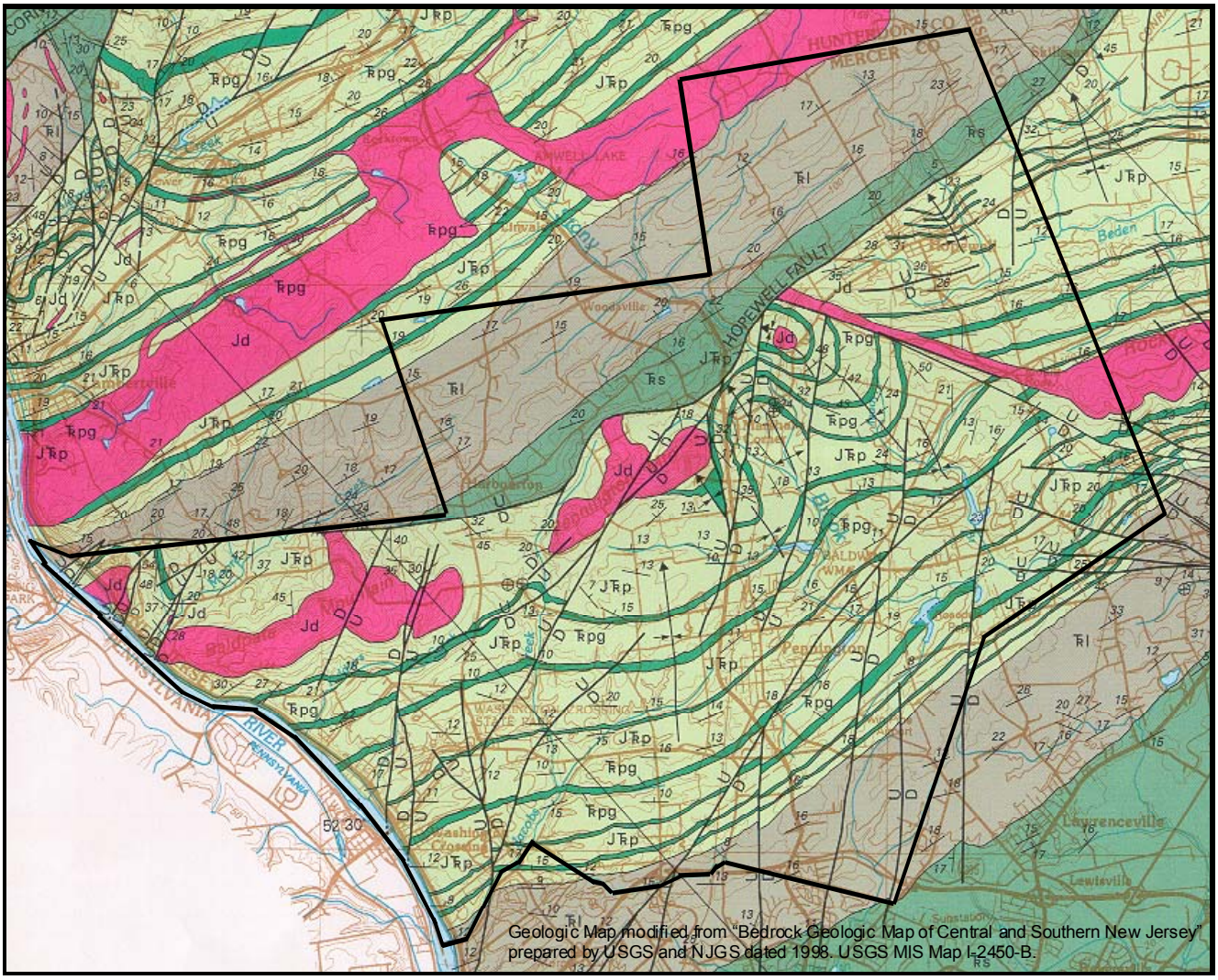
Evaluation of Groundwater Resources of Hopewell Township, Mercer County, New Jersey



Geologic Map modified from "Bedrock Geologic Map of Central and Southern New Jersey" prepared by USGS and NJGS dated 1998. USGS MIS Map I-2450-B.

Water: A Natural Renewable Resource

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EVALUATION OF GROUNDWATER RESOURCES OF HOPEWELL TOWNSHIP, MERCER COUNTY, NEW JERSEY

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EVALUATION OF GROUNDWATER RESOURCES OF HOPEWELL TOWNSHIP, MERCER COUNTY, NEW JERSEY

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EVALUATION OF GROUNDWATER RESOURCES OF HOPEWELL TOWNSHIP, MERCER COUNTY, NEW JERSEY

INTRODUCTION

The Township of Hopewell, Mercer County retained M^2 Associates in May 2000 to conduct an evaluation of the groundwater resources of the Township. The location of Mercer County in New Jersey is shown on Figure 1. The location of Hopewell Township in Mercer County is shown on Figure 2.

The Township of Hopewell requested the groundwater resource evaluation because of the following:

1. The primary source of drinking water for Township residents is groundwater. Water is supplied to these residents from individual wells completed in fractured bedrock aquifers. The hydrogeologic characteristics of these aquifers are dependent on the type of bedrock and nature of the fractures and other openings. The type of bedrock limits recharge rates, sustained yields, interference effects, groundwater quality, and contaminant removal/dilution rates.

2. Much of the Township is located within the “Northwest New Jersey Sole Source Aquifer” and a smaller portion near the Delaware River is located within the “New Jersey Coastal Plain Aquifer System” (Hoffman 1999A) as shown on Figure 3. The sole source aquifer boundaries were defined by the New Jersey Department of Environmental Protection (NJDEP) and designated by the US Environmental Protection Agency (USEPA) in the Federal Register on May 23, 1988 and June 24, 1988, respectively. The NJDEP and USEPA consider groundwater to be the single source of potable water within the designated areas and indicate that measures should be taken to protect this critical resource from potential health hazards.

3. Hopewell Township is primarily located within New Jersey Regional Water Resource Planning Area (RWRPA) 10, which is the third most populated RWRPA in the State and this population is expected to grow an additional 31 percent in the next 50 years (NJDEP 1996). Hopewell Township has some of the highest elevations within the southwestern portion of RWRPA 10 and is an upland recharge area for the Raritan River Watershed. The westernmost portions of the Township are located within RWRPA 9, which is the Trenton Delaware Tributaries. This area encompasses the portion of the Township that drains toward the Delaware River. In 1990, approximately 66.7 million gallons per day (mgd) of water was transferred from this basin.

4. The density of housing and application of surface/subsurface improvements can impact aquifers and may 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 impact current users of groundwater.

The Township of Hopewell wants to protect its valuable groundwater resources for current and future residents and businesses. Furthermore, as a recharge area for one of the most populous and fastest growing regions in the State, Hopewell Township is concerned with protecting the water resource availability and quality for downstream consumers in RWRPAs 9 and 10. The Township also wants to protect the ecological needs and receptors in the Raritan and Delaware River Watersheds.

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 Hopewell Township and neighboring municipalities in Mercer County.

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 nitrate contaminants from a septic system discharge. In addition, the recharge area requirements were evaluated to minimize potential downstream impacts to the water resources and ecology of the Raritan and Delaware River Watersheds.

GEOLOGY

PHYSIOGRAPHIC PROVINCE

Hopewell Township is bounded to the northwest by West Amwell and East Amwell Townships of Hunterdon County, to the northeast by Montgomery Township of Somerset County, to the east by Princeton Township, to the southeast by Lawrence Township and to the southwest by Ewing Township. Pennington Borough and Hopewell Borough are both located within the approximately 60.3 square miles of the Township boundaries (see Figure 2). Dimensions provided herein generally include the two Boroughs enclosed within

the Hopewell Township perimeter. Furthermore, since hydrogeologic systems are not limited to political boundaries, references to Hopewell Township in this report include the two enclosed Boroughs.

Hopewell Township is entirely located within the Piedmont Physiographic Province of New Jersey. The Physiographic Provinces of New Jersey are shown on Figure 4. The Township is generally characterized by gently rolling hills in the western portion and flatter open areas to the east. Steep slopes are found in the northern portion of Hopewell Township at Baldpate, Belle, and Pennington Mountains and along the Hopewell Fault escarpment.

Based on the U.S. Geological Survey (USGS) topographic maps depicting the Township, the highest elevation is approximately 480 feet above mean sea level and was measured on Baldpate Mountain. The lowest elevation depicted on the topographic maps is approximately 60 feet above mean sea level and is located in the southwest corner of the Township along the Delaware River. Figure 5 shows the topography of Hopewell Township.

SURFACE WATER

Hopewell Township is nearly equally divided between the Raritan River and the Delaware River Watersheds. Figure 5 shows the topographic divide between these watersheds. East of this divide, water flows to the Raritan River Basin through Stony Brook and Beden Brook. West of the topographic divide, surface water drains to the Delaware River primarily through the Moore Creek, Fiddler Creek, and Jacobs Creek systems. The three largest drainage systems in Hopewell Township are Stony Brook, Beden Brook, and Jacobs Creek.

The headwaters for several important tributaries to Stony and Beden Brooks and ultimately the Raritan River are located within Hopewell Township or immediately adjacent municipalities. These tributaries include Stony Brook Branch, Honey Branch, Baldwins Creek, and Lewis Brook. Similarly, the headwaters for Moore Creek, Fiddler Creek, Jacobs Creek and several of their tributaries are located in Hopewell Township or the adjacent West Amwell Township. Since the headwaters for these streams are located within or very near to Hopewell Township there is insufficient contributing drainage to provide a continuing source of water especially during dry weather. Therefore, the Township cannot rely on water flowing from other areas of the State to provide drinking water.

SOILS

The U.S. Department of Agriculture Soil Conservation Service has mapped soils throughout New Jersey and these maps have been included in the New Jersey Geological Survey (NJGS) Geographic Information System (GIS). Based on the Soil Conservation Service mapping, twenty-four general soil classifications have

been delineated within Hopewell Township. These general soil classifications along with areas containing standing water are shown on Figure 6.

Table 1 provides a summary of the areas encompassed by the various soil types and areas containing standing water such as ponds or lakes. The Bucks, Chalfont, Penn, Quakertown, Reaville, and Readington-Abbottstown soils underlie approximately 66 percent of the Township.

Bucks and Penn soils are generally characterized as moderate to deep, gentle to steeply sloping well-drained soils. Chalfont soils are deep, fairly flat to steeply sloping, poorly drained soils with typically, a shallow water table. Quakertown soils are characterized as deep, nearly level to moderately steep and well drained. The Reaville soils are similar to the Quakertown soils in many characteristics; however, these soils may also be poorly drained. The Readington-Abbottstown soils are deep with gentle to steep slopes and are typically underlain by a fragipan layer that slows or restricts water movement.

Doylestown, Bowmansville, Neshaminy, Lawrenceville, Klinesville, Legore, Rowland, Birdsboro, and Lehigh soils underlie approximately 30 percent of Hopewell Township. Doylestown and Bowmansville are generally considered poorly drained and Bowmansville soils are often found in areas prone to flooding. Neshaminy soils are well-drained and found in steep slope areas and are often comprised of large unweathered blocks of diabase or other igneous rock. Lawrenceville, Legore and Birdsboro are deep, well-drained soils found in gentle to strongly sloping areas. Klinesville soils are shallow, well drained materials that form gentle to steep slopes. Rowland soils are found in nearly flat areas and are poorly drained. Lehigh soils are characterized as deep, gentle to moderately sloping, well drained to poorly drained.

The Soil Conservation Service indicates that the following soils in Hopewell Township have severe limitations for the disposal of septic system effluent: Chalfont, Penn, Reaville, Abbotstown, Doylestown, Bowmansville, Lawrenceville, Klinesville, Rowland, Lehigh, Mount Lucas, and Watchung. These soils in conjunction with the areas underlain by very stony soils encompass approximately 62 percent of Hopewell Township. If soils with moderate restrictions are included, approximately 95 percent of the Township is underlain by soils with septic discharge limitations.

BEDROCK

Formations

The bedrock of Hopewell Township was deposited in a series of basins in the Triassic (208 to 245 million years ago) and Jurassic (208 to 145 million years ago). These basins were formed as a result of continental separation or rifting.

The bedrock geology of Hopewell Township is shown on Figure 7, which was primarily developed from an extensive mapping effort of the USGS and New Jersey Geological Survey (NJGS) and is shown on the “Bedrock Geologic Map of Central and Southern New Jersey” (Owens 1998).

The oldest of these deposits is primarily comprised of sand, gravel, and silt-sized sediments that are currently encountered as light-gray and yellow arkosic sandstones of the Stockton Formation. Conglomerates formed of rounded cobble, boulder, and pebble-sized fragments are often encountered near the base of the Stockton Formation. Near Harbourton, the Stockton Formation is nearly 4,000 feet in thickness.

Very fine to fine-grained silts, clays, and sands were deposited in lake-type environments over the coarse-grain sediments of the Stockton Formation. These lacustrine deposits are known as the Lockatong Formation and are primarily comprised of gray-red, dark brown, and grayish-purple mudstones, argillaceous sandstones, and siltstones. The older beds of this formation are associated with transgressive, fluvial, or lake-margin sediments. The middle portion of the formation is primarily comprised of lake-bottom materials, and the youngest portion is associated with regressive waters, mudflats, and lake-margin materials. The thickness of these deposits in the northern portion of the Township may exceed 2,900 feet and in the southern portion is approximately 2,100 feet.

Fine-grained sands, silts, and some clay were the sediments deposited in the fluvial, lake, and mudflat environments of the late Triassic-early Jurassic. These deposits were later cemented into the red-brown, brownish-purple, and grayish red shales, siltstones, silty mudstones, and argillaceous very-fine grained sandstones of the Passaic Formation. In some areas, gray lake deposits are distinct from other portions of the Passaic Formation and therefore, are mapped as a subunit of the formation. These gray lake deposits are comprised of gray to black silty mudstones, gray and greenish- to purplish-gray argillaceous siltstone, black shale, and gray argillaceous fine-grained sandstone. The thickness of the Passaic Formation near Washington Crossing Park is approximately 5,000 feet.

The youngest rocks in Hopewell Township were intruded as sheets of medium to fine-grained diabase. These dense, hard, and poorly fractured crystalline-rocks were magmas that filled fractures and other openings as the Newark Basin opened. The heat from the magmas thermally metamorphosed adjacent rocks within 1,000 feet above, below and on either side of the sill. The metamorphosed red-brown shales appear as bluish-gray hornfels and the transformed gray argillites appear as brittle, black very-fine-grained hornfels. The diabase sills are obvious throughout the Township because of their high elevation and are found beneath Sourland, Belle, Baldpate and Pennington Mountains and along Crusher Road. Beneath Baldpate Mountain, the diabase sills are estimated at approximately 1,250 feet in thickness.

Structure

Hopewell Township is transected by at least one major regional fault, the Hopewell Fault (see Figure 7). This fault, located in the northern portion of the Township, separates the older Stockton Formation from the younger Passaic Formation. Based on the USGS and NJGS mapping, the movement on this fault may have been as much as 11,700 feet to the southeast. The younger Triassic-Jurassic formations on the upper block (northern) have been eroded exposing the older Stockton Formation.

Possibly in response to some of the movement along the regional Hopewell Fault, at least 15 local fault systems were formed in Hopewell Township and these systems resulted in extensive fracturing of the bedrock. Most of these fault systems are mapped southeast of the Hopewell Fault and resulted in the fracturing of the more brittle Passaic Formation shales, mudstones, and sandstones. However, at least four local faults transect the Lockatong Formation in the southern portion of the Township and the diabase sills forming Belle, Baldpate, and Pennington Mountains have also been fractured by local faulting.

The regional Hopewell Fault and the local fault systems are classified as normal faults and are formed as a result of tension associated with the opening of the basin and separation of the continent. In some areas of the Township, horst and graben features of a rift valley are apparent.

In addition to the large-scale fractures resulting from the regional faulting, narrow vertical to near-vertical joints are encountered in the Triassic-Jurassic rocks. These joints within this portion of the State will often have one of three distinct orientations: northeast, orthogonal to the northwest, or nearly east-west. The closely spaced joints may not extend between beds of differing grain-size such as sandstones and shales. However, the bedding planes, which are shallow dipping to the northwest, are often fractured especially between layers of slightly differing grain size or deposits, and can interconnect joints between layers.

Rocks such as those encountered beneath Hopewell Township generally have no intergranular openings and therefore no primary porosity. In these types of rocks, groundwater storage and transmittal is dependent on the secondary porosity or the openings between blocks of impermeable rock. In shales, sandstones, argillites, siltstones, mudstones, and diabase sills, these openings are typically associated with fractures from faults, joints, or along bedding planes.

GROUNDWATER SYSTEMS

STORAGE AND TRANSMISSION CAPABILITY

Since groundwater in bedrock aquifer systems is stored and transmitted along fractures, joints, and bedding planes, the availability of water 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. In some areas such as near major regional faults, fractures form highly connected networks and therefore, more water can be stored and transmitted. In other areas, single or few fractures are available and there is little storage or transmission capability.

In some rock types, silts and clays are the predominant residual soil developed from weathering and in other rocks, sands, gravels, cobbles, and boulder-sized particles will result. Similar to a river or stream, smaller particles such as silts and clays can migrate more readily, stay in suspension till water velocities decrease sufficiently, and in-fill narrowed openings between fracture planes. Whereas, with sand- and gravel-sized particles, groundwater velocities are usually too slow to move the particles and the fracture is more likely to remain open. Furthermore, the sand- and gravel-sized particles will permit intergranular flow.

USGS studies indicate that weathering of the fractured rock beneath Hopewell Township 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 the yield, which is a measure of the volume of water that can be pumped from the well, may be derived from the shallow portion of the aquifer. In some formations such as the Passaic and Stockton Formations, high yielding fractures are often intersected at depths exceeding 75 feet. In other rocks such as the Lockatong and diabase, a single high yielding fracture is much less likely to be encountered.

In the Passaic and Stockton Formations, wells are usually drilled to deeper depths because of the potential to encounter additional water-bearing fractures and therefore, to increase the yield. In the Lockatong Formation and diabase, since increased yields are unlikely, wells are usually drilled to greater depths in order to store water. The well borehole serves as a subsurface storage tank. Most 6-inch diameter residential wells can store nearly 1.5 gallons per foot and this additional volume of water in storage may be necessary to meet the needs of the residence.

STOCKTON FORMATION

The Stockton Formation, which is pinched out by the Hopewell Fault to the southwest near Harbourton, encompasses approximately 3.6 square miles of the 60.3 square mile area within the borders of Hopewell Township including the two boroughs (see Figure 7). The sandstones of this formation are the primary water-bearing layers and are often confined by the less permeable siltstones (Lewis-Brown 1995).

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Widmer (1965) indicates that the Stockton Formation provides some of the highest yields within Hopewell Township. This study indicated that domestic well yields generally range from 1 to 50 gallons per minute (gpm) with a median yield of 12 gpm. Data for 271 domestic wells studied by the USGS also indicate that the Stockton Formation is one of the higher yielding aquifer systems within the Stony Brook, Beden Brook, and Jacobs Creek drainage basins. These data indicate a median yield of 15 gpm.

The data compiled by the USGS indicate that the Stockton Formation has a median specific capacity per foot of open hole of 0.00545 gpm per foot of drawdown per foot of open hole (gpm/ft/ft) (Lewis-Brown 1995). This median specific capacity per foot of open hole indicates that the Stockton Formation has a slightly higher potential to transmit water than the Passaic Formation but a significantly greater transmissivity than the Lockatong Formation and diabase beneath Hopewell Township.

The results from the USGS evaluation of median specific capacity per foot of open hole also indicate an order of magnitude decrease with depth in this measure of aquifer transmission potential. The data for shallow wells, less than 75 feet deep, have a median value of 0.03210 gpm/ft/ft. At depths greater than 300 feet, the median specific capacity declined to 0.00393 gpm/ft/ft. These results may indicate that the highly weathered shallow zones of the formation are more likely to transmit the largest percentage of water.

However, it should be noted for the Stockton Formation, that the median yields and median specific capacity values that do not account for length of open hole, were significantly higher for wells completed to depths exceeding 300 feet than for shallower wells. Furthermore, there is little change in the measure of median specific capacity per foot of open hole after a depth of 100 feet. Therefore, it is beneficial to drill wells in the Stockton Formation to depths exceeding 100 feet because additional water-bearing fractures are likely to be encountered and these fractures are likely to increase the ultimate yield of the well. Wells are typically drilled to depths exceeding 100 feet to intersect additional water-bearing fractures and/or to increase the storage capacity of the well.

In summary, the well data published by the NJGS in 1965 and the USGS in 1995 indicates that the Stockton Formation has a median yield ranging from 12 to 15 gpm. The data also indicate that the Stockton Formation has a higher capacity to transmit water than the three other bedrock formations beneath Hopewell Township. The USGS results indicate that a well completed in the Stockton Formation to a depth of approximately 300 feet is likely to encounter more water-bearing fractures and therefore, have a higher yield, than a well completed to a depth of approximately 100 feet.

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LOCKATONG FORMATION

The Lockatong Formation is encountered in the northern and southern portions of the Township. The northern band of the Lockatong Formation encompasses approximately 9.2 square miles and is located north of the Hopewell Fault (see Figure 7). The southern band encompasses approximately 2.9 square miles of Hopewell Township. The thin-bedded shales of this formation are the primary water-bearing layers and are often confined by thick-bedded siltstones (Lewis-Brown 1995).

Kasabach (1966) indicated that the Lockatong Formation is one of the poorest yielding aquifer systems in nearby Hunterdon County. Widmer (1965) indicates that thirty-three percent of the wells completed in the Lockatong Formation in Mercer County had yields of less than 4 gpm and he considered this yield "inadequate". The Mercer County study indicated that yields for Hopewell Township domestic wells completed in the Lockatong Formation generally range from 0.75 to 35 gpm with a median yield of 5 gpm. Data for 348 domestic wells studied by the USGS also indicate that the Lockatong Formation within the Stony Brook, Beden Brook, and Jacobs Creek drainage basins is poor yielding. These data indicate a median yield of 7.0 gpm, which is less than half the median yield of the Stockton Formation.

The data compiled by the USGS indicate that the Lockatong Formation has a median specific capacity per foot of open hole of 0.00115 gpm/ft/ft (Lewis-Brown 1995). This value is less than one-fourth the specific capacity per foot of open hole determined for the Stockton Formation and indicates that the Lockatong Formation has a significantly lower potential to transmit water.

The results from the USGS evaluation of median specific capacity per foot of open hole indicate that this measure of aquifer transmission potential declines two orders of magnitude with depth. The data for shallow wells, less than 75 feet deep, have a median value of 0.01240 gpm/ft/ft. At depths greater than 300 feet, the median specific capacity per foot of open hole declined to 0.00011 gpm/ft/ft. These results may indicate that the highly weathered shallow zones of the formation are more likely to transmit most of the water yielded by a well.

Unlike the Stockton Formation, the median yields and median specific capacity values do not indicate a significant increase with depth. In general, the median yields are unchanged with depth and the median specific capacities decline with depth. Based on these results, drilling wells in the Lockatong Formation to depths exceeding 150 feet is unlikely to result in increased yield. Therefore, drilling a well in this formation to a depth greater than 150 feet primarily serves to increase the volume of water within the well-bore reservoir.

In summary, the well data published by the NJGS in 1965 and the USGS in 1995 indicates that the Lockatong Formation is a poor yielding aquifer with a median

yield ranging from 5 to 7 gpm or less than half the median yield for the Stockton Formation. The data also indicate that the Lockatong Formation has a significantly lower capacity to transmit water than the Stockton Formation. The USGS results indicate that a well completed in the Lockatong Formation to a depth of approximately 300 feet is not likely to have a higher yield than a well completed to a depth of approximately 100 feet.

PASSAIC FORMATION

The Passaic Formation is primarily encountered in Hopewell Township south of the Hopewell Fault. Two small bands of the Passaic Formation are also located near the West Amwell and East Amwell borders in the northern portion of the Township.

The red-brown shales, siltstones, and sandstones of the Passaic Formation encompass approximately 35.9 square miles of Hopewell Township (see Figure 7). The gray lake deposits of this formation encompass an additional 4.1 square miles.

The fine-grained sandstones, shales, and thin-bedded siltstones of the Passaic Formation are the primary water-bearing layers. Confining units are often comprised of massive siltstone beds. In this formation, vertical to near-vertical joints interconnect water-bearing layers.

Widmer (1965) indicates that the Passaic Formation is only slightly less yielding than the Stockton Formation in Hopewell Township. This study indicated that domestic well yields generally range from 0.5 to 60 gpm with a median yield of 10 gpm. Data for 709 domestic wells within the Stony Brook, Beden Brook, and Jacobs Creek drainage basins that were compiled by the USGS indicate that the Passaic Formation has a yield similar to the Stockton Formation. These data indicate a median yield of 15 gpm for both formations.

The data compiled by the USGS indicate that the Passaic Formation has a median specific capacity per foot of open hole of 0.00393 gpm/ft/ft (Lewis-Brown 1995). This median specific capacity per foot of open hole is slightly less than the value determined for the Stockton Formation.

The results from the USGS evaluation of median specific capacity per foot of open hole indicate an order of magnitude decrease with depth. This evaluation suggests that the aquifer's ability to transmit water decreases with depth. The data for shallow wells, less than 75 feet deep, have a median specific capacity per foot of open hole of 0.01520 gpm/ft/ft. At depths greater than 300 feet, the median specific capacity declined to 0.00076 gpm/ft/ft. These results indicate that the highly weathered shallow zones of the formation are more likely to transmit the largest percentage of water.

Unlike the Stockton Formation, the median yields and median specific capacity values for the Passaic Formation are not significantly changed with depth. The results of the USGS depth analysis on median specific capacity per foot of open hole for the Passaic Formation suggests that drilling to depths greater than 200 feet is unlikely to provide significant additional yield.

In summary, the well data published by the NJGS in 1965 and the USGS in 1995 indicate that the Passaic Formation has a median yield ranging from 10 to 15 gpm. The data also indicate that the Passaic Formation has a slightly lower capacity to transmit water than the Stockton Formation but significantly greater transmissivity than the Lockatong Formation. The USGS results might suggest that a well completed in the Passaic Formation to a depth of approximately 300 feet is not likely to have a significantly greater yield than a well completed to a depth of approximately 100 feet.

DIABASE

The diabase intrusions are highly resistant to erosion and as a result are found at the highest elevations in Hopewell Township. The diabase sills are encountered beneath Sourland, Belle, Baldpate, and Pennington Mountains and along Crusher Road (see Figure 7). These diabase intrusions encompass approximately 4.6 square miles of Hopewell Township. In addition to the diabase, the hornfels produced from the metamorphism of the Passaic Formation host rock are often found within 1,000 feet of the diabase sills.

The diabase and the surrounding hornfels combine to form very poor aquifer systems. Except where transected by a local fault, these units have few fractures, which are often separated by distances of more than 1 foot and in outcrop, these fractures are often not vertically extensive.

Kasabach (1966) indicated that the diabase was the "…poorest source of water…" in nearby Hunterdon County. Widmer (1965) indicated that wells in the diabase of Mercer County had poor yields. His study indicated that yields for Hopewell Township domestic wells completed in the diabase generally range from 0.5 to 27 gpm with a median yield of 6 gpm. Data for 97 domestic wells within the Stony Brook, Beden Brook, and Jacobs Creek drainage basins evaluated by the USGS indicate that the diabase sills have poor yields. These data indicate a median yield of 5.0 gpm for the diabase and 6.0 gpm for the hornfels.

The data compiled by the USGS indicate that the diabase has a median specific capacity per foot of open hole of 0.00143 gpm/ft/ft (Lewis-Brown 1995). This value is equivalent to approximately 26 percent of the specific capacity per foot of open hole determined for the Stockton Formation and indicates that the diabase has a transmissivity similar to the Lockatong Formation. The median specific

capacity per foot of open hole for 49 wells completed in hornfels was 0.00097 gpm/ft/ft. These values might be significantly lower if data from wells with little or no usable yield that were drilled but not placed in service or tested, were included in the USGS data. The USGS database was limited to wells placed in service. Discussions with local well drillers indicate that wells have been drilled in the diabase with little or no usable yield and therefore, not used and placed in service.

The results from the USGS evaluation of median specific capacity per foot of open hole indicate that this measure of aquifer transmission potential declines nearly two orders of magnitude with depth. The data for shallow wells, less than 75 feet deep, have a median value of 0.00906 gpm/ft/ft. At depths greater than 126 feet, the median specific capacity per foot of open hole declined to 0.00023 gpm/ft/ft. These results indicate that nearly all water from a diabase well is derived in shallow bedrock where weathering has enhanced fracture openings. Furthermore, these data indicate that unless a well is completed in a weathered portion of the diabase sill, that there may be insufficient water available. Based on these results, drilling of wells in the diabase to depths exceeding 125 feet is unlikely to provide additional water to the well.

In summary, the well data published by the NJGS in 1965 and the USGS in 1995 indicate that the diabase and surrounding hornfels is a poor yielding aquifer with a median yield ranging from 5 to 6 gpm, which is less than half the median yield for the Stockton and Passaic Formations. The data also indicate that the diabase has a significantly lower capacity to transmit water at depth. The USGS results indicate that wells completed to depths exceeding 125 feet are unlikely to intersect additional water-bearing fractures.

HYDROGEOLOGIC ZONES

Based on the USGS and NJGS studies of well yields and specific capacities, Hopewell Township can be subdivided into a minimum of two distinct hydrogeologic zones. Figure 8 shows these zones.

The first zone encompasses approximately 43.6 square miles or 72 percent of the Township. This zone includes the Stockton Formation and the Passaic Formation, which both have median yields ranging from 10 to 15 gpm. Furthermore, wells in these bedrock formations may intersect additional water-bearing fractures with depth and are not dependent on shallow highly weathered zones to transmit and store groundwater. Based on the median specific capacities reported for these formations by the USGS, the median aquifer transmissivity within this zone is estimated at approximately 950 gallons per day per foot (gpd/ft).

The second zone includes the poor aquifers encountered within the Lockatong Formation and diabase intrusions. Since the hornfels surrounding the diabase intrusions are also poor aquifers, the rocks within 1,000-feet of the diabase intrusions are included in this second hydrogeologic zone. This zone encompasses approximately 16.7 square miles or 28 percent of the Township. Median yields in this zone are likely to range from 5 to 7 gpm and drilling to depths exceeding 125 feet below ground surface is unlikely to result in the intersection of additional water-bearing fractures. Based on the median specific capacities reported for the Lockatong Formation and diabase by the USGS, the median aquifer transmissivity within this zone is estimated at approximately 225 gallons per day per foot (gpd/ft). The estimated transmissivity, which is a measure of the aquifer's ability to transmit water, of the Lockatong/Diabase Zone is approximately one-fourth the estimated transmissivity of the Stockton/Passaic Zone.

AQUIFER RECHARGE

Water Balance

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, groundwater recharge, and surface-water runoff are determined by indirect methods. The water balance can be used to evaluate the assumptions made in estimating these indirect parameters. Since the equation is a balance, the inflows must equal the outflows. This balance allows for improvements in the outflow parameter estimations.

Bedrock aquifers are replenished by incident precipitation that infiltrates through soils into fractures and other openings in the rock. Rough estimates have been developed that 10 to 25 percent of incident precipitation infiltrates through soils and recharges groundwater in fractured bedrock aquifers (Kasabach 1966).

Based on historical precipitation measurements collected by the National Climatic Data Center and as shown in the 1996 Statewide Water Supply Plan (NJDEP 1996), Hopewell Township receives approximately 45.1 inches of precipitation per year during a year of normal precipitation. In general, this precipitation is evenly divided throughout the year. As reported herein, normal precipitation is equal to median precipitation as measured over several decades and determined by the National Oceanic and Atmospheric Administration (NOAA). Median or normal precipitation means that during the period of recording, precipitation exceeded 45.1 inches in 50 percent of the years and was less than 45.1 inches in 50 percent of the years.

Using the water balance of the hydrologic cycle, precipitation must equal the sum of groundwater recharge, evapotranspiration, and surface runoff. If an area has one or more large water bodies, direct precipitation to this body and the resulting evaporation from this body, may also be included in the water balance. The water balance is often described by the following equation:

$$P = GWR + SWR + ET + (DP-E)$$

Where:

P = Precipitation
GWR = Groundwater Recharge
SWR = Surface-Water Runoff
ET = Evapotranspiration
DP = Direct Precipitation to large surface water body
E = Evaporation from large surface water body

This equation can be rearranged to evaluate the groundwater recharge parameter.

Surface-Water Runoff

Surface-water runoff is dependent on the types and density of vegetation, surface area of impervious materials, 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 and/or 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 and includes water that infiltrates soils to a shallow depth and then follows an impermeable surface such as a clay layer or bedrock surface, to a discharge point. Interflow should not be included with groundwater recharge because this water is quickly discharged to a stream and does not infiltrate to an aquifer system.

As part of a detailed evaluation of groundwater conditions within the Stony Brook, Beden Brook, and Jacobs Creek drainage basins, the USGS evaluated surface-water runoff. Based on this evaluation, surface-water runoff in the Stony Brook basin is approximately 11.8 inches per year or 26 percent of annual precipitation in Hopewell Township (Lewis-Brown 1995). In areas underlain by diabase, the USGS determined that surface-water runoff is approximately 15.9 inches per year or approximately 35 percent of annual normal precipitation (Lewis-Brown 1995).

Water: A Natural Renewable Resource

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 is usually negligible. Evapotranspiration is the largest component of the water balance and may account for approximately 55 percent of precipitation. The USGS estimated that the average evapotranspiration in the Little Lehigh Creek drainage basin, which is located approximately 40 miles northwest of Hopewell Township, between 1975 and 1984 was 24.6 inches per year or approximately 56 percent of annual precipitation.

As part of the Stony Brook, Beden Brook, and Jacobs Creek evaluation, the USGS developed an evapotranspiration estimate of 27.28 inches per year. This estimate is a measure of the potential evapotranspiration for the Hopewell area and was deemed too high by this agency because the estimate did not consider land use, topography, and soil type. Another reason this estimate is considered high is that the method used to calculate the value assumes that there is a constant source of water in soils for transpiration and/or evaporation. During summer months between precipitation events, water is not always available for evapotranspiration.

Based on the USGS Lehigh Valley study, evapotranspiration in Hopewell Township should be approximately 25.3 inches per year. This value is slightly lower than the potential evapotranspiration value calculated in the Stony Brook, Beden Brook, and Jacobs Creek study, which assumed that water was always available for recycling to the atmosphere.

Direct Precipitation/Evaporation

Direct precipitation is equal to the amount of precipitation that falls onto surface-water bodies such as streams, ponds, and/or lakes and evaporation in the above equation is equal to the amount of water that is lost to the atmosphere from these bodies. Except in areas where surface-water bodies comprise a large percentage of the land surface, these value are typically very small and are therefore, included in the other parameters of the water-balance equation. Based on the US Soil Conservation Service mapping, standing water in ponds and lakes encompasses less than 0.3 percent of Hopewell Township (see Table 1). Therefore, direct precipitation and evaporation are likely to account for a very small percentage of precipitation within the entire Township and are therefore, considered negligible in the above water balance equation.

Water: A Natural Renewable Resource

Groundwater

Based on the values of surface-water runoff and evapotranspiration, the water-balance equation indicates that groundwater recharge to the Stockton/Passaic Zone and Lockatong/Diabase Zone should be approximately 8 and 4 inches per year, respectively. The water balance indicates that recharge to the sandstones and shales is twice the rate to the argillites and igneous rocks.

MA7CD10

During periods of dry weather, the flow of water in a stream is a result of groundwater discharging to that stream. This discharge of groundwater is referred to as baseflow. Since groundwater recharge is generally considered equal to groundwater discharge, the baseflow in a stream equals groundwater recharge.

The NJDEP considers baseflow as the primary criterion in managing the water resources of New Jersey (NJDEP 1996). The most common method suggested by the NJDEP is the 7-day, 10-year (MA7CD10) method, which is referred to by the USGS as the 7Q10 method. With this method, the lowest streamflow over 7 consecutive days of a 10-year period is used. This method is considered conservative because the lowest flow occurs during periods of extensive dry weather. However, the method provides the best approach for ensuring adequate and safe water supplies during extensive periods of drought. The NJDEP recommends that water supplies should be capable of sustaining withdrawals without adverse impacts during dry weather conditions similar to the “Drought of Record”. The “Drought of Record” occurred in the mid-1960’s.

M^2 Associates obtained streamflow data from the USGS in an attempt to determine conservative recharge rates to the aquifers beneath the Township. Seventeen of the twenty-two streams with long-term monitoring records in the USGS database have calculated MA7CD10 values of 0.00 cubic feet per second indicating no baseflow. Since groundwater discharge equals groundwater recharge, no baseflow would suggest that the aquifers are not receiving recharge. Water-level records for wells within the Township indicate that the aquifers are recharged.

Hopewell Township is at the headwaters for the major streams flowing through the Township and the drainage basins upstream of the measuring stations apparently do not have sufficient size to adequately capture discharge within the Triassic-Jurassic basin. At higher elevations underlain by the Passaic Formation, some water-level data from wells indicate a downward component to groundwater flow; whereas at lower elevations, the data indicate groundwater is discharging. Without sufficient sized basins to capture all discharge within the

areas underlain by the Passaic Formation, the MA7CD10 method cannot be used to conservatively evaluate recharge for this formation.

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 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 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 soils in a bedrock environment but unless it encounters a fracture or opening in the rock, this water will discharge to a stream or seep as interflow. If the water does not recharge an aquifer, residents of Hopewell 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. Since this method calculates soil recharge and a percentage of the water is most likely lost prior to infiltrating an aquifer, the method is assumed to provide high estimates of groundwater recharge.

Throughout this M^2 Associates report and as typically referenced in USGS reports and hydrogeologic texts, the term groundwater recharge refers to water that infiltrates to an aquifer system. 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

Table 2 summarizes soil recharge rates calculated with NJGS method using a Microsoft Excel Workbook (Hoffman 1999B) for the soils encountered in Hopewell Township. The soil estimates were calculated assuming 0.5 to 1-acre lots, which is one of twelve land use types provided in the NJGS method. The median value of the soil recharge rates calculated for the twelve land use types

was approximately equal to the value calculated for the 0.5 to 1-acre lots. Therefore, it has been assumed that the soil recharge rates summarized in Table 2 are approximately equal to the median rates for the various land uses in Hopewell Township.

The NJGS method cannot be used to calculate soil recharge rates for wetland or hydric soils such as Doylestown and Bowmansville or for areas primarily comprised of rock outcroppings such as those labeled Watchung or Very Stony Land Watchung. The method also cannot be used to calculate soil recharge rates for disturbed areas such as Cut and Fill Land or Pits.

The Legore soils are primarily found in areas underlain by diabase and the Chalfont soils are in areas underlain by the Lockatong argillites. The NJGS method indicates that these soil types have soil recharge rates of 9.9 and 9.0 inches per year, respectively. Bucks soils are encountered primarily in areas underlain by the Stockton and Passaic Formations and have a soil recharge rate calculated with the NJGS method of 9.8 inches per year.

The water balance does not support equivalent recharge to the Lockatong/Diabase Zone and Stockton/Passaic Zone aquifer systems. Furthermore, empirical data such as baseflow in streams does not support equivalent recharge to the Lockatong and diabase rocks in comparison to the Passaic and Stockton rocks. The NJGS model does not account for steep slopes, which are encountered within areas underlain by the diabase, and these slopes increase the runoff potential and decrease the infiltration potential. Since the NJGS made the clear distinction that the method does not calculate aquifer recharge, it should not be used to evaluate groundwater resources in Hopewell Township.

USGS Studies

Baseflow Studies

The USGS has conducted two extensive studies of the Stony Brook, Beden Brook, and Jacobs Creek drainage basins (Jacobsen 1993 and Lewis-Brown 1995). Data from the Jacobsen (1993) study were used to prepare a computer model during the Lewis-Brown (1995) study. This model was calibrated to simulate hydrogeologic conditions within the three basins.

As part of the early study, baseflow rates were determined at several locations along the main branches and within some of the tributaries for these streams. Baseflow in streams should be measured during periods of dry weather when surface runoff and interflow are not contributing any water to the stream channel.

Under these dry conditions, the only flow in the stream is derived from groundwater and therefore, is a measure of groundwater discharge. Since an aquifer should be a balanced natural system with inflow equal to outflow, the rate of groundwater discharge is considered to equal the rate of groundwater recharge. Therefore, baseflow/groundwater discharge is generally assumed equal to groundwater recharge.

As part of the second study, the USGS used the baseflow data from the first study to initiate calibration of a computer model simulating the hydrogeologic conditions of the three basins. The baseflow data reported in the 1993 study indicate average areal recharge rates of 8.06 inches per year for the Stony Brook basin, 10.2 inches per year for the Beden Brook basin, and 10.3 inches per year for the Jacobs Creek basin. These rates are considered high since they were determined during a year of above normal precipitation and streamflow rates. Furthermore, they appeared to have been measured during the early portion of stream recessions and are likely to include interflow discharges.

Average Areal Recharge

Further study with the USGS computer model (Lewis-Brown 1995) of the Stony Brook, Beden Brook, and Jacobs Creek hydrogeologic conditions indicates an average recharge rate of 8.58 inches per year for the entire area encompassed by these three drainage basins. The computer model was used to better define recharge rates to the Stony Brook, Beden Brook, and Jacobs Creek basins and indicated that these rates are approximately 8.25, 9.11, and 8.11 inches per year, respectively. These rates are averages over the entire basins, which are underlain by varying percentages of the four Triassic-Jurassic rock types; however, the Passaic Formation is the predominant rock type beneath all three basins. All recharge rates determined with the USGS model were based on the assumption of normal-year precipitation, which is approximately 45.1 inches.

Diabase Recharge

As part of the Stony Brook, Beden Brook, Jacobs Creek study, the USGS determined that the recharge rate to the diabase is approximately 4.11 inches per year. However, this recharge rate is approximately one inch greater than the average recharge rate determined from the baseflow data summarized in the 1993 and 1995 USGS reports for streams underlain by diabase. The baseflow data indicate a recharge rate of approximately 3.15 inches per year. Since these baseflow measurements were made during a year of above normal precipitation and streamflow, the recharge estimate of 3.15 inches per year is most likely high. Although the recharge rate to the diabase is most likely less than 3.15 inches per year, apparently there are no long-term streamflow data available to refine this measurement. The report on groundwater management for Sourland Mountain

indicates recharge to the diabase ranges from 0.84 to 1.7 inches per year (Hordon 1984).

The USGS model indicates that the steep slopes and poorly fractured diabase result in increased surface runoff and decreased recharge. The USGS model did not determine a recharge rate specific to the Lockatong Formation, Passaic Formation, or Stockton Formation but determined a combined rate of 8.20 inches per year for these sedimentary formations.

Baseflow data from the earlier USGS study (Jacobsen 1993) indicate that some of the increased runoff from the mountains underlain by diabase infiltrates the Passaic Formation at lower elevations. The computer model suggests that the 4.09 inches per year recharge difference between the diabase and sedimentary rocks entered the aquifer system of the Passaic Formation topographically downgradient of the diabase-hornfels contact with the Passaic Formation.

The computer simulation and baseflow data suggested that there was no net loss or gain of recharge across the entire basin as a result of diabase within the basin. The model indicated that if the diabase were replaced with the sedimentary formations, the recharge rate would be approximately 8.20 inches per year across the basins. Since the model is balanced across the entire basin, it does not appear sensitive to changes in recharge to the diabase.

The USGS model and data indicate that precipitation that cannot infiltrate the poorly fractured diabase runs overland and infiltrates the Passaic Formation at lower elevations. Although there is not net gain or loss over the entire drainage basin, the diabase rocks have a poor recharge rate and this characteristic must be considered when evaluating site-specific hydrogeologic conditions in areas underlain by diabase and/or hornfels.

Since the baseflow data were collected during period of above normal streamflow and precipitation and appear to include interflow, recharge to the diabase most likely is less than 3.15 inches per year. Based on the computer model, recharge to the diabase may be as high as 4.11 inches per year. The computer model does not appear sensitive to the diabase recharge rate and a lower rate would not have altered the model results since the model was balanced over the entire drainage systems.

Recharge Balance

In balancing the recharge parameters of the computer model, the USGS noted a difference between the average area-wide recharge rate of 8.58 inches per year and the rate of 8.20 inches per year associated with the rock-types encountered in the basins. The difference between the area-wide recharge rate and the rock-type rate indicates that additional water is capable of entering the aquifer system.

Water: A Natural Renewable Resource

Along the eastern section of the Hopewell Fault and downgradient of the fault escarpment, the USGS determined from their model that groundwater was recharged at a rate of approximately 95 inches per year. In this area near Hopewell Borough and almost entirely within the Beden Brook basin, the USGS used the analogy of a roof and gutter system to describe flow from northwest of the fault into the fault. Water runs off the steep escarpment northwest of the fault into the highly fractured fault zone accounting for approximately 64.4 inches of recharge. An additional 31 inches of recharge is provided by direct precipitation to the fault zone. The USGS concluded that the fault zone was highly fractured and therefore water infiltrated quickly with little loss to evapotranspiration. This increased recharge along the fault zone most likely accounts for the one-inch of additional recharge to the Beden Brook basin (9.11 inches per year) in comparison to the Stony Brook (8.25 inches per year) and Jacobs Creek basins (8.11 inches per year).

As part of the computer model, the USGS simulated the Hopewell Fault within the Township perimeter as a zone approximately 22,000 feet in length by 500 feet in width. Although the USGS limited the width to 500 feet, given the potential extent of movement along this fault, the zone of highly fractured rock is likely to be wider than 500 feet in some areas and narrower than 500 feet in others. Geomorphic features such as topography, geology, stream patterns, wetlands, and linear fracture traces may be useful in determining the width of the zone of extensive fracturing and high recharge.

Along the western portion of the fault and primarily within the Stony Brook and Jacobs Creek basins, the USGS model did not indicate a significant increase in recharge to the Hopewell Fault. Stony Brook and Jacobs Creek drain the fault zone and the escarpment has a lower topographic relief, which would result in less runoff. Further west and beyond the boundaries of the USGS studies in Hopewell Township, a portion of Moore Creek flows parallel to the fault and appears to drain the fault zone. Therefore, recharge is unlikely to be as significantly increased along the westernmost portion of the Hopewell Fault as it is along the eastern portion. However, the fault in the western portion of the Township encompasses an area of highly fractured rock and is likely to be a zone of increased recharge.

Based on the USGS model, the Hopewell Fault zone within the Beden Brook basin and Hopewell Township is approximately 14,200 feet in length by 500 feet in width and may be recharged with more than 420 million gallons per year. The fault zone may account for nearly 6 percent of the recharge to the 60 square mile area encompassed by the Township perimeter. Based on the model dimensions, this narrow fault zone encompasses less than 0.4 percent of the land area within these same boundaries. The USGS model indicates that the Hopewell Fault within the Beden Brook basin is a valuable recharge zone.

The Hopewell Fault, primarily within the Beden Brook basin, may warrant protection from potential sources of contamination and alterations that could limit recharge. Given the high permeability of the fault zone as indicated by the high rate of recharge, spills or discharges of contaminants could quickly migrate into the aquifer system of this basin and have adverse long-term impacts on water quality. Water infiltrating along this fault zone is not only a critical resource to Hopewell Township and Hopewell Borough but also to downstream portions of the basin in Somerset County.

Summary

The USGS computer model of the Stony Brook, Beden Brook, and Jacobs Creek basins indicate recharge rates to diabase rocks and sedimentary rocks of 4.11 and 8.20 inches per year. However, the model is balanced for each entire basin and does not appear sensitive to changes in recharge to the diabase. Baseflow data summarized in both USGS (1993 and 1995) studies indicate that recharge to the diabase is approximately 3.15 inches per year; however this estimate is most likely high because the baseflow measurements were made during a year of above normal precipitation and streamflow. Although the recharge rate of 3.15 inches per year is likely a high estimate, without further detailed streamflow measurements necessary for refinement, this apparently is the best currently available estimate for Hopewell Township. The diabase rocks have a poor recharge rate and this characteristic must be considered when evaluating site-specific hydrogeologic conditions in areas underlain by diabase and associated hornfels.

The computer model of the hydrogeologic system within these basins indicates that the Hopewell Fault primarily within the Beden Brook basin is a critical water resource that provides a significant increase in recharge to the Passaic Formation aquifer downgradient of the fault zone. This fault zone and the upgradient escarpment warrant protection to prevent impacts to water quality or quantity downstream, especially in the Beden Brook basin.

Lockatong Formation

The USGS computer model of the Stony Brook, Beden Brook, and Jacobs Creek basins determined recharge rates for areas underlain by diabase and the Triassic-Jurassic sedimentary rocks. The USGS model of these basins did not differentiate recharge rates by specific geologic formation.

In the USGS 1993 study of the Stony Brook, Beden Brook, and Jacobs Creek basins, streamflow measurements from two stations on Ewing Creek are provided. The portion of Ewing Creek upstream of these stations is underlain by Lockatong Formation and the baseflow measurements indicate a recharge range from 3.5 to 13.6 inches per year, with an average of 7.85 inches per year.

Water: A Natural Renewable Resource

Streamflow data provided to M^2 Associates by the USGS indicates that the November 1987 baseflow measurements reported in the 1993 USGS studies were nearly double the median flow in this creek and are not reflective of baseflow conditions. The data provided in the 1993 reports suggests that the baseflow measurements made in August and November 1987 were obtained during the early portion of stream recessions and may have been biased by continuing interflow discharges. In addition, 1987 was a year of above normal precipitation and flow in streams was higher than normal (Jacobsen 1993). Therefore, the baseflow rates reported for August and November 1987 in the 1993 USGS report are most likely higher than normal and the recharge rates determined from these data are also higher than suggested by measurements made over a longer term.

Long term Ewing Creek data obtained from the USGS database of streamflow measurements indicate that within this 1.24 square mile basin underlain by Lockatong Formation, the flow rate exceeded 50 percent of the time is approximately 0.58 cubic feet per second. The flow rate exceeded 75 percent of the time is 0.14 cubic feet per second. These results indicate that recharge to the aquifer should range from approximately 1.5 to 6.3 inches per year. Recharge to the Lockatong Formation is most likely within the lower end of this range since the 75 percent flow exceedence is less likely to include significant interflow discharges and is usually reflective of dryer weather conditions.

Hordon (1984, 1987, and 1995) has conducted several studies of groundwater recharge to the Lockatong Formation. Hordon summarized various streamflow analyses conducted to determine recharge to the Lockatong Formation. Based on these analyses, Hordon summarized a recharge range from approximately 52,000 to 319,000 gallons per day per square mile (gpd/mi^2). The lower end of this range was determined from data for streams with only partial records and the upper end of the range was for streams that were not primarily underlain by Lockatong Formation. Hordon concludes that a reasonable estimate of recharge to the Lockatong Formation during periods of normal precipitation generally ranges from 100,000 to 200,000 gpd/mi^2, which is equivalent to 2.1 to 4.2 inches per year.

In addition to the summary of recharge rates, Hordon used the Posten method to evaluate recharge in the Walnut Creek basin near Flemington. This basin is nearly entirely underlain by Lockatong Formation. Based on this analysis, Hordon determined a recharge rate of 92,000 gpd/mi^2, which is equivalent to 1.9 inches per year. This analysis and the other data compiled by Hordon indicate that the Lockatong Formation is poorly recharged.

Similar to the diabase, a recharge rate of approximately 3.15 inches per year is most likely a high estimate but is within the range suggested by the USGS streamflow data. A recharge rate of 3.15 inches per year to the

Lockatong/diabase zone in Hopewell Township is likely a high estimate for years of normal precipitation. However, without collecting detailed baseflow measurements from streams within this zone, this estimate may be the best currently available estimate for the Township.

Passaic and Stockton Formations

The USGS model (Lewis-Brown 1995) of the Stony Brook, Beden Brook, and Jacobs Creek basins indicates a recharge rate to the Triassic-Jurassic sedimentary rocks of 8.20 inches per year. The recharge rate to the Jacobs Creek basin was approximately 8.11 inches per year and based on Owens (1998); this basin is almost entirely underlain by the Passaic and Stockton Formations. The Lockatong Formation or diabase underlies less than one square mile of the 13.3 square mile basin.

In a separate study with different authors and data, the USGS calculated a recharge rate of approximately 8.3 inches per year using baseflow data and a computer model of the hydrogeologic system beneath Lansdale, Pennsylvania (Senior 1999). Lansdale, Pennsylvania is located approximately 25 miles west-southwest of Hopewell Township and based on Lyttle (1987), the model area is almost entirely underlain by the Passaic Formation. This second USGS study appears to independently confirm the recharge rates to the Passaic Formation and a recharge rate of 8.20 inches per year for the Passaic Formation beneath Hopewell Township is reasonable for years of normal precipitation.

Studies have shown that the Stockton Formation may have a recharge rate of approximately 0.75 inches per year greater than the recharge rate for the Passaic Formation; however these studies have generally indicated recharge rates lower than 8.20 inches per year. The Stockton Formation underlies less than 6 percent of Hopewell Township and forms much of the escarpment to the Hopewell Fault in the Beden Brook basin. Additional recharge to the Stockton Formation is likely to be included in the significantly greater recharge to the Hopewell Fault. Given the limited area of the Stockton Formation and the inclusion of much of this formation within the Hopewell Fault zone, a recharge rate of 8.20 inches per year for the remaining portions of the Stockton Formation beneath Hopewell Township appears reasonable.

Water: A Natural Renewable Resource

Summary

Reasonable recharge rates to the Triassic-Jurassic rocks and the Hopewell Fault beneath Hopewell Township were evaluated and are summarized below:

Rock Type	Percent of Hopewell Township Underlain by Rock Type	Normal (Median) Year Recharge Rate (inches per year)	Normal (Median) Year Recharge Rate (gallons per day per acre)	Annual Recharge to Hopewell Township (millions of gallons)
Stockton	5.9	8.20	610	509.7
Lockatong	20.1	3.15	235	664.1
Passaic	65.9	8.20	610	5,665.6
Diabase	7.7	3.15	235	254.8
Hopewell Fault	0.4	95	7065	420.4

These recharge rates are similar to the initial approximations made with the water balance. The Hopewell Fault apparently is a significant sink for groundwater recharge, especially to the Beden Brook basin. Since the Hopewell Fault is a critical recharge zone for the aquifer systems south of the fault, the fault and associated escarpment may warrant distinction from the two hydrogeologic zones of the Township.

WATER SUPPLY

DEMAND

Current

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. 7:10-3.32 and 7:10-12.6 and the Hopewell Township Board of Health Ordinance BH 86-1 both indicate that the average daily demand is 100 gallons per day per person. The per capita demand suggested by the New Jersey Administrative Code and Township ordinance appears to be a reasonable mid-range estimate of daily personal water demands.

Based on US Census data, Hopewell Township is occupied by an estimated 15,600 people. Approximately 3,500 of these people live within a development near the southeast corner of the Township and receive water from Elizabethtown Water Company and are not dependent on the water resources of Hopewell Township. Based on the population of the Township relying on the water resources and the average daily demand indicated in N.J.A.C. 7:10, Hopewell residents currently consume nearly 37 million gallons per month of water.

Within the perimeter boundary of Hopewell Township, several municipal agencies and private corporations have NJDEP Water Allocation permits to divert groundwater. These include Bristol-Myers Squibb, Hopewell Borough Water Department, Hopewell Valley Golf Club, Hopewell Township, Lucent Technologies, Pennington Borough, Pennington School, and Penwell Holdings. In addition to these water allocation permits, one farm, the organic farm at the Stony Brook-Millstone Watershed Association site, has an agricultural registration permitting pumping of up to 3 million gallons per month for irrigation. Table 3 summarizes the maximum monthly groundwater diversions for each of these permits and is based on data provided by the NJDEP-Bureau of Water Allocation on September 13, 2000. The water allocation permits and residential self-supplied use indicate that approximately 83.2 million gallons of groundwater could be used on a monthly basis within the Hopewell Township perimeter.

Future

New construction in Hopewell Township is primarily comprised of 4 to 5 bedroom single-family homes. Recent demographic analyses conducted on behalf of subdivision applicants to the Township Planning Board indicate that future homes are likely to be occupied by 4 to 5 persons per unit and that the median dwelling unit density will be 4.2 persons.

Based on the 100 gallons per day per capita use rate indicated in the New Jersey Administrative Code and the anticipated future dwelling unit density of 4.2 persons, the average future daily demand per residence will be approximately 420 gallons per day. This use rate includes potable water usage and does not include excess water use for items such as irrigation systems and/or swimming pools.

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." The

"Drought of Record" occurred in the mid-1960's 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 this 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 impact groundwater recharge and to a lesser degree, surface-water runoff. Evapotranspiration is negligible in winter months so this parameter is unaffected by precipitation shortfalls during cold weather. During summer months, precipitation shortages adversely impact 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 significantly affected by a warm weather drought. Droughts that occur over several years such as the "Drought of Record" adversely impact all water-balance parameters.

Based on stream discharge measurements compiled by the USGS in Stony Brook from October 1, 1953 to September 30, 1998, the median flow rate as measured in Princeton is 22 cubic feet per second. For the years 1962 through 1966, the median flow rate was 11 cubic feet per second or 50 percent of normal flow for the period of record. These streamflow data suggest that if prolonged drought conditions equally affect all water-balance parameters, that groundwater recharge may be reduced 50 percent.

Using this same streamflow data, the NJGS estimated baseflow for the periods 1954 to 1989 and 1960 to 1966 (Canace 1992). From 1954 to 1989, baseflow ranged from 5.12 to 7.63 inches per year. During the period of 1960 to 1966, baseflow ranged from 4.20 to 6.26 inches per year. The 1960 to 1966 baseflow estimates are approximately 82 percent of the long-term estimates. Although these estimates are below normal-year recharge, they may be slightly high because data from 1960 and 1961 were included. Precipitation in 1960 and 1961 slightly exceeded normal precipitation and therefore, is not a period of drought. Given the precipitation data and using the NJGS baseflow estimates, it could be assumed that a drought similar to the "Drought of Record" would likely result in precipitation rates and groundwater recharge rates equal to approximately 82 percent of normal-year rates.

Reasonable arguments could be made using the Stony Brook at Princeton streamflow data that groundwater recharge during a prolonged drought is equal to 50 percent or 82 percent of normal-year recharge. However, recharge rates based on these percentages will most likely result in either overly conservative or

non-existent margins of safety. Although groundwater in storage within an aquifer could be used to buffer a short-term drought, this limited resource could be quickly consumed resulting in adverse long-term impacts to the aquifer system in a prolonged drought. Therefore, a reasonable margin of safety is necessary to ensure adequate water supplies in a repeat of the “Drought of Record”.

In 1965, the lowest precipitation in the last 100 years was recorded. During this year, precipitation was equal to approximately 66 percent of normal precipitation. Assuming drought groundwater recharge is equal to 66 percent of normal-year recharge will provide a reasonable margin of safety and ensure adequate water availability during a prolonged drought.

Planning Threshold

To ensure that water is available during all weather conditions for human consumption as well as ecosystems dependent on groundwater discharges without creating undesirable effects, the NJDEP established the “Planning Threshold”. The NJDEP determined that the Planning Threshold should equal 20 percent of aquifer recharge. The threshold proposes to limit human consumption of water within a watershed/basin to 20 percent of recharge and establishes the dependable yield at this level.

Summarized below are the normal precipitation year recharge rates, severe drought recharge rates, and the dependable yields as established with the Planning Threshold for the two hydrogeologic zones.

Hydrogeologic Zone	Normal-Year Recharge Rate (gallons per day per acre)	Severe Drought Recharge Rate (gallons per day per acre)	Dependable Yield (gallons per day per acre)
Stockton/ Passaic	610	410	82
Lockatong/ Diabase	235	160	32

AVAILABLE DEPENDABLE YIELD

Based on the areas of hydrogeologic zones and Hopewell Fault, and the severe drought recharge rates, during a “Drought of Record” Hopewell Township will receive approximately 5,056.6 million gallons of recharge per year. Applying the “Planning Threshold” indicates that the dependable yield for the Township is

approximately 84.3 million gallons per month. As indicated above, current residential self-supply and existing NJDEP Water Allocation Permits/Agricultural Registrations could result in consumption of approximately 83.2 million gallons per month. Hopewell Township is nearing the dependable yield for the area encompassed within the Township perimeter and continued demands could adversely impact stream ecosystems, downstream consumers, or current residents of the Township and/or Boroughs.

Hopewell Township is located at or very near the headwaters for all surface-water streams flowing within its borders. As a result, the Township and the two enclosed Boroughs cannot rely on upstream sources or conservation measures to ensure a long-term adequate water supply. If the Township and Boroughs are to be self sustained without adverse impacts to existing ecosystems during a recurrence of the "Drought of Record", it may be necessary to institute measures to limit additional water use and to increase conservation of groundwater within the Township perimeter. Since the Township and Boroughs are apparently nearing the long-term dependable yield limit, adverse impacts to groundwater quality from accidental or purposeful discharges of contaminants can further reduce the margin of safety between current demand and long-term dependable yield.

RECHARGE AREAS

Current demographics indicate a density of 3 persons per dwelling unit for Hopewell Township. This current density includes condominiums, apartments, townhouses and other smaller dwellings that are usually occupied by two or fewer people. Based on recently proposed subdivision plans presented to the Township Planning Board, future residences served by on-site wells and septic systems within the Township will be primarily single-family 4 to 5 bedroom homes and will have a density of 4.2 persons per dwelling unit.

Current demographics indicate that each existing dwelling unit consumes approximately 300 gallons per day. Given the dependable yields of the hydrogeologic zones, each of these existing dwelling units requires a recharge area of 3.7 acres for the Stockton/Passaic Zone and 9.4 acres for the Lockatong/Diabase Zone to ensure an adequate long-term safe yield. In areas of the Township with existing lot sizes smaller than these recharge areas, it may be necessary to preserve or protect upstream open areas within the same watershed to ensure sufficient water infiltrates the aquifer to support the existing demands. Even in areas where the existing lot sizes are equal to these recharge areas, it may be necessary to protect upstream open areas to balance portions of the existing lots covered with impervious materials.

Based on the dependable yields for the hydrogeologic zones, a 4.2 person dwelling unit using approximately 420 gallons of water per day would require a

recharge area in the Stockton/Passaic Zone of 5.1 acres. Within the Lockatong/Diabase Zone, this same dwelling unit would require a recharge area of 13.1 acres.

The recharge areas per dwelling unit should permit precipitation to infiltrate an aquifer system and ensure that water is available for both human consumption within the dwelling unit and also for downstream ecosystems during severe dry weather. The recharge areas per dwelling unit should be flat to gently sloping and open to incident precipitation. These areas 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 of the fractures.

Portions of lots that include seeps, wetlands, streams, bedrock outcrops, and/or steep slopes should not be included in the recharge areas. All site improvements, especially those that include impervious surfaces should be in addition to the recharge area per lot. As an example, if the recharge area was established on the same lot as the dwelling unit and this lot contains a 0.2-acre wetland, 0.1 acres of steep slopes, and a house with driveway and other impervious surfaces that combined encompass 0.2 acres, the future dwelling unit lot size should be a minimum of 5.6 acres in the Stockton/Passaic Zone and 13.6 acres in the Lockatong/Diabase Zone.

The minimum recharge areas per lot have been calculated to provide a dependable water-supply yield to existing dwelling units and a future single-family residence occupied by 4.2 persons. These recharge areas assume that the water is depleted from the aquifer and not returned.

In Hopewell Township, septic systems are used for disposal of wastewater. As a result, an estimated 80 percent of the water removed from the aquifer is returned. However, the wastewater contains contaminants such as nitrates, bacteria, and viruses that are highly mobile and are not readily removed. Therefore, additional recharge is required to dilute these and other contaminants to a level that is deemed safe for consumption.

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.

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Elevated nitrates can cause methemoglobinemia in infants and can also be an indicator of pathogenic bacterial contamination.

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 can migrate large distances and result in an extensive plume of groundwater contamination. Since nitrate is 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.

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 Hopewell 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.

As part of the 1993 study of the Stony Brook, Beden Brook, and Jacobs Creek basin, the USGS collected groundwater samples, some of which were analyzed for nitrite plus nitrate. These analytical results indicate background nitrate concentrations ranging from the detection limit of 0.1 milligram per liter (mg/l) to 4.7 mg/l with a median concentration of 0.82 mg/l. Based on this study, the background concentration of nitrates in groundwater beneath Hopewell Township is approximately 1 mg/l. Therefore, the antidegradation limit for nitrate discharges is approximately 5.5 mg/l.

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. In the draft document entitled "A Model of Residential Carrying Capacity for New Jersey, Based on Water Quality" included as part of the July 3, 2000 draft Watershed Management Rules issued by the NJDEP, a nitrate discharge limit of 2 mg/l was suggested. Although the

NJDEP suggested a nitrate limit for discharges it has not as of the date of this report, established a nitrate discharge limit lower than permitted by the existing antidegradation policy.

Although the antidegradation limit would result in discharge concentrations of 5.5 mg/l, which is below the drinking water standard, this limit would permit background concentrations to increase 5.5 times above the current background limit and will likely result in adverse impairment of groundwater quality. Since nearly all Hopewell 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 groundwater. Hopewell Township has experienced adverse water-quality impacts in areas where residential septic systems are suspected as the source of coliform bacteria. Given this experience with septic degradation of groundwater quality and the characteristics of the fractured bedrock aquifers, a discharge limit of 5.5 mg/l provides little margin of safety. A limit of 2 mg/l would provide a more reasonable margin of safety, therefore, minimizing the potential for adverse septic contamination of groundwater while still allowing for a doubling of background concentrations. This 2-mg/l discharge limit is identical to the discharge limit suggested by the NJDEP in the May 30, 2000 carrying capacity model.

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 20 years when evaluating potential nitrate discharges from septic systems to groundwater and for determining the recharge area necessary to dilute nitrate concentrations. The Trela-Douglas Model is the nitrate-dilution model recommended in the draft document “A Model of Residential Carrying Capacity for New Jersey, Based on Water Quality” and apparently will continue to be used by the NJDEP for evaluating potential impacts from septic systems.

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. The thin layer of soils and bedrock fractures offer limited retention time and groundwater is oxidized and there will be little if any, denitrification of the septic system effluent.

Nitrates can quickly migrate from a septic system with infiltration through a bedrock fracture into a water-bearing zone. Once the nitrate is in one or more

water-bearing fractures, there is little opportunity for removal or retardation. Since approximately 62 percent of Hopewell Township is underlain by soils with severe limitations for septic systems, these soils are unlikely to prevent nitrates or other contaminants from impacting groundwater used for water supply. Therefore, adequate recharge is necessary to dilute the concentration of contaminants to safe drinking conditions.

Assumptions

Similar to the water-supply evaluation discussed above, the Trela-Douglas model was applied to Hopewell Township to evaluate existing needs based on current demographics and future needs based on proposed construction. The Trela-Douglas nitrate dilution model is based on several assumptions, which for Hopewell Township include the following (the values used in the calculations are provided in parenthesis):

1. The groundwater use rate is 100 gallons per day per person and 3.0 persons occupy each existing residence and 4.2 persons will occupy future residences. These assumptions are the same assumptions used in determining recharge areas for water supply use. Typical septic systems in New Jersey are designed for discharge rates of 100 gallons per day per person. Since approximately 20 percent of water used in a home is likely to be lost through evaporation, it has been assumed that approximately 80 percent of the groundwater used by each person is returned to the aquifer through the septic system. Therefore, a groundwater use of 300 gallons per day results in approximately 240 gallons per day (32.09 ft^3/day) discharged to the aquifer. A groundwater use of 420 gallons per day results in approximately 336 gallons per day (44.92 ft^3/day) discharged to the aquifer.

2. The aquifer recharge rate is 410 gpd/acre (1.26×10^{-3} feet/day) for the Stockton/Passaic Zone and 160 gpd/acre (4.91×10^{-4} feet/day) for the Lockatong/Diabase Zone. To ensure that groundwater quality is not adversely impacted during a prolonged drought, the recharge rates for the “Drought of Record” were assumed.

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

4. The nitrate concentration at the boundary of the recharge area, which is in accordance with the NJDEP antidegradation policy for Class II-A groundwater is 5.5 mg/l for Hopewell Township.

5. No additional sources of nitrate such as lawn fertilizers are added to the environment and migrate to groundwater.

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The model parameters and the equations used to calculate these parameters are as follows:

C The concentration of nitrate at the boundary of the recharge area, which is 5.5 mg/l.

C_0 The nitrate concentration in the septic system effluent, which is estimated at 40 mg/l.

DF The dilution factor, which is calculated from the following equation: $DF = C_0/C$. The dilution factor is 7.27 for Hopewell Township.

SD The septic discharge per day, which as listed above, is approximately 32.09 ft^3/day for existing residences and 44.92 ft^3/day for future residences.

IA The infiltration rate over the area necessary to ensure dilution, which is calculated from the following equation: IA = [(DF)(SD)]-SD. For Hopewell Township, IA equals 609.63 ft^3/day for existing residences and 853.48 ft^3/day for future residences

IR The infiltration rate of precipitation, which is 1.26×10^{-3} feet/day for the Stockton/Passaic Zone and 4.91×10^{-4} feet/day for the Lockatong/Diabase Zone.

RA The recharge area is calculated by the following equation: RA = IA/IR. For an existing 3 person dwelling unit in the Stockton/Passaic Zone, RA equals approximately 3.7 acres and in the Lockatong/Diabase Zone, RA equals approximately 9.4 acres. For a future residence with 4.2 persons per dwelling unit in the Stockton/Passaic Zone, RA equals approximately 5.1 acres and in the Lockatong/Diabase Zone, RA equals approximately 13.2 acres.

If the nitrate discharge rate was established at 2 mg/l instead of 5.5 mg/l, the recharge areas for the Stockton/Passaic Zone would be 11.1 and 15.6 acres for existing and future residences, respectively. The recharge areas within the Lockatong/Diabase Zone would be 28.5 and 39.9 acres for existing and future residences, respectively.

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.

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In areas of the Township with existing lot sizes smaller than the recharge areas needed for adequate nitrate dilution, 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 equal to these recharge areas, it may be necessary to protect upstream open areas to balance portions of the existing lots covered with impervious materials.

CONCLUSIONS

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

1. Hopewell Township is located within RWRPA 10, the Raritan River Watershed, and RWRPA 9, which is the Trenton Delaware Tributaries Watershed. As a recharge and headwaters area for one of the most populous and fastest growing regions in the State, Hopewell Township is concerned with water resource availability and water quality for its citizens, ecosystems, and downstream consumers in RWRPAs 9 and 10.

2. Hopewell Township's groundwater resources are of value to the current and future residents of the Township as well as downstream consumers and ecological receptors. Hopewell Township wants to protect these critical resources for these residents, receptors and consumers.

3. Hopewell Township is located within the Piedmont Physiographic Province and is nearly equally divided between the Raritan River and the Delaware River Watersheds. Triassic-Jurassic sedimentary deposits of the Stockton, Lockatong, and Passaic Formation and igneous diabase intrusions underlie the Township. Groundwater is stored and transmitted in fractures and other openings in these rocks. Unfractured portions of the bedrock are considered impermeable and incapable of yielding sufficient water for supply. Well yields are dependent on the number and interconnection of fractures/openings in the bedrock.

4. Well yields, aquifer characteristics and geology indicate that two very different aquifer systems or hydrogeologic zones underlie the Township. The Lockatong/Diabase Zone has well yields, specific capacities, and transmissivities that are significantly less than the Stockton/Passaic Zone.

5. Groundwater recharge to the Stockton/Passaic Zone during years of normal precipitation should be approximately 8.2 inches per year, which is approximately equivalent to 610 gpd/acre. Groundwater recharge to the Lockatong/Diabase Zone is approximately 3.15 inches per year, which is approximately equivalent to 235 gpd/acre. During a drought similar to the

"Drought of Record" groundwater recharge rates should be approximately 410 gpd/acre and 160 gpd/acre for the Stockton/Passaic Zone and Lockatong/Diabase Zone, respectively.

6. To ensure adequate water is available for human consumption, ecological receptors, and downstream consumers, the dependable yield for the Stockton/Passaic Zone is approximately 82 gpd/acre and for the Lockatong/Diabase Zone is approximately 32 gpd/acre.

7. During a recurrence of the "Drought of Record" Hopewell Township will receive approximately 5,056.6 million gallons of recharge per year of which the dependable yield for the Township is approximately 84.3 million gallons per month. Current residential self-supply and existing NJDEP Water Allocation Permits/Agricultural Registrations could result in consumption of approximately 83.2 million gallons per month. Hopewell Township is nearing the dependable yield for the area encompassed within the Township perimeter and continued demands could adversely impact stream ecosystems, downstream consumers, or current residents of the Township and/or Boroughs.

8. Hopewell Township is located at or very near the headwaters for all surface-water streams flowing within its borders. As a result, the Township and the two enclosed Boroughs cannot rely on upstream sources or conservation measures to ensure a long-term adequate water supply. If the Township and Boroughs are to be self sustained without adverse impacts to existing ecosystems during a recurrence of the "Drought of Record", it may be necessary to institute measures to limit additional water use and to increase conservation of groundwater within the Township perimeter. Since the Township and Boroughs are apparently nearing the long-term dependable yield limit adverse impacts to groundwater quality from accidental or purposeful discharges of contaminants can further reduce the margin of safety between current demand and long-term dependable yield.

9. Current demographics indicate that each existing dwelling unit consumes approximately 300 gallons per day. Given the dependable yields of the hydrogeologic zones, each of these existing dwelling units requires a recharge area of 3.7 acres for the Stockton/Passaic Zone and 9.4 acres for the Lockatong/Diabase Zone to ensure an adequate long-term safe yield.

10. Based on demographic studies presented to the Township Planning Board, dwelling units constructed in the future will have 4 to 5 bedrooms and will be occupied by approximately 4.2 persons. These dwelling units will have a resulting water demand of approximately 420 gallons per day and would require a recharge area in the Stockton/Passaic Zone of 5.1 acres. Within the Lockatong/Diabase Zone, this same dwelling unit would require a recharge area of 13.1 acres.

11. Nitrate is a highly soluble, stable, and mobile compound in groundwater and can migrate large distances resulting in an extensive plume of contamination. The background concentration of nitrates in groundwater within Hopewell Township is approximately 1 mg/l. Since nearly all Hopewell Township residents rely on groundwater for drinking water and 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 groundwater. Given Hopewell Township's experience with septic discharges resulting in coliform bacterial contamination of groundwater and the characteristics of the fractured bedrock aquifers, a discharge limit of 5.5 mg/l would provide little margin of safety. A limit of 2 mg/l would provide a more reasonable safety margin while still doubling background concentrations. This 2 mg/l discharge limit is identical to the discharge limit suggested by the NJDEP in the May 30, 2000 carrying capacity model.

12. The Trela-Douglas model was used to calculate recharge areas for diluting nitrates from septic system effluent in groundwater. Based on the results of this model, the recharge areas per dwelling unit were calculated. Based on current demographics, existing lots with 3 persons per dwelling unit will require recharge areas in the Stockton/Passaic Zone of approximately 3.7 acres and in the Lockatong/Diabase Zone of approximately 9.4 acres to adequately dilute nitrates. For a future residence with 4.2 persons per dwelling unit the recharge area necessary to adequately dilute nitrates in the Stockton/Passaic Zone is approximately 5.1 acres and in the Lockatong/Diabase Zone is approximately 13.2 acres. If the nitrate discharge rate was established at 2 mg/l instead of 5.5 mg/l, the recharge areas for existing and future residences for the Stockton/Passaic Zone would be 11.1 and 15.6 acres and for the Lockatong/Diabase Zone would be 28.5 and 39.9 acres.

13. The recharge areas should have flat to gentle slopes and be open to precipitation. The areas should not include impervious surfaces or buildings that can prevent precipitation from infiltrating into bedrock fractures. Portions of lots that include seeps, wetlands, streams, bedrock outcrops, impervious surfaces, buildings, and/or steep slopes should be in addition to the recharge areas.

14. In areas of the Township with existing lot sizes smaller than the recharge areas, it may be necessary to preserve or protect upstream open areas within the same watershed to ensure sufficient water infiltrates the aquifer to support the existing demands. Even in areas where the existing lot sizes are equal to the recharge areas, it may be necessary to protect upstream open areas to balance portions of the lots covered with impervious materials.

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.

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

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. 1999B. Microsoft Excel Workbook Implementing the New Jersey Geological Survey's Ground-Water Recharge Methodology. New Jersey Geological Survey Digital Geodata Series DGS 99-2.

Hordon, Robert M. 1984. Sourland Mountain Ground Water Management Report. Middlesex-Somerset-Mercer Regional Study Council, Inc. Princeton, NJ.

Hordon, Robert M. 1987. The Ground Water Resources of Delaware Township, New Jersey. Delaware Township, Hunterdon County, New Jersey.

Hordon, Robert M. 1995. Ground Water Study of the Argillite Formation in Kingwood Township, Hunterdon County, New Jersey. Kingwood Township Planning Board.

Jacobsen, Eric, Mark A. Hardy, Barbara A. Kurtz. 1993. Hydrologic Conditions in the Jacobs Creek, Stony Brook, and Beden Brook Drainage Basins, West-Central New Jersey, 1986-88. USGS Water Resources Investigation Report 91-4164.

Kasabach, Haig F. 1966. Geology and Ground Water Resources of Hunterdon County, N. J. Special Report No. 24. Bureau of Geology and Topography, Division of Resource Development, Department of Conservation and Economic Development.

Laskowski, Stanley L. 1970. Statistical Summaries of New Jersey Streamflow Records. NJDEP Water Resources Circular 23.

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.

Lyttle, Peter T., Jack B. Epstein. 1987. Geologic Map of the Newark 1° x 2° Quadrangle, New Jersey, Pennsylvania, and New York. Miscellaneous Investigation Series I-1715. United States Geological Survey.

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

Owens, James P., Peter J. Sugarman, Norma F. Sohl, Ronald A. Parker, Hugh F. Houghton, Richard A. Volkert, Avery A. Drake, Jr. and Randall C. Orndorff. 1998. Bedrock Geologic Map of Central and Southern New Jersey. Miscellaneous Investigation Series I-2540-B. United States Geological Survey.

Senior, Lisa A., Daniel J Goode. 1999. Ground-Water System, Estimation of Aquifer Hydraulic Properties, and Effects of Pumping on Ground-Water Flow in Triassic Sedimentary Rocks in and Near Lansdale, Pennsylvania. USGS Water-Resources Investigations Report 99-4228.

Widmer, Kemble. 1965. Geology of the Ground Water Resources of Mercer County Geologic Report Series No. 7. New Jersey Geological Survey.

Water: A Natural Renewable Resource

Table 1: Approximate Areas of Generalized Soils in Hopewell Township, Mercer County, New Jersey.

General Soil Type	Total Area (sq. ft)	Total Area (acres)	Total Area (sq. mi)
Bucks	392964991.93	9021.23	14.10
Chalfont	189990858.84	4361.59	6.81
Penn	176898971.57	4061.04	6.35
Quakertown	135338468.70	3106.94	4.85
Reaville	109555101.13	2515.04	3.93
Readington-Abbottstown	90326158.87	2073.60	3.24
Doylestown	76794672.53	1762.96	2.75
Bowmansville	68276859.99	1567.42	2.45
Neshaminy	66433093.39	1525.09	2.38
Lawrenceville	56378244.21	1294.27	2.02
Klinesville	53655072.26	1231.75	1.92
Legore	51141879.43	1174.06	1.83
Rowland	48825199.66	1120.87	1.75
Birdsboro	34817322.34	799.30	1.25
Lehigh	33501861.82	769.10	1.20
Mount Lucas	14084077.47	323.33	0.51
Landsdale	12830331.76	294.54	0.46
Cut and Fill Land	10838124.77	248.81	0.39
Tioga	9457823.85	217.12	0.34
Pits	9106241.67	209.05	0.33
Very Stony Land Mt. Lucas-Neshaminy	8976602.86	206.07	0.32
Water	4858430.49	111.53	0.17
Very Stony Land Neshaminy	3434914.74	78.85	0.12
Very Stony Land Watchung	2884497.40	66.22	0.10
Watchung	2212548.44	50.79	0.08

Water: A Natural Renewable Resource

Table 2: Recharge Estimates Calculated with the NJGS GSR-32 Method for Soil Types in Hopewell Township, Mercer County, New Jersey.

General Soil Type	Calculated Recharge (inches/year)
Bucks	9.8
Chalfont	9.0
Penn	8.9
Quakertown	8.1
Reaville	8.9
Readington-Abbottstown	8.7
Doylestown	
Bowmansville	
Neshaminy	10.3
Lawrenceville	8.7
Klinesville	10.4
Legore	9.9
Rowland	8.3
Birdsboro	10.0
Lehigh	8.2
Mount Lucas	8.3
Landsdale	9.9
Cut and Fill Land	
Tioga	10.0
Pits	
Very Stony Land Mt. Lucas-Neshaminy	7.9
Water	
Very Stony Land Neshaminy	8.3
Very Stony Land Watchung	
Watchung	

Notes: 1. NJGGS DGS 99-2 Excel Spreadsheet was used to perform soil recharge calculations.
2. The recharge estimates are based on 0.5 to 1 acre lots, which provided values nearly equal to the median recharge for all land use types provided in the spreadsheet.
3. Method cannot calculate groundwater recharge rates for Doylestown, Bowmansville, Cut & Fill Land, Pits, Very Stony Land Watchung, or Watchung.

Water: A Natural Renewable Resource

Table 3: Estimated Maximum Monthly Consumption of Water Derived from within Perimeter of Hopewell Township, Mercer County, New Jersey.

Consumer	Estimated Population	Estimated Per Capita Usage (gallons)	Monthly Usage (gallons)	Maximum Monthly Allocation (gallons)
Domestic	12,100	100	36,832,400	
Bristol-Myers Squibb				5,000,000
Hopewell Borough Water Dept.				9,000,000
Hopewell Valley Golf Club				4,600,000
Hopewell Township				3,000,000
Lucent Technologies				3,000,000
Pennington Borough				12,600,000
Pennington School				3,100,000
Penwell Holdings, LLC				3,100,000
SBMWA Organic Farm				3,000,000
Maximum Total Monthly Water Consumption:				83,232,400

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Figure 1: Location of Mercer County in the State of New Jersey

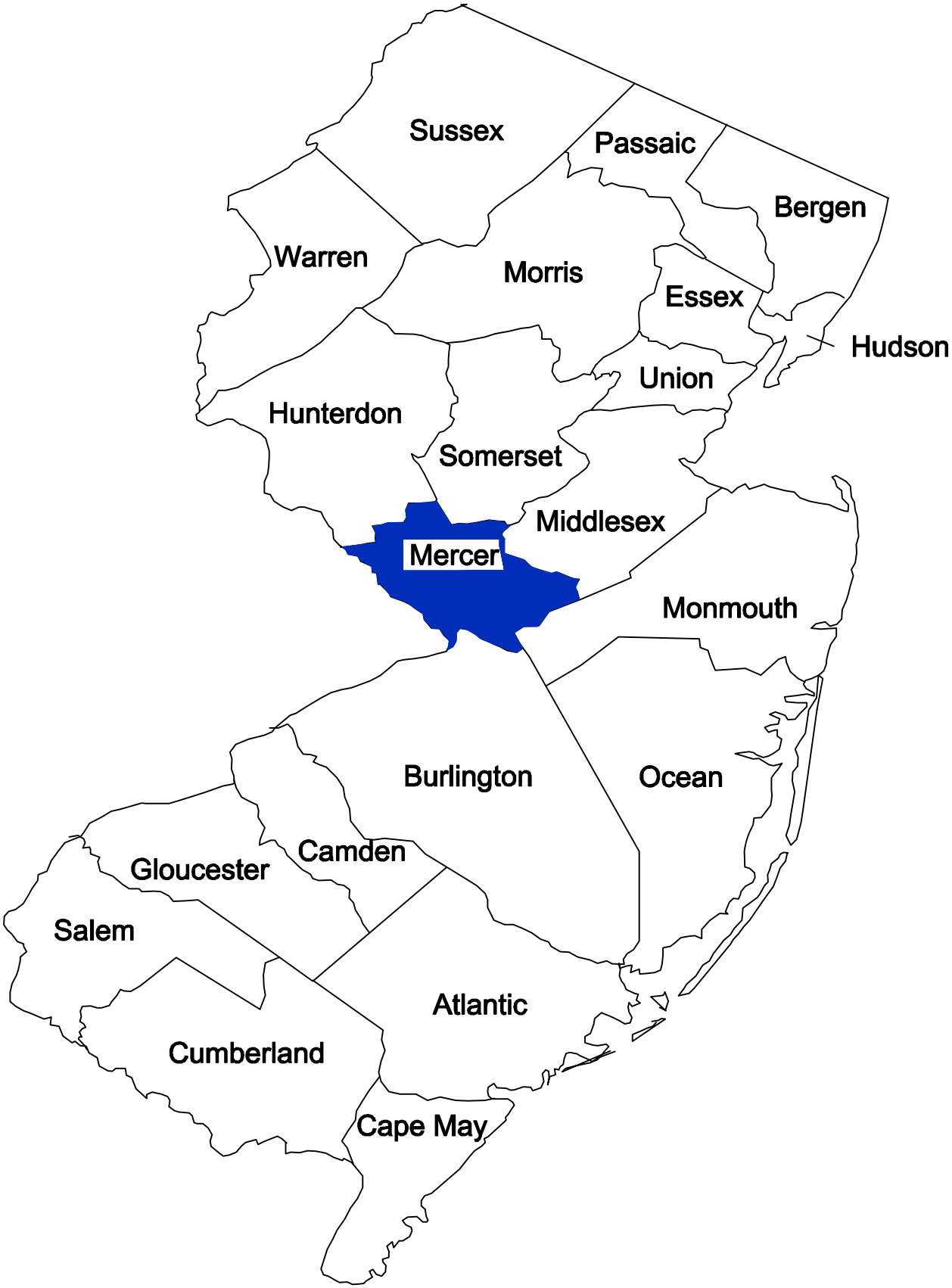
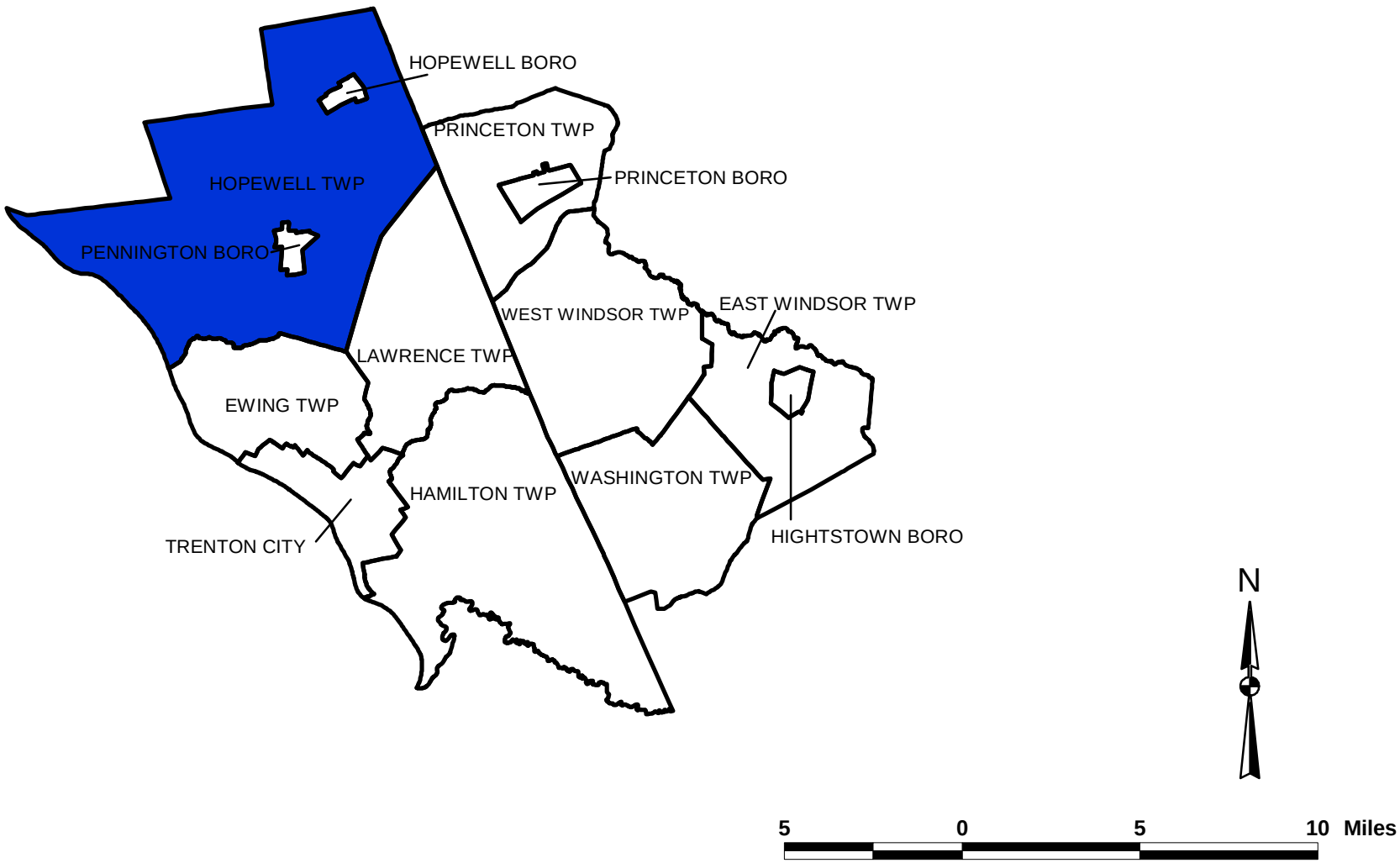
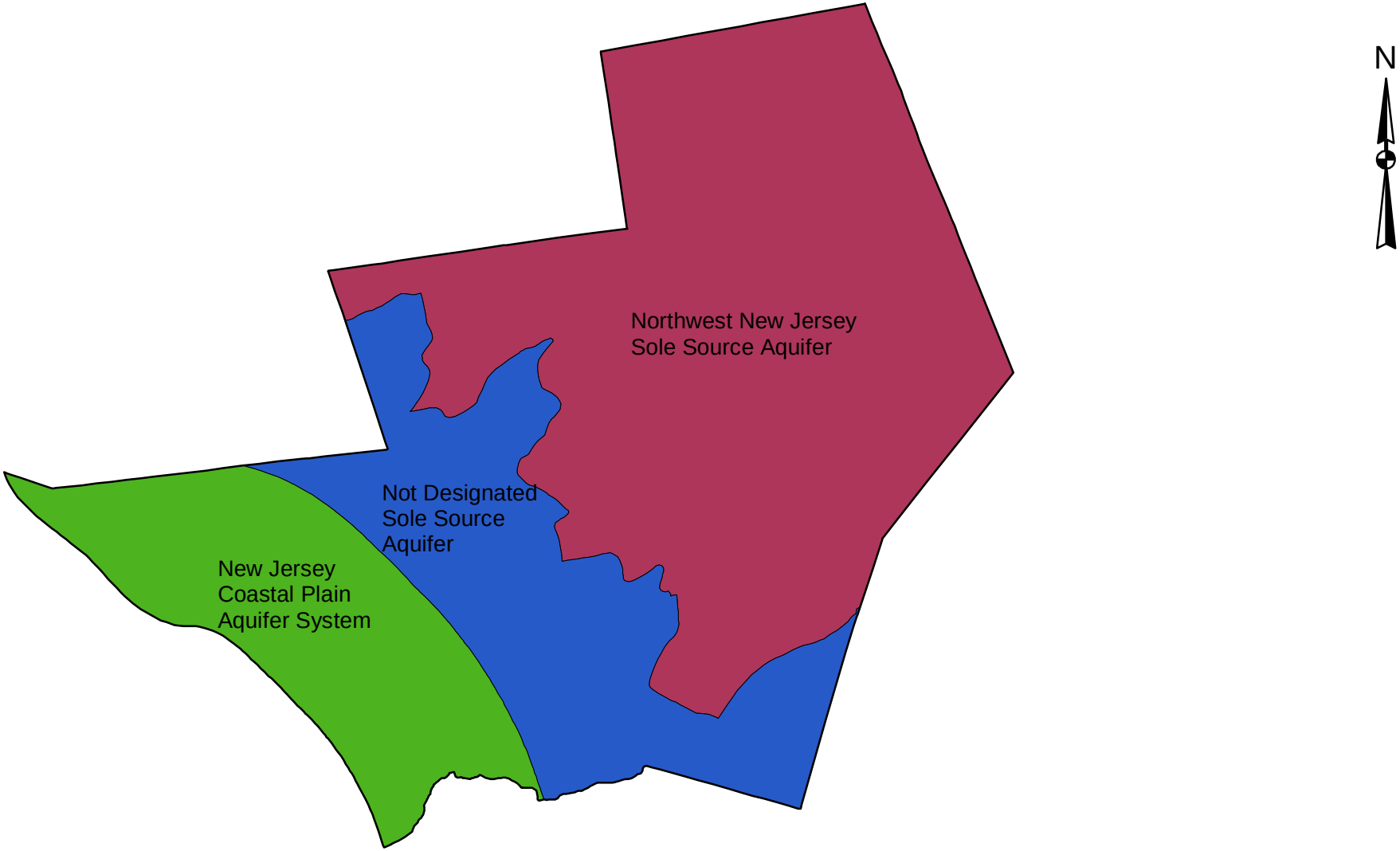


Figure 2: Location of Hopewell Township Within Mercer County, New Jersey.



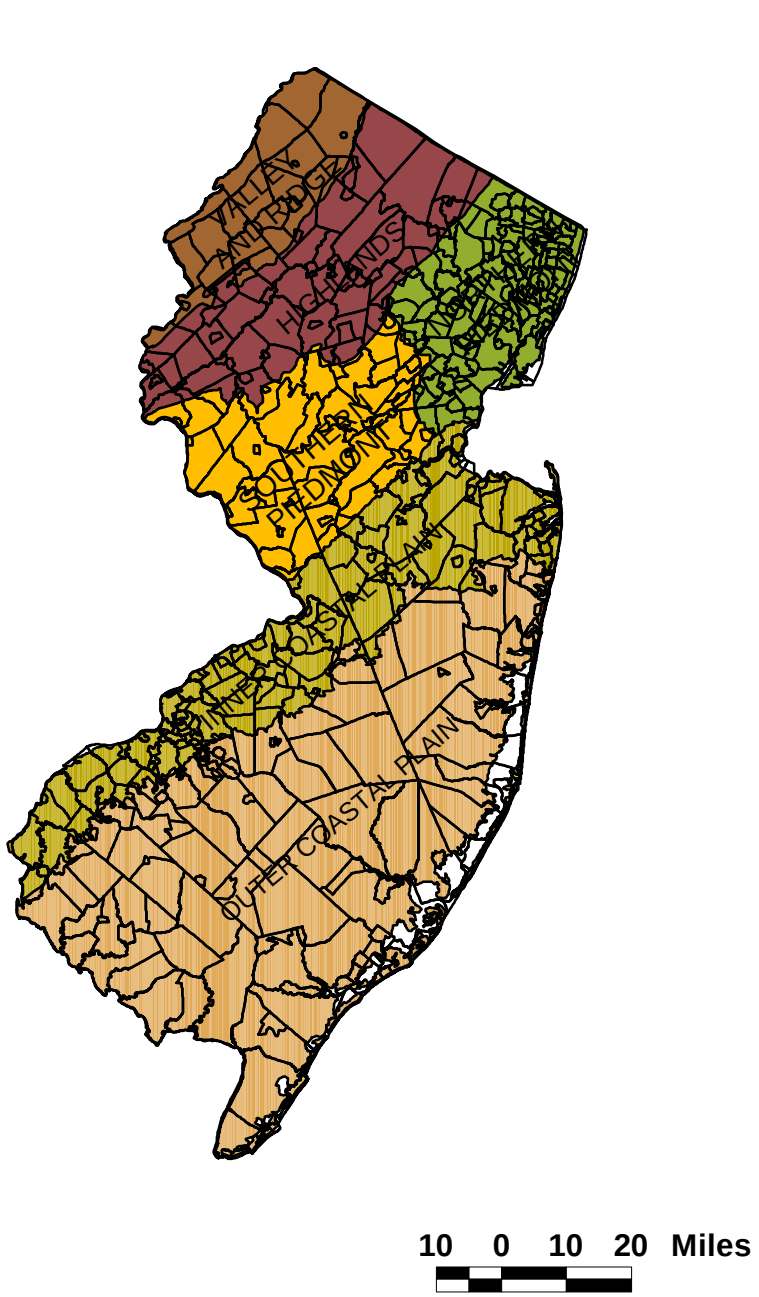
Modified from NJGS GIS County Environmental Profiles dated March 7, 1996.

Figure 3: USEPA-Designated Sole Source Aquifers in Hopewell Township, Mercer County, New Jersey.



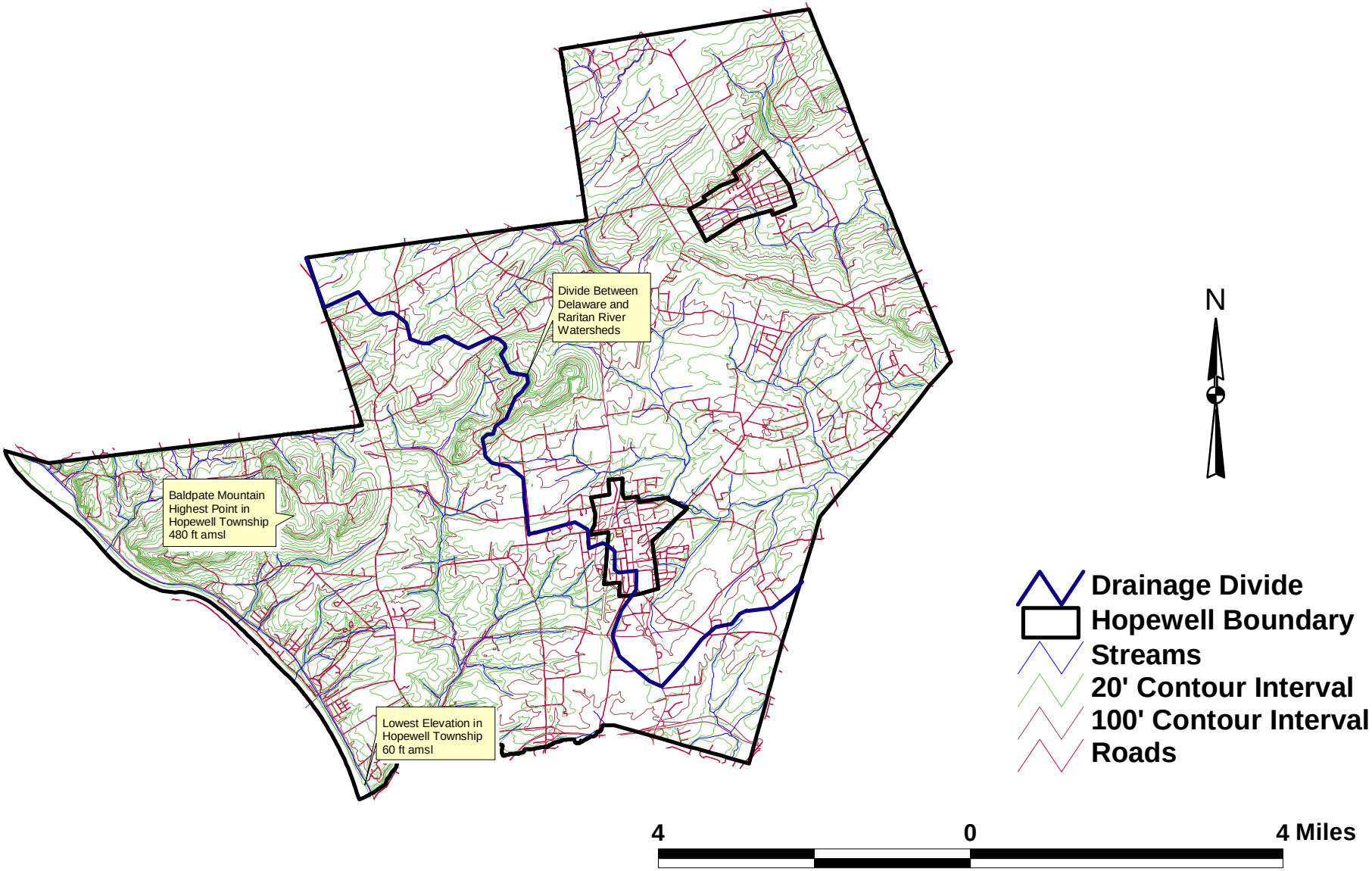
Modified from NJGS GIS Maps depicting Sole Source Aquifers of New Jersey and Van Cleef Engineering GIS Mapping of Hopewell Township.

Figure 4: Physiographic Provinces of New Jersey.



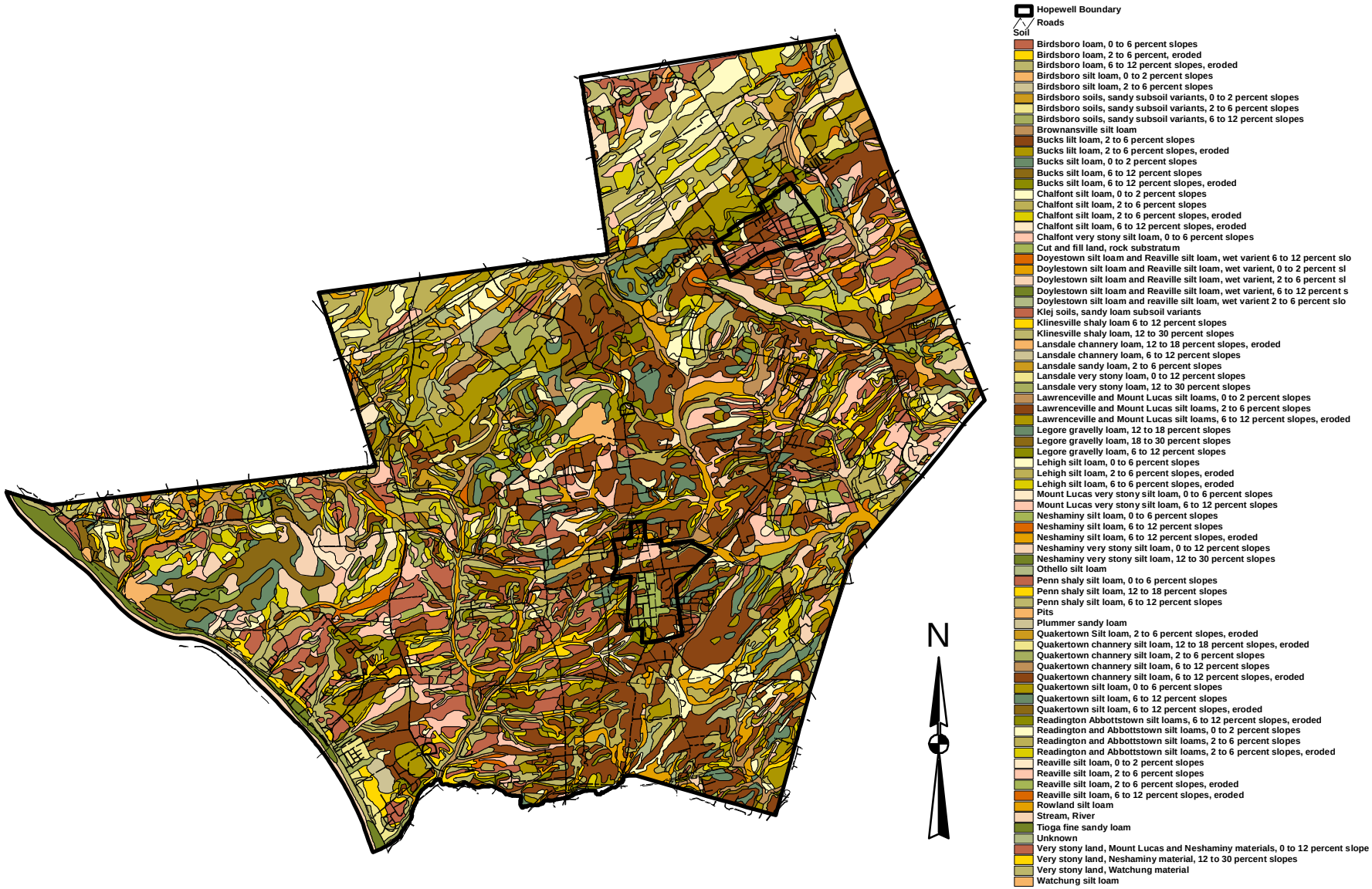
Modified from NJGS GIS County Profiles dated March 7, 1996.

Figure 5: Topography of Hopewell Township, Mercer County, New Jersey.



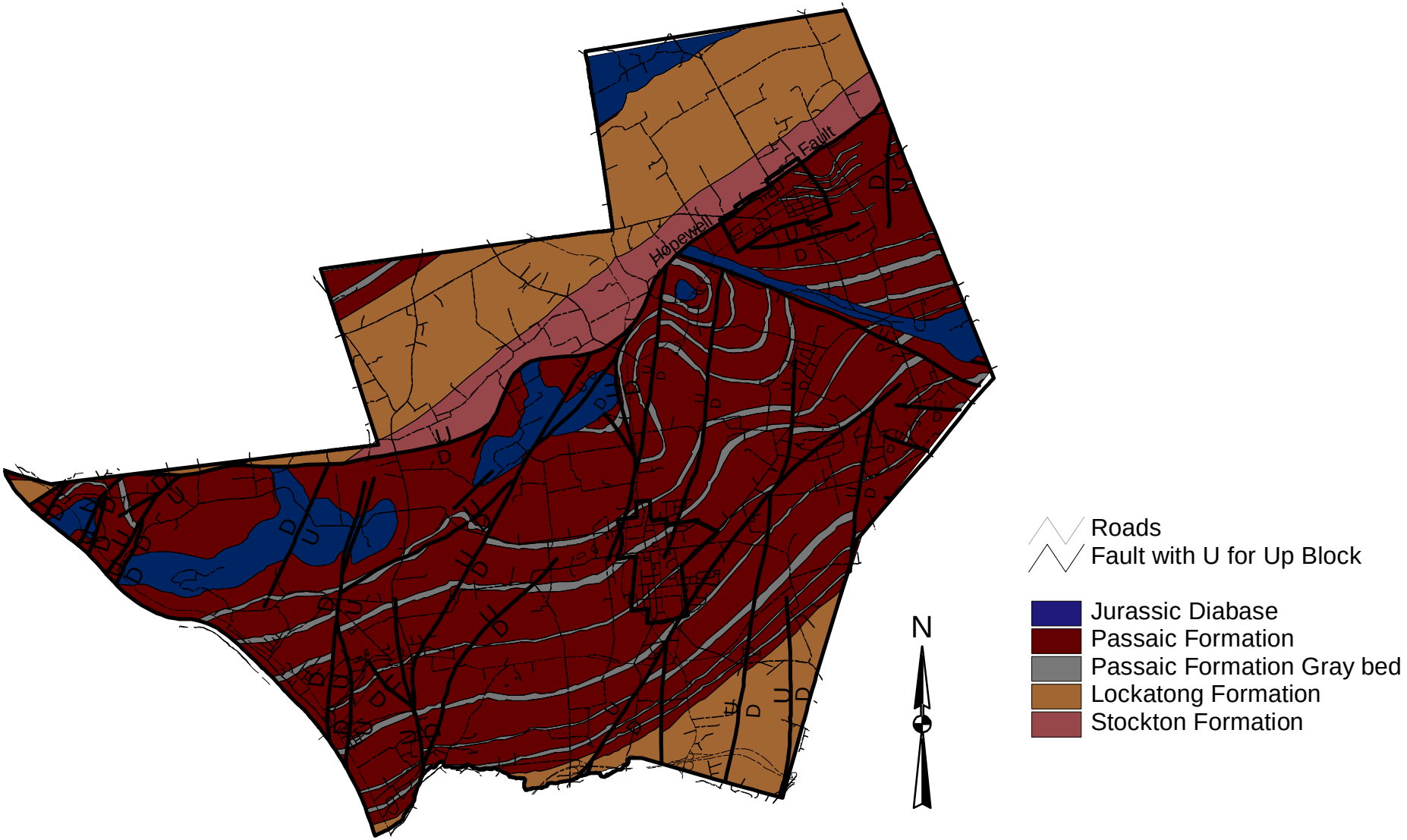
Modified from NJGS GIS Maps of New Jersey and
Van Cleef Engineering GIS Mapping of Hopewell Township.

Figure 6: Generalized Soils of Hopewell Township, Mercer County, New Jersey.



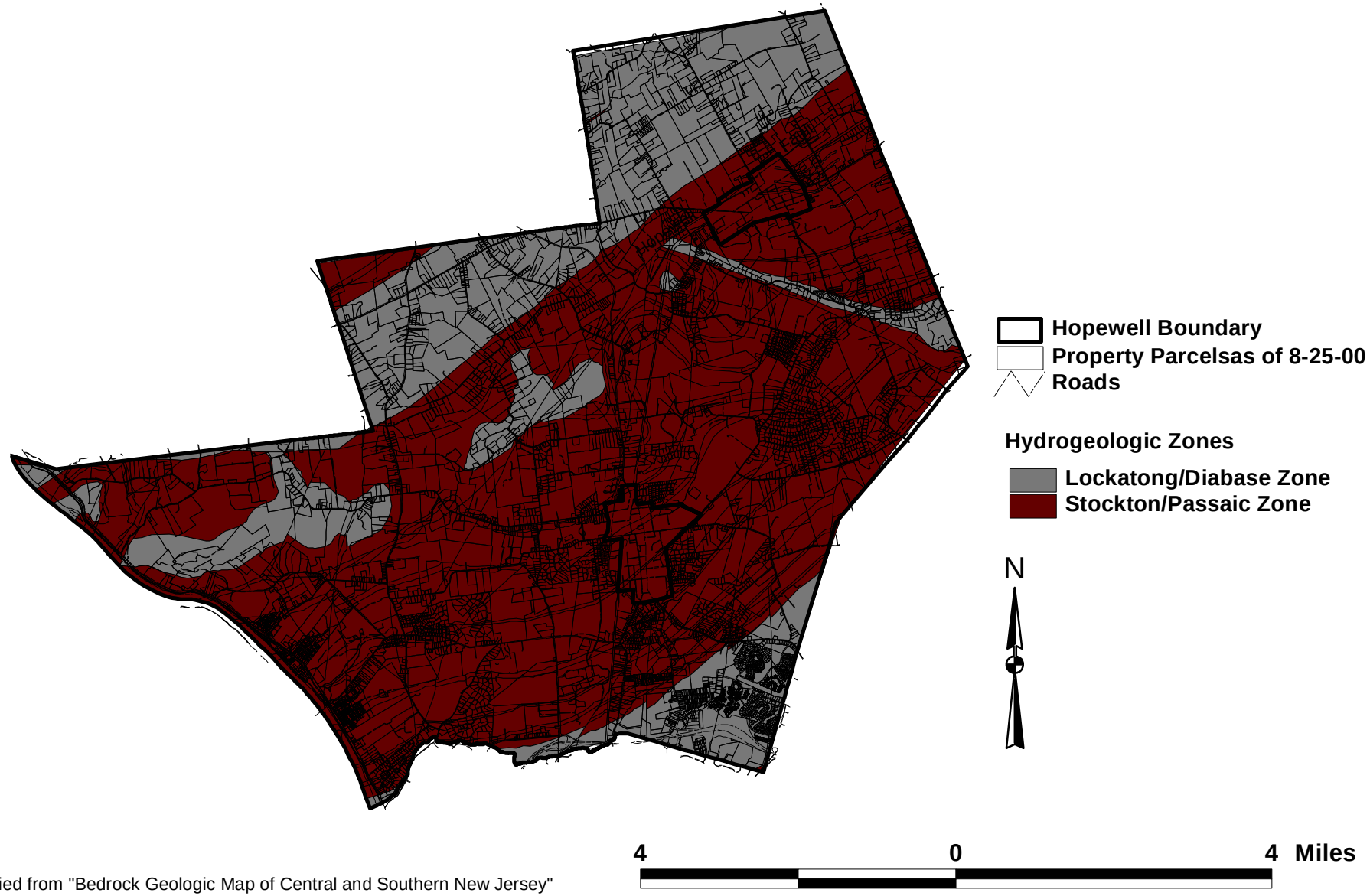
Modified from NJGS GIS Maps of New Jersey and
Van Cleef Engineering GIS Mapping of Hopewell Township.

Figure 7: Bedrock Geology of Hopewell Township, Mercer County, New Jersey.



Modified from "Bedrock Geologic Map of Central and Southern New Jersey" prepared by USGS and NJGS dated 1998. USGS MIS Map i-2450-B.
GIS Mapping for Hopewell Township from Van Cleef Engineering.

Figure 8: Hydrogeologic Zones of Hopewell Township, Mercer County, New Jersey.



Modified from "Bedrock Geologic Map of Central and Southern New Jersey" prepared by USGS and NJGS dated 1998. USGS MIS Map I-2450-B.
GIS Mapping for Hopewell Township from Van Cleef Engineering.