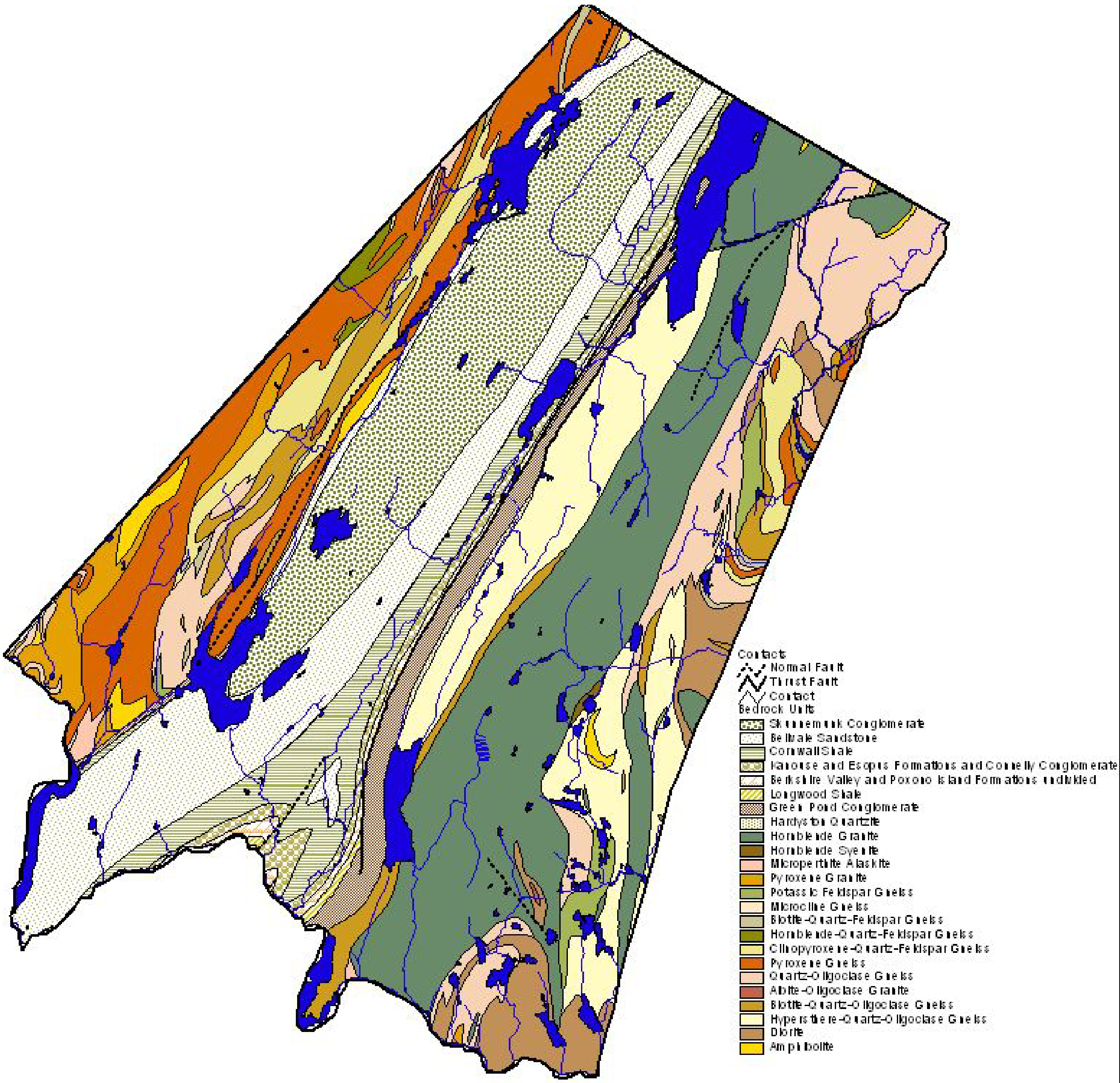
Evaluation of Groundwater Resources of West Milford Township, Passaic County, New Jersey



Water: A Natural Renewable Resource

M[2] Associates Inc.
56 Country Acres Drive
Hampton, New Jersey 08827

Water: A Natural Renewable Resource

EVALUATION OF GROUNDWATER RESOURCES OF WEST MILFORD TOWNSHIP PASSAIC COUNTY, NEW JERSEY

NOVEMBER 26, 2003

Prepared for:

West Milford Township
1480 Union Valley Road
West Milford, New Jersey 07840

Prepared by:

Matthew J. Mulhall, P.G.

M² Associates Inc.
56 Country Acres Drive
Hampton, New Jersey 08827
908-238-0827 Fax: 908-238-0830

Water: A Natural Renewable Resource

EVALUATION OF GROUNDWATER RESOURCES OF WEST MILFORD TOWNSHIP PASSAIC COUNTY, NEW JERSEY

TABLE OF CONTENTS

Water: A Natural Renewable Resource

TABLES

Water: A Natural Renewable Resource

FIGURES

Water: A Natural Renewable Resource

EVALUATION OF GROUNDWATER RESOURCES OF WEST MILFORD TOWNSHIP PASSAIC COUNTY, NEW JERSEY

INTRODUCTION

West Milford Township of Passaic County, New Jersey retained M^2 Associates in December 2002 to conduct an evaluation of the groundwater resources of the township. Figure 1 shows the locations of West Milford Township in Passaic County and Passaic County in New Jersey. Figure 2 shows the location of West Milford Township with respect to neighboring municipalities.

West Milford Township requested the groundwater resource evaluation because of the following:

1. The primary source of drinking water for township residents is groundwater, whether that water is derived from individual wells or public community wells associated with the West Milford Municipal Utilities Authority, United Water New Jersey, or Passaic Valley Water Commission. Although there are a number of lakes and reservoirs wholly or partially within the township boundaries, these surface-water resources are primarily dedicated to downstream consumers in eastern counties of New Jersey. Figure 3 depicts the reservoirs, large surface-water bodies, and public community water-supply wells within West Milford Township.

2. Township residents must obtain drinking water from fractured bedrock aquifer-systems that may or may not be interconnected to overlying glacial deposits. The ability of these aquifer systems to provide the water needed by the residents is highly dependent on the number and interconnection of fractures in the bedrock and void spaces in the glacial deposits, and the nature of the geologic materials that comprise the bedrock or glacial deposits. The type of bedrock and glacial deposits and the interconnection of these distinct geologic materials limit the aquifers ability to store and transmit water, attenuate contaminants, and reduce the impacts from pumping on the township's natural resources.

3. West Milford Township is located within the Highlands Region, which extends across New Jersey into New York and Connecticut. Because of high quality and availability of water, this region has historically been considered as having some of the most valuable water resources

necessary to sustain major cities and related populated urban areas in New Jersey and New York. Of the eleven major reservoirs in the Highlands Region in New Jersey, four reservoirs are located partially or wholly within West Milford Township. The water levels in these four reservoirs are maintained with surface water and groundwater flowing from West Milford Township.

4. West Milford Township is located within two Sole Source Aquifers as designated by the United States Environmental Protection Agency (USEPA) and New Jersey Department of Environmental Protection (NJDEP). Figure 4 shows the sole-source aquifers beneath the township. Sole-source aquifers are designated as such because they contribute as much as 50 percent of drinking water to an area and are irreplaceable as a water resource if contaminated. Approximately 10 percent of the township, in the northwestern corner, is located within the Northwest New Jersey Sole Source Aquifer as designated in the Federal Register on May 23, 1988. The remaining 90 percent of the Township is located within the Highlands Sole Source Aquifer as designated in the Federal Register on October 5, 1987.

5. The eighty-square mile West Milford Township is located in one of the fastest growing portions of the New Jersey with the population increasing nearly 12 percent from 1980 to 1990 and an additional 4 percent from 1990 to 2000.

6. The density of housing and application of surface/subsurface improvements can affect aquifer systems and result in reduced recharge, lowered yields, increased interference, and degradation of groundwater quality. In areas of the township where aquifer yields and/or recharge are limited or strained, additional housing/ improvements may affect current users of groundwater.

West Milford Township wants to protect its valuable groundwater resources for current and future residents and businesses. Furthermore, as a vital headwaters and recharge area for several surface-water reservoirs necessary to sustain the most populated and one of the fastest growing regions in New Jersey, West Milford Township is concerned with protecting the water resources availability and quality for downstream citizens of New Jersey.

The township also wants to protect water availability and quality to meet the needs of ecological receptors within the critical Highlands Region. Township officials understand that the protection of water quality and quantity is critical to supporting public health and quality of life. They also understand the protection of these resources is not only critical for their own citizens but also for other citizens of New Jersey and the Highlands Region.

The evaluation of the groundwater resources included but was not limited to the following:

1. A review of published maps and reports on the geology of West Milford Township and neighboring municipalities in Passaic, Morris, and Sussex Counties.

2. An assessment of surface-water basins and potential groundwater recharge rates within these basins.

3. A review of published reports and data regarding groundwater quality and aquifer yields.

The data/information from this review was used to assess the recharge area requirements for supporting the drinking-water needs for a single-family residence and to dilute contaminants from septic system discharges. In addition, the recharge area requirements were evaluated to minimize potential downstream impacts to the water, ecological, and other natural resources within the Highlands Region.

GEOLOGY

PHYSIOGRAPHIC PROVINCE

As shown on Figure 2, West Milford Township is bounded to the north by New York State, to the west by Vernon and Hardyston Townships of Sussex County, to the south by Jefferson and Rockaway Townships, and Kinnelon and Butler Boroughs of Morris County, to the east by Bloomingdale and Ringwood Boroughs of Passaic County. West Milford Township encompasses approximately 80 square miles.

West Milford Township is entirely located within the Highlands Physiographic Province of New Jersey. Greenwood Lake, Upper Greenwood Lake, Pinecliff Lake, West Milford Lake, Cedar Pond, Clinton Reservoir, Hanks Pond, Oak Ridge Reservoir, Echo Lake Reservoir, Butler Reservoir, and Charlotteburg Reservoir are some of the named lakes/reservoirs within the township. Bearfort Mountain and Kanouse Mountain are two of the more prominent northeast trending ridgelines crossing the township.

Elevations in excess of 1400 feet above mean sea level (amsl) are measured along Bearfort Mountain west of Pinecliff Lake. Elevations less than 320 feet are encountered along the Wanaque River as it crosses the eastern township boundary into Ringwood Borough. Figure 5 shows the general topography of West Milford Township as developed from the NJDEP Geographic Information System (GIS) database of elevation contours for the State of New Jersey.

SURFACE WATER

Watersheds

West Milford Township is divided by the NJDEP and United States Geological Survey (USGS) into two Watershed Management Areas (WMAs). The northwestern corner of the township is within the Walkill River WMA. Within West Milford Township in the Walkill River WMA, Sawmill Pond Brook flows into Upper Greenwood Lake, which drains to the north through Long House Creek.

South and east of the Wallkill WMA is the Pompton, Pequannock, Wanaque, Ramapo WMA. The western portion of the Township within this WMA drains through Mossmans Brook to the Clinton Reservoir, which drains through the Pequannock River into the Oak Ridge Reservoir. Immediately north of the Oak Ridge Reservoir, the Pequannock River is joined by Dunkers Brook. To the east of the outfall from the Oak Ridge Reservoir, the Pequannock River is joined by Clinton Brook and Kanouse Brook before flowing into Charlotteburg Reservoir. East of the outfall from the Charlotteburg Reservoir, the Echo Lake Channel, Macopin River, Apshawa Brook, and smaller tributaries join the Pequannock River before flowing beyond the eastern boundary of the Township.

The northeastern portion of West Milford Township drains through the Wanaque River. Greenwood Lake receives water from Green Brook, Cooley Brook, Belcher Creek, and Morestown Brook. Greenwood Lake drains into the Wanaque River, which is also joined by Jennings Creek, Beech Brook, and Hewitt Brook before flowing across the eastern boundary of the township. Burnt Meadow Brook and West Brook also flow across the eastern boundary of the township toward the confluence with the Wanaque Reservoir. Figure 6 shows the Watershed Management Areas delineated by the NJDEP and some of the streams within these areas. Figure 7 shows the subwatersheds within West Milford Township as defined by the NJDEP and USGS.

Headwaters

With the exception of the Pequannock River and a few tributaries to Sawmill Creek, Jennings Creek, and Beech Brook, every stream flowing through West Milford Township starts flowing or headwaters within the township. Nearly all of these headwaters are located at high elevations. At these headwaters, discharging groundwater starts the surface-water flow in the streams. With the exception of Long House Creek, all of the streams in West Milford Township ultimately flow to the Pequannock and Wanaque River systems and into water-supply reservoirs for Newark and other eastern New Jersey municipalities.

At high elevations, the drainage area contributing water to the headwaters is likely to be very small. As a result, impacts within this contributing drainage area can significantly alter and degrade water quality and quantity discharging to the stream. Studies summarized by Kaplan et al. (2000) indicate that adverse impacts to stream water quality can occur when impervious surface coverage exceeds 10 percent of the contributing drainage area. Further impacts can result from surface or subsurface discharges. At headwaters, where the volume of water available for dilution can be diminished because of decreased groundwater recharge or increase stormwater discharge, these potential impacts can extend downstream to other resources, consumers, or ecosystems.

Surface-Water Classifications

Table 1 provides a summary of surface-water bodies as well as the NJDEP surface-water classifications as designated in N.J.A.C 7:9B for these bodies within West Milford Township. Waters classified as FW1 are considered highest-quality freshwaters that are to be maintained in their natural state of quality and set aside for posterity because of their clarity, color, scenic setting, and/or other aesthetic characteristics; and/or because of their significance as unique ecological, recreational, exceptional water supply, and/or exceptional fisheries resources. These waters are not to be subjected to any man-made discharges or anthropogenic impacts resulting from increased runoff. FW2 waters are general freshwaters of the State that are not classified as FW1 or Pinelands Waters.

Trout are used as a measure of water quality since these fish are highly sensitive to changes in water quality. TP waters are classified as high-quality waters capable of trout production. TM waters are capable of maintaining trout populations throughout the year. NT waters or non-trout waters are incapable of sustaining trout but could maintain other species.

The Category 1 (C1) classification indicates that these waters have been designated in N.J.A.C 7:9B for protection from measurable changes in water quality because of "…clarity, color, scenic setting, other characteristics of aesthetic value, exceptional ecological significance, exceptional recreational significance, exceptional water supply significance, or exceptional fisheries resource(s)." Waters not designated as C1 would be considered as Category 2 or C2 waters and may not be afforded similar levels of protection from degradation of water quality. Potential impacts from man-made discharges and runoff may be less constrained in C2 waters than they would be in C1 waters.

Within West Milford Township, six surface-water bodies are designated as FW1 and therefore, have been afforded the highest levels of protection to sustain the quality of these waters for posterity (see Table 1). The NJDEP regulations indicate that these streams should not be affected by man-made impacts. Sixteen surface-water bodies have been designated as trout production waters and nine have been designated as trout maintenance waters. Twelve surface-water bodies have been designated as non-trout waters. Twenty-two surface-water bodies within West Milford Township are classified as C1 waters and are therefore, afforded protective measures from degradation of water quality.

The NJDEP regulations indicate that the surface-water resources within West Milford Township are very high quality and worthy of extensive protection against degradation of water quality. Many of these surface-water resources are protected against further degradation to maintain the quality of water diverted from the major reservoirs to New Jersey's major cities.

Available Surface Water Resources

The surface-water resources within West Milford Township are almost entirely dedicated to providing water for the City of Newark. The water flowing into the Clinton, Oak Ridge, Echo Lake, and Charlotteburg Reservoirs provides water for Newark' residents and businesses. The City of Newark Water Department indicates that the safe yield for this system is 49.1 million gallons per day (mgd) with a maximum permitted diversion of 57 mgd during periods of normal precipitation. NJDEP data indicate that in 1995, withdrawals from the City of Newark Reservoirs were approximately 40.6 mgd (Phelps 2002). As of 1995, nearly 83 percent of the safe yield was used on a daily basis.

The Wanaque Reservoir system, which is provided water by the Wanaque River, Burnt Meadow Brook, and West Brook after flowing from West Milford Township is owned and operated by the North Jersey District Water Supply Commission (NJDWSC), an agency of the State of New Jersey. The safe yield of this system is 173 mgd, which the City of Newark is allocated nearly 56 mgd with a contracted peak daily flow of 83.9 mgd. NJDEP data indicate that in 1995, withdrawals from the Wanaque Reservoirs system were approximately 149.7 mgd (Phelps 2002). Nearly 87 percent of the Wanaque Reservoir system safe yield was consumed in 1995.

The surface-water resources originating in and flowing through West Milford Township are dedicated to downstream consumers. Little of the safe yield of these systems was available in 1995 and during the drought of 2002, it was necessary to divert water from central portions of the State to supplement the water from the City of Newark and NJDWSC systems in order to meet the needs of northern New Jersey's cities and urban areas. The surface-water resources of West Milford Township are not available to the residents of this township and therefore, they must rely on groundwater resources to meet their needs.

SOILS

The United States Department of Agriculture (USDA) Soil Conservation Service mapped soils throughout much of New Jersey including Passaic County (Seglin 1975). These maps of soils have been included in the NJGS GIS database and were used to prepare Figure 8, which depicts soils mapped beneath West Milford Township. Based on the mapping by the Soil Conservation Service, thirty-one general soil types have been delineated within West Milford Township. Some of these general soil types are further subdivided based on slope gradients and/or variations in grain-sizes. Areas with standing water were also mapped by the Soil Conservation Service. Table 2 summarizes the soil types, slope ranges and approximate acreage of each soil type within the township and potential limitations for septic systems.

Water covers almost 7 percent of West Milford Township. Soils within the Rockaway and Swartswood series and associated rock outcrop complexes are the most commonly encountered soils mapped beneath the township. Soils associated with the Rockaway series or Rockaway/rock outcrop complexes are encountered beneath approximately 37.5 percent of the township primarily in the eastern and western sections. Soils associated with the Swartswood or Swartswood/rock outcrop complexes are mapped beneath approximately 25.6 percent of the township primarily in the west-central section along Bearfort Mountain.

The data from the Soil Conservation Service indicate that 72 percent of the soils beneath West Milford Township would have severe limitations for septic-system discharges. Approximately 19 percent of the soils have moderate limitations for septic systems. These limitations may include but are not limited to frequent flooding, shallow seasonal perched groundwater, steep slopes, and shallow depth to bedrock or poorly permeable layer such as fragipan. Seven percent of West Milford Township is covered with water, which when taken in conjunction with the data for soils with severe or moderate limitations, indicates that soils beneath only 2 percent of the township may be appropriate for conventional septic systems. Discharges to soils with limited capacity for infiltration, dispersion, and dilution could result in degradation of surface-water and/or groundwater quality.

GLACIAL DEPOSITS

Transmission and Storage

Glacial deposits, because of the ability to store and transmit water in pore spaces between particles, are considered to have primary porosity. These deposits in some areas of New Jersey such as western Essex and eastern Morris Counties serve as highly-valuable groundwater resources capable of transmitting and storing large volumes of water for major urban areas of the State.

The capability of glacial deposits to store and transmit groundwater is highly dependent on sorting and size of the particles or grains, and the thickness of depositional layers. Well-sorted deposits will often have interconnected pore spaces. Deposits primarily or entirely comprised of coarse-grained sand and gravel will often have large pore spaces that are capable of storing and transmitting large volumes of groundwater. Thick layers of sand and gravel can store and transmit large volumes of water, whereas, thin layers could initially appear to provide large quantities of water but could become quickly dewatered if pumped extensively.

Well-sorted former river deposits comprised primarily of coarse-grained sands and gravels with little silt or clay will often serve as prolific aquifers. Moraine and till deposits comprised of heterogeneous mixtures of clay, silt, sand, gravel, cobbles, and boulders are often very poor aquifer systems because of the limited interconnection of poor spaces and capacity to store or transmit water. The pore spaces in these poorly-sorted deposits are often filled with fine-grained clays and silts in lieu of water. Lacustrine or former lake deposits and deltaic deposits are often very poor aquifer systems because they are primarily comprised of clays and silts with very small and often poorly interconnected pore spaces.

Mapped Deposits

Figure 9 shows the locations of glacial deposits in West Milford Township as mapped by the NJGS (2002). Beneath approximately 65 percent of West Milford Township, thin layers of till deposits are encountered with rock outcrop. These glacial deposits do not have sufficient thickness, composition, grain-size, or homogeneity to serve as aquifer-systems for the township residents. Poorly sorted, heterogeneous moraine and ice-contact deposits are encountered beneath approximately 1.4 percent of the township. These deposits have insufficient thickness, distribution, and composition to serve as significant groundwater resources. At some locations, these deposits may store small quantities that would leak into underlying bedrock fractures.

Lake Bottom deposits are encountered beneath approximately 1.5 percent of the township. Typically, these fine-grained deposits have insufficient capacity to transmit or store groundwater because the pore spaces between grains are very small and not well connected. Deltaic and lacustrine fan deposits are encountered beneath approximately 3.5 percent of the township. These deposits are often similar in composition and grain-size to the lake bottom deposits and therefore, have very limited capacity to transmit groundwater.

Till deposits are heterogeneous compilations of sand, gravel, clay, silt, cobble, and boulder-sized materials that were pushed forward as the glaciers advanced and left behind as the glaciers retreated. These poorly-sorted materials are usually very poor aquifers. Although till deposits may not serve as very good aquifer-systems, at some locations, water may drain from these deposits into underlying bedrock fractures and therefore, serve as a reservoir for the fractures and slightly increase the long-term yield of wells in these fractures.

Materials deposited by streams or rivers in a fluvial environment may serve as good to very good aquifer-systems because of the sorting resulting from the glacial streamflow and the increased percentage of coarse-grained sands and gravels. Buried river valleys in some sections of Essex and Morris Counties have long-served to sustain water-supply demands of urbanized areas of these counties. Where these fluvial deposits are available, the thickness and depth must be sufficient to be encountered at a minimum depth of 50 feet below ground surface and to provide adequate storage/transmission to sustain long-term demands. NJDEP regulations require a minimum of 50 feet of casing to be installed in a well to reduce the potential for shallow contaminated groundwater from entering a well and therefore, the minimum depth for a well satisfying these regulations is 50 feet below ground surface.

Thickness

The NJGS (2002) has mapped the thickness of glacial deposits in the northern portion of New Jersey and this mapping information was used to prepare Figure 10, which shows the thickness of unconsolidated glacial materials beneath West Milford Township. Near the village of West Milford, glacial deposits may have sufficient thickness for the installation of a well to a depth greater than 50 feet.

However, only one well listed on the NJDEP database of public community water-supply wells is completed in glacial materials. West Milford Municipal Utilities Authority Well 1A in the Birch Hill Park system is completed in glacial sands and gravels from 83 to 93 feet below ground surface. Apparently, these sands and gravels were not extensive because nearby Well 1B, 2 and 2A were drilled through the glacial materials and completed in the underlying bedrock materials at depths of 400, 303, 500 feet below ground surface, respectively.

Sufficient thickness of glacial materials may be present beneath some portions of West Milford Township for the installation of wells. However, where these materials have sufficient thickness, the composition of the deposits is insufficient to yield large volumes of water.

Aquifers

Figure 11 shows the glacial aquifer-systems mapped beneath West Milford Township by the NJGS. The NJDEP has ranked these aquifers based on their ability to yield large quantities of water to high-capacity wells. The ranks range from A through E, with aquifers ranked A having the greatest potential to sustain high capacity wells and aquifers ranked E having the lowest potential. The NJDEP ranking system does not include the letter F.

The ranking system for glacial aquifers is based on data from the northern portion of the State and is not based on local data. The NJDEP ranking system may indicate a high rank for a particular deposit such as sand and gravel layer because of well yields in Essex and Morris Counties and not necessarily because of well data for West Milford Township. As discussed above, local public community water-supply well data do not indicate any extensive high-yielding glacial deposits beneath West Milford Township.

Within West Milford Township, sand and gravel aquifer-systems have been ranked B by the NJDEP, which suggests that these deposits may be capable of yields ranging from 250 to 500 gallons per minute (gpm). Given the data from the public community water-supply wells in the township and the limited horizontal and vertical extent of these deposits, it is highly unlikely that of the glacial sand and gravel layers beneath West Milford Township could sustain the long-term yields suggested by the NJDEP ranking system.

Till deposits beneath West Milford Township have been ranked D by the NJDEP indicating that these poor aquifers may be capable of yields for high-capacity wells ranging from 25 to 100 gpm. Local public community water-supply well data do not indicate yields for the till deposits within this range. The local data indicate that the till deposits are not useful aquifer-systems.

The NJDEP ranks the lake-bottom deposits as E indicating that these very poor aquifers can only sustain yields of less than 25 gpm. Unconsolidated deposits ranked E in the NJDEP aquifer database typically serve as confined/semi-confined-layers and do not serve as aquifer-systems capable of economically yielding water to a well.

The glacial geologic data and the local public community water-supply well data indicate that the glacial deposits in West Milford Township are not high-yielding aquifers capable of sustaining large yields for prolonged periods. The data indicate that the glacial deposits are not a reliable source of groundwater for the residents of the township. Although the glacial deposits may not yield water directly to wells completed in these deposits, they may serve as local reservoirs capable of storing water that can drain into underlying bedrock fractures. As water is pumped from these fractures, gravity may induce drainage from the glacial deposits to replace the pumped water and therefore, slightly increase the long-term yield of the bedrock fractures.

BEDROCK

Transmission and Storage

Bedrock aquifers typically do not have primary porosity or openings between grains and therefore, must rely on secondary porosity for the transmission and storage of groundwater. Secondary porosity results from fractures or breaks between layers or through layers of competent rock.

Groundwater in bedrock aquifer-systems is stored and transmitted along fractures, joints, and bedding planes. The availability of water in bedrock aquifers is dependent on the separation between fractures, the degree to which these fractures are interconnected, and weathering of the materials between fracture planes. In some rocks, fractures are separated by a few inches of competent, unweathered, and impermeable bedrock. In other rocks, the distance between fracture openings may be several feet to several tens of feet. Near major regional faults, fractures may form highly connected networks permitting the storage and transmission of large quantities of water. Distant from these faults, single or few fractures are often available for water storage or transmission.

USGS studies indicate that weathering of fractured rock is greatest within 75 feet of ground surface and is negligible at depths greater than 500 feet below ground surface. Since weathering increases fracture size and may result in increased fracture interconnection, much of a well's yield is likely derived from shallow portions of the bedrock aquifer-system. In most rock formations such as those beneath West Milford Township, drilling to greater depths does not increase the potential for intersecting high-yielding fractures and simply serves to increase the reservoir capacity of the well. A 6-inch diameter domestic well will hold nearly 1.5 gallons of water for every foot of water within the well.

Formations

Figure 12 shows the bedrock geologic formations mapped beneath West Milford Township. The bedrock mapping was completed as a joint effort by the USGS and NJGS and is depicted on the 1996 "Bedrock Geologic Map of Northern New Jersey" (Drake 1996).

Precambrian Igneous and Metamorphic Rocks

Precambrian igneous and metamorphic rocks underlie approximately 63 percent of West Milford Township. These rocks, all of which are older than 600 million years and some of which are older than 1 billion years, underlie the eastern 45 percent of the township and beneath the western 18 percent of the township. The Precambrian rocks are depicted on Figure 12 in solid colors and include the rocks listed in the legend from amphibolite to hornblende granite.

The Precambrian rocks have undergone several episodes of past tectonic deformation associated with continental collisions and separations. Although the Precambrian rocks have been deformed, they are poorly fractured except at locations near major faults. Within West Milford Township, four normal faults intersect the Precambrian rocks. These faults, which typically form as continents separate, are not extensive. With the exception of the normal fault near Upper Greenwood Lake, which may be a splay of the regional Reservoir Fault, the former earthquake fractures in the Precambrian rocks beneath West Milford

Township appear to have attenuated very quickly over short distances. The attenuation of these faults is indicative of the poorly fractured nature of Precambrian igneous and metamorphic rocks.

In addition to the four normal faults, a pair of thrust faults caused by the collision of continents has been mapped along the western shore of Greenwood Lake extending to the south. These two thrust faults form a boundary between the Precambrian igneous and metamorphic rocks and the younger rocks beneath slightly more than one-third of the township.

Cambrian Formation

The Cambrian Hardyston Quartzite underlies approximately 117.5 acres or 0.23 percent of the township in a northeasterly trending strip located approximately halfway between Upper Macopin and Postville. This 550 to 570 million year old quartzite has been considered by the NJGS to have hydrogeologic characteristics similar to the older Precambrian rocks. Given the limited extent of the Hardyston Quartzite and its hydrogeologic characteristics, this formation is not considered a significant groundwater resource for the township.

Silurian Formations

Three bedrock formations deposited from 435 to 400 million years ago underlie approximately 4.7 percent of West Milford Township. These three formations are mapped as the Green Pond Conglomerate, Longwood Shale, and the undivided Berkshire Valley and Poxono Island Formations. The Green Pond Conglomerate has been mapped immediately west of the Precambrian rocks in the eastern portion of the township and is bordered by two thrust faults. The Longwood Shale and undivided Berkshire Valley and Poxono Island Formations are mapped in the southern portion of the township near Newfoundland.

Devonian Formations

The Kanouse and Esopus Formations and Connelly Conglomerate is one of four Devonian-age geologic units mapped beneath West Milford Township. The Cornwall Shale, Bellvale Shale, and Skunnemunk Conglomerate are the other three geologic units deposited from 400 to 360 million years ago. These four geologic units are mapped beneath nearly one-third of West Milford Township and are primarily encountered beneath Bearfort Mountain forming the core and steepest slopes of the highest topographic feature within the township.

GROUNDWATER SYSTEMS

BEDROCK AQUIFERS

Similar to the glacial aquifer-systems, the NJGS has mapped and the NJDEP has ranked bedrock aquifers in northern New Jersey. Within West Milford Township, the NJGS has delineated three bedrock aquifers based on the age of the rock. These aquifer-systems are the igneous and metamorphic rocks of the Precambrian; Cambrian limestone, dolomite, and quartzite rocks; and the rocks of the Green Pond Mountain Region. The rocks of the Green Pond Mountain Region include the Silurian- and Devonian-age rocks beneath West Milford Township. The three aquifer-systems as mapped by the NJGS with respect to West Milford Township are shown on Figure 13.

The NJGS mapping combined the Hardyston Quartzite with several slightly younger carbonate-rock aquifer systems because all of these rocks are Cambrian age. However, the Hardyston Quartzite is not capable of groundwater yields similar to the Cambrian limestones and dolomites, which are recognized as highly prolific aquifer systems. Carbonate rocks can be dissolved with weak acids forming caves, caverns, and other solution openings that can transmit and store very large quantities of water. The Hardyston Quartzite does not dissolve to form solution openings and is considered well-cemented and very hard. Because of its poorly fractured nature, the Hardyston Quartzite has long been regarded as a very poor aquifer-system and as having hydrogeologic characteristics that are similar to the Precambrian igneous and metamorphic rocks.

Given the limited extent of the Hardyston Quartzite in West Milford Township and the results of previous research on the hydrogeologic characteristics of these rocks, the Hardyston Quartzite aquifer should be considered equivalent to the aquifer-systems associated with the Precambrian rocks. The NJDEP ranking of aquifers within West Milford Township indicates that Precambrian rocks and the rocks of the Green Pond Mountain Region should be considered D aquifers. These rankings indicate that the bedrock aquifer-systems beneath West Milford Township are very poor with limited capability of yielding groundwater to high-capacity wells.

WELL YIELDS

Table 4 summarizes well yields, depths, and static water levels for public community water-supply wells and domestic wells in West Milford Township. The NJGS database of public community water-supply wells was used to evaluate well yields and aquifer characteristics for the 37 wells in West Milford Township that are classified in this category. The locations of these wells are shown on Figure 3.

The data for the one West Milford Municipal Utilities Authority Well (Birch Park Well 1A) completed in the glacial deposits indicates a yield of 72 gpm. However, the long-term pumping rate for this well is listed as 18 gpm. The data indicate a specific capacity for Well 1A of 1.8 gpm/foot of drawdown (gpm/ft). With approximately 40 feet of available drawdown and a specific capacity of 1.8 gpm/ft, this well could not sustain a pumping rate of 72 gpm for a prolonged period. A pumping rate of 18 gpm indicates that the glacial deposits beneath West Milford Township are not very good aquifer-systems in comparison to glacial deposits in nearby counties.

Data for nine public community water-supply wells completed in the Green Pond Mountain Region rocks indicate median yields of 40 gpm. Only two of these nine wells had specific capacity measurements, and these two wells indicate specific capacities of 0.15 and 0.57 gpm/ft. These specific capacity measurements indicate that the Devonian and Silurian rocks that underlie the Green Pond Mountain Region have aquifer transmissivities ranging from approximately 300 to slightly more than 1100 gallons per day per foot (gpd/ft). These measures of an aquifer's ability to transmit water indicate that the Green Pond Mountain Region aquifer has a very poor capacity to transmit groundwater to a well or wells.

Data for 27 public community water-supply wells completed in the Precambrian rocks indicate a median yield of 40 gpm. The median specific capacity of the five wells in the database for which this parameter was determined is 0.92 gpm/ft, which indicates an aquifer transmissivity of approximately 1800 gpd/ft. These measurements indicate that the Precambrian rocks have limited capacity to transmit groundwater.

The well yield and specific capacity data for the 37 public community water-supply wells in West Milford Township indicate that the bedrock and glacial aquifer-systems beneath the township are not high yielding and that the aquifers have limited capacity to transmit groundwater.

Data from 2449 domestic wells in West Milford Township were compiled from Health Department records and provided by the township to M^2 Associates. These data, which include lot and block numbers, were used to identify the location of the wells within the township and the geologic formation in which, the well was completed. Figure 14 shows the locations of the domestic wells used to evaluate yields of the hydrogeologic units beneath West Milford Township. Table 4 summarizes the yield, depth, and static water level results for the rocks in each of the four geologic ages.

The data from 1348 wells completed in the Precambrian igneous and metamorphic rocks indicate a median yield of seven gpm and a median depth of 163 feet below ground surface. The data from two wells completed in the Hardyston Quartzite indicate yields of 10 and 24 gpm. The extent and number of potential wells completed in the Hardyston Quartzite is unlikely to indicate that these rocks beneath West Milford Township are significantly greater yielding than they are elsewhere in New Jersey. As discussed above, the Hardyston Quartzite is typically combined with the Precambrian rocks because of the poor hydrogeologic characteristics of the quartzite.

Data from 175 wells completed in the Silurian formations and 924 wells completed in Devonian rocks indicate median yields of 10 gpm. Wells completed in the Silurian-age rocks have a median depth of 145 feet below ground surface, whereas, wells completed in the Devonian-age rocks have a median depth of 135 feet below ground surface. The median yields of the Devonian and Silurian rocks are slightly greater than the median yield for the Precambrian igneous and metamorphic rocks. The well yields indicate that the Precambrian and Green Pond Mountain Region rocks are very poor aquifer-systems.

Water-level measurements from the wells indicate that the static-water level is likely to be approximately 20 feet below ground surface. The likely shallow depth to water indicates that although yields are low, water could be stored in the well-bore reservoir to meet short-term peak demands.

HYDROGEOLOGIC ZONES

The data from the 37 public community water-supply wells and the 2449 domestic wells indicate that the aquifer-systems beneath West Milford Township are poor yielding and poorly transmissive. The well data do not indicate any significant differences in yields between the Precambrian igneous and metamorphic rocks and the Devonian and Silurian rocks of the Green Pond Mountain Region. While the NJGS has divided the aquifer-systems beneath the township based on age of the units, these units are equivalently ranked.

The township could be subdivided into separate hydrogeologic zones based on geology; however, there would be little difference in aquifer characteristics between the zones. The well yield data suggest that there might be a slight difference between the Precambrian rocks and the Devonian/Silurian-age rocks but that difference could be considered insignificant with respect to the entire township. Similar to aquifer characteristics, recharge to the fractured bedrock aquifers is very likely to be the same or very nearly the same throughout the township.

AQUIFER RECHARGE

Hydrologic Cycle

WATER BALANCE

The hydrologic cycle is a balance of the earth's water. Precipitation falls to the earth's surface where it ultimately flows through streams to the ocean and evaporates to the atmosphere, or is transpired through living organisms and ultimately returned to the atmosphere. Locally this balance is comprised of the following three general components:

1. Evapotranspiration is the component where water is returned to the atmosphere by plants and/or evaporated from puddles or other small surface-water features.

2. Surface-water runoff is the component where precipitation runs off the ground surface or immediately below the ground surface and quickly flows to streams during and/or shortly after precipitation.

3. Groundwater runoff is the percentage of precipitation that enters a subsurface perennial or seasonally saturated zone through which, it slowly migrates to a stream for the return to the atmosphere. This component is most obvious during dry weather when flow in streams is entirely derived from groundwater discharges.

Each of these general components; evapotranspiration, surface-water runoff, and groundwater runoff, can be further subdivided. Groundwater runoff includes the portion of precipitation that sufficiently infiltrates soils and bedrock to enter an aquifer system where it can be used as a water-supply resource for residents of West Milford Township. However, the groundwater runoff parameter also includes water in shallow wet and sometimes saturated zones such as wetlands, floodplains, and stream banks that slowly migrates to a stream but does infiltrate to an aquifer where it could be used as a groundwater-supply resource. Where a water balance can be used to assess percentages of annual precipitation that evaporate or transpire, runoff the ground surface, or runoff through the subsurface, more detailed analyses are necessary to ascertain the portion of precipitation that actually infiltrates to an aquifer.

Similar to the capacities to transmit and yield water, the recharge capability of a bedrock aquifer is dependent on the frequency and intensity of fractures, the size of the fracture openings, the interconnection of these openings to each other and to ground surface or other saturated media, and the depth of weathering. Bedrock units with the greatest frequency/intensity of fractures interconnected to other fractures and the ground surface and/or saturated media will have low surface-water runoff rates and high aquifer recharge rates. Weakly fractured bedrock will have high surface-water runoff rates and low aquifer recharge rates. Glacial deposits comprised of sand and gravel will have high recharge rates and low surface-water runoff rates whereas, glacial materials such as till and lake-bottom deposits will have very low recharge rates and high surface-water runoff.

PRECIPITATION

A water balance can be used to evaluate inflow and outflow parameters associated with a hydrologic system. The inflow parameter to the equation, precipitation, can be directly determined from historical information. The outflow parameters, evapotranspiration, surface-water runoff, and groundwater runoff are determined by indirect methods. The water balance can be used to evaluate the assumptions made in estimating these indirect parameters and provides a general range of possible values for these parameters. Since the equation is a balance, the inflows must equal the outflows and therefore, the assumptions can be tested as the parameter values are refined.

Based on historical precipitation measurements collected by the National Climatic Data Center at Greenwood Lake and Charlotteburg Reservoir for the past 62 and 110 years, respectively, West Milford Township receives approximately 51.4 inches of precipitation during a year of normal precipitation. Table 5 summarizes the normal precipitation for West Milford Township as determined from the data for the Greenwood Lake and Charlotteburg Reservoir climatic data stations. Precipitation is evenly divided throughout the year with January, February, October, and December receiving slightly less than average rainfall and April, May, July, August, September, and November receiving slightly more than average monthly precipitation.

Using the water balance of the hydrologic cycle, precipitation equals the sum of groundwater runoff, surface-water runoff, and evapotranspiration. If an area has one or more large water bodies with respect to total surface area, direct precipitation to this body and the resulting evaporation from this body, would also be included in the water balance. In West Milford Township, lakes, ponds, and reservoirs encompass approximately 3465 acres or slightly less than 7 percent of the township. While the precipitation to these surface-water bodies is part of the water resources of New Jersey, as discussed above, that water is dedicated to downstream cities. Therefore, precipitation to and evaporation from these surface-water bodies are not considered with respect to the township's overall water resources.

The water balance is often described by the following equation:

$$P = GW + SW + ET \qquad \text{(Equation 1)}$$

Where:

P = Precipitation
GW = Groundwater Runoff
SW = Surface-Water Runoff
ET = Evapotranspiration

For West Milford Township, P would equal 51.4 inches per year in Equation 1.

EVAPOTRANSPIRATION

As part of the hydrologic cycle, water is returned to the atmosphere by evaporation from open water bodies and surface soils, and transpiration from vegetation. These two variables of the water balance are referred to as evapotranspiration.

Evapotranspiration is greatest during the summer months because of higher temperatures and active growth of plants and trees. During the winter months, evapotranspiration in northern New Jersey is usually negligible. Evapotranspiration is the largest component of the water balance and may account for the return to the atmosphere of approximately 50 to 60 percent of annual precipitation in New Jersey.

In the USGS (Nicholson 1996) study of the water resources of Long Valley in Morris County, a potential evapotranspiration rate of 25 inches per year or 50 percent of annual precipitation was determined. The northern portion of the Long Valley study area is in Rockaway Township, which borders West Milford Township (see Figure 2). The USGS used the Thornthwaite Method, which was developed for calculating potential evapotranspiration in New Jersey and other Mid-Atlantic States to determine a rate of evapotranspiration for the Long Valley study. Studies have shown that the Thornthwaite Method provides reasonable estimates of monthly and annual evapotranspiration for New Jersey.

Mean temperature data for the Charlotteburg Reservoir climatic data station were compiled by the National Climatic Data Center to calculate the expected mean temperature in the township (see Table 5). Temperature data are not available for the Greenwood Lake climatic data station. Inclusion of the temperature and precipitation data in the Thornthwaite Method, results in an estimate that approximately 24.7 inches of precipitation will be returned to the atmosphere from vegetation in West Milford Township. In Equation 1, ET equals 24.7 inches per year and the sum of GW and SW terms equals 26.7 inches per year.

SURFACE-WATER RUNOFF

Surface-water runoff is dependent on the infiltration capacity and rate of soils, types and density of vegetation, surface area of impervious materials, gradient or steepness of slopes, and the intensity and duration of rainfall. Surface-water runoff is comprised of two components. One of these components is overland flow, which occurs when the infiltration capacity of the soils is exceeded and the water flows over the land surface to a stream channel. In poorly drained soils, along steep slopes, and/or in highly developed areas with impervious surfaces, overland flow can account for much if not all, of precipitation to the area.

The second of these components of surface-water runoff is referred to as interflow or throughflow and includes water that infiltrates soils to a shallow depth and then follows along an impermeable or very low permeability surface such as a clay layer, fragipan, or bedrock surface, to a discharge point. Interflow/throughflow is not groundwater recharge because this water does not infiltrate to a perennial saturated zone or water table and is quickly discharged to a stream. Since bedrock aquifers supply drinking water to West Milford Township residents, if precipitation does not infiltrate to the aquifer, it is not a water-supply resource for the township.

In areas such as in West Milford Township with dense, hard, poorly weathered bedrock, few fractures, hilly terrains, and steep slopes, streams will start at high elevations. In these areas, the slopes provide sufficient gradient to induce surface-water runoff and the low permeability of the bedrock limits the capacity of an area to infiltrate precipitation. As a result, groundwater in the underlying bedrock aquifer systems is not significantly recharged and the water quickly runs off the land surface or throughflows immediately below the ground surface often along the top of bedrock to the nearest stream system. In the Long Valley study, the USGS concluded that very little incident precipitation was capable of infiltrating Precambrian igneous and metamorphic rocks because of the shallow nature of the fracture systems in these rocks (Nicholson 1996). These researchers concluded the following:

> "… (T)he upland bedrock flow system is not considered to be a pathway for significant recharge to the aquifer system. In the uplands, much of the incident precipitation percolates downward to a shallow fracture system, flows through the fractures, and discharges locally either to streams that dissect the uplands and hillslopes or as springs on the slopes."

As shown on Figures 2 and 5, many of the streams in West Milford Township start at or very near the upper slopes of the mountains and hills within the township. Based on soils mapping (Seglin1975) and excluding the areas covered with water, approximately 16 percent of the township has slopes less 3 to 5 percent. Fifty-four percent of the township has moderately steep slopes ranging from 3 to 8 percent, and eight percent of the township is underlain by steeper slopes ranging from 8 to 15 percent. Twenty-two percent of the township is underlain by soils on very steep slopes with gradients in excess of 15 percent. Eighty-four percent of West Milford Township has slope gradients that are sufficient to promote surface-water runoff in lieu of groundwater infiltration.

Nearly 94 percent of the soils beneath West Milford Township are considered to have a hydrologic soil group code of C or are classified as hydric. These types of soils have very low if any infiltration rates and therefore, would have high rates of surface-water runoff. Soils and slopes beneath much of West Milford Township promote surface-water runoff in lieu of groundwater recharge.

The study completed by the USGS in Long Valley (Nicholson 1996) included areas underlain by Precambrian igneous and metamorphic rocks. Nicholson et al. (1996) indicated that groundwater recharge to the Precambrian rocks was “negligible” and therefore, most incident precipitation ran off to local streams. In a separate USGS study (Lewis-Brown 1995) within the Piedmont Physiographic Province, in areas underlain by Jurassic igneous and metamorphic rocks, the results indicate surface-water runoff rates of nearly 36 percent of annual precipitation. Based on the geologic and hydrogeologic conditions beneath West Milford Township and given the high elevations of the stream headwaters throughout the township, a surface-water runoff rate of 18.5 or more inches per year could be expected. If SW in Equation 1 were equal to 18.5 inches per year, then GW should equal 8.2 inches per year.

GROUNDWATER RUNOFF

Streamflow data can be separated into two components, surface-water runoff and groundwater runoff. During and shortly after periods of precipitation, the surface-water runoff component is the primary source of water flowing in a stream whereas, during dry weather, the groundwater runoff component is maintaining baseflow in the stream. Groundwater runoff includes water that enters subsurface environments including but not limited to perennially saturated zones or bedrock aquifers. In contrast, groundwater recharge is water that infiltrates to a perennial saturated zone or aquifer. With respect to West Milford Township, groundwater runoff includes water that infiltrates through soils to bedrock aquifers as groundwater recharge and is collected, stored, and transmitted in shallow sources such as wetlands, flood plain soils, stream banks, and seasonal perched zones.

Equation 1 can be rearranged to develop estimates of groundwater runoff for West Milford Township. In Equation 1, P equals 51.4 inches per year, ET equals 24.7 inches per year, and SW equals 18.5 inches per year. Based on these values, GW should be approximately 8.2 inches per year. Some portion of the water included in the groundwater runoff parameter in the water-balance equation includes water captured and stored in wetlands systems, flood plain soils, stream banks and other shallow sources that are distinct from the bedrock aquifers used as groundwater-supply resources for township residents. Further detailed analyses of hydrogeologic data are necessary to determine how much groundwater runoff is derived from groundwater recharging an aquifer and ultimately discharging to a stream.

The water balance serves as a guide to evaluate recharge to the township as a whole and should not be assumed to provide detailed aquifer recharge rates for the geologic units within the township. Actual recharge rates are highly dependent on the type of rock, the intensity/frequency of fractures, and the interconnection of these fractures to each other, ground surface, and/or other saturated media.

Groundwater Recharge Methods

GROUNDWATER

The following is a quote from the textbook Groundwater (Freeze & Cherry 1979):

> "The term groundwater is usually reserved for the subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated".

Water must enter a fully and perennially saturated zone also known as an aquifer system to be available as a water resource exploitable with wells. In New Jersey, because steel casing must be installed to prevent shallow water from entering a well, water must be capable of infiltrating to a depth of at least 50 feet below ground surface to be captured by a water-supply well.

Although water in stream banks, flood plains, snowpack, wetlands or seasonally wet perched zones in soils or bedrock may be considered part of groundwater runoff in maintaining baseflow in streams, water that does not enter a fully and perennially saturated aquifer is not considered groundwater recharge. Water pooled on a fragipan layer or bedrock surface would not be considered groundwater for water-supply purposes unless this zone extends to a depth of at least 50 feet below ground surface or is interconnected to fractures that extend to depths of at least 50 feet. Water that infiltrates through soils but not to a fully saturated zone is not groundwater because it would not be available to wells within the township. Water that does not migrate to an aquifer system is not available to wells and therefore, should not be included in groundwater recharge estimates with respect to West Milford Township because if the water does not enter a saturated aquifer system, it cannot be used for water-supply by residents.

BASEFLOW

Several methods have been developed for evaluating groundwater recharge to aquifer systems. The volume or rate of water infiltrating to an aquifer cannot be directly measured. However, the rate and/or volume of water discharging from an aquifer to a stream are part of baseflow within the stream during dry weather and can be estimated from this portion of streamflow data. Since the hydrologic system is a balance equation, the rate/volume of water exiting an aquifer system is assumed equal to the rate/volume entering the groundwater system.

Water flowing in streams during periods of dry weather is referred to as baseflow and in the past, was often assumed equal to groundwater discharge. However, a better understanding of hydrologic systems including wetlands, streams, aquifers, seasonal wet zones, flood plains, and stream banks and the role these systems have in providing water to streams during periods of dry weather has shown that not all water flowing during dry weather is derived from aquifer/groundwater discharge.

The water flowing during most dry weather periods is very likely to include water from shallow sources such as but not limited to flood-plain soils, stream bank-storage, wetlands, isolated ponds, and perched zones. Discharges from these shallow sources should not be assumed entirely associated with flow from an aquifer serving as a water resource. It will take extensive periods of dry weather or droughts to sufficiently dry up or dewater these shallow sources in order to determine the contribution to baseflow/groundwater runoff from an underlying aquifer system.

HYDROGRAPH SEPARATION

Several graphical methods have been developed for evaluating streamflow data and are often referred to as “hydrograph separation”. These methods are used for separating streamflow associated with surface-water runoff from streamflow associated with discharges from other sources, which is then assumed equal to baseflow. The baseflow rates are used to estimate groundwater recharge rates. Because streamflow rates increase, peak, and then decline as a result of overland runoff from precipitation events, the hydrograph separation methods assume a time delay after a storm event to impose similar increased, peaked, and declining baseflow rate changes resulting from that same precipitation event. However, these methods most likely include a faulty assumption that water migrating through an aquifer-system to a stream would discharge within a few days of a storm event.

The overland flow component is often referenced in these hydrograph separation methods as “quickflow” because it arrives rapidly in the stream channel and causes readily identifiable increases in streamflow rates. Whereas, “delayed flow” is often the term used to refer to the component of hydrograph that takes several hours or days to migrate through the subsurface and/or to be released by wetlands, floodplains, or other shallow sources to the stream channel. In hydrograph separation methods, a delayed flow or baseflow peak is estimated and the volume of water associated with this peak is included in the estimate of groundwater recharge. The increased baseflow/delayed flow component is not readily identifiable in the streamflow data because they are often obscured by declining quickflow components.

The peak in delayed flow is very likely a result of discharges from shallow sources but it is highly improbable, that discharges from a bedrock aquifer system would significantly increase. Groundwater migrating through a bedrock aquifer system will take years to several tens of years to flow through to a stream and it is improbable that this component of streamflow would show a spike as a result of a single or even several precipitation events.

Hydrograph separation methods are highly dependent on how the observer/hydrologist differentiates streamflow into baseflow and if the baseflow component includes discharges from sources other than the underlying aquifer system. The USGS notes in the document entitled "HYSEP: A Computer Program For Streamflow Hydrograph Separation And Analysis" (Sloto et al. 1996) that even when the same hydrograph-separation method is followed by two different scientists, each scientist is likely to produce a different baseflow estimate. Different baseflow estimates will often result when the same observer uses two different methods. Hydrograph separation methods are highly dependent on observer and method bias.

In addition to observer and/or method bias, in the article entitled "Problems Associated with Estimating Ground Water Discharge and Recharge from Stream-Discharge Records", the authors found that hydrograph-separation techniques are "poor tools" for estimating groundwater discharge or recharge (Halford 2000). These authors found that the groundwater recharge component in streamflow records could not be clearly defined because of complications associated with discharges from bank-storage, floodplain soils, wetlands, surface-water bodies, and seasonal sources such as snowpack and perched zones in soils and bedrock. These authors concluded that because of the difficulty separating groundwater discharges from shallow non-aquifer sources that significant overestimates of groundwater recharge resulted.

Discharges from sources other than an aquifer system should not be included in a groundwater recharge analysis because this water did not infiltrate to the underlying aquifer system. Inclusion of discharges from these shallow sources would result in significant overestimates of groundwater recharge. Simply, if the water did not infiltrate to the perennially saturated zone, it did not enter the groundwater/aquifer system used to supply water to wells and therefore, should not be included in estimates of groundwater/aquifer recharge. Although there are several assumptions included in hydrograph separation methods that will very likely result in overestimates of groundwater recharge, these methods are one of the few tools available for indirectly estimating recharge rates. When these methods are used, the results should be assumed overestimates and safety margins should be considered to ensure adequate water supplies.

POSTEN (1984) METHOD

Although hydrograph separation methods are highly dependent on observer and method bias, they are an available tool for estimating baseflow and groundwater recharge. When these tools are used, it should be understood that the methods will result in an overestimate of groundwater recharge because of the difficulties separating aquifer/groundwater discharge from discharges associated with shallow sources such as wetlands, ponds, bank-storage, floodplain materials, and seasonal perched zones.

One method has been developed in New Jersey (Posten 1984) that distinguishes delayed flow from hydrograph separation and then ranks these delayed flow rates to determine exceedence probability values. The exceedence probability values and the delayed flow rates are depicted on arithmetic probability graphs to estimate groundwater recharge and aquifer yields. The author took the extra step of plotting the annual delayed flow rates and exceedence probability values to define a line along which, baseflow rates under dry weather conditions could be determined.

Streamflow data are separated into quickflow or water draining an area shortly after a precipitation event from delayed flow or water draining the area after a period of delay caused by migration in the subsurface. Although the rate of delayed flow is significantly dependent on the rate of quick flow in this method, the author assumed that delayed flow is equal to baseflow.

Posten (1984) developed this method to reduce the number of "personal judgments" and therefore, reduce potential overestimates of groundwater recharge. A study of groundwater recharge rates in New Jersey conducted by Canace et al. (1992) indicates that the Posten (1984) Method does result in lower recharge rates than the "Sliding Interval Method". However, the Posten (1984) Method continues to result in overestimates of groundwater recharge because the fundamental method of separating streamflow records into delayed flow rates must include discharges from shallow sources in the delayed flow estimates. As a result, the Posten (1984) Method will result in overestimates of groundwater recharge rates to aquifer systems.

As part of his research, Posten (1984) evaluated streamflow data from West Brook and Blue Mine Brook in Passaic County. West Brook's 11.8 square mile drainage basin is located in West Milford Township and neighboring Ringwood

Borough. Blue Mine Brook drains Bloomingdale and Ringwood Boroughs and has a 1.01 square mile basin. Both drainage basins are entirely underlain by Precambrian igneous and metamorphic rocks.

Posten (1984) using his method determined recharge rates of 280 and 310 gallons per day per acre (gpd/acre) for the West Brook and Blue Mine Brook drainage basins, respectively. These rates are equivalent to 3.8 and 4.2 inches per year. The Posten (1984) Method calculates recharge under dry weather conditions to ensure adequate water is available during periods of drought. However, the method, like all current hydrograph separation methods, includes water that does not infiltrate into an aquifer-system and therefore, should be assumed to overestimate groundwater recharge rates.

NJGS MODIFIED METHOD

Aquifer versus "Groundwater" Recharge

The NJGS developed a method for estimating "groundwater" recharge based on soil types, land use, and municipal climate factors (Charles 1993). The NJGS method, which has been proposed for use statewide as a "planning tool" to identify areas of potential groundwater recharge, modifies the water balance equation by using factors for recharge, climate, and drainage basin that are based on general soil types, municipal location, and land use/land cover. The NJGS modified method does not consider differences in slope gradients, depth to bedrock, presence of impervious surfaces, topography, and/or type of bedrock underlying soils. As a result, the method does not measure rates of recharge to aquifer systems such as those systems beneath West Milford Township.

The NJGS states that this method is for determining "groundwater" recharge as opposed to "aquifer" recharge. The NJGS makes the distinction by indicating that "groundwater" recharge is the volume of water that migrates through soils whereas, "aquifer" recharge is the volume of water that enters a geologic formation that is capable of economically yielding water to wells or springs. This distinction is significant because water may migrate through unsaturated soils but not sufficiently infiltrate to a water-table aquifer or the saturated zone. If the water does not infiltrate to the saturated zone, it should be considered throughflow or interflow or some component of groundwater runoff other than groundwater recharge. If the water does not recharge an aquifer, residents of West Milford Township cannot use it for water supply.

Based on traditional hydrogeologic definitions, the results of the NJGS method should be referred to as soil recharge rates as opposed to groundwater or aquifer recharge rates. As indicated in the textbook Groundwater (Freeze & Cherry 1979) "(t)he term groundwater is usually reserved for the subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated." In West Milford Township, nearly all water-supply wells are completed in fractured bedrock aquifers that are under water-table conditions and/or interconnected to the water-table aquifer. Therefore, inclusion of water that does not infiltrate to the water-table aquifer in a recharge analysis will result in significant overestimates of water-supply availability and underestimates of the areas necessary to ensure adequate recharge is available to dilute contaminants in groundwater.

Throughout this M^2 Associates report and as typically referenced in hydrogeologic texts and USGS reports, the term groundwater recharge refers to water that infiltrates to the saturated zone, which for West Milford Township are water-supply aquifer systems. With the exception of few references to groundwater recharge within quotation marks in this section of the report, the terms aquifer recharge and groundwater recharge have the same definition and refer to water that infiltrates to an aquifer system. The term soil recharge will be used in reference to rates determined with the NJGS Modified Method.

Soil Recharge Rates

Although the soil recharge rates calculated with the NJGS method are not appropriate for evaluating groundwater recharge or water-supply availability for West Milford Township, they are summarized in Table 6 for comparison purposes to other methods and because they are sometimes inappropriately presented to Planning Boards as supporting evidence that adequate groundwater is available to meet water-supply demands and/or to dilute contaminants from septic systems. The soil recharge rates summarized in Table 6 were calculated with NJGS method using a Microsoft Excel Workbook (Hoffman 2002) for the soils mapped in West Milford Township.

Based on the soil types and climatic conditions of West Milford Township, soil recharge rates ranging from 13.0 to 23.5 inches per year were calculated for non-hydric soils with the NJGS method. Some of the highest rates of soil recharge were calculated for rock outcrops, steep sloping materials, and areas with exposed bedrock, where it would be expected that because of impervious materials and steep gradients associated with the rock and/or steep slopes, runoff rates would be highest and recharge rates lowest. The NJGS method cannot be used to calculate soil recharge rates for several soils associated with wetlands, open water, or hydric soils or for altered soils in urbanized areas or beneath man-made fill areas.

The high rates of soil recharge calculated with the NJGS method cannot be substantiated with local streamflow data. The USGS streamflow data for the Wanaque River, Kanouse River, Belcher Creek, Morestown Brook, Cooley Brook, West Brook, and Blue Mine Brook do not indicate baseflow rates that could support these soil recharge rates. The streamflow data indicate that many of the streams in West Milford Township are very flashy streams in which, very high flow rates are measured during and for a few hours/days after a precipitation episode and then quickly decline when flows are not sustained as a result of discharges from the many lakes and reservoirs. The streamflow data indicate that soils and bedrock have little storage and that water rapidly runs off the land surface into the surface-water systems.

Based on the poor to very poor aquifer characteristics, the steep slopes, and empirical streamflow data for West Milford Township, the NJGS method is not appropriate for assessing recharge for this municipality. Since the NJGS made a clear distinction that their model does not determine "aquifer" recharge, this method should not be used to assess recharge rates to aquifer systems beneath West Milford Township. Based on the geologic conditions of the township, the results of the NJGS GSR-32 evaluation are not reliable for assessing groundwater resources.

WATER SUPPLY

DEMAND

As part of the recent statewide planning efforts, the NJDEP (1996) assumed a per capita water use rate of 75 gallons per day for residential self-supplied demand. The New Jersey Water Supply Authority (NJWSA 2000) indicates a guideline value of 140 gallons per day per capita. N.J.A.C. 7:10-12.6 indicates that in planning water supply needs, an average daily demand of 100 gallons per day per person should be used. The per capita demand suggested by the New Jersey Administrative Code appears to be a reasonable mid-range estimate of daily personal water demands and may include a factor of safety if the NJDEP 1996 estimate is accurate.

Based on US Census data for 2000, West Milford Township has a population of 26,410 people and 9,190 occupied dwelling units indicating a dwelling unit density of 2.9 persons per unit. Based on the population of the township and the average daily demand indicated in N.J.A.C. 7:10-12.6, West Milford Township residents currently consume groundwater at rates of approximately 2.64 million gallons per day or 964 million gallons per year.

DEPENDABLE YIELD

Definition

The NJDEP (1996) Statewide Water Supply Plan defines the dependable yield as "…the water yield maintainable by a ground water system during projected future conditions, including both a repetition of the most severe drought of record and long-term withdrawal rates without creating undesirable effects." A similar definition is included in N.J.A.C. 7:19-6 and the New Jersey Water Supply Management Act 58:1A-3h. The "Drought of Record" as currently defined occurred in the mid-1960s with 1962 to 1966 recording below normal precipitation equal to approximately 82 percent of normal precipitation. In 1965, New Jersey received approximately 30 inches of precipitation, which is two-thirds of normal precipitation and that year was the most severe year of the drought.

Maintainable Yield

Drought conditions can alter the hydrologic water balance for an area depending on the time of year the precipitation shortfall occurs. During the winter months, a precipitation shortfall will adversely affect groundwater recharge and to a lesser degree, surface-water runoff. Evapotranspiration is negligible in winter months so this parameter is generally unaffected by precipitation shortfalls during cold weather. During summer months, precipitation shortages adversely affect evapotranspiration and surface-water runoff. Groundwater recharge is naturally reduced during the summer when most precipitation is rapidly consumed by vegetation and generally, this parameter is not as significantly affected by a warm weather drought as are surface-water runoff and evapotranspiration. Droughts that occur over several years such as the "Drought of Record" adversely impact all water-balance parameters.

Posten (1984) in evaluating West Brook, determined that annual streamflow rates in 1963 through 1965 were one-third to one-half rates reported for the other six years (1945, 1953, 1971, 1974, 1975, 1976) used in his analyses. He estimated that delayed flow rates for these same three years were approximately 50 to 75 percent of the average rate for the nine years he used in the analyses. The NJGS estimated baseflow using hydrograph separation methods for the periods of record and compared these flow rates to those determined for 1960 to 1966 (Canace 1992). The 1960 to 1966 baseflow estimates are approximately 70 to 71 percent of the long-term estimates. Although these estimates indicate below normal baseflow, they are likely overestimates of drought baseflow because data from 1960 and 1961 were included. Precipitation in 1960 and 1961 exceeded normal precipitation and therefore, these two years were not drought years. Posten (1984) and the NJGS analyses indicate that drought can significantly reduce baseflow and groundwater recharge.

The Posten (1984) Method, as part of the graphical analyses associated with percent exceedence and flow, includes consideration of dry weather recharge rates and therefore, drought conditions were included in the determination of the recharge rates of 3.8 to 4.2 inches per year or 280 to 310 gpd/acre for West Brook and Blue Mine Brook. However, this method includes baseflow components from sources other than underlying aquifer systems and therefore, is biased to provide overestimates of groundwater recharge rates. Provided that it is understood that these additional baseflow components were included in determining recharge rates, adjustments for reduced precipitation are most likely not necessary if sufficient safety margins are also included when assessing maintainable yields.

Planning Threshold

To ensure that water is available during all weather conditions for human consumption as well as ecosystems dependent on water, the NJDEP established the “Planning Threshold”. In the 1996 Statewide Water Supply Plan (NJDEP 1996), the NJDEP indicated that the dependable yield of most areas of the State had not been determined. Therefore, they established the “Planning Threshold” to reduce uncertainties associated with determining dependable yields and recharge rates for aquifers, and to limit human consumption within a basin. Through use of the Planning Threshold, the NJDEP proposes to limit human consumption of water within a basin to 20 percent of recharge and establishes the dependable yield at this level. Table 7 summarizes the recharge rates and dependable yields for the bedrock aquifers beneath West Milford Township.

Sustainable Population/Dwelling Unit Densities

Assuming a per capita demand of 100 gpd in accordance with N.J.A.C. 7:10-12.6, at a dependable yield of 56 to 62 gpd/acre, each resident would require approximately 1.7 to 1.8 acres of open land to provide sufficient recharge to meet demands. At the current residential dwelling unit density of 2.9 persons per unit, each dwelling unit would require 4.7 to 5.2 acres of open area to provide sufficient recharge to sustain the water-supply demands of the residence.

The dependable yields of the bedrock aquifers beneath West Milford Township could sustain a population ranging from 28,700 to 31,800 persons. Based on a 2000 population of 26,410 persons, the township’s groundwater resources could potentially sustain an additional 2,290 to 5,390 persons. The township’s groundwater resources could potentially sustain 9,890 to 10,950 dwelling units occupied at a density of 2.9 persons per unit. As of 2000, the township had 9,190 occupied dwelling units and therefore, could potentially sustain an additional 700 to 1,760 units.

RECHARGE AREAS

In areas of West Milford Township with lot sizes less than 4.7 to 5.2 acres per unit, water demands could be sustained provided that sufficient areas are available to permit recharge and the overall density is not exceeded. Old agricultural villages with small village lots surrounded by active farmlands would be an example of an area with lots less than 5-acres but an overall density less than 0.20 units per acre. In this example, the village’s water supply demands are sustained by recharge to upgradient lands beneath which, groundwater migrates to the village wells. Little precipitation would infiltrate to the aquifer beneath the village because of the high percentage of impervious surfaces, while sufficient precipitation could infiltrate through the adjoining open farm fields during late fall and winter months to sustain the local water-supply demands.

The areas available for recharge within West Milford Township should permit precipitation to infiltrate to an aquifer system and ensure that groundwater is available for both human consumption within the dwelling units associated with the recharge area, and also for downstream ecosystems and consumers. The recharge areas should be upgradient of wells to maximize available storage and aquifer replenishment. These areas should be flat to gently sloping, open to incident precipitation, and should not be covered with impervious materials or buildings. The aquifer recharge areas should be located within areas in which the underlying bedrock is highly fractured with little to no impervious coverage along strike or trend of the fractures. The recharge areas do not have to be coincident with the dwelling unit but must be within the same topographic drainage area. Seeps, wetlands, streams, bedrock outcrops, and/or steep slopes should not be included in the recharge areas.

In addition to ensuring adequate water supplies are available to residents of West Milford Township during all weather conditions including a repetition of the "Drought of Record", groundwater quality must be maintained to provide safe-drinking water. The recharge areas within the township permit water to infiltrate to an aquifer and dilute natural and man-made contaminants. Although some portion and potentially all water used in a residence within West Milford Township is recycled through septic systems, the water from these wastewater disposal systems does not meet Federal or State Drinking Water Quality Standards and requires dilution within the aquifer to reduce contaminant concentrations.

NITRATE DILUTION

Nitrate

Nitrate is not typically found in groundwater because of natural conditions. Nitrate can be introduced to groundwater from sewage discharges, fertilizers, animal waste, and decomposing plants. In addition, some agricultural crops such as legumes and alfalfa can fix atmospheric nitrogen and transfer it to soils where it can then enter groundwater. Nitrate is used as an indicator of anthropogenic impacts to groundwater, especially impacts associated with sewage disposal. Elevated nitrates can cause methemoglobinemia (Blue Baby Syndrome) in infants and can also be an indicator of pathogenic bacterial or viral contamination as well as contamination from other man-made chemical compounds.

Nitrate is a highly soluble, stable, and mobile compound in groundwater when sufficient dissolved oxygen is available. Fractured bedrock aquifers, especially those interconnected with water-table systems, contain high concentrations of dissolved oxygen. Under these conditions, nitrate, much like the other contaminants for which nitrate serves as an indicator, can migrate large distances and result in an extensive plume of groundwater contamination. Since nitrate and the other contaminants are not easily removed from groundwater, the source(s) of the contamination must be identified and removed, and the contaminant concentrations diluted to achieve safer drinking-water conditions.

Background Concentrations

On January 7, 1993, the NJDEP established groundwater classifications and quality criteria (N.J.A.C. 7:9-6). In accordance with these New Jersey Ground Water Quality Standards, groundwater within West Milford Township is classified as Class II-A. The nitrate as nitrogen criteria for Class II-A water is 10 milligrams per liter (mg/l). This criterion is the same as the USEPA standard for nitrate as nitrogen in drinking water.

As part of New Jersey's groundwater quality standards, the NJDEP established an antidegradation policy to protect groundwater in which, the background concentration of a contaminant does not exceed the quality criteria. The policy limits the discharge of contaminants to groundwater to a percentage of the difference between the background concentration and the quality criteria. For Class II-A water, the limit is the background concentration plus 50 percent of the difference between the background concentration and the quality criteria.

The NJGS (Hoffman 2001) summarized analytical data for samples throughout New Jersey and these data indicate that background concentrations of nitrate in groundwater within the Highlands Province in areas underlain by Precambrian igneous and metamorphic rocks, range from less than 0.01 to 4.7 mg/l with a median concentration of 0.76 mg/l. Based on the median background concentration of nitrate in groundwater within the Highlands, the NJDEP anti-degradation policy would permit concentrations to increase to 5.38 mg/l or 7 times greater than current levels. In other portions of New Jersey with Class I-A or I-PL groundwater, the antidegradation limit does not permit discharges to increase background concentrations. In these areas, the NJDEP has determined that groundwater quality must receive additional protection. Since nearly all West Milford Township residents rely on groundwater for drinking water and fractured bedrock aquifers provide minimal if any, contaminant removal, the aquifers beneath the township have similar needs for protection as those areas designated by the NJDEP as Class I-A and I-PL.

Trela-Douglas Model

ACCEPTANCE

The Trela-Douglas nitrate-dilution model was developed in 1978 and presented at the First Annual Pine Barrens Research Conference. This model has been widely accepted and used by the NJDEP for more than 24 years when evaluating potential nitrate discharges from septic systems to groundwater and for determining the recharge areas necessary to dilute nitrate concentrations. The model continues to be used by the NJDEP when evaluating septic system impacts from subdivisions of 50 lots or more.

The Trela-Douglas model is considered conservative because it does not account for denitrification of nitrate in soils. However, this assumption is appropriate for a fractured bedrock environment with a thin soil cover such as found beneath most of West Milford Township. The thin layer of soils and bedrock fractures provide limited retention time and groundwater is oxidized, and therefore, there will be little if any, denitrification of the septic system effluent or removal of other contaminants.

Nitrates and other contaminants such as bacteria, viruses and man-made chemicals, can quickly migrate from a septic system with infiltration through a bedrock fracture into a water-bearing zone. Once the nitrate or other contaminants are in one or more water-bearing fractures, there is little opportunity for removal or retardation. Since approximately 91 percent of West Milford Township is underlain by soils with severe or moderate limitations for septic systems and an additional 7 percent is covered with water, soils beneath West Milford Township are unlikely to prevent nitrates or other contaminants from impacting water used for water supply. Therefore, adequate recharge is necessary to dilute the concentration of contaminants from septic systems.

ASSUMPTIONS

Similar to the water-supply evaluation discussed above, the Trela-Douglas model was applied to West Milford Township to evaluate existing needs based on current demographics of 2.9 persons per dwelling unit. The Trela-Douglas nitrate dilution model is based on several assumptions, which for West Milford Township include the following:

1. The groundwater use rate is 100 gallons per day per person and 2.9 persons occupy each existing residence. These assumptions are the same assumptions used in determining recharge areas for water supply use. Therefore, groundwater use per dwelling unit is 290 gpd.

2. Groundwater recharge ranges from 3.8 to 4.2 inches per year, which are the same rates as those used in the water-supply evaluation.

3. The nitrate-nitrogen concentration in the septic system effluent is approximately 40 mg/l.

4. The nitrate concentration at the boundary of the property, which is in accordance with the NJDEP antidegradation policy for Class II-A groundwater, is 5.38 mg/l for West Milford Township.

5. No sources of nitrate from fertilizers are included in the assessment of impacts to groundwater quality.

EQUATION

The Trela-Douglas Model is defined by the following equation:

$$V_eC_e=(V_i+V_e)C_q \qquad \text{(Equation 2)}$$

Where:

V_e = Volume of effluent.
C_e = Concentration of nitrate in effluent.
V_i = Volume of recharge.
C_q = Concentration of nitrate at downgradient property boundary.

The volume of effluent and volume of recharge parameters can be modified as follows:

$$V_e=HW_u \qquad \text{(Equation 3)}$$
$$V_l=AR \qquad \text{(Equation 4)}$$

Where:

H = Number of persons per home.
W_u = Per capita water use in gallons per day.
A = Recharge area in acres.
R = Recharge rate in inches per year.
And 74.39 is a factor to convert inches per year to gallons per day.

Equation 2 can be modified with Equations 3 and 4 and rearranged to solve for recharge area as follows:

$$A=HW_u(C_e-C_q)/74.39(RC_q) \qquad \text{(Equation 5)}$$

With the following values for these parameters:

H = 2.9 persons per home.
W_u = 100 gallons per day.

C_e = 40 mg/l.
C_q = 5.38 mg/l.
R = 3.8 to 4.2 inches per year.

Table 8 summarizes the solutions of Equation 5 for West Milford Township. Recharge areas ranging from 6 to 6.6 acres per dwelling unit are required to dilute septic-system contaminants to a nitrate concentration of 5.38 mg/l. Recharge to the township could adequately dilute septic-system contaminants from 7,760 to 8,530 dwelling units. Dwelling units discharging to a sanitary sewer system connected to a wastewater treatment facility would be in addition to the 7,760 to 8,530 units that could rely on septic systems. Although discharging to a wastewater treatment facility may result in improved water quality, these discharges will most likely diminish groundwater quantity since it is unlikely that the water will be returned to the aquifer after treatment.

Similar to the recharge areas for water supply, the recharge areas necessary to dilute nitrate concentrations should be in areas with flat to gentle slopes and open to precipitation. The areas should not be covered with impervious surfaces or buildings that can prevent precipitation from infiltrating into bedrock fractures. Portions of lots that include seeps, wetlands, streams, bedrock outcrops, and/or steep slopes should not be included in the recharge areas.

In areas of the township with existing lot sizes smaller than the recharge areas, additional areas or recharge enhancements may be needed for adequate nitrate dilution. Within these areas, it may be necessary to preserve or protect upstream open areas within the same watershed to ensure sufficient water infiltrates the aquifer to dilute septic system contaminants from these existing dwellings. Even in areas where the existing lot sizes are capable of supporting existing dwelling units equal to these recharge areas, it may be necessary to protect upstream open areas or enhance recharge to balance portions of the existing lots covered with impervious materials.

CONCLUSIONS

Based on the data, reports, and maps reviewed in preparation of the West Milford Township water resource evaluation, the following conclusions are made:

1. The source of drinking water for West Milford Township residents is groundwater. Water is supplied to these residents from individual wells or public community wells completed in fractured bedrock aquifers. Surface-water resources within the township have been long-dedicated to downstream urban areas of New Jersey.

2. West Milford Township is located within the Highlands Region, which extends across New Jersey into New York and Connecticut. Because of high quality and availability of water, this region has historically been considered as having the most valuable water resources necessary to sustain major cities and related populated urban areas in New Jersey and New York. Of the eleven major reservoirs in the Highlands Region in New Jersey, four reservoirs are located partially or wholly within West Milford Township. The water levels in these four reservoirs are maintained with surface water and groundwater flowing from West Milford Township.

3. The eighty-square mile West Milford Township is located in one of the fastest growing portions of the New Jersey with the population increasing nearly 12 percent from 1980 to 1990 and an additional 4 percent from 1990 to 2000.

4. NJDEP regulations indicate that the surface-water resources within West Milford Township are very high quality and worthy of extensive protection against degradation of water quality. Many of these surface-water resources are protected against further degradation to maintain the quality of water diverted from the major reservoirs to New Jersey's major cities. Nearly all of streams flowing in the township originate or headwater within West Milford Township at or very near the highest elevations. At these headwaters, discharging groundwater starts the surface-water flow in the streams.

5. Seventy-two percent of the soils beneath West Milford Township have severe limitations and an additional 19 percent have moderate limitations for septic-system discharges. These limitations may include but are not limited to frequent flooding, shallow seasonal perched groundwater, steep slopes, and shallow depth to bedrock or poorly permeable layer such as fragipan. Nearly seven percent of West Milford Township is covered with water, which when taken in conjunction with the data for soils with severe or moderate limitations, indicates that soils beneath only 2 percent of the township may be appropriate for conventional septic systems. Discharges to soils with limited capacity for infiltration, dispersion, and dilution could result in degradation of surface-water and/or groundwater quality.

6. Glacial geologic data and the local public community water-supply well data indicate that the glacial deposits in West Milford Township are not high-yielding aquifers capable of sustaining large yields for prolonged periods. The data indicate that the glacial deposits are not a reliable source of groundwater for the residents of the township.

7. The NJDEP ranking of bedrock aquifers within West Milford Township indicates that Precambrian rocks and the rocks of the Green Pond

Mountain Region should be considered D aquifers. These rankings indicate that the bedrock aquifer-systems beneath West Milford Township are very poor with limited capability of yielding groundwater to high-capacity wells. Data from the 37 public community water-supply wells and the 2449 domestic wells indicate that the aquifer-systems beneath West Milford Township are poor yielding and poorly transmissive. The well data do not indicate any significant differences in yields between the Precambrian igneous and metamorphic rocks and the Devonian and Silurian rocks of the Green Pond Mountain Region.

8. Eighty-four percent of West Milford Township has slope gradients that are sufficient to promote surface-water runoff in lieu of groundwater infiltration. Nearly 94 percent of the soils beneath West Milford Township are considered to have a hydrologic soil group code of C or are classified as hydric and as a result, have very low if any infiltration rates and high runoff rates. Soils and slopes beneath much of West Milford Township promote surface-water runoff in lieu of groundwater recharge.

9. Although hydrograph separation methods are highly dependent on observer and method bias, they are an available tool for estimating baseflow and groundwater recharge. When these tools are used, it should be understood that the methods will result in an overestimate of groundwater recharge because of the difficulties separating aquifer discharge from discharges associated with shallow sources such as wetlands, ponds, bank-storage, floodplain materials, and seasonal perched zones. Posten (1984) developed a method to reduce the number of “personal judgments” and therefore, slightly reduce but not eliminate potential overestimates of groundwater recharge. Posten (1984) evaluated streamflow data from West Brook and Blue Mine Brook to determine recharge rates of 280 and 310 gpd/acre, which are equivalent to 3.8 and 4.2 inches per year.

10. Based on US Census data for 2000, West Milford Township has a population of 26,410 people and 9,190 occupied dwelling units indicating a dwelling unit density of 2.9 persons per unit. Based on the population of the township and the average daily demand indicated in N.J.A.C. 7:10-12.6, West Milford Township residents currently consume groundwater at rates of approximately 2.64 million gallons per day or 964 million gallons per year.

11. Based on the recharge rates, the dependable yield for the aquifers beneath the township range from 56 to 62 gpd/acre. Each dwelling unit would require 4.7 to 5.2 acres of open area to provide sufficient recharge to sustain the water-supply demands of the residence. The dependable yields of the bedrock aquifers beneath West Milford Township could

sustain a population ranging from 28,700 to 31,800 persons. The township's groundwater resources could potentially sustain 9,890 to 10,950 dwelling units occupied at a density of 2.9 persons per unit.

12. Nitrate is not typically found in groundwater because of natural conditions and is an indicator of anthropogenic impacts to groundwater quality. Fractured bedrock aquifers, especially those interconnected with water-table systems, contain high concentrations of dissolved oxygen. Under these conditions, nitrate, much like the other contaminants for which nitrate serves as an indicator, can migrate large distances and result in an extensive plume of groundwater contamination. Since nitrate and the other contaminants are not easily removed from groundwater, the source(s) of the contamination must be identified and removed, and the contaminant concentrations diluted to achieve safe drinking-water conditions.

13. Based on the median background concentration of nitrate in groundwater within the Highlands, the NJDEP anti-degradation policy would permit concentrations to increase to 5.38 mg/l or 7 times greater than current levels.

14. Recharge areas ranging from 6 to 6.6 acres per dwelling unit are required to dilute septic-system contaminants to a nitrate concentration of 5.38 mg/l. Recharge to the township could adequately dilute septic-system contaminants from 7,760 to 8,530 dwelling units.

15. The recharge areas necessary for adequate water supply and quality should be in areas with flat to gentle slopes and open to precipitation. The areas should not be covered with impervious surfaces or buildings that can prevent precipitation from infiltrating into bedrock fractures. Portions of lots that include seeps, wetlands, streams, bedrock outcrops, and/or steep slopes should not be included in the recharge areas.

16. In areas of the township with existing lot sizes smaller than the recharge areas, additional areas or recharge enhancements may be needed for adequate water supply and quality. Within these areas, it may be necessary to preserve or protect upstream open areas within the same watershed to ensure sufficient water infiltrates the aquifer to meet water-supply demands and to dilute septic system contaminants.

Water: A Natural Renewable Resource

REFERENCES

Canace, Robert, James Boyle, Mark French. 1992. Analysis of Ground-Water Recharge in Regional Water Resource Planning Areas in New Jersey, Task 2-Water Supply Availability Assessment Revised Statewide Water Supply Master Plan. New Jersey Geological Survey.

Charles, Emmanuel G., Cyrus Behroozi, Jack Schooley, Jeffrey L. Hoffman. 1993. A Method for Evaluating Ground-Water Recharge Areas in New Jersey. New Jersey Geological Survey Report GSR-32.

Drake, Avery Ala, Jr., Richard A. Volkert, Donald H. Monteverde, Gregory C. Herman, Hugh F. Houghton, Ronald A. Parker, Richard F. Dalton. 1996. Bedrock Geologic Map of Northern New Jersey. Miscellaneous Investigation Series Map I-2540-A. United States Geological Survey.

Fetter, C.W. 1988. Applied Hydrogeology. Second Edition. Merrill Publishing Company.

Freeze, R. Allan, John A. Cherry. 1979. Groundwater. Prentice-Hall Inc.

Halford, Keith J., Gregory C. Mayer. 2000. Problems Associated with Estimating Ground Water Discharge and Recharge from Stream-Discharge Records. Ground Water May-June 2000 vol. 38 no. 3 pp 331-342.

Hoffman, Jeffrey L. 1999A. USEPA-Designated Sole-Source Aquifer Project Review Areas in New Jersey. New Jersey Geological Survey Open File Map OFM 26.

Hoffman, Jeffrey L., Robert J. Canace. 2001. A Recharge-Based Nitrate-Dilution Model for New Jersey, NJGS Technical Guidance. July 2001.

Hoffman, Jeffrey L., Robert J. Canace. 2002. A Recharge-Based Nitrate-Dilution Model for New Jersey MS Excel Workbook, version 5.0: N.J. Geological Survey Digital Geodata Series DGS02-06, Trenton.

Seglin, Lester, L. 1975. Soil Survey of Passaic County, New Jersey. U.S. Department of Agriculture (USDA), Soil Conservation Service.

Kaplan, Marjorie, Mark Ayers. 2000. Impervious Surface Cover Concepts and Thresholds. NJDEP and USGS. April 5, 2000. http://www.state.nj.us/dep/watershedmgt/DOCS/BMP_DOCS/ISC4.pdf

Lewis-Brown, Jean C., Eric Jacobsen. 1995. Hydrogeology and Ground-Water Flow, Fractured Mesozoic Structural-Basin Rocks, Stony Brook, Beden

Brook, and Jacobs Creek Drainage Basins, West-Central New Jersey. USGS Water-Resources Investigations Report 94-4147.

New Jersey Department of Environmental Protection Office of Environmental Planning. 1996. Water for the 21st Century: The Vital Resource, New Jersey Statewide Water Supply Plan.

New Jersey Geological Survey. 2002. Hydrogeologic Character and Thickness of the Glacial Sediment of New Jersey. 2002 Revision to Open-File Map OFM-3.

New Jersey Water Supply Authority. March 2000. Water Supply Availability and Water Budget in the Raritan Basin.

Nicholson, R.S., S.D. McAuley, J.L. Barringer, and A.D. Gordon. 1996. Hydrogeology of, and Ground-Water Flow In, A Valley-Fill and Carbonate-Rock Aquifer System Near Long Valley in the New Jersey Highlands. United States Geological Survey (USGS) Water Resources Investigations Report 93-4157.

Phelps, Marcus G. and Martina C. Hoppe as compilers. 2002. New York-New Jersey Highlands Regional Study: 2002 Update. US Department of Agriculture, Forest Service. December 2002.

Posten, Stephen E., 1984. Estimation of Mean Groundwater Runoff in Hard-Rock Aquifers of New Jersey. Pp. 109-154 in Halasi-Kun, G.J. (ed.) Pollution and Water Resources, Columbia University Seminar Series, Vol. 26. New York: Pergamon Press.

Sloto, Ronald A., Michèle Y. Crouse. 1996. HYSEP: A Computer Program For Streamflow Hydrograph Separation And Analysis.

Table 1: Streams and Surface-Water Classifications in West Milford Township, Passaic County, New Jersey.

Stream Segment	Classification
Beech Brook (State line downstream to Monksville Reservoir)	FW2-TM
Belcher Creek	FW2-NT
Burnt Meadow Brook (source downstream to confluence with Green Pond Brook)	FW2-NT
Cooley Brook (all segments outside Hewitt State Forest)	FW2-TP (C1)
Cooley Brook (segment of brook and all tributaries originating and entirely located within Hewitt State Forest)	FW1(tp)
Green Brook (all segments outside Hewitt State Forest)	FW2-TP (C1)
Green Brook (segment of brook and all tributaries originating and entirely located within Hewitt State Forest)	FW1(tp)
Greenwood Lake	FW2-TM
Hewitt Brook	FW2-TP (C1)
Jennings Creek (State line to Wanaque River)	FW2-TP (C1)
Nosenzo Pond	FW2-NT (C1)
Posts Brook (Norvin Green State Forest)	FW2-NT (C1)
Posts Brook (Source to Wanaque River except Wanaque Reservoir)	FW2-NT
Wanaque River (Entire length of tributary south of Jennings Creek)	FW2-TP (C1)
Wanaque River (Greenwood Lake outlet through Wanaque Wildlife Management Area to Long Pond Iron Works State Park)	FW2-TM (C1)
West Brook	FW2-TP (C1)
West Pond	FW1
Sawmill Pond Brook (Entire length except for portion in Waywanda State Park)	FW2-NT
Sawmill Pond Brook (Section in Waywanda State Park)	FW2-NT (C1)
Upper Greenwood Lake (Section in Hewitt State Forest)	FW2-NT (C1)
Upper Greenwood Lake (Source to State Boundary)	FW2-NT
Apshwawa Brook	FW2-TP (C1)
Buckabear Pond (Pond, tributaries, and stream connecting to Clinton Reservoir)	FW2-NT (C1)
Cedar Pond (Pond and all tributaries)	FW1
Charlotteburg Reservoir	FW2-TP (C1)
Clinton Brook (Clinton Reservoir Dam to Pequannock River)	FW2-TP (C1)
Clinton Reservoir	FW2-TM (C1)
Hanks Pond (Pond and all tributaries)	FW1
Kanouse Brook	FW2-TP (C1)
Macopin River (Echo Lake Dam to Pequannock River)	FW2-TM
Macopin River (Source to Echo Lake Dam)	FW2-NT
Mossmans Brook (Source to Confluence with Clinton Reservoir)	FW2-TP (C1)
Oak Ridge Reservoir	FW2-TM
Oak Ridge Reservoir (Northwestern tributary to Reservoir)	FW1-TM
Pequannock River (Charlotteburg Reservoir outlet to Macopin Reservoir)	FW2-TM
Pequannock River (Macopin Reservoir outlet to Hamburg Turnpike Bridge)	FW2-TP (C1)
Pequannock River (Oak Ridge Reservoir outlet to Charlotteburg Reservoir)	FW2-TP (C1)
Pequannock River (Pacock Brook to Oak Ridge Reservoir)	FW2-TP (C1)
Wonder Lake	FW2-NT (C1)

Table 2: Types, Slopes, Approximate Areas, and Septic Limitations of Soils in West Milford, Passaic County, New Jersey.

General Soil Type	Map Label (see Figure 8)	Slope Range (percent)	Approximate Area (acres)	Septic Limitations
Alluvial land	Ae		315.74	Severe: frequent flooding, stream pollution hazard
Braceville gravelly silt loam	BtA	0 to 5	261.49	Moderate: seasonal high water table; ground water pollution hazard
Carlisle muck	Ca		1,115.96	Severe: frequent flooding; groundwater pollution hazard
Chenango silt loam	CkB	3 to 8	807.42	Slight: rapid permeability; groundwater pollution hazard
Chenango silt loam	CkC	8 to 15	286.78	Moderate: strong slopes; rapid permeability; groundwater pollution hazard
Hibernia extremely stony loam	HpC	3 to 15	2,374.61	Severe: seasonal high perched water table; groundwater pollution hazard
Made land, sanitary land fill	Ma		27.91	Severe: variable material at moderate depths
Muck, shallow	Ms		517.08	Severe: seasonal water table at surface; frequent flooding
Netcong extremely stony loam	NkC	3 to 15	678.77	Severe: extremely stony; groundwater pollution hazard
Netcong extremely stony loam	NkD	15 to 25	209.32	Severe: extremely stony; steep slopes
Norwich extremely stony silt loam	NpA	0 to 3	1,483.81	Severe: seasonal high water table; extremely stony
Norwich extremely stony silt loam	NpB	3 to 8	500.97	Severe: seasonal high water table; extremely stony
Otisville sandy loam	OrC	3 to 15	1.42	Slight-Moderate:depends on slope;rapid permeability;groundwater pollution hazard
Otisville gravelly sandy loam	OsD	15 to 30	10.40	Severe: steep slopes; rapid permeability; groundwater pollution hazard
Parsippany silt loam, sandy loam substratum	Pk		762.67	Severe:frequent flooding; high perched water table;groundwater pollution hazard
Pits, sand and gravel	Pt		204.60	Too variable to be rated
Pompton fine sandy loam	PvA	0 to 5	102.29	Severe: seasonal high water table;groundwater pollution hazard
Preakness silt loam	Px		288.50	Severe: seasonal high water table;groundwater pollution hazard
Ridgebury extremely stony loam	RbA	0 to 3	1,589.77	Severe: seasonal high water table; extremely stony
Ridgebury extremely stony loam	RbB	3 to 8	823.76	Severe: seasonal high water table; extremely stony
Riverhead sandy loam	RhB	3 to 8	361.53	Slight: rapid permeability; groundwater pollution hazard
Riverhead sandy loam	RhC	8 to 15	220.68	Moderate: strong slopes;rapid permeability;groundwater pollution hazard
Rockaway very stony sandy loam	RmB	3 to 8	1,423.04	Moderate: slow permeability;lateral seepage above fragipan;very stony
Rockaway very stony sandy loam	RmC	8 to 15	688.76	Moderate: slow permeability;deep ditches needed;very stony
Rockaway extremely stony sandy loam	RrC	3 to 15	3,721.20	Severe:extremely stony
Rockaway extremely stony sandy loam	RrD	15 to 25	1,268.85	Severe: extremely stony;steep slopes
Rockaway-Rock outcrop complex	RsC	3 to 15	6,749.33	Moderate where very stony;Severe where extremely stony
Rock outcrop-Rockaway complex	RxE	15 to 35	5,337.87	Severe: rock outcrops; very steep slopes
Rock outcrop-Swartswood complex	RyE	15 to 45	2,547.50	Severe: rock outcrops; very steep slopes
Swartswood very stony fine sandy loam	SdB	3 to 8	2,195.38	Severe: slow permeability

Table 2: Types, Slopes, Approximate Areas, and Septic Limitations of Soils in West Milford, Passaic County, New Jersey.

General Soil Type	Map Label (see Figure 8)	Slope Range (percent)	Approximate Area (acres)	Septic Limitations
Swartswood very stony fine sandy loam	SdC	8 to 15	881.11	Severe: slow permeability; strong slopes
Swartswood extremely stony fine sandy loam	SeB	3 to 8	1,101.10	Severe: slow permeability
Swartswood extremely stony fine sandy loam	SeC	8 to 15	1,283.13	Severe: slow permeability; strong slopes
Swartswood extremely stony fine sandy loam	SeD	15 to 25	1,177.02	Severe: slow permeability;steep slopes;extremely stony
Swartswood-Rock outcrop complex	SrC	3 to 15	3,911.36	Severe: slow permeability;steep slopes
Urban land-Riverhead complex	UrB	gently	60.52	
Urban land-Rockaway complex	Ux		854.59	
Water	WAT		3,465.45	
Whippany silt loam	WIA	0 to 5	73.38	Severe: seasonal high water table;occasional flooding near large streams
Wurtsboro extremely stony silt loam	WvB	3 to 8	1,116.15	Severe: seasonal high water table
Wurtsboro extremely stony silt loam	WvC	8 to 15	375.00	Severe: seasonal high water table

Table 3: Bedrock Types and Approximate Areas Beneath West Milford, Passaic County, New Jersey.

Rock Type	Area of Township Underlain by Rock Type (square feet)	Area of Township Underlain by Rock Type (acres)	Percent of Township Underlain by Rock Type
Devonian			
Skunnemunk Conglomerate	283,067,181.92	6,498.33	12.70%
Bellvale Sandstone	265,429,691.49	6,093.43	11.91%
Cornwall Shale	128,379,219.26	2,947.18	5.76%
Kanouse and Esopus Formations and Connelly Conglomerate	45,431,536.47	1,042.96	2.04%
Total Area Underlain by Devonian Formations:	722,307,629.14	16,581.90	32.40%
Silurian			
Berkshire Valley and Poxono Island Formations undivided	23,596,985.21	541.71	1.06%
Longwood Shale	3,864,003.62	88.71	0.17%
Green Pond Conglomerate	77,946,523.49	1,789.41	3.50%
Total Area Underlain by Silurian Formations:	105,407,512.32	2,419.82	4.73%
Cambrian			
Hardyston Quartzite	5,116,191.00	117.45	0.23%
Total Area Underlain by Cambrian Formations:	5,116,191.00	117.45	0.23%
Precambrian			
Hornblende Granite	438,434,517.22	10,065.07	19.67%
Hornblende Syenite	1,578,105.00	36.23	0.07%
Microperthite Alaskite	6,059,381.36	139.10	0.27%
Pyroxene Granite	41,465,969.13	951.93	1.86%
Potassic Feldspar Gneiss	24,129,436.55	553.94	1.08%
Microcline Gneiss	415,619.30	9.54	0.02%
Biotite-Quartz-Feldspar Gneiss	10,184,055.35	233.79	0.46%
Hornblende-Quartz-Feldspar Gneiss	7,414,591.96	170.22	0.33%
Clinopyroxene-Quartz-Feldspar Gneiss	67,403,106.53	1,547.36	3.02%
Pyroxene Gneiss	193,602,381.51	4,444.50	8.68%
Quartz-Oligoclase Gneiss	192,636,013.15	4,422.31	8.64%
Albite-Oligoclase Granite	326,522.00	7.50	0.01%
Biotite-Quartz-Oligoclase Gneiss	85,026,657.43	1,951.94	3.81%
Hypersthene-Quartz-Oligoclase	218,892,963.77	5,025.09	9.82%
Diorite	85,686,990.26	1,967.10	3.84%
Amphibolite	23,150,296.74	531.46	1.04%
Total Area Underlain by Precambrian Formations:	1,396,406,607.26	32,057.08	62.64%

Table 4: Summary of Well Yields, Depths, and Static Water Levels for West Milford Township, Passaic County, New Jersey.

Aquifer System	Number of Wells	Yield (gpm) Minimum	Yield (gpm) Maximum	Yield (gpm) Median	Depth (fbgs) Minimum	Depth (fbgs) Maximum	Depth (fbgs) Median	Static Water Level (feet) Minimum	Static Water Level (feet) Maximum	Static Water Level (feet) Median
Public Community Water-Supply Wells										
Glacial	1			18			95			40
Green Pond Mt. Region	9	20.1	125	40	260	502	425	5	70	48.5
Precambrian	27	15	120	36.5	125	975	353.5	-10	115	21
Domestic Wells										
Devonian	924	1	150	10	40	562	135	0	105	20
Silurian	175	0	80	10	50	502	145	0	81	16
Cambrian	2	10	24	17	215	320	268	0	20	10
Precambrian	1348	1	150	7	17	830	163	0	200	20

Table 5: Normal Rainfall and Mean Temperature As Determined for West Milford Township, Passaic County, New Jersey from Measurements Recorded by National Climatic Data Center.

Month	Precipitation (inches)	Mean Temperature (Farenheit)	Potential Evapotranspiration (inches)
January	3.81	24.5	0.00
February	3.57	26.2	0.00
March	4.21	35.8	0.30
April	4.51	46.6	1.50
May	4.85	56.8	3.09
June	4.23	65.4	4.39
July	4.40	70.3	5.22
August	4.58	68.6	4.61
September	4.40	61.4	3.16
October	4.00	50.6	1.72
November	4.83	41.4	0.68
December	4.06	29.9	0.00
Annual Total:	51.4	48.1	24.7

1 inch of rainfall equals 27152.4 gallons per acre.

Potential evapotranspiration calculated with Thornthwaite Method.

Table 6: Soil Recharge and Nitrate Dilution Calculations Made with NJDEP Model DGS02-09 for Soil Types in West Milford, Passaic County, New Jersey.

Soil Type	Soil Recharge Rate (inpy)	Recharge Area Per Septic System (acres)
Alluvial land	Hydric soil, method not applicable	
Braceville	17.5	1.6
Carlisle muck	Hydric soil, method not applicable	
Chenango	22.8	1.2
Hibernia	17.3	1.6
Made land, sanitary land fill	Method not applicable	
Muck, shallow	Hydric soil, method not applicable	
Netcong	20.8	1.4
Norwich	Hydric soil, method not applicable	
Otisville	22.5	1.3
Parsippany	Hydric soil, method not applicable	
Pits, sand and gravel	23.5	1.2
Pompton	20.8	1.4
Preakness	Hydric soil, method not applicable	
Ridgebury	Hydric soil, method not applicable	
Riverhead	20.6	1.4
Rockaway	17.2	1.6
Rockaway-Rock outcrop complex	14.8	1.8
Rock outcrop-Rockaway complex	13.0	2.1
Rock outcrop-Swartswood complex	13.2	2.0
Swartswood	17.4	1.6
Swartswood-Rock outcrop complex	14.8	1.8
Urban land	Method not applicable	
Whippany	17.1	1.6
Wurtsboro	17.5	1.6

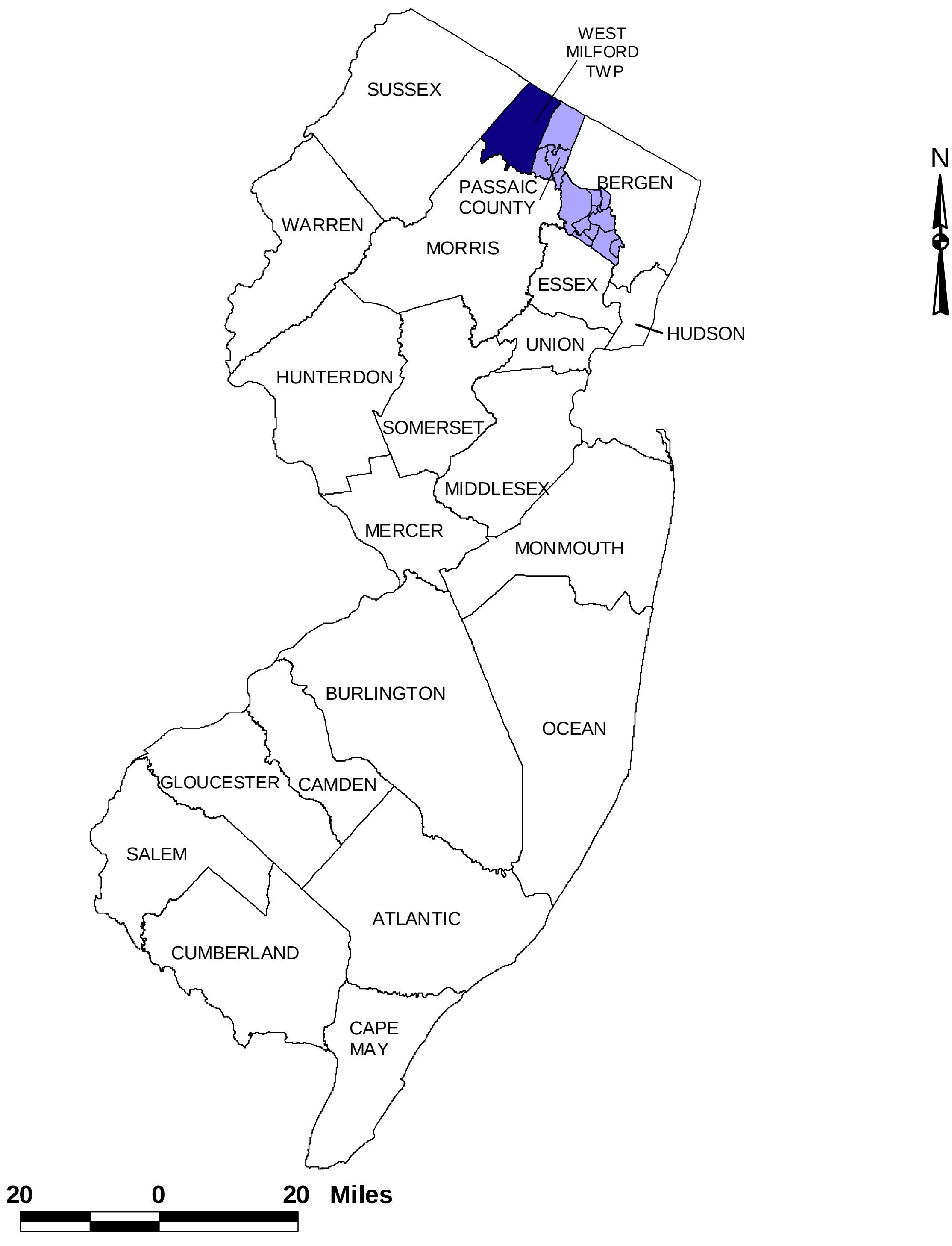
Table 7: Groundwater Recharge Rates, Dependable Yields, Sustainable Populations for Bedrock Aquifers Beneath West Milford Township, Passaic County, New Jersey.

Recharge Rate (gpd/acre)	Dependable Yield (gpd/acre)	Recharge Area per Person (acres)	Dwelling Unit Daily Demand (gpd)	Recharge Area Per Dwelling Unit (acres)	Sustainable Population	Sustainable Number of Dwelling Units
280	56	1.8	290	5.2	28700	9890
310	62	1.7	290	4.7	31800	10950

Table 8: Recharge Areas Needed to Dilute Septic Contaminants Beneath West Milford Township, Passaic County, New Jersey.

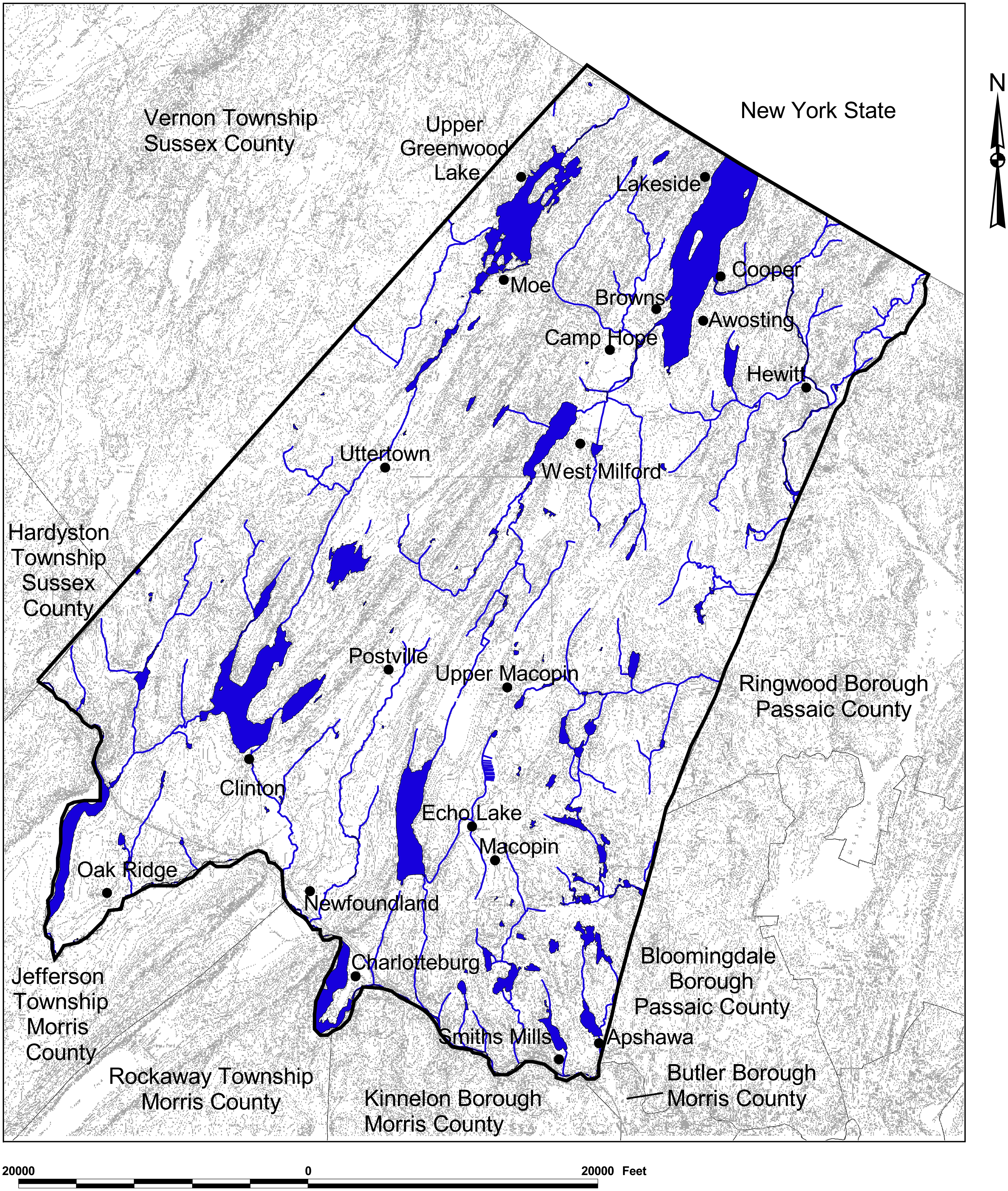
Antidegradation Limit (mg/l)	Recharge Rate (in/yr)	Recharge Rate (gpd/acre)	Recharge Area Per Dwelling Unit (acres)	Sustainable Number of Dwelling Units
5.38	3.8	280	6.6	7760
5.38	4.2	310	6.0	8530

Figure 1: Location of West Milford Township and Passaic County in the State of New Jersey.



Modified from NJGS GIS information. This map was developed with GIS digital data developed under the auspices of the NJDEP, but this secondary product as not been verified by the NJDEP and is not State authorized.

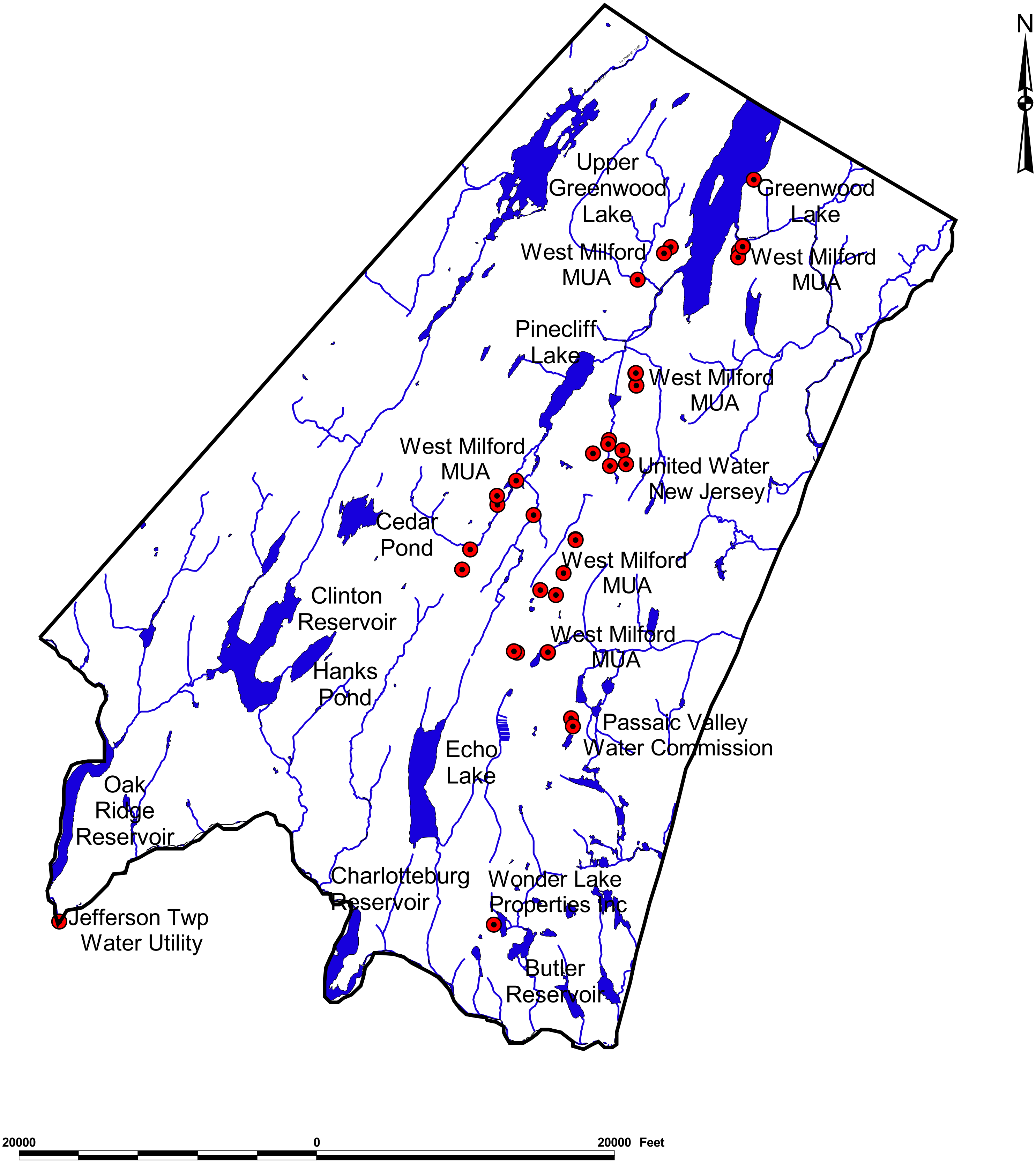
Figure 2: Neighboring Municipalities and Place Names in West Milford Township, Passaic County, New Jersey.



Modified from NJGS CD Series CD-00-1 and other GIS data and information from NJDEP sources.
This map was developed using GIS digital data developed under the auspices of the NJDEP,
but this secondary product has not been verified by the NJDEP and is not State authorized.

M²
Water: A Natural Renewable Resource

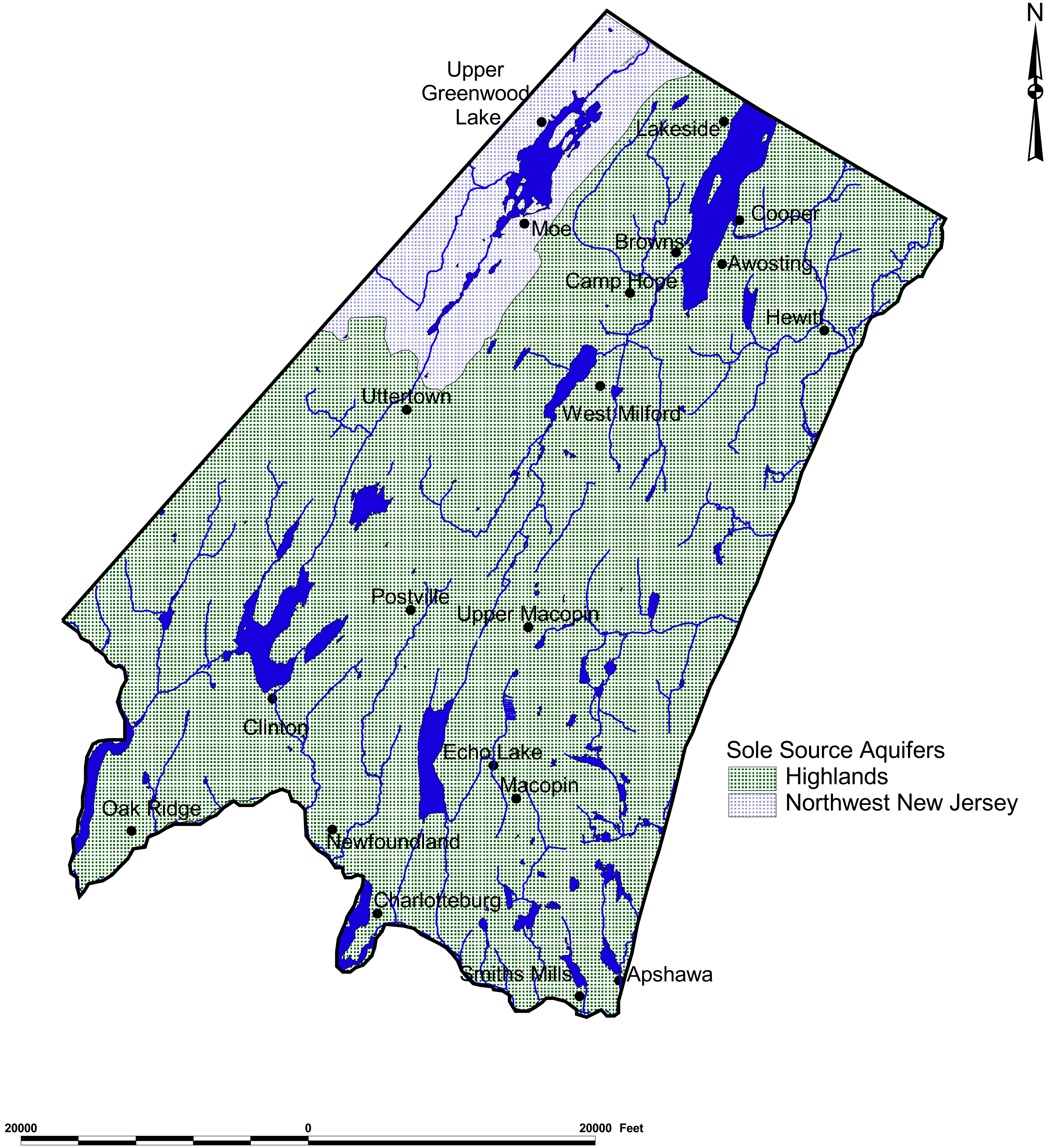
Figure 3: Reservoirs and Public Community Water-Supply Wells in West Milford Township, Passaic County, New Jersey.



Modified from NJGS CD Series CD-00-1 and other GIS data and information from NJDEP sources.
This map was developed using GIS digital data developed under the auspices of the NJDEP,
but this secondary product has not been verified by the NJDEP and is not State authorized.

M²
Water: A Natural Renewable Resource

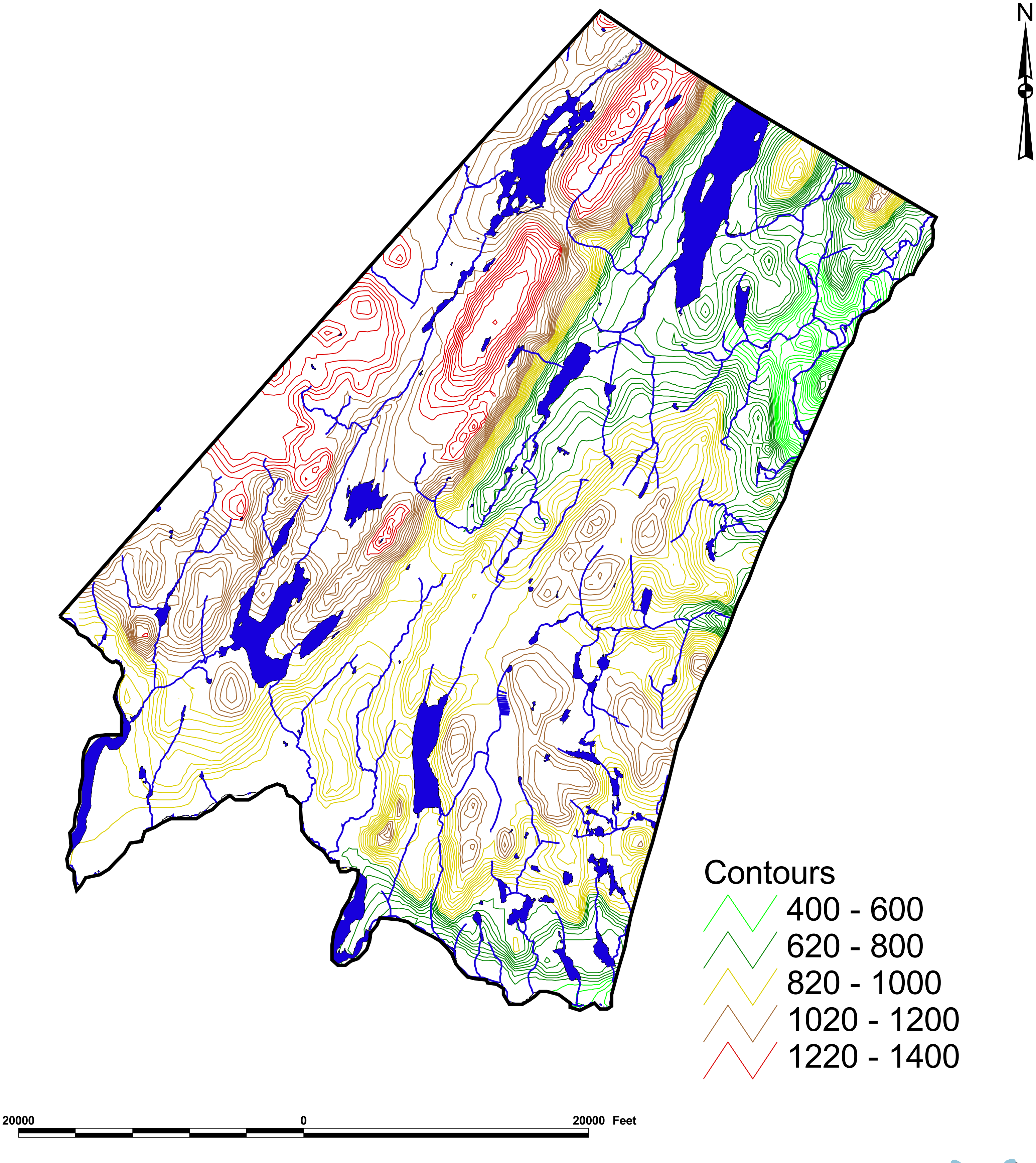
Figure 4: Sole Source Aquifers Beneath West Milford Township, Passaic County, New Jersey.



Modified from NJGS CD Series CD-00-1 and other GIS data and information from NJDEP sources.
This map was developed using GIS digital data developed under the auspices of the NJDEP,
but this secondary product has not been verified by the NJDEP and is not State authorized.

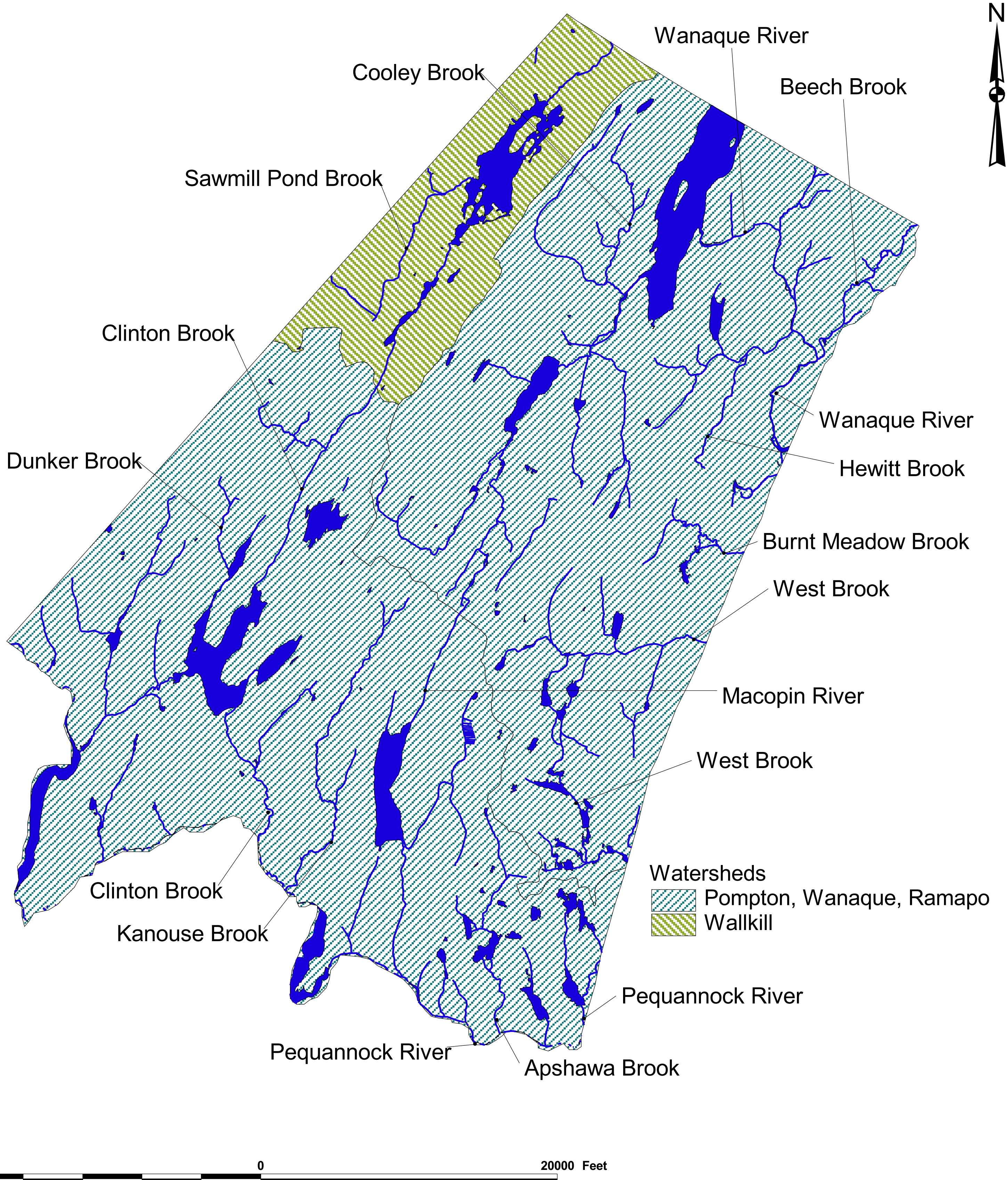
M²
Water: A Natural Renewable Resource

Figure 5: Topographic Contours for West Milford Township, Passaic County, New Jersey.



Modified from NJGS CD Series CD-00-1 and other GIS data and information from NJDEP sources.
This map was developed using GIS digital data developed under the auspices of the NJDEP,
but this secondary product has not been verified by the NJDEP and is not State authorized.

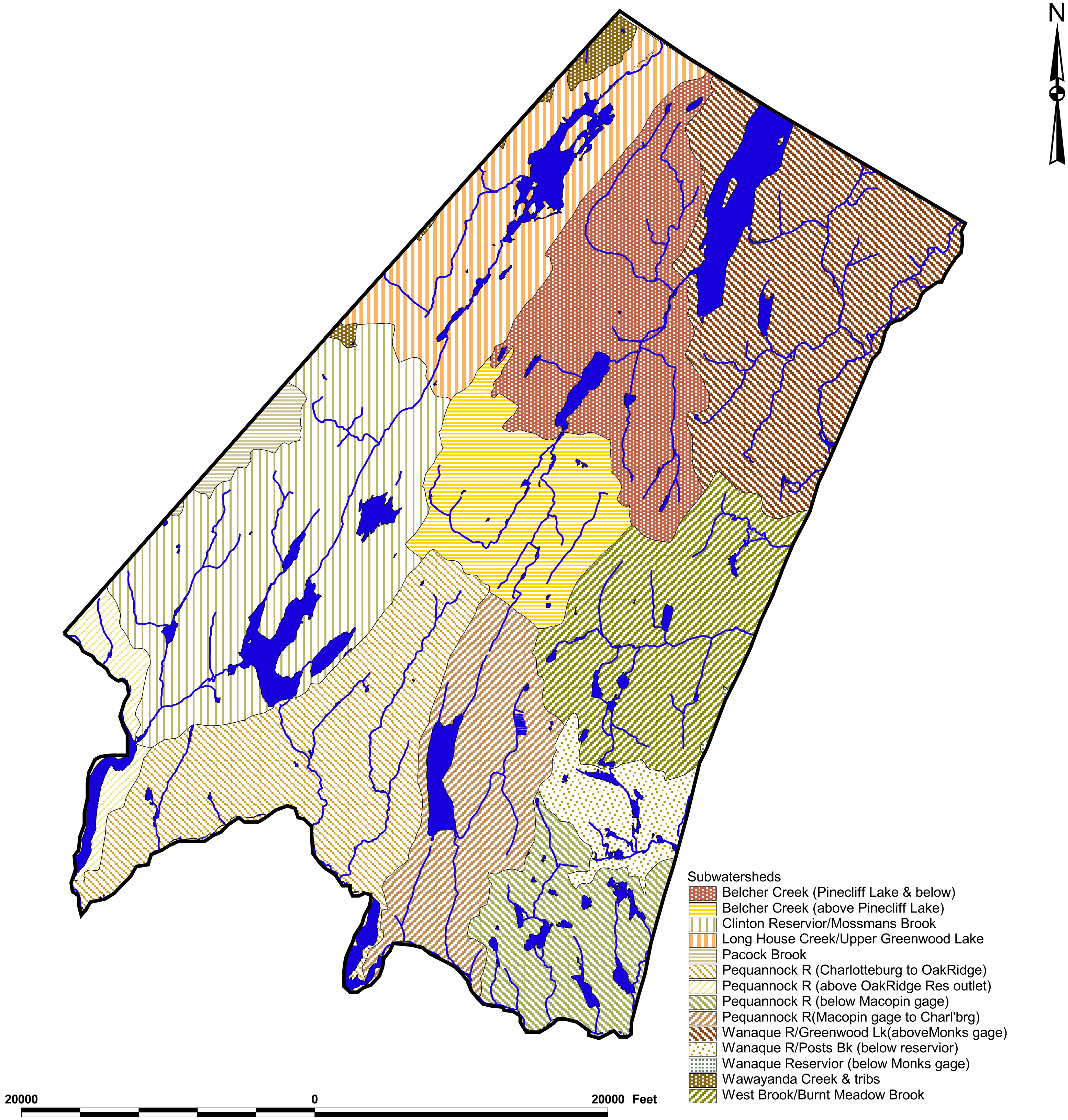
Figure 6: Watershed Management Areas within West Milford Township, Passaic County, New Jersey.



Modified from NJGS CD Series CD-00-1 and other GIS data and information from NJDEP sources.
This map was developed using GIS digital data developed under the auspices of the NJDEP,
but this secondary product has not been verified by the NJDEP and is not State authorized.

M²
Water: A Natural Renewable Resource

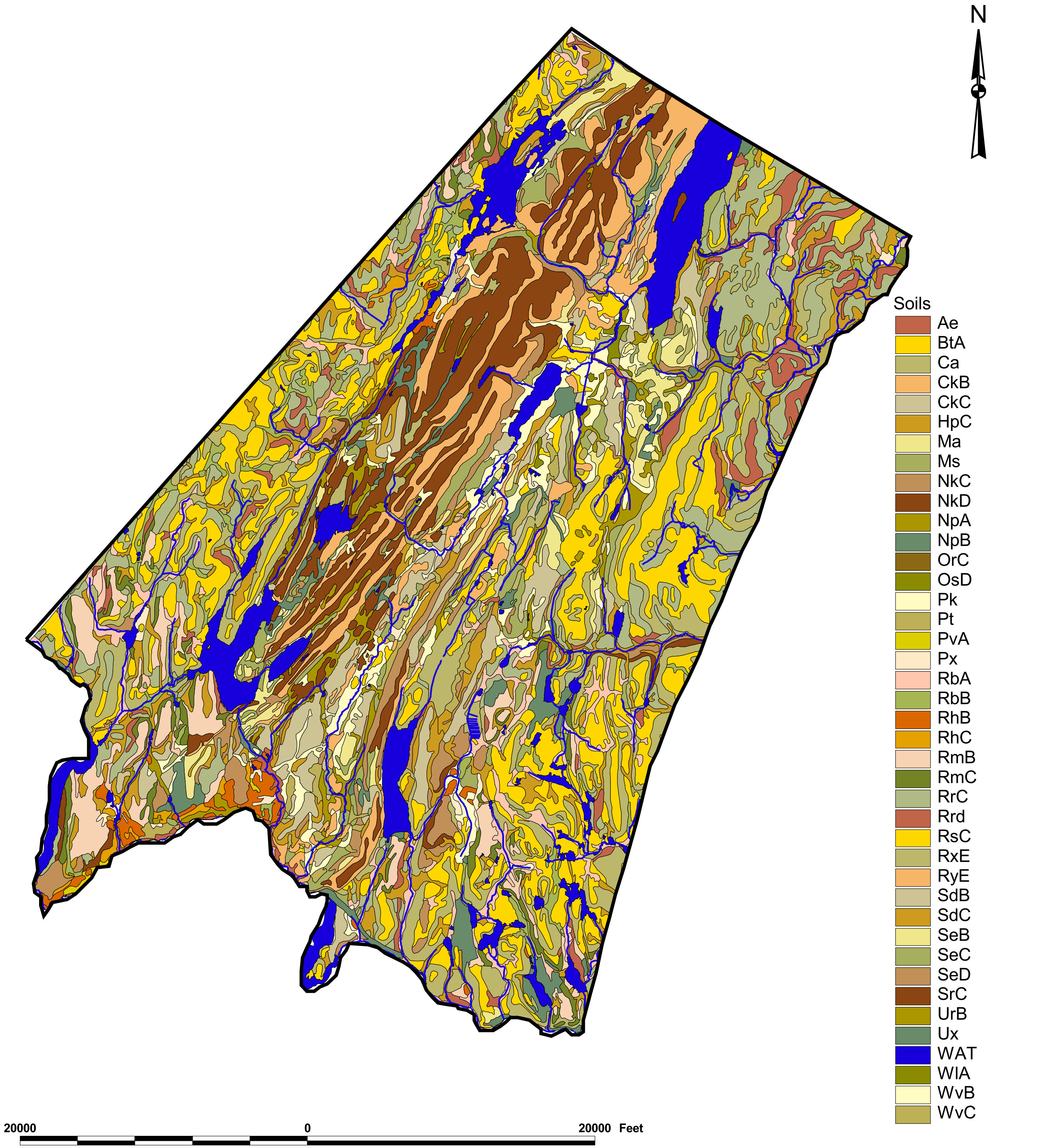
Figure 7: Subwatersheds within West Milford Township, Passaic County, New Jersey.



Modified from NJGS CD Series CD-00-1 and other GIS data and information from NJDEP sources.
This map was developed using GIS digital data developed under the auspices of the NJDEP,
but this secondary product has not been verified by the NJDEP and is not State authorized.

Water: A Natural Renewable Resource

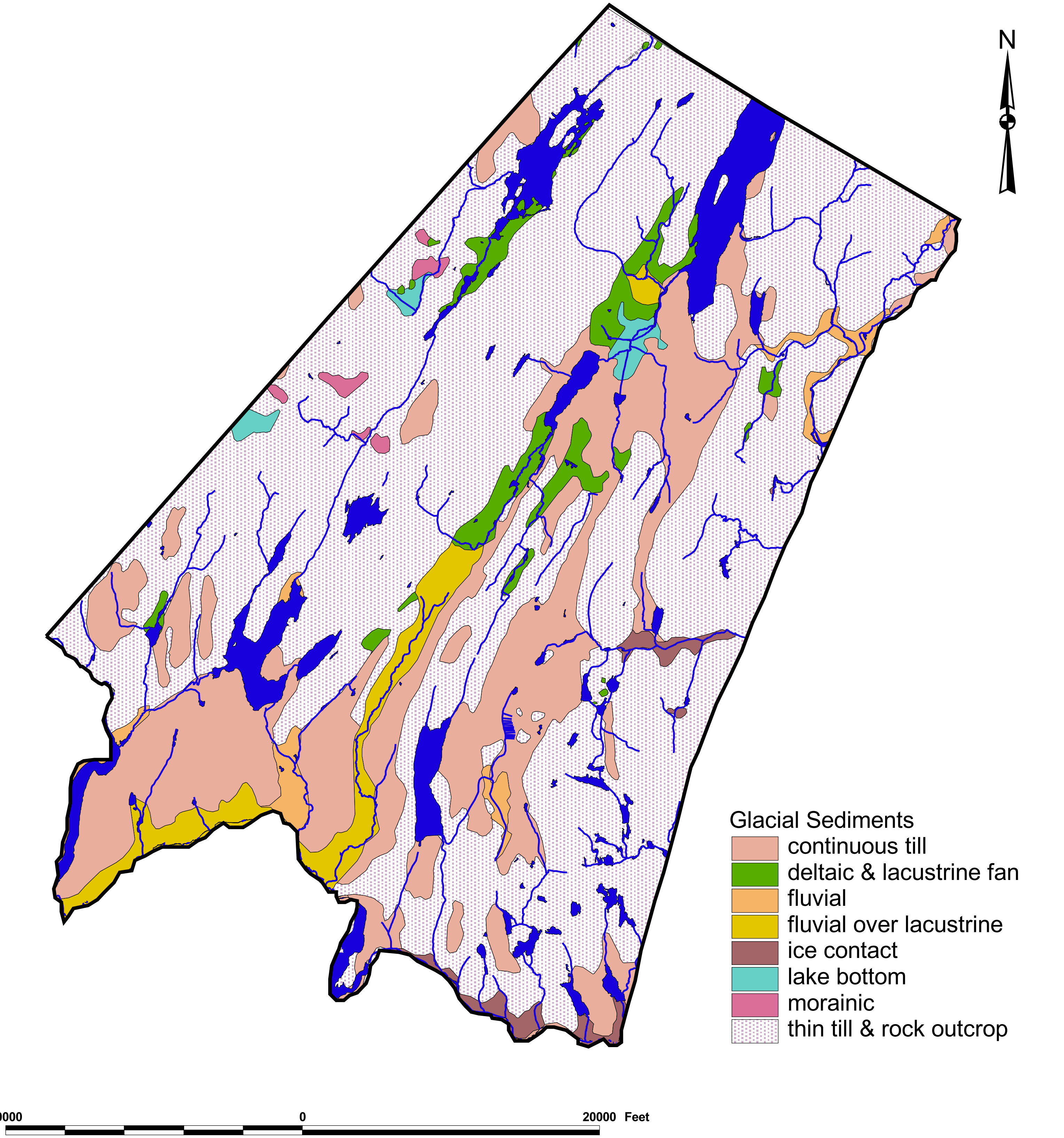
Figure 8: Soils Beneath West Milford Township, Passaic County, New Jersey.



Modified from NJGS CD Series CD-00-1 and other GIS data and information from NJDEP sources.
This map was developed using GIS digital data developed under the auspices of the NJDEP,
but this secondary product has not been verified by the NJDEP and is not State authorized.

Water: A Natural Renewable Resource

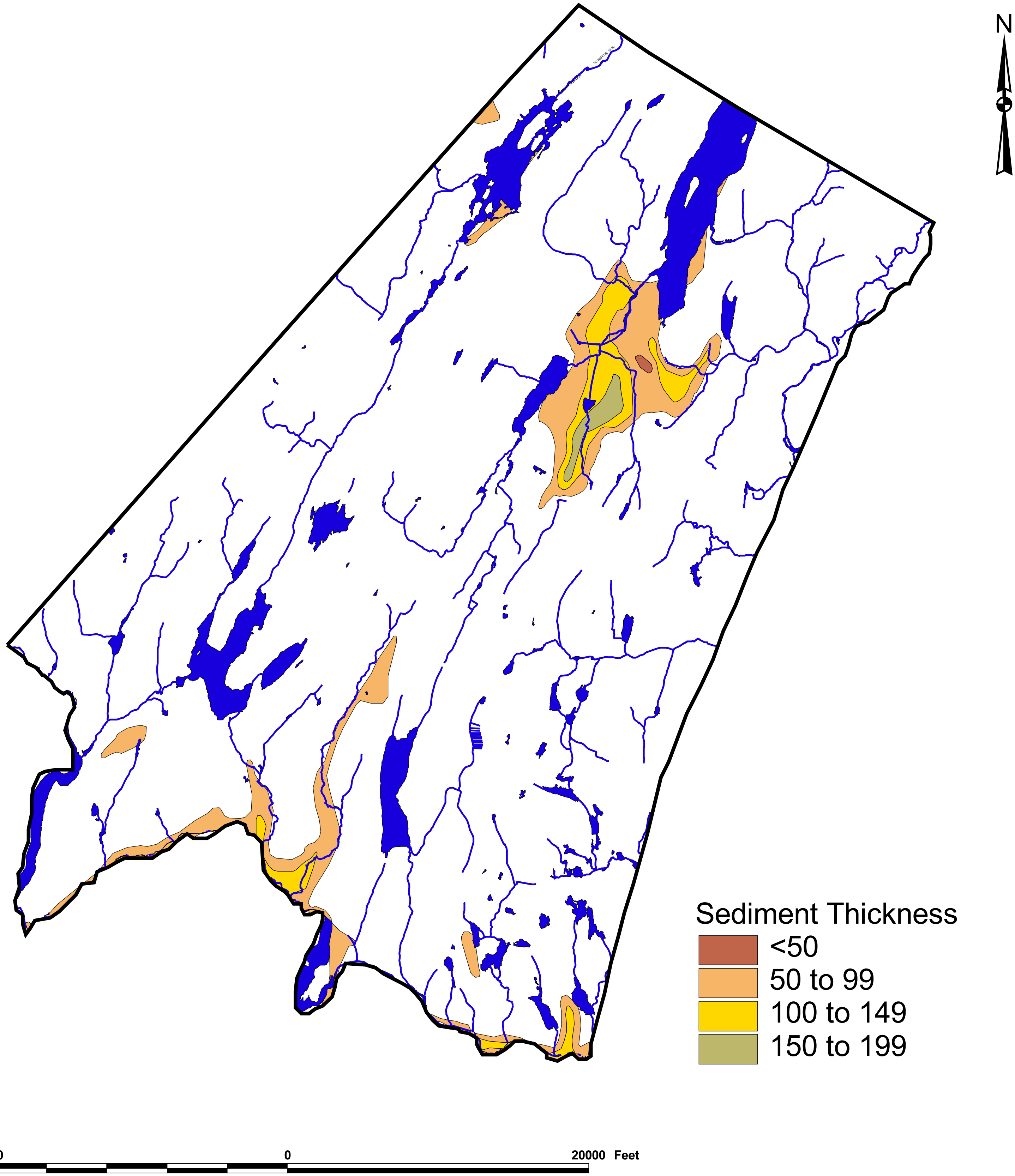
Figure 9: Glacial Deposits Beneath West Milford Township, Passaic County, New Jersey.



Modified from NJGS CD Series CD-00-1 and other GIS data and information from NJDEP sources.
This map was developed using GIS digital data developed under the auspices of the NJDEP,
but this secondary product has not been verified by the NJDEP and is not State authorized.

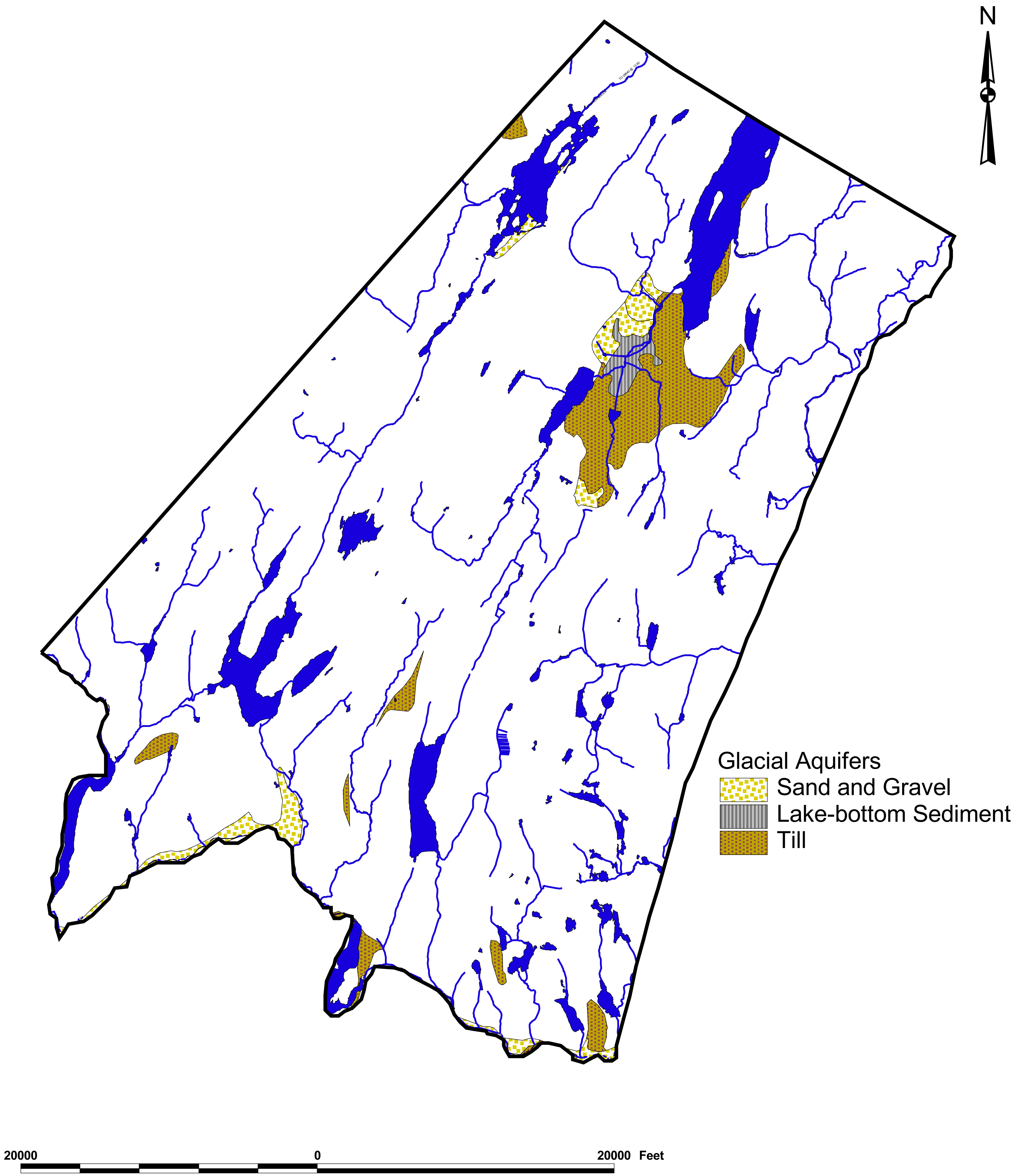
M²
Water: A Natural Renewable Resource

Figure 10: Thickness of Glacial Deposits Beneath West Milford Township, Passaic County, New Jersey.



Modified from NJGS CD Series CD-00-1 and other GIS data and information from NJDEP sources.
This map was developed using GIS digital data developed under the auspices of the NJDEP,
but this secondary product has not been verified by the NJDEP and is not State authorized.

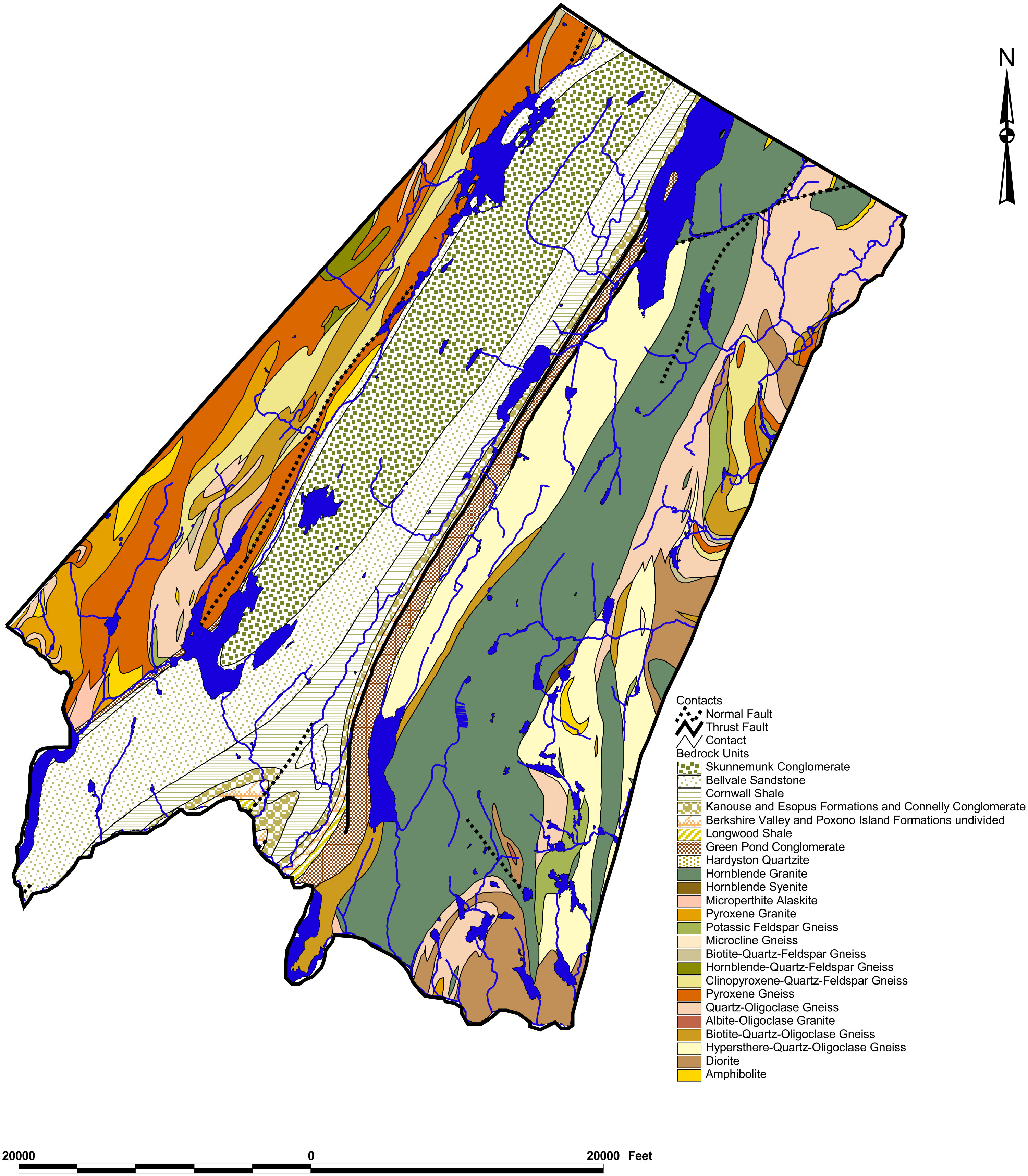
Figure 11: Glacial Aquifers Beneath West Milford Township, Passaic County, New Jersey.



Modified from NJGS CD Series CD-00-1 and other GIS data and information from NJDEP sources.
This map was developed using GIS digital data developed under the auspices of the NJDEP,
but this secondary product has not been verified by the NJDEP and is not State authorized.

M²
Water: A Natural Renewable Resource

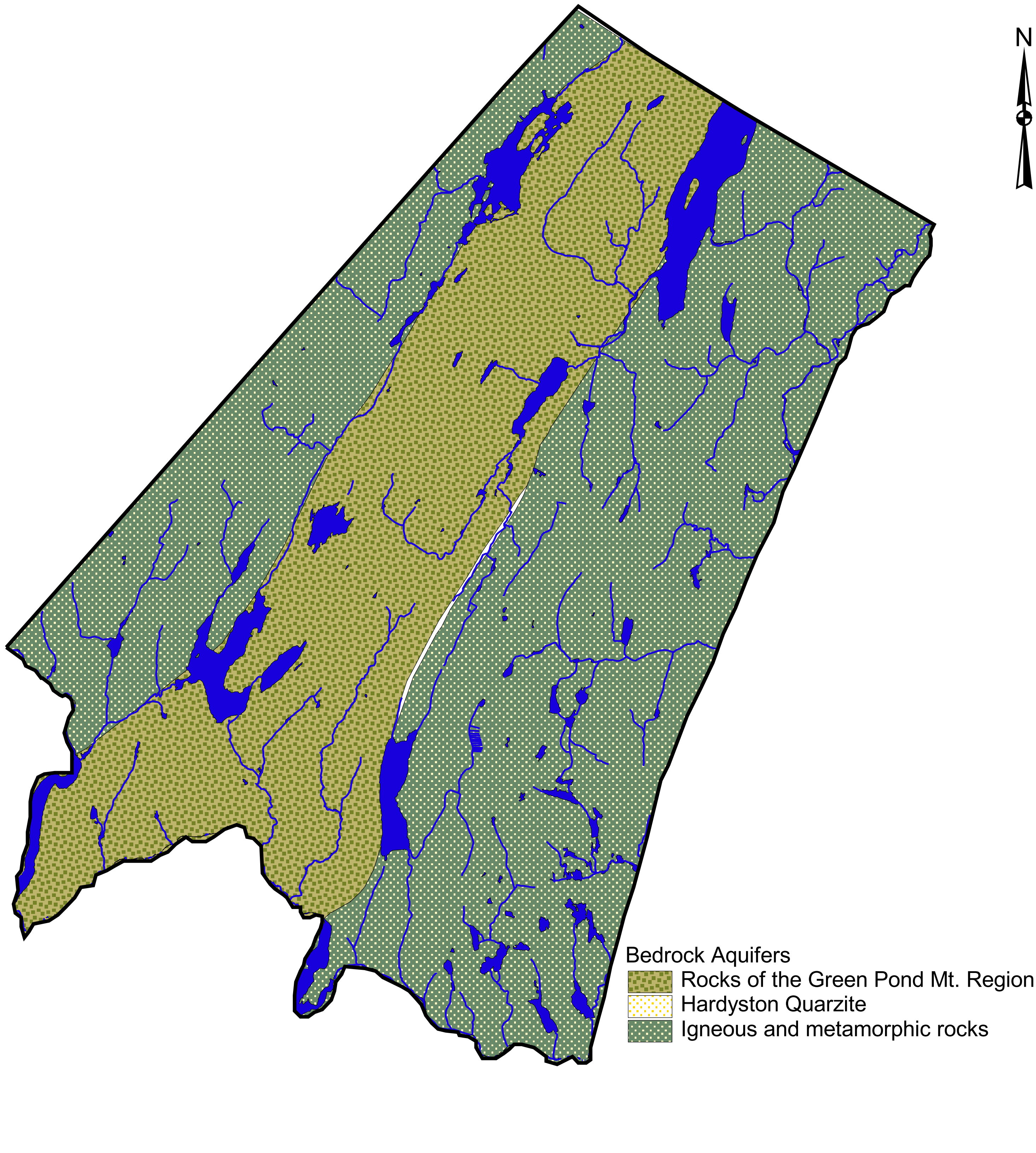
Figure 12: Bedrock Geology of West Milford Township, Passaic County, New Jersey.



Modified from NJGS CD Series CD-00-1 and other GIS data and information from NJDEP sources.
This map was developed using GIS digital data developed under the auspices of the NJDEP,
but this secondary product has not been verified by the NJDEP and is not State authorized.

M²
Water: A Natural Renewable Resource

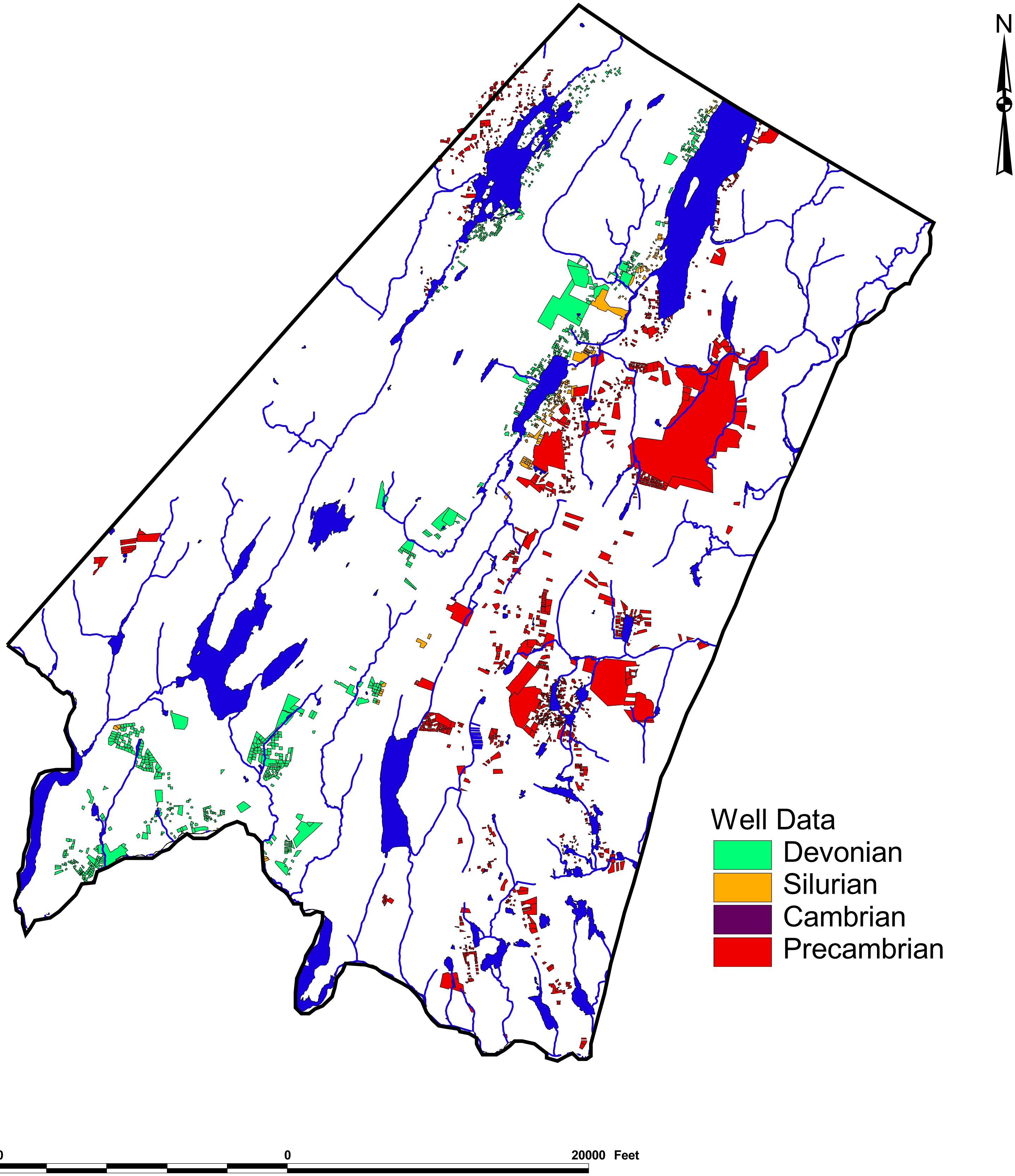
Figure 13: Bedrock Aquifers Beneath West Milford Township, Passaic County, New Jersey.



Modified from NJGS CD Series CD-00-1 and other GIS data and information from NJDEP sources.
This map was developed using GIS digital data developed under the auspices of the NJDEP,
but this secondary product has not been verified by the NJDEP and is not State authorized.

Water: A Natural Renewable Resource

Figure 14: Locations of Wells Used to Evaluate Yields in West Milford Township, Passaic County, New Jersey.



Modified from NJGS CD Series CD-00-1 and other GIS data and information from NJDEP sources.
This map was developed using GIS digital data developed under the auspices of the NJDEP,
but this secondary product has not been verified by the NJDEP and is not State authorized.

Water: A Natural Renewable Resource