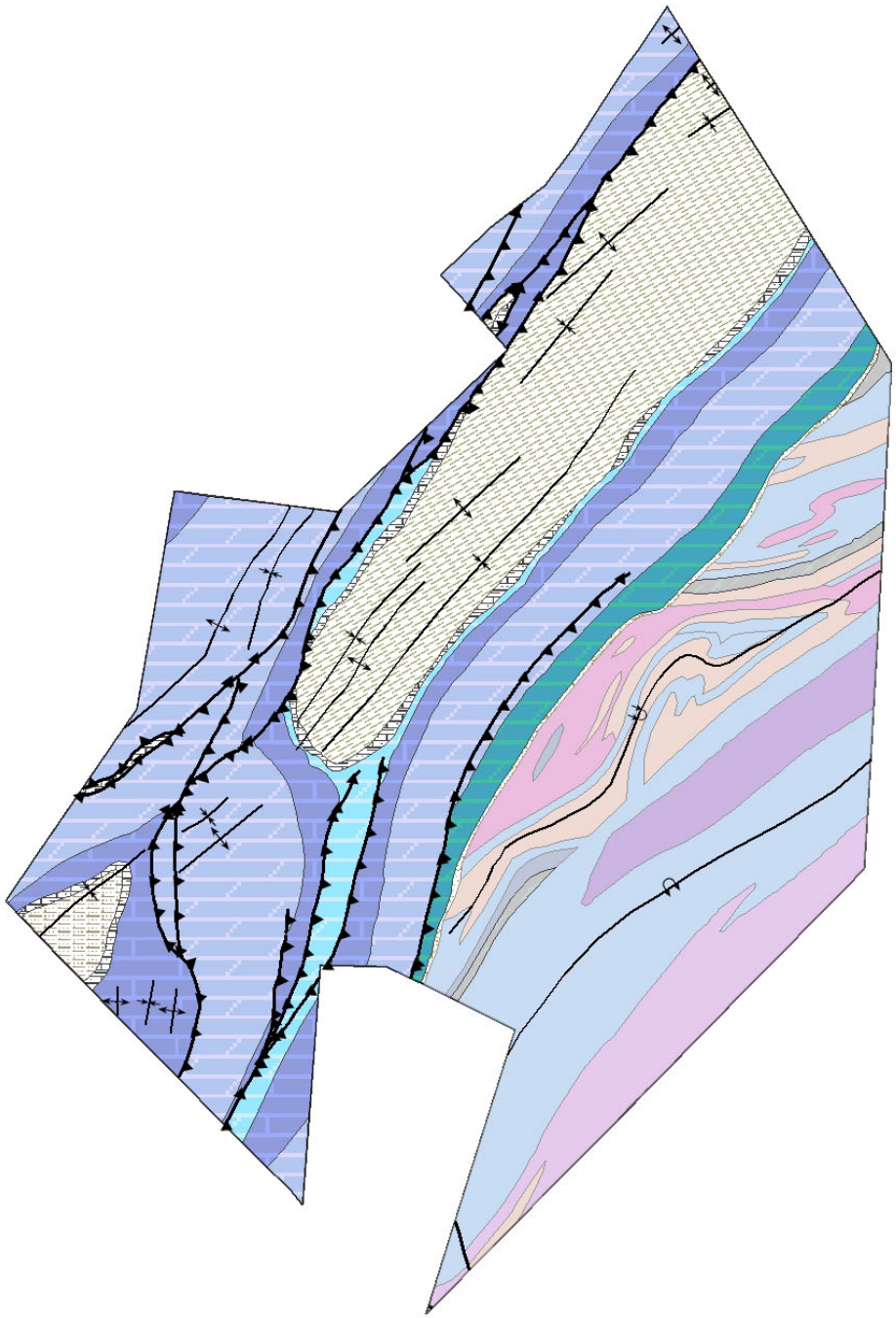
Evaluation of Groundwater Resources of Andover Township, Sussex County, New Jersey



Water: A Natural Renewable Resource

M² Associates Inc.
56 Country Acres Drive
Hampton, New Jersey 08827

Water: A Natural Renewable Resource

EVALUATION OF GROUNDWATER RESOURCES OF ANDOVER TOWNSHIP, SUSSEX COUNTY, NEW JERSEY

DECEMBER 17, 2009

Prepared for:

Andover Township
134 Newton Sparta Road
Newton, NJ 07860

Prepared by:

Matthew J. Mulhall, P.G.

M^2 Associates Inc.
56 Country Acres Drive
Hampton, New Jersey 08827
(908) 238-0827

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EVALUATION OF GROUNDWATER RESOURCES OF ANDOVER TOWNSHIP, SUSSEX COUNTY, NEW JERSEY

TABLE OF CONTENTS

INTRODUCTION 1

GEOLOGY 4
- LOCATION 4
- POPULATION DENSITY 4
- PHYSIOGRAPHIC PROVINCE 5
- TOPOGRAPHY 6
- SURFACE WATER 6
  - Watersheds 6
  - Stream Classifications 7
- SOILS 10
- SURFICIAL GEOLOGY 14
- BEDROCK 16
- STRUCTURE 20
  - Secondary Porosity 20
  - Faults 21

GROUNDWATER SYSTEMS 22
- STORAGE AND TRANSMISSION CAPABILITY 22
- PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS/HARDYSTON QUARTZITE 23
  - Location 23
  - Franklin Marble 24
  - Silicate Crystalline Rocks 25
  - Poor Ranking 26
  - Fractures 26
  - Yields/Depths/Specific Capacity 28
  - Summary 30
- CAMBRIAN-ORDOVICIAN CARBONATE ROCKS 31
  - Location 31
  - Fractures/Solution Openings 32
  - Easily Contaminated 33
  - Yields/Depths/Specific Capacity 33
  - Public Community Wells 35
  - Summary 35
- MARTINSBURG FORMATION 35
  - Location 35
  - Yields/Depths/Specific Capacity 36
- GLACIAL 38

HYDROGEOLOGIC FRAMEWORK 39
AQUIFER RECHARGE 40
Hydrologic Cycle 40
WATER BALANCE 40
PRECIPITATION 41
EVAPOTRANSPIRATION 41
SURFACE-WATER RUNOFF 42
GROUNDWATER RUNOFF 44
Groundwater Recharge 45
GROUNDWATER 45
BASEFLOW 46
HYDROGRAPH SEPARATION 46
POSTEN (1984) METHOD 47
COMPUTER MODELS 48
NJGS MODIFIED METHOD 48
AQUIFER VERSUS "GROUNDWATER" RECHARGE 48
SOIL RECHARGE RATES 49
Groundwater Recharge Rates 51
PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS 51
COMBINED GLACIAL/CARBONATE ROCK SYSTEM 52
OUTCROPPING CARBONATE ROCK SYSTEM 52
MARTINSBURG FORMATION 52
SUMMARY 53

WATER SUPPLY 53
DEMAND 53
DEPENDABLE YIELD 54
Definition 54
Maintainable Yield 54
Planning Threshold 56
Summary 56
GROUNDWATER AVAILABILITY 56
DWELLING UNIT DENSITIES 59
NITRATE DILUTION 61
Nitrate 61
CURRENT REGULATIONS 61
Trela-Douglas Model 62
ACCEPTANCE 62
NJGS METHOD RESULTS 62
BEDROCK SYSTEMS 63
EQUATION 65

CONCLUSIONS 66

REFERENCES 74

FIGURES

1. Location of Andover Township and Sussex County, New Jersey.

2. Physiographic Provinces Beneath Andover Township.

3. Watersheds Beneath Andover Township.

4. Surface-Water Classifications for Andover Township.

5. Soils Beneath Andover Township.

6. Areas of Andover Township with Soils Classified as Not Limited to Somewhat Limited for Septic Systems.

7. Surficial Geology Beneath Andover Township.

8. Bedrock Geology Beneath Andover Township.

9. Precambrian Rocks and Hardyston Quartzite Beneath Andover Township.

10. Cambrian-Ordovician Carbonate Rocks Beneath Andover Township.

11. Ordovician Martinsburg Formation Beneath Andover Township.

12. Glacial Sediment Thickness Beneath Andover Township.

APPENDIX

A. Summary Table of Well Record Details for Andover Township, Sussex County, New Jersey.

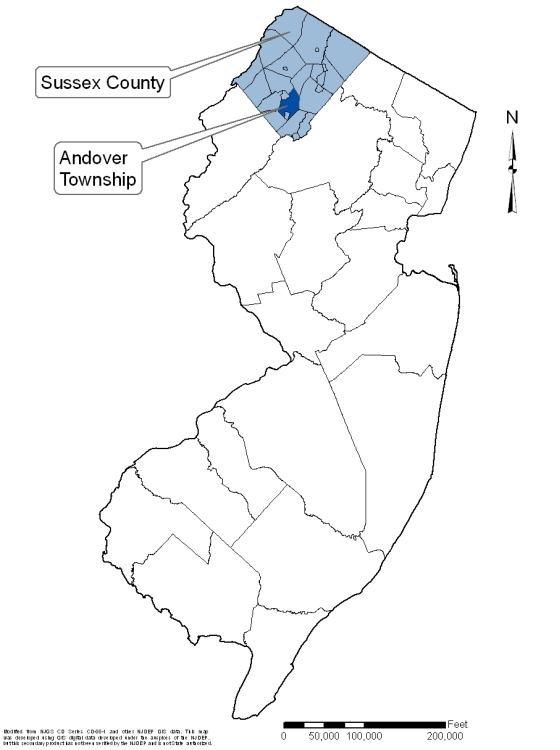
Water: A Natural Renewable Resource

EVALUATION OF GROUNDWATER RESOURCES OF ANDOVER TOWNSHIP, SUSSEX COUNTY, NEW JERSEY

INTRODUCTION

Andover Township, Sussex County, New Jersey retained M^2 Associates in August 2008 to conduct an evaluation of the groundwater resources of the Township. The location of Andover Township and Sussex County in New Jersey are shown on Figure 1.

Figure 1: Location of Andover Township and Sussex County, New Jersey.



The Township of Andover requested the evaluation because of the following:

1. The source of drinking water for residents is groundwater. Water is supplied from individual or local public community wells completed in fractured bedrock and in a few cases, glacial deposit aquifers. The hydrogeologic characteristics of these aquifers are dependent on the type of bedrock, and the nature of the fractures and other openings. The type of bedrock and the extent of fractures/openings limit recharge rates, sustained yields, interference effects, groundwater quality, and contaminant removal and attenuation rates. The Township recognizes that the protection of water quality and quantity is critical to supporting public health and quality of life of its residents and business but also others in New Jersey.

2. The entire township is located within the "Northwest New Jersey Sole Source Aquifer" (Hoffman 1999A). Aquifers beneath Andover Township are the only source of drinking water for Township residents. 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. The NJDEP and USEPA consider groundwater to be the single source of potable water within the designated sole source aquifer and indicate that measures should be taken to protect this critical resource from potential health hazards.

3. The Township is located immediately adjacent to the area designated for protection by the New Jersey legislature in the Highlands Water Protection and Planning Act. The designated Highlands boundary parallels the Township's southern and eastern boundaries. Groundwater resources beneath the municipalities designated for protection by the legislation extend beneath Andover Township. Headwaters of streams protected by the Highlands Act are located in Andover Township. The same water resources designated by the State for protection exist within Andover Township.

4. Before enactment of the Highlands Water Preservation and Planning Act, New Jersey has a long history of protecting water resources in upstream rural areas of the State for downstream consumers in its urban and suburban communities. The Township understands the need for protecting vital water resources so that they are not diminished or damaged in upstream communities such as Andover Township, and therefore, not available for those in need downstream where groundwater resources were long ago eliminated as drinking-water resources. Andover Township recognizes its important location and role in preserving resources for downstream communities.

5. Andover Township is located in a fast growing region of New Jersey. Municipal officials and citizens are concerned that because the water resources of the Township were not designated for protection by the Highlands Water Preservation and Planning Act, growth that would have occurred in the neighboring Highlands communities will focus and further expedite development in Andover Township affecting sustainability of water resources and water quality. Commercial and residential development can impact the quantity and quality of water stored and withdrawn from aquifer systems. Construction of improvements can affect water quality through introduction of contaminants or creation of pathways that expedite migration. These improvements can reduce the volume of recharge infiltrating to aquifer systems and therefore, adversely result in 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 commercial or residential development may impact current users of groundwater. In areas of the Township underlain by aquifers with high potential yields, increased development could adversely affect these resources and their availability for current and future generations.

6. Based on US Census data, between 1990 and 2000, the population of Andover Township increased 595 persons from 5,438 to 6,033. Between 2000 and 2008, the U.S. Census Bureau estimated that the population increased another 498 persons to 6,531. In the past 18 years, the population of the Township increased approximately 20 percent. Prior to this period of increased population growth, the Township's groundwater resources may have served as potential reservoirs for areas of New Jersey with significantly greater populations. As a result of the population growth, greater demand has been applied to the resources within the municipal boundaries and the potential reservoir capabilities of the aquifer systems for other areas of the State were reduced. The Township is concerned with protecting these potential reservoirs before they are further diminished or permanently damaged.

7. The groundwater resources of the Township could be readily exploited to service populations in other areas of New Jersey. The Highlands Water Protection and Planning Act was adopted to protect vital water resources in northern New Jersey and those same resources underlie Andover Township but are not afforded the same levels of protection. Andover Township has direct experience with adverse impacts to groundwater and natural resources from overpumping of aquifers extending beneath its Township. Township officials and citizens understands that its groundwater resources have significant value to both, existing municipal residents and others living beyond its municipal boundaries. The Township implemented this evaluation to obtain the necessary information for furthering this understanding.

Andover Township wants to protect its valuable groundwater resources for current and future residents and businesses. Furthermore, as one of the potentially faster growing municipalities in the State, Andover Township understands that it must act now to protect the water resources of the Township in regard to both quality and quantity for its citizens as well as others in the region. The Township understands that current population trends could quickly overwhelm groundwater resources. Their understanding and planning is similar to the thinking of the leaders of New Jersey's eastern cities in the 19th and early 20th centuries when they realized a need to protect upstream reservoirs and groundwater resources to ensure that the citizens of these cities had sufficient water to meet demands of the late 20th century. The Highlands Water Preservation and Planning Act was passed to continue protecting the resources of these cities for the 21st century. Unlike the cities, Andover Township is located near the headwaters of its water resources and does not have the option of preserving lands upstream to ensure long-term water supplies. Andover Township and its residents must rely on the resources beneath the Township.

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 Andover Township and neighboring municipalities in Sussex 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.

4. A compilation of data from wells completed within Andover Township and surrounding municipalities.

The data/information from this review was used to assess the groundwater resources and to develop a conceptual model of the hydrogeologic conditions beneath the Township. The model was used to identify areas of the Township with differing hydrogeologic capabilities to receive recharge, and store and transmit groundwater, and to asses the interrelationship/interdependence between the aquifer and surface-water systems throughout. The model was also used to assess potential concerns and impacts to water quality from existing and possible future contaminant sources. From the model, areas of the Township were identified, where groundwater resources are limited or are of such high value for current and future generations that protective measures should be considered.

GEOLOGY

LOCATION

Andover Township is bounded to the southwest by Andover Borough and Green Township; to the west by Fredon Township, Hampton Township, and the Town of Newton; to the north by Lafayette Township; and to the east by Sparta and Byram Townships. Figure 1 shows the location of Andover Township in Sussex County and New Jersey.

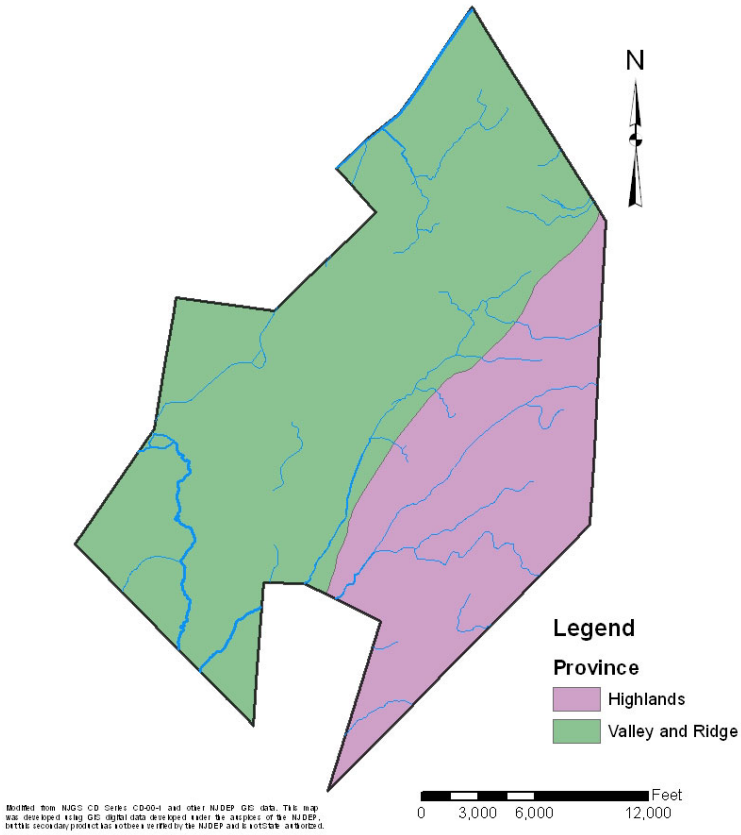
POPULATION DENSITY

Andover Township encompasses 20.86 square miles. Based on land area, Andover Township is the 12th largest municipality within Sussex County but based on 2000 population counts, is the eighth most populated municipality in the County. The US Census' 2000 data indicate that Andover Township is the 13th most densely populated municipality in Sussex County and has remained in this position since 1980. Between 1980 and 2000, the density increased from 216 persons per square mile to 289 persons per square mile. Based on the US Census population estimate for 2008, the population density for Andover Township has increased to 313 persons per square mile.

PHYSIOGRAPHIC PROVINCE

The western portion of Andover Township is located within the Valley and Ridge Physiographic Province and the eastern portion within the Highlands Physiographic Provinces. Approximately 66 percent of the land area of the Township is located within the Valley and Ridge Province as shown on Figure 2 with the remaining 34 percent located within the Highlands Province. The Highlands Physiographic Province is based on geologic conditions and although there is some overlap, it is distinct from the portions of New Jersey labeled Highlands Preservation and Planning Areas. The Highlands Physiographic Province is a much larger area comprised of similar bedrock geology and geomorphic characteristics.

Figure 2: Physiographic Provinces Beneath Andover Township.



The Highlands Physiographic Province is characterized by steep rounded to flat-topped ridges separated by narrow valleys. The Valley and Ridge Province is characterized by steep, linear ridges separated by broad valleys. In both provinces, the valleys are underlain by softer, more easily weathered sedimentary rocks and the ridges by dense, weather-resistant rock. Typically, below the surface the ridges within the Highlands Province are erosion-resistant Precambrian (older than 570 million years) igneous and metamorphic rocks and the valleys are underlain by more easily eroded Cambrian and

Ordovician (440 to 570 million years old) sedimentary and meta-sedimentary rocks. The valleys and ridges beneath the Valley and Ridge Province are underlain by sedimentary rocks but those beneath the ridges are more resistant to weathering and erosion.

TOPOGRAPHY

Based on USGS 7.5-minute Newton East, Newton West, Tranquility, and Stanhope, New Jersey topographic quadrangles, the highest elevation within Andover Township is approximately 1,120 feet above mean sea level (amsl). This high point is located in the southeastern portion of the Township, south and east of Andover-Mohawk Road. The lowest elevation within the Township is approximately 560 feet amsl. The low points are located in the southern section, west of Andover Borough where the Pequest River drains from the Township, and in the northwestern corner where the Paulins Kill flows along the boundary with Hampton Township.

The eastern section of the Township, which as discussed above is part of the Highlands Physiographic Province, is characterized by steep rounded ridges. The western two-thirds of the Township is separated by a low ridge extending to the northeast from the radio tower between Camp St. Benedict and Twin Lakes to the northern municipal boundary with Lafayette Township. This ridge approximately parallels Goodale, Lake Iliff, and Lawrence Roads as they trend to the northeast across the Township.

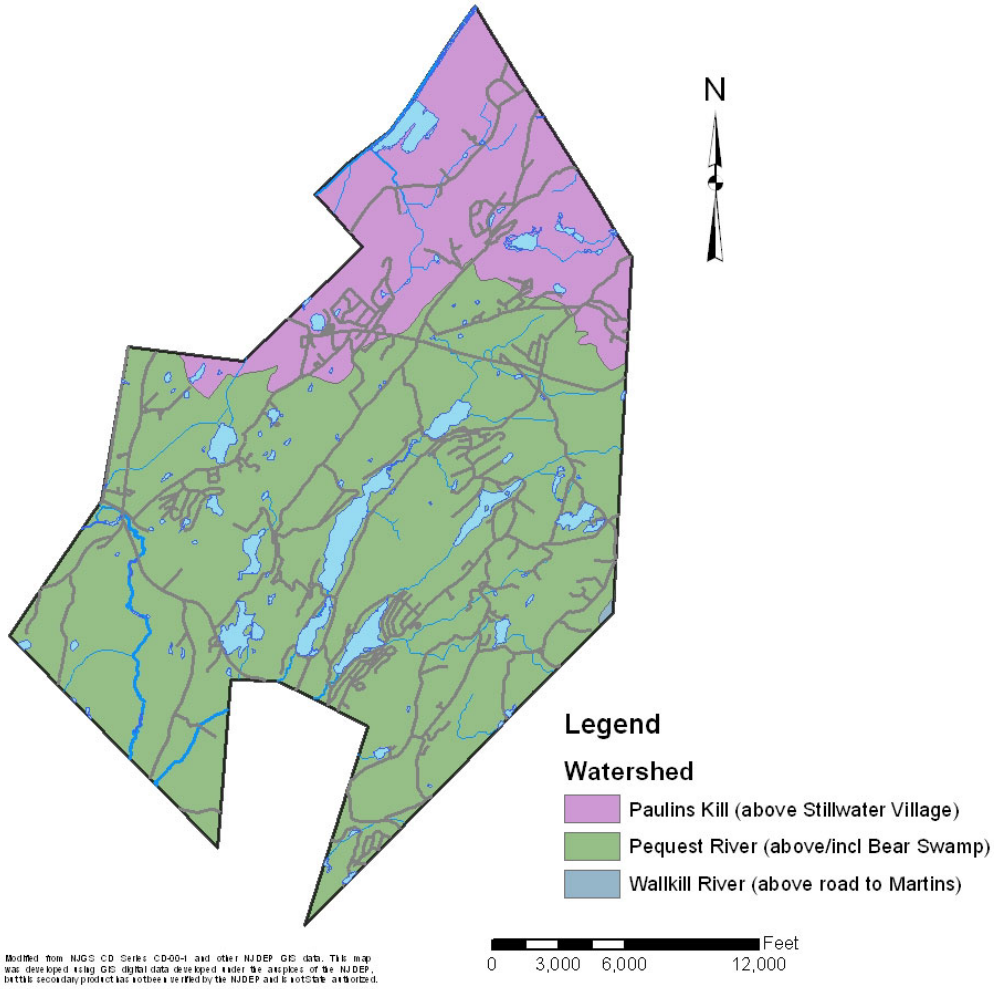
East of the ridge is the Germany Flats Valley, which narrows near Lake Iliff and New Wawayanda Lake between the ridge and the Highlands Province. This eastern valley is drained by Kymer Brook before merging with the Pequest River. To the southeast of the terminus of the ridge near Twin Lakes is the valley formed by the main branch of the Pequest River. Northwest of the low ridge is the drainage valley for the Paulins Kill.

SURFACE WATER

Watersheds

The USGS has mapped three watersheds beneath Andover Township. Approximately 8-acres or 0.06-percent of the Township land area are located within the Walkill River drainage basin in the eastern portion of the Township. The northern 4.9-square miles of the Township is located within the Paulins Kill drainage basin and the southern nearly 16-square miles are located in the Pequest River watershed. Headwaters for streams within these watersheds are located within Andover Township. The USGS used local topography to identify the extent of the watersheds within the Township. The watersheds extents are shown on Figure 3.

Figure 3: Watersheds Beneath Andover Township.



Stream Classifications

Each of these watersheds was further divided into subwatersheds by the USGS of which, there are eight beneath the Township. However, there are no streams mapped within the Walkill River, Trout Brook/Lake Tranquility, and Pequest River (Trout Brook to Brighton) subwatersheds in Andover Township. NJDEP designated streams have been mapped in five of the eight subwatersheds.

Streams within Andover Township have been designated by the NJDEP in N.J.A.C. 7:9B Surface Water Quality Standards for various levels of regulatory protection. FW2 waters are general classification freshwaters found in most parts of New Jersey. A TP designation indicates waters with sufficient quality to allow for trout production; whereas, TM indicates high-quality waters in which, trout populations can be maintained. An NT designation indicates Non-Trout waters or waters incapable of sustaining a trout population. However, NT waters may be capable of sustaining other species. Trout are highly susceptible to changes in water quality and therefore, are used as an indicator of

stream conditions. Waters capable of allowing trout production or maintenance are considered high-quality waters. Waters designated NT can range from high quality to much lower quality depending on the upstream environment.

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

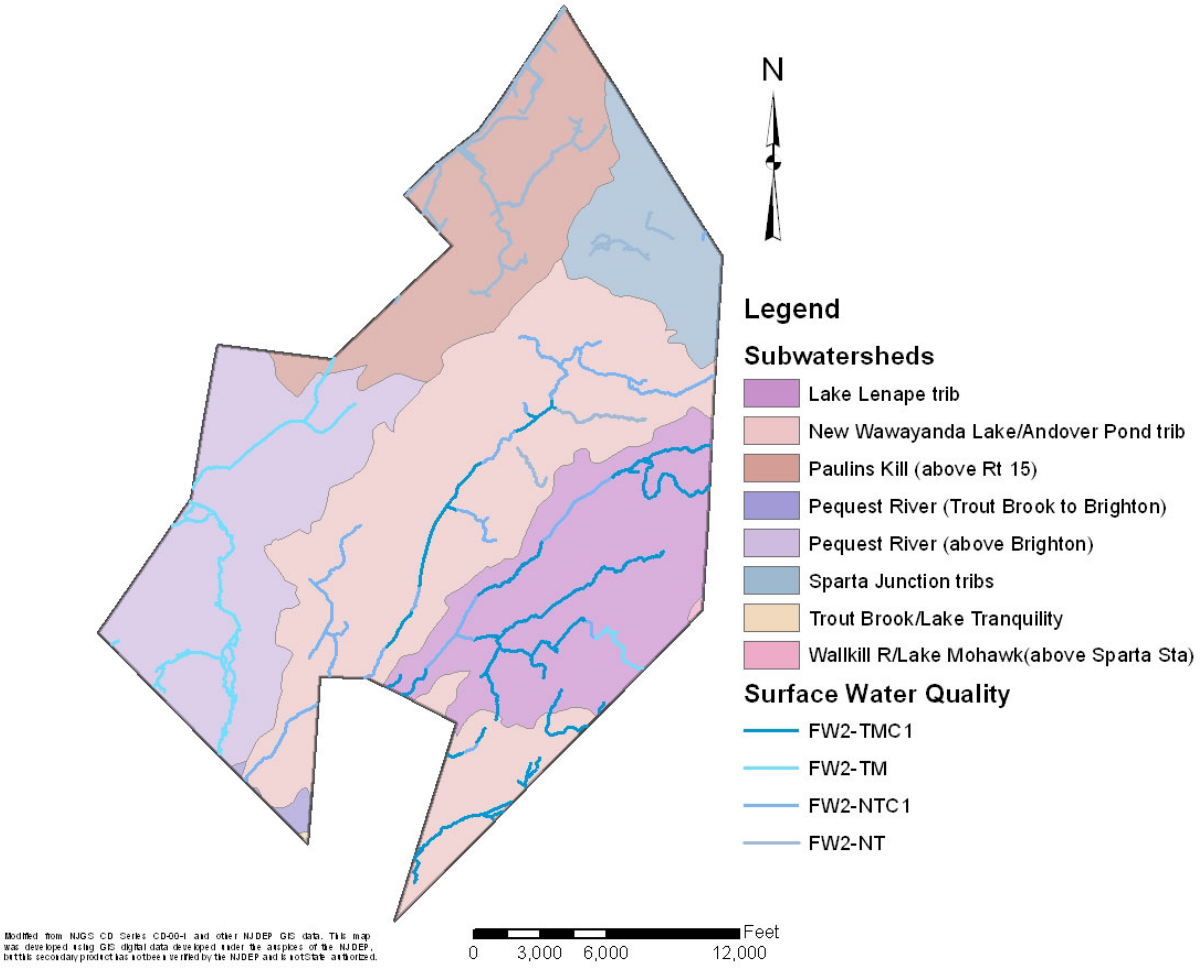
The following table summarizes the NJDEP classifications for the streams within Andover Township as of January 12, 2009 and provided through their GIS database. Figure 4 shows the locations of these streams and their classifications.

Watershed	Subwatershed	Surface Water Body	Water-Quality Classification
Paulins Kill	Paulins Kill (above Route 15)	Paulins Kill and Tributaries	FW2-NT
	Sparta Junction Tributaries	Uncoded Tributaries	FW2-NT
		Paulins Kill Unnamed Tributary	FW2-NTC1
Pequest River	Pequest River (above Brighton)	Pequest River and Tributaries	FW2-TM
	New Wawayanda Lake/Andover Pond Tributaries	Kymer Brook	FW2-NTC1
		Kymer Brook Unnamed Tributaries	FW2-NTC1
		Kymer Brook Unnamed Tributaries	FW2-NT
		Iliff Lake	FW2-TMC1
		Uncoded Tributary	FW2-NT
		New Wawayanda Lake	FW2-TMC1
		Gardners Lake	FW2-TMC1
		Twin Lakes	FW2-NTC1
		Whites Pond	FW2-NTC1
		Andover Junction Brook Unnamed Tributaries	FW2-TMC1
		Rocker Pond	FW2-TMC1
		Andover Junction Brook Unnamed Tributaries	FW2-TM
		Andover Junction Brook	FW2-TMC1
		Hemlock Lake	FW2-TMC1
	Lake Lenape Tributaries	Tar Hill Brook and Tributaries	FW2-TMC1
		Hidden Valley Lake	FW2-NTC1
		Lake Lenape	FW2-NTC1
		Valentines Pond	FW2-NTC1

Within the Paulins Kill Watershed in Andover Township, the streams are considered non-trout waters. One stretch of an unnamed tributary to the Paulins Kill near the northern border with Lafayette Township was mapped by NJDEP in its GIS database as FW2-NTC1 indicating this stretch is afforded protection through the NJDEP regulations from water-quality degradation.

As shown in the summary table above, the NJDEP has designated many of the surface-water bodies within the Pequest River Watershed in Andover Township as trout maintenance waters and most of these streams are also protected from degradation as Category 1 or C1 waters. Most of the non-trout waters within this watershed are also designated by NJDEP as C1 waters and therefore, are protected from degradation.

Figure 4: Surface-Water Classifications for Andover Township.



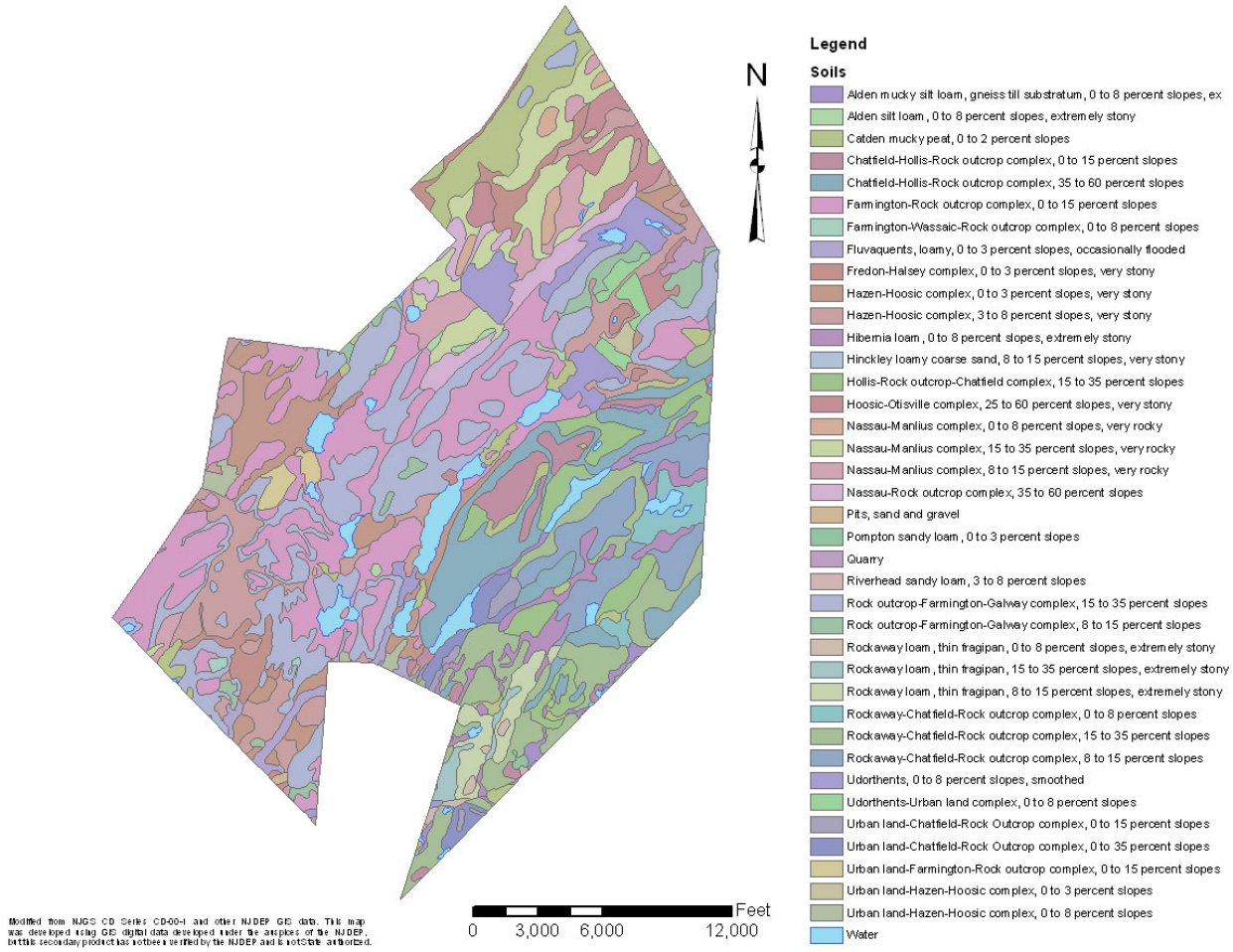
Andover Township's streams are considered high-quality resources worthy of protective measures. Surface-water bodies designated as C1 waters are protected from degradation resulting from discharges such as those from wastewater treatment plants. While it may be possible that a wastewater treatment plant could be developed that would not degrade surface-water quality, this type of facility is most likely, not economically feasible at this time. Therefore, discharges to groundwater through septic systems or small community wastewater treatment facilities would likely be the only option for disposal of wastewater from further development.

In addition to limitations for wastewater discharges to C1 streams, the February 2, 2004 stormwater regulations listed in N.J.A.C 7:8-5.5(h) indicates that on either side of each C1 stream, a 300-foot buffer must be maintained to protect these "special water resources". The buffers protect water quality, aesthetic value, ecological conditions, recreational benefits, water supplies, and fisheries. The presence of these buffers in conjunction with the limitations on wastewater disposal can significantly effect potential development within areas draining to these surface-water bodies.

SOILS

The U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) has mapped soils in New Jersey and these maps have been included in the NJDEP GIS. Based on the NRCS mapping, 27 soil types and areas covered with water have been delineated in Andover Township. Some of these general soil classifications are further subdivided based on slope gradients. The soil classifications along with areas surface-water bodies are shown on Figure 5.

Figure 5: Soils Beneath Andover Township.



The following table summarizes soil types, map symbols as depicted on Figure 5, slope ranges, and approximate total area within the Township beneath which these soils have been mapped. USDA-NRCS mapping indicates that 3.5 percent of the land area within the Township borders is covered with water. An additional nearly 9 percent of the Township land area is covered with soils considered hydric or occasionally flooded. The soils mapped as part of a rock outcrop complex encompass more than 57 percent of the

land area within the Township, indicating that bedrock is shallow beneath the majority of the Township. Soils indicating steep slopes (greater than or equal to 15 percent) have been mapped beneath nearly 39 percent of the Township. The areas with soils designated Quarry or Pits were not included in the steep slopes.

Soil Type	Map Label	Slope Range (percent)	Area (acres)
Alden silt loam, extremely stony	AhbBc	0 to 8	38.49
Alden mucky silt loam, gneiss till substratum	AhcBc	0 to 8	79.49
Catden mucky peat	CatbA	0 to 2	612.80
Chatfield-Hollis-Rock outcrop complex	ChkC	0 to 15	257.65
	ChkE	35 to 60	814.84
Farmington-Rock outcrop complex	FaxC	0 to 15	1995.52
Farmington-Wassaic-Rock outcrop complex	FdwB	0 to 8	15.19
Fluvaquents, loamy, occasionally flooded	FmhAs	0 to 3	107.68
Fredon-Halsey complex, very stony	FrdAb	0 to 3	340.70
Hazen-Hoosic complex, very stony	HdxAb	0 to 3	605.10
	HdxBb	3 to 8	896.61
Hibernia loam, extremely stony	HhmBc	0 to 8	304.72
Hinckley loamy coarse sand, very stony	HkrgCb	8 to 15	0.48
Hollis-Rock outcrop-Chatfield complex	HncD	15 to 35	436.79
Hoosic-Otisville complex, very stony	HopEb	25 to 60	292.18
Nassau-Manlius complex, very rocky	NauBh	0 to 8	85.13
	NauCh	8 to 15	285.07
	NauDh	15 to 35	636.12
Nassau-Rock outcrop complex	NavE	35 to 60	273.49
Pits, sand and gravel	PHG		11.58
Pompton sandy loam	PohA	0 to 3	10.50
Quarry	QY		50.97
Riverhead sandy loam	RkrB	3 to 8	9.13
Rock outcrop-Farmington-Galway complex	RnfC	8 to 15	199.76
	RnfD	15 to 35	1876.97
Rockaway loam, thin fragipan, extremely stony	RoefBc	0 to 8	24.55
	RoefCc	8 to 15	186.66
	RoefDc	15 to 35	66.23
Rockaway-Chatfield-Rock outcrop complex	RokB	0 to 8	157.49
	RokC	8 to 15	511.27
	RokD	15 to 35	810.83
Udorthents, smoothed	UdaB	0 to 8	425.22
Udorthents-Urban land complex	UdauB	0 to 8	106.60
Urban land-Chatfield-Rock Outcrop complex	USCHRC	0 to 15	58.46
	USCHRD	0 to 35	137.90
Urban land-Farmington-Rock outcrop complex	USFARC	0 to 15	75.08
Urban land-Hazen-Hoosic complex	USHAZA	0 to 3	27.27
	USHAZB	0 to 8	61.06
Water	Water		469.91

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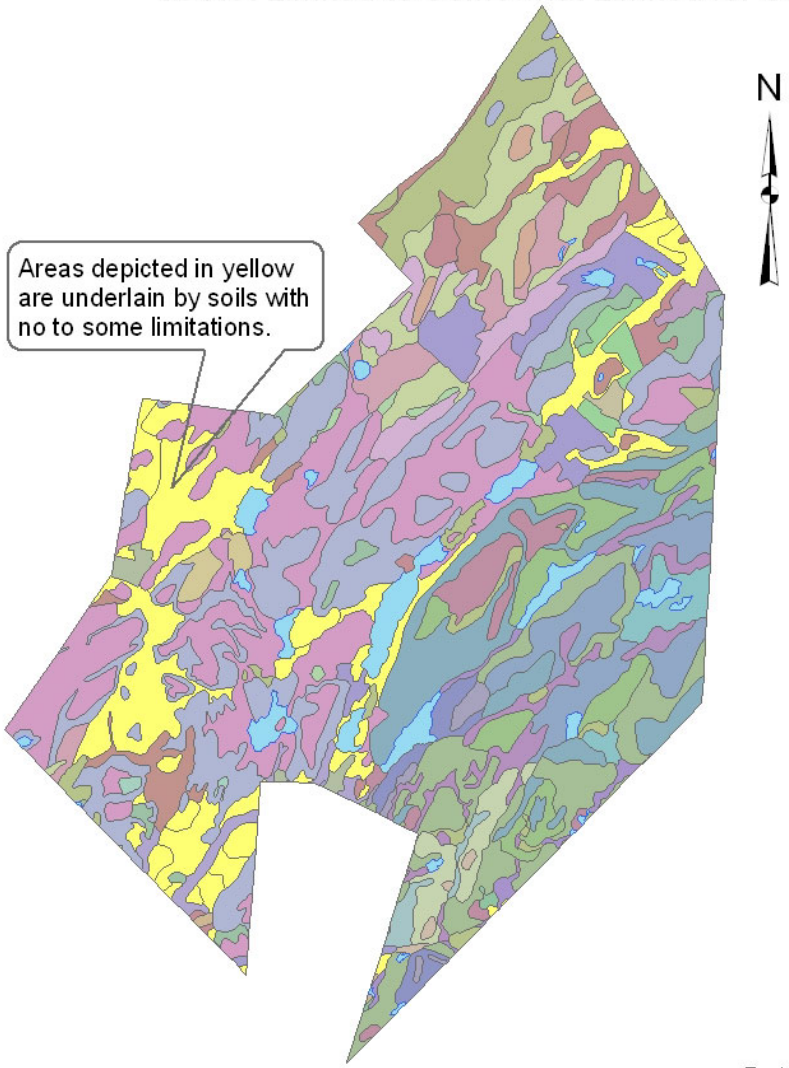
The USDA-NRCS mapping data and N.J.A.C 7:9A were used to evaluate limitations for wastewater disposal through septic systems and suitability of these types of systems for soils mapped beneath Andover Township. Limitations and the septic suitability ratings soils within the Township are summarized as follows:

Map Label	Septic Limitations and N.J.A.C 7:9A Septic Suitability Ratings
AhbBc	Very limited-shallow groundwater, hydric soil. IIIWr-Unsuitable to not permitted.
AhcBc	Very limited-shallow groundwater, hydric soil. IIIWr-Unsuitable to not permitted.
CatbA	Very limited-shallow groundwater, hydric soil. IIIWr-Unsuitable to not permitted.
ChkC	Very limited-shallow restrictive substratum and massive bedrock. IIISr-Unsuitable.
ChkE	Very limited-shallow restrictive substratum and massive bedrock, and steep slopes. IIISr-Unsuitable to not permitt
FaxC	Very limited-shallow depth to massive bedrock. IIISr-Unsuitable.
FdwB	Very limited-shallow depth to massive bedrock. IIISr-Unsuitable.
FmhAs	Very limited-shallow groundwater, hydric soil, and flooding. IIIWr-Unsuitable to not permitted.
FrdAb	Very limited-shallow groundwater, excessively coarse horizon, possible hydric soil. IIIWr-Unsuitable, Not permittec
HdxAb	Not limited to somewhat limited by coarse horizon. I to IIHc or IISc.
HdxBb	Not limited to somewhat limited by coarse horizon. I to IIHc or IISc.
HhmBc	Very limited-shallow groundwater and restrictive substratum/horizon. IIIWP, IIIHr, IIISr-unsuitable.
HkrgCb	Somewhat limited-excessively coarse horizon/substratum. IIHc, IISc.
HncD	Very limited-shallow restrictive substratum and massive bedrock. IIISr-Unsuitable.
HopEb	Very limited-steep slopes, excessively coarse horizon or substratum. Not permitted on steep slopes. IIHc, IISc.
NauBh	Very limited-shallow restrictive substratum and massive bedrock, and excessively coarse horizon. IIISr-Unsuitable
NauCh	Very limited-shallow restrictive substratum and massive bedrock, and excessively coarse horizon. IIISr-Unsuitable
NauDh	Very limited-shallow restrictive substratum and massive bedrock, and excessively coarse horizon. IIISr-Unsuitable
NavE	Very limited-shallow restrictive substratum, steep slopes, and massive bedrock, and excessively coarse horizon. IIISr-Unsuitable, Not permitted, IIHc.
PHG	Not rated.
PohA	Very limited-shallow groundwater. IIIWr-Unsuitable.
QY	Not rated.
RkrB	Somewhat limited-excessively coarse horizon and substratum, depth to groundwater. IIHc, IISc, IIWr.
RnfC	Very limited-Depth to massive bedrock. IIISr-Unsuitable.
RnfD	Very limited-Depth to massive bedrock. IIISr-Unsuitable.
RoefBc	Very limited-shallow restrictive substratum/horizon, depth to groundwater. IIIHr, IIIWp, IIISr-Unsuitable.
RoefCc	Very limited-shallow restrictive substratum/horizon, depth to groundwater. IIIHr, IIIWp, IIISr-Unsuitable.
RoefDc	Very limited-shallow restrictive substratum/horizon, depth to groundwater. IIIHr, IIIWp, IIISr-Unsuitable.
RokB	Very limited-shallow restrictive substratum/horizon, depth to groundwater. IIIHr, IIIWp, IIISr-Unsuitable.
RokC	Very limited-shallow restrictive substratum/horizon, depth to groundwater. IIIHr, IIIWp, IIISr-Unsuitable.
RokD	Very limited-shallow restrictive substratum/horizon, depth to groundwater. IIIHr, IIIWp, IIISr-Unsuitable.
UdaB	Very limited-restrictive substratum/horizon. IIIHr, IIISr-Unsuitable.
UdauB	Very limited-restrictive substratum/horizon. IIIHr, IIISr-Unsuitable.
USCHRC	Not rated to very limited. Restrictive substratum and massive bedrock. IIISr-Unsuitable.
USCHRD	Not rated to very limited. Restrictive substratum and massive bedrock. IIISr-Unsuitable.
USFARC	Not rated to very limited. Shallow depth to massive bedrock. IIISr-Unsuitable.
USHAZA	Not rated to not limited to somewhat limited. Excessively coarse horizon/substratum. I, IIHc, IISc.
USHAZB	Not rated to not limited to somewhat limited. Excessively coarse horizon/substratum. I, IIHc, IISc.

The mapping and NJDEP regulations indicate that more than 87 percent of the land area within the Township is underlain with soils characterized by NRCS as very limited for wastewater disposal. Nearly 85 percent of the land area is underlain by soils that are considered in N.J.A.C 7:9A as unsuitable for construction of septic systems. The limitations include shallow groundwater, massive bedrock, restrictive substratum or horizons, hydric soils, flooding, and steep slopes. Areas of the Township with soils listed by NRCS as not limited to somewhat limited are shown on Figure 6.

Water: A Natural Renewable Resource

Figure 6: Areas of Andover Township with Soils Classified as Not Limited to Somewhat Limited for Septic Systems.



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

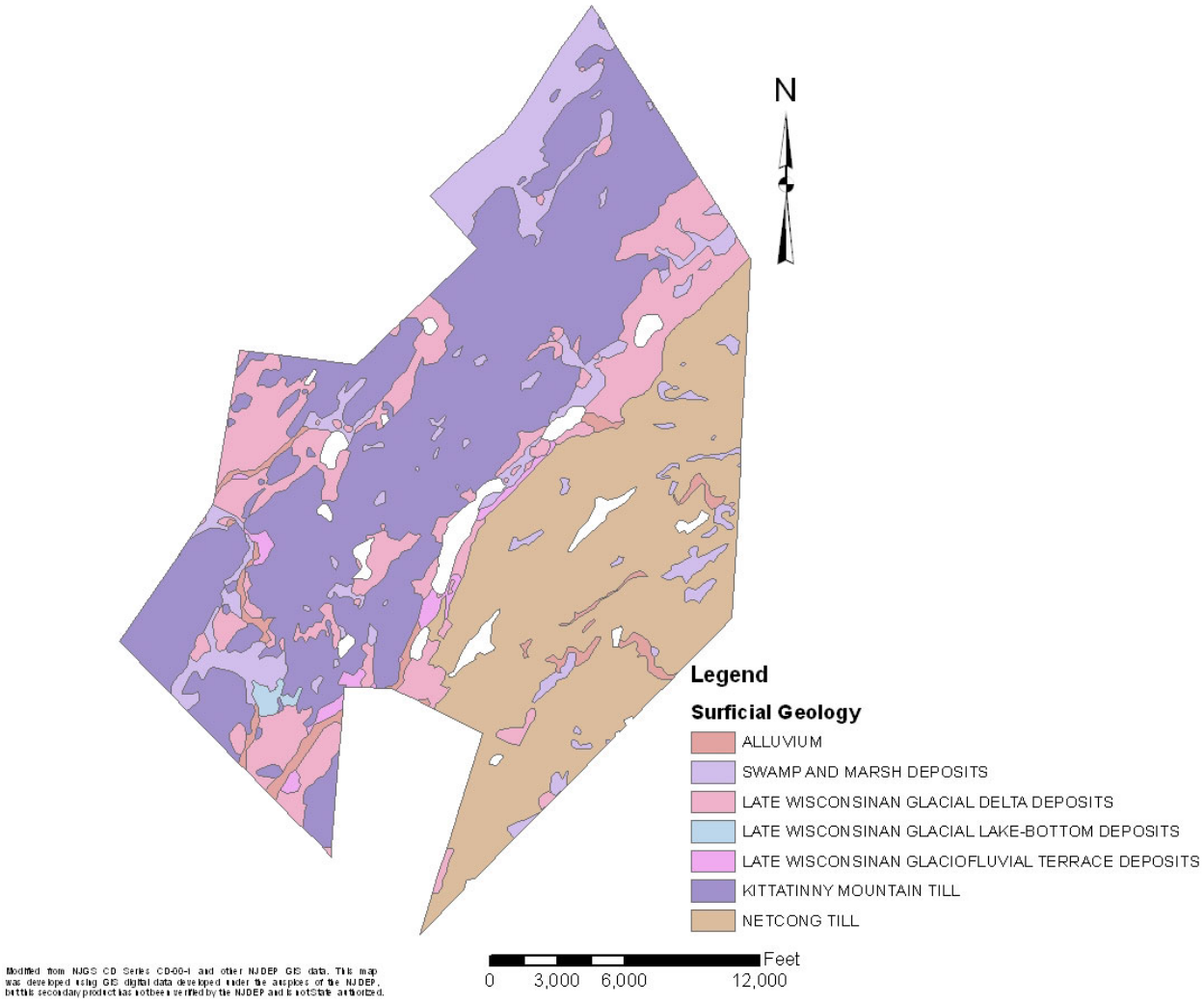
Nearly all of the areas of the Township underlain by soils with no to moderate limitations for septic systems are in turn underlain by carbonate rock. Wastewater disposed through a septic system into carbonate bedrock could result in significant impacts including sinkholes and degraded groundwater quality. In summary, soils beneath more than 85 percent of Andover Township are limited with respect to disposal of wastewater via septic systems. In those areas where soils are not a limiting factor, bedrock should be evaluated to minimize or reduce the potential for sinkhole development and/or adverse impacts to groundwater quality.

Water: A Natural Renewable Resource

SURFICIAL GEOLOGY

Andover Township is located in a previously glaciated portion of New Jersey. As such, glacial deposits have been mapped beneath portions of the municipality. Figure 7 shows the surficial geology for the area as based on mapping completed by New Jersey Geological Survey (NJGS) and provided through the NJDEP GIS database (Stone, et al. 2002).

Figure 7: Surficial Geology Beneath Andover Township.



The youngest deposits are alluvium and swamp sediments found along streams, stream banks, and beneath wetlands. The alluvial deposits encompass approximately 259 acres and are comprised of up to 20 feet of red-brown, yellow-brown, brown, and gray sand, gravel, silt, some clay and peat. The swamp deposits have been mapped beneath approximately 1,280 acres or nearly 10 percent of the Township land area. These

recent deposits are comprised of as much as 40 feet of brown, gray and black peat and organic clay with lesser percentages of silt and sand.

As a result of Wisconsinan glaciation (10,000 to 100,000 years ago), deltaic, lake-bottom, fluvial, and till deposits are present beneath approximately 1,969 acres or 15 percent of Andover Township. The deltaic deposits have been mapped near modern streams, rivers, and lakes. The deltaic sediments can range to 150 feet in thickness and are primarily comprised of red-brown, yellow-brow, brown, and light gray sand, pebble-to-cobble-sized gravel, with some silt. At locations where these sediments are well-stratified with little to no silt and greater than 70 feet in thickness, they likely represent significant groundwater resources. These deposits may serve as direct sources of water to wells completed in the sediments or as indirect sources through leakage into underlying bedrock aquifer systems. The NJGS indicates that the greatest thicknesses of the delta deposits have been mapped along Kymer Brook (Lake Iliff and New Wawayanda Lake area) and in the western portions where the Paulins Kill drains from the Township and Pequest River crosses the municipal border.

Glacial lake deposits are rarely significant direct groundwater resources and are usually aquitards or layers that have very limited ability to transmit water. These deposits may leak water into underlying bedrock or stratified-drift aquifer systems. Within Andover Township, the lake deposits have been mapped beneath approximately 44 acres in an area mapped by USGS as swamp/marsh and therefore, are not significant groundwater resources. These lacustrine deposits are comprised primarily of brown, gray-brown, yellow-brown silt, clay, and some fine-grained sand.

Glacial fluvial sediments were deposited by streams and rivers draining from the ice-sheet or glacier. These deposits are comprised of red-brown, yellow-brown, brown sand, pebble-to-cobble-sized gravel, with lesser percentages of silt. The fluvial and associated terrace deposits may range to 40 feet in thickness and have been mapped beneath approximately 138-acres or approximately 1 percent of the Township. The fluvial sediments, given the limited thickness, are unlikely direct groundwater resources but may indirectly provide water to some wells located in the immediate vicinity. However, where these fluvial deposits are buried by younger materials, they are likely to be significant direct sources of groundwater. These fluvial deposits may store water that drains to underlying stratified glacial or bedrock aquifers. At Kittatinny Valley State Park, fluvial deposits have been mapped at ground surface but it is likely that these deposits are in turn, underlain by other glacial sediments as the thickness of unconsolidated materials at this location is reported on a well record to be at least 325 feet.

Till deposits are the most common surficial sediments mapped beneath Andover Township. Beneath the western valley areas, Kittatinny Mountain Till has been mapped and beneath the eastern Highlands Province, Netcong Till is mapped. Both of these till deposits are comprised of heterogeneous mixtures of silt, clay, sand, pebble-to-cobble-sized gravel and occasional boulders. The Kittatinny Mountain Till has been mapped beneath approximately 40 percent of the Township land area and may range to 40 feet in thickness. The Netcong Till has been mapped beneath approximately 31 percent of

the Township and may range to 30 feet in thickness. Based on the soils mapping, it is unlikely that either of these till deposits exceeds 10 to 20 feet in thickness beneath Andover Township. In most areas where the till has been mapped by NJGS, the USDA-NRCS has mapped soils associated with rock outcrops. Till deposits are rarely significant direct groundwater resources and given the limited thicknesses likely beneath Andover Township, they are not considered significant direct groundwater resources that could be exploited with wells.

In summary, thick glacial deposits have been mapped beneath slightly more than 900-acres of Andover Township. Near the Kittatinny Valley State Park ranger station, the combined thickness of these deposits extend to at least 325 feet below ground surface indicating that in the Lake Iliff to New Wawayanda Lake valley, these unconsolidated sediments could be useful groundwater resources. However, except for a few locations along major rivers or valleys within the Township, it is unlikely that these deposits are significant direct groundwater resources such that they yield water to wells completed in the deposits. Where sufficient thicknesses of glacial deposits are encountered and where these materials have hydraulic connection to subsurface bedrock aquifers, they could serve as reservoirs leaking water into underlying bedrock aquifers.

At locations where water-table aquifers are present in the glacial deposits and these shallow groundwater systems are not hydraulically connected to underlying bedrock aquifers, they may offer some protection from water-quality impacts resulting from discharges of contaminants including those released by septic systems. The characteristics of glacial deposits beneath parcels proposed for development within the Township should be evaluated to determine potential levels of protection and the hydraulic connection with underlying water-supply aquifers.

BEDROCK

As discussed above, Andover Township is located within two physiographic provinces. The 34 percent of the Township near the eastern municipal boundary is located within the Highlands Physiographic Province and the bedrock underlying this section of the Township is likely more than 1-billion years old. Approximately 66 percent of the land area of the Township is located within the Valley and Ridge Province and bedrock beneath this western section ranges from 440 to 570 million years old.

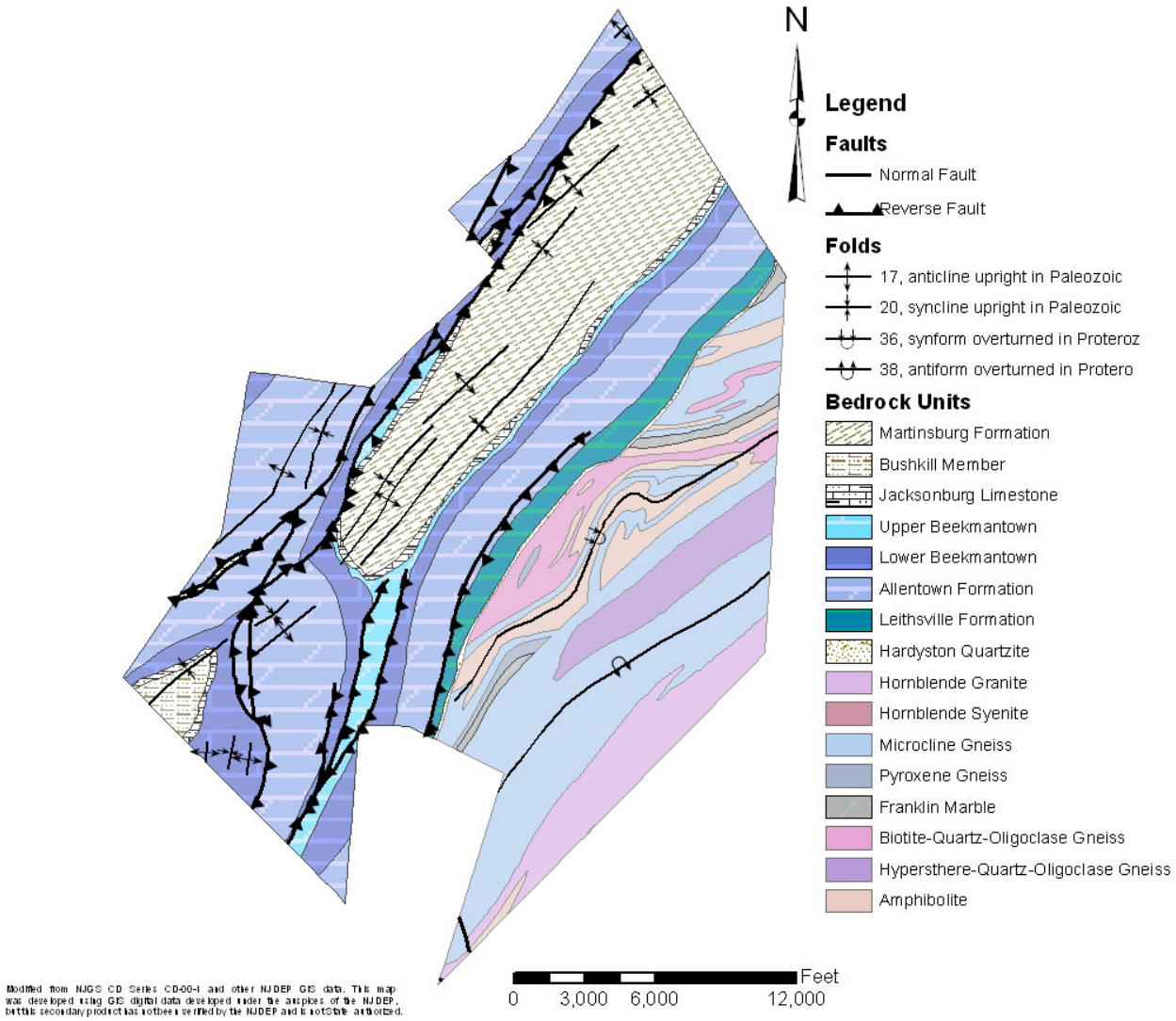
The Precambrian rocks beneath the Highlands Province are igneous and metamorphic and as a result, are highly resistant to erosion forming the ridges near the eastern boundary. The younger rocks are primarily limestones, dolomites, slates and other sedimentary rocks. The more weather-resistant slates and shales are present beneath the ridges in the western portion of the municipality and the softer, more easily weathered carbonate rocks are mapped beneath the valley floors.

The bedrock geology of Andover Township is shown on Figure 8, which was developed from the NJGS 2007 (most recent) distribution of its 1999 “Bedrock Geology of New Jersey” in Geographic Information System (GIS) format. This figure and the GIS

Water: A Natural Renewable Resource

coverage are based on the map entitled “Bedrock Map of Northern New Jersey” (Drake et al. 1996), which was developed from extensive geologic mapping completed by the United States Geological Survey (USGS) and NJGS.

Figure 8: Bedrock Geology Beneath Andover Township.



The Precambrian igneous and metamorphic rocks beneath the eastern section of the Township are amphibolite, gneiss, marble, syenite, and granite. Thirty-four percent or 4,528 acres of the Township, is underlain by these crystalline rocks. With the exception of the Franklin Marble, which has been mapped beneath approximately 106 acres, the Precambrian rocks have some minor differences in mineralogy and formational history but are considered siliceous or almost entirely comprised of silicate minerals. With

respect to groundwater resources, these rocks have very similar characteristics including highly resistant to erosion, dense, hard, and poorly to weakly fractured. These rocks are over a billion years old and still form the ridges at some of the highest elevations within the Township and Highlands Physiographic Province.

Franklin Marble is a Precambrian metamorphic rock. Where the other Precambrian rocks beneath Andover Township are primarily comprised of silicate minerals, the marble is derived from carbonate minerals. The USGS describes Franklin Marble as white to gray, pink-orange; coarse- to fine-grained, crystalline calcite marble. The presence of calcite makes the Franklin Marble a carbonate rock. Carbonate rocks are highly susceptible to weathering and dissolution. Cavities may be present within carbonate rocks and these enlarged openings can store and transmit very large quantities of groundwater. Franklin Marble has been mined at Limecrest Quarry in the northeastern corner of Andover Township and has been mapped as two narrow bands elsewhere within the Township.

Beneath 66 percent of Andover Township the USGS/NJGS has mapped Cambrian-Ordovician quartzite, dolomite, limestone, siltstone, shale, and slate rocks (Drake et al. 1996). From oldest to youngest, these rocks are as follows:

> Hardyston Quartzite – is described by USGS (Drake et al. 1996) as medium- to light-gray, fine- to coarse-grained, medium- to thick-bedded quartzite and sandstone. The Hardyston Quartzite may range in thickness to 200 feet beneath New Jersey and has been mapped beneath approximately 72 acres or 0.5 percent of the Township land area.
>
> Leithsville Formation – is described by USGS as thin- to thick-bedded dolomite. With upper units of medium- to medium-dark gray, fine- to medium-grained dolomite. The middle units are medium-gray, fine-grained, thin- to medium-bedded dolomite interbedded with shaly dolomite. The lower part is medium-gray, medium-grained, medium-bedded dolomite. The Leithsville Formation may achieve thicknesses in New Jersey ranging to 1,000 feet and has been mapped beneath approximately 502 acres or 3.8 percent of the Township.
>
> Allentown Formation – is described by USGS as very-thin to thick-bedded dolomite with minor shale and quartzite. The upper units are medium-light to medium-dark gray, fine- to medium-grained, medium- to thick-bedded dolomite. The middle units are comprised of two sequences of medium-light to very-light gray, thin-bedded quartzite and discontinuous chert beds. The lower units are rhythmically bedded alternating medium and very-light-gray, fine- and medium-grained, and thin- and medium-bedded dolomite interbedded with shaly dolomite. The shaly dolomite increases toward the contact with the older Leithsville Formation (Drake et al. 1996). The Allentown Formation is often characterized by the presence of oolites and stromatolites and therefore, can be distinguished from other carbonate rocks. The Allentown Formation has been measured to

1,900 feet thick in New Jersey and mapped beneath nearly 3,350 acres or slightly more than 25 percent of the Township land area.

The Lower Beekmantown Formation - is described by USGS from the upper to middle portions of the formation as light-olive-gray to dark-gray, fine- to medium-grained, thin- to thick-bedded dolomite; to olive-gray to dark-gray, aphanitic to fine-grained, laminated to medium-bedded dolomite and medium-dark to dark-gray, fine-grained, thin- to medium-bedded limestone. The lower beds are medium-light to dark gray, aphanitic to coarse-grained, laminated to medium-bedded, dolomite with thin black chert beds, quartz-sand and oolites (Drake et al. 1996). The thickness of the Lower Beekmantown can range to 600 feet beneath New Jersey and these dolomites/limestones have been mapped beneath slightly more than 1,600 acres or 12 percent of Andover Township's land area.

Upper Beekmantown Formation - is described by the USGS as medium-light to medium-gray, aphanitic to medium-grained, thin- to thick-bedded, dolomite with local medium-dark to dark-gray, fine-grained, medium-bedded limestone. The lower beds of this formation are described as medium-dark to dark-gray, medium- to coarse-grained, medium- to thick-bedded, dolomite with black chert (Drake et al. 1996). This unit can range in thickness to 800 feet beneath New Jersey and has been mapped by the USGS/NJGS beneath nearly 450 acres or approximately 3.3 percent of the land surface in Andover Township.

Jacksonburg Limestone - is described by the USGS as medium- to dark-gray, laminated to thin-bedded shaly limestone to medium- to dark-gray, fine- to medium-grained, very thin to medium-bedded fossiliferous limestone interbedded with medium- to thick-bedded dolomite-cobble conglomerate in a limestone matrix (Drake et al. 1996). The thickness of this unit may range to 800 feet beneath New Jersey and this formation has been mapped by the USGS/NJGS beneath approximately 242 acres or 1.8 percent of the Township.

Bushkill Member of Martinsburg Formation – is described by the USGS as medium- to dark-gray, thinly laminated to thick-bedded shale and slate interbedded with medium-gray to brown-gray, laminated to thin-bedded siltstone. The thickness of this unit can achieve 1,250 feet in sections of New Jersey and as mapped by USGS/NJGS, it is present beneath approximately nearly 130 acres or 1 percent of the Township land area.

Martinsburg Formation – the undifferentiated Martinsburg Formation is described as medium-dark to dark gray, laminated to medium-bedded graywacke and siltstone interbedded with medium-dark to dark-gray slate. This unit is characterized by turbidite sequences. This unit has been mapped to 1,000 feet in thickness beneath New Jersey and nearly 2500 acres or 19 percent of the Andover Township land area. While a distinction is made between the Bushkill Member and the undifferentiated Martinsburg Formation for geologic purpose, these two units are virtually identical from a hydrogeologic perspective.

The Leithsville, Allentown, Lower and Upper Beekmantown, and Jacksonburg Formations are all comprised of carbonate rocks such as limestones and dolomites, which, when exposed to acidic solutions including weakly acidic rainwater, will dissolve forming solution cavities, voids, caves, and caverns. There may be as many as 14 mapped caves near Andover Township indicating that solution cavities are extensive in the carbonate rocks, especially the Allentown Formation within the area (Dalton 1976). Carbonate rock aquifers have long been regarded as some of the best water-resources in the United States. The 1996 Statewide Water Supply Plan prepared by the NJDEP indicates that carbonate-rock aquifers are some of the most prolific systems in New Jersey. Since solution cavities can store and transmit large quantities of water, these carbonate rocks have distinctly different hydrogeologic characteristics than the Hardyston Quartzite, Bushkill Member and undifferentiated Martinsburg Formation.

The Hardyston Quartzite is most often included with nearby Precambrian rocks when assessing aquifer characteristics. Miller (1974) indicates that the Hardyston Quartzite and Precambrian rocks have "…similar hydrologic characteristics." The slates and shales of the Martinsburg Formation also create low-yielding aquifer systems, which may also have poor water-quality. Miller (1974) describes the Martinsburg Formation in Sussex County as "…quite tight and it is, on the whole, a very poor aquifer."

STRUCTURE

Secondary Porosity

Unconsolidated glacial deposits can store and transmit water through openings between grains or sediment particles. These openings are a measure of the primary porosity of the unconsolidated materials. As discussed above, except in a few areas of Andover Township, it is unlikely that these unconsolidated glacial sediments can be directly exploited to provide water to wells as they have insufficient thickness. However, groundwater stored in the intergranular openings can leak or drain vertically to underlying consolidated rock aquifers and supplement or replenish water withdrawn by wells completed in the underlying bedrock.

Rocks that form the bedrock beneath Andover Township do not have intergranular openings and therefore, do not have primary porosity for transmitting and storing groundwater. In bedrock, groundwater storage and transmittal are dependent on secondary porosity or openings between blocks of impermeable rock. In the carbonate rocks of the Leithsville, Allentown, Upper and Lower Beekmantown, and Jacksonburg Formations, these secondary openings are typically associated with solution features and fractures along fault planes, bedding discontinuities, and joints. In this area of New Jersey, solution openings can sometimes be several inches to more than 20-feet in diameter. While the fracture openings between blocks of impermeable rock are usually not as great, the zone where the rock is fractured may be several feet to several tens of feet across and the spacing between fractures may be measured in fractions of an inch.

In the Precambrian igneous and metamorphic rocks, and Hardyston Quartzite, fractures from faulting may be the only openings between the blocks of solid rock and often these openings are very small with several feet to several tens to hundreds of feet of impermeable rock between these hairline breaks. Within the Bushkill Member and undifferentiated Martinsburg Formation, fractures parallel or closely parallel to bedding and foliation formed as a result of folding are also likely present. While some of the fractures in these rocks resulted from tectonic activity hundreds of millions of years ago, more recent weather-related fractures resulted from unloading of the bedrock by retreating ice sheets and glaciers. The weathered openings are most often found at shallow depths and the frequency of openings quickly diminishes with increasing depth.

Faults

Within the Highlands, and Valley and Ridge Physiographic Provinces, there are two general types of faults. The first of these types of faults is a normal fault formed as a result of continents moving apart. These faults are most often found near the border between the Piedmont and Highlands Physiographic Provinces well east of Andover Township but in some cases, are found within the Highlands Province. Two very small and discontinuous normal faults have been mapped in the southeastern corner of Andover Township near Forest and Panther Lakes, which are located in neighboring Byram Township. These faults have limited extent and are oriented perpendicular to the regional border faults and therefore, do not indicate significant bedrock fracturing.

Reverse or thrust faults formed as a result of past continental collisions where blocks of rock were thrust over younger or contemporaneous blocks of rock is the second type of fault. The Jenny Jump and Tranquility Thrust and related faults are examples mapped beneath Andover Township within the Valley and Ridge Province. Movement on these faults was likely more than 400 million years ago and they are no longer considered active. These relic thrust faults have been mapped crossing through the western two-thirds of Andover Township (see Figure 8). All of these faults have been mapped within the carbonate rock formations with one forming the boundary between the Martinsburg Formation and adjoining carbonate rocks.

Where carbonate bedrock is fractured, the potential for increased dissolution of carbonate rock is increased because the already weakened rock can be more quickly dissolved. However, Miller (1974) indicates that faults in the carbonate rocks beneath Sussex and parts of Warren Counties are no longer zones of high intensity fracturing because of re-cementing. Calcite minerals dissolve in weak acidic solutions forming solution cavities. As the slightly acidic water moves through openings in the rock and contacts additional carbonate rock, the pH of the solution increases, and the dissolved calcite minerals re-precipitate. The precipitated calcite narrows or seals fracture openings. Stalactites and stalagmites are examples of calcite minerals dissolving at one location and re-precipitating to form these structures at another location.

So while carbonate rocks can be high volume sources of groundwater where solution cavities or caves are encountered, re-cementing or re-precipitation of calcite narrows or

seals tectonic fractures that in most areas of New Jersey, are considered high potential locations for exploiting groundwater resources. The presence of extensive faulting such as shown on local bedrock mapping would suggest a high probability of significant groundwater resources near these faults. However, in Andover Township and other areas of Sussex County, the very old faults transecting the carbonate rocks are likely no longer extensively fractured and therefore, have a lowered probability for developing groundwater resources.

In addition to the faulting, some of the rocks beneath Andover Township have been folded as a result of past tectonic activity (Drake et al. 1996). The Precambrian rocks in the eastern portion of the Township indicate a series of folds that were later overturned by continued compression associated with continental collision. In addition to the two folds mapped in the Precambrian rocks, folds have been mapped within carbonate rocks and Martinsburg Formation beneath the Township. While the presence of the folds is not indicative of the same extent of fracturing as would be expected near the faults, the folds are indicative of significant compressional forces and small scale fractures or foliations are likely to be present. These small fractures/ foliations may not transmit and store as much water as larger fractures formed by faulting, but they could permit groundwater to move from a shallow water-bearing zone to a deeper zone.

In summary, the structural geology of Andover Township indicates that the rocks beneath this municipality have undergone extensive faulting and folding as a result of past tectonic activity associated with continental collisions. The compressional history of these rocks indicates a significant potential for the rocks to be highly fractured in some areas of the Township such as in the southwestern and western portions where the Jenny Jump Thrust and related faults have been mapped or in the central section where the Tranquility Thrust and related faults cross through Andover Township. The extensive faulting and the presence of the carbonate rocks should indicate high potential for significant groundwater resources but as suggested by Miller (1974), it is likely that these fault zones have been re-cemented. Re-precipitation of minerals has narrowed or closed fractures limiting the storage and transmittal of groundwater within these former fault zones. The best groundwater resources beneath Andover Township are likely to be in areas where large solution cavities are present.

GROUNDWATER SYSTEMS

STORAGE AND TRANSMISSION CAPABILITY

In unconsolidated aquifers such as the glacial deposits in the Lake Iliff/New Wawayanda Lake valley, groundwater is stored and transmitted through pore spaces or openings between grains or particles. In well-stratified sand and gravel deposits, these openings are larger and therefore, more groundwater can be stored and transmitted. In poorly stratified or heterogeneous till deposits, or fine-grained lake deposits, the pore spaces are small and therefore, groundwater movement and storage is limited. The fine-grained lake deposits and heterogeneous tills can form confining layers over layers of

well-stratified fluvial or drift deposits. In some sections of Morris and Essex Counties, these stratified sand and gravel deposits are considered highly productive aquifers. In Andover Township, the glacial deposits are limited in extent and are unlikely to form aquifers as prolific as those found in the counties to the east. However, in some areas of the Township, these materials could serve as important sources of water.

Groundwater in bedrock aquifer systems is stored and transmitted along fractures, joints, bedding planes, and in carbonate rocks within solution openings. Therefore, the availability of water is dependent on the separation between fractures/openings, the degree to which these fractures/openings are interconnected, and weathering of the materials between fracture planes and solution features. In some rocks, fractures or openings are separated by a few inches or less of competent, unweathered, and impermeable bedrock. In other rocks, the distance between fractures/openings may be several feet to several tens or hundreds of feet. Usually near major regional faults, open fracture form highly connected networks that can store and transmit large quantities of water. Distant from faults or major solution features, where groundwater movement and storage is dependent on a single or few open fractures, groundwater resources will have much less potential for meeting regional or local demands.

USGS studies indicate that weathering is greatest within 75 feet of ground surface and is negligible at depths greater than 500 feet. Since weathering increases fracture size and could increase fracture interconnection, much of the water derived from a well is likely to come from shallow portions of the aquifer. In some formations such as the carbonate rocks, high yielding fractures are often intersected at depths exceeding 75 feet. In other rocks such as the Precambrian igneous and metamorphic rocks, Cambrian Hardyston Quartzite, and Ordovician Martinsburg Formation high yielding fractures are less likely to be encountered at depths in excess of 150 feet.

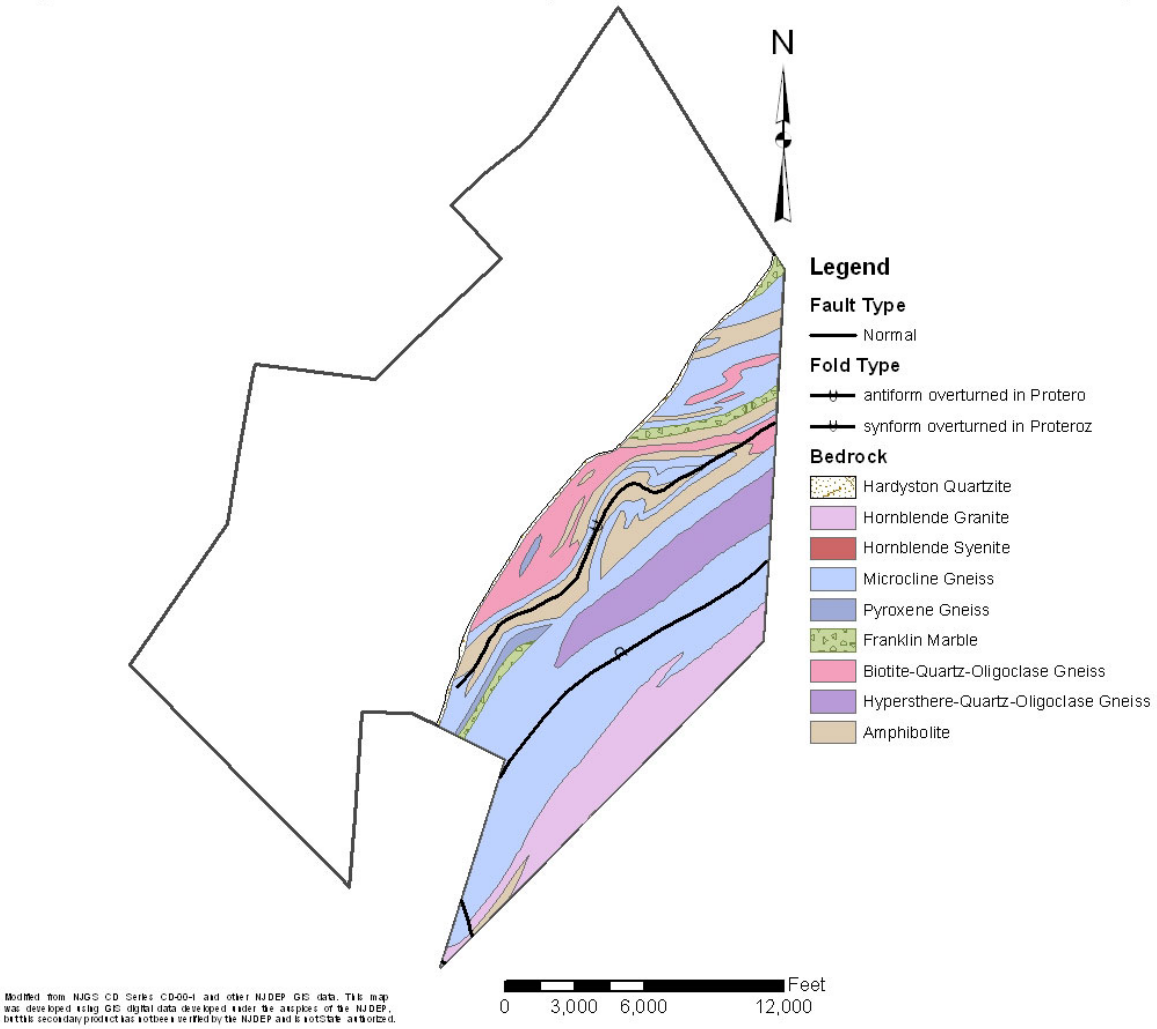
In the Cambrian-Ordovician limestones and dolomites, wells are usually drilled to deeper depths because of the potential to encounter additional water-bearing fractures/solution openings and therefore, to increase the yield. In the Precambrian igneous and metamorphic rocks, Cambrian Hardyston Quartzite, and Ordovician Martinsburg Formation, since increased yields are unlikely, wells are usually drilled to greater depths to store water within the borehole. 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 stored water may be necessary to meet the peak needs of the residence or business relying on the well.

PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS/HARDYSTON QUARTZITE

Location

Precambrian igneous and metamorphic rocks are encountered beneath approximately 34 percent of Andover Township. The Cambrian Hardyston Quartzite is encountered beneath approximately 72 acres or 0.5 percent of the Township. The locations of these rocks beneath Andover Township are shown on Figure 9.

Figure 9: Precambrian Rocks and Hardyston Quartzite Beneath Andover Township.



As discussed above, there are two local normal faults that transect the southeastern corner of the Township and two folds that have been mapped in the Precambrian rocks. No other major fractures or structural features have been mapped in these rocks.

Franklin Marble

The Franklin Marble is mapped as three small bands encompassing slightly less than 106 acres within the Township. Local well records suggest that one or more small bands may also be present in the Perona, Andover-Sparta, and Kilroy Roads areas. Although no marble or other carbonate rock is mapped in this area of the Township, records for wells prepared by local drillers suggest that carbonate rock may have been encountered.

Franklin Marble, where solution cavities are present will have hydrogeologic characteristics significantly different from the seven other Precambrian igneous and

metamorphic rocks beneath Andover Township. At locations where the Franklin Marble is unfractured and no solution cavities are present, it is a very poor groundwater resource. In those areas such as near Limecrest Quarry, where solution cavities are present, the Franklin Marble is considered a productive aquifer. Two caves were encountered during the mining at Limecrest Quarry (Dalton, 1976). The presence of these caves confirms large-scale dissolution of carbonate rock in that area.

Miller (1974) indicates that a well completed in Franklin Marble at Limecrest Quarry was capable of yields to 2,300 gallons per minute. Based on information submitted to NJDEP, this quarry is capable of sustained withdrawals in excess of 8.6 million gallons per day. As documented by Nicholson (1995), a hydraulic connection exists between the Franklin Marble at Limecrest Quarry and Cambrian-Ordovician carbonate rocks and Wisconsinan glacial deposits beneath the Germany Flats Valley extending to the southwest beneath Andover Township. Nicholson (1995) documented that the pumping influences from the quarry operations, starting in the 1970's, effectively lowered water levels in connected aquifer systems and drained water from Howells Pond located 1.5-miles to the southwest of the quarry. Franklin Marble at Limecrest Quarry is considered a very good aquifer system. In other areas of Andover Township, the groundwater resource potential is likely not as high unless solution cavities are encountered.

Silicate Crystalline Rocks

Franklin Marble is primarily comprised of calcite minerals, some of which are prone to dissolution in weak-acidic solutions including rainwater. The seven other Precambrian igneous and metamorphic rocks mapped beneath Andover Township (see Figure 9) and the Hardyston Quartzite are comprised of silica-based minerals or silicates. Silicates are not susceptible to dissolution in weak-acidic solutions. Furthermore, the rocks comprised of these minerals are considered dense, hard, highly-resistant to weathering (many are over 1-billion years old), and poorly to weakly fractured.

Unlike Franklin Marble, the gneiss, granite, amphibolite and syenite that comprise the seven other Precambrian igneous and metamorphic rocks mapped beneath Andover Township are considered poor to very poor aquifer systems. The Hardyston Quartzite has hydrogeologic characteristics similar to the Precambrian silicate rocks (Miller 1974). Miller's (1974) findings are similar to other researchers evaluating the Hardyston Quartzite in more distant areas of New Jersey. Kasabach (1966) indicates in his study of the groundwater resources of Hunterdon County, that the Hardyston Quartzite has hydrogeologic characteristics that are very similar to those of the Precambrian rocks.

Because there is a difference in the hydraulic behavior between the Franklin Marble and the silicate crystalline rocks beneath Andover Township, discussions herein on hydrogeology of these rocks are separated. Although the data have been separated for purposes of evaluating hydrogeologic differences, except in proximity to Limecrest Quarry, the Franklin Marble is surrounded by silicate-crystalline rocks and is not laterally extensive. Therefore, the marble is dependent on the transmission capacity of the silicate-crystalline rocks to replenish water removed from cavities/openings in the

Franklin Marble. The Franklin Marble at Limecrest Quarry is hydraulically connected to glacial and carbonate-rock aquifer systems that extend to the southwest beneath the Germany Flats Valley (Nicholson 1995).

Since in most areas of Andover Township where the Franklin Marble is mapped, it is surrounded by silicate-crystalline rocks, aquifers within the marble are unlikely to be significant independent groundwater resources. Near Limecrest Quarry, the Franklin Marble is hydraulically connected to aquifers within the glacial deposits and underlying carbonate rock and therefore, in this area of Andover Township the Franklin Marble should be considered part of the more extensive glacial/carbonate-rock systems extending to the southwest.

Poor Ranking

The groundwater resources of Sussex County were studied by Miller (1974) as part of the evaluation of the Tocks Island Dam project. Miller's 1974 report provides data on well yields and specific capacities with respect to geologic formations. In this study, Miller (1974) indicates that the Precambrian silicate-crystalline rocks and Hardyston Quartzite are poor yielding aquifers but usually with sufficient capacity to meet the needs of individual homes. The 1996 New Jersey Statewide Water Supply Plan (NJDEP 1996) indicates that these crystalline rocks are poor aquifers with low yields.

In its mapping of bedrock aquifers of New Jersey, the NJDEP ranks the Precambrian aquifer system in Andover Township on a scale from A through E, as a D aquifer. The NJDEP ranking system gives an A ranking to high yielding aquifers and an E to very low yielding aquifers. The NJDEP ranking system does not include the letter F. The ranking system is based on large capacity industrial, commercial, and public wells and does not include local well data such as discussed in the 1974 report by Miller. An aquifer with a rating of D may have wells, when properly located, that are capable of yields ranging from 25 to 100 gallons per minute (gpm). Usually, these large capacity wells in Precambrian rocks are located near fault boundaries or surface-water resources. It should also be noted that the NJDEP ranking of aquifers in New Jersey did not distinguish between the Franklin Marble and the silicate crystalline rocks.

Fractures

Generally, groundwater in a silicate-crystalline rock aquifer system occurs under water-table conditions in areas where fractures are open to the overlying weathered residual soils and yields of wells completed near major faults or streams are usually greater than wells completed distant from these features (Kasabach 1966). In areas where fractures are distant from each other or not interconnected, each fracture will have a differing water level. For example, along Hunters Way, water levels in two wells were reported at 50 and 80 feet below ground surface. The water level in the well on the lot located between these two wells was reported at 460 feet below ground surface.

The yield of a well is essentially entirely dependent on the number and size of fractures directly intersected by the well bore. As indicated by Kasabach (1966), in these rocks, if a well is completed near a stream or major fault, the yield may increase because the fractures intersected by the well extend to the stream or fault where additional water can be stored and transmitted. Miller (1974) indicates that the average specific capacity of wells completed in silicate crystalline rocks near a lake or stream was three times greater than for wells located distant from a surface-water body.

In silicate crystalline rocks, groundwater is stored and transmitted along fractures and joints. These openings in the bedrock are separated by a few inches to several tens to hundreds of feet of competent and unweathered bedrock. Since the unweathered portions have no primary or secondary porosity and therefore, are impermeable, the water-supply characteristics of silicate crystalline rocks are dependent on the degree of weathering, the size and interconnection of openings in the rock, and the spacing between these openings.

On occasion, a well will be drilled through unweathered Precambrian bedrock into a series of highly weathered and interconnected fractures and these fractures can yield several tens to possibly as much as 100 gpm. Just as often, a well drilled on the neighboring lot will encounter one or very few fractures and will yield significantly less water. Because of the limited interconnection of fractures in Precambrian rocks, wells are often completed to a wide-range in depths and usually, the deepest wells will have the lowest yields. For example, on Woodland Trail one well was drilled to 300 feet below ground surface and could yield 6 gpm whereas, two lots away the well needed to be drilled to 1000 feet below ground surface to produce 1 gpm.

Miller (1974) indicates that four zones of weathering exist in the silicate crystalline rocks. The shallowest zone is comprised of soils and decomposed rock and is in turn underlain by a zone of weathered and fractured rock. The third zone is relatively unweathered fractured rock and the fourth zone is unweathered and unfractured rock. Many of the fractures observed in the first three zones resulted from rebound after the ice sheets and glaciers retreated approximately 10,000 years ago. Miller (1974) indicates that the first three zones may extend to 150 feet below ground surface. Deeper fractures may be encountered near faults.

Miller (1974) indicates that the unweathered and unfractured Franklin Marble is also poorly permeable and two of three mines in Sussex County that intersect the marble are “dry.” As discussed above, solution cavities intersected at the Limecrest Quarry during mining produced very large quantities of water. Because fractures and narrow openings in calcium-rich rocks can be further narrowed or closed by re-precipitation of calcite, the availability of water in the Franklin Marble is dependent on the presence, size, and interconnection of solution cavities. Furthermore, except in the vicinity of Limecrest Quarry, the Franklin Marble beneath Andover Township is bounded by silicate-crystalline rocks. At these locations, water removed from a Franklin Marble aquifer must be replaced by groundwater migrating from the surrounding silicate-crystalline rock

system. Therefore, the groundwater systems in the Franklin Marble in these areas of the Township are not independent of the Precambrian silicate-crystalline systems.

Yields/Depths/Specific Capacity

Miller (1974) compiled data from 1,018 wells completed in silicate-crystalline rock aquifers within his study area. The data from these wells indicate yields ranging from 0 to 100 gallons per minute (gpm) with a median yield of 8 gpm, which is sufficient for residential purposes. The data indicate specific capacities ranging from 0.0 to 1.86 gallons per foot of drawdown (gpm/ft) with an average specific capacity of 0.30 gpm/ft. The data further indicate that the specific capacity of a well is dependent on depth with the highest average capacities encountered from 50 to 100 feet below ground surface but rapidly declining at depths greater than 100 feet. The decrease in specific capacity is a direct result of decreasing fracture densities with increasing depth.

In Andover Township, Miller (1974) indicates that yields for 18 residential wells completed in silicate crystalline rocks ranges from 0.5 to 45 gpm with a median yield of 8 gpm. He further indicates that well depths range from 37 to 300 feet below ground surface with a median depth of 142 feet below ground surface.

Miller (1974) does not provide data for wells completed in the Franklin Marble within Andover Township but does include data derived from 162 wells completed in this Precambrian carbonate rock located elsewhere in Sussex County or parts of Warren County. These data indicate yields for residential wells ranging from 0.25 to 100 gpm with a median yield of 10 gpm. Depths for these wells ranged from 45 to 520 feet below ground surface with a median depth of 130 feet below ground surface. Specific capacities for the wells completed in the Franklin Marble also decreased with depth from a high of 4.0 gpm/ft reported for the interval to 49 feet below ground surface to a low of 0.04 gpm/ft for depths greater than 300 feet below ground surface. The average specific capacity for the Franklin Marble reported by Miller (1974) is 0.57 gpm/ft. The data from Miller's 1974 report indicates that the Franklin Marble, when randomly drilled for residential wells, is not significantly higher yielding or more transmissive than the Precambrian silicate crystalline rocks.

Local well records were compiled and used to assess aquifer parameters for the silicate crystalline and Franklin Marble beneath Andover Township. A total of 601 well records were reviewed and 543 of these records had sufficient information to assess aquifer parameters and determine their approximate location within the Township. The locations were based on State Atlas Sheet grid coordinates, street address, and block and lot information. Some well records did not have sufficient information and therefore, were not included. Of the 543 well records reviewed, 232 were for wells completed in areas underlain by Precambrian silicate-crystalline rocks and seven others were for wells completed in Franklin Marble as mapped by USGS/NJGS. Twenty-five of the 232 records for wells completed in areas mapped as underlain by silicate-crystalline rocks indicated the presence of carbonate rock and these records suggest the presence of an unmapped band or bands of Franklin Marble in the Andover-Sparta, Perona, and Kilroy

Roads area or that the well driller was not familiar with the difference between silicate crystalline rocks and marble. The well data are summarized in Appendix A.

The local well data were used to evaluate ranges in depth, yield, and the aquifer characteristics of specific capacity and specific capacity per foot of open hole. The specific capacity is based on the yield of the well and drawdown induced by pumping and provides a measure of the aquifer's ability to transmit water. The specific capacity per foot of open hole removes the variability caused by having wells completed to differing depths. For example, a well drilled to 400 feet in one formation could have the same specific capacity as a well drilled to 200 feet in a second formation. However, when the specific capacities are divided by the open hole interval, a significant difference between the formations is often apparent. This parameter is useful for evaluating the transmission capacities of aquifer systems. As discussed above, in some formations such as the silicate crystalline rocks and Martinsburg shales, wells are drilled to greater depths to increase storage whereas, in carbonate rocks, wells are often drilled to lesser depths because adequate yields are encountered early. The specific capacity per foot of open hole parameter allows for comparisons to be made between formations. The local well data indicate the following:

Aquifer System	Minimum Depth (fbgs)	Maximum Depth (fbgs)	Median Depth (fbgs)
Silicate Crystalline	72	1000	300
Franklin Marble	57	400	235

Aquifer System	Minimum Yield (gpm)	Maximum Yield (gpm)	Median Yield (gpm)
Silicate Crystalline	0.5	100	10
Franklin Marble	5	50	13

Aquifer System	Minimum Specific Capacity (gpm/ft)	Maximum Specific Capacity (gpm/ft)	Median Specific Capacity (gpm/ft)
Silicate Crystalline	0.001	2	0.061
Franklin Marble	0.025	0.13	0.038

Aquifer System	Minimum Specific Capacity per foot open hole (gpm/ft/ft)	Maximum Specific Capacity per foot open hole (gpm/ft/ft)	Median Specific Capacity per foot open hole (gpm/ft/ft)
Silicate Crystalline	1.65E-06	1.67E-02	2.50E-04
Franklin Marble	9.67E-05	3.21E-03	1.16E-04

The data indicate that wells completed in the silicate-rocks need to be completed to greater depths than wells in the Franklin Marble but even when completed to greater depths, the yield of the crystalline rock well is less than for the well completed in marble. The median depth and yield for wells completed in the Precambrian silicate-crystalline are 300 feet and 10 gallons per minute (gpm) versus 235 feet and 13 gpm for wells completed in the Franklin Marble. In contrast to the yield/depth results, the data indicate that the transmission capacity of the Franklin Marble is less than for the Precambrian silicate-crystalline rocks. Only four of the seven records for wells completed in Franklin Marble had sufficient data to analyze the specific capacities and therefore, the differences observed in the data may be a result of an insufficient number of well records. Given the nature of the Franklin Marble, unless large solution cavities are encountered such as at Limecrest Quarry, fractures in this rock can be closed or sealed by precipitating calcite and narrowed apertures will limit groundwater transmission. Except near Limecrest Quarry, the transmission capacity of the Franklin Marble is ultimately dependent on the ability of the surrounding Precambrian silicate-crystalline rocks to transmit water.

Twenty-five of the 232 records for wells completed in areas mapped as underlain by Precambrian silicate crystalline rocks indicated the possibility that these wells intersected carbonate rock. The data from these 25 well records were removed from the table of wells completed in Precambrian crystalline rocks and the differences in the median depths, yields, and specific capacities were non-existent to negligible. When the data from the 25 well records were added to the database for the Franklin Marble, the results indicated increased depths and specific capacities but decreased yields. The data do not conclusively support the presence of unmapped bands of Franklin Marble in the area of Andover-Sparta, Perona, and Kilroy Roads. However, even if bands of marble do exist in these areas, they do not appear to be significantly greater yielding or more transmissive than the Precambrian silicate-crystalline rocks or Franklin Marble mapped elsewhere in the Township.

Summary

In summary, data from wells completed in silicate-crystalline rock aquifers beneath Andover Township indicate that these rocks are poor aquifers. The silicate-crystalline rock aquifers are capable of yielding sufficient water to meet the demands of single-family homes but incapable of serving as significant public-water resources. The findings with respect to Precambrian rocks are similar to other areas in the Highlands

Province of New Jersey. The total area of Andover Township underlain by these rocks and Hardyston Quartzite is approximately 4,600 acres.

When the data for wells completed in the Precambrian silicate-crystalline rocks are reviewed on a local basis, they indicate a significant variation in depths and yields. For example, from the Hunter Way-Woodlands Trail neighborhood, wells can range from 300 to 1000 feet deep with yields ranging from 1 to 6 gpm. Static water levels can also vary greatly over short distances from high of 6 feet below ground surface to as deep as 460 feet below ground surface in this same neighborhood. Hydrogeologic conditions in areas underlain by Precambrian rocks can vary over small distances.

An additional 106 acres of Andover Township are underlain by Franklin Marble. The Franklin Marble can be a very prolific aquifer when large solution cavities are intersected such as at the Limecrest Quarry and those cavities are in turn, hydraulically connected to glacial and/or other carbonate-rock aquifer systems. But when randomly drilled for residential use, yields and groundwater transmission capacities of the Franklin Marble are not appreciably greater than measured for the silicate-crystalline rock.

CAMBRIAN-ORDOVICIAN CARBONATE ROCKS

Location

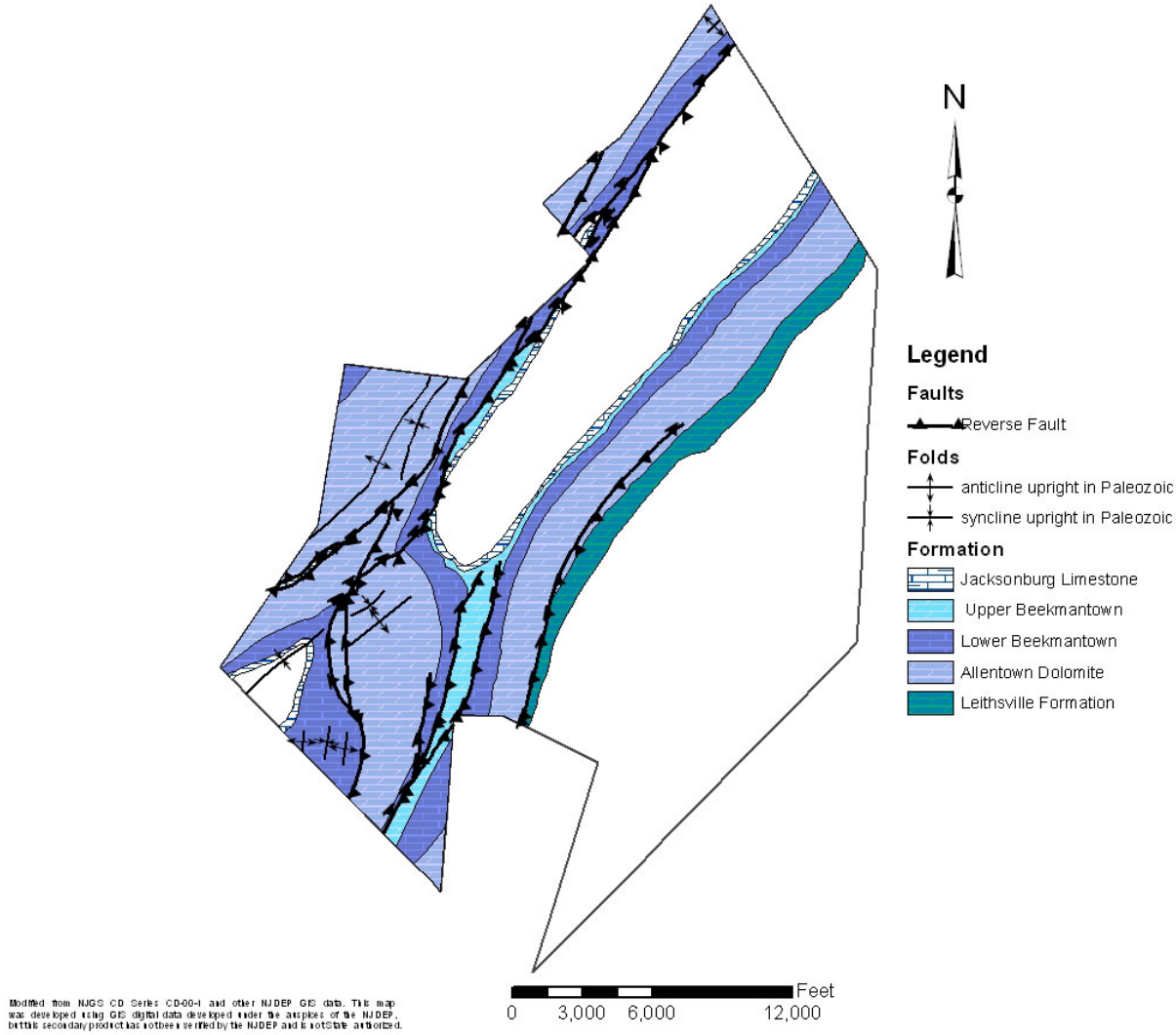
Based on the geologic mapping conducted by the USGS/NJGS, 6,140 acres or 46 percent of Andover Township are underlain by Cambrian-Ordovician carbonate rocks of the Leithsville, Allentown, Lower and Upper Beekmantown, and Jacksonburg Formations. Figure 10 shows where these formations are mapped in the Township.

The hydrogeologic characteristics of the five Cambrian-Ordovician carbonate rock formations are very similar. Some sections of the Jacksonburg Formation have lower capacities to transmit and store water because they are less susceptible to dissolution than other sections or the other four carbonate rock formations. Generally, these formations are all considered good aquifer systems. Kasabach (1966) indicated that combining the carbonate rock aquifers in Hunterdon County was appropriate because of the similar hydrogeologic characteristics. In addition, the NJDEP in its mapping of bedrock aquifers in New Jersey combines the formations as the Jacksonburg Limestone-Kittatinny Supergroup and ranks this aquifer system as C-B indicating yields up to 500 gpm are possible.

Miller (1974) does not describe the hydrogeologic conditions of the Jacksonburg Formation because he did not have sufficient well data for evaluating this unit. Within Andover Township, the Jacksonburg Formation encompasses an area of approximately 242 acres near the contact with the Martinsburg Formation. In the 1996 State-Wide Water Supply Plan, the NJDEP combined the limestone/dolomite formations into carbonate rock aquifers and indicated that these aquifers were some of the most prolific in the State. Aquifer systems in carbonate rocks beneath New Jersey are usually considered prolific.

Water: A Natural Renewable Resource

Figure 10: Cambrian-Ordovician Carbonate Rocks Beneath Andover Township.



Fractures/Solution Openings

Similar to the Precambrian rocks, the Cambrian-Ordovician carbonate rocks have undergone several episodes of past tectonic deformation as a result of continental plate collisions and separations. Unlike the Precambrian rocks, the sedimentary carbonate rocks are brittle and have responded to these tectonic episodes by fracturing along a series of fault planes or by folding. In carbonate rocks, groundwater is stored and transmitted through fractures, relic bedding planes and disconformities between beds, and solution cavities. These openings in the rock can become further enlarged by continued dissolution of the carbonate minerals within the rock or re-cemented as the minerals re-precipitate in narrow openings. As indicated by Miller (1974), it is likely that fractures formed as a result of faulting that occurred more than 400 million years ago

have been re-filled with precipitating minerals and therefore, these faults no longer represent significant groundwater resources in Andover Township.

Carbonate minerals can dissolve in weakly acidic waters forming large holes such as cavities, caves, and caverns in the rock. Several caves have been mapped in and near Andover Township indicating wide-scale dissolution of carbonate rock in the area. These cavities can store and transmit very large quantities of water. The presence of solution openings or voids is characteristic of carbonate rocks and these types of openings are not found in Precambrian silicate-crystalline rocks or in sedimentary rocks comprised primarily of non-carbonate minerals.

Easily Contaminated

For the same reason that carbonate rock aquifers are capable of very high well yields, they are also extremely susceptible to contamination from anthropogenic sources. Solution features and sinkholes can rapidly transmit man-made or man-introduced contaminants into these prolific water resources. Because of the nature of these aquifers, additional measures are often necessary to protect water quality and quantity. In many New Jersey municipalities underlain by carbonate rock, ordinances have been adopted requiring the investigation and remediation of solution cavities and sinkholes. Sinkholes can serve as direct conduits for contaminants migrating to groundwater, especially when discharged in septic system effluent.

Yields/Depths/Specific Capacity

Miller (1974) evaluated yields of 422 residential wells completed in carbonate rock aquifers beneath Sussex and parts of Warren Counties. His analyses indicated yields ranging from 0.25 to 120 gpm with a median yield of 10 gpm. The depths of these wells range from 27 to 485 feet below ground surface with a median depth of 113 feet below ground surface. He also evaluated industrial/commercial wells and determined a median yield of 100 gpm and depth of 200 feet below ground surface for the carbonate-rock aquifer systems. Generally industrial wells will have greater yields because additional efforts are made to locate wells to maximize yields.

From the domestic well data, Miller (1974) determined an average specific capacity of 1.05 gpm/ft. The specific capacity was highest in the shallowest wells and declined with depth. At nearly every depth interval, the specific capacity for carbonate rock wells is approximately twice those determined for the wells completed in the Precambrian silicate-crystalline rocks. For the intervals from 50 to 150 feet below ground surface, the specific capacity determined by Miller (1974) for the wells in carbonate rocks was approximately four times greater than determined for the wells completed in the Precambrian rocks.

Of the 543 records compiled for local wells, 118 records are for wells completed in the carbonate rocks. The data from these well records indicate the following for wells in Andover Township:

Aquifer System	Minimum Depth (fbgs)	Maximum Depth (fbgs)	Median Depth (fbgs)
Carbonate Rock	53	950	300

Aquifer System	Minimum Yield (gpm)	Maximum Yield (gpm)	Median Yield (gpm)
Carbonate Rock	0.5	300	12

Aquifer System	Minimum Specific Capacity (gpm/ft)	Maximum Specific Capacity (gpm/ft)	Median Specific Capacity (gpm/ft)
Carbonate Rock	0.002	1.58	0.067

Aquifer System	Minimum Specific Capacity per foot open hole (gpm/ft/ft)	Maximum Specific Capacity per foot open hole (gpm/ft/ft)	Median Specific Capacity per foot open hole (gpm/ft/ft)
Carbonate Rock	3.85E-06	1.08E-01	3.08E-04

Similar to the data for the Precambrian silicate-crystalline rocks, the well records for the carbonate-rock aquifer wells indicate a wide range in depths from 53 to 950 feet below ground surface and an identical median depth of 300 feet below ground surface. Low yields are similar for both types of bedrock aquifers but the maximum yield reported for the carbonate rocks is three times greater; the median yield is also slightly higher for the carbonate rocks.

The specific capacities and the specific capacities per foot of open hole are not significantly greater for the carbonate rock wells in comparison to the Precambrian rocks. While usually data from wells completed in carbonate rocks indicate characteristics of aquifers that are much more prolific than for Precambrian silicate-crystalline rock aquifers, the local data and those compiled by Miller (1974) for the larger Sussex County study do not indicate substantial differences. When drilled for domestic well purposes, the carbonate rock aquifers beneath Andover Township are not significantly greater groundwater resources than the poorly yielding Precambrian silicate-crystalline rocks.

Public Community Wells

In addition to the domestic wells, seven public community wells have been completed in the carbonate rock aquifers beneath Andover Township. Based on information available from the NJDEP, these seven wells have yields ranging from 10 to 200 gpm with a median yield of nearly 50 gpm. The NJDEP data do not indicate if these yields are limited by the aquifer or the demands placed by consumers. It is possible that one or more of these wells has significantly greater yield than reported. The seven wells have depths ranging from 74 to 530 feet below ground surface with a median depth of 275 feet below ground surface. All of these wells are in the northern portion of the Township near Howells Pond with six of the seven completed in the Allentown Formation and one completed in the Leithsville Formation. Given the locations of these wells, their higher yields may be supported by leakage from thick overlying glacial sediments.

Summary

In most areas of New Jersey, carbonate-rock aquifers are some of the most prolific groundwater resources with wells yielding sometimes in excess of 2000 gpm. Local well data indicate that wells are significantly lower yielding and the carbonate-rock aquifer systems are not as transmissive beneath Andover Township as elsewhere in New Jersey. Miller (1974) points out that the fault zones do not represent significant groundwater resources as many of these relic fractures have been narrowed or closed by re-precipitating carbonate minerals.

MARTINSBURG FORMATION

Location

The Bushkill Member and the undifferentiated Martinsburg Formation have been mapped beneath approximately 2,600 acres of Andover Township. The locations where these slates, shales, and siltstones have been mapped are shown on Figure 11. While the Bushkill Member has been mapped as a subunit of the Martinsburg Formation, from a hydrogeologic perspective, the rocks of this subunit and the undifferentiated sections are virtually identical and do not warrant separation.

The NJGS ranking of bedrock aquifers indicates the Martinsburg Formation is a D aquifer or not highly productive. While properly located commercial/industrial wells may have yields ranging between 25 and 100 gpm, as suggested by the NJGS ranking, it is unlikely that residential wells will be as high yielding.

Figure 11: Ordovician Martinsburg Formation Beneath Andover Township.

Yields/Depths/Specific Capacity

Miller (1974) describes the Martinsburg Formation and its related Bushkill Member as "…quite tight and it is, on the whole, a very poor aquifer." Compiling data from 495 wells completed in the Martinsburg, Miller (1974) concluded that yields range from 0.5 to 120 gpm with a median yield of 6 gpm and well depths range from 35 to 683 feet below ground surface with a median depth of 132 feet below ground surface. Specific capacities start at 1.04 gpm/ft for the shallowest interval from 0 to 49 feet below ground surface and decrease rapidly with increasing depth. The average specific capacity he determined from the data was 0.39 gpm/ft. Based on 16 residential wells located in Andover Township, he determined a median yield and depth of 5 gpm and 122 feet below ground surface. Miller's (1974) results indicate that the Martinsburg Formation is

somewhat better groundwater resource than the Precambrian crystalline rocks with respect to transmission capacity but slightly lower yielding.

Records from 170 wells completed in the Martinsburg Formation beneath Andover Township were reviewed to assess depths, yields, and the capacities of these rocks to transmit groundwater. The data are summarized as follows:

Aquifer System	Minimum Depth (fbgs)	Maximum Depth (fbgs)	Median Depth (fbgs)
Martinsburg Formation	99	800	220

Aquifer System	Minimum Yield (gpm)	Maximum Yield (gpm)	Median Yield (gpm)
Martinsburg Formation	1	100	15

Aquifer System	Minimum Specific Capacity (gpm/ft)	Maximum Specific Capacity (gpm/ft)	Median Specific Capacity (gpm/ft)
Martinsburg Formation	0.003	5.00	0.174

Aquifer System	Minimum Specific Capacity per foot open hole (gpm/ft/ft)	Maximum Specific Capacity per foot open hole (gpm/ft/ft)	Median Specific Capacity per foot open hole (gpm/ft/ft)
Martinsburg Formation	4.75E-06	5.10E-02	9.76E-04

Well depths and yields are similar in range to the values determined for the silicate crystalline rock and carbonate-rock aquifers. However, the median values indicate that 50 percent of the wells completed in the Martinsburg Formation beneath Andover Township had to be drilled to 220 feet below ground surface or less to produce 15 gpm or more. The local data support the findings of Miller (1974) that the Martinsburg Formation is a somewhat better source of groundwater than the Precambrian silicate crystalline rocks.

The local data also suggest that the Martinsburg Formation is a better groundwater resource than the carbonate rocks beneath the Township. The data from the wells completed in Andover Township indicate that yields and specific capacities are higher for wells completed in the Martinsburg Formation than for wells completed in either the Precambrian rocks (including Franklin Marble) or carbonate rocks.

The local well data indicate that the Martinsburg Formation beneath Andover Township has nearly twice the capacity to transmit water in comparison to the Precambrian silicate-crystalline rocks, Franklin Marble, and carbonate-rock systems. The specific capacities per foot of open hole indicate that the transmission capacity of the Martinsburg Formation is as much as three times greater per foot of aquifer than either the Precambrian silicate crystalline or carbonate rocks beneath the Township.

Although the transmission capacity may be greater for the Martinsburg Formation, it is very low in comparison to bedrock aquifers elsewhere in New Jersey. As indicated by Miller (1974) and shown by the local well data, the Martinsburg Formation is a poorly transmissive aquifer. When compared to the other bedrock aquifers beneath the Township, the data indicate that the Precambrian crystalline and carbonate-rock aquifers are lower yielding and less transmissive than the Martinsburg Formation.

GLACIAL

NJGS has mapped the thickness of glacial sediments beneath Andover Township and the locations of the thickest deposits are shown on Figure 12. However, it should be noted that in one area where NJGS mapped the thickness as less than 100 feet, a well was installed for the Kittatinny Valley State Park that encountered glacial materials as much as 325 feet thick. Very thick layers of glacial sediments likely exist along the Kymer Brook, Lake Iliff, New Wawayanda Lake valley.

Five public community water-supply wells have been completed in glacial deposits beneath Andover Township and these wells reportedly yield from 10 to 125 gpm. The wells range in depth from 60 to 74 feet below ground surface. Miller (1974) evaluated data from seven domestic wells completed in glacial sediments beneath Andover Township and determined a depth range from 54 to 170 feet below ground surface with a median depth of 122 feet below ground surface. These wells had yields ranging from 10 to 60 gpm with a median yield of 23 gpm.

Of the 543 local well records compiled, 16 were for wells completed entirely in unconsolidated glacial sediment aquifers. These wells indicated depths ranging from 62 to 325 feet below ground surface with a median depth of 111.5 feet below ground surface. Yields range from 10 to 450 gpm with a median yield of 22.5 gpm. Specific capacities were much greater for the glacial aquifer systems then for the bedrock aquifers with the range from 0.13 to 151 gpm/ft and a median value of 0.6 gpm/ft. Because the open intervals are small and yields high, the specific capacities per foot of open interval are three orders of magnitude greater for the wells completed in the glacial materials beneath Andover Township.

Although the thick deposits of glacial sands and gravels are not extensive beneath Andover Township, these sediments likely represent the best groundwater resources. In a few areas, the potential exists for directly developing these resources. In other areas along the flanks of the glacial valleys, leakage from the unconsolidated materials to the underlying bedrock aquifers may support withdrawals.

Figure 12: Glacial Sediment Thickness Beneath Andover Township.

HYDROGEOLOGIC FRAMEWORK

The data indicate that there are four major groundwater systems beneath Andover Township. These systems are as follows:

1. The Precambrian igneous and metamorphic rocks including the Franklin Marble at locations except near Limecrest Quarry. Well data indicate that the Franklin Marble is a higher yielding aquifer than the silicate-crystalline rocks with a median yield of 15 gpm in comparison to 10 gpm. However, the Franklin Marble is not sufficiently extensive within the Township to serve as an independent resource. The groundwater resources beneath the eastern third of Andover Township are dependent on the availability of water in the Precambrian rocks.

2. Combined glacial/carbonate-rock systems that follow Kymer Brook and extend beneath Lake Iliff and New Wawayanda Lake. This system was studied by

Nicholson (1995) and while the glacial and carbonate-rock systems could be considered independently, they are hydraulically interrelated. The combined glacial/carbonate-rock system is also present beneath the Paulins Kill watershed in the northwestern portion of Andover Township and beneath the southwestern corner where the Pequest River enters the Township. In both of these areas, NJGS has mapped thick layers of glacial material overlying carbonate rock (see Figure 12 above). The combined glacial/carbonate-rock system is similar to the Lower Valley Fill/Carbonate Rock system in Long Valley, New Jersey evaluated by Nicholson et al. (1996). Based on NJGS mapping, this combined system likely encompasses approximately 909 acres of Andover Township.

3. Exposed or shallowly buried carbonate rocks primarily located in the southern portion of Andover Township but also along the flanks of the Kymer Brook valley where the glacial fluvial and delta deposits are replaced by thin layers of till. This system is likely similar to the Carbonate Rock Aquifer described by Nicholson et al. (1996) in the southern section of Long Valley. Karst features are present in southern Andover Township such as near Twin Lakes where streams flow into but not out of the lakes and several small ponds in the area.

4. Martinsburg Formation is the fourth groundwater system beneath Andover Township. The Martinsburg Formation is generally considered a poor aquifer system. The hydrogeologic characteristics of the Martinsburg Formation have not been widely studied in New Jersey because of its limited water resource potential. This formation has been studied in Pennsylvania and Virginia where it is more widely found. However, essentially all of the studies that include the Martinsburg Formation and were reviewed for this report, are primarily focused on the adjoining carbonate rock aquifers. These studies describe the Martinsburg Formation as a barrier to groundwater flow, and while capable of sustaining domestic wells, it is not considered a major source of water.

AQUIFER RECHARGE

Hydrologic Cycle

WATER BALANCE

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

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

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

3. Groundwater runoff is the percentage of precipitation that enters a subsurface perennial or seasonal saturated zone through which, it slowly migrates to a stream. This component is most obvious during dry periods where it maintains the baseflow in streams.

The water balance is often described by the following equation:

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

Where:

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

PRECIPITATION

A water balance can be used to evaluate inflow and outflow parameters associated with a hydrologic system. The inflow parameter to the equation, precipitation, can be directly determined from historical information. The outflow parameters, evapotranspiration, surface-water runoff, and groundwater runoff are determined by indirect methods. The water balance provides a general understanding of water availability and losses within the hydrologic cycle of an area. Precipitation has been measured directly in most areas of New Jersey for more than 100 years. Data compiled since 1971 are currently used by the National Oceanic and Atmospheric Administration (NOAA) to determine normal or average rates of precipitation.

The National Climatic Data Center and the Office of the State Climatologist at Rutgers University have compiled precipitation and temperature data for a weather station located in Newtown. These data indicate that Andover Township receives approximately 47.2 inches of precipitation per year during a year of normal precipitation. Precipitation is evenly divided throughout the year with January, February, March, October, November, and December receiving slightly less and the other months receiving slightly more, than the monthly average precipitation. In Equation 1, P equals 47.2 inches.

EVAPOTRANSPIRATION

As part of the hydrologic cycle, water is returned to the atmosphere by evapotranspiration from vegetation. Evapotranspiration is greatest during the summer months because of higher temperatures and active growth of plants and trees. During the winter months, evapotranspiration in northern New Jersey is usually negligible.

Evapotranspiration is the largest component on the right side of Equation 1 accounting for 50 to 60 percent of annual precipitation.

In the USGS (Nicholson et al. 1996) study of Long Valley, a potential evapotranspiration rate of 25 inches per year or 50 percent of annual precipitation was determined. The USGS used the Thornthwaite Method, which was developed for calculating potential evapotranspiration in New Jersey and other Mid-Atlantic States. Studies have shown that the Thornthwaite Method provides reasonable estimates of monthly and annual potential evapotranspiration for New Jersey. Actual evapotranspiration is likely to be lower than potential evapotranspiration because water is not always available within the root zone for plant transpiration.

Mean temperature data for the Newton climatic data station have been compiled for more than 100 years by the National Climatic Data Center. These temperature data were used to calculate the expected mean temperature in Andover Township. The temperatures were in turn used with the Thornthwaite Method to calculate potential evapotranspiration rates for Andover Township. Monthly normal precipitation rates and mean temperatures based on the data from the National Climatic Data Center and Office of the State Climatologist, and potential evapotranspiration rates for Andover Township are summarized as follows:

Month	Precipitation (inches)	Temperature (degrees Fahrenheit	Potential Evapotranspiration (inches)
January	3.56	24.9	0.00
February	2.71	27.2	0.00
March	3.71	36.7	0.36
April	4.05	47.5	1.58
May	4.42	58.0	3.23
June	4.55	66.6	4.55
July	4.42	71.3	5.36
August	4.44	69.3	4.69
September	4.51	61.4	3.13
October	3.61	49.8	1.60
November	3.79	40.5	0.58
December	3.45	30.3	0.00
Totals:	47.22	48.6	25.08

Based on the precipitation and temperature expectations for Andover Township, approximately 25.1 inches or 53 percent of annual precipitation will be returned to the atmosphere through evapotranspiration processes. Actual evapotranspiration is likely to be lower than potential evapotranspiration as calculated with the Thornthwaite method. In Equation 1, the parameter ET equals 25.1 inches per year.

SURFACE-WATER RUNOFF

Surface-water runoff is dependent on the infiltration capacity and rate of soils, types and density of vegetation, surface area of impervious materials, gradient or steepness of

slopes, and the intensity and duration of rainfall. Surface-water runoff is comprised of two components. One of these components is overland flow, which occurs when the infiltration capacity of the soils is exceeded and the water flows over the land surface to a stream channel. In poorly drained soils, along steep slopes, and/or in highly developed areas with impervious surfaces, overland flow can account for essentially all of precipitation to the area.

The second of component of surface-water runoff is referred to as interflow or throughflow and includes water that infiltrates soils to a shallow depth and then follows along an impermeable or very low permeability surface such as a clay layer, fragipan, or bedrock surface, to a discharge point. Interflow/throughflow is not groundwater recharge because this water does not infiltrate to a perennial saturated zone or water table before discharging to a stream. Since groundwater resources supply drinking water to all Andover Township residents, precipitation that does not infiltrate to the aquifer is not a local water-supply resource.

In the elevated sections of the eastern third of Andover Township, which is underlain by dense, hard, poorly fractured Precambrian bedrock, surface water starts flowing at high elevations. In these areas, the slopes provide sufficient gradient to induce surface-water runoff, and the poorly fractured nature and resulting low permeability limits the infiltration capacity of the bedrock. As a result, precipitation quickly runs off the land surface or throughflows immediately below the ground surface often along the top of bedrock to the nearest stream system.

Similarly, beneath areas underlain by the Martinsburg Formation, elevations are higher, the ground surface is more steeply sloping, and the underlying bedrock is poorly fractured, creating conditions that induce rapid surface-water runoff and limited infiltration to groundwater resources. Surface-water runoff from the areas underlain by the Martinsburg Formation is further enhanced by the limited infiltration capacity of thin layer of overlying till deposits. Stream patterns in Andover Township show that essentially all of the first order streams in the Township are located in areas underlain by Precambrian rocks or the Martinsburg Formation, which is further indication that water quickly drains from these rocks before infiltrating.

Whereas, in the flatter, lower elevation areas underlain by carbonate rock and/or thick glacial sediments, especially in those areas where coarse-grained materials predominate, the infiltration capacity of these materials is greater and therefore, significantly less incident precipitation runs off the land surface.

Nicholson et al. (1996) evaluated the relationship between ridges underlain by Precambrian rocks and valleys underlain by glacial deposits and carbonate rocks in proximity to Long Valley, New Jersey. The results of their study indicate that in the upland areas underlain by Precambrian rocks, surface-water runoff is likely to be 18.2 inches per year or 3 inches per year of direct runoff and 15.2 inches per year of throughflow. The Nicholson (1996) study indicates that beneath Precambrian rocks, 36.4 percent of annual precipitation will discharge as surface-water runoff. Studies

conducted by the USGS in other areas of New Jersey underlain by igneous and metamorphic rocks indicate that the surface-water component of the water balance is equal to 36 percent of annual precipitation (Lewis-Brown 1995). Applying this same percentage to Andover Township's climatic data indicates that beneath the areas underlain by Precambrian rocks, annual surface-water runoff would equal 17.2 inches.

The Nicholson et al. (1996) study indicated that surface-water runoff equaled approximately 3 inches or 6 percent of annual precipitation in the carbonate valleys. Applying this same percentage to Andover Township would suggest that surface-water runoff beneath the 46 percent of the municipality underlain by carbonate rock should be approximately 2.8 inches per year.

The Martinsburg Formation has not been independently evaluated with respect to surface-water runoff. This formation is limited in extent in New Jersey and has been primarily studied in Pennsylvania, Virginia, and West Virginia where the shales, siltstones, and slates are encountered more frequently. However, most of the studies that focus on hydrogeology, assume that the poorly permeable Martinsburg Formation is a boundary to groundwater movement and storage and address the more prolific carbonate rocks in the adjoining valleys. Based on the limited infiltration capacity of the Martinsburg Formation, for purposes of the water balance it can be assumed that surface-water runoff is likely similar to the rate for the Precambrian crystalline rocks.

GROUNDWATER RUNOFF

Groundwater runoff includes two components. The first component is water that infiltrates to a seasonal or perennial saturated zone but does not infiltrate to a water-table or deeper aquifer system where it can be withdrawn from wells. The groundwater runoff in these shallow systems flows enters shallow and local subsurface environments such as flood plain soils, stream banks and seasonal perched zones, but does not infiltrate to an aquifer where it could be used for water supply. This component typically sustains stream headwaters and wetlands.

The second component is water that infiltrates to a water-table aquifer or perennial saturated zone hydraulically connected to deeper aquifer systems. Groundwater recharge is the component of groundwater runoff that actually infiltrates sufficiently to enter perennially saturated zones or bedrock aquifers where it can be economically extracted for water supply. As indicated by Nicholson et al. (1996), groundwater recharge to the Precambrian rocks in the uplands was negligible but to the carbonate-rock and combined glacial/carbonate-rock systems was much greater.

Applying the annual precipitation rate and estimates of evapotranspiration and surface-water runoff to Equation 1 indicates that groundwater runoff will equal approximately 5 inches per year for the areas underlain by Precambrian crystalline rocks and 19 to 20 inches per year for the outcropping carbonate-rock and combined glacial/carbonate-rock systems.

The water balance provides a general understanding of water inflow and outflow parameters of the hydrologic cycle for an area. The groundwater runoff rate is not equal to groundwater recharge and additional evaluation is necessary to determine rates for water entering aquifer systems. Nicholson et al. (1996) calculated a water balance for Long Valley, New Jersey, which suggested recharge to the carbonate rock aquifers was approximately 22 inches per year. Further evaluation determined that as a result of stream losses and infiltrating throughflow from areas underlain by Precambrian rocks, that groundwater recharge to the carbonate rocks was closer to 28.5 inches per year.

Groundwater recharge is the rate at which water enters an aquifer system on an annual basis or in other terms, is the rate at which the aquifer system is naturally replenished. The rate of natural replenishment is often used to determine the rate at which, groundwater can be safely withdrawn from an aquifer system without causing adverse impacts. If withdrawals exceed long-term replenishment, water will be removed from storage and the aquifer will be adversely impacted. These impacts could include degradation of water quality, reductions in available yield, well failure, and especially in karst environments, subsidence of the land surface. In New Jersey, a percentage of the groundwater recharge rate is often used for determining the dependable yield or the volume of water that can be safely withdrawn over long periods of time.

Groundwater Recharge

GROUNDWATER

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

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

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

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

Andover Township because water that does not enter a saturated aquifer system, is not available to residents for water-supply use.

BASEFLOW

Several methods have been developed for evaluating groundwater recharge to aquifer systems in environments where streams are gaining water from groundwater discharges. Most of these methods for evaluating groundwater recharge are not applicable in areas underlain by carbonate bedrock because of the significant potential for streams to lose water to the underlying aquifers.

For areas underlain by non-carbonate bedrock, the rate of water infiltrating to an aquifer cannot be directly measured. However, the rate water is discharging from an aquifer to a stream can be evaluated by measuring baseflow within the stream during dry weather. Since the hydrologic system is a balance equation, the rate of water exiting an aquifer system is assumed equal to the rate entering the groundwater system.

Water flowing in streams during periods of dry weather is referred to as baseflow and in the past, was often assumed equal to groundwater discharge. However, a better understanding of hydrologic systems including wetlands, streams, aquifers, seasonal wet zones, flood plains, and stream banks and the role these systems have in providing water to streams during periods of dry weather has shown that not all water flowing during dry weather is derived from aquifer/groundwater discharge. The water flowing during most dry weather periods is very likely to include water from shallow sources such as but not limited to flood-plain soils, stream bank-storage, wetlands, isolated ponds, and perched zones. Discharges from these shallow sources should not be assumed entirely associated with flow from an aquifer serving as a water resource. It may take extensive periods of dry weather or droughts to sufficiently dry up or dewater these shallow sources in order to determine the contribution to baseflow from an underlying aquifer system.

HYDROGRAPH SEPARATION

Several graphical methods have been developed for evaluating streamflow data and are often referred to as “hydrograph separation”. These methods are used for separating flow associated with surface-water runoff from flow associated with discharges from other sources, which is then assumed equal to baseflow. The baseflow rates are used to estimate groundwater recharge rates for areas underlain by non-carbonate rock aquifers. Because streamflow rates increase, peak, and then decline as a result of overland runoff from precipitation events, the hydrograph separation methods assume a time delay after a storm event to impose similar increased, peaked, and declining baseflow rate changes resulting from that same precipitation event. The overland flow component may be referenced as quickflow because it arrives rapidly in the stream channel and causes readily identifiable increases in streamflow rates whereas, the increased baseflow may take several hours or days to migrate through the subsurface or to be released by wetlands or other sources to the stream channel. The increased

baseflow rates are not readily identifiable in the streamflow data because they are often obscured by declining quickflow components.

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

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

Discharges from sources other than an aquifer system should not be included in a groundwater recharge analysis because this water did not infiltrate to the underlying aquifer system. Inclusion of discharges from these shallow sources would result in significant overestimates of groundwater recharge. Simply, if the water did not infiltrate to the perennially saturated zone, it did not enter the groundwater/aquifer system used to supply water to wells and therefore, should not be included in estimates of groundwater/aquifer recharge.

POSTEN (1984) METHOD

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

One method has been developed in New Jersey (Posten 1984) that determines “delayed flow” from hydrograph separation and then ranks these “delayed flow” rates to determine exceedence probability values. The exceedence probability values and the delayed flow rates are depicted on arithmetic probability graphs to estimate groundwater recharge and aquifer yields that could be safely removed without causing

adverse impacts. The author took the extra step of plotting the annual delayed flow rates and exceedence probability values to define a line along which, baseflow rates under dry weather conditions could be determined.

Posten (1984) developed this method to reduce the number of "personal judgments" and therefore, reduce potential overestimates of groundwater recharge. A study of groundwater recharge rates in New Jersey conducted by Canace et al. (1992) indicates that the Posten (1984) Method does result in lower recharge rates than another hydrograph separation method. However, the Posten (1984) Method continues to result in overestimates albeit, smaller ones, of groundwater recharge because the fundamental method of separating streamflow records into delayed flow rates must include discharges from shallow sources in the delayed flow estimates. As a result, the Posten (1984) Method will result in overestimates of groundwater recharge rates to aquifer systems; however, these overestimates are likely to be smaller than estimates made with other hydrograph separation approaches.

COMPUTER MODELS

Hydrograph separation techniques are one tool for assessing groundwater recharge rates. A second tool is the use of computer models for simulating hydrogeologic conditions. Two such models have been completed for areas underlain by carbonate rock and are useful for evaluating groundwater recharge rates.

The first model was completed by Nicholson (1995) as part of her evaluation of impacts from dewatering operations at Limecrest Quarry to the glacial and carbonate-rock aquifer systems extending beneath Andover Township. The second model was completed by Nicholson et al. (1996) for evaluating hydrogeologic conditions beneath Long Valley. The northern portion of the Long Valley is underlain by glacial sediments and carbonate rock similar to sections of Andover Township. The southern portion of the valley is underlain by carbonate rock exposed at or very near ground surface also similar to sections of Andover Township. These models are useful for evaluating groundwater recharge to the combined glacial/carbonate-rock systems as well as the outcropping or shallowly buried carbonate rock beneath Andover Township.

NJGS MODIFIED METHOD

AQUIFER VERSUS "GROUNDWATER" RECHARGE

The NJGS developed a "planning tool" to identify areas of potential groundwater recharge to be used by municipal planners and not hydrogeologists. This method, which is referred to as GSR-32 (Charles 1993) is not accepted by NJDEP-Bureau of Water Allocation for determining rates of natural replenishment as it does not calculate rates at which, aquifers are recharged.

The NJGS developed the GSR-32 method for estimating "groundwater" recharge based on soil types, land use, and municipal climate factors (Charles 1993). The method modifies the water balance equation by using factors for recharge, climate, and

drainage basin that are based on general soil types, municipal location, and land use/land cover. The NJGS modified method does not consider differences in slope gradients, depth to bedrock, presence of impervious surfaces, topography, and/or type of bedrock underlying soils. One of the major assumptions is that the evaluated area is flat with no changes in elevation. As a result, the method does not measure rates of recharge to aquifer systems such as those systems beneath Andover Township.

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

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

Throughout this M^2 Associates report and as typically referenced in hydrogeologic texts and USGS reports, the term groundwater recharge refers to water that infiltrates to the saturated zone, which for Andover Township are the groundwater resource relied upon for meeting water-supply demands. 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 and are only discussed herein, because they are sometimes submitted to Planning Boards as part of groundwater resource evaluations or environmental impact statements.

Soil Recharge Rates

Soil recharge rates calculated with the NJGS method are not appropriate for evaluating groundwater recharge or water-supply availability for Andover Township and would not be acceptable to NJDEP for water-supply evaluations. However, they are sometimes

presented to Planning Boards as supporting evidence that adequate groundwater is available. The soil recharge rates calculated with NJGS method using a Microsoft Excel Workbook (Hoffman 2002) for the soils mapped in Andover Township are summarized as follows:

Soil Type	Soil Recharge Rate (inches per year)
Alden	Hydric Not Applicable
Catden mucky peat	Hydric Not Applicable
Chatfield-Hollis-Rock outcrop complex	12.2
Farmington-Rock outcrop complex	16.2
Farmington-Wassaic-Rock outcrop complex	16.2
Fluvaquents	Hydric Not Applicable
Fredon-Halsey complex, very stony	Hydric Not Applicable
Hazen-Hoosic complex	17.4 to 18.5
Hibernia loam	14.2
Hinckley	19.8
Hollis-Rock outcrop-Chatfield complex	12.2
Hoosic-Otisville complex	18.5 to 19.8
Nassau-Manlius complex	15.4
Pits, sand and gravel	20.4
Pompton	17.5
Quarry	Not Applicable
Riverhead	17.7
Rock outcrop-Farmington-Galway complex	14.2
Rockaway	15.2
Rockaway-Rock outcrop complex (Sussex)	12.2
Udorthents	Not Applicable
Udorthents-Urban land complex	Not Applicable
Urban land-Chatfield-Rock Outcrop complex	Not Applicable
Urban land-Farmington-Rock outcrop complex	Not Applicable
Urban land-Hazen-Hoosic complex	Not Applicable

Based on the soil types and climatic conditions of Andover Township, soil recharge rates ranging from 12.2 to 20.4 inches per year were calculated with the NJGS method. These rates show little to no difference in recharge for areas of the Township underlain by Precambrian rocks versus carbonate rocks or glacial materials. Some of the highest rates of soil recharge were calculated for rock outcrops, steep sloping materials, and areas with bedrock exposed, where it would be expected that because of impervious materials and steep gradients associated with the rock and/or steep slopes, runoff rates would be highest and recharge rates lowest. The NJGS method cannot be used to calculate soil recharge rates for several soils in the Township that are associated with wetlands, open water, or hydric soils. The method also does not differentiate between steeply sloping and flat-lying soils.

Since the NJGS made a clear distinction that their model does not determine "aquifer" recharge, this method should not be used to assess recharge rates to aquifer systems beneath Andover Township. Based on the geologic conditions of the Township, the recharge rates calculated with the NJGS GSR-32 method are not reliable for assessing groundwater resources or the rates at which these resources are naturally replenished. These rates have been presented herein because they have been used by representatives of applicants to planning boards in New Jersey in support of development applications. These rates are not useful for evaluating groundwater resources and planning boards should not accept water-resource analyses for which, the NJGS GSR-32 methodology has been used. The NJDEP-Bureau of Water Allocation will not accept analyses using this method for water allocation permits.

Groundwater Recharge Rates

PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS

The USGS (Nicholson et al. 1996) determined that groundwater recharge to the Precambrian igneous and metamorphic rocks in Long Valley was negligible and that this water quickly discharged from shallow weathered zones to springs and seeps into streams draining upland areas. Furthermore, in developing the computer model of the Long Valley aquifer systems, Nicholson et al. (1996) determined that there was no flow across the natural aquifer boundary formed by the contact between the Precambrian rocks and the younger carbonate rocks. Although this study indicates that there is very little recharge to the Precambrian rocks, there is sufficient recharge to support use of residential wells completed in these rocks.

To assess recharge rates to the Precambrian igneous and metamorphic rocks in Andover Township, the Posten (1984) hydrograph separation method was used. Posten as part of his research in developing his method, evaluated streamflow data from West Brook and Blue Mine Brook in Passaic County. Both drainage basins are entirely underlain by Precambrian igneous and metamorphic rocks.

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

The Posten (1984) Method was also used by M^2 Associates to evaluate streamflow data for the water years (October 1 through September 30) 1973 through 1996 for Upper Cold Brook near Pottersville, New Jersey and for the water years 1979 through 1988 and 1993 through 2000 for Spruce Run at Glen Gardner. The USGS does not report streamflow data for Spruce Run at Glen Gardner for the period from November 1, 1988 to December 10, 1991. Both of these drainage basins upgradient of the measuring station are entirely underlain by Precambrian igneous and metamorphic rocks. In

accordance with the method outlined by Posten (1984) the groundwater recharge rate determined for Upper Cold Brook is 4.4 inches per year and for Spruce Run at Glen Gardner is 3.6 inches per year.

The Posten (1984) method analyses of the four streams entirely underlain by Precambrian igneous and metamorphic rocks indicates recharge to the aquifer systems in these rocks ranges between 3.6 and 4.4 inches per year. The data indicate a median recharge rate to Precambrian igneous and metamorphic rocks of 4.0 inches per year.

COMBINED GLACIAL/CARBONATE ROCK SYSTEM

Nicholson (1995) in her evaluation of Limecrest Quarry dewatering operations developed a computer model to simulate groundwater flow. In preparing this model, she determined that groundwater in the glacial sediments and underlying carbonate rock beneath the Germany Flats Valley is recharged at a rate of 12.1 inches per year.

OUTCROPPING CARBONATE ROCK SYSTEM

The Nicholson et al. (1996) study of Long Valley indicates recharge from direct precipitation to carbonate rocks similar to those mapped beneath Andover Township is approximately 22 inches per year. This study further indicated that total recharge to the carbonate rocks after including runoff from Precambrian rocks in the uplands was approximately 28.5 inches per year.

It is likely that the carbonate rock system beneath Andover Township is recharged at a rate less than 28.5 inches per year because runoff/throughflow from the Precambrian rocks would intersect the combined glacial/carbonate rock system along Kymer Brook to the Pequest River and not the outcropping carbonate rock system. Runoff/throughflow from the Martinsburg Formation would drain to the shallow carbonate rock system. Tthe Andover Township well data do not indicate aquifer systems in the carbonate rock that are as high yielding or transmissive as those beneath Long Valley. Therefore, it is reasonable to assume that the carbonate rock system is recharged at a rate closer the direct precipitation value determined by Nicholson et al. (1996).

Based on the Nicholson et al. (1996) study, recharge to groundwater in carbonate rock aquifers beneath Long Valley from direct precipitation is equivalent to 22 inches per year, which is approximately 44 percent of annual precipitation. Long Valley receives slightly more precipitation per year than Andover Township. Applying this percentage to the precipitation data for Andover Township indicates the outcropping carbonate rock system is replenished at a rate of 20.8 inches per year.

MARTINSBURG FORMATION

The Martinsburg Formation is not considered a major water supply resource and therefore, has not been widely studied. Most studies appear to focus on the carbonate rock in the valley and indicate that the Martinsburg Formation is a barrier to flow.

A recent computer model of the Opequon Creek watershed in Virginia and West Virginia was prepared by Kozar and Weary (2009). This model simulates an area with a carbonate rock aquifer bisected by the Martinsburg Formation. The Martinsburg Formation in Andover Township is surrounded by carbonate rock. In calibrating their computer model, Kozar and Weary (2009) determined that recharge to the Martinsburg Formation was significantly less than to the carbonate-rock aquifers. They concluded that the Martinsburg Formation received 5.9 inches per year of recharge during a year of normal precipitation. The study area received 38.5 inches per year of precipitation and if the ratio or recharge to precipitation is applied to Andover Township, it would indicate that the Martinsburg Formation beneath the Township receives 7.1 inches per year of natural replenishment.

SUMMARY

Based on the Posten (1984) Method, or computer modeling, groundwater is recharged during a year of normal precipitation at the following rates for the aquifer systems beneath Andover Township.

Precambrian rocks = 4.0 inches per year.

Combined glacial/carbonate-rock = 12.1 inches per year.

Outcropping carbonate-rock = 20.8 inches per year.

Martinsburg Formation = 7.1 inches per year.

WATER SUPPLY

DEMAND

As part of the most recent statewide planning efforts, the NJDEP (1996) assumed a per capita water use rate of 75 gallons per day for residential self-supplied demand. The New Jersey Water Supply Authority (NJWSA 2000) indicates a guideline value of 140 gallons per day per capita. N.J.A.C. 7:10-12.6 indicates that in planning water supply needs, an average daily demand of 100 gallons per day per person should be used. The Residential Site Improvement Standards (Subchapter 5) also indicate a single-family home water use rate of 100 gallons per day per person. The per capita demand suggested by the New Jersey Administrative Code appears to be a reasonable mid-range estimate of daily personal water demands and may include a factor of safety if the NJDEP 1996 estimate is accurate.

Based on US Census data for 2000, Andover Township had a population of 6,033 people and 1,889 occupied dwelling units indicating a dwelling unit density of 3.2 persons per unit. Based on the population of the Township and the average daily demand indicated in N.J.A.C. 7:10-12.6, Andover Township residents currently consume approximately 0.60 million gallons per day or 220 million gallons per year of

groundwater through their wells. Additional water withdrawals associated with mining and irrigation will increase the annual water use. Limecrest Quarry continues to retain a water allocation permit that allows withdrawals up to 8.6 million gallons per day or 3.2 billion gallons per year.

DEPENDABLE YIELD

Definition

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

Maintainable Yield

Drought conditions can alter the hydrologic water balance for an area depending on the time of year the precipitation shortfall occurs. During the winter months, a precipitation shortfall will impact groundwater recharge and to a lesser degree, surface-water runoff. Evapotranspiration is negligible in winter months so this parameter is generally unaffected by precipitation shortfalls during cold weather. During summer months, precipitation shortages 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 as significantly affected by a warm weather drought, as are surface-water runoff and evapotranspiration. Droughts that occur over several years such as the "Drought of Record" adversely impact all water-balance parameters.

The Posten (1984) Method includes consideration of dry weather recharge rates. However, this method includes baseflow components from sources other than underlying aquifer systems and therefore, is biased to provide overestimates of groundwater recharge rates. Provided that it is understood that these additional baseflow components were included in determining recharge rates, adjustments for reduced precipitation are most likely not necessary if sufficient safety margins are also included when assessing maintainable yields.

The computer models used by Nicholson (1995) in her evaluation of dewatering impacts, by Nicholson et al. (1996) in their evaluation of Long Valley aquifer systems, and by Kozar et al. (2009) for assessing recharge to the Martinsburg Formation, all used normal precipitation conditions. As a result, adjustments for reduced precipitation

during a drought must be made for groundwater recharge rates determined with these models for the combined glacial/carbonate-rock aquifers, outcropping carbonate-rock system, and for the Martinsburg Formation.

The USGS has a stream gauge in the Pequest River at Huntsville (Station Id No. 01445000) from which, streamflow measurements are made during the years November 1939 to October 1962 and October 2002 to the present. No streamflow measurements were recorded during the “Drought of Record” and therefore, direct impacts to flow rates from drought cannot be assessed at this location.

The Musconetcong River near Bloomsbury drains geology similar to the Pequest River near Andover Township. Based on stream discharge measurements compiled by the USGS in the Musconetcong River near Bloomsbury from October 1, 1921 to September 30, 2004, the median flow rate is 184 cubic feet per second. For the period from October 1, 1961 through to September 30, 1967, the median flow rate was 106 cubic feet per second or 58 percent of normal flow for the period of record.

Using these same streamflow data for the Musconetcong River near Bloomsbury, the NJGS estimated baseflow using hydrograph separation methods for the periods 1922 to 1989, 1940 to 1989 and 1960 to 1966 (Canace 1992). For the periods from 1922 to 1989 and 1940 to 1989, baseflow was 22.79 and 23.28 inches per year. During the period of 1960 to 1966, baseflow was 15.89 inches per year. The 1960 to 1966 baseflow estimates are approximately 68 to 70 percent of the long-term estimates.

Similar to baseflow, groundwater recharge would be affected by the lack of precipitation during drought. Based on the Musconetcong River near Bloomsbury streamflow data, groundwater recharge during a prolonged drought is likely to be approximately 58 to 70 percent of normal-year recharge. In other words, the streamflow data indicate that during drought, groundwater recharge is reduced 30 to 42 percent. 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 prolonged drought. Therefore, a reasonable margin of safety is necessary to ensure adequate water supplies in a repeat of the “Drought of Record”.

Using the precipitation data for 1965, which was 66 percent of normal year precipitation for New Jersey, recharge during a repetition of the “Drought of Record” is likely to be as follows:

> Precambrian rocks = 4.0 inches per year (the Posten (1984) Method includes consideration of dry weather conditions so, this rate is unchanged from normal conditions).
>
> Combined glacial/carbonate-rock = 8.1 inches per year.
>
> Outcropping Carbonate-rock = 13.9 inches per year.
>
> Martinsburg Formation = 4.7 inches per year.

Planning Threshold

To ensure that water is available during all weather conditions for human consumption as well as for other consumers located downstream and ecosystems dependent on water, the NJDEP established the "Planning Threshold". In the 1996 Statewide Water Supply Plan (NJDEP 1996), the NJDEP indicated that the dependable yield of most areas of the State had not been determined. Therefore, they established the "Planning Threshold" to reduce uncertainties associated with determining dependable yields and recharge rates for aquifers, and to limit human consumption within a basin. Through use of the Planning Threshold, the NJDEP proposes to limit human consumption of water within a basin to 20 percent of recharge and establishes the dependable yield at this level. Applying the NJDEP's Planning Threshold Policy to the drought recharge rates indicates dependable yields for the four groundwater systems beneath Andover Township as follows:

Precambrian rocks = 0.8 inches per year.

Combined glacial/carbonate-rock = 1.6 inches per year.

Outcropping Carbonate-rock = 2.8 inches per year.

Martinsburg Formation = 0.9 inches per year.

Summary

The area of each groundwater resource, the drought recharge rate in inches per year and gallons per day per acre, and the dependable yield in gallons per day per acre as calculated with the NJDEP Planning Threshold Policy are summarized as follows:

Groundwater Resource	Area (acres)	Drought Recharge Rate (inches/year)	Drought Recharge Rate (gpd/acre)	Dependable Yield (gpd/acre)
Precambrian rocks	4600	4.0	298	60
Combined Glacial/Carbonate Rock	909	8.1	603	121
Carbonate Rock	5233	13.9	1034	207
Martinsburg Formation	2613	3.9	290	58

The area of the combined glacial/carbonate rock aquifer system was determined from the NJGS mapping of the sediment thickness exceeding 50 feet. This combined system coincides with the mapping of the sediment thickness shown on Figure 12.

GROUNDWATER AVAILABILITY

Based on the areas of each aquifer system, during drought, the Township's groundwater resources are replenished at a rate of 8.24 million gallons per day (mgd). The rates for each aquifer systems is summarized as follows:

Groundwater Resource	Potential Total Recharge (mgd)	Potential Total Dependable Yield (mgd)
Precambrian rocks	1.37	0.27
Combined Glacial/Carbonate Rock	0.55	0.11
Carbonate Rock	5.41	1.08
Martinsburg Formation	0.91	0.18

Andover Township has a dependable yield for all of its aquifer system of 1.65 mgd. This dependable yield indicates that a population of 16,500 persons, or approximately 2.5 times the current population could be sustained without adverse impacts to natural resources or others users of groundwater. However, Limecrest Quarry has permission to withdraw 8.6 million gallons per day from the combined glacial/carbonate rock aquifer. Pumping at the permitted rate will not only exceed the dependable yields of all the aquifer systems beneath Andover Township but would exceed recharge to these aquifers in drought. In addition to the 0.60 mgd withdrawn to meet domestic water demands of the population, there are three golf courses that have water allocation permits allowing maximum withdrawals of 0.5 mgd. Also, the Town of Newton and Andover Borough are permitted to withdraw a combined maximum of 1.4 mgd from the carbonate rock aquifers.

The data may suggest that the population could be more than doubled without resulting in adverse impacts, but based on the currently permitted withdrawals from or very near Andover Township, the dependable yields of the aquifers are likely exceeded. Andover Township has direct experience with adverse impacts to natural resources and groundwater systems from over-pumping groundwater resources. Nicholson (1995) documented that the pumping influences from the Limecrest Quarry dewatering operations, starting in the 1970's, were effectively draining water from the aquifer systems beneath Andover Township and impacting water levels in Howells Pond, located 1.5 miles to the southwest. Her research efforts concluded that the dewatering operations at the quarry resulted in the following impacts:

1. Water levels were lowered in the Germany Flats Valley. Groundwater levels in the carbonate rock aquifer were lowered 10 feet or more within 4000 feet of the quarry and 5 feet or more within 8000 feet of the quarry. The pumping at the quarry was inducing groundwater flow from beneath Andover Township toward the quarry.

2. Baseflow was depleted in the Pequest River basin located more than 1-mile south of the quarry showing pumping influences were extensive beneath Andover Township. Groundwater discharges needed to maintain baseflow in the Paulins Kill basin likely were also decreased but would not be evident because water pumped from the quarry to this basin would have obscured any data indicative of the effect. The quarry is located within the Paulins Kill basin.

3. Steep gradients beneath streams were created by quarry pumping. These gradients induce infiltration of surface water to groundwater. The quarry dewatering operations in effect, were depleting water from streams.

4. Quarry pumping changed groundwater flow directions and divides. The dewatering operations were inducing groundwater flow toward the quarry. The pumping influences and the impacts to groundwater flow are clear indication of a strong hydraulic relationship between water in the quarry and the surrounding aquifer systems beneath the valley extending along Kymer Brook.

5. Groundwater drawdown in the water-table aquifer was greatest where the most permeable glacial deposits exist, which is to the southwest of the quarry and beneath Andover Township.

6. The carbonate rock aquifers were directly influenced by pumping resulting in an elliptical cone of depression with the major axis oriented northeast to southwest. The anisotropic response was 2 to 1 in the northeast to southwest direction in comparison to the northwest to southeast. The poorly permeable Precambrian igneous and metamorphic rocks to the east through south of the site limited the impacts from pumping in these directions focusing greater impacts to the southwest beneath Andover Township. The most significant impacts from the quarry dewatering operations extended beneath Andover Township. The groundwater resources beneath the Township are strongly interconnected to those within the quarry/reservoir at the Limecrest site.

Empirical evidence of the impacts from dewatering at Limecrest Quarry are apparent on aerial photographs. Nicholson (1995) indicates that Howells Pond likely encompassed 30 acres prior to the start of dewatering at the quarry in the 1970s. 1995 aerial photographs depicting Howells Pond show that the surface area of water in the pond encompasses 2.63 acres. 2002 aerial photographs of the same area show a water surface area of 0.45 acre. Late 2007-early 2008 aerial photographs taken after dewatering operations had been shut down for approximately 2 years show that the water surface encompasses approximately 19.8-acres in the pond.

Another example of potential adverse impacts from exceeding the dependable yield is summarized by Canace and Hoffman (2009). These authors indicate that a requested water allocation permit for a withdrawal of 0.365 mgd from the glacial aquifer system beneath Andover Township would result in baseflow depletion of 0.168 mgd from the Paulins Kill and a similar amount from the Pequest River watersheds for a total baseflow depletion of 0.336 mgd. They concluded that the diversion request would reduce baseflow in streams by 92 percent. The resulting diversion would nearly eliminate discharges from the glacial aquifer to nearby streams during dry weather potentially resulting in adverse impacts to natural resources and others dependent on these discharges such as the downstream lake communities.

Although the dependable yields of the Andover Township aquifer systems are more than adequate to sustain the current population, commercial and industrial withdrawals have resulted in exceedences of these safe yields and ultimately, adverse impacts.

DWELLING UNIT DENSITIES

Based on the average number of people per home and the per capita water demands indicated by N.J.A.C 7:10-12.6, each home in Andover Township consumes 320 gpd. The dependable yields per aquifer system and consumption rate of 320 gpd per unit can be used to determine the recharge area per dwelling unit necessary to meet the water-supply demands of the unit. These recharge areas per dwelling unit are summarized as follows:

Groundwater Resource	Dependable Yield (gpd/acre)	Recharge Area per Dwelling Unit (acres)
Precambrian rocks	60	5.4
Combined Glacial/Carbonate Rock	121	2.7
Carbonate Rock	207	1.5
Martinsburg Formation	70	4.6

These recharge areas have been calculated assuming that all groundwater usage in the Township is for meeting residential demands and that groundwater will not be diverted for commercial or industrial purposes. If dewatering operations at Limecrest Quarry were to return to pre-2005 rates, the combined glacial/carbonate-rock systems will not sustain residential densities as small as 2.7 acres per unit. Also, near the golf courses and other users, it will be necessary to refine densities to ensure that the dependable yields of the aquifers in these areas are not exceeded.

The recharge areas per dwelling unit are not equal to lot sizes. Smaller lot sizes could be sustained provided that sufficient areas are available to permit upgradient recharge and the overall densities within the associated contributing drainage basin are not exceeded. Old agricultural villages with small lots surrounded by active farmlands are an example of an area with lot sizes smaller than the recharge areas listed above. Provided that the overall density within the contributing drainage area is not exceeded, recharge to upgradient farmlands sustains the village's water demands without adverse impact. Little precipitation infiltrates beneath the village because of the high percentage of impervious surfaces, while sufficient precipitation infiltrates through the adjoining open farm fields during late fall and winter months to sustain the local water-supply demands. In areas where smaller lot sizes exist, it may be necessary to preserve upgradient lands to ensure long-term reliability of water resources to these residences.

The recharge areas per dwelling unit are based on the dependable yields of the aquifer systems. Therefore, these areas should permit sufficient precipitation to infiltrate an aquifer system and ensure that water is available for both human consumption within the dwelling unit and also for ecosystems and downstream consumers during severe

dry weather. These recharge areas per dwelling unit do not include water diverted for commercial or industrial use and therefore, in contributing drainage basins where groundwater is diverted for commercial or industrial purposes, the recharge areas per dwelling unit must be increased to balance the additional groundwater withdrawals.

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. 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 not be included in the recharge area. The areas covered with improvements/impervious surfaces and environmental constraints would be added to the recharge area per dwelling unit and therefore, the net number of dwelling units per aquifer system will be less calculated by dividing the total area of the system by the recharge area. For example, the total area of Precambrian rocks encompasses 4,600 acres. This groundwater resource could not sustain 852 units because impervious surfaces and environmental constraints, such as but not limited to wetlands and steep slopes, that do not permit infiltration of recharge must be subtracted from the total area.

The aquifer recharge areas should be located within areas in which the underlying bedrock is fractured with little to no impervious coverage along strike of the fractures. The recharge areas do not have to be coincident with the dwelling unit. Often, the geology near a particular dwelling unit is insufficient to sustain the demands and water from upgradient areas is captured or used as it flows beneath the property. It should also not be assumed that stormwater measures taken to maintain pre- and post-development soil recharge rates will adequately replenish groundwater resources beneath the Township. These stormwater measures focus captured precipitation to a much smaller point and unless conditions are adequate to permit large rates of infiltration to an aquifer, much of the stormwater will throughflow to the nearest stream or seep and does not recharge groundwater.

The minimum recharge areas per dwelling unit have been calculated to provide a dependable water-supply yield to existing dwelling units and a future single-family residence occupied by 3.2 persons. These recharge areas assume that the water is depleted from the aquifer and not returned.

In Andover Township, septic systems are used for disposal of wastewater. As a result, most if not all water removed from the aquifer is returned. However, the wastewater contains contaminants such as nitrates, bacteria, viruses and man-made chemicals that are highly mobile and are not readily removed. Therefore, additional recharge is required to dilute these and other contaminants to a level that would satisfy Federal or State Drinking Water Quality Standards.

NITRATE DILUTION

Nitrate

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

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

CURRENT REGULATIONS

The NJDEP recently adopted N.J.A.C 7:15, which are the wastewater management planning regulations. When preparing a wastewater management plan for an area where septic system are used, an analysis of septic system effluent impacts can be completed using the NJDEP's "Recharge-Based Nitrate-Dilution Model for New Jersey". The most recent version of this model is 6.1 as published in October 2009 and made available on the NJGS website. In adopting N.J.A.C 7:15, the NJDEP established a target nitrate concentration of 2 milligrams per liter (mg/l) (N.J.A.C 7:15-5.25(e)1) and therefore, adequate recharge must be permitted to reduce nitrate concentrations in septic system effluent to a level equal to 2 mg/l.

In addition to the wastewater management planning regulations. NJDEP, on January 7, 1993, 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 Andover 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. The recently proposed (December 7, 2009) N.J.A.C 7:9C Ground Water Quality Standards do not change the 10 mg/l standard.

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. For Class II-A groundwater not

located within the Highlands Preservation Area but requiring a wastewater management plan, NJDEP established a limit of 2 mg/l (N.J.A.C 7:9C-1.8(b)3). For a similarly located project but requiring a New Jersey Pollutant Discharge Elimination System permit (NJPDES), the NJDEP established a limit of 6 mg/l.

While individual residential septic systems do not require amendments to wastewater management plans or NJPDES permits, wastewater discharges within the Township are regulated by NJDEP through its wastewater management planning regulations. Therefore, the Township would be required to maintain a limit of 2 mg/l.

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 31 years when evaluating potential nitrate discharges from septic systems to groundwater and for determining the recharge area necessary to dilute nitrate concentrations. The model continues to be used by the NJDEP and is the nitrate dilution model included in their “Recharge-Based Nitrate Dilution Model for New Jersey” (Hoffman and Canace 2004).

NJGS METHOD RESULTS

The recharge area per dwelling unit for the soils beneath Andover Township were calculated using the NJGS’ October 2009 version 6.1 of the NJDEP’s “Recharge Based Nitrate Dilution Model for New Jersey.” The calculations were completed using a target nitrate concentration of 2 mg/l and assuming 3.2 persons per dwelling unit.

The recharge area per dwelling unit cannot be calculated for soils underlying approximately 19.4 percent of Andover Township. The method is not applicable to hydric soils or for areas where soils have been disturbed and are classified as urban. The NJGS method does not include slopes and assumes all soils are relatively flat lying. Soils indicating steep slopes (greater than or equal to 15 percent) have been mapped beneath nearly 39 percent of the Township.

Soils beneath 59 percent of Andover Township are associated with rock outcrop complexes indicating that bedrock is encountered at very shallow depths. Beneath these areas, septic systems are often installed below soils and into shallow weathered bedrock. As a result, effluent from these septic systems is discharged to bedrock fractures that serve as the same conduits for recharging groundwater. The potential for adverse impacts is much greater for carbonate rock, where discharges can migrate quickly to solution cavities result in sinkhole formation, failure or loss of the leaching field, and wide-spread contaminant distribution. As a result, the only precipitation available for diluting septic system contaminants is the limited amount that migrated past soil layers and into bedrock.

The NJGS method cannot be used to determine the recharge area needed to ensure adequate dilution of septic system contaminants discharged to the bedrock aquifer systems beneath Andover Township. The recharge areas per septic system calculated with the NJGS method are summarized as follows:

Soil Type	Recharge Area per Septic System (acres)
Alden	Hydric Not Applicable
Catden mucky peat	Hydric Not Applicable
Chatfield-Hollis-Rock outcrop complex	6.2
Farmington-Rock outcrop complex	4.7
Farmington-Wassaic-Rock outcrop complex	4.7
Fluvaquents	Hydric Not Applicable
Fredon-Halsey complex, very stony	Hydric Not Applicable
Hazen-Hoosic complex	4.4 to 4.2
Hibernia loam	5.1
Hinckley	3.9
Hollis-Rock outcrop-Chatfield complex	6.2
Hoosic-Otisville complex	4.2 to 3.9
Nassau-Manlius complex	4.9
Pits, sand and gravel	3.9
Pompton	4.4
Quarry	Not Applicable
Riverhead	4.3
Rock outcrop-Farmington-Galway complex	5.3
Rockaway	5.0
Rockaway-Rock outcrop complex (Sussex)	6.2
Udorthents	Not Applicable
Udorthents-Urban land complex	Not Applicable
Urban land-Chatfield-Rock Outcrop complex	Not Applicable
Urban land-Farmington-Rock outcrop complex	Not Applicable
Urban land-Hazen-Hoosic complex	Not Applicable

BEDROCK 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 and/or carbonate-rock environments with thin soil cover such as the systems beneath much of Andover Township. The thin layer of soils and bedrock fractures/cavities offer limited retention time and there will be little if any, denitrification of the septic system effluent or removal of other contaminants.

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 87 percent of the land area within the Township is covered with soils that are characterized by USDA-

NRCS as very limited for wastewater disposal via septic systems and 85 percent of the land area is covered with soils that are characterized in N.J.A.C 7:9A as unsuitable for construction of septic systems, it is highly probable that adverse impacts to bedrock aquifer systems will result unless adequate recharge is available to dilute septic system contaminants and ensure safe drinking-water conditions.

The Trela-Douglas model was used to evaluate recharge areas needed to dilute septic system contaminants beneath the 12,450 acres of the Township directly underlain by bedrock aquifers. The analysis was completed for the 909 acres underlain by the thick glacial deposits associated with the combined glacial/carbonate rock aquifer because discharges to stratified coarse-grained layers can result in rapid transmittal of contaminants to an aquifer.

The Trela-Douglas nitrate dilution model is based on several assumptions, which were the same assumptions used in the analyses completed with the October 2009 version 6.1 of the NJDEP's "Recharge Based Nitrate Dilution Model for New Jersey" except that the NJDEP method employs soil recharge rates and not aquifer/groundwater recharge. These assumptions for Andover Township are as follows:

1. The groundwater use rate is 100 gallons per day per person and 3.2 persons occupy each dwelling unit. These assumptions are the same assumptions used in determining recharge areas for water supply use. Therefore, groundwater use per dwelling unit is 320 gpd.

2. The aquifer recharge rate is 4.0 inches per year for the Precambrian rocks, 8.1 inches per year for the combined glacial/carbonate-rock system, 13.9 inches per year for the outcropping carbonate rocks, and 4.7 inches per year for the Martinsburg Formation. These recharge rates were selected for this analysis to minimize potential adverse impacts to groundwater quality as well as to the health of residents and other water consumers during an extended drought similar to the "Drought of Record" in the 1960's.

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 are based on the limits established in N.J.A.C 7:9C-1.8 for Class II-A groundwater. The calculations were completed using a target concentration of 6 mg/l and then for a target concentration of 2 mg/l.

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

EQUATION

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

$$V_eC_e=(V_i+V_e)C_q \quad (2)$$

Where:

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

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

$$V_e=HW_u \quad (3)$$
$$V_I=AR \quad (4)$$

Where:

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

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

$$A=HW_u(C_e-C_q)/74.39(RC_q) \quad (5)$$

With the following values for these parameters:

H = 3.2 persons per home.
W_u = 100 gallons per day.
C_e = 40 mg/l.
C_q = 6 mg/l for the first evaluation and 2 mg/l for the second.
R = 4.0 inches per year for Precambrian rocks, 8.1 inches per year for the combined glacial/carbonate-rock system,13.9 inches per year for carbonate rocks, and 4.7 inches per year for the Martinsburg Formation.

The results of the calculations are summarized as follows:

Groundwater Resource	Drought Recharge Rate (inches/year)	Recharge Area per Dwelling Unit for Septic Contaminant Dilution to 6 mg/l (acres)	Recharge Area per Dwelling Unit for Septic Contaminant Dilution to 2 mg/l (acres)
Precambrian rocks	4.0	6.1	20.4
Combined Glacial/Carbonate Rock	8.1	3.0	10.1
Carbonate Rock	13.9	1.8	5.9
Martinsburg Formation	4.7	5.2	17.4

Similar to the recharge areas for water supply, the recharge areas necessary to dilute septic system contaminants should be flat to gently sloping 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. Carbonate rock systems are highly susceptible to anthropogenic contamination and therefore, in sections of Andover Township underlain by these rocks, especially where karst features are evident, it is necessary to evaluate potential adverse impacts on a lot by lot basis. The results of this evaluation may indicate recharge areas greater than those listed above for the Carbonate-Rock system are required.

In areas of the Township with existing recharge areas less than the densities required, additional areas or recharge enhancements may be needed for adequate contaminant 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 recharge areas are capable of supporting existing dwelling units, it may be necessary to protect upstream open areas or enhance recharge to balance portions of the existing lots covered with impervious materials.

CONCLUSIONS

Based on the data, reports, and maps reviewed in preparation for this evaluation of the groundwater resources of Andover Township, the following conclusions are made:

1. The source of drinking water for Andover Township residents is groundwater. The NJDEP and USEPA consider groundwater to be the single source of potable water within the designated Northwest New Jersey Sole Source Aquifer that underlies the Township and indicate that measures should be taken to protect this critical resource from potential health hazards.

2. Groundwater resources beneath neighboring municipalities designated for protection by the Highlands Water Protection and Planning Act extend

beneath Andover Township. Headwaters of streams protected by the Highlands Act are located in Andover Township. The same water resources designated by the State for protection exist within Andover Township but the Township is not afforded the protective measures included in the Act. Municipal officials and citizens are concerned that because the water resources of the Township were not designated for protection, growth that would have occurred in the neighboring Highlands communities will focus and further expedite development in Andover Township affecting water resource sustainability and quality.

3. The northern 4.9-square miles of the Township is located within the Paulins Kill drainage basin and the southern nearly 16-square miles are located in the Pequest River watershed. Headwaters for streams within these watersheds are located within Andover Township. Andover Township's streams are considered high-quality resources designated by NJDEP as worthy of regulatory protective measures.

4. USDA-NRCS mapping indicates that 3.5 percent of the land area within the Township borders is covered with water. An additional nearly 9 percent of the Township land area is covered with soils considered hydric or occasionally flooded. The soils mapped as part of rock outcrop complexes encompass more than 57 percent of the land area within the Township, indicating that bedrock is shallow beneath these areas. Soils indicating steep slopes (greater than or equal to 15 percent) have been mapped beneath nearly 39 percent of the Township.

5. More than 87 percent of the land area within the Township is underlain with soils that are characterized by USDA-NRCS as very limited for wastewater disposal via septic systems. Nearly 85 percent of the land area is underlain by soils that are considered in N.J.A.C 7:9A as unsuitable for construction of septic systems. The limitations include shallow groundwater, massive bedrock, restrictive substratum or horizons, hydric soils, flooding, and steep slopes. As indicated by the USDA-NRCS and in the NJDEP regulations, the soils beneath most of Andover Township require extensive remediation and design effort for septic systems to operate. The long-term efficiency and life-time of these systems are likely to be shorter than conventional systems installed in more suitable soils.

6. Nearly all of the areas of the Township underlain by soils with no to moderate limitations for septic systems are in turn underlain by carbonate rock. Wastewater disposed through a septic system into carbonate bedrock could result in significant impacts including sinkholes and degraded water quality.

7. Thick glacial deposits have been mapped beneath slightly more than 900-acres of Andover Township. Near the Kittatinny Valley State Park ranger station, the combined thickness of these deposits extend to at least 325 feet

below ground surface indicating that in the Lake Iliff to New Wawayanda Lake valley, these unconsolidated sediments could be useful groundwater resources. However, except for a few locations along major rivers or valleys within the Township, it is unlikely that these deposits are significant direct groundwater resources such that they yield water to wells completed in the deposits. Where sufficient thicknesses of glacial deposits are encountered and where these materials have hydraulic connection to subsurface bedrock aquifers, they could serve as reservoirs leaking water into underlying bedrock.

8. The Precambrian igneous and metamorphic rocks beneath the eastern section of the Township are amphibolite, gneiss, marble, syenite, and granite. Thirty-four percent or 4,528 acres of the Township, is underlain by these crystalline rocks. These hard, dense, weakly fractured rocks are over a billion years old and form the ridges at some of the highest elevations within the Township and Highlands Physiographic Province.

9. Beneath 66 percent of Andover Township the USGS/NJGS has mapped Cambrian-Ordovician quartzite, dolomite, limestone, siltstone, shale, and slate. The Leithsville, Allentown, Lower and Upper Beekmantown, and Jacksonburg Formations are all comprised of carbonate rocks such as limestones and dolomites, which, when exposed to acidic solutions including weakly acidic rainwater, will dissolve forming solution cavities, voids, caves, and caverns. The Hardyston Quartzite and Martinsburg Formation also found in the western portion of the Township are not carbonate rocks.

10. Reverse or thrust faults such as the Jenny Jump and Tranquility Thrust have been mapped within the carbonate rocks beneath Andover Township. Movement on these faults was likely more than 400 million years ago and they are no longer considered active. Where carbonate bedrock is fractured, the potential is increased for dissolution of calcite minerals forming enlarged cavities. However, Miller (1974) indicates that faults in the carbonate rocks beneath Sussex and parts of Warren Counties are no longer zones of high intensity fracturing because of re-cementing. These faults, unlike in other areas of New Jersey, no longer represent potential zones of high yielding groundwater resources.

11. In unconsolidated aquifers such as the glacial deposits in the Lake Iliff/New Wawayanda Lake valley, groundwater is stored and transmitted through pore spaces or openings between grains or particles. In well-stratified sand and gravel deposits, these openings are larger and therefore, more groundwater can be stored and transmitted. In poorly stratified or heterogeneous till deposits, or fine-grained lake deposits, the pore spaces are small and therefore, groundwater movement and storage is limited. The fine-grained lake deposits and heterogeneous tills can form confining units overlying more permeable, well-stratified fluvial or drift deposits.

12. Groundwater in bedrock aquifer systems is stored and transmitted along fractures, joints, bedding planes, and in carbonate rocks within solution openings. The availability of water is dependent on the separation between fractures/openings, the degree to which these fractures/openings are interconnected, and weathering of the materials between fracture planes and solution features. In some rocks, fractures or openings are separated by a few inches or less of competent, unweathered, and impermeable bedrock. In other rocks, the distance between fractures/openings may be several feet to several tens or hundreds of feet.

13. Data from wells completed in silicate-crystalline rock aquifers beneath Andover Township indicate that these rocks are poor aquifers. The silicate-crystalline rock aquifers are capable of yielding sufficient water to meet the demands of single-family homes but incapable of serving as significant public-water resources. The median yield, depth, and specific capacity for the Precambrian rocks beneath the Township are 10 gpm, 300 feet below ground surface, and 0.061 gpm/ft. The findings with respect to Precambrian rocks are similar to other areas in the Highlands Province of New Jersey.

14. Data from wells completed in the Franklin Marble indicate that this carbonate rock is higher yielding (median yield 13 gpm) but likely has a lower transmission capacity than the Precambrian silicate-crystalline rocks. With the exception of the band of Franklin Marble beneath Limecrest Quarry, the marble beneath Andover Township is completely surrounded by silicate-crystalline rocks and therefore, is dependent on these poorly transmissive rocks to replace water withdrawn from the Franklin Marble. The Franklin Marble is only a significant groundwater resources within and in close proximity to Limecrest Quarry, where the marble is in direct hydraulic contact with the glacial and carbonate-rock aquifers that extend beneath the Germany Flats Valley to the southwest.

15. Similar to the data for the Precambrian silicate-crystalline rocks, the records for wells completed in carbonate-rock aquifers indicate a median depth of 300 feet below ground surface but a slightly higher median yield of 12 gpm. In addition, the transmission capacity of the carbonate rock wells in comparison to the Precambrian rocks is not significantly different. While usually data from wells completed in carbonate rocks indicate characteristics of aquifers that are much more productive than Precambrian rocks, the local data and those compiled by Miller (1974) for the larger Sussex County study do not indicate substantial differences. The carbonate rock aquifers beneath Andover Township are not significantly greater groundwater resources than the poorly transmissive Precambrian rocks.

16. Local well data indicate that the Martinsburg Formation is the highest yielding and most transmissive of the bedrock systems beneath the Township. However, well depths and yields are not significantly different than those

determined for the silicate crystalline rock and carbonate-rock aquifers. The local data support the findings of Miller (1974) that the Martinsburg Formation is a somewhat better source of groundwater than the Precambrian and carbonate-rock systems. Miller (1974) describes the Martinsburg Formation as "…quite tight and it is, on the whole, a very poor aquifer."

17. The data indicate that there are four major groundwater resources beneath Andover Township. These are as follows:

    a. Precambrian igneous and metamorphic rocks including the Franklin Marble at locations except near Limecrest Quarry.

    b. Combined glacial/carbonate-rock systems that follow Kymer Brook and extend beneath Lake Iliff and New Wawayanda Lake. This system is also present beneath the Paulins Kill watershed in the northwestern portion of Andover Township and beneath the southwestern corner where the Pequest River enters the Township. The Franklin Marble beneath Limecrest Quarry is hydraulically connected to the combined system.

    c. Exposed or shallowly buried carbonate rocks primarily located in the southern portion of Andover Township but also along the flanks of the Kymer Brook valley where the glacial fluvial and delta deposits are replaced by thin layers of till.

    d. Martinsburg Formation.

18. The USGS (Nicholson et al. 1996) determined that groundwater recharge to the Precambrian igneous and metamorphic rocks in Long Valley was negligible and that this water quickly discharged from shallow weathered zones to springs and seeps into streams draining upland areas. Flow data for streams entirely underlain by Precambrian rocks that were evaluated with the Posten (1984) Method indicate a median recharge rate to these igneous and metamorphic rocks of 4.0 inches per year.

19. Nicholson (1995) in her evaluation of Limecrest Quarry dewatering operations developed a computer model to simulate groundwater flow. In preparing this model, she determined that groundwater in the glacial sediments and underlying carbonate rock beneath the Germany Flats Valley is recharged at a rate of 12.1 inches per year.

20. Based on the Nicholson et al. (1996) study, recharge to groundwater in carbonate rock aquifers beneath Long Valley from direct precipitation is equivalent to 22 inches per year, which is approximately 44 percent of annual precipitation. Long Valley receives slightly more precipitation per year than Andover Township. Applying this percentage to the precipitation data for Andover Township indicates the outcropping carbonate rock system is replenished at a rate of 20.8 inches per year.

21. The Martinsburg Formation is not considered a major water supply resource and therefore, has not been widely studied. Most studies appear to focus on the carbonate rock in the valley and indicate that the Martinsburg Formation is a barrier to flow. A recent computer model of the Opequon Creek watershed in Virginia and West Virginia was prepared by Kozar and Weary (2009). This model simulates an area with a carbonate rock aquifer bisected by the Martinsburg Formation. The Martinsburg Formation in Andover Township is surrounded by carbonate rock. Kozar and Weary (2009) determined that recharge to the Martinsburg Formation was significantly less than to the carbonate-rock aquifers. They concluded that the Martinsburg Formation received 5.9 inches per year of recharge during a year of normal precipitation. The study area received 38.5 inches per year of precipitation and if the ratio or recharge to precipitation is applied to Andover Township, it would indicate that the Martinsburg Formation beneath the Township receives 7.1 inches per year of natural replenishment.

22. Recharge during a repetition of the “Drought of Record” is likely to equal 4.0 inches per year for the Precambrian rocks, 8.1 inches per year for the combined glacial/carbonate-rock system, 13.9 inches per year for the outcropping carbonate-rock system, and 4.7 inches per year for the Martinsburg Formation.

23. Applying the NJDEP’s Planning Threshold Policy to the drought recharge rates indicates dependable yields for the four groundwater systems beneath Andover Township as follows: Precambrian rocks = 0.8 inches per year; combined glacial/carbonate-rock = 1.6 inches per year; outcropping carbonate-rock = 2.8 inches per year; and Martinsburg Formation = 0.9 inches per year.

24. Based on the areas of each aquifer system, during drought, the Township’s groundwater resources are replenished at a rate of 8.24 million gallons per day (mgd). Andover Township has a dependable yield for all of its aquifer system of 1.65 mgd. Andover Township residents currently consume approximately 0.60 mgd. Limecrest Quarry has permission to withdraw 8.6 mgd from the combined glacial/carbonate rock aquifer. Pumping at the permitted rate will not only exceed the dependable yields of all the aquifer systems beneath Andover Township but would exceed recharge to these aquifers in drought. In addition, there are three golf courses that have water allocation permits allowing maximum withdrawals of 0.5 mgd. The data may suggest that the population could be more than doubled without resulting in adverse impacts, but based on the currently permitted withdrawals from or very near Andover Township, the dependable yields of the aquifers are likely exceeded.

25. Andover Township has direct experience with adverse impacts to natural resources and groundwater systems from overpumping groundwater

resources. Nicholson (1995) documented that the pumping influences from the Limecrest Quarry dewatering operations, starting in the 1970's, were effectively draining water from the aquifer systems beneath Andover Township and impacting water levels as much as 1.5 miles to the southwest.

26. The dependable yields per aquifer system and consumption rate of 320 gpd per unit can be used to determine the recharge area per dwelling unit necessary to meet the water-supply demands of the unit. These recharge areas per dwelling unit range from 1.5 to 5.4 acres and were calculated assuming that all groundwater is used to meet residential demands and that groundwater will not be diverted for commercial or industrial purposes. If dewatering operations at Limecrest Quarry were to return to pre-2005 rates, the combined glacial/carbonate-rock systems will not sustain residential densities as small as 2.7 acres per unit. Also, near the golf courses and other users, it will be necessary to refine densities to ensure that the dependable yields of the aquifers in these areas are not exceeded.

27. The recharge areas per dwelling unit are not equal to lot sizes. Smaller lot sizes could be sustained provided that sufficient areas are available to permit upgradient recharge and the overall densities within the associated contributing drainage basin are not exceeded. In areas where smaller lot sizes exist, it may be necessary to preserve upgradient lands to ensure long-term reliability of water resources to these residences. These recharge areas per dwelling unit do not include water diverted for commercial or industrial use and therefore, in contributing drainage basins where groundwater is diverted for commercial or industrial purposes, the recharge areas per dwelling unit must be increased to balance the additional groundwater withdrawals.

28. The NJDEP recently adopted N.J.A.C 7:15, which are the wastewater management planning regulations and they indicate that septic system effluent impacts must be completed for municipal management of wastewater. In adopting N.J.A.C 7:15, the NJDEP established a target nitrate concentration of 2 milligrams per liter (mg/l) (N.J.A.C 7:15-5.25(e)1) and therefore, adequate recharge must be permitted to reduce nitrate concentrations in septic system effluent to a level equal to 2 mg/l. The recharge area per dwelling unit for the soils beneath Andover Township were calculated using the NJGS' October 2009 version 6.1 "Recharge Based Nitrate Dilution Model for New Jersey." The calculations indicate recharge areas ranging from 3.9 to 6.2 acres per septic system.

29. The recharge area per dwelling unit cannot be calculated using the NJGS method for soils underlying approximately 19.4 percent of Andover Township. The method is not applicable to hydric soils or for areas where soils have been disturbed and are classified as urban. The NJGS method does not include slopes and assumes all soils are relatively flat lying. Soils indicating steep slopes (greater than or equal to 15 percent) have been mapped

beneath nearly 39 percent of the Township. Soils beneath 59 percent of Andover Township are associated with rock outcrop complexes indicating that bedrock is encountered at very shallow depths. Beneath these areas, septic systems are often installed below soils and into shallow weathered bedrock. As a result, effluent from these septic systems is discharged to bedrock fractures/openings that serve as the same conduits for recharging groundwater. As a result, the only precipitation available for diluting septic system contaminants is the limited amount that migrated past soil layers and into bedrock. The NJGS method cannot be used to determine the recharge area needed to ensure adequate dilution of septic system contaminants discharged to the bedrock aquifer systems beneath Andover Township.

30. 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 87 percent of the land area within the Township is covered with soils that are characterized by USDA-NRCS as very limited for wastewater disposal via septic systems and 85 percent of the land area is covered with soils that are characterized in N.J.A.C 7:9A as unsuitable for construction of septic systems, it is highly probable that adverse impacts to bedrock aquifer systems will result unless adequate recharge is available to dilute septic system contaminants and ensure safe drinking-water conditions.

31. Using the same nitrate-dilution technique employed in the NJGS method but applying recharge rates for the bedrock aquifers during drought, recharge areas per septic system ranging from 1.8 to 20.4 acres per system calculated. The larger areas are based on a 2 mg/l target concentration, whereas, the smaller areas were calculated using a target limit of 6 mg/l.

32. Andover Township has four major groundwater resources available for residents. These resources should have adequate safe and dependable groundwater for several decades provided that population growth does not exceed rates exhibited during the last 30 years and commercial/industrial diversions do not return to levels equal to those observed prior to 2005. The NJDEP's Planning Threshold limiting human consumption to 20 percent of groundwater recharge provides a buffer of available water during drought. However, that buffer may be exceeded in Andover Township. The Township has experienced direct effects from withdrawals that exceed the dependable yield and needs to manage future demands to prevent further impacts.

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Water: A Natural Renewable Resource

APPENDIX A:
SUMMARY TABLE OF
WELL RECORD DETAILS
FOR ANDOVER TOWNSHIP,
SUSSEX COUNTY, NEW JERSEY

Summary of Well Records obtained from Files for Wells within Andover Township, Sussex County, New Jersey.

Well Owner	Permit No.	State Atlas Grid Location	Date of Installation	Location	Block	Lot	Completed Depth (feet)	Casing Depth (feet)	Yield (gpm)	Static Water Level (fbgs)	Pumping Water Level (fbgs)	Specific Capacity (gpm/ft)	Geologic Formation
Hoffman, Karl	22-36206	22:41:271	9/26/1997	Forest Lake Drive No.	1	6.04	400	60	20	30	375	0.0580	Precambrian crystalline
Roschoch, Joe	22-19754	22:31:864	9/11/1980	Kilroy Road	6	11	96	50	50	15	80	0.7692	Precambrian crystalline
Westby Corporation	22-21293	22:41:244	11/23/1982	Roseville Road	5	1	146	90	40	38			Precambrian crystalline
Westby Farms	22-19517	22:41:242	4/23/1980	Andover Mohawk Road	5	5	100	50	16	36			Precambrian crystalline
Flamouropoulos, Theodore	22-38309	22:41:219	7/17/2000	Andover Mohawk Road	5	79.05	250	60	20	31	225	0.1031	Precambrian crystalline
Dusche & Eskin	22-36120	22:31:894	10/16/1997	Rt. 613	6	79.06	200	65	45	60	180	0.3750	Precambrian crystalline
Dusche & Eskin	22-31913	22:31:899	6/24/1992	Rt. 613	5	80	500	50	20	88			Precambrian crystalline
Dusche & Eskin	22-36798	22:31:894	8/13/1998	Rt. 613	5	80.01	225	53	18	40	160	0.1500	Precambrian crystalline
Loede, Fred	22-16545	22:41:224	7/19/1977	Ballantine Road	6	3A	148	63	20				Precambrian crystalline
Marcus, Edward	22-22230	22:31:888	2/22/1984		6	3C	100	50	30				Precambrian crystalline
Love, Charles	22-23240	22:41:218	5/25/1985		6	3D	150	50	15				Precambrian crystalline
Ryan, Roderick	22-23801	22:41:224	9/1/1985	Ballantine Road	6	3F	325	85	2	44	300	0.0078	Precambrian crystalline
Colabelli, Richard	22-42338	22:41:224	9/1/1995	Ballantine Road	6	3.07	300	60	10	30	250	0.0455	Precambrian crystalline
Destefan, Helen & Don	22-23220	22:31:891	9/23/1985		6	12	275	50	5	38			Precambrian crystalline
Newton Country Club	22-32386	22:31:549	1/4/1993	Club Road	6	111	275	54	10	50			Martinsburg shale
Shaw Built	22-32267	22:41:163	11/19/1993	Cliffside Way	7	6.027	448	50	4	25			Precambrian crystalline
Shaw Built	22-32266	22:41:163	6/8/1995	Cliffside Way	7	6.03	198	52	6	15			Precambrian crystalline
Shaw Built	22-32264	22:41:163	6/30/1994	Cliffside Way	7	6.06	198	51	15	45			Precambrian crystalline
Shaw Built	22-32263	22:41:163	6/30/1994	Cliffside Way	7	6.07	223	51	11	48			Precambrian crystalline
Shaw Built	22-32262	22:41:163	5/11/1994	Cliffside Way	7	6.08	298	50	5	40			Precambrian crystalline
Shaw Built	22-32261	22:41:163	6/7/1993	Cliffside Way	7	6.09	398	56	30	10			Precambrian crystalline
Shaw Built	22-32260	22:41:163	10/26/1993	Cliffside Way	7	6.10	298	50	5	62			Precambrian crystalline
Shaw Built	22-32259	22:41:163	9/22/1994	Cliffside Way	7	6.11	372	55	50	41			Precambrian crystalline
Shaw Built	22-32258	22:41:163	9/21/1994	Cliffside Way	7	6.12	723	53	4	40			Precambrian crystalline
Shaw Built	22-32268	22:41:163	12/28/1993	Cliffside Way	7	6.13	598	52	8	65			Precambrian crystalline
Always & Forever LLC	22-40367	22:31:878	8/14/2002	12 Ridge Road	7	9.01	500		5	50	70	0.2500	Precambrian crystalline
Brennan, Steve	22-25044	22:31:884	8/27/1986		7	9C	200	50	20	61	180	0.1681	Precambrian crystalline
Koontz, Alan	22-26022	22:31:882	4/5/1988	Rt. 517	7	9D	125	50	30	56	100	0.6818	Precambrian crystalline
Mortensen, Ronald	22-27724	22:31:882	7/25/1988	Rt. 517	7	9A	200	50	30	36	180	0.2083	Precambrian crystalline
	22-40246	22:31:882	8/20/2002	Rt. 517	7	9.13	625	60	6	42	500	0.0131	Precambrian crystalline
Cronin, James	22-18920	22:31:897	10/11/1979	Andover Mohawk Road	6	11F	148	60	6				Precambrian crystalline
Sussex Properties Ltd.	22-33016	22:41:126	9/15/1993	Rt. 206 and Smith Road	12	1,4,6	400	100	10	30			Carbonate Rock
Sussex Properties Ltd.	22-33017	22:41:126	9/27/1993	Rt. 206 and Smith Road	12	1,4.6	550	81	120	71			Carbonate Rock
Sussex Properties Ltd.	22-33018	22:41:126	9/23/1993	Rt. 206 and Smith Road	12	1,4,6	500	87	200	45			Carbonate Rock
Sussex Properties Ltd.	22-33019	22:41:126	9/18/1993	Rt. 206 and Smith Road	12	1,4,6	500	127	300	48			Carbonate Rock
Sussex Properties Ltd.	22-33020	22:41:126	9/15/1993	Rt. 206 and Smith Road	12	1,4,6	500	51	120	38			Carbonate Rock
Ferry, Douglas	22-27044	22:31:796	3/5/1988	Limecrest Road	34	5	250	50					Precambrian crystalline
Burke, Kenneth	22-35602	22:31:799		Old Creamery Road	34	4.01	200	55	30	15	100	0.3529	Precambrian crystalline
Cranberry Builders	22-27828	22:41:133	4/4/1989		34	6.01	175	55	5	39	120	0.0617	Precambrian crystalline
Ferry, Douglas	22-27073	22:41:133	7/18/1988	Old Creamery Road	34	6.02	57	50	50				Franklin Marble
G & L Homes	22-32491	22:31:796	1/24/1995	Limecrest Road	34	6.03	622	102	7	22			Precambrian crystalline
Bortone, Michael	22-38204	22:41:133	2/12/2000	Limecrest Road	34	6.05	180	140	18	20	160	0.1286	Franklin Marble
Edward, Walter	22-39754	22:31:799	3/2/2002	Old Creamery Road	34	6.07	673	51	5	30			Precambrian crystalline
Miranda, Victor	22-41291	22:31:799	11/10/2003	Old Creamery Road	34	6.08	65	65	20	15	50	0.5714	Glacial
Devenezia, Jason		22:31:799	1/2/2003	Old Creamery Road	34	6.09	400	66	3	36	380	0.0087	Precambrian crystalline
Olde Village Homes	22-39322	22:41:133	8/6/2001	Limecrest Road	34	6.10	135	129.5	20	20			Franklin Marble
Thuen, Douglas	22-38839	22:41:133	5/7/2001	Rt. 669	34	6.12	173	173	60	12	140	0.4688	Glacial
Alpaugh, Robert	22-32583	22:31:537	6/16/1993	20 Dorset Lane	11	51	200	50	15	20	160	0.1071	Martinsburg shale
Sniffen, Tom	22-37776	22:31:946	9/16/1999	Perona Road	65	1.03	500	50	1.5	40	480	0.0034	Precambrian crystalline

Summary of Well Records obtained from Files for Wells within Andover Township, Sussex County, New Jersey.

Well Owner	Permit No.	State Atlas Grid Location	Date of Installation	Location	Block	Lot	Completed Depth (feet)	Casing Depth (feet)	Yield (gpm)	Static Water Level (fbgs)	Pumping Water Level (fbgs)	Specific Capacity (gpm/ft)	Geologic Formation
Riggi, Anthony	22-26227	22:31:974	8/24/1987		65	1A	425	50	6	45	400	0.0169	Precambrian crystalline
Lesko, Robert	22-29368	22:31:895	11/16/1989	Rt. 613	64	2	250	51	20	54	240	0.1075	Precambrian crystalline
Rohmann, Jerry	22-38188	22:31:894	11/26/1999	Kilroy Road	62	4.02	300	80	15	46	200	0.0974	Precambrian crystalline
McCarthy, Cornelius	22-27021	22:31:894	3/9/1988	Kilroy and Anodover Mohawk	62	4A	250	60	10	25	200	0.0571	Precambrian crystalline
Dusche & Eskin Inc.	22-35426	22:31:894	7/1/1996	Kilroy Road	62	3	125	50	20	27	100	0.2740	Precambrian crystalline
Glenmont Development	22-27034	22:31:891	1/4/1988	37 Kilroy Road	62	2A	350	50	15	30	200	0.0882	Precambrian crystalline
DePeri, Angelo	22-40159	22:31:974	4/10/2002	Perona Road	63	1.08	200	80	20	61	160	0.2020	Precambrian crystalline
J & J Builders	22-24208	22:31:974	9/1/1986		65	1F	175	50	9	49	160	0.0811	Precambrian crystalline
Mulvihill, Andrew	22-38312	22:31:974	6/5/2000	Perona Road	65	1.05	300	75	30	60	280	0.1364	Precambrian crystalline
Dusche & Eskin Inc.	22-39507	22:31:973	10/9/2001	Perona Road	66	2.05	325	61	14	68	300	0.0603	Precambrian crystalline
Basile, Luigi	22-39537	22:31:973	7/2/2002	Perona Road	66	2.04	700	50	15	56	680	0.0240	Precambrian crystalline
Masiello, Kenneth	22-33369	22:31:949	7/13/1994	Perona Farms Road	66	2.03	207	54	10	44	92	0.2083	Precambrian crystalline
Leland Builders	22-32767	22:31:972	6/14/1993	Perona Road	66	2.02	275	60	3	30	250	0.0136	Precambrian crystalline
Leland Builders	22-33968	22:31:973	10/14/1994	Perona Road	66	2.01	175	52	4	50	155	0.0381	Precambrian crystalline
Liberty Village Constructior	22-34721	22:31:973	9/27/1995	Perona Road	66	2	150	72	60	30			Precambrian crystalline
North Jersey Homes	22-34343	22:31:949	4/2/1996	Perona Farms Road	66	2.06	500	50	2	18	480	0.0043	Precambrian crystalline
Liberty Valley Construction	22-36001	22:31:973	3/7/1997	Perona Road	66	2.07	200	50	7	12	180	0.0417	Precambrian crystalline
Ringlier, C. J.	22-31419	22:31:973	10/28/1991	Perona Farms Road	66	2.08	225	60	3	20	200	0.0167	Precambrian crystalline
Deacon Homes	22-22643	22:31:957	8/14/1984		66	3A	198	50	6				Precambrian crystalline
Fritz, Jerry	22-23022	22:31:949	1/1/1985	Perona Farms Road	66	3B	250	51	5	48	240	0.0260	Precambrian crystalline
Woodmont Builders LLC	22-38696	22:31:946	11/2/2000	60 Perona Road	66	4	425	60	4	25	310	0.0140	Precambrian crystalline
Olivia & Tucci	22-21157	22:31:946	4/7/1983	Perona Farms Road	66	4A	72	51	12	43			Precambrian crystalline
Olivia & Tucci	22-21158	22:31:946	4/6/1983	Perona Farms Road	66	4B	72	51	12	40			Precambrian crystalline
Woodmont Properties	22-40122	22:31:973	3/25/2002	Perona Road	67	2.04	340	50	5	20	320	0.0167	Precambrian crystalline
Knehr, George	22-24501	22:31:941	6/18/1986		68	1D	127	52	30	13			Precambrian crystalline
Wolk, Jeffery & Magda	22-24730	22:31:915	7/9/1986	Current Drive	68	1B	275	50	4	15			Precambrian crystalline
Morel Builders LLC	22-40930	22:31:947	12/1/2005	282 Andover Sparta Roac	69	4.03	800	60	5	30	230	0.0250	Precambrian crystalline
Morel Builders LLC	22-40360	22:31:869	4/10/2003	Freedom Trail	69	4.04	900	52	3	40	120	0.0375	Precambrian crystalline
Morel Builders LLC	22-40926	22:31:869	9/27/2004	5 Liberty Trail	69	4.05	875	60	2	15	460	0.0045	Precambrian crystalline
Morel Builders LLC	22-42003	22:31:869	2/8/2006	7 Liberty Trail	69	4.06	750	60	10	20	175	0.0645	Precambrian crystalline
Morel Builders LLC	22-42453	22:31:869	6/8/2006	13 Liberty Trail	69	4.08	750	60	18	20	190	0.1059	Precambrian crystalline
Morel Builders LLC	22-42450	22:31:868	1/12/2007	13 Eileens Way	69	4.18	300	60	12	40	180	0.0857	Precambrian crystalline
Morel Builders LLC	22-42406	22:31:869	1/16/2007	15 Eileens Way	69	4.19	600	60	15	40	200	0.0938	Precambrian crystalline
Morel Builders LLC	22-43600	22:31:947	1/24/2007		69	4.26	700	52	5	30	160	0.0385	Precambrian crystalline
Morel Builders LLC	22-40929	22:31:869	6/26/2003	4 Liberty Trail	69	28	1000	52	1	35	160	0.0080	Precambrian crystalline
Morel Builders LLC	22-40928	22:31:869	9/22/2004	2 Liberty Trail	69	4.29	800	60	5	10	420	0.0122	Precambrian crystalline
Roschach, Joseph	22-23928	22:31:894	7/20/1986	Kilroy Road	69	7A	125	50	20	20	80	0.3333	Precambrian crystalline
Gyscek, Gary	22-19755	22:31:894	9/17/1980		69	7B	136	50	6	30	120	0.0667	Precambrian crystalline
Carafello, John	22-29340	22:31:865	10/11/1989	260 Andover Sparta Roac	69	7.04	200	50	10	19	180	0.0621	Precambrian crystalline
Carafello, John	22-28419	22:31:865	1/3/1989	Rt. 517	69	7E	148	52	45	15	120	0.4286	Precambrian crystalline
Dautel Builders Inc.	22-19086	22:31:864	2/5/1980	Rt. 517	69	7F	123	50	20				Precambrian crystalline
Ulversoy Const. Inc.	22-19000	22:31:865	10/15/1979	Andover Sparta Roac	69	7L	298	50	3	27			Precambrian crystalline
Herbst, Warren	22-21834	22:31:867	9/13/1983	Kilroy Road	69	7N	122	50	5	-1	56	0.0877	Precambrian crystalline
Perona Estates	22-40577	22:31:972	5/21/2003	Perona Road	69	16	185	51	100	20			Precambrian crystalline
Perona Estates	22-41419	22:31:972	10/15/2004	Perona Road	69	17	422	59	25	50			Precambrian crystalline
Perona Estates	22-41420	22:31:972	10/18/2004	Perona Road	69	18	297	55	20	30			Precambrian crystalline
Perona Estates	22-41421	22:31:972	10/19/2004	Perona Road	69	19	264	60	50	30			Precambrian crystalline
Perona Estates	22-41422	22:31:972	7/13/2005	Perona Road	69	20	298	51	10	30			Precambrian crystalline
Perona Estates	22-41716	22:31:972	9/21/2005	Perona Road	69	21	273	53	7	30			Precambrian crystalline

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Perona Estates	22-41717	22:31:972	9/22/2005	Perona Road	69	22	297	51	7	20			Precambrian crystalline
Perona Estates	22-41718	22:31:948	10/6/2005	Perona Road	69	23	523	51	4	40			Precambrian crystalline
Perona Estates	22-41719	22:31:948	9/22/2005	Perona Road	69	24	197	61	15	12			Precambrian crystalline
Perona Estates	22-43607	22:31:946	11/8/2006	Andover Sparta Roac	69	25	348	51	40	29			Precambrian crystalline
Davenport	22-43768	22:31:945	2/17/2007	Rt. 517	69	27	175	50	20	20	60	0.5000	Precambrian crystalline
Perona Estates	22-43596	22:31:971	3/28/2007	11 Lourdes Court	69	34	273	52	45	50			Precambrian crystalline
Perona Estates	22-41423	22:31:971	10/7/2005	Perona Road	69	40	248	71	10	40			Precambrian crystalline
Metts, Jr., Howard	22-22706	22:31:883	9/1/1984	Rt. 517	70	1A	525	50	30	26	200	0.1724	Precambrian crystalline
Poccia, Angelo	22-24576	22:31:883	6/13/1986		70	1D	127	51	20	24			Precambrian crystalline
Jefferson Construction	22-26671	22:31:883	7/19/1977	Rt. 517	70	2B	220	50	1				Precambrian crystalline
Seabell Corp.	22-19875	22:31:859	10/15/1980	Marlene Lane	71	2	186	60	6	80	180	0.0600	Precambrian crystalline
Seabell Corp.	22-18534	22:31:859	6/18/1979	Marlene Lane	71	2F	156	55	30	35	150	0.2609	Precambrian crystalline
Deacon Homes	22-21626	22:31:859	6/30/1983		71	2G	149	50	7				Precambrian crystalline
Deacon Homes	22-21677	22:31:859	7/1/1983		71	2H	98	50	15				Precambrian crystalline
Deacon Homes	22-21628	22:31:859	6/30/1983		71	21	98	50	20				Precambrian crystalline
Salerno, Michael	22-22397	22:31:859	11/20/1984		71	2K	235	80	5	50	160	0.0455	Precambrian crystalline
Deacon Homes	22-21629	22:31:859	6/29/1983		71	2L	148	50	20				Precambrian crystalline
A.L.E. Builders	22-20846	22:31:859	4/15/1982		71	2M	105	50	15	40	100	0.2500	Precambrian crystalline
Spadafora, Joseph	22-37644	22:31:859	10/4/1999	Marlene Lane	71	2.15	225	51	7	30	200	0.0412	Precambrian crystalline
Morel Builders LLC	22-37884	22:31:862	9/21/1999	16 Hidden Valley Way	71	3.01	360	52	25	40	180	0.1786	Precambrian crystalline
Morel Builders LLC	22-36852	22:31:862	7/18/1998	14 Hidden Valley Way	71	3.02	225	62	30	35	105	0.4286	Precambrian crystalline
Morel Builders LLC	22-37599	22:31:864	9/14/1999	3 Highland Court	71	3.03	340	70	30	45	140	0.3158	Precambrian crystalline
Morel Builders LLC	22-37637	22:31:864	9/13/1999	5 Highland Court	71	3.04	360	50	40	60	150	0.4444	Precambrian crystalline
Morel Builders LLC	22-37887	22:31:864	6/12/2000	6 Highland Court	71	3.06	160	100	25	30	80	0.5000	Precambrian crystalline
Morel Builders LLC	22-37474	22:31:864	3/29/1999	4 Highland Court	71	3.07	300	134	18	27	98	0.2535	Precambrian crystalline
Morel Builders LLC	22-37580	22:31:862	3/6/2000	12 Hidden Valley Way	71	3.08	450	160	25	35	75	0.6250	Precambrian crystalline
Morel Builders LLC	22-37888	22:31:862	3/8/2000	10 Hidden Valley Way	71	3.09	400	100	18	30	200	0.1059	Precambrian crystalline
Kristen Development LLC	22-39143	22:31:863	4/9/2001	E Hidden Valley Lake Roac	71	3.12	300	100	8	6	95	0.0899	Precambrian crystalline
Kristen Development LLC	22-36276	22:31:862	3/25/1998	Hidden Valley Roac	71	3.13	250	110	10	25	100	0.1333	Precambrian crystalline
Morel Builders LLC	22-38799	22:31:862	10/30/2000	82 Skytop Road	71	3.14	800	233	2	40	350	0.0065	Precambrian crystalline
Morel Builders LLC	22-38736	22:31:862	10/17/2000	80 Skytop Road	71	3.15	850	162	2	50	350	0.0067	Precambrian crystalline
Morel Builders LLC	22-38798	22:31:838	9/10/2001	70 Skytop Road	71	3.16	600	60	10	45	120	0.1333	Precambrian crystalline
Greebel, Lisa	22-41708	22:31:862	5/12/2004		71	3.17	400	51	20	10	380	0.0541	Precambrian crystalline
Kristen Development LLC	22-41083	22:31:837	4/19/2004	Bonnie Glen Court	71	3.18	500	50	5	20	200	0.0278	Precambrian crystalline
Morel Builders LLC	22-39172	22:31:862	9/13/2001	8 Hidden Valley Roac	71	3.10	275	127	20	15	80	0.3077	Precambrian crystalline
Kesselman, William	22-40346	22:31:837	7/31/2002	3 Bonnie Glen Court	71	3.19	275	60	20	15	175	0.1250	Precambrian crystalline
Kristen Development LLC	22-37638	22:31:837	11/24/1999	Skytop Roac	71	3.20	500	50	5	40	400	0.0139	Precambrian crystalline
Kristen Development LLC	22-37803	22:31:829	5/10/2000	Glen Court	71	3.21	350	50	10	20	200	0.0556	Precambrian crystalline
Kristen Development LLC	22-39268	22:31:837	4/13/2001	44 Skytop Road	71	3.28	300	50	15	20	150	0.1154	Precambrian crystalline
Crepeau Developmen	22-40031	22:31:824	4/5/2002	Hunters Way	71	9.00	600	50	3.5	52	480	0.0082	Precambrian crystalline
Crepeau Developmen	22-40236	22:31:824	11/21/2002	Hunters Way	71	9.01	1000	60	1.5	10	980	0.0015	Precambrian crystalline
Crepeau Developmen	22-40235	22:31:824	5/23/2002	Hunters Way	71	9.03	600	51	1.5	50	580	0.0028	Precambrian crystalline
Crepeau Developmen	22-40234	22:31:824	10/15/2002	Hunters Way	71	9.04	800	50	5	6	700	0.0072	Precambrian crystalline
Crepeau Developmen	22-40232	22:31:824	7/23/2002	Hunters Way	71	9.06	800	51	4	80	780	0.0057	Precambrian crystalline
Crepeau Developmen	22-40238	22:31:824	6/18/2002	Hunters Way	71	9.07	900	51	2	460	880	0.0048	Precambrian crystalline
Crepeau Developmen	22-40237	22:31:824	5/21/2002	Woodland Trail	71	9.08	650	52	1	50	630	0.0017	Precambrian crystalline
Crepeau Developmen	22-40253	22:31:824	7/18/2002	Woodland Trail	71	9.09	650	51	2.5	12	580	0.0044	Precambrian crystalline
Crepeau Developmen	22-40250	22:31:824	7/25/2002	Woodland Trail	71	9.10	1000	51	1	48			Precambrian crystalline
Crepeau Developmen	22-40037	22:31:824	4/12/2002	Woodland Trail	71	9.11	636	50	1.75	48	580	0.0033	Precambrian crystalline

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Crepeau Developmen	22-40249	22:31:824	11/18/2002	Woodland Trail	71	9.12	300	54	6	42	280	0.0252	Precambrian crystalline
Morel Builders LLC	22-37185	22:31:862	4/5/1999	90 Skytop Road	71.02	2	250	52	20	40	105	0.3077	Precambrian crystalline
Morel Builders LLC	22-37885	22:31:862	3/1/2000	88 Skytop Road	71.02	3	275	52	25	30	150	0.2083	Precambrian crystalline
Morel Builders LLC	22-37201	22:31:862	11/10/1998	1 Hidden Valley Road	71.02	4	305	92	40				Precambrian crystalline
Morel Builders LLC	22-37700	22:31:862	9/24/1999	5 Hidden Valley Road	71.02	5	360	130	15	35	200	0.0909	Precambrian crystalline
Morel Builders LLC	22-37463	22:31:862	3/25/1999	6 Hidden Valley Road	71.02	6	375	127	15	45	120	0.2000	Precambrian crystalline
Morel Builders LLC	22-37891	22:31:862	3/2/2000	13 Hidden Valley Road	71.02	6	225	60	25	30	60	0.8333	Precambrian crystalline
Morel Builders LLC	22-37200	22:31:862	3/31/1999	15 Hidden Valley Way	71.02		300	52	16	40	110	0.2286	Precambrian crystalline
Stafford, Michael & Sandy	22-29878	22:31:832	3/7/1990	Limecrest Road	73	3B	250	80	20	10	200	0.1053	Precambrian crystalline
Kunesch, Ian & Elizabeth	22-42302	22:31:832	12/19/2005	Limecrest Road	73	6.01	600	58.5	1.5	10			Precambrian crystalline
Lake Iliff Comm. Club	22-20818	22:31:824	4/26/1982	Rt. 669	75	1	148	62	15				Carbonate Rock
Bell, Donald	22-35708	22:31:823	8/11/1997	Lake Shore Drive	75	5	83	80	15	32	50	0.8333	Glacial
Conklin, M	22-22142	22:31:823	12/5/1984		78	4	115	86	15	15			Glacial
Sidnam, Dorothy	22-20605	22:31:823	11/5/1982	Limecrest Road	78	19	62	60	20				Glacial
Skyland Enterprizes	22-25735	22:31:756	4/8/1987		80	2.1	62	60	20	20			Glacial
Nepa, Victor Jr.	22-34246	22:31:834	1/6/1995	Limecrest Road	87	1	200	95	7	68			Precambrian crystalline
Skyland Enterprizes	22-27951	22:31:834	9/8/1988	Limecrest Road	87	2	325	60	4	30	300	0.0148	Precambrian crystalline
Kazhar, Jack	22-38826	22:31:826	10/3/2000	Hillside Drive	87	3	550	101	2.5	42	520	0.0052	Precambrian crystalline
Kretzmer, Thomas	22-29324	22:31:826	9/14/1989	Hillside Drive	87	6	375	50	20	70	200	0.1538	Precambrian crystalline
Memesmith, Joseph	22-28248	22:31:826	12/9/1988	9 Fenner Drive	90	47-48	500	52	1.5	100	400	0.0050	Precambrian crystalline
Van der mark, Clifford	22-33084	22:31:826	9/22/1993	1 Fenner Drive	90	50	100	61	20	31			Precambrian crystalline
Rowett, Dan	22-42402	22:31:825	5/5/2005	5 Knollwood Drive	91	26	600	100	1	50	580	0.0019	Precambrian crystalline
Bennett, Thomas	22-35632	22:31:839	10/4/1996	Skytop Road	93	3.01	500	50	2	39	480	0.0045	Precambrian crystalline
Tagliatela, Gil	22-28039	22:31:837	7/10/1989	Skytop Road	93	2C	350	50	6	64	320	0.0234	Precambrian crystalline
B F R Construction	22-37329	22:31:829	3/20/1999	Hasta Way	93	3.04	350	51	3	28	330	0.0099	Precambrian crystalline
B F R Construction	22-37985	22:31:829	10/14/1999	Hasta Way	93	3.05	375	51	20	0	300	0.0667	Precambrian crystalline
B F R Construction	22-38037	22:31:829	3/14/2000	Hasta Way	93	3.07	200	50	6	15	160	0.0414	Precambrian crystalline
B F R Construction	22-38035	22:31:829	3/19/2000	Hasta Way	93	3.09	350	50	4	14	300	0.0140	Precambrian crystalline
B F R Construction	22-37983	22:31:829	9/19/2000	Hasta Way	93	3.11	300	51	6	42	280	0.0252	Precambrian crystalline
B F R Construction	22-38034	22:31:829	10/15/1999	Hasta Way	93	3.06	200	50	15	1	140	0.1079	Precambrian crystalline
B F R Construction	22-37984	22:31:829	10/18/1999	Hasta Way	93	3.12	235	51	20	48	140	0.2174	Precambrian crystalline
Renke, Bill	22-40165	22:31:826	6/12/2002	Oak Tree Drive	93	3.13	400	50	3	20	380	0.0083	Precambrian crystalline
Renke, Bill	22-40166	22:31:826	6/8/2002	Oak Tree Drive	93	3.14	400	50	3	20	380	0.0083	Precambrian crystalline
Renke, Bill	22-40164	22:31:826	6/5/2002	Oak Tree Drive	93	3.15	500	50	2	20	480	0.0043	Precambrian crystalline
Snyder, Eric	22-374	22:31:826	6/11/1999	Oak Tree Drive	94	18	500		1	120	480	0.0028	Precambrian crystalline
Cambell, Robert	22-29119	22:31:834	10/12/1989	Hillside Drive	95	2.1	435	50	8	30	400	0.0216	Precambrian crystalline
Cerbra, Alan	22-33458	22:31:834	2/17/1994	Hillside Drive	95	2.2	500	61	4.5	36			Precambrian crystalline
Herbst, Warren	22-20320	22:31:834	7/9/1981	Hillside Drive	95	24	198	50	5	120			Precambrian crystalline
Webster Associates		22:31:834	10/8/1980	Broadview & Hillside Drive	96	6	223	50	2				Precambrian crystalline
Vitovic, Paul	22-33150	22:31:834	10/26/1993	122 Hillside Drive	97	15	450	50	0.5	130			Precambrian crystalline
Campbell, Allen J.	22-36335	22:31:834	1/8/1998	Lakeview Drive	97	22	557	50	2	80	500	0.0048	Precambrian crystalline
Kunkle, Loretta	22-39928	22:31:834	1/10/2002	7 Mountainside Drive	99	36	345	125	4	39			Precambrian crystalline
Bensley, Ellsworth	22-36296	22:31:829	9/5/1997	Skytop Road	100	1	250	70	4	28	240	0.0189	Precambrian crystalline
Schneider Construction Co.	22-36984	22:31:837	9/10/1998	Mountainside Drive	100	4,5,6	228	61	12	30	200	0.0706	Precambrian crystalline
O'Brien, James	22-37092	22:31:837	9/8/1998	Mountainside Drive	100	7	250		20	40	200	0.1250	Precambrian crystalline
Corey, T	22-26332	22:31:834	7/15/1987		100	13	400	50	1.5	33	380	0.0043	Precambrian crystalline
Gregori, Jack	22-39541	22:31:837	9/28/2001	Mountainside Drive	101	9.04	700	51	1	200	680	0.0021	Precambrian crystalline
Spartenal Homes, Inc.	22-19546	22:31:865	5/19/1980	Andover Sparta Road	102	2C	273	50	5				Precambrian crystalline
Duffy, James	22-20202	22:31:865	6/4/1981	Rt. 517	102	2D	200	50	30	30	50	1.5000	Precambrian crystalline

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Megletti, James	22-23331	22:31:865	Apr-85	Rt. 517	102	2E	275	50	35	24	200	0.1989	Precambrian crystalline
Kevil, George	22-22296	22:31:865	Apr-84	Rt. 517	102	2F	275	51	3	12	260	0.0121	Precambrian crystalline
Powers, Robert	22-25667	22:31:865	3/2/1987		102	2G	525	62	4	31	500	0.0085	Precambrian crystalline
Kristen Development LLC	22-39333	22:31:862	4/27/2001	57 Skytop Road	102	3.01	200	50	15	20	100	0.1875	Precambrian crystalline
Kristen Development LLC	22-37422	22:31:862	5/29/1999	67 Skytop Road	102	3.02	500	50	3	15	480	0.0065	Precambrian crystalline
Kristen Development LLC	22-37507	22:31:862	6/24/1999	73 Skytop Road	102	3.03	500	50	3	20	480	0.0065	Precambrian crystalline
Kristen Development LLC	22-38560	22:31:863	10/3/2000	E Hidden Valley Court	102	3.04	300	120	10	20	100	0.1250	Precambrian crystalline
Kristen Development LLC	22-37802	22:31:863	11/23/1999	E Hidden Valley Court	102	3.05	300	120	12	30	80	0.2400	Precambrian crystalline
Kristen Development LLC	22-36572	22:31:863	10/16/1998	E Hidden Valley Court	102	3.07	125	70	15	20	60	0.3750	Precambrian crystalline
Kristen Development LLC	22-36569	22:31:862	10/19/1998	Hidden Valley Court	102	3.06	400	50	5	20	300	0.0179	Precambrian crystalline
Kristen Development LLC	22-38242	22:31:862	6/16/2000	Hidden Valley Court	102	3.09	250	50	15	35	100	0.2308	Precambrian crystalline
Schultz, Brad	22-40602	22:31:863	9/18/2003	E Hidden Valley Court	102	3.10	300	50	20	20	240	0.0909	Precambrian crystalline
Kristen Development LLC	22-36571	22:31:863	10/13/1998	E Hidden Valley Court	102	3.11	300	50	15	20	200	0.0833	Precambrian crystalline
Kristen Development LLC	22-38240	22:31:862	5/18/2000	2 Hidden Valley Court	102	3.12	250	50	15	20	100	0.1875	Precambrian crystalline
Kristen Development LLC	22-37470	22:31:862	5/25/1999	81 Sky Top Road	102	3.13	400	50	20	20	200	0.1111	Precambrian crystalline
Ehehalt, Robert	22-23739	22:31:838	8/20/1985		102	4.01	100	50	4	32			Precambrian crystalline
Williams, Jeffery	22-22968	22:31:838	12/11/1984		102	4	225	50	5	30			Precambrian crystalline
Hernandez, J	22-41116	22:31:833	4/29/2004	Alpine Road	102	7.03	400	50	8	20	200	0.0444	Franklin Marble
Zisa, John	22-40831	22:31:599	10/4/2004	124 Current Drive	102	7.04	425	50	25	43	400	0.0700	Precambrian crystalline
Fobert, Joseph & Diane	22-39557	22:31:833	4/2/2002	Alpine Road	102	7.05	325	60	15	30	325	0.0508	Precambrian crystalline
Raffino, Ronald	22-40737	22:31:911	7/25/2003	Alpine Road	102	7.06	400	50	2	17	380	0.0055	Precambrian crystalline
Purvis, Scott	22-22875	22:31:834	11/00/1984	Hillside Drive	102	10	300	50	1	16	280	0.0038	Precambrian crystalline
Schaffer, Charles	22-22877	22:31:677	11/28/1984		103	3A	165	150	12	10	100	0.1333	Glacial
Deacon Homes	22-28189	22:31:679	12/22/1988	Newton-Sparta Road	103	4D	375	100	5	18	360	0.0146	Precambrian crystalline
Crepeau Developmen	22-40248	22:31:825	6/13/2002	Woodland Trail	71	9.13	800	51	2	6	780	0.0026	Precambrian crystalline
Crepeau Developmen	22-40247	22:31:825	10/25/2002	Woodland Trail	71	9.14	800	51	1	50	780	0.0014	Precambrian crystalline
Crepeau Developmen	22-40245	22:31:825	10/23/2002	Hunters Way	71	9.15	900	50	4	20	700	0.0059	Precambrian crystalline
Morel Builders LLC	22-36853	22:31:865	7/10/1998	92 Skytop Road	71.02	1	300	52	20	35	140	0.1905	Precambrian crystalline
Joseph & Sons Const.	22-35970	22:31:681	7/28/1997	Wisteria Road	106	9.04	225	50	20	15	180	0.1212	Precambrian crystalline
Joseph & Sons Const.	22-36310	22:31:681	8/15/1997	Wisteria Road	106	9.06	250	50	3	36	240	0.0147	Precambrian crystalline
Joseph & Sons Const.		22:31:681	7/29/1997	Wisteria Road	106	9.05	250	51	20	58	180	0.1639	Precambrian crystalline
Natale, Joseph	22-36479	22:31:681	10/14/1997	Victoria Pines Lane	106	1	500	51	3	47	480	0.0069	Precambrian crystalline
Sussex & Warren Holding	22-35931	22:31:648	2/24/1997	Limecrest Road	106	1.01	74	74	300	32	60	10.7143	Glacial
Natale, Joseph	22-35722	22:31:673	5/2/1997	Victoria Pines Lane	106	2	300	50	3	43	280	0.0127	Precambrian crystalline
Nouiskey, Bernie		22:31:648	9/17/1990	Limecrest Road	106	16	300	60	6	40	280	0.0250	Franklin Marble
PJR Builders	22-42162	22:31:678	1/10/2006	Rt. 616	106	17.05	385	51	25	50	300	0.1000	Precambrian crystalline
PJR Builders	22-31677	22:31:674	2/23/2006	Rt. 616	106	17.06	400	51	30	40	380	0.0882	Precambrian crystalline
Shotwell, Ralph	22-32815	22:31:674	7/6/1993	Rt. 616	106	17.09-1(	200	52	25	48			Precambrian crystalline
Mosner, Paul	22-28927	22:31:674	6/18/1998	Limecrest Road	106	16	350	60	4	20	300	0.0143	Precambrian crystalline
Joy Mar Devel. Company	22-33950	22:31:649	12/19/1994	Victoria Pines Lane	106	18	500	50	3.75	60	253	0.0194	Precambrian crystalline
Country Car Wash	22-28195	22:31:596	11/9/1988	Newton-Sparta Road	106	17C	180	50	25	20	150	0.1923	Precambrian crystalline
Joseph & Sons Const.	22-36367	22:31:681	6/15/1998	Wisteria Road	106.02	8.03	175	52	15	15	140	0.1200	Precambrian crystalline
Natale, Joseph	22-35723	22:31:649	4/30/1997	Victoria Pines Lane	106	19	525	50	1	70	500	0.0023	Precambrian crystalline
Joy Mar Devel. Company	22-33633	22:31:649	9/13/1994	Victoria Pines Lane	106	22	175	50	5	61	138	0.0649	Precambrian crystalline
Joy Mar Devel. Company	22-32527	22:31:649	8/18/1993	Victoria Pines Lane	106	24	173	52	20	30	43	1.5385	Precambrian crystalline
Joy Mar Devel. Company	22-32528	22:31:649	8/20/1993	Victoria Pines Lane	106	26	325	52	25	50	70	1.2500	Precambrian crystalline
Sprectrum Const. & Dev.	22-29650	22:31:673	2/6/1990		106	8	202	50	20	32	160	0.1563	Precambrian crystalline
Joseph & Sons Const.	22-37219	22:31:681	9/16/1998	Wisteria Road	106.02	8.01	275	50	2.5	52	260	0.0120	Precambrian crystalline
Joseph & Sons Const.	22-37220	22:31:681	10/28/1998	Wisteria Road	106.02	8.02	250	51	30	61	200	0.2158	Precambrian crystalline

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Joseph & Sons Const.	22-31824	22:31:649	5/14/1992	Victoria Pines Lane	106	10	323	50	22	36	47	2.0000	Precambrian crystalline
Joseph & Sons Const.	22-32046	22:31:648	12/4/1992	Victoria Pines Lane	106.02	11.02	373	50	5	40	200	0.0313	Franklin Marble
Joy Mar Devel. Company	22-33560	22:31:681	7/8/1994	Victoria Pines Lane	106.02	11.03	428	50	5	31	320	0.0173	Precambrian crystalline
Spectrum Const. & Dev.	22-32444	22:31:673	4/23/1993	Victoria Pines Lane	106.02	11	230	50	10	20	100	0.1250	Precambrian crystalline
Natale, Joseph	22-35724	22:31:649	2/13/1997	Wisteria Road	106.02	12	275	50	3	40	260	0.0136	Precambrian crystalline
Deacon Homes	22-42257	22:31:649	5/6/2005	Pinkneyville Road	107	3.03	500	50	7	10	480	0.0149	Precambrian crystalline
Deacon Homes	22-42013	22:31:649	12/3/2004	Pinkneyville Road	107	3.04	360	50	7	15	340	0.0215	Precambrian crystalline
Joy Mar Devel. Company	22-32457	22:31:649	6/3/1993	Victoria Pines Lane	106.02	11.01	175	60	20	20	60	0.5000	Precambrian crystalline
Sussex & Warren Holding	22-32016	22:31:569	8/11/1992	Lifecare Drive	108	1A	73	65	450	39.27	42.25	151.0067	Glacial
Sussex & Warren Holding	22-40013	22:31:569	2/14/2002	Mulford Road	108	1.01, 5	298	45	0.5	15			Carbonate Rock
Gardner, Robert	22-34121	22:31:564	10/29/1994	Rt. 623	109	5.03	325						Martinsburg shale
Rolling Hills of Andover	22-28010	22:31:614	9/21/1988	Germany Flats Road	109	6	275	52	15	25	240	0.0698	Carbonate Rock
Limecrest Corporation	42-35212	22:31:651	6/21/1944	1026 Sussex Mills Road	108.01	1	235	20					Franklin Marble
Pheobis, Robert	22-33398	22:31:561	3/31/1994	Lawrence Road	109	5A	400	60	2.5	19	190	0.0146	Martinsburg shale
Farmstead Golf	22-26364	22:31:561	8/14/1987	Lawrence Road	109	5	400	60	20	39			Carbonate Rock
Morel Builders LLC	22-38849	22:31:298	12/22/2000	7 Mindys Way	111	19.02	260	60	20	25	80	0.3636	Martinsburg shale
Haber, John	22-35686	22:31:299	11/26/1996	Pierce Road	111	19.05	175	50	60	30	100	0.8571	Martinsburg shale
Dutkevitch, Robert	22-32779	22:31:583	8/12/1993		110	34	140	60	10	18	60	0.2381	Carbonate Rock
Haggerty, James	22-36351	22:31:295	9/10/1997	Rt. 633	111	19.06	168	50	10	0	140	0.0714	Martinsburg shale
Morel Builders LLC	22-38728	22:31:298	12/21/2000	6 Mindys Way	111	19.08	220	60	25	30	106	0.3289	Martinsburg shale
Morel Builders LLC	22-38730	22:31:298	8/28/2001	4 Mindys Way	111	19.09	300	80	15	25	80	0.2727	Martinsburg shale
Rolling Hills of Andover	22-28000	22:31:614	9/20/1988	Germany Flats Road	110	1A	175	50	25	23	120	0.2577	Carbonate Rock
Dorset Farms	22-26776	22:31:553	10/19/1987		111	6	175	60	20	37			Martinsburg shale
Morel Builders LLC	22-39057	22:31:297	8/28/2001	2 Mindys Way	111	19.11	300	60	20	45	90	0.4444	Martinsburg shale
Morel Builders LLC	22-38733	22:31:298	8/29/2001	3 Jacks Drive	111	19.13	250	60	25	24	80	0.4464	Martinsburg shale
Morel Builders LLC	22-38503	22:31:298	6/22/2000	5 Jacks Drive	111	3	160	60	25	20	100	0.3125	Martinsburg shale
Morel Builders LLC	22-39058	22:31:298	6/9/2001	2 Jacks Drive	111	19.17	275	60	25	25	80	0.4545	Martinsburg shale
		22:31:581	4/13/2000	Rt. 623	111	8.02	250	51	30	19	220	0.1493	Martinsburg shale
Morel Builders LLC	22-39099	22:31:297	6/21/2001	1 Mindys Way	111	19.18	300	60	18	20	180	0.1125	Martinsburg shale
Morel Builders LLC	22-38732	22:31:297	1/9/2001	3 Mindys Way	111	19.19	500	65	10	40	200	0.0625	Martinsburg shale
Morel Builders LLC	22-38729	22:31:297	1/8/2001	5 Mindys Way	111	19.20	500	60	8	43	200	0.0510	Martinsburg shale
Bodhi Monastery	22-39491	22:31:552	6/29/2001	Lawrence Road	111	10	800		15	83	700	0.0243	Martinsburg shale
Willekes, George	22-32335	22:31:561	11/25/1992	Dorset Ln. & Cambridge Rd.	111	21	200	60	15	25	150	0.1200	Martinsburg shale
Dorset Farms	22-25879	22:31:553	5/8/1987		111	22	450	60	2	21			Martinsburg shale
Morel Builders LLC	22-38503	22:31:298	6/22/2000	5 Jacks Drive	111	3	160	60	25	20	100	0.3125	Martinsburg shale
Burgio, Edward	22-34062	22:31:537	11/11/1994	Oxford Drive	111	3	151	53	11	25			Martinsburg shale
King Steele	22-26485	22:31:552	12/7/1987		111	23	100	50	15	30			Martinsburg shale
NJ Classic Homes	22-34749	22:31:537	11/13/1995	9 Cambridge Road	111	25	175	58	30	40	100	0.5000	Martinsburg shale
Biondo, Donald	22-29006	22:31:531	6/2/1989	Rt. 663	111	14	150	55	20	22	100	0.2564	Martinsburg shale
Jaf Builders	22-36785	22:31:529	11/5/1998	Cambridge Road	111	26	173	49.5	15	38			Martinsburg shale
Fischer, Peter	22-36566	22:31:529	3/4/1998	Cambridge Road	111	27	125	60	15	26	100	0.2027	Martinsburg shale
Haber, John		22:31:523	9/00/1984	Newton-Branchville Road	111	14.01	125	50	12	26	100	0.1622	Martinsburg shale
Cox, James	22-25749	22:31:523	5/28/1987	Newton-Branchville Road	111	14.02	148	50	25	30			Martinsburg shale
Countryside Homes	22-34653	22:31:553	7/24/1995	Cambridge Road	111	28	300	50	12	35			Martinsburg shale
Deacon Homes	22-36850	22:31:529	6/23/1998	Cambridge Road	111	29	300	50		40	280		Martinsburg shale
Jaf Builders	22-36908	22:31:529	11/5/1998	Cambridge Road	111	30`	498	49.5	10	44			Martinsburg shale
RSA Homes	22-31699	22:31:537	5/12/1992	Dorset Lane	111	47	175	70	20	31	100	0.2899	Martinsburg shale
RSA Homes	22-31678	22:31:537	4/6/1992	Dorset Lane	111	48	200	70	20	31	100	0.2899	Martinsburg shale
Jaf Builders	22-37857	22:31:537	7/30/1999	Cambridge Road	111	31	698	49.5	6	59			Martinsburg shale

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Stephens Custom Homes	22-32233	22:31:538	10/28/1992	Oxford Rd. & Pierce Rd.	111	54	298	50	5	22			Martinsburg shale
Alpaugh, Robert	22-32583	22:31:537	6/16/1993	20 Dorset Lane	111	51	200	50	15	20	160	0.1071	Martinsburg shale
Kappauf, Charles	22-31709	22:31:537	2/7/1992	Dorset Lane	111	53	130	50	20	23			Martinsburg shale
Hook, Dave	22-39124	22:31:525	12/15/2000	Brecia Court	111	68	160	50	30	20	100	0.3750	Martinsburg shale
Hook, Dave	22-40162	22:31:525	11/28/2003	Brecia Court	111	70	160	50	20	30	140	0.1818	Martinsburg shale
Paramount Homes	22-37085	22:31:529	11/10/1998	Cambridge Road	111	32	300	50	4	20	280	0.0154	Martinsburg shale
Hook, Dave	22-39614	22:31:525	12/7/2001	Brecia Court	111	69	200	50	20	40	180	0.1429	Martinsburg shale
Hook, Dave	22-39770	22:31:528	5/31/2002	Brecia Court	111	71	160	50	20	10	140	0.1538	Martinsburg shale
Paramount Homes	22-37648	22:31:553	5/18/1999	25 Cambridge Road	111	33	300	50	8	20	200	0.0444	Martinsburg shale
Hook, Dave	22-39734	22:31:525	6/3/2002	Brecia Court	111	73	180	50	25	10	160	0.1667	Martinsburg shale
Hook, Dave	22-40307	22:31:525	4/15/2002	Brecia Court	111	74	240	50	20	40	220	0.1111	Martinsburg shale
Stewart, Debra	22-38001	22:31:553	10/18/1999	Cambridge Road	111	43	300	50	6	30	280	0.0240	Martinsburg shale
	22-35157	22:31:529	7/30/1996	Cambridge Road	111	36	150	52	30	42	120	0.3846	Martinsburg shale
Gailums Bros. Const.	22-35423	22:31:553	8/15/1996	Cambridge Road	111	35	175	50	8	20	100	0.1000	Martinsburg shale
Willekes, George	22-34381	22:31:529	4/3/1995	Cambridge Road	111	38	175	61	25	22			Martinsburg shale
Willekes, George	22-33972	22:31:529	1/20/1995	Cambridge Road	111	39	175	72	20	20			Martinsburg shale
Dorset Farms	22-27380	22:31:537	9/21/1988	Cambridge Road	111	43	175	63	10	25	150	0.0800	Martinsburg shale
George, James	22-33304	22:31:537	12/21/1993	Dorset Drive	111	44	145	51	50	10	120	0.4545	Martinsburg shale
Wilshire Credit Corp.	22-37597	22:31:575	3/4/1999	Linda Lane	119	4.04	200		10	31	180	0.0671	Martinsburg shale
Freda, James	22-39202	22:31:573	5/9/2001	Ottawa Lane	119	3.15	400	55	5	50	360	0.0161	Martinsburg shale
Beamonte, Lewis	22-38555	22:31:571	4/11/2000	Linda Lane	119	4	150	88	20	38	120	0.2439	Martinsburg shale
George, James	22-39547	22:31:575	10/31/2001	Ottawa Lane	119	3.14	350	50	10	50	300	0.0400	Martinsburg shale
Forge Hill Construction	22-36753	22:31:575	6/26/1998	Ottawa Lane	119	3.12	125	50	20	30	100	0.2857	Martinsburg shale
ETM Enterprises Inc.	22-39863	22:31:575	3/25/2002	Ottawa Lane	119	3.11	500	50	2	28	460	0.0046	Martinsburg shale
George, James	22-38914	22:31:575	10/27/2000	Ottawa Lane	119	3.13	145	50	60	40	120	0.7500	Martinsburg shale
Forge Hill Construction	22-37215	22:31:573	6/15/1999	Ottawa Lane	119	3.10	250	52	7	48	220	0.0407	Martinsburg shale
Cummings, James	22-39152	22:31:573	1/27/2001	Ottawa Lane	119	3.09	700	51	2	45	680	0.0031	Martinsburg shale
Forge Hill Construction	22-37940	22:31:575	7/16/1999	Ottawa Lane	119	3.08	125	51	12	37	100	0.1905	Martinsburg shale
Forge Hill Construction	22-36751	22:31:575	2/3/1999	Florence Lane	119	3.03	275	51	6	27	240	0.0282	Martinsburg shale
Forge Hill Construction	22-37679	22:31:575	4/20/1999	Ottawa Lane	119	3.07	150	51	20	80	120	0.5000	Martinsburg shale
Crepeau Developmen	22-41683	22:31:584	3/23/2005	Walnut Trail	118	25	240	101	100	60			Carbonate Rock
Crepeau Developmen	22-41632	22:31:584	3/22/2005	Walnut Trail	118	24	600	101	1	80	580	0.0020	Carbonate Rock
Crepeau Developmen	22-41636	22:31:584	12/2/2004	Walnut Trail	118	23	300	101	15	60	160	0.1500	Carbonate Rock
Crepeau Developmen	22-41633	22:31:584	9/24/2004	Cove Hollow Court	118	21	300	51	6	22	130	0.0556	Carbonate Rock
Crepeau Developmen	22-41692	22:31:584	3/25/2005	Walnut Trail	118	22	230	101	25	60	160	0.2500	Carbonate Rock
Crepeau Developmen	22-41619	22:31:584	9/27/2004	Cove Hollow Court	118	15	300	101	7	30	280	0.0280	Carbonate Rock
Crepeau, Mike	22-43544	22:31:587	10/9/2006	Lake Iliff Road	118	31	200	74	20	40	180	0.1429	Carbonate Rock
Crepeau Developmen	22-41684	22:31:584	12/7/2004	Walnut Trail	118	13	600	101	1	60	580	0.0019	Carbonate Rock
Crepeau Developmen	22-41693	22:31:584	11/5/2005	Cove Hollow Court	118	20	600	101		30	580		Carbonate Rock
Crepeau Developmen	22-41618	22:31:584	9/25/2004	Walnut Trail	118	12	300	81	15	20	280	0.0577	Carbonate Rock
Crepeau Developmen	22-41691	22:31:584	2/2/2005	Lake Iliff Road	118	29	100	80	20	16	50	0.5882	Carbonate Rock
Crepeau Developmen	22-41685	22:31:584	8/8/2005	Walnut Trail	118	11	400	100	10	60	380	0.0313	Carbonate Rock
Crepeau Developmen	22-41620	22:31:584	11/3/2005	Cove Hollow Court	118	19	600	101	2	35	500	0.0043	Carbonate Rock
Crepeau Developmen	22-41617	22:31:584	4/1/2005	Walnut Trail	118	10	175	80	60	42	80	1.5789	Carbonate Rock
Crepeau Developmen	22-41690	22:31:584		Cove Hollow Court	118	18	150	100	15	40	120	0.1875	Carbonate Rock
Crepeau Developmen	22-41707	22:31:584	1/9/2006	Walnut Trail	118	3	600	101	3		580		Carbonate Rock
Bohmann, Eric	22-35658	22:31:567	11/11/1996	Tanglewood Drive	116	35	125	80	45	25	60	1.2857	Carbonate Rock
Woodmount Homes Inc.	22-37357	22:31:559	3/6/1999	MacIntosh Drive	116	32	400	81	30	80	300	0.1364	Carbonate Rock
Woodmount Homes Inc.	22-37358	22:31:559	3/18/1999	MacIntosh Drive	116	31	325	51	7	80	300	0.0318	Carbonate Rock

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Woodmount Homes Inc.	22-37360	22:31:559	2/3/1999	MacIntosh Drive	116	28	225	51	60	35	150	0.5217	Carbonate Rock
Cranberry Park Inc.	22-33138	22:31:567	11/1/1993	MacIntosh Drive	116	27	100	52	20	38			Carbonate Rock
Woodmount Homes Inc.	22-36786	22:31:583	8/10/1998	MacIntosh Drive	116	26	300	81	20		200		Carbonate Rock
David	22-30900	22:31:591	4/30/1991	Mulford Road	116	25	450	75	1	58			Carbonate Rock
Martin & Gaul Ltd.	22-33407	22:31:583	1/24/1994		116	24.04	530	95	87	31	154.5	0.7045	Carbonate Rock
Demianyah, Peter	22-31340	22:31:559	10/9/1991	Lawrence Road	116		615	51	1.5	40	600	0.0027	Martinsburg shale
Takacs, Christopher	22-27995	22:31:567	10/18/1988	Mulford Road	116	24B	202	52	12	60			Carbonate Rock
Crepeau Developmen	22-01685	22:31:584	8/5/2005	Walnut Trail	118	2	200	60	35	25	180	0.2258	Carbonate Rock
Crepeau Developmen	22-41621	22:31:585	9/27/2004	Cove Hollow Court	118	17	400	101	4	55	380	0.0123	Carbonate Rock
Wilson, Richard	22-28272	22:31:591	11/22/1988	Mulford Station Road	117	8C	500	50	6	44	480	0.0138	Carbonate Rock
First Hope Bank	22-41277	22:31:585	10/24/2003	Newton Sparta Road	117	4.01	150	60	30	10	60	0.6000	Carbonate Rock
Morel Builders LLC	22-38850	22:31:291	1/11/2001	3 Garry Lane	112	5.12	220	60	25	38	100	0.4032	Martinsburg shale
Morel Builders LLC	22-38872	22:31:292	6/16/2001	1 Garry Lane	112	5.11	300	60	20	28	80	0.3846	Martinsburg shale
Terry, Ann & Curculo, Jer	22-32691	22:31:567	7/13/1993	Tanglewood Drive	116.01	4	510	54	4	46			Carbonate Rock
Morel Builders LLC	22-37699	22:31:295	9/29/1999	15 Dana Drive	112	5.10	360	52	40	30	160	0.3077	Martinsburg shale
Marilla, Martin	22-36167	22:31:567	8/4/1997	MacIntosh Drive	116.01	3	350	100	10	20	150	0.0769	Carbonate Rock
Morel Builders LLC	22-37650	22:31:295	2/28/2000	13 Dana Drive	112	5.09	200	52	30	30	100	0.4286	Martinsburg shale
Morel Builders LLC	22-37494	22:31:295	3/23/1999	11 Dana Drive	112	5.06	400	52	15	40	110	0.2143	Martinsburg shale
Devine, Wendy	22-32948	22:31:567	8/19/1991	Tanglewood Drive	116	42	600	60	1	20	400	0.0026	Carbonate Rock
Morel Builders LLC	22-37889	22:31:295	9/29/1999	9 Dana Drive	112	5.07	420	52	35	35	190	0.2258	Martinsburg shale
Federici, Mark	22-33735	22:31:567	6/17/1994	Tanglewood Drive	116	40	125	97	15	21			Carbonate Rock
Cranberry Park Inc.	22-35408	22:31:567	7/27/1996	Tanglewood Drive	116	39	270	52	45	36	180	0.3125	Carbonate Rock
Morel Builders LLC	22-37636	22:31:295	4/12/1999	Dana Drive	112	5.06	300	52	25	30	110	0.3125	Martinsburg shale
Nicosia, Richard	22-33440	22:31:567	5/1/1994	Tanglewood Drive	116	38	152	54	20	40			Carbonate Rock
Morel Builders LLC	22-36774	22:31:295	8/1/1998	1 Dana Drive	112	5.04	400	70	8	40	145	0.0762	Martinsburg shale
Pitfoa Partnership	22-31886	22:31:581	6/11/1992	Rt. 623	116	3.03	400	52	15	25			Martinsburg shale
Morel Builders LLC	22-39190	22:31:295	12/13/2001	24 Dana Drive	112.01	7	340	60	15	50	80	0.5000	Martinsburg shale
Morel Builders LLC	22-38214	22:31:294	6/21/2000	22 Dana Drive	112.01	6.7	600	60	12	60	400	0.0353	Martinsburg shale
Morel Builders LLC	22-38213	22:31:295	6/16/2000	18 Dana Drive	112.01	5.18	340	60	15	30	30		Martinsburg shale
Morel Builders LLC	22-37634	22:31:295	3/20/1999	14 Dana Drive	112.01	4	300	52	20	35	90	0.3636	Martinsburg shale
Morel Builders LLC	22-37593	22:31:295	3/26/1999	5 Dana Drive	112	5.01	375	52	15	42	100	0.2586	Martinsburg shale
Morel Builders LLC	22-37890	22:31:295	3/6/2000	12 Dana Drive	112.01	3	300	60	25	25	150	0.2000	Martinsburg shale
Morel Builders LLC	22-37382	22:31:295	4/9/1999	4 Dana Drive	112.01	2	450	52	8	35	115	0.1000	Martinsburg shale
Dello Russo, Carmine	22-33241	22:31:295	6/20/1994	Newton Branchville Road	112	3.02	177	52	15	35			Martinsburg shale
Morel Builders LLC	22-36735	22:31:295	10/1/1999	2 Dana Drive	112.01		300	52	12	35	180	0.0828	Martinsburg shale
Morel Builders LLC	22-38734	22:31:286	12/19/2000	27 Dana Drive	112	5.24	240	60	30	20	80	0.5000	Martinsburg shale
Morel Builders LLC	22-39151	22:31:294	6/8/2001	25 Dana Drive	112	5.23	300	60	12	30	90	0.2000	Martinsburg shale
Morel Builders LLC	22-38386	22:31:294	6/26/2000	23 Dana Drive	112	5.22	400	60	12	30	200	0.0706	Martinsburg shale
Morel Builders LLC	22-38215	22:31:294	3/1/2000	21 Dana Drive	112	5.21	300	51	20	25	120	0.2105	Martinsburg shale
Schooner, Ira	22-24104	22:31:297	12/27/1985		112	1	200	50	8	14	180	0.0482	Martinsburg shale
Morel Builders LLC	22-39100	22:31:291	6/14/2001	2 Garry lane	112	5.20	300	60	20	24	87	0.3175	Martinsburg shale
Morel Builders LLC	22-39186	22:31:292	12/11/2001	4 Garry Lane	112	5.19	300	60	30	40	80	0.7500	Martinsburg shale
Morel Builders LLC	22-38216	22:31:294	2/29/2000	6 Garry Lane	112	5.18	250	60	25	25	100	0.3333	Martinsburg shale
Jaf Builders	22-37858	22:31:537	6/24/1999	Cambridge Road	111.10	9	598	49.5	16	62			Martinsburg shale
Morel Builders LLC	22-39189	22:31:292	6/18/2001	9 Garry Lane	112	5.15	500	60	18	30	190	0.1125	Martinsburg shale
George, James	22-37105	22:31:553	9/12/1998	Cambridge Road	111.1	8	515	51	3	45	500	0.0066	Martinsburg shale
Morel Builders LLC	22-38848	22:31:294	1/10/2001	7 Garry Lane	112	5.14	340	57	25	41	100	0.4237	Martinsburg shale
Jaf Builders	22-36909	22:31:529	11/4/1998	Cambridge Road	111.10	7	298	49.5	5	48			Martinsburg shale
Gailums, Jim	22-34592	22:31:526	5/19/1995	Southtown Road	111.10	6	127	53	8	32			Martinsburg shale

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George, James	22-35510	22:31:526	8/22/1996	Southdown Road	111.10	5	145	50	30	30	140	0.2727	Martinsburg shale
Stewart, Debra	22-37684	22:31:526	12/17/1999	Southdown Road	111.10	4	200	50	20	20	180	0.1250	Martinsburg shale
Jaf Builders	22-36783	22:31:526	6/19/1998	Southdown Road	111.09	13	173	49.5	10	10			Martinsburg shale
Jaf Builders	22-36784	22:31:526	6/11/1998	Southdown Road	111.10	3	173	49.5	20	45			Martinsburg shale
Vinter Construction Co.	22-36411	22:31:526	10/23/1997	Southdown Road	111.09	12	248	49.5	10	18			Martinsburg shale
Countryside Homes	22-36086	22:31:526	3/11/1998	Southdown Road	111.10	2	300	50	2	37	280	0.0082	Martinsburg shale
Countryside Homes	22-35862	22:31:526	8/1/1997	Southdown Road	111.10	1	400	60	2	54	380	0.0061	Martinsburg shale
McMullan, David	22-36225	22:31:534	12/8/1997	Cambridge Road	111.09	11	250	60	10	30	160	0.0769	Martinsburg shale
Rivara-Nicomini Co, Inc.	22-28812	22:31:534	5/5/1989	Dorsett Lane	111	52	100	50	20	22	80	0.3448	Martinsburg shale
Dorset Farms	22-26777	22:31:537	10/19/1987		111	24	200	60	20	31			Martinsburg shale
Raffi Sarkis Arslanian En	22-27019	22:31:535	1/6/1988		111	7	150	55	18	35			Martinsburg shale
Willekes, George	22-33417	22:31:534	1/13/1994	Cambridge Road	111.09	21	275	140	10	26			Martinsburg shale
Jaf Builders	22-36338	22:31:526	1/3/1998	Southdown Road	111.09	14	223	51	5	20			Martinsburg shale
Willekes, George	22-33884	22:31:529	12/19/1994	Cambridge Road	111.09	20	200	61	30	42			Martinsburg shale
Willekes, George	22-33879	22:31:553	9/6/1994	Cambridge Road	111.09	1B	150	56	20	14			Martinsburg shale
Dole, Bob & Donna	22-35999	22:31:526	5/16/1997	Southdown Road	111.09	17	405	61.5	15	30	405	0.0400	Martinsburg shale
Dole, Bob & Donna	22-35974	22:31:526	5/14/1997	Southdown Road	111.09	17	245	61.5	35	30	245	0.1628	Martinsburg shale
Dorset Farms	22-25878	22:31:537	4/13/1987		111	4	225	50	15	26			Martinsburg shale
Dorset Farms	22-27381	22:31:538	9/20/1988	Dorset Lane	111	2	150	64	20	25	100	0.2667	Martinsburg shale
Countryside Homes	22-36493	22:31:526	3/12/1998	Southdown Road	111.09	16	300	50	3	38	280	0.0124	Martinsburg shale
Jaf Builders	22-36339	22:31:526	10/23/1997	Southdown Road	111.09	15	148	49.5	17	28			Martinsburg shale
Rumpf, Regis	22-30288	22:31:529	7/18/1990		111	4	175	60	15	15	165	0.1000	Martinsburg shale
Dello Russo, Carmine		22:31:535	5/15/1995	Pierce Road	111.08	2	102	53	12	15			Martinsburg shale
Pushkar, Evelyn	21-10917	21:35:762	8/23/2001	20 Fredon Sringdale Rd.	154	4	150	140	20	30	100	0.2857	Glacial
Stohr, James	22-44235	22:31:719	1/2/2008	Bernard Drive	146	5	160	50	12	40	140	0.1200	Carbonate Rock
Forer, Doug	22-27613	22:31:727	9/22/1988	Hilltop Road	145	2	600	225	2	62	580	0.0039	Martinsburg shale
Janck Inc. Newton Golf	22-32769	22:31:474	6/15/1993	Rt. 206	151	22	125	100	20	40	80	0.5000	Carbonate Rock
Pannaman, John	22-25135	22:31:743	9/29/1986		144	20	300	50	8	50	140	0.0889	Carbonate Rock
Rider, Lillian	22-21493	22:31:743	4/00/1983	Irving Place	144	13	125	50	40	30	60	1.3333	Carbonate Rock
McWilliams, Jeffrey	22-43192	22:31:743	12/12/2006	Irving Place	144	1	200	50	6	42	120	0.0769	Carbonate Rock
Ryker, Gladys	21-10922	22:31:474	8/9/2001	Rt. 206	151	4	300	70	12	40	280	0.0500	Carbonate Rock
Kresge, William	22-28772	22:31:743	4/26/1989		144	34	273	50	2	50	200	0.0133	Carbonate Rock
Home World Inc.	22-39644	22:31:743	3/11/2002	Irving Place	144	1.01	600	50	3	80	560	0.0063	Carbonate Rock
Balardi, Elvira	22-34690	22:31:727		West Lake View Road	150	2	300	221	5	29			Martinsburg shale
	22-26137	22:31:743	8/1/1987		144	24	125	60					Carbonate Rock
Monticello Homes	22-19363	22:31:742	2/8/1980	Vivian Plaza	143	19	97	50	5				Carbonate Rock
Carrara, Michael	22-40081	22:31:742	5/6/2002	1 Vivian Plaza	143	18	520	160	7	40	420	0.0184	Carbonate Rock
Sussex Co. Strawberry Farm	22-36583	21:35:739	3/17/1998	Rt. 206	134	17	225	80	20	13	200	0.1070	Carbonate Rock
Chodos & Company	22-32756	22:31:742	5/20/1993	Irving Place	143	6.03	400	50	30	40			Carbonate Rock
Chodos & Company	22-32518	22:31:743	2/19/1993	Irving Place	143	6.03	500	51	2.4	44			Carbonate Rock
Besteed, Donald	22-38485	22:31:743	8/28/2000	Irving Place	143	6.02	200	60	10	70	140	0.1429	Carbonate Rock
Tab Enterprises	22-23915	21:35:763	3/11/1986		134	11A	200	50	3	17			Carbonate Rock
Wallace, Thomas	22-32503	22:31:742	6/1/1993	Irving Place	143	6.01	400	50	5	50	200	0.0333	Carbonate Rock
Quayle, Fred	22-23697	22:31:742	8/00/1985	Howard Drive	141	5C	324	56	3	30	300	0.0111	Carbonate Rock
Majestic Domain Inc.	22-21968	22:31:742	10/24/1983		141	5B	400	50	3.5				Carbonate Rock
Home World Inc.	22-25521	22:31:742			141	5	500	70	4	60	250	0.0211	Carbonate Rock
Stillwagon, Paul	22-24684	22:31:719	10/14/1986		140	9	355	50	15	32	170	0.1087	Carbonate Rock
Hadden, Robert	22-38738	22:31:761	8/18/2000	Goodale Road	133	5.05	500	51	3.5	22	480	0.0076	Martinsburg shale
Golden, Edward	22-40609	22:31:743	5/30/2003	Dennis Drive	140	1.02	400	53	20	75	380	0.0656	Carbonate Rock

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Dusche & Eskin Const.	22-37741	22:31:761	6/30/1999	Goodale Roac	133	5.02	300	51	30	55	260	0.1463	Martinsburg shale
Home World Inc.	22-39512	22:31:743	12/11/1001	Dennis Drive	140	1.01	500	50	3	80	460	0.0079	Carbonate Rock
Paramount Homes of NJ	22-38369	22:31:743	4/25/2000	Martin Street	140	1	250	50	20	20	80	0.3333	Carbonate Rock
Huelbig, Gerald	22-39351	22:31:743	4/25/2001	Martin Street	139	26	250	51	10	50	200	0.0667	Carbonate Rock
Devito, Debbie	22-39350	22:31:743	8/25/2001	Dennis Drive	139	25	600	51	1.5	60	580	0.0029	Carbonate Rock
Lind, Mary	22-39633	22:31:743	12/21/2001	Dennis Drive	139	4	200	100	25	40	70	0.8333	Carbonate Rock
Kittatinny Valley State Park		22:31:795	4/4/2000	Limecrest Rd./ Old Creamery	132	1	175	156	50	4	165	0.3106	Carbonate Rock
Cassell, Phillip	22-43538	22:31:842	12/12/2006	515 Limecrest Road	132	5	108	106	50	50	80	1.6667	Glacial
Kittatinny Valley State Park	22-38395	22:31:792	4/3/2000	Limecrest Road	132	4	325	320	40	15	315	0.1333	Glacial
	22-49529	22:31:579	1/30/2003		130	10	100	61	15	30	60	0.5000	Carbonate Rock
Designer Homes of NJ	22-41281	22:31:727	1/12/2005	29 Arthur Avenue	136	2.01	698	61.5	8	20			Carbonate Rock
Cirri Classic Homes Inc.	22-41005	22:31:719	12/10/2003	Arthur Avenue	136	1	525	60	7	25	140	0.0609	Carbonate Rock
White, David	22-38264	22:31:844	12/18/1999	Limecrest Road	130	2.01	100	100	10	48	90	0.2381	Glacial
VanCuden Inc.	22-25967	22:31:743	6/19/1987		135	7	350	56	10	40			Carbonate Rock
Smith, Mark	22-34654	22:31:811	7/21/1995	66 Goodale Roac	129	5	150	51	60	60			Martinsburg shale
Stillwagon, Charles	22-23925	22:31:773	4/4/1986		134	30	450	50	3	80	400	0.0094	Carbonate Rock
Luchetti, Gino	22-42392	22:31:574	4/20/2005	Luchetti Lane	129	1.05	208	50	20	30	180	0.1333	Martinsburg shale
Sussex Co. Bldgs. & Grounds	22-27678	22:31:773	5/24/1988	Off Rt. 206	134	27	300	99	12	44	280	0.0508	Carbonate Rock
Luchetti, Nancy	22-33689	22:31:574	5/31/1994	Pine Crest Drive	129	1.04	310	51	5	30	280	0.0200	Martinsburg shale
Luchetti, Joseph	22-33682	22:31:574	5/26/1994	Pine Crest Drive	129	1.03	168	61	15	30	140	0.1364	Martinsburg shale
Last Frontier	21-11387	21:35:766	5/28/2003		134	17.12	648	203	3	4			Carbonate Rock
Paramount Homes of NJ	22-39504	22:31:574	6/25/2002	40 Luchetti Way	129	1.02	250	50	15	25	150	0.1200	Martinsburg shale
Bob McEwan Const. Inc.	22-28293	22:31:723	11/16/1988	Caitlin Court	128	13	145	50	60	43	100	1.0526	Martinsburg shale
Schwan's Sales Enter.	22-34717	22:31:723	5/22/1996	Stickle Pond Road	126	5.03	105	50	20	12	80	0.2941	Martinsburg shale
Bob McEwan Const. Inc.	22-28292	22:31:723	11/17/1988	Caitlin Court	126	12	150	50	12	21	140	0.1008	Martinsburg shale
Bob McEwan Const. Inc.	22-28291	22:31:723	11/18/1988	Caitlin Court	126	11	100	53	45	43	80	1.2162	Martinsburg shale
Bob McEwan Const. Inc.	22-29441	22:31:731	10/12/1989	Caitlin Court	128	9	276	50	100	12	120	0.9259	Martinsburg shale
Bob McEwan Const. Inc.	22-29656	22:31:731	2/12/1990	Caitlin Court	128	8	125	50	20	8	100	0.2174	Martinsburg shale
Morse, Bruce	22-31960	22:31:731	6/16/1992	Brook Valley Way	126	7	148	50	25	20	25	5.0000	Martinsburg shale
Piccolo, John	22-27911	22:31:493	8/25/1988	Newton-Sparta Road	124	14.01	331	50	3	23	280	0.0117	Martinsburg shale
Bob McEwan Const. Inc.	22-29367	22:31:497	10/26/1989	Brook Valley Way	126	6	150	50	25	14	120	0.2358	Martinsburg shale
Bob McEwan Const. Inc.	22-29448	22:31:497	10/24/1989	Brook Valley Way	126	5	200	50	20	11	140	0.1550	Martinsburg shale
Malkin, Kenneth	22-42009	22:31:571	9/30/2005	Yates Avenue	124	11.02	300	51	10	60	280	0.0455	Martinsburg shale
Bob McEwan Const. Inc.	22-28940	22:31:489	5/23/1989	Brook Valley Way	126	5	150	50	10	0	140	0.0714	Martinsburg shale
Homestead Dev. Co	22-28334	22:31:496	11/21/1988	Yates Avenue	124	10	250	50	3.5	25	240	0.0163	Martinsburg shale
Bob McEwan Const. Inc.	22-29267	22:31:731	9/13/1989	Brook Valley Way	128	3	125	56	15	19	80	0.2459	Martinsburg shale
Scheer, Harold	22-32749	22:31:496	6/1/1993	Yates Avenue	124	8A	273	60	5	30	250	0.0227	Martinsburg shale
Bob McEwan Const. Inc.	22-29266	22:31:731	9/18/1989	Brook Valley Way	128	2	175	55	35	0	120	0.2917	Martinsburg shale
Coston, Bruce	22-33536	22:31:498	8/11/1994	Yates Avenue	124	1	223	50	8	39			Martinsburg shale
Bob McEwan Const. Inc.	22-29440	22:31:731	10/16/1089	Brook Valley Way	128	1	150	56	12	4	140	0.0882	Martinsburg shale
Bob McEwan Const. Inc.	22-28357	22:31:723	12/15/1988	Stickles Pond Road	127	19	150	50	15	48	120	0.2083	Martinsburg shale
McNelis, Brian	22-22922	22:31:572	11/00/1984	4 Linda Lane	122	5	124	87	15	44	100	0.2679	Martinsburg shale
Bob McEwan Const. Inc.	22-29045	22:31:489	7/6/1989	Stickles Pond Road	127	18	200	74	6	58	180	0.0492	Martinsburg shale
Lombardi, John	22-18814	22:31:572	8/10/1979	Linda Lane			125	51.5	15	66	115	0.3061	Martinsburg shale
Bob McEwan Const. Inc.	22-29659	22:31:497	2/20/1990	Brook Valley Way	127	17	100	70	20	15	60	0.4444	Martinsburg shale
Heather Homes, Inc.	22-19451	22:31:572	6/5/1980	Park View Drive	120	12F	198	60	1				Martinsburg shale
Mai, James	22-24407	22:31:573	5/00/1986		120	12E	100	50	30	27	80	0.5660	Martinsburg shale
Cornerstone Construction	22-25151	22:31:572	11/3/1986		120	12C	125	50	20	29	80	0.3922	Martinsburg shale
Bob McEwan Const. Inc.	22-29298	22:31:489	2/15/1990	Brook Valley Way	127	16	150	60	30	15	120	0.2857	Martinsburg shale

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E. G. Anderson, Inc.	22-19283	22:31:572	3/27/1980	Parkview Road	120	12B	148	50	5				Martinsburg shale
Bob McEwan Const. Inc.	22-28294	22:31:723	11/16/1988	Caitlin Court	127	14	150	50	20	21	120	0.2020	Martinsburg shale
Rady-Pentek, Arthur	22-19479	22:31:572	4/2/1980	Parkview Road	120	12A	208	50	5	30	180	0.0333	Martinsburg shale
Uygur, Ihsan	22-2456	22:31:577	7/9/1986		119	12	150	60	20	33			Martinsburg shale
Uygur, Ihsan		22:31:577	9/7/1983		119	20	475	50	2				Martinsburg shale
WHF Enterprises	22-28259	22:31:497	11/15/1988	Stickles Pond Road	127	4A	580	50	10	15	400	0.0260	Martinsburg shale
Da-Vine Homes, Inc.	22-19262	22:31:577	11/17/1979		119	19	147	50	10				Martinsburg shale
Da-Vine Homes, Inc.	22-19261	22:31:577	11/23/1979	Pine Crest Drive	119	18	123	50	20				Martinsburg shale
Uygur Construction Co.	22-36112	22:31:811	6/6/1997	28 Goodale Road	119	15-16	300	60	28	40	150	0.2545	Martinsburg shale
	22-31831	22:31:489	1/21/1993	Stickles Pond Road	126	7A	400	55	5	2			Martinsburg shale
Burtis, Karen	22-37933	22:31:577	11/00/1999	Pine Crest Drive	119	7.01	450	51	4	40	400	0.0111	Martinsburg shale
Perona Estates LLC	22-40577	22:31:972	5/21/2003	Perona Road	69	16	185	51	100	20			Precambrian crystalline
H/T Sales & Service	22-31814	22:31:788	9/10/1992	Rt. 206	161	5.01	173	50	5	9	150	0.0355	Carbonate Rock
D & E Road Service	22-23390	22:41:122	7/11/1985	Rt. 206	161	5	53	53	40	5			Carbonate Rock
Goldmine Enterprises Inc.	22-38182	22:31:779	2/7/2000	Rt. 606	163	4.03	87	69	20	5	50	0.4444	Carbonate Rock
Kirby Development Corp	21-09634	21:35:768	11/19/1996	Rt. 206	157	7	150	50	20	15	120	0.1905	Carbonate Rock
Cornine, Robert	21-07863	21:35:791	2/22/1990	Hunstville	157	24B	950	60	10	30	400	0.0270	Carbonate Rock
Deacon Homes	21-10424	21:35:767	2/17/2000	Hunstville Road	157	24.03	160	50	20	15	150	0.1481	Carbonate Rock
Deacon Homes	21-10745	21:35:767	6/6/2001	Tallyho	157	8.09	200	50	12	40	180	0.0857	Carbonate Rock
Kildolff, Thomas	22-27677	22:31:779	6/7/1988	Brighton Road	158	14.05	300	50	15	47	200	0.0980	Carbonate Rock
Deacon Homes	21-10744	21:35:768	4/13/2001	Tallyho	157	8.08	400	50	2	20	380	0.0056	Carbonate Rock
Deacon Homes	21-10540	21:35:768	8/28/2000	Tallyho Lane	157	8.07	280	50	5	50	260	0.0238	Carbonate Rock
Deacon Homes	21-10744	21:35:768	4/13/2001	Tallyho Lane	157	8.08	400	50	2	20	380	0.0056	Carbonate Rock
Deacon Homes	21-10541	21:35:767	5/2/2000	Tallyho Lane	157	8.06	200	50	15	10	180	0.0882	Carbonate Rock
Designer Homes of NJ	21-11561	21:35:791	1/12/2005	Huntsville Road	157	24.06	447	61	25	60			Carbonate Rock
Agens, George	22-37686	22:31:775	3/30/2000	Brighton Road	157	3.02	146	140	50	18	100	0.6098	Glacial
Deacon Homes		21:35:767	1/17/2001	Tallyho Lane	157	8.25	340	50	3	30	320	0.0103	Carbonate Rock
King, Douglas	22-26124	22:31:775	10/22/1987		157	3.01	150	144	25	31			Glacial
Deacon Homes	21-10525	21:35:765	1/10/2001	Tallyho Lane	157	8.24	340	50	3.5	60	320	0.0135	Carbonate Rock
Deacon Homes	21-10526	21:35:765	8/30/2000	Tallyho Lane	157	8.23	400	50	3	50	380	0.0091	Carbonate Rock
Deacon Homes	21-10527	21:35:766	9/27/2000	Tallyho Lane	157	8.22	300	50	20	50	280	0.0870	Carbonate Rock
Jaf Builders	21-10654	21:35:783	8/16/2000	Huntsville Road	156	1.05	200	50	17	25	180	0.1097	Carbonate Rock
Deacon Homes		21:35:765	8/6/2001	Tallyho Lane	157	8.21	300	50	30	40	280	0.1250	Carbonate Rock
Elwood, John	22-38844	22:31:778	10/9/2000	Brighton Road	157	2.01	135	133	100	21	100	1.2658	Glacial
Deacon Homes	21-10529	21:35:767	6/7/2000	Tallyho Lane	157	8.20	240	50	8	20	220	0.0400	Carbonate Rock
Deacon Homes		21:35:767	11/28/2000	Tallyho Lane	157	8.19	340	50	3	40	320	0.0107	Carbonate Rock
Deacon Homes	21-10531	21:35:768	2/16/2001	Tallyho Lane	157	8.18	300	50	10	20	280	0.0385	Carbonate Rock
Ewald Westra	21-05180	21:35:783	12/16/1982		156	1	258	50	3				Carbonate Rock
Miraglotta, Anthony	21-08251	21:35:765	11/20/1991	Rt. 611/Springdale/Greendell Rc	155	5.04	250	51	20	16			Carbonate Rock
Deacon Homes	21-10795	21:35:768	6/11/2001	Tallyho Lane	157	8.17	340	50	20	30	320	0.0690	Carbonate Rock
Deacon Homes	21-10533	21:35:767	6/8/2000	Tallyho Lane	157	8.16	260	50	8	30	240	0.0381	Carbonate Rock
Gould, Randy & Annella	21-11516	21:35:767	12/10/2003	Springdale-Greendell Rd	155	4	200	60	20	20	180	0.1250	Carbonate Rock
Deacon Homes	21-10534	21:35:767	5/3/2000	Tallyho Lane	157	8.15	225	50	10	20	180	0.0625	Carbonate Rock
Miraglotta, Anthony	21-07999	21:35:765	9/5/1990	Rt. 611/Greendell Road	155	5.03	275	54	25	12	200	0.1330	Carbonate Rock
Deacon Homes	21-10535	21:35:767	5/1/2000	Tallyho Lane	200	50	200	50	17	20	180	0.1063	Carbonate Rock
Deacon Homes	21-10536	21:35:767	8/25/2000	Tallyho Lane	157	8.13	400	50	2	30	380	0.0057	Carbonate Rock
Tsitsiragos, Maria	21-10945	21:35:763	9/26/2001	Rt. 206	155	5.01	400	51	20	25	380	0.0563	Carbonate Rock
		21:35:765	11/25/2000	Tallyho Lane	157	8.12	400	50	2	40	380	0.0059	Carbonate Rock
Deacon Homes	21-10794	21:35:765	3/8/2001	Tallyho Lane	157	8.11	340	50	4	50	320	0.0148	Carbonate Rock

Summary of Well Records obtained from Files for Wells within Andover Township, Sussex County, New Jersey.

Well Owner	Permit No.	State Atlas Grid Location	Date of Installation	Location	Block	Lot	Completed Depth (feet)	Casing Depth (feet)	Yield (gpm)	Static Water Level (fbgs)	Pumping Water Level (fbgs)	Specific Capacity (gpm/ft)	Geologic Formation
Deacon Homes		21:35:768	8/9/2001	Tallyho Lane	157	8.10	480	50	10	30	400	0.0270	Carbonate Rock
Gaynor, Jim	21-11596	21:35:739	6/4/2004	17 Springdale Gardens Roac	154	28	150	145	75	6	145	0.5396	Carbonate Rock
Gould, Carl	21-10172	21:35:791	6/14/1999	Huntsvile Road	156	1.04	500	51	2	32	480	0.0045	Carbonate Rock
de Vries, Lois	22-18624	22:31:561	5/15/1979	85 Lawrence Rd.	111	15	99	50	10	25	80	0.1818	Martinsburg shale