advantage of stream reaches with low-gradient sections (i.e., headwaters of the Homowack Kill south of Summitville). This further accents the need to have sufficient water available to maintain canal water levels after repairs were made.

In modern environmentally conscious times, it is highly unlikely that similar canal construction capable of altering the hydrology of numerous streams and ecosystems would be approved without numerous site plans, environmental permits, and continency plans. Yet, resultant water-filled canal segments and adjacent wetlands in northeastern Mamakating appear to be ecologically thriving. As discussed elsewhere, however, the Wurtsboro Lead Mine may be adversely impacting canal ecology.

D&H Canal engineers designed its valley route to weave between the Town's lake district highlands to the west and the resistant, steeply-sloping, quartzitic Shawangunk Ridge to the east. Construction took advantage of and modified the natural pre-canal hydrology. North of Gumaer Brook to the Summitville/Phillipsport area and beyond the canal was excavated within very low gradient (i.e., low-sloping) glacial sediments that fill what was once a very deep gorge before glacial infilling. Geologists refer to this ancestral channel as the Port Jervis Trough, a tribute to John B. Jervis who staked out the canal route through what he called the Mamakating Valley (Lowenthal, 1997). Jervis' use of the term "Mamakating Valley" may stem from the former name of the Basher Kill which was the Mamakating River (as used in the 1700s and likely derived from the Munsee word, *mahmaxkatun*, 'red mountain'; Grumet and Whritenour, 2014).

The D&H Canal Linear Park lies within the Town of Mamakating. A most interesting feature of the canal is the divide between southwest flow in the Basher Kill in the Delaware River watershed and northeast flow in the Sandburg Creek feeding the Hudson River via the Rondout Creek. The presence of water-filled portions of the relict D&H Canal are significant in delineating watersheds for the purpose of designating aquifer protection measures. The segment of greatest interest is some 2.19 miles in length. It extends south-southeast of Rt. 209 in Summitville to about 775 feet northeast of the McDonald Road bridge.

North of Gumaer Brook, streams and wetlands all grade into the D&H Canal from the east and west, thereby contributing water to maintain the canal for boat floatation and lock functioning. Map 2 (slope degree map) shows this relationship well. As discussed previously, the location of a singular beaver dam determines the divide between surface water that forms the headwaters of the Homowack Kill and Sandburg Creek to the north and the Basher Kill to the south. This beaver dam is situated approximately 775 feet northeast of the McDonald Road bridge at these NAD83 UTM coordinates: 545137mE 4604378mN. The impounded canal water height on the northeast side of the dam is 1.0 feet higher than the Gumaer Brook side. Outside of the northward flow of water in the canal itself, the exact placement of the hydrologic divide requires field confirmation, especially along the southern border of the Wurtsboro-Sullivan County Airport. Clearly, during periods of low and moderate stream flow, all Gumaer Brook flow forms the headwaters of the Basher Kill. However, review of historic aerial photography reveals that high flow events shunt floodwaters over the brook's northern bank, across a flat area, and into the north-flowing D&H Canal. This situation is similar to that near the downstream end of the Pine Kill where floodwaters have periodically carved new channels.

Beaver dam that forms the Delaware River - Hudson River hydrologic divide (April 2017).

In the southern portions of the Town of Mamakating, portions of the D&H Canal were constructed above the Town's present base level hydraulic control of the Bashakill Marsh. As is evident in historic accounts, in a relict, now flooded, dam across part of the Bashakill Marsh (approximately 1,000 feet south of the southern end of McCune Place), and in the well-developed dendritic drainage pattern within the Bashakill Marsh, the areal extent of the marsh has expanded through time. Elsewhere, especially north of Haven Road and to about 2,300 feet south of Haven Road, linear and rectilinear drainage features within the Bashakill Marsh that are evident on 1990s color infrared photography provide evidence of former artificial drainage for agricultural purposes. Assorted web pages discuss flood debris damming of the lower Pine Kill prior to NYSDEC's installation of a permanent dam in the early 1970s which contributed to the current areal extent of the marsh.

4.4 FEMA Flood Hazard Zone Maps (Maps 12 to 14)

The FEMA Flood Hazard Zone maps have been superimposed on three watershed maps (Maps 12-14) to show the floodplains in relationship to the topography and stream locations. Three flood areas have been color coded:

- A - 100-year flood (estimated) [green]
- AE - 100-year flood (analyzed to nearest foot of elevation relative to mean sea level) [orange]
- 500-year flood [purple]

More detailed mapping is available for all flood stream segments on the FEMA panel maps that are available online. The places of major concern with flooding are where roads and flood zones intersect and where infrastructure and buildings are in the floodway.

Increased precipitation is of significance because more precipitation per storm and more per year is enlarging wetlands and waterways, as well as increasing the hazards of flooding. The Sullivan County Soil Survey reports that average rainfall between 1951 and 1980 at Liberty, NY was 49.58 inches per year. Newer records have indicated averages of about 60 inches per year, that is a 21 percent increase. As the amount of rainfall continues to increase and the duration of storms continues to increase, potential damage and height of flood stage will increase accordingly. This may necessitate expansion of flood hazard zones and modification of roadway height and culvert sizing.

4.5 Recommendation: Flood Hazard Mitigation

We have provided similar services for other agencies and projects to predict flood parameters and propose mitigation procedures. We would be happy to present a short discussion on what information can be provided to the town to implement flood mitigation in specific areas.

4.6 Map of Soil Types (Map 15)

Two types of data show the smallest areas in this GIS study: soil units mapped by the USDA and land parcels mapped by the Tax Assessment Office of the Town and County. Soil Map Units in the Town of Mamakating (Map 15) displays the full range of soils throughout the town. Based on the *Soil Survey of Sullivan County, New York* (July 1989), 122 separate soil units were mapped throughout the town and county. The variety of soil types is remarkable and reflects their origin from physical and chemical weathering of the underlying overburden materials and bedrock and many textures and grain sizes. The technical detail used to define and describe soil type is a very comprehensive process beyond the scope of this report. However, the utility of the soil survey with respect to hydrogeology and zoning lies in the classifications of soil type for land use. Based on physical and engineering properties, land use for specific soils can be recommended. Specifically, important land use categories for zoning include suitability for agriculture, practical construction of buildings and infrastructure as well as resource mining and extraction.

Another very important feature of soil type, the characteristic of soil permeability, will be discussed under the topic of Aquifers. "**Permeability**" in fluid mechanics and the earth sciences (commonly symbolized as κ, or k) is a measure of the ability of a porous material (often, a rock or an unconsolidated material) to allow fluids such as air and water to pass through it.

4.7 Prime Farmland: Agricultural Suitability Soil Map (Map 16)

According to Table 5 in the Soil Survey of Sullivan County, based on specific characteristics of each soil type, the following prime farmland types include:

Bb	Barbour loam	Ra	Raynham silt loam
Bs	Bash silt loam	Re	Red Hook sandy loam
ChA, ChB	Chenango gravelly loam	RhA, RhB	Riverhead sandy loam
LaB	Lackawanna channery loam	SaB	Scio silt loam
LeB	Lewbeach silt loam	TkA, TkB	Tunkhannock gr loam
LoB	Lordstown silt loam	UnA, UnB	Unadilla silt loam
Pe	Philo silt loam	VaB	Valois gravel sand lm
PmA, PmB	Pompton gravelly fine sandy loam	Wa	Wallington silt loam
Po, Pp	Pope silt loam & very fine sandy loam		

Map 16 shows the best soil for various kinds of agriculture. As agricultural lands disappear into subdivisions, it is important to preserve farmland for growing food. As would be expected, much of the agricultural land occurs on the floodplains of the Basher Kill and Homowack Kill waterways. Also, there are significant farmlands in Winterton and Burlingham along the Shawangunk Kill and tributaries.

4.7.1 Agricultural Land Protection

The locations of lands in Sullivan County Agricultural District 4 are superimposed on Map 16 to show where farming occurs. Agricultural Districts are active farm lands and a tax break is given to the owners. From inspection of the map, one can see that much less than half of the appropriate land are actually used for farming. A farm advocacy program sponsored by the town might be a good endeavor to attract and encourage local farming.

4.7.2 Agricultural Preservation Recommendation

Given that there is limited acreage of prime agricultural land in the Town, it might be advantageous for the Town to develop a plan to encourage the use of lands for farming and encourage application to the Ag District. For example, the area of Burlingham has very little Ag District designation, but many acres of prime agricultural land. Because farm land continues to be developed into subdivisions, the time is now to try to get establish more land for agricultural endeavors.

4.8 Building Suitability Soil Map (Map 17)

Specific soils properties relate to building suitability including high water table, flooding, shrink-swell potential and organic layers, which can cause shifting of footings. High water table, depth to bedrock, large stones and boulders, and flooding affect the ease of excavation and construction. Building suitability is shown on Map 17 by degree and kind of soil limitations that affect shallow excavations, dwellings with and without basements, small commercial buildings, local roads and streets, lawns and landscaping as classified in Table 11 of the Soil Survey of Sullivan County as follows:

- Slightly Restricted: (rose) generally favorable for uses, minor limitations.
- Moderately Restricted: (light yellow) soil properties not favorable, require special planning, design, and maintenance to overcome or minimize limitations.
- Severely Restricted: (light green) special design and extra costs required, increased maintenance.

Factors restricting suitability include high water table; compact dense, firm pan layers; organic layers, shrink-swell potential, slope, load limits, sloughing or caving, septic capabilities, depth to bedrock, and large stones.

4.9 Soil Type Maps for Resources

Developed soils and underlying overburden provide necessary raw materials for road construction, septic and drainage fields. Topsoil is an agricultural resource for crop cultivation as well as landscaping, lawns, and riparian buffers. These natural resource areas may not require special zoning; however, it is important to know their location.

4.9.1 Roadfill Construction Materials Map (Map 18)

Using the properties of soils, Table 13 in the Soil Survey of Sullivan County identifies and classifies the nature of materials with respect to road construction in the two categories shown on Map 18:

- “Fair” (light orange) materials are more than 35 percent silt and clay-size particles and have plasticity index of less than 10. They have moderate shrink-swell potential, slopes of 15 to 25 percent or many stones. Depth to water is 1 to 3 feet.
- “Good” (light green) material contains significant amounts of sand and gravel or both (e.g., Bb; Barbour; good). They have a least 5 feet of suitable material, low shrink-swell potential, few cobble and stones, and slopes of 15 percent or less. Depth to water is more than 3 feet.

4.9.2 Sand and Gravel Soil Map (Map 19)

Similarly, Map 19 (Sand and Gravel Construction Material in the Town of Mamakating) separates out soil classes comprised of both sand and gravel (e.g., Otisville classes) from those described solely as gravel (e.g., Valois classes). Sand and gravel are important resources for future construction. Consideration should be given to removing sand and gravel deposits from undeveloped areas so that they are available for future use. Map 19 reflects the classification of soil types presented in Table 13 of the Soil Survey of Sullivan County. The sand and gravel deposits are generally similar to the areas outlined on the unconsolidated aquifers map. The unsaturated deposits are the best to consider for mining, thereby leaving saturated deposits as potential groundwater and aquifer recharge sources.

4.10 Surficial Geology Map (Map 20)

The sand and gravel soil types are included on the Surficial Geology Map (Map 20). The Surficial Geology Map also includes many larger and unconsolidated deposits such as overburden, undeveloped soils, weathering bedrock and glacial deposits. Permeable surficial materials are classified by geologic origin, such as kames, kame terraces, eskers, moraines, deltas, outwash, or alluvium and are generally the coarse grain materials (sand size and greater). Other less permeable surficial materials include glacial till, silt, clay, mud, swamp deposits and bedrock. The overburden or surficial geology content includes all unconsolidated sedimentary deposits formed by wind, glacial, lacustrine, streams, and other geologic processes. Less permeable surficial materials are made up of fine grain or mixed size deposits, including glacial till, silt, clay, mud, swamp deposits and bedrock. All of these materials have some value, but their widespread occurrence in small deposits may make them not easily protected or preserved. One fine-grained resource that may have some economic value is clay deposits. Bedrock is widespread and has many construction uses such as crushed stone.

4.11 Unconsolidated Aquifers and High Permeability Sediments (Map 21)

The highly permeable sediments on Map 21 represent soil classes extracted from Soil Survey maps based on published permeability values. They were derived from SCS and NYS Museum data. They include the following SCS soil units: Barbour (Bb), Chenango (ChA, ChB, ChC, ChD), Otisville (OtA, OtB, OtC, OtD), Pompton (PmA, PmB), Gravel pits (Pg), Riverhead (RhA, RhB, RhC), Scio (SaB), Suncook (Sn), Tunkhannock (TkA, TkB, TkC, TkD, ToE, ToF), Unadilla (UnA, UnB), and Valois (VaB, VaC, VaD, VaE, VaF).

Permeable soils tend to be mixtures of sand and gravel sediments with small amounts of silt, clay or mud. The porosity is the space between grains and permeability is the capacity for water and air to flow through the soil mixture. Many of these permeable soil deposits correspond directly to materials shown on the *Surficial Geology Map.* As mentioned above the surficial materials are larger deposits of geologic origin, such as kames, kame terraces, eskers, moraines, deltas, outwash, or alluvium. Other less permeable surficial materials include generally finer-grain deposits such as glacial till, silt, clay, mud, swamp deposits and bedrock. The permeable materials can be considered unconsolidated aquifers if saturated or building construction materials if not water-bearing. It is logical not to build housing or other structures on such resources because they are best used for future building and infrastructure.

The Town of Mamakating Map of Unconsolidated Aquifers is a portion of the aquifers mapped by Edward F. Bugliosi and Ruth A. Trudell on a publication entitled *Potential Yield of Wells in Unconsolidated Aquifers in Upstate New York, Lower Hudson Sheet* 1:250,000, USGS Water Resources Investigations Report 87-4274.

Map 24 is constructed from three Unconsolidated Aquifer classifications in our area of concern: 10 - 100 gpm (red bordered polygons), greater than 100 gpm (red polygon with yellow fill near map center), and sand and gravel deposits of unknown yield (two blue-bordered polygons). These areas should be protected because they may be needed for water supply purposes as population and build-out increases. One can see that the locations of unconsolidated aquifers are similar to the distribution of sand and gravel deposits mapped during the Soil Survey and many of the sand and gravel deposits on the Surficial Geology Map.

There are five major unconsolidated aquifer areas in the Town of Mamakating, all associated with surface waters. Such areas include the Bashakill Marsh, the The Canal/Homowack Kill Complex, the Winterton and Burlington areas on the Shawangunk Kill, Gumaer Brook, and Sandburg Creek.

In Division of Water Technical and Operational Guidance Series (2.1.3.) Memo: *PRIMARY AND PRINCIPAL AQUIFER DETERMINATIONS* (Originator: Mr. DeGaetano), NYSDEC identified two classes of unconsolidated aquifers:

(1) Principal Aquifers: Aquifers known to be highly productive or whose geology suggests abundant potential water supply, but which are not intensively used as sources of water supply by major municipal systems at the present time.

(2) The Primary Water Supply Aquifers were originally identified by the NYSDOH in the "Report on Groundwater Dependence in New York State", 1981. The municipal populations supplied with water from the 18 identified Primary Water Supply Aquifers range in size from 8,100 people (Croton-on-Hudson) to roughly 150,000 people (Schenectady).

The major difference in the two classifications is associated with the word "potential" describing the principal aquifers. Principal Aquifers may not be used at this time, but are a known resource waiting to be used as a water supply, whereas Primary Aquifers are already used as a productive municipal water supply.

In New York State, there are 18 mapped primary aquifers used for water supply. None are located in the Town of Mamakating. **While the areal and vertical extent of high permeability sediments underlying the Mamakating Valley are currently poorly defined (i.e., limited well and boring log information), it is highly likely that the Bashakill Marsh and valley overlie an as yet unidentified and largely unused high permeability aquifer (i.e., a future 19th primary aquifer).** Aquifer protection provides justification for carefully assessing what are and what are not desirable activities in watersheds tributary to the Bashakill Marsh. A general watershed delineation is provided in this report, but additional characterization is required to apply for consideration as a Primary Aquifer by the NYSDEC at this time.

Unconsolidated Aquifer Recommendation: The unconsolidated aquifers are probably the most important water supply resource within the town. Since their permeable materials are exposed at the land surface, they are incredibly vulnerable to potential contamination from human activities. Some or all of the areas of unconsolidated materials outlined on Map 21 could be protected within a special zone immediately.

Where possible, it would be wise to establish and enforce a 100-foot or other width buffer around the aquifers as a preliminary protective measure.

There are ways to map and characterize them as Principal or Primary aquifers and have them approved by NYSDEC and/or US EPA as Sole Source Aquifers. Additional investigation could be conducted to further classification of the Basher Kill - Sandberg Creek sub-surface water-bearing zones as Primary Aquifer(s). HydroQuest and Mid-Hudson Geosciences can help with field procedures to characterize the aquifers and prepare maps for Aquifer designation if desired.

4.12 Bedrock Map (Map 22) and Geologic Cross Section (Map 23)

The bedrock units shown on this map are from the New York Geologic Map, Lower Hudson Sheet 1:250,000 identified as NYS Museum and Science Service Map and Chart Series No. 15 (1971) compiled by D.W. Fisher, Y.W. Isachsen, and L.V. Rickard. The oldest rocks are the Cambrian-Ordovician Martinsburg Shale outcropping on the eastern side of the map along the Shawangunk Kill and the rock leading up to the Shawangunk Ridge to the northwest. The Shawangunk Ridge is topped with the highly resistant white Shawangunk Conglomerate (quartzite) of Silurian age. The majority of the west side of the ridge is also made of the cliff forming Bloomsburg Formation similar to the Shawangunk Conglomerate with three members known as the Basher Kill Tongue, the Ellenville Tongue, and the Wurtsboro Tongue. The Route 209 corridor is underlain by Upper Silurian and Lower Devonian carbonate beds such as the Rondout Formation, Helderberg Group and Onondaga Limestone from east to west. On the west side of the Basher Kill – Sandberg Creek lowland, the relatively flat lying Devonian Catskill beds of the Hamilton Group, Oneonta Formation, and Lower Walton Formation rise up toward the northwestern boundary of the Town.

Map 23 shows a map and a geologic cross section drawn along a northwest to southeast trending line to show the three-dimensional relationship of the different stratigraphic units with the oldest rock on the right and the youngest on the left.

4.13 Water Well Inventory Map (Map 24)

Water well information was obtained from three sources: (1) town records of water well driller logs maintained in the Town building department (2) records on file with NYSDEC for wells drilled after April 2000, and (3) well records and maps in a USGS Bulletin GW-46 *Groundwater Resources of Sullivan County, NY* by Julian Soren, USGS Geologist in conjunction with the New York State Water Resources Commission, 1961. Specific well locations are shown on Map 24. Symbols are coded to indicate approximate well yield and whether the wells produce water from overburden (unconsolidated sediments) or bedrock.

High permeability soils are depicted in light green. These soil areas were derived from SCS soil survey map data (1989). They are comprised of Barbour, Chenango, Otisville, Pompton, Riverhead, Scio, Suncook, Tunkhannock, Unadilla, and Valois soils and gravel pit areas.

The yield of wells constructed in sand and gravel deposits, as outlined in dark blue on Map 24, is unknown. The unconsolidated aquifer information, also shown as Map 21, is from an Unconsolidated Aquifer map published by Bugliosi and Trudell (1987).

Open pink circles represent wells where the depth to bedrock is greater than 50 feet. Areas where these wells overlap with high permeability soils warrant investigation for possible high yield sand and gravel-rich unconsolidated aquifers.

Water wells provide the most direct hydrologic information to characterize groundwater availability. However, there are some limitations, such as shallow wells that indicate near surface conditions, but may not penetrate deeper horizons of overburden and bedrock which may be aquitards or aquifers. Also, proper pumping tests may not have been conducted on all wells, so the recorded well yield may be a driller's guestimate. The County and State Health Departments require a four-hour yield test after a well is completed, but for many reasons the results are at best a good guess. For instance, if the pumped well is discharged onto the ground near the wellhead, the water can recirculate and be re-pumped thereby giving an overly optimistic yield. Also, more than one well can be drawing from the same underground zone, so the yield may be shared by neighbors. Also, changing hydrologic conditions can lower the water table over time so that wells can go dry during drought conditions or from over pumping. Drillers' well records are better than independent mapping of permeable soils with no yield information or, possibly, with little or no saturated soils.

The greatest concentration of recorded wells is located in the area of Wurtsboro Hills. This area is higher in elevation than the Basher Kill and is located west of the Village of Wurtsboro on the eastern flank of the Catskill Plateau. Of a group of 18 wells drilled into bedrock, 15 produce 20 gallons per minute (gpm) or less and three produce between 41 and 100 gpm. Many low-yielding wells are recorded along the southeastern Town boundary. A bedrock well located on Doll Road in the northeastern portion of town has a reported yield of 300 gpm, indicating that while high yielding bedrock wells are present in well-interconnected fracture sets, they are uncommon.

The highest yielding wells (100 to 400 gpm) are located in the unconsolidated aquifer in the Mamakating Valley (aka Port Jervis Trough) beneath the Basher Kill and the Homowack Kill. At least one well near the Town's southern border has a yield of up to 100 gpm. Additional well records may reveal other high yielding unconsolidated wells in the Mamakating Valley.

Examination of wells logs revealed the presence of thick sediment deposits blanketing bedrock in many areas of the Town. A well log from Cox Road reveals a sediment depth of 291 feet. Map 24 has pink circles placed around wells where the depth to bedrock equaled or exceeded 50 feet. It is interesting to note that the highest yielding bedrock wells (300 gpm; 30-40 gpm) are overlain by thick sediment deposits. Thus, their high yield may, in part, result from recharge induced downward from overlying sediments. A bedrock well on Mount Vernon Road in the Summitville area documents the presence of unconsolidated sediments to a depth of 190 feet with a yield of 40 gpm. Such depths provide evidence that the thickness of unconsolidated deposits beneath the Bashakill Marsh and Mamakating Valley exceeds 200 feet, suggesting the presence of a vast groundwater aquifer.

Potential expanded use of the aquifer must strike a balance between water demand and resource protection. Excessive aquifer water withdrawal south of Gumaer Brook has the potential of lowering the level of the Bashakill Marsh, thereby adversely impacting wetland ecology and ecotourism. For this reason, it is important to monitor water and contaminant inputs and outputs into and from the Bashakill Marsh. This assessment entails delineation of the watershed and numerous subbasins tributary to the marsh, which was completed as part of this project.

Reynolds (2007, sheet 1) describes the central Mamakating aquifer as follows:

> "*The principal aquifer in the Port Jervis Trough is a 50 feet thick outwash aquifer that extends from the Phillipsport Moraine near Summitville, southward through the study area to Port Jervis, N.Y. Previous studies had estimated as much as 500 feet of saturated drift in parts of the Trough, but new well data show that much of the valley fill consists of fine-grained lacustrine sediments. Drillers' logs show that the outwash aquifer south of Summitville is underlain by as much as 275 feet of lacustrine silt and clay. North of the Phillipsport Moraine, three large glaciolacustrine deltas that were built into Glacial Lake Wawarsing provide some local and discontinuous confined aquifers through their coarser bottomset beds. Elsewhere in the Trough, collapsed and buried portions of kame deltas and terraces provide local confined aquifers. The outwash aquifer appears to be very transmissive, as evidenced by the high specific capacity of 130 gallons per minute per foot [(gal/min)/ft] of a commercial test well screened in the aquifer*."

Reynold's report does not seem as optimistic as our limited well yield data indicates. Additional evaluation of new well data may help clarify the magnitude and extent of aquifer conditions.

4.14 Bedrock Aquifers (Map 24)

The well records document the presence of only a few high yield bedrock wells. For the most part, drilling a well into bedrock on the eastern flank of the Catskill Plateau or the eastern flank of the Shawangunk Ridge is likely to produce a well with sufficient yield of 2 gpm or more for an average household. Well drilling along other parts of the Ridge, where there is little porosity or permeability in the sandstone, have yielded dry wells. However, most wells produce water from the fractures in the bedrock. The more interconnected the fractures are, generally the higher the well yield. Fracture interconnectivity between wells in nearby Deerpark Village has been documented to 4,300 feet during a pumping test. This finding accents the need to conduct aquifer tests in advance of projects requiring large quantities of groundwater.

Atop the Ridge, Shawangunk Formation sandstones and conglomerates overlie Ordovician Martinsburg Formation shales and sandstones. Sometimes white conglomerate slabs have sheets of rumpled dark shale in between the slabs. This bedrock configuration presents an area of complicated water supply interpretation. As a consequence of topography and elevation, the top of the Shawangunk Ridge is an island in the sky. All recharge comes to the mountain top by way of precipitation. Since there is no higher ground, there is no subsurface groundwater flow into the top of the Ridge. One example of the groundwater situation is that of the Proposed Seven Peaks Subdivision. Information gleaned from project testing is instructive regarding ridge top water availability.

The Seven Peaks Subdivison was proposed with 48 lots for homes and one for a resort, all greater than 5 acres, probably averaging close to 6 acres with 21 acres for the resort. The site is on the top of the Shawangunk Ridge on the west side of Mountain Road. The terrain is craggy with large slabs of conglomerate with wetlands interspersed and broad plateaus at the high home sites. The site presents many challenges, but is truly a remarkable area for natural beauty.

As part of the application process, wells were drilled and pumping tests were conducted. Seven bedrock wells (numbered W-1 to W-7) were drilled on the site to a depth of 500 feet with the exception of well W-5, which has a total depth of 550 feet. Of those seven wells, three wells were reported to have yields of less than 2 gallons per minute (gpm). On page 7 in Appendix E: discharge rates for W-4 and W-7 were less than 1 gpm; on the NYSDEC Water Well Completion Form for W-6, a 4-hour test showed a well yield of less than 2 gpm. Clearly, many mountain top wells are low yielding and are not suitable for major developments.

The following Conclusions and Recommendations were made by Mid-Hudson Geosciences (February 19, 2010 in a letter to the Town of Mamakating Planning Board):

> “Conclusions and Recommendations
>
> “Based on the findings of this review of the details of the hydrogeologic investigation, water supply for this project remains uncertain at best.
>
> “Conclusions:
>
> - If the sampling of the seven wells drilled for the DEIS is accurate, forty percent of the homeowner wells are likely to yield less than 2 gpm. The NYSDOH considers wells with less than 2 gpm inadequate for a domestic water supply.
> - The best well tested was capable of pumping at about 12 gpm.
> - The one well drilled in the Resort area has a yield of less than 1 gpm.
> - The well for the Model House has a yield of less than 2 gpm.
> - Both of the wells pumped did not fully recovery to pretest static water levels. Another well showed drawdown in response to pumping and did not recover. Two of these wells showed about 5 feet of unrecovered drawdown.
> - The transmissivities calculated from pumping tests for the bedrock aquifer are on the order of 10 ft^2/day and rated as poor to fair for domestic water supplies.
> - The only source of recharge of groundwater beneath this ridge top location is vertical infiltration of rainfall and snowmelt.
> - The wetlands are not likely sources of recharge because they are all connected with streams.
> - Locations of recharge areas are unknown at this time.
> - The numeric groundwater model developed to simulate drawdown from pumping wells on site does not contribute anything to the questions of water availability.
>
> “Recommendations:
>
> ♦ The groundwater problem on this site is recharge. It might be possible to drill enough wells, which could be pumped to supply the homes, but if recharge does not occur, the water levels will drop continuously. This was a problem when Marriott wanted to build a resort at Minnewaska. This same problem occurs in the hamlet of Cragsmoor. Another proposed development north of Route 17 on the Ridge also has never been able to demonstrate adequate water supply.

- The hydrogeology of this site is complex. An understanding of the recharge and flow regime are necessary to demonstrate adequate water supply. It would be wise on the part of the site owner to continue to monitor precipitation and water levels in some of the existing wells. It is important to try to understand the seasonal and annual water level cycles. Also, to see if any recharge occurs when the wetlands may be frozen, but snowmelt or rainfall finds its way downward through cracks and crevices.
- The applicants' consultant did demonstrate that precipitation does correlate with recharge, but the limited data also showed a trend of dropping water table. Monitoring the water levels for months and years will help resolve these mysteries.
- If this project is approved by the Town, before a building permit can be issued or prior to the sale of any lot, a well must be drilled and tested to demonstrate sufficient yield and recharge to provide enough water for the proposed home. Also, drawdown in nearby wells should be investigated.
- If the applicant has any idea of continuing to propose a Resort on the site, adequate water will have to be demonstrated with drilled wells and testing. Monitoring of nearby wells will be necessary to try to determine the radial influence of pumping." (from Mid-Hudson Geosciences letter to Town of Mamakating Planning Board, February 19, 2010)

On the top of the Shawangunk Ridge water supply from wells is limited by the fact that recharge can only come from precipitation. Also, the Shawangunk Conglomerate is made of quartzite, a hard rock of sandstone and pebble-conglomerate bedrock cemented together by quartz. There is very little pore space and very little permeability within the rock. Most of the groundwater lies in fractures between blocks of rock. If the fractures are open and interconnected, then groundwater can be conducted downward to the level of the Basher Kill or other streams via circuitous pathways. Obviously some water stays near the top of the Ridge because some wells do produce, but usually small yields less than 10 gallons per minute (gpm). If recharge was a constant process and drought did not occur, then there might be sufficient water for residential subdivisions on the ridge. However, even though rainfall is increasing, we have very little information on recharge sufficient to be able to predict water supply sustainability from groundwater resources. For these reasons, special testing must be conducted to demonstrate adequate water supply for proposed projects.

Recommendations: Each project should be judged on its own technical merits. With more drilling and testing, patterns of distribution and correlation with bedrock configurations may provide better keys to groundwater exploration. In the meantime, drilling and pumping tests and interference tests are the best tools to assess water supply availability. Also taking water level measurements over periods of time will help too. Often, a very simple test of putting a recording transducer in a well and letting it collect water level information for a year can be very cost effective to observe recharge and discharge of groundwater. All too often, applicants omit this step and then no information is available to predict groundwater supply sustainability.

The hydrogeologic situation on top of the Shawangunk Ridge probably does not require any zoning action, but does warrant diligence on the part of the Planning Board to make sure adequate drilling and testing is conducted for proposed development.

4.15 Carbonate Bedrock and Karst Features (Maps 25 and 26)

The Bedrock Geology Map (Map 22) shows the areal distribution of three individual carbonate units: Onondaga Limestone, Helderberg Group, and Rondout Formation. Surprisingly, communication with geologists at the NYS Museum revealed a lack of detailed geologic mapping of the Helderberg carbonate sequence present in Mamakating region. Assessing the formations there and the operable karst hydrogeology (i.e., cave or conduit-bearing) is important in determining areas that should be considered for special water quality protection due to the high vulnerability of karst aquifers and their receiving waterbodies (e.g., Bashakill Marsh). The Carbonate Bedrock Map (Map 25) shows one band of carbonate rocks including all three stratigraphic units. Because of the vulnerable nature of karst features within the carbonate band, a Karst Protection Area is proposed in the area of Surprise Cave in the lower Bashakill Marsh watershed area (see Maps 31, 22, 25 and 27). The significance of Surprise Cave and related geologic conditions are described below.

4.15.1 Karst Geology and Groundwater Flow Conditions

The presence or absence of functioning karstic groundwater flow systems can seldom be discerned when examining a single site area. Rapid, non-Darcian, groundwater flow is the single most important characteristic denoting karst terrains. Such flow occurs within conduit portions of karst aquifers that receive slower Darcian flow from joint and fault pathways present in up-gradient carbonate and non-carbonate portions of interconnected aquifers. Many karst terrains exhibit no surficial karst features (e.g., sinking streams, sinkholes, caves). Experienced karst hydrologists recognize that the determination as to whether a particular area lies within a karst terrain cannot be made when examining a site in isolation from the operative and surrounding hydrogeologic flow regime.

Karstic groundwater flow is well-documented throughout the Helderberg Group from far west of Schoharie County, through Albany County and then southward through Green, Ulster Counties, Sullivan and Orange counties, continuing further southward. There are probably few areas, if any, along the arcuate Helderberg carbonate band that are non-karstic.

Small and large conduits in the Helderberg carbonate group have been documented, entered and mapped all along this carbonate band - including Surprise Cave in the Town of Mamakating. Through a combination of geologic mapping in the field, examination of the generalized NYS Museum geologic map, and much field reconnaissance, we have identified three springs that are likely discharge points for water flow in Surprise Cave (Maps 26 and 28). While tracer testing is needed to confirm, or not, these springs as discharge locations from stream waters that sink into the bed of the stream above the cave and flow through it - there is little doubt that groundwater from the stream discharges into the Bashakill Marsh.

Recognition of the hydrogeology present here is particularly important for four reasons: 1) Surprise Cave (one of the longest in NYS) is home to threatened or endangered bat species (the reason NYS DEC acquired the cave entrance), 2) the Bashakill Wildlife Management Area provides critical habitat to numerous wildlife species, 3) the Bashakill is very important relative ecotourism, and 4) NYSDEC has an active SPDES permit that allows contaminants to traverse through Surprise Cave and into the Bashakill. I believe this stems from the Otisville Prison. Fecal coliform has previously been documented as a major issue here. In light of potential adverse environmental impacts, a rigorous review of this situation is warranted.

A key point that cannot be overly stressed here is the need to examine the broader area than includes and extends beyond any site areas where a contaminant-based land use is contemplated. Karstic flow routes provide little or no natural cleansing of contaminants. Therefore, it is important from a hydrogeologic and environmental standpoint to document groundwater flow paths, spring discharge locations and potential contaminant receptors (e.g., wetlands, streams, rivers, lakes, water supplies).

Such studies should include assessment of groundwater recharge incident to carbonate formations. Specifically, extensive jointing and faulting in the New Scotland Formation often readily allow downward infiltration into underlying carbonates of the Helderberg Group.

4.15.2 Carbonate Band and Contaminant Transport

A thick band of carbonate bedrock transects the Town of Mamakating, trending from north-northeast to south-southwest. It is comprised of a number of soluble limestone and dolostone beds that, in places, have developed conduits and caves (see Figures 23, 24 and 26). The geologic units that make up this carbonate band are listed on New York State Museum maps as the Onondaga limestone, the Helderberg Group limestones, and the Rondout Formation. Different authors have sometimes attributed different names to some of these carbonate beds. Some of the uppermost beds of the Helderberg Group carbonates have a lower percentage of calcium carbonate and are, as a result, less favorable relatively conduit development (i.e., Kalkberg and New Scotland formations). In places, a silica-rich component further reduces bedrock solubility. The most prominent conduit formations within the Helderberg Group are the Manlius and Coeymans limestones that, together with the underlying Rondout Formation, are known throughout New York State as major cave or conduit-forming bedrock formations.

The Rondout Formation is included within the carbonate band because of it soluble, cave-forming, nature. For example, down-gradient portions of Howe Caverns are developed in the Rondout Formation. Locally, an excellent example of conduit development in the Rondout Formation is found in Guymard Lake which is located 5.6 miles south-southwest of the Sullivan/Orange County border along the trend of the limestone/carbonate bedrock band (see Map 25 that shows part of the carbonate band). Geologically, the lake bottom lies mostly within the Rondout Formation and partially within Helderberg Group limestones, both being well-recognized for their extensive cave and sinkhole-forming character. Episodically, much of the lake rapidly drains into a sinkhole conduit that must resurge in a spring close to the Neversink River, some 2000± feet away horizontally and 260 feet lower vertically. Episodic disappearance of ponds and lakes into sinkhole drains is a well-recognized occurrence, depending on opening and plugging of conduit drains. Surprise Cave represents a physically enterable segment of a similar conduit network.

Conduits provide pathways where groundwater and any contaminants in it can move rapidly with little or no dilution to down-gradient receptor. Groundwater resources present in bedrock formations with conduits developed in them are referred to as karst aquifers. They represent the most vulnerable aquifers anywhere. Contaminants in karst aquifers can travel miles in hours versus groundwater flow rates in non-karstic (i.e., non-conduit or cave-bearing) aquifers of feet per day or less.

While the most significant feature of karst aquifers is the presence of rapid, turbulent, groundwater flow, karst aquifers also have fractured bedrock portions with slow laminar flow. Many, but not all, karst aquifer exhibit surface features including sinking and losing streams, sinkholes, caves, and springs. The lack of these features does not document that no karst aquifer is present. The Town of Mamakating has well-developed karst resources, inclusive of all of these features. Surprise Cave is well known by geologists and cavers in the northeastern United States.

4.15.3 Surprise Cave and Water Quality Concern

Surprise Cave (also referred to as Mystery, Fallbrook and Snaggletooth Cave) is situated near the southern border of the Town of Mamakating (Figure 27). It has a surveyed length of 9,974 feet (1.9 miles), making it the seventh longest cave in New York State. Geologically, it has developed within the Helderberg Group limestones and possibly within the underlying Rondout Formation (Figures 23 and 26). Its development spans a vertical extent of about 176 feet. Its five levels, pits, mazes, variable-sized passages, and complex physical pattern make it one of the most interesting and challenging caves in the state. The ground surface above the cave is riddled with numerous shallow and deep sinkholes that provide infiltration input into the cave. However, the two largest sources of water input into the cave are from the stream that sinks into the streambed upstream of the cave entrance and from direct input into the cave entrance during times of high stream flow (Figure 27). During times of low and moderate streamflow, the entire stream is pirated into the streambed and underlying cave. Figure 27 depicts three springs that were located as part of this study. It is likely that the two springs labeled Cave Resurgence Springs are where surface water that sinks into the cave and flows through the cave discharges. While tracer test confirmation is required to verify this, these two springs are the only known springs in the area that exhibit appreciable flow during very dry surficial conditions. The physical location of these springs is aligned along the strike of the bedrock beds (i.e., perpendicular to its slope). The limestone beds are in and immediately overlying the cave slope steeply to the northwest at angles ranging between 21 and 37 degrees (Figure 24). We hypothesize all or most groundwater within the cave cannot exit directly to the west because it cannot breach the more silica-rich overlying Kalkberg and New Scotland limestones. Instead, it must follow the alignment of these less soluble beds to the south-southwest to spring outlets that then discharge into the Bashakill Marsh.

The cave is closed seasonally to protect hibernating bats. The bat population in the cave and elsewhere has been severely reduced due to White-nose syndrome (WNS), a disease named for the white fungus, *Pseudogymnoascus destructans*, which infects skin of the muzzle, ears, and wings of hibernating bats. In 1984, the NYS Department of Environmental Conservation purchased the entrance to Surprise Cave to control access to protect endangered bat species in the cave long before the 2005-2006 advent of WNS.

The Otisville Federal Correctional Facility (aka Otisville Prison) has a NYSDEC issued SPDES permit (DEC ID: 3-3344-00002/00002; SPDES No.: NY0037397) to discharge 500,000 gallons per day of sanitary wastewater into receiving waters known as "*Tributary of Basher Kill*." Fecal Coliform is among the numerous parameters permitted in the prison's waste stream, up to 7-day geometric mean of 400 colonies per 100 ml. Fecal coliform stems from human and animal waste and is generally accompanied by *Escherichia coli* (*E. coli*) bacteria that has a groundwater standard of 0 colonies per 100 ml. *E. coli* is responsible for human sickness and fatalities. Palmer (2007) and Worthington et al. (2003), for example, document the death of 7 people and illness of more than 2000 people in Ontario stemming from rapid flow of pathogenic bacteria in manure, including E. coli, in solution conduits to wells in a carbonate aquifer. Here, the waste effluent is permitted to flow from the Otisville Prison in a small stream that during much of the year sinks entirely into the streambed, flows through Surprise Cave, and discharges in the Bashakill Marsh. It is highly likely that during dry times, the entire flow of the small stream incident to Surprise Cave is comprised of prison effluent. Unless the effluent is 100 percent treated so that no pathogenic bacteria are in the waste stream, this permitted discharge may be adversely impacting the water quality in both Surprise Cave and the fauna-rich Bashakill Marsh and the resident bat population. There is a history of highly concentrated septic waste flowing from the prison either untreated or poorly treated into the permitted receiving stream. Examples include John and Irene Janeczko's observation of raw sewage flowing over the falls along the cave stream (pers. comm., 5-29-93) and Peter Febroriello's documentation (Northeastern Caver Volume XV, Number 3, 1984; Mystery Cave) of the formation of the Sullivan County Task Force in response to the prison's discharge of sewage to the Tributary of the Basher Kill. Febroriello and others documented high levels of phosphate and coliform bacteria in surface and cave waters. Over the years, contaminant concern has continued and would appear to be well founded based on current SPDES permit levels. We recommend a thorough review of all water quality monitoring data, followed by a review of the existing permit. It is highly likely that the SPDES permit fails to adequately address contaminant loading incident to the surface stream, cave environment, and the Bashakill Marsh. Furthermore, it is likely that water quality monitoring does not take into account the highly vulnerable karst flow conditions present, the endangered bat population, and potential degradation of the Bashakill Marsh.

4.15.4 Proposed Karst Protection Area

A significant portion of the hydrologically vulnerable carbonate band is protected from development through a combination of the Bashakill Marsh, wetlands, NYSDEC lands, floodplains and the D&H Canal towpath corridor. However, two areas lie outside these lowlands that are conduit-bearing and thus pose a water quality concern. The most glaring karst terrain that is not protected is the Surprise Cave area.

Surprise Cave and the surrounding carbonate formations that host New York State's seventh longest cave and an endangered bat population warrant special protection. We propose the establishment of a Karst Protection Area designed to protect groundwater and surface water quality, bat hibernacula, the fauna and ecology of the Bashakill Marsh, a unique natural area and ecotourism. The proposed area is depicted on Figures 22, 25, 27 and 31. It is bounded to the west by NYSDEC lands, to the east by the basal (bottom) contact of the Rondout Formation, to the south by the Town boundary, and by private land to the north. The proposed area encompasses about 306 acres.

4.15.5 Karst Aquifer Protection Recommendations

As discussed above, the Bedrock Geology Map (Map 22) shows the areal distribution of three individual carbonate units: Onondaga Limestone, Helderberg Group, and Rondout Formation. The Carbonate Bedrock Map (Map 25) shows one band of carbonate rocks including all three stratigraphic units. Because of the vulnerable nature of karst features within the carbonate band, a Karst Protection Area (shown on Maps 31, 22, 25 and 27) is proposed in the area of Surprise Cave in the lower Bashakill Marsh watershed area.

We recommend designating the Surprise Cave and surrounding area as sensitive critical environmental areas (CEAs). CEA designation is justified for both bat species and water quality protection. Map 31 highlights a proposed Karst Protection Area. Thus, we recommend that the Town:

- Establish a Karst Protection Area. In recognition of the extreme vulnerability of groundwater to contaminants in karst settings, of the need to promote recovery of endangered bat species in and around Surprise Cave, and to protect water quality in the Bashakill Marsh - legally designate and protect a Karst Protection Area from all construction (~ 306 acres including South Road)). The Karst Protection Area is situated at and abutting the southeastern end of NYSDEC Bashakill Marsh lands and extends northwest of the geologic contact between the Bloomsburg and Rondout formations (see Map 31 that depicts this area); and
- Consider extending the eastern boundary of the proposed Karst Protection Area further upslope to avoid development that might generate contaminants that could flow downslope and into sinkholes, Surprise Cave, and fractured carbonate bedrock present beneath glacial alluvium.

4.15.6 Phillipsport Karst Area

A second karst area present within the Town of Mamakating occurs between Summitville and Phillipsport (Figure 25). As discussed above, from a water quality perspective, the geologic formations within the carbonate belt that are the best conduit and cave-formers and thus the most hydrologically vulnerable to contamination are the units within the Helderberg Group and the Rondout Formation. These bedrock units are most extensively exposed to dissolution (i.e., conduit development) in the southern portion of the Town. There, carbonates of both the Helderberg Group and the Rondout Formation outcrop along the western flank of the Shawangunk Ridge. Not surprising, this where Surprise Cave has developed, making both bat and water quality protection important in this area. To the north-northeast of the Surprise Cave area, the carbonate belt and the Helderberg Group largely occur in or near the valley bottom, mostly in areas of low topographic relief that have limited conduit-forming potential.

Carbonates are structurally weak and poorly resistant to natural erosion, which commonly results in valleys forming within them over geologic time. Notably, carbonates within the carbonate belt are found in the Town of Mamakating underlying the Basher Kill within the Bashakill Marsh watershed, continuing northward under the D&H Canal corridor area to Summitville. North of Summitville, soluble Helderberg Group and Rondout Formation carbonates, as in the Surprise Cave area, are once again exposed along the western flank of the Shawangunk Ridge far above the base level elevation of the Homowack Kill. This exposed carbonate area extends northward of Summitville to close to Herlings Road where the carbonate band then extends beneath the D&H Canal and the Homowack Kill (Figures 22 and 25). In this exposed area, carbonate beds rise some 200 feet above the headwaters of the Homowack Kill. The great vertical elevation and the presence of several large and deep sinkholes in this region document the well-karstified nature of this area (i.e., the presence of conduits that discharge groundwater and contaminants with little or no dilution from sinkholes and fractured bedrock to springs along or near the Homowack Kill or adjacent wetlands). While one or more springs from this karst upland must discharge to the current Homowack Kill base level, it is likely that conduits and springs were formerly adjusted to a much lower base level when the valley here was much deeper and not filled with glacial sediments. Reynolds (2007) has documented buried valley depths here in this portion of what is referred to as the Port Jervis Trough of about 270 feet.

Consideration should be given to establishing zoning protective of a second Karst Protection Area here that minimizes the presence and potential transport of contaminants westward to the Homowack Kill (orange polygon area on Map 25). This area is situated east of Phillipsport Road, generally follows the 600-foot elevational contour closing along the eastern geologic contact of the Rondout Formation (i.e., the eastern edge of the carbonate band).

- Recommendation: Examine mapped and unmapped sinkholes situated approximately 3,000 feet south-southeast of Phillipsport. Also, field check this carbonate area for springs and caves;

- Recommendation: Review sewage disposal activities in the Town relative to water quality;

- Recommendation: Do not permit new development within the Karst Protection Area;

- Recommendation: Consider extending the eastern boundary of the Karst Protection Area upslope to the watershed divide. A significant portion of the proposed Karst Protection Area is owned by the Oak Ridge Rod & Gun Club, Inc. Perhaps, a conservation easement can be obtained that would allow existing hunting land use with no development beyond what may be present at this time. A component of the easement could state that no effluent or other discharge from the Otisville Prison will be permitted over the land.

4.16 Areas of Known Contamination (Maps 10, 13 and 27)

In addition to common septic discharge, two specific sources of surface and groundwater contamination are actively polluting water in the Town of Mamakating, specifically the historic Wurtsboro Lead Mine and the Otisville Prison.

4.16.1 Wurtsboro Lead Mine and Delaware - Hudson Hydrologic Divide

The Wurtsboro Lead Mine area (NYSDEC Site Code: 353013 of the State Superfund Program) represents an ongoing source of groundwater and surface water contamination to waters of the D&H Canal and down gradient receptors. Additionally, lead and perhaps zinc-laden sediments remain within and continue to migrate into the D&H Canal. The mine area is located directly east of the D&H Canal near the southern end of the Sandburg Creek headwater watershed area in the Wurtsboro Ridge State Forest in the Town of Mamakating along a west-facing flank of the Shawangunk Ridge (Maps 10 and 13). Historically, the mine has been known as both the Shawangunk Mine and the Mamakating Mine. Mining operations extended from the 1830s until about 1930 (NYSDEC). High grade galena was extracted from shafts constructed in lead-zinc ore, with spoils deposited in four tailings piles. The source area includes four areas of mine tailings and underground mine workings east of the Delaware and Hudson Canal Linear Park.

Surface and groundwater flow from the contaminant source area flow down gradient into the D&H Canal, a regional zone of low hydraulic head (i.e., base level). Lead is the primary contaminant of concern. Lead concentrations have been documented up to 13,400 ppm and to

2,370 ppm in site and canal sediments, respectively. The severe effects threshold for benthic organisms is 110 ppm. Groundwater seeps in tailings piles were found to have lead concentrations up to 4,800 ppb, compared to the drinking water standard of 25 ppb (http://www.dec.ny.gov/cfmx/extapps/derexternal/haz/details.cfm).

USEPA performed an Interim Remedial Measure (IRM) to reduce human exposure along the canal towpath, the lower railroad bed and the lower mill tailings area. NYSDEC site detail information states: "*The IRM consisted of covering area with surface contamination exceeding 400 ppm lead with a non-woven fabric covered with stone ranging from 6 inches to 18 inches in depth.*" Site information warns of contact with contaminated canal sediments or ingestion of water or fish from the canal. While the IRM is designed to reduce onsite exposure to contaminated sediments, hydrologically the IRM is not designed to protect surface and groundwater quality. To our knowledge, contaminant source removal was not conducted despite documentation that conditions at the site meet the requirements of Section 300.415(b) of the National Contingency Plan for the undertaking of a CERCLA removal action. Thus, the highly permeable IRM cover will not retard the influx of contaminated surface and groundwater into the D&H Canal.

The location of a single beaver dam determines whether site contamination flows northward to Summitville and Phillipsport or southward into the Bashakill Marsh with water in the canal (i.e., the dam is the hydrologic watershed divide). The protected area of the Wurtsboro Lead Mine site is situated very close to or at the hydrologic drainage divide between the Delaware River to the south and the Hudson River to the north. Because the hydraulic gradient of the D&H Canal is very low, the exact position of the divide that separates northward from southward flow varies over a distance of approximately 1,400 feet, dependent on the location of beaver dams constructed across the canal in any given year. Maps generated for this study reflect the location of a beaver dam present in the fall of 2016 and spring 2017. Canal water ponded on the north side of the beaver dam flows northward while leakage through the beaver dam flows southward into the Bashakill Marsh. Review of historic aerial photography reveals that the location of the "*dividing*" beaver dam in 1963 and 1968, for example, was 1,400 feet north of its 2016 location - approximately midway along the site's western boundary. In the 1960's, it is likely that lead contamination may have entered surface canal water flowing both north and south. Thus, while the present location of the beaver dam that forms the Delaware-Hudson hydrologic divide reduces the watershed tributary to the Bashakill Marsh, it indicates that ongoing contamination from the Wurtsboro Lead Mine is flowing northward into the Homowack Kill.

In 2017, contamination from the Wurtsboro Lead Mine area is all almost certainly captured by the D&H Canal that flows northward. Significant water and sediment outflow from the contaminant source area occurs during wet conditions. In 2017, surface runoff close to the southern end of the contaminated area was captured by a wetland and then a tributary that flows from southeast to northwest into the D&H Canal.

Wildlife observed along the canal corridor north of the Wurtsboro Lead Mine includes beaver, painted turtles, American woodcock, Canada geese, mallards, belted kingfishers and common bird species. A dead fish was observed on April 4, 2017, cause unknown. Signage present bordering the large contaminated area of the Wurtsboro Lead Mine warns "*DANGER RESTRICTED AREA DO NOT ENTER The soil and water in this area are highly contaminated with lead. No one is permitted to enter.*" A second posted sign states "*WARNING*

CONTAMINATED WATERS DO NOT DRINK Avoid prolonged contact with skin." (NYSDOH and NYSDEC) Surface runoff from this area directly enters the D&H Canal.

We recommend review of all historic and recent reports and chemical analyses related to this site. Also, we recommend that additional investigation be conducted to ascertain offsite sediment and water quality concentration information and to assess what, if any, actual site remediation work might be planned. It is possible, but unlikely, that USEPA will consider hazardous substance source removal in the future (https://response.epa.gov/site/site_profile.aspx?site_id=11295). This should be looked into as this site remains a significant contaminant and ongoing threat in the Town of Mamakating

4.16.2 Otisville Prison Waste Water Discharge (Map 28)

Previous cave visits and studies have identified discharge from the Otisville Prison into a stream which enters the Surprise/Mystery Cave system downgradient. Specific permit details on for Surprise Cave surface stream Permitted Discharge Point include SPDES Outfall No.: 001; SPDES Permit number: NY 0037397. Permittee Name: US Dept. of Justice; Permittee Contact: Facility Manager; Permittee Phone: 845-386-6700. Also listed: NYSDEC Division of Water: 914-428-2505.

Field work conducted for this study has identified the likely locations where these cave discharge springs, and portrayed them on Map 28. Regarding water quality, we strongly recommend review of the SPDES permit that allows discharge from the Otisville prison into a stream that is pirated into Surprise/Mystery Cave where endangered bat species hibernate, and then to springs that discharge into the Bashakill Marsh. Confirmatory tracer testing should be conducted.

4.16.2.1 Longevity of *E. coli*

Esherichia coli is a member of the coliform group and is a rod-shaped bacterium. *E. coli* is naturally found in the intestines of humans and warm-blooded animals. Although *E. coli* are part of the natural fecal flora, some strains of this bacterium can cause gastrointestinal illness along with other, more serious health problems. The *E. coli* strain 0157:H7 is of particular concern. Of the contaminants that are waterborne and may be found in drinking water, those present in human and animal feces pose the greatest threat to public health.

Groundwater to be used for drinking water purposes must be free of *E coli*. Depending on assorted environmental factors (e.g., temperature, exposure to sunlight, surface water, groundwater) *E. coli* has different die off rates. In general terms, *E. coli* survives for about 4-12 weeks in water containing a moderate microflora at a temperature of 15-18º C (Kudryavtseva, 1972; Filip et al., 1987; Edberg et al., 2000). *E. coli* have been noted to have an estimated half-life (i.e., the time taken for 50% reduction in numbers) in temperate groundwater of being as high as 10 to 12 days, with survival of high numbers up to 32 days (Sugden, 2006). In karst terrains, if the time taken for pathogens to be transported to a point where they are pirated underground into solution conduits is large, the pathogens may have died off and the threat to public health may no longer be present. However, upstream of Surprise Cave where the distance from the Otisville Prison to where stream water sinks into the streambed and enters the cave is only 1.3 miles distant. Historically, virulent *E. coli* has been found in Surprise Cave waters, thereby documenting the water quality threat present.

Rapid transport of pathogens in highly permeable sediments poses a water quality risk from inground septic tanks and leach fields. If E. coli enter the groundwater flow system rapidly (e.g., via streambed or leach field infiltration from a nearby pathogen source), then *E. coli* may survive for a number of months in relatively cold groundwater. The inability of *E. coli* to grow in water, combined with its relatively short survival time in water environments, means that the detection of E. coli in a water system (e.g., well, spring) is a good indicator of recent fecal contamination (Health Canada, 2009). Protection of stream and wetland water quality must factor in the quantity of fecal contamination, factors controlling groundwater flow rates (i.e., hydraulic conductivity, groundwater slope, effective porosity of sediments), and pathogen survival time. Logically, then, highly permeable sand and gravel deposits adjacent to streams present the greatest water quality risk because groundwater flow rates can exceed E. coli die off rates and/or natural cleansing. If, for example, E. coli survive for 90 days in the groundwater environment, it would be desirable from a protective water quality standpoint to not place septic leach fields closer than the distance it takes groundwater to move in this time period. This rate of groundwater movement, or seepage velocity rate, varies with aquifer hydraulic conductivity, hydraulic gradient and the porosity of the unconsolidated material present. The best means of determining groundwater flow rates is via many empirical measurements. This is time consuming, expensive, and is not practical for small development situations. Thus, examination of a reasonable range of published literature values for geologic materials present provides a workable substitute.

Groundwater flow through highly permeable sand and gravel can readily move at rates of many feet per day or more. If we reasonably assume a hydraulic conductivity of 280 ft/day for well-sorted glacial sands (Fetter, 1994), a slope of 0.01 (or 1 ft vertically per 100 ft horizontally), and an effective porosity of 0.25, we calculate that groundwater may flow at a rate of 11 ft/day through permeable materials. At this seepage velocity rate and an *E. coli* survival time of 90 days, we can approximate the *E. coli* die off distance as being on the order of 1,000 feet.

Clearly, this distance is not practical from a zoning standpoint, but it does point out 1) the flawed concept of a 100-foot "*protective*" buffer, and 2) the water quality risk associated with placing septic systems in highly permeable sediments proximal to streams. Perhaps, because there is often great heterogeneity in glacial sediments and partial *E. coli* die off will occur in less than 90 days, it may be reasonable to reduce the protective buffer distance between leach fields and stream receptors to 300 feet. Of course, the greater the density of leach fields placed in permeable sediments, the greater the pathogen loading and the greater risk to water quality. Greater water quality protection of stream reaches bordered by highly permeable sediments would be afforded through a combination of buffer distance and multi-acre lots.

Thus, from a hydrogeologic standpoint, it makes sense to empirically determine groundwater flow rates close to streams and wetlands before permitting construction of any kind above highly permeable sediments. However, from a practical standpoint, few if any Town planners are likely to require such hydrogeologic studies and landowners would balk at empirically-based buffer distances. Thus, the best means of reducing adverse water quality impacts in areas with highly permeable sediments may be a compromise that defers to a combination of 1) multi-acre parcel size, and 2) an acceptable buffer distance (e.g., 300 feet) that provides for some natural pathogen filtration. Three hundred feet represents a reasonable buffer separation distance between septic systems constructed in permeable sediments and streams and State wetlands hydraulically connected by flowing groundwater.

4.16.2.2 Otisville Prison Recommendations

Obtain and review historic and current water quality data of Otisville Prison outflow and SPDES water quality monitoring data. Close out SPDES Permit No.: 0037397 because, absent 100 percent effluent treatment, effluent will degrade Surprise Cave and Bashakill Marsh water quality.

4.16.3 Mamakating Lf Site

The Mamakating Lf Superfund Site is located at Sneed Street in Wurtsboro. The Environmental protection Agency identified this site because it once posed a potential risk to human health due to contamination by one or more hazardous wastes. This site is currently registered as an archived superfund site and does not require any clean up action or further investigation at this time.

4.17 Areas of Potential Contamination (Map 27)

Other possible contaminant sources may include the Sullivan County Landfill, Mamakating Town Dump, and other point and non-point source contributions. Transport of pathogenic bacteria from septic leach fields and manure spreading pose a water quality risk, especially in areas with high permeability soils.

4.17.1 Contamination from Oil & Gas Development

Oil and gas development, especially hydraulic fracturing of wells poses a future risk to water quality in the Town of Mamakating. This issue is one of those "hot button" matters which has not been discussed elsewhere in this report, however, it may be a logical step for the Town to consider a ban on Hydraulic Fracturing ("Fracking") of oil and gas wells. At this time, high volume hydraulic fracturing is banned in New York State by NYSDEC. However, that ban could be removed by future administrations and low volume hydraulic fracturing poses similar surface and groundwater quality risks. Hydraulic fracturing chemicals forced into subsurface geologic formations would be classified as Hazardous Waste by any other industry. Why would anyone want to put toxic chemicals into the subsurface and risk the potential of polluting a water supply or other body of water? Also the release of methane to the atmosphere is another bad practice for contaminating the air we breathe. Beyond this, use of fracking fluids for road desalinization, land spreading or as a disposal item all pose great risk to water quality.

4.17.2 Recommendation to Ban Hydraulic Fracturing

This issue is not mitigated by zoning. It would require a Town law. Both authors of this report have written and testified on the water quality hazards of hydraulic fracturing and provided example laws for Towns. Such could be provided for the Town of Mamakating if desired. Key recommendations here are:

- Establish legislation banning all oil and gas exploration and exploitation activity throughout the Town;

- Ban the use of hydraulic fracturing and petroleum-derived fluids and solids for land spreading, road deicing, disposal, or agricultural purposes throughout the Town; and

- Establish legislation banning pipeline construction for transport of liquid and gaseous hydrocarbons throughout the Town.

5. 0 INTEGRATION OF HYDROGEOLOGY INTO ZONING AND RECOMMENDATIONS

The Town of Mamakating has many land use protections in place which help to preserve water quality, natural ecosystems, and historical features. These include public lands held by New York State, Sullivan County, the Town of Mamakating, Villages of Wurtsboro and Bloomsburg; Federal and State Protected Wetlands, the D&H Canal Linear Park, and Agricultural District 4. There are other land use situations which comprise sites of existing contamination and continued release of toxics into the environment, such as the Wurtsboro Lead Mine and Otisville Prison.

Some natural resources could use additional protection such as natural caves (such as Surprise Cave) in the carbonate bedrock belt and the Bashakill Marsh and Sandburg Creek floodplain considered as an Unconsolidated Aquifer. In the case of classifying land areas for zoning, some areas may have been or will be set aside from residential development for other uses such as agricultural use, extraction of mineral resources, protected parkland, open space easements, and easements for no future development.

Recommendations provided here are of a general nature. The specific details with respect to hydrogeology have been provided. Additional information can be provided if needed. Implementation of zoning is not within the scope of this report.

5.1 Recommendations

Many recommendations and justification for them have been made throughout this report. Here, a comprehensive listing of major recommendations is provided in bullet form.

- Analyze and examine existing and future potential water demand from the Mamakating Aquifer;
- Consider seeking Principal Aquifer status for the unconsolidated aquifer(s) underlying the Mamakating Valley;
- Establish a 100-foot protective buffer around high permeability unconsolidated aquifers;
- Establish multi-acre lots and a 300-foot buffer distance between septic leach fields in high permeability sediments and streams and State wetlands;
- Minimize septic system installations in highly permeable soils proximal to streams;
- Allow no further development west of South Road;
- Fund and establish a USGS stream gaging station at the outlet dam of the Bashakill Marsh;
- Further investigate the Wurtsboro Lead Mine and Otisville Prison effluent and initiate actions to remove these water quality threats;
- Remove or remediate major existing contaminant sources (i.e., Wurtsboro Lead Mine, Otisville Prison effluent input to the Bashakill Marsh);
- Determine the presence of other SPDES permits in the Town and review water quality data relative to surface and groundwater quality;

- Establish a Karst Protection Area proximal to Surprise Cave to protect Bashakill Marsh water quality and the bat population severely impacted by White-Nose Syndrome (WNS);
- Consider extending the eastern boundary of the proposed Surprise Cave Karst Protection Area further upslope to avoid development that might generate contaminants that could flow downslope and into sinkholes, Surprise Cave, and fractured carbonate bedrock present beneath glacial alluvium;
- Establish protection zones for other areas determined to be particularly vulnerable to water quality degradation (e.g., Phillipsport Karst Area);
- Examine mapped and unmapped sinkholes situated approximately 3,000 feet south-southeast of Phillipsport. Also, field check this carbonate area for springs and caves;
- Avoid dense housing on steep slopes;
- Review housing density adjacent to Town lakes (e.g., Yankee and Mastens) with respect to potential eutrophication;
- Avoid overly dense housing proximal to lakes with no community septic systems to avoid lake eutrophication;
- Review sewage disposal activities in the Town relative to water quality;
- Incorporate use of our watershed and subbasin delineations as integral parts of zoning boundary assessment, especially as related to water quality protection;
- Review existing land-use and zoning within the Pine Kill subbasin, recognizing that any contaminant inputs will enter the Bashakill Marsh;
- Work with adjacent towns to protect Town of Mamakating water quality. Water quality protection requires input into and control over land use practices throughout entire watersheds. In places, as depicted on GIS maps, Town of Mamakating watersheds extend beyond Town boundaries;
- Encourage the use of prime agricultural land and expand Agricultural District 4;
- Avoid Oil and Gas Development, especially Hydraulic Fracturing;
- Establish legislation banning all oil and gas exploration and exploitation activity throughout the Town;
- Ban the use of hydraulic fracturing and gas and oil well derived fluids and solids for land spreading, road deicing, disposal, agricultural or other purposes throughout the Town;
- Establish legislation banning pipeline construction for transport of liquid and gaseous hydrocarbons throughout the Town;
- Drill wells and conduct pumping tests for all proposed home sites on the Shawangunk Ridge to demonstrate adequate water supply prior to construction; and
- Recognize that Town wells constructed in both bedrock and unconsolidated aquifers may by hydraulically interconnected over great distances. Thus, proposed housing developments or major water withdrawal proposals should be required to demonstrate adequate water supply, absent significant interference with nearby wells, prior to advancing major development proposals.

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