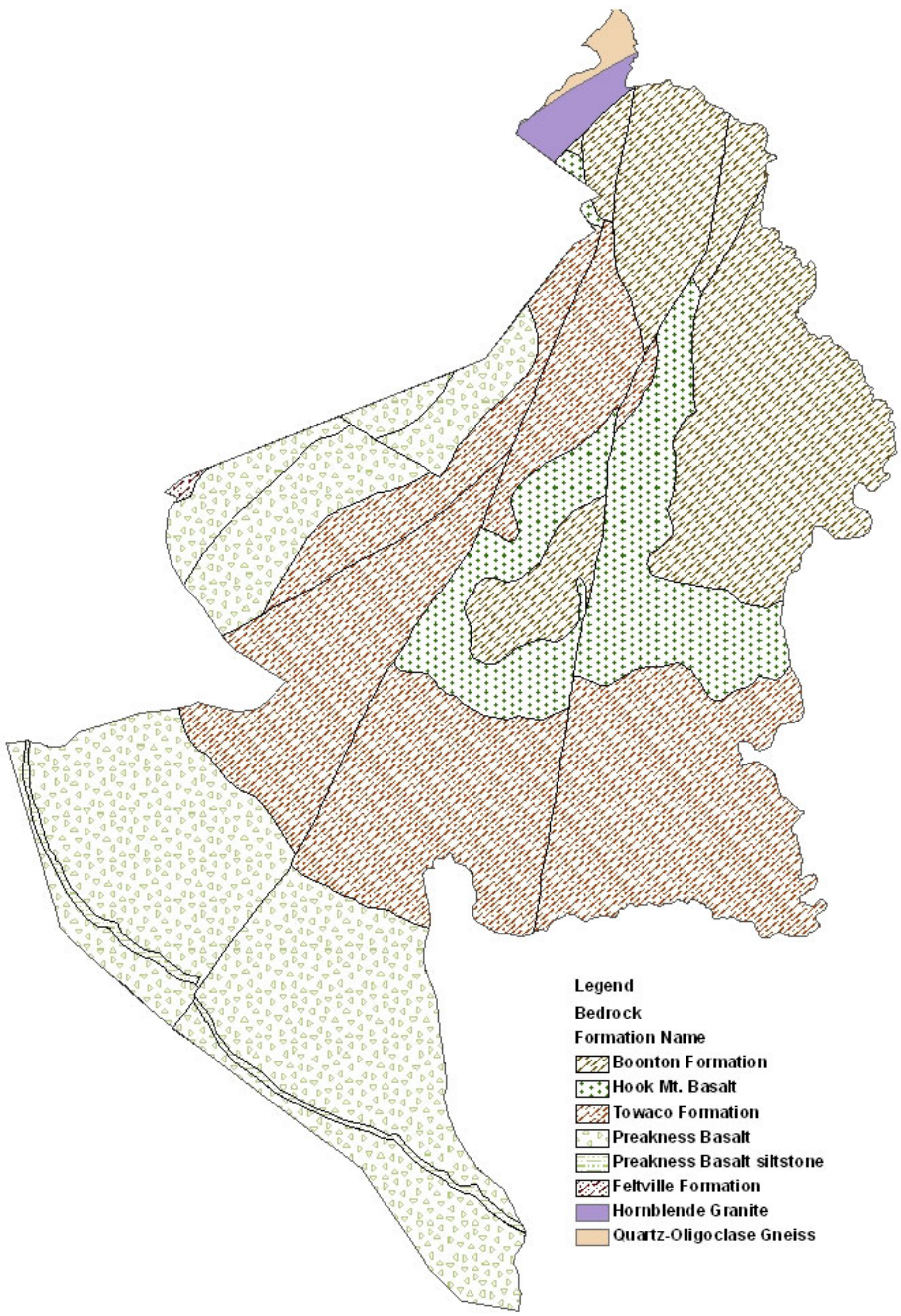
Evaluation of Groundwater Resources of Bernards Township, Somerset County, New Jersey



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Water: A Natural Renewable Resource

Water: A Natural Renewable Resource

EVALUATION OF GROUNDWATER RESOURCES OF BERNARDS TOWNSHIP SOMERSET COUNTY, NEW JERSEY

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EVALUATION OF GROUNDWATER RESOURCES OF BERNARDS TOWNSHIP SOMERSET COUNTY, NEW JERSEY

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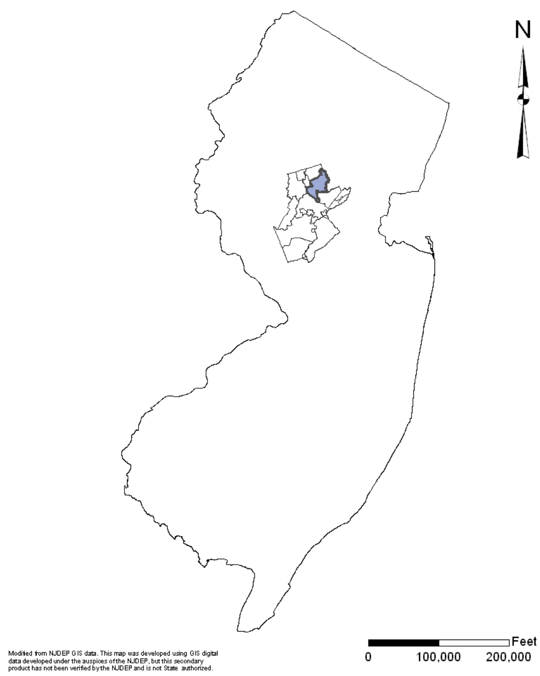
INTRODUCTION

The Township of Bernards, Somerset County retained M^2 Associates in May 2007 to conduct an evaluation of the groundwater resources of the township. The location of Bernards Township and Somerset County in New Jersey are shown on Figure 1.

Figure 1: Location of Bernards Township in Somerset County, New Jersey.

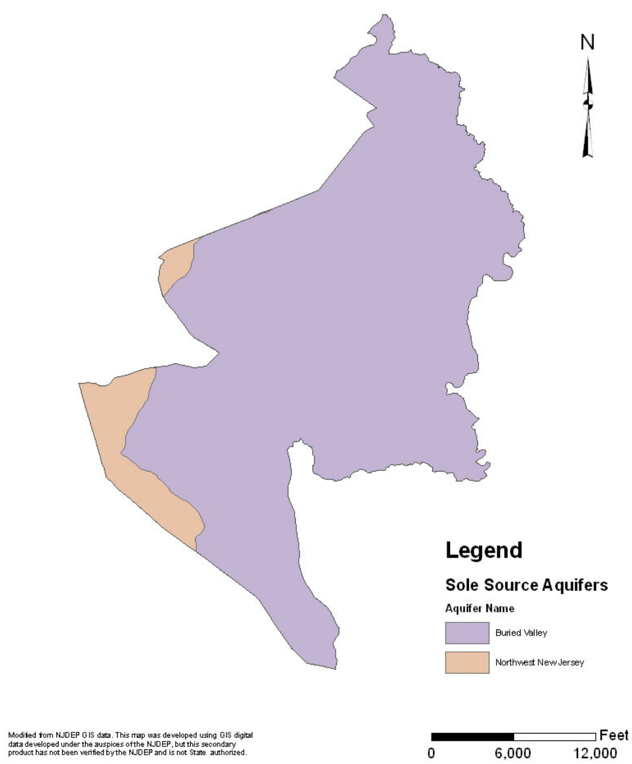


The Township of Bernards requested the groundwater resource evaluation because of the following:

1. Within large portions of the township, the source of drinking water for residents is groundwater supplied from individual, on-lot wells completed in fractured bedrock aquifers. Other residents in the township are reliant on water provided by New Jersey American Water Company (NJAWC), some of which, may be derived from a well located within the township. The hydrogeologic characteristics of these aquifers are dependent on the type of bedrock and nature and interconnection of fractures and other openings. The type of bedrock limits groundwater storage and transmission, recharge rates, sustained yields, interference effects, quality, and contaminant removal/dilution rates.

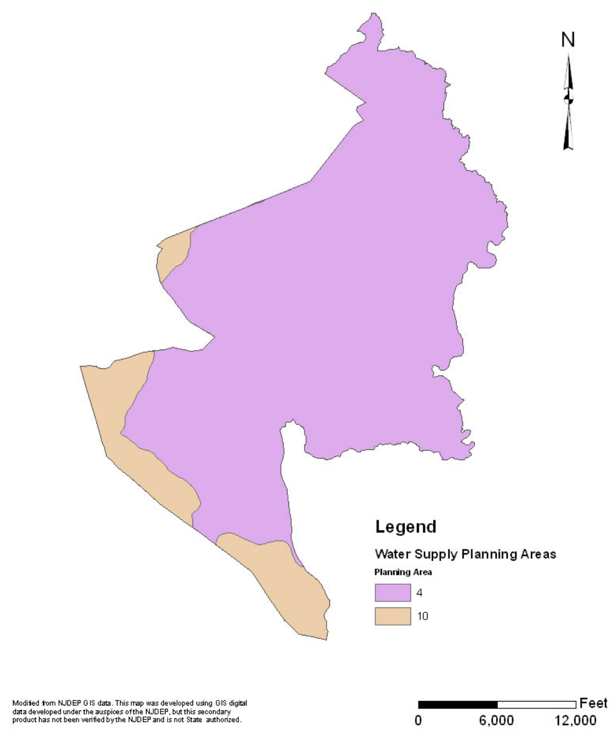
2. Bernards Township is underlain by two sole source aquifers as designated by the US Environmental Protection Agency (USEPA). Figure 2 depicts the portions of the township underlain by these two groundwater resources. The western edges of the township are underlain by the “Northwest New Jersey Sole Source Aquifer” and the vast majority of the township is underlain by the “Buried Valley Sole Source Aquifer” (Hoffman 1999A). The sole source aquifer boundaries were defined by the New Jersey Department of Environmental Protection (NJDEP) and designated by the USEPA in Federal Registers Volume 53, No. 121, published May 23, 1988 and Volume 45, No. 91, published May 8, 1980, respectively. The NJDEP and USEPA designated these aquifers for protection because groundwater provides more than 50 percent of the drinking water and therefore, warranted implementation of measures to protect these critical resources from potential health hazards. Bernards Township is located within the designated recharge area for the Buried Valley Sole Source Aquifer and many New Jersey residents downgradient of the township are reliant on the quality of water entering this system within township boundaries.

Figure 2: USEPA Designated Sole Source Aquifers
Beneath Bernards Township, Somerset County, New Jersey.



3. Bernards Township is located within two Regional Water Resource Planning Areas (RWRPA-4 and -10) as designated by NJDEP in the 1996 Statewide Water Supply Master Plan. The locations of the portions of the township underlain by each are shown on Figure 3. RWRPA-4 is the Upper Passaic River and Tributaries and RWRPA-10 is the Raritan River. These Planning Areas are two of the most populated in the State and NJDEP expected significant population increases in the 50 years subsequent to publication of its water supply master plan (NJDEP 1996).

Figure 3: Water-Supply Planning Areas Beneath
Bernards Township, Somerset County, New Jersey.



4. Streams headwatering in Bernards Township ultimately drain into the Passaic River or Raritan River. NJDEP indicates in its 1996 Water Supply Master Plan that much of the population within the Upper Passaic River basin derives needed water from groundwater within the Buried Valley Aquifer systems. Much of the population within the Raritan River basin derives water from this surface-water resource that is dependent on groundwater discharges to maintain dry weather streamflow. Bernards Township plays a vital role in the protection of the quantity and quality of water transmitted to and used as drinking water in these two regions of New Jersey.

5. The density of housing and application of surface/subsurface improvements can impact aquifers and may result in reduced recharge, lowered yields, increased interference, and degradation of groundwater quality. Furthermore, these changes can alter streamflow dynamics resulting in higher flows after storm events and lowered flows between events. In areas of the township where aquifer yields and/or recharge are limited or strained, additional housing and associated improvements may impact current users of groundwater.

The Township of Bernards wants to protect groundwater resources for current and future residents and businesses. Furthermore, as a recharge area for two of the most populous and fastest growing regions in New Jersey, Bernards Township is concerned with protecting the water resource availability and quality for downstream consumers in RWRPA-4 and -10. The township wants to protect water quantity and quality to meet the needs of ecological and human receptors downstream in the Passaic River and Raritan River watersheds. Township officials understand that the protection of water quality and quantity is critical to supporting public health and quality of life. They also understand that protection of these resources is not only critical for their own citizens but also for other citizens of New Jersey located downstream of Bernards 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 Bernards Township and neighboring municipalities in Somerset, Hunterdon, and Morris Counties.

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

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

The data reviewed were used to assess the recharge area requirements for supporting the drinking-water needs for residential dwelling units and to dilute nitrate and therefore, other contaminants from septic system discharges. In addition, the recharge area requirements were evaluated to minimize potential downstream impacts to the water resources and ecology of the Passaic River and Raritan River watersheds.

A conceptual model of the hydrogeologic conditions beneath Bernards Township was developed from the data and reports compiled in this study. The model was used to identify areas of the township with differing hydrogeologic capabilities to receive recharge, and store and transmit groundwater, and to assess the interrelationship and/or interdependence between the aquifer and surface-water systems throughout the township. The model was used to determine dependable yields for each of the differing geologic units and to evaluate recharge areas required to minimize potential adverse impacts from septic system discharges.

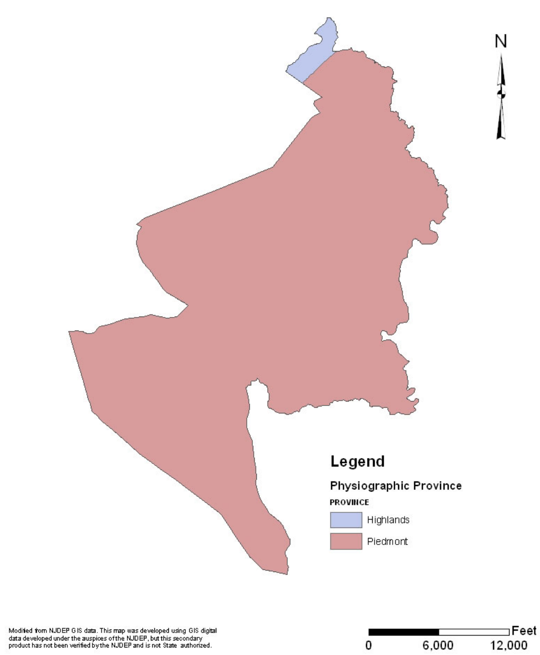
GEOLOGY

PHYSIOGRAPHIC PROVINCE

Bernards Township is bounded by other Somerset County municipalities including Bernardsville Borough to the north, Far Hills Borough and Bedminster Township to the west, and Bridgewater and Warren Townships to the south. The eastern section of the township is bordered by Harding and Long Hill Townships of Morris County. Based on the NJDEP Geographic Information System (GIS) database, Bernards Township encompasses approximately 24.2 square miles.

Bernards Township is located in two of New Jersey's four Physiographic Provinces. The Physiographic Provinces with respect to Bernards Township's boundaries are shown on Figure 4. Of the 24.2 square miles within the township borders, 23.8 square miles are within the Piedmont Physiographic Province and the remaining 0.4-square mile portion is within the Highlands Physiographic Province.

Figure 4: Physiographic Provinces Beneath
Bernards Township, Somerset County, New Jersey.



The northern tip of the township is located in the Highlands Province and this province is characterized by steep rounded to flat-topped ridges separated by narrow valleys. The Highland Province has longed been recognized as a vital water-resource region worthy of protection. Typically, the surface below the ridges are erosion-resistant Precambrian (older than 570 million years) igneous and metamorphic rocks whereas the subsurface of the valleys consist of more easily eroded Cambrian and Ordovician (570 to 440 million years old) sedimentary and meta-sedimentary rocks.

Based on USGS 7.5-minute Bernardsville topographic quadrangle, elevations within the Highlands Province of Bernards Township range from slightly less than 280 feet to 540 feet above mean sea level (amsl). The highest elevations are encountered along Old Army Road. The lowest elevations are located along the Passaic River near Hardscrabble Road.

Slightly more than 98 percent of Bernards Township is located within the Piedmont Physiographic Province and this province is generally characterized by lower elevations and broad to flat landscapes. Within the Piedmont Province, occasional hills with a subsurface of erosion-resistant igneous and metamorphic rocks are encountered. These higher elevations are usually underlain by erosion-resistant Jurassic diabase and basalt and associated metamorphic rocks. Typically, the surface below the Piedmont lowlands is underlain by Triassic-Jurassic (250 to 145 million years old) sedimentary and meta-sedimentary rocks. Beneath Bernards Township, the sedimentary rocks are Jurassic (208 to 145 million years ago) age and were deposited between lava flows from volcanoes that once formed the Second Watchung Mountain.

Within the Piedmont Province in Bernards Township, the USGS topographic quadrangles indicate that the highest elevations are encountered along the Second Watchung Mountain ranging from 540 to 600 feet amsl. The lowest elevations within the township are encountered in the southeast portion at approximately 210 feet amsl as the Passaic River drains from the township.

SURFACE WATER

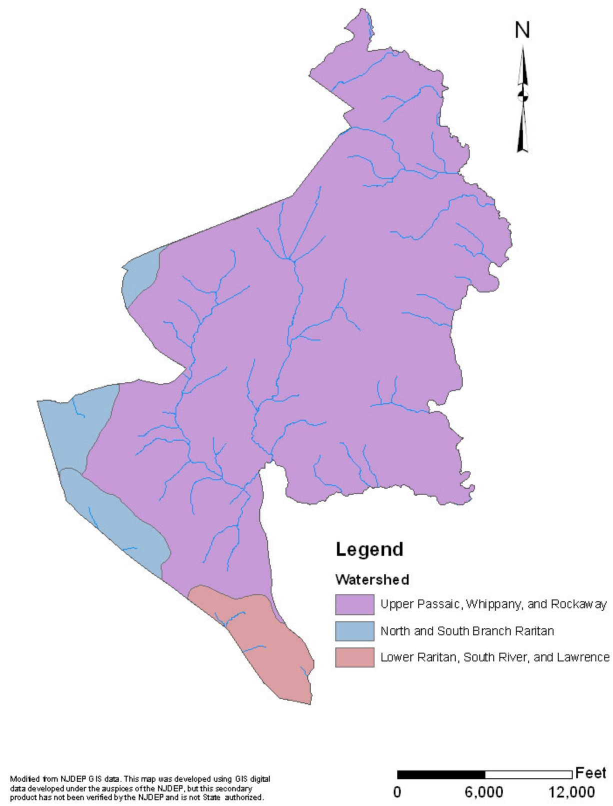
Watersheds

Bernards Township is divided between the Upper Passaic River and Raritan River basins with slightly more than 88 percent of the township draining to the Passaic River system. Based on the USGS, three watersheds have been mapped within the township. These watersheds are as follows:

1. Upper Passaic, Whippany, and Rockaway Rivers,
2. North and South Branches of Raritan River, and
3. Lower Raritan River, South River and Lawrence.

These watersheds are depicted on Figure 5.

Figure 5: Watersheds Within Bernards Township,
Somerset County, New Jersey.



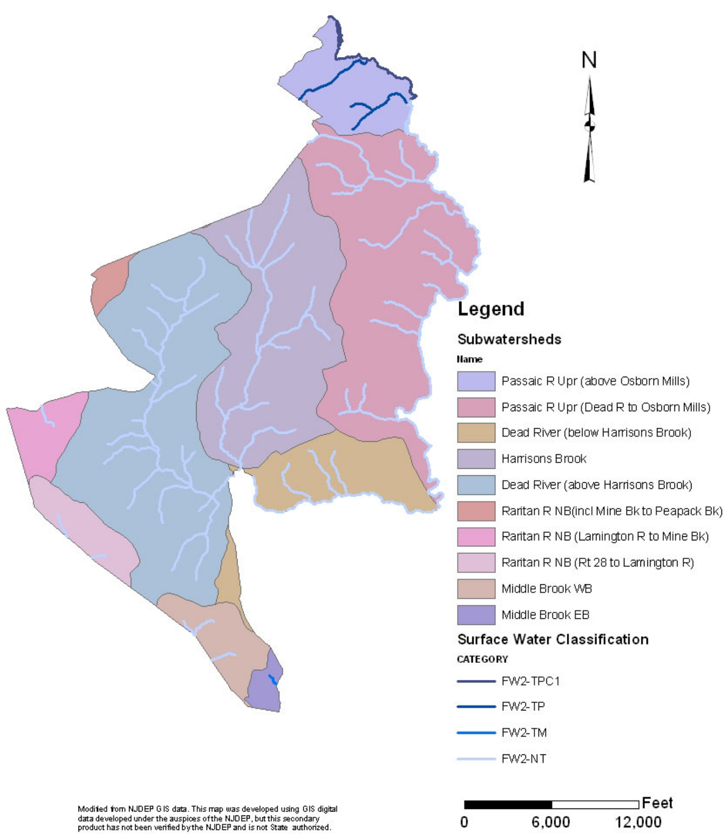
Stream Classifications

Within Bernards Township, ten subwatersheds have also been mapped by the USGS. Table 1 lists the watersheds, subwatersheds, and the NJDEP surface-water classifications for the streams within Bernards Township in these watersheds. Figure 6 shows the subwatersheds and the NJDEP surface-water classifications for sections of streams within these subwatersheds. The data summarized in Table 1 and shown on Figure 6 were obtained from the NJDEP's most recent mapping dated February 28, 2008, in its GIS database.

Table 1: Watersheds, Streams, and Surface-Water Classifications in Bernards Township, Somerset County, New Jersey.

Watershed	Subwatershed	Stream Segment	Current Classification
Upper Passaic River	Upper Passaic (above Osborn Mills)	Passaic River (Upstream of Osborn Pond)	FW2-TP (C1)
		Passaic River Tributary	FW2-TP (C2)
		Passaic River (Downstream of Osborn Pond)	FW2-NT (C2)
	Upper Passaic (Dead River to Osborn Mills)	Penns Brook and Tributaries	FW2-NT (C2)
		Passaic River Tributaries	FW2-NT (C2)
	Dead River (below Harrisons Brook)	Dead River	FW2-NT (C2)
		Dead River Tributaries	FW2-NT (C2)
	Harrisons Brook	Harrisons Brook	FW2-NT (C2)
		Harrisons Brook Tributaries	FW2-NT (C2)
	Dead River (above Harrisons Brook)	Dead River	FW2-NT (C2)
		Dead River Tributaries	FW2-NT (C2)
		Spring Brook	FW2-NT (C2)
North Branch Raritan River	Raritan River North Branch (Mine Brook to Peapack Brook)	No Streams in Township	
	Raritan River North Branch (Lamington River to Mine Brook)	North Branch Raritan River Tributary	FW2-NT (C2)
	Raritan River North Branch (Rt 28 to Lamington River)	Chambers Brook and Tributaries	FW2-NT (C2)
Lower Raritan River	Middle Brook West Branch	West Branch Middle Brook	FW2-NT (C2)
	Middle Brook East Branch	Dock Watch Hollow Brook and Tributaries	FW2-TM (C2)

Figure 6: Subwatersheds and Stream Classifications
Within Bernards Township, Somerset County, New Jersey.



As noted in Table 1, the Upper Passaic River upstream of Osborn Mills within Bernards Township is classified as FW2-TP (C1). In this same subwatershed, there are two tributaries to the Passaic River that join the main stream prior to Osborn Pond that are both classified as FW2-TP (C2). Downstream of Osborn Pond, the Upper Passaic River is classified in N.J.A.C. 7:9B Surface Water Quality Standards as FW2-NT (C2). With the exception of a small portion of Dock Watch Hollow Brook within Bernards Township, the remaining streams within the township borders are classified by NJDEP as FW2-NT (C2). Dock Watch Hollow Brook and tributaries are classified as FW2-TM (C2).

N.J.A.C. 7:9B indicates that FW2 waters are general classification freshwaters. A TP designation indicates that the water has sufficient quality for trout reproduction. A TM designation indicates that the water quality is sufficient to maintain trout. An NT designation indicates Non-Trout waters; however, these waters could sustain other species. Trout are highly susceptible to changes in water quality and therefore, are used as an indicator of stream conditions.

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 Bernards Township are 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.

Headwaters

Harrisons Brook and Dead River headwater or originate within the borders of Bernards Township. Several other tributaries to these two rivers headwater within Township borders as shown on Figure 6. In addition to these two stream systems, tributaries to the Passaic River, North Branch of the Raritan River, Chambers Brook, West Branch of the Middle Brook, and Dock Watch Hollow Brook also originate within township borders. At these headwaters, discharging groundwater provides the initial flow in the streams, which ultimately drain to the Passaic or Raritan Rivers.

The headwaters within the township are located at high elevations or near topographic divides between subwatersheds. At high elevations, the drainage area contributing water to headwaters is small. As a result, impacts within these contributing drainage areas can significantly alter and degrade water quality and quantity in a stream.

Studies summarized by Kaplan et al. (2000) indicate that adverse impacts to water quality can occur when impervious surface coverage exceeds 10 percent of the contributing drainage area. Further impacts can result from surface or subsurface discharges within these drainage areas. Where the volume of water available for dilution is diminished because decreased groundwater discharge or increased stormwater flows, these adverse impacts can extend downstream to other resources, consumers, or ecosystems. As a result, high quality surface waters can quickly degrade because of impacts to groundwater quality and/or increased runoff.

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 USDA-NRCS mapping, 29 general soil types have been delineated within Bernards Township (USDA Soil Survey Geographic SSURGO Database 1999). One quarry and several areas covered with water have also been mapped by USDA-NRCS. Some of these general soil classifications are further subdivided based on slope gradients. These general soil classifications along with areas containing standing water and a quarry pit are shown on Figure 7.

Table 2 provides a summary of soil types, map symbols as depicted on Figure 7, slope ranges, approximate areas encompassed, and potential septic system limitations as described by the Soil Conservation Service in the 1989 “Soil Survey of Somerset County, New Jersey”. The current mapping by USDA-NRCS continues to show that 33 of the 50 soil types mapped beneath the township have very limited sewage disposal capabilities and that with the exception of Birdsboro soils, all of the soils beneath the township have some limitations with respect to sewage disposal. The report from the USDA-NRCS database is included in Appendix A. The USDA-NRCS did not evaluate sewage disposal characteristics for quarry, rock outcrops, or ponds.

Based on appropriate site-specific investigations, it is possible that septic systems could be constructed in accordance with N.J.A.C 7:9A, which is the NJDEP’s “Standards for Individual Subsurface Sewage Disposal Systems,” in poor soils beneath the township. Only the Birdsboro soils, which encompass an area of approximately 291-acres scattered in the central and northeastern portions of the township, are considered “Not Limited” with respect to sewage disposal by USDA-NRCS. This federal agency considers soils beneath more than 98 percent of the township to have limitations with respect to the disposal of wastewater primarily because of shallow groundwater or restrictive substratum.

The USDA-NRCS indicates that in some areas underlain by Bowmansville, Fluvaquents, Parsippany, Parsippany variant, Raritan, Rowland, Udifluvents and Udepts, sewage disposal fields would not be permitted because of flooding. In other areas underlain by Croton, Mount Lucas-Watchung, and Watchung soils, sewage disposal fields would not be permitted because of hydric conditions and related wetlands. And, this federal agency indicates that in some areas underlain by Neshaminy silt loam; 18 to 35 percent slopes, and Parker very gravelly sandy loam; 25 to 45 percent slopes, sewage disposal fields would not be permitted because of steep slopes. The soils in which, disposal fields may not be permitted, have been mapped beneath more than 37 percent of the area within the Bernards Township borders.

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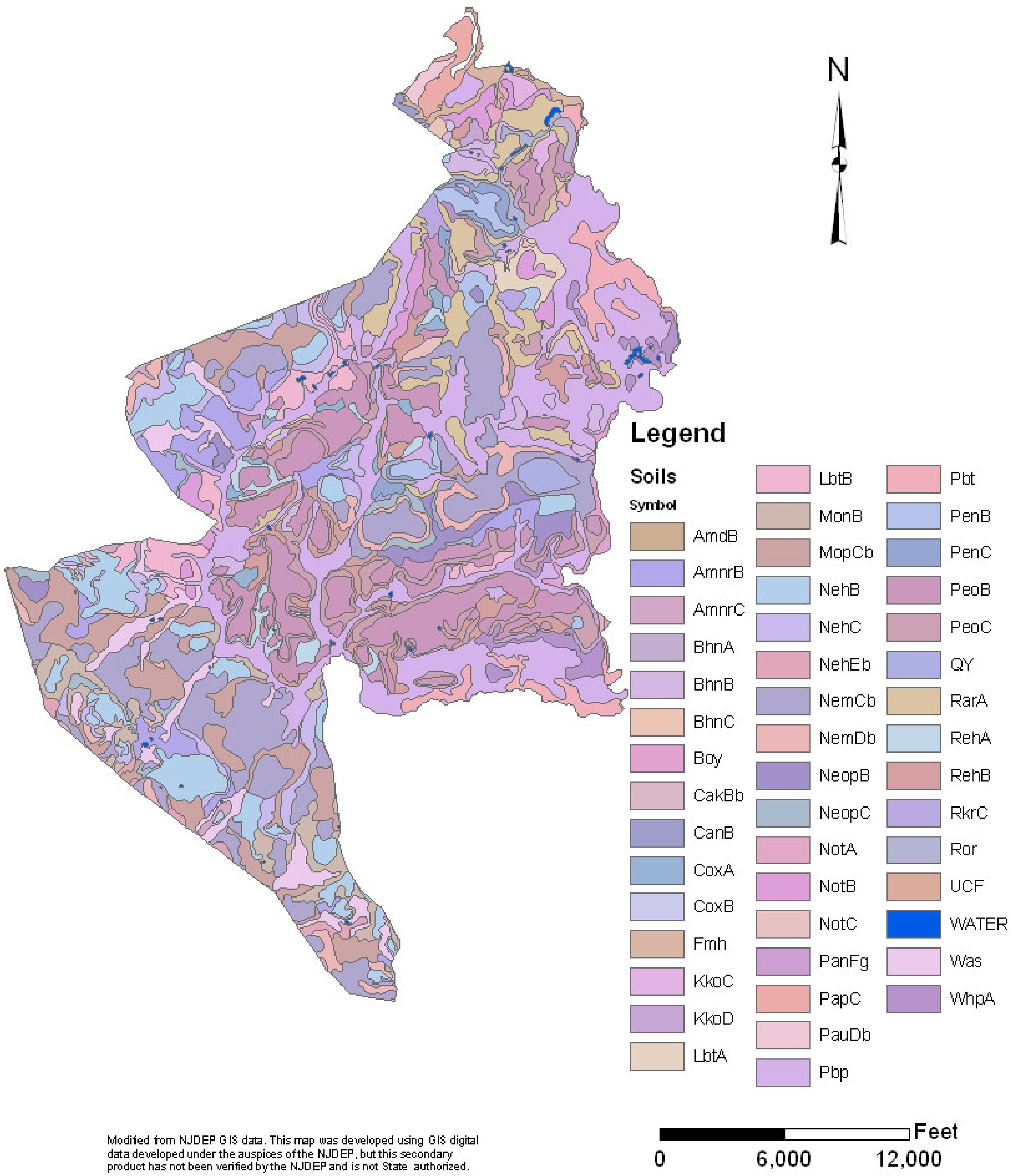
Figure 7: Soils Beneath Bernards Township, Somerset County, New Jersey.



Modified from 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.

Table 2: Types, Slopes, Approximate Areas, and Septic Limitations of Soils in Bernards Township, Somerset County, New Jersey.

Soil Type	Map Label (see Figure 7)	Approximate Area (acres)	Septic Limitations
Amwell gravelly loam; 2 to 6 percent slopes	AmdB	0.62	Severe-seasonal high water table; fragipan; shallow hard bedrock
Amwell gravelly silt loam; rock substratum; 2 to 6 percent slopes	AmnrB	553.63	Severe-seasonal high water table; fragipan; shallow hard bedrock
Amwell gravelly silt loam; rock substratum; 6 to 12 percent slopes	AmnrC	39.77	Severe-seasonal high water table; fragipan; shallow hard bedrock
Birdsboro silt loam; 0 to 2 percent slopes	BhnA	24.48	Slight - groundwater pollution hazard
Birdsboro silt loam; 2 to 6 percent slopes	BhnB	226.50	Slight - groundwater pollution hazard
Birdsboro silt loam; 6 to 12 percent slopes	BhnC	40.34	Moderate- strongly sloping; groundwater pollution hazard
Bowmansville silt loam; frequently flooded	Boy	72.52	Severe- flooding hazard, shallow seasonal water table
Califon loam; 3 to 8 percent slopes	CakBb	1.78	Severe - slow permeability, shallow seasonal water table
Califon gravelly loam; 3 to 8 percent slopes	CanB	16.55	Severe - slow permeability, shallow seasonal water table
Croton silt loam; 0 to 2 percent slopes	CoxA	86.26	Severe - shallow seasonal high water table
Croton silt loam; 2 to 6 percent slopes	CoxB	4.34	Severe - shallow seasonal high water table
Fluvaquents; frequently flooded	Fmh	99.40	Severe - flooding
Klinesville channery loam; 6 to 12 percent slopes	KkoC	63.34	Severe - shallow permeable shale; moderately steep
Klinesville channery loam; 12 to 18 percent slopes	KkoD	79.43	Severe - shallow permeable shale; steeply sloping
Lansdowne silt loam; 0 to 2 percent slopes	LbtA	111.71	Severe - shallow seasonal high water table
Lansdowne silt loam; 2 to 6 percent slopes	LbtB	330.11	Severe - shallow seasonal high water table
Mount Lucas silt loam; 2 to 6 percent slopes	MonB	376.16	Severe - shallow seasonal high water table; shallow hard bedrock
Mount Lucas-Watchung silt loams; 6 to 12 percent slopes; very stony	MopCb	1,020.87	Severe - shallow seasonal high water table; shallow hard bedrock
Neshaminy silt loam; 2 to 6 percent slopes	NehB	859.50	Severe - shallow hard bedrock; shallow seasonal water table
Neshaminy silt loam; 6 to 12 percent slopes	NehC	441.48	Severe - shallow hard bedrock; shallow seasonal water table
Neshaminy silt loam; 18 to 35 percent slopes; very stony	NehEb	74.23	Severe - shallow hard bedrock; shallow seasonal water table; steeply sloping
Neshaminy-Mount Lucas silt loams; 6 to 12 percent slopes; very stony	NemCb	1,805.44	Severe - shallow hard bedrock; shallow seasonal water table
Neshaminy-Mount Lucas silt loams; 12 to 18 percent slopes; very stony	NemDb	342.37	Severe - shallow hard bedrock; shallow seasonal water table
Neshaminy variant silt loam; 2 to 6 percent slopes	NeopB	224.83	Severe - shallow hard bedrock; shallow seasonal water table
Neshaminy variant silt loam; 6 to 12 percent slopes	NeopC	128.71	Severe - shallow hard bedrock; shallow seasonal water table
Norton loam; 0 to 2 percent slopes	NotA	22.32	Severe - slow permeability in subsoil
Norton loam; 2 to 6 percent slopes	NotB	254.86	Severe - slow permeability in subsoil
Norton loam; 6 to 12 percent slopes	NotC	27.30	Severe - slow permeability in subsoil
Parker very gravelly sandy loam; 3 to 15 percent slopes	PapC	113.97	Moderate - strongly sloping
Parker very gravelly sandy loam; 25 to 45 percent slopes; rocky	PapFg	17.60	Severe - steeply sloping
Parker-Gladstone complex; 15 to 25 percent slopes; very stony	PauDb	36.86	Severe - steeply sloping
Parsippany silt loam; frequently flooded	Pbp	2,660.42	Severe - frequent flooding; shallow seasonal high water table
Parsippany very poorly drained variant silt loam; frequently flooded	Pbt	383.89	Severe - frequent flooding; shallow seasonal high water table
Penn silt loam; 2 to 6 percent slopes	PenB	195.92	Severe - rippable bedrock at very shallow depths
Penn silt loam; 6 to 12 percent slopes	PenC	113.32	Severe - rippable bedrock at very shallow depths
Penn channery silt loam; 2 to 6 percent slopes	PeoB	1,696.35	Severe - rippable bedrock at very shallow depths
Penn channery silt loam; 6 to 12 percent slopes	PeoC	730.56	Severe - rippable bedrock at very shallow depths
Quarry	QY	78.62	
Raritan silt loam; 0 to 3 percent slopes	RarA	595.66	Severe - shallow seasonal water table; flooding
Reaville silt loam; 0 to 2 percent slopes	RehA	160.60	Severe - shallow seasonal water table; very shallow bedrock
Reaville silt loam; 2 to 6 percent slopes	RehB	388.94	Severe - shallow seasonal water table; very shallow bedrock
Riverhead sandy loam; 8 to 15 percent slopes	RkrC	57.85	Moderate - high permeability hazard of groundwater pollution
Rowland silt loam	Ror	93.30	Severe - frequent flooding
Udifluvents and Udepts	UCF	14.39	Severe - frequent flooding
Watchung silt loam	Was	477.01	Severe - shallow seasonal high water table
Water	WATER	43.99	
Whippany silt loam; 0 to 3 percent slopes	WhpA	219.19	Severe - shallow seasonal high water table; slow permeability

Slightly less than 44-acres of Bernards Township are covered with water. Parsippany silt loam, Neshaminy-Mount Lucas silt loam, Penn channery silt loam, and Mount Lucas-Watchung silt loam are the most common soils beneath the township. These soils have been mapped beneath approximately 47 percent of Bernards Township.

Parsippany silt loam is described by the USDA-NRCS as deep, poorly drained soils found in flat to low level areas and slight depressions near streams and in former glacial Lake Passaic. These soils may be frequently flooded.

The USDA-NRCS describes Neshaminy-Mount Lucas silt loam as primarily comprised of Neshaminy-type soils with less than half derived from Mount Lucas-type soils. These soils are deep to very deep, well drained, and typically found in areas with moderate to steep slopes with sometimes frequent cobbles and boulders. Both the Neshaminy and Mount Lucas soil types were derived from the weathering of the underlying igneous bedrock along the Watchung Mountains. Bedrock is typically encountered at depths less than 5 feet below ground surface.

The USDA-NRCS describes Penn channery silt loam as moderately deep, well drained soils found in upland areas. These soils were derived from weathering of underlying red shale, siltstone, and fine grained sandstone. Bedrock is typically encountered at very shallow depths of less than 3 feet below ground surface and slopes can range from shallow to very steep.

Mount Lucas-Watchung silt loam is also derived from weathering of the underlying basalt bedrock beneath the Watchung Mountains and is described by USDA-NRCS as very deep to deep, moderately well to somewhat poorly-drained. These soils are typically encountered in upland areas.

In summary, the USDA-NRCS mapping indicates that soils beneath more than 98 percent of Bernards Township have limitations for the disposal of septic system effluent (see Table 2 and Appendix A). Sewage disposal fields may not be permissible beneath as much as 37 percent of the township because of flooding hazards, hydric soil conditions, or steep slopes. Site-specific investigation must be conducted to evaluate the presence of limiting conditions and to design disposal fields in accordance with N.J.A.C 7:9A and NJDEP requirements.

BEDROCK

Formations

HIGHLANDS

As discussed above, less than 2 percent of Bernards Township is located in the Highlands Physiographic Province. More than 98 percent of the township is located in the Piedmont Physiographic Province. Bedrock underlying the Highlands portion of the

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township is made up of rocks some of which exceed 1 billion years in age. The Piedmont portion of the township has a subsurface of rocks deposited as the Newark basin opened in the Triassic (208 to 245 million years ago) and Jurassic (208 to 145 million years ago) periods. These basins were formed as a result of continental separation or rifting.

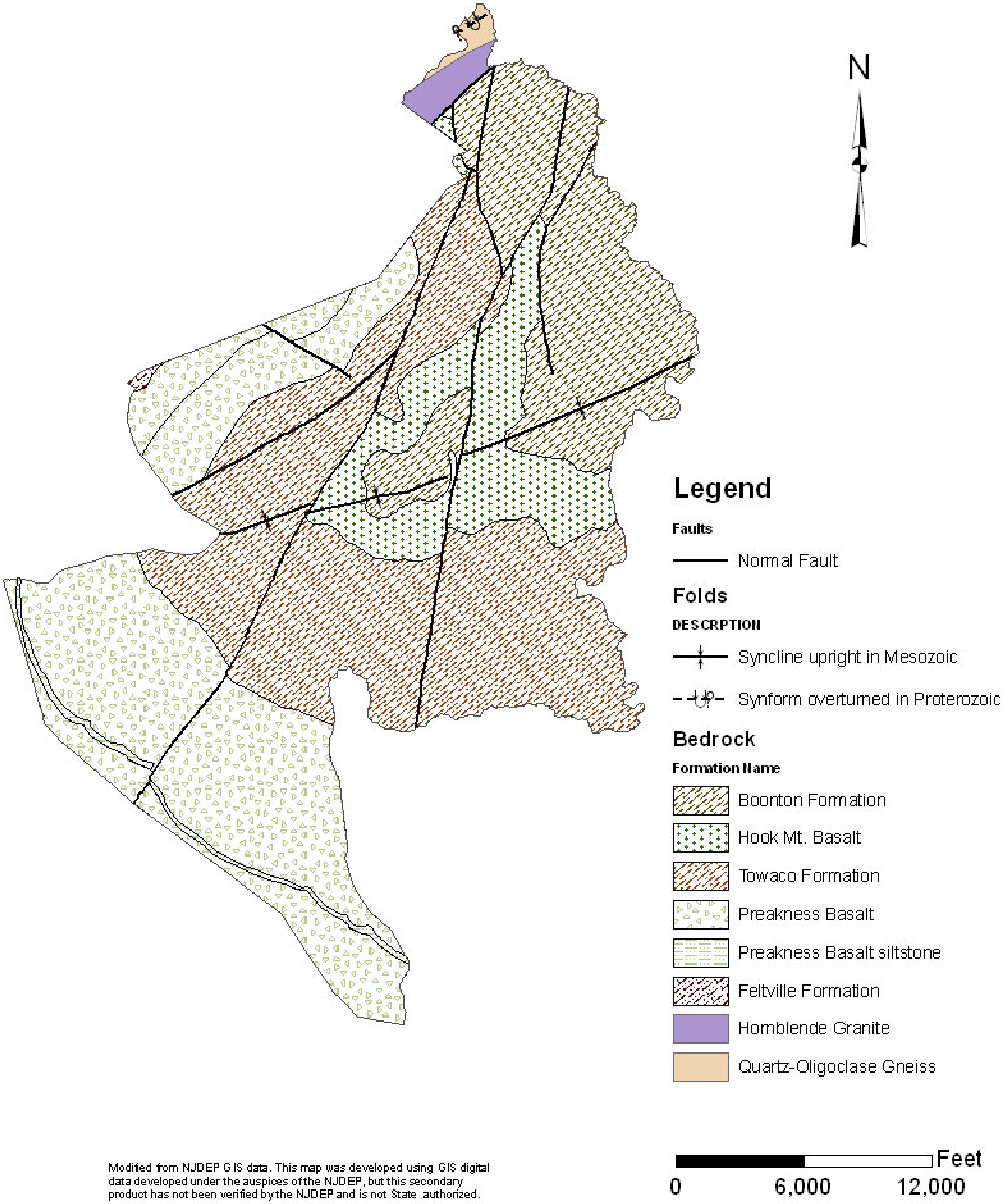
The bedrock geology of Bernards Township is shown on Figure 8, which was primarily developed from an extensive mapping effort of the USGS and New Jersey Geological Survey (NJGS) and is shown on the "Bedrock Geologic Map of Northern New Jersey" (Drake et al. 1996). Figure 8 was also developed from the "Bedrock Geology for New Jersey 1:100,000 Scale" mapping provided by the NJDEP in their GIS database and updated as recently as May 10, 2007. Table 3 summarizes the areal extent of the bedrock geologic formations beneath the township.

Table 3: Bedrock Types and Approximate Areas Beneath Bernards Township, Somerset County, New Jersey.

Rock Type	Area of Township Underlain by Rock Type (acres)	Percent of Township Underlain by Rock Type
Jurassic		
Boonton Formation	3,019.34	19.50%
Hook Mt. Basalt	1,774.39	11.46%
Towaco Formation	5,515.10	35.62%
Preakness Basalt	4,791.28	30.94%
Preakness Basalt Siltstone	142.04	0.92%
Feltville Formation	16.69	0.11%
Total Area Underlain by Jurassic Formations:	15,258.84	98.55%
Precambrian		
Hornblende Granite	151.12	0.98%
Quartz-Oligoclase Gneiss	73.38	0.47%
Total Area Underlain by Precambrian Formations:	224.50	1.45%

Within the Highlands Physiographic Province, Precambrian (older than 570 million years) igneous and metamorphic rocks are encountered. The Precambrian igneous and metamorphic rocks are hornblende granite and quartz-oligoclase gneiss. These Precambrian rocks have been mapped beneath approximately 225-acres or 1.5 percent of Bernards Township. The Precambrian igneous and metamorphic rocks are encountered beneath properties along Old Army Road, Hardscrabble Road, Old Farm Road, and Butternut Lane in the far northern limits of the township and are shown as solid colors on Figure 8.

Figure 8: Bedrock Geology of Bernards Township, Somerset County, New Jersey.



Modified from 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.

Water: A Natural Renewable Resource

PIEDMONT

More than 98 percent of Bernards Township is within the Piedmont Physiographic Province. This area is underlain by Jurassic (208 to 145 million years ago) sedimentary, igneous, and metamorphic rocks deposited or extruded as the Newark Basin opened with the rifting or separation of the North American and African plates.

The oldest of the sedimentary rocks are Lower Jurassic brown-red to light gray-red, fine- to coarse-grained sandstone interlayered with gray and black, coarse-grained siltstone and silty mudstones (Drake et al. 1996) that were deposited in fluvial, lake, and mudflat environments. The Feltville Formation rocks are encountered beneath slightly more than 0.1 percent of the township and therefore, are not a significant bedrock aquifer for residents of Bernards Township. These rocks are encountered in the northwestern portion of the township beneath the Mine Brook section. The thickness of the Feltville Formation and associated facies may range to 450 feet. Given the limited extent and proximity to the Preakness Basalt, the Feltville Formation beneath Bernards Township most likely, has been metamorphosed to bluish-gray hornfels.

The next oldest set of rocks in the bedrock sequence beneath Bernards Township is the Lower Jurassic Preakness Basalt and associated interlayered siltstone. The Preakness Basalt has been separated into three distinct major flows of magma from volcanoes that once formed the Watchung Mountains. The thin (6 to 30 feet) siltstone unit separates the two lower or older flows. The Preakness Basalt is comprised of dark-greenish-gray to black, very fine-grained, dense, and hard former magma flows. The thickness of the Preakness Basalt beneath Bernards Township may range between 800 to nearly 1100 feet (Drake et al. 1996). These basalts have been mapped beneath approximately 31 percent and the siltstones beneath slightly less than 1 percent of the township. The Preakness Basalt is present beneath the northwestern, western, southwestern, and southern portions of the township (see Figure 8).

The next youngest rock formation beneath Bernards Township is the sedimentary Towaco Formation, which is comprised of red-brown to purple-brown, fine- to medium-grained micaceous sandstone, siltstone, and silty mudstone deposited in fluvial and lacustrine environments in the Lower Jurassic (Olsen 1980). The Towaco Formation has been mapped beneath nearly 36 percent of Bernards Township and was deposited during a period of relative volcanic inactivity. This formation may have a thickness of as much as 1250 feet beneath Bernards Township. The Towaco Formation forms a partial or semi-circular ring separating the older Preakness magmatic flows from the younger Hook Mountain Basalt mapped closer to the center of the township. It is very likely that the later Hook Mountain Basalt flows resulted in metamorphism of the Towaco Formation within a distance of 1000 feet of the contact between the units.

The Hook Mountain Basalt is another series of major volcanic magmatic flows resulting from the rifting of the Newark Basin. The Hook Mountain Basalt has been divided into two major flows and is described as light- to dark-green-gray, medium- to coarse-grained, amygdaloidal basalt. These flows may have a thickness of 360 feet (Drake et al. 1996) and are mapped beneath slightly more than 11 percent of the township.

The youngest consolidated rocks beneath Bernards Township are the sedimentary units of the Boonton Formation, which was also deposited in the Lower Jurassic in fluvial- and lacustrine-type environments (Olsen 1980). The Boonton Formation is described as red-brown to brown-purple, fine-grained sandstone, siltstone, and mudstone; interbedded micaceous sandstone with siltstone and mudstone; and red-gray and brown-purple siltstone with black, blocky, partly dolomitic siltstone and shale (Drake et al. 1996). The Boonton Formation may have a thickness of 1640 feet beneath the nearly 20 percent of Bernards Township beneath which, it has been mapped. This formation is found in the eastern portions of the township (see Figure 8).

Structure

Secondary Porosity

Consolidated rocks such as those encountered beneath Bernards Township generally do not have intergranular openings and therefore, do not have primary porosity for transmitting water. In these types of rocks, groundwater storage and transmittal are dependent on secondary porosity or openings between blocks of impermeable rock.

In sedimentary rocks such as shale, sandstone, siltstone, and mudstones, these secondary openings are associated with fractures along fault planes, joints, or bedding planes. In some Jurassic metamorphic rocks, relic bedding plane fractures may be encountered. In Jurassic basalt, columnar joints, pillow and pahoehoe structures, and interconnected vesicles formed from gas bubbles in the magma may provide for transmittal and storage of groundwater. In Precambrian igneous and metamorphic rocks, fractures from faulting may be the only openings between blocks of solid rock.

Faults

Between the Highlands and Piedmont Physiographic Provinces, faults formed as a result of past earthquakes associated with the Triassic-Jurassic rifting/opening of the Newark Basin. These faults are referred to as “border faults” and generally trend to the northeast from the southwest forming the boundary between the older Highlands Province rocks and the younger Piedmont Province. The Ramapo Fault, which closely follows portions of Route 206 in adjoining Bernardsville Borough through the township, is a border fault separating older Highlands Province rocks from younger Piedmont Province rocks. Along most of these border faults, the lower or southeastern block of younger rocks moved vertically downward with respect to the upper or northwestern block of older rocks and these types of faults are referred to as normal faults.

Splays of the Ramapo Fault and possibly the interbasinal Hopewell Fault have been mapped beneath Bernards Township. Local faults indicative of rifting are also apparent primarily in the northeastern portion of the township (see Figure 8). The rocks beneath the township have also experienced folding as a result of the tectonic expansion. The fold in the central portion of the township as well as all of the Jurassic sedimentary and igneous rocks have all been transected by faults indicating that movement continued after deposition, as the basin continued to expand. As would be expected given the relative strength of the sedimentary rocks in comparison to the harder igneous rocks, most of the fracturing along these faults occurred in the Towaco and Boonton Formations and to a much lesser extent in the Preakness Basalt.

Bedding/Jointing

In addition to the fractures formed as a result of local and regional faulting, two other sets of fractures may be encountered in Jurassic sedimentary rocks beneath the township. The first set is associated with bedding resulting from changes in the characteristics of the sediments at the time of deposition. Within the Jurassic sedimentary rocks, these bedding plane fractures generally strike to the northeast and gently dip to the northwest as a result of deposition in a subsiding basin. However, as a result of folding and faulting, in some areas beds will have significantly different strike and dip orientations. The strike of bedding will often serve as a strong controlling factor on the movement of groundwater and therefore, it is often necessary to evaluate site-specific or local bedding orientation data when evaluating groundwater flow and contaminant migration. Figure 8 does not depict bedding strike and dip data but some of the regional data as mapped by the USGS and NJGS is shown on the “Bedrock Geologic Map of Northern New Jersey” (Drake et al. 1996).

In some areas of the township, the metamorphic effects from the lava flows associated with the Preakness and Hook Mountain Basalts could have destroyed or eliminated residual bedding plane fractures in sections of the Feltville and Towaco Formations. Within the Precambrian metamorphic rocks, relic bedding has been destroyed and very few if any, bedding parallel fractures are observed in these rocks.

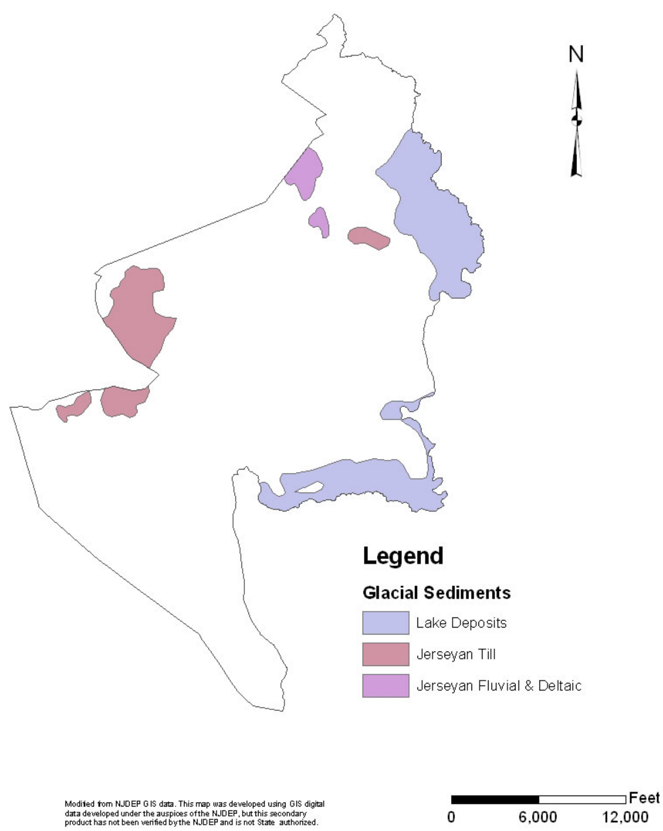
In addition to fault and bedding fractures, small scale joints may be encountered in weak sedimentary layers which were pulled apart as the continents separated. Often these fractures will have a vertical to near vertical orientation and will extend a few inches to a few feet across weaker layers primarily comprised of softer rocks but will quickly dissipate or terminate within more competent rocks. Depending on the proximity to regional or local fault systems and the brittleness of the rocks, the spacing between these vertical to near vertical joints will range from fractions of an inch to several tens or hundreds of feet. In some areas, the joints serve to interconnect fractured beds and in others, the beds interconnect joints.

In the basalts, columnar joints are likely to be present and formed as these extrusive magmas quickly cooled and contracted. Additional openings in these basalts may be between pahoehoe and/or pillow structures, or vesicles. The pahoehoe structures are rope-like flow features also caused by rapid cooling of the magma. The pillow features are generally caused by contact of the magma with water, which causes rapid contraction/shrinkage of the magma into pillow shapes. The vesicles are a result of gas bubbles in the magma from which the gas dissipates leaving behind a bubble shaped impression in the cooled rock. While the vesicles and/or openings between the pillows and pahoehoe structures can store water, unless these openings are connected to other openings or fractures, little if any of this water can be transmitted to wells or surface-water systems.

GLACIAL DEPOSITS

Subsequent to the Jurassic sedimentary activities and magmatic flows, fluvial and lacustrine materials have been deposited in portions of Bernards Township as a result of glacial activity within the past 100,000 years. Figure 9 shows the locations of glacial deposits.

Figure 9: Glacial Deposits Beneath Bernards Township, Somerset County, New Jersey.



Jerseyan fluvial and deltaic deposits and Jerseyan till are likely remnants of glacial activity that terminated approximately 100,000 years ago or more. The till materials are described by NJGS as primarily red-yellow to red-brown, clayey silt, with some sand, gravel, pebbles, and cobbles. Some localized basalt cobbles are likely present in these deposits beneath Bernards Township. The fluvial deposits are primarily red-yellow silt and clay with some pebbles and cobbles. The fluvial deposits may be as much as five feet thick and the till deposits may extend to 20 feet in thickness. The composition of these deposits, and the extents and thicknesses are not sufficient to serve as significant groundwater resources.

In addition to the older and thin Jerseyan till and fluvial deposits, there are significantly thicker Wisonsinan lacustrine (lake) deposits along the eastern border of the township and the Passaic River. These silt and clay lake deposits have been mapped by NJGS as having thicknesses near the river of more than 100 feet. Given the very fine-grained nature of these lake-bottom deposits, it is unlikely that they would serve as a significant groundwater resource. The thickest deposits are mapped along the Passaic River in Lord Stirling Park and near the Great Swamp National Wildlife Refuge and therefore, even if significant quantities of groundwater were available, it is unlikely that permission could be obtained to access these waters. Therefore, Bernards Township residents using groundwater are reliant on resources within the fractured bedrock aquifers underlying the township.

GROUNDWATER SYSTEMS

STORAGE AND TRANSMISSION CAPABILITY

Groundwater in bedrock aquifer systems is stored and transmitted in openings between blocks of impermeable rock. These openings include fractures, joints, and bedding planes. The availability of water is dependent on the separation between fractures, the degree to which these fractures are interconnected, and weathering of the materials between fractures. In some rocks, fractures are separated by a few inches of competent, unweathered, and impermeable bedrock. In others, the distance between fracture openings may be several feet to several tens of feet. In some areas such as near major regional faults, fractures form highly connected networks and therefore, more water can be stored and transmitted. In other areas, single or few fractures are available and the rock within these areas has little storage or transmission capability.

USGS studies indicate that weathering of fractured rock is greatest within 75 feet of ground surface and is negligible at depths greater than 500 feet below ground surface. Since weathering increases fracture size and may result in increased fracture interconnection, much of the yield, which is a measure of the volume of water that can be pumped from a well, may be derived from the shallow portion of the aquifer. In some formations, high yielding fractures may be intersected at depths exceeding 75 feet. However, in most rocks high yielding fractures are unlikely to be encountered at depths exceeding 150 feet.

In some bedrock aquifers, wells may be drilled to deeper depths because of the potential to encounter additional water-bearing fractures and therefore, to increase the yield. In bedrock aquifers where increased yields are unlikely, wells are usually drilled to depths exceeding 150 feet to store additional water for meeting peak-period needs such as in morning hours when residents are preparing for work and school. In the typical 6-inch diameter residential well, nearly 1.5 gallons can be stored for each extra foot of hole and this additional volume of water in storage may be necessary to meet peak-period demands each day.

PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS

Location

Precambrian igneous and metamorphic rocks are encountered beneath less than 1.5 percent or 225 acres of Bernards Township (see Figure 8). These rocks, some of which are more than 1 billion years old, have undergone several episodes of past tectonic deformation associated with continental collisions and separations. Although these rocks have been deformed, they are poorly fractured except at locations near major faults such as the Ramapo Fault. The Ramapo Fault separates the Precambrian rocks located to the northwest of the fault from Triassic-Jurassic of the Piedmont Province located to the southeast of the fault. Near border faults, the southeastern block moved downward with respect to the northwestern block and most of the fracturing is in these southeastern blocks. These normal faults were formed as a result of tensional forces pulling apart the Newark Basin.

In many areas of the Highlands Physiographic Province, Precambrian rocks have not been extensively fractured. The nature of these rocks allows for the attenuation of tectonic deformation within the minerals. These rocks generally behave in a plastic or malleable manner in comparison to more brittle sedimentary rocks such as shale. Because of the nature of the Precambrian igneous and metamorphic rocks, fractures not associated with major faults are often not highly interconnected or closely spaced.

Aquifer Characteristics

The 1966 report entitled "Geology and Ground Water Resources of Hunterdon County, N.J." prepared by Haig F. Kasabach provides data on well yields and specific capacities with respect to geologic formations. A similar study of Somerset County was not completed by New Jersey, although one was completed for nearby Morris County that evaluated large-capacity wells. The Morris County and Hunterdon County reports both indicate that Precambrian rocks are not good aquifers.

In his study, Kasabach (1966) indicates that Precambrian rocks are one of the poorest yielding aquifers. The 1996 New Jersey Statewide Water Supply Plan (NJDEP 1996) indicates that the Precambrian rocks are poor aquifers with low yields. In their ranking of bedrock aquifers of New Jersey, the NJGS indicates that Precambrian igneous and metamorphic rocks are poor aquifers with a rank of D. The NJGS rankings range from A through E with A indicating very good conditions and E indicating very poor yielding aquifers. The NJGS did not include the letter F in their rankings.

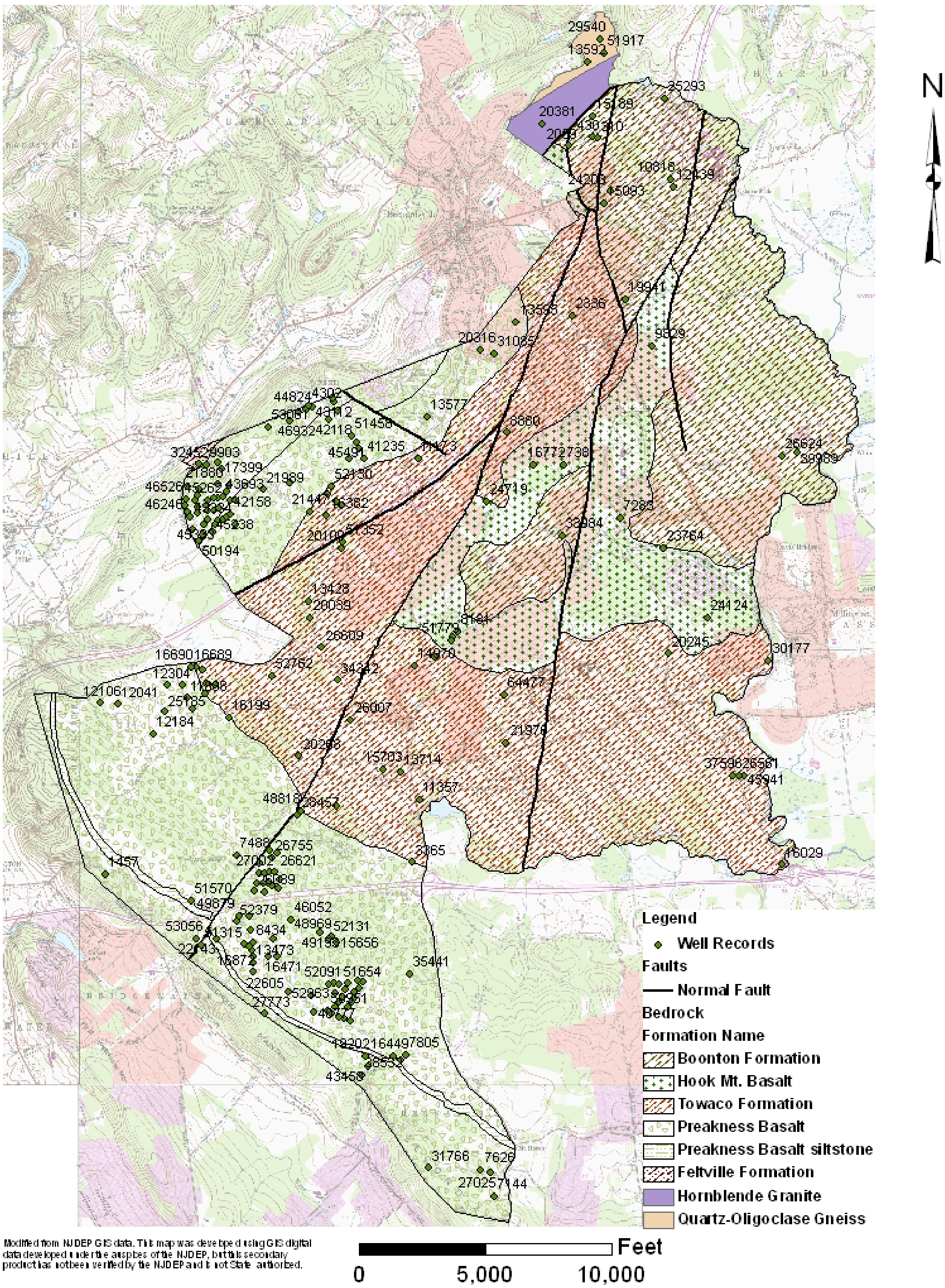
Generally, groundwater in the Precambrian rocks occurs under water-table conditions in areas where fractures are open to the overlying weathered residual soils and yields of wells completed near major faults or streams are usually greater than wells completed distant from these features (Kasabach 1966). In areas where fractures are distant from each other or not interconnected, each fracture could have a differing water level.

The yield of a well is primarily 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 fractures intersected by the well extend to the stream or fault where additional water can be stored and transmitted. Within Hunterdon County, Kasabach (1966) indicates that based on 203 wells completed in the Precambrian rocks, yields range from 0 to 66 gallons per minute (gpm) with a median yield of 15 gpm.

While studies of wells and aquifers were conducted in the mid-1960s by the State of New Jersey in Morris and Hunterdon Counties, a contemporaneous study of wells and aquifers within Somerset County was not completed. Therefore, records for wells completed in Bernards Township were obtained from the NJDEP-Bureau of Water Allocation database in October and November 2007. Initially, records for more than 266 wells were reviewed and used to prepare a database. Based on the well records, it was determined that some of these wells were located in Bernardsville Borough or other nearby municipalities and not in Bernards Township. Sufficient data was available on well records to reasonably locate 214 wells within the township. The available data used in locating wells included block and lot numbers, street addresses, and New Jersey State atlas grid locations. The locations of these 214 wells are shown on Figure 10 and the data from these well records are provided in Appendix B.

Water: A Natural Renewable Resource

Figure 10: Wells From Which NJDEP Well Records Are Available in Bernards Township, Somerset County, New Jersey.



Modified from 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.

Of the 214 well records, only four are for wells completed within the Precambrian rocks. These wells range in depth from 185 to 360 feet with a median depth of 223 feet below ground surface. Yields range from 6 to 30 gpm with a median yield of 17.5 gpm. Static water levels range from 2 feet above to 35 feet below ground surface.

The specific capacity of a well is the yield of the well divided by the change in water level (a.k.a. drawdown) induced by pumping. This parameter can be used to develop reasonable approximations of an aquifer's capability to transmit water for comparison to other aquifers within a region (Driscoll 1986). Data in the 1966 Kasabach report indicates that specific capacities for 124 wells in Hunterdon County completed in Precambrian rocks range from 0 to 8.3 gallons per minute per foot of drawdown (gpm/ft) with an average of 0.83 gpm/ft.

Two of the four wells in Bernards Township for which a well record was available, provided some pumping test data. These data indicated a median and average specific capacity of 0.35 gpm/ft or less than half the average value determined by Kasabach (1966) for these rocks. The data for the four wells for which a well record was available, indicate that these wells are sufficient to meet the needs of single-family homes and that the Precambrian rocks beneath the township are poorly transmissive. These data indicate findings similar to those made by Kasabach (1966) with respect to the poor aquifer characteristics of the Precambrian rocks.

FELTVILLE FORMATION

Location

The Feltville Formation is the oldest of the Jurassic rocks mapped beneath Bernards Township and these rocks encompass less than 17 acres or 0.12 percent of the land area within the municipal borders. The Feltville Formation has been mapped by the USGS and NJGS near the Mine Brook portion of the township along the western municipal boundary.

Aquifer Characteristics

Given the limited extent of the Feltville Formation beneath Bernards Township, it is not considered a major groundwater resource. Of the 214 well records obtained for the township, only one well was located within the very small area where these rocks have been mapped along Mine Brook Road. This well was completed to 330 feet below ground surface in 1988 with a reported yield of 10 gpm. The initial static water level at the time of installation was 20 feet below ground surface and the specific capacity determined after 4 hours of pumping was 0.05 gpm/ft. The specific capacity of the well indicates a poorly transmissive aquifer.

PREAKNESS BASALT

Location

The Preakness Basalt and the interbedded siltstone have been mapped beneath nearly 32 percent or more than 4900 acres of Bernards Township primarily along the western and southern portions (see Figure 8 or 10). The Preakness Basalt has been separated into three distinct major flows of magma from volcanoes that once formed the Watchung Mountains. The thin (6 to 30 feet) siltstone unit separates the two lower or older flows. The thickness of these basalts beneath Bernards Township may range between 800 to nearly 1100 feet (Drake et al. 1996).

Aquifer Characteristics

The NJGS mapping of bedrock aquifers indicates that basalt has a ranking of D indicating a poor yielding aquifer system. Of the 214 well records obtained from NJDEP for Bernards Township, 151 of these records were for wells completed in the Preakness Basalt. Data from these well records indicate well depths that range from 60 to 1,125 feet below ground surface. The median depth of wells completed in the Preakness Basalt beneath Bernards Township is 400 feet below ground surface.

Data from the well records indicate yields for wells completed in the Preakness Basalt range from 1 to 150 gpm with a median yield of 12 gpm. Static water levels recorded at the time of installation range from 0 to 280 feet below ground surface with a median depth to water of 40 feet below ground surface.

Of the 118 well records with sufficient pumping test data to determine specific capacities, values of this aquifer characteristic ranged from 0.0012 to 2.5 gpm/ft with a median value of 0.054 gpm/ft. The data from these wells indicate that the Preakness Basalt aquifer system is very poorly transmissive and has few interconnected fractures that can store and transmit water.

As indicated above, Kasabach (1966) considered the Precambrian rocks to be a poor aquifer with limited ability to transmit and store groundwater. The specific capacity he determined for the Precambrian aquifer from well records was 0.83 gpm/ft or more than one order of magnitude greater than the median specific capacity determined for the Preakness Basalt beneath Bernards Township. The data from the well records indicate that while the Preakness Basalt may be capable of providing sufficient water to meet the needs of individual single-family homes, it is not a significant resource capable of meeting larger-scale demands.

Water: A Natural Renewable Resource

TOWACO FORMATION

Location

The Towaco Formation is the second oldest sedimentary rock beneath Bernards Township and has been mapped beneath nearly 36 percent of the land area or approximately 5500 acres within the municipal boundaries. The Towaco Formation is mapped beneath the central portion of the township beneath Stone House, Lyons Hospital, Liberty Corner and along Interstate 287 to Basking Ridge and Madisonville. The Towaco Formation was deposited during a period of relative volcanic inactivity and may have a thickness of as much as 1250 feet beneath Bernards Township. The rocks of this unit are comprised of red-brown to purple-brown, fine- to medium-grained micaceous sandstone, siltstone, and silty mudstone deposited in fluvial and lacustrine environments in the Lower Jurassic (Olsen 1980).

Aquifer Characteristics

The Feltville, Towaco, and Boonton Formations as well as the Preakness and Hook Mountain Basalts were not evaluated by Kasabach (1966) because these units are not widely found within Hunterdon County. These rocks were not evaluated beneath Morris County also because of limited extent. These sedimentary units and basalts have not been extensively studied as groundwater resources in New Jersey because of limited extent and/or the presence of much greater resources nearby. Herman (2001) includes these units as the “Watchung Zone” in the “Brunswick Aquifer” and further indicates that evaluation of this aquifer must focus on local data as the aquifer cannot be considered a regional system. Herman (2001) indicates that the Watchung Zone is primarily confined to the area along the Watchung Mountains.

The local data from the well records for Bernards Township indicate that the Towaco Formation is perhaps the best groundwater resource within the township but one of limited capacity to transmit groundwater. Of the 214 well records reviewed, 35 were for wells completed in the Towaco Formation. These wells range in depth from 97 to 400 feet below ground surface with a median depth of 190 feet below ground surface. Yields range from 7.5 to 400 gpm with a median yield of 22 gpm. The median depth of wells completed in the Towaco Formation beneath Bernards Township is less than one-half the median depth of wells completed in the Preakness Basalt. The median yield of wells completed in the Towaco Formation beneath the township is nearly twice the median yield of wells completed in the Preakness Basalt.

Water levels measured at the time of well installation range from 3.5 to 79 feet below ground surface with a median static level of 30 feet below ground surface. The median specific capacity for wells completed in the Towaco Formation is 0.52 gpm/ft or an order of magnitude greater than median specific capacity for the Preakness Basalt.

Hook Mountain Basalt

Location

The Hook Mountain Basalt has been mapped beneath the portion of Bernards Township extending from north of the Veterans Administration hospital to the east of Basking Ridge. These rocks were formed by two magmatic flows associated with Newark Basin rifting. These flows may have a thickness of 360 feet (Drake et al. 1996) and are mapped beneath slightly more than 11 percent or nearly 1800 acres of the township.

Aquifer Characteristics

Similar to the Feltville and Towaco Formations and the Preakness Basalt, there has been very limited evaluation of the water-bearing resources of the Hook Mountain Basalt. Within New Jersey, this basalt has a much smaller mapped extent when compared to the older Preakness Basalt beneath Second Watchung Mountain.

Local data obtained from 10 records for wells completed in the Hook Mountain Basalt beneath Bernards Township indicate completed depths range from 85 to 800 feet below ground surface with a median depth of 156 feet below ground surface. Yields range from 1 to 40 gpm with a median yield of 15 gpm. Water levels measured at the time of well installation range from 0 to 150 feet below ground surface with a median depth to water of 30 feet below ground surface.

Six well records provided pumping test data that can be used to determine specific capacities. These data indicate specific capacities ranging from 0.002 to 1.25 gpm/ft with a median value of 0.14 gpm/ft. The data suggest that the Hook Mountain Basalt may be a slightly better groundwater resource than the older and more-widespread Preakness Basalt but should be considered a poor to very poor aquifer with limited fracture interconnection for storage and transmittal of groundwater.

Boonton Formation

Location

The youngest consolidated rocks beneath Bernards Township are the sedimentary units of the Boonton Formation, which was also deposited in the Lower Jurassic in fluvial- and lacustrine-type environments (Olsen 1980). The Boonton Formation is described as red-brown to brown-purple, fine-grained sandstone, siltstone, and mudstone; interbedded micaceous sandstone with siltstone and mudstone; and red-gray and brown-purple siltstone with black, blocky, partly dolomitic siltstone and shale (Drake et al. 1996). The Boonton Formation may have a thickness of 1640 feet beneath the nearly 20 percent or more than 3000 acres of Bernards Township where it has been mapped. This formation is found in the eastern portions of the township (see Figure 8 or 10).

Aquifer Characteristics

Thirteen well records were obtained from the NJDEP database for wells completed within the areas of Bernards Township underlain by the Boonton Formation. These records indicate well depths ranging from 50 to 360 feet below ground surface with a median depth of 160 feet below ground surface. Yields of these wells range from 3.5 to 100 gpm with a median yield of 21 gpm. Water levels at the time of installation ranged from 6 to 40 feet below ground surface with a median depth to water of 23 feet below ground surface. Specific capacities determined from the 11 well records that provide pumping test data indicate values ranging from 0.08 to 13.3 gpm/ft with a median specific capacity of 0.5 gpm/ft.

HYDROGEOLOGIC ZONES

The following table provides a summary of the bedrock aquifer characteristics determined from the 214 well records obtained for Bernards Township. The data indicate that wells must be drilled to significantly greater depths in the areas of the township underlain by the Preakness Basalt than other bedrock units.

Table 4: Median Depths, Yields, Water Levels, and Specific Capacities

Bedrock Unit	Number of Available Well Records	Completed Depth (feet)	Yield (gpm)	Static Water Level (fbgs)	Specific Capacity (gpm/ft)	Specific Capacity per foot of Open Hole (gpm/ft/ft)
Precambrian Rocks	4	223	17.5	2.5	0.347	2.53E-03
Feltville Formation	1	330	10	20	0.050	1.79E-04
Preakness Basalt	151	400	12	40	0.054	1.80E-04
Towaco Formation	35	190	22	30	0.515	4.45E-03
Hook Mountain Basalt	10	156	15	30	0.137	1.19E-03
Boonton Formation	13	160	21	23	0.500	8.05E-03

These data also indicate that the two sedimentary formations (Towaco and Boonton) yield 40 to 75 percent more water to wells than the Preakness and Hook Mountain Basalts. The depth to water in the areas of the township underlain by Preakness Basalt is also likely deeper than in other areas.

One measure for evaluating differences between hydrogeologic units developed by the USGS (Lewis-Brown 1995) is the parameter of specific capacity per foot of open hole interval. 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 (likely to be 350 feet in the first formation and 150 feet in the second formation), a significant difference between the formations is often apparent. In the above data, the Boonton Formation and the Towaco Formation have similar specific capacities and yields. However, when the depth of the open hole interval of the wells is considered, the Boonton Formation appears to have a nearly twice the capacity to transmit water than the Towaco Formation.

When the median specific capacities per foot of open hole for all of the bedrock units beneath Bernards Township are considered, the data clearly indicate that the Preakness Basalt has a very low capacity to transmit water by at least one order of magnitude. The Feltville Formation apparently has a poor capacity to transmit water beneath the township but the values summarized in the above table for this formation are based on one well and the Feltville Formation is likely present beneath less than 17 acres within the township. Furthermore, the Feltville Formation beneath the township was very likely to have been metamorphosed by the later Preakness Basalts.

The Hook Mountain Basalt also has limited capacity to transmit groundwater in comparison to the Towaco and Boonton Formations. As indicated above, in his evaluation of groundwater resources of Hunterdon County, Kasabach (1966) considered the Precambrian igneous and metamorphic rocks to be poor aquifers. When the specific capacities from Bernards Township are compared to the Kasabach (1966) specific capacity for the Precambrian rocks, it is apparent that the ability of these rocks beneath Bernards Township to transmit water is significantly lower than beneath Hunterdon County. The Preakness and Hook Mountain Basalts and Feltville Formation should be considered very poor aquifers as they have much less capacity to transmit water beneath Bernards Township than the Precambrian rocks.

Diabase, which is geochemically similar to basalt and was contemporaneously emplaced, has long been considered one of the poorest aquifer systems in the Piedmont Province of New Jersey as indicated by Kasabach (1966) and Widmer (1965). Lewis-Brown (1995) evaluated diabase aquifers in Mercer and parts of Somerset County and determined a median specific capacity per foot of open hole interval of 1.4×10^{-3} (1.4E-03) gpm/ft/ft. Based on the Lewis-Brown (1995) analyses, the Hook Mountain Basalt has similar capacity to transmit water as diabase. However, the Preakness Basalt beneath Bernards Township has much less capacity by at least an order of magnitude, to transmit water than the diabase studied by Lewis-Brown (1995).

Lewis-Brown (1995) also evaluated Triassic-Jurassic sedimentary rocks deposited as the Newark Basin expanded but prior to the deposition of the Towaco and Boonton Formations. The data from the Lewis-Brown (1995) study indicate that the Stockton and Passaic Formations in Mercer and southern Somerset Counties have median specific capacities per foot of open hole interval that are similar to those determined for the Towaco and Boonton Formations beneath Bernards Township. The data for wells completed in the Stockton Formation and Passaic Formation indicate median values of 5.45×10^{-3} and 3.93×10^{-3} gpm/ft/ft, respectively. The Stockton and Passaic Formations are considered to be good bedrock aquifers that can in some highly fractured areas, yield more than 100 gpm.

Based on the data from Bernards Township when compared to other areas of New Jersey underlain by diabase or Precambrian rocks, the basalts beneath the township must be considered poor to very poor aquifers with limited capacity to transmit water. The areas underlain by the Towaco and Boonton Formations should be considered to be underlain by better bedrock aquifer systems, especially near faults.

The township could be divided into hydrogeologic zones with the Preakness Basalt and adjacent 17 acres underlain by Feltville Formation considered to have very limited groundwater resource capacity. The areas of the township underlain by Hook Mountain Basalt and Precambrian igneous and metamorphic rocks could be considered a second zone with only slightly greater capacity to serve as groundwater resources. The Towaco and Boonton Formations could be considered to be underlain by better bedrock aquifers capable of yielding larger quantities of water, especially near faults.

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 living organisms 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 the perennial or seasonal subsurface-saturated zone through which, it slowly migrates to a stream. This component is most obvious during dry periods where it maintains baseflow in streams.

Each of these general components; evapotranspiration, surface-water runoff, and groundwater runoff, can be further subdivided. Groundwater runoff includes the portion of precipitation that sufficiently infiltrates soils and bedrock to enter an aquifer system where it can be used as a water-supply resource for residents of Bernards Township. However, the groundwater runoff parameter also includes water in shallow wet and sometimes saturated zones such as wetlands, floodplains, and stream banks that slowly migrates to a stream but does not enter an aquifer where it could be used as a groundwater-supply resource. Where a water balance can be used to assess percentages of annual precipitation that evaporate or transpire, runoff the ground surface, or runoff through the subsurface, more detailed analyses are necessary to ascertain the portion of precipitation that actually infiltrates to an aquifer and becomes groundwater.

Similar to the capacities to transmit and yield water, the recharge capability of a bedrock aquifer is dependent on the frequency and intensity of fractures, the size of the fracture openings, the interconnection of these openings to each other and to ground surface or other saturated media, and the depth of weathering. Bedrock units with the greatest frequency/intensity of fracture openings interconnected to each other and the ground surface and/or saturated media will have low surface-water runoff rates and high aquifer recharge rates. Weakly fractured bedrock will have high surface-water runoff rates and low aquifer recharge rates.

For example, carbonate rocks because of the frequency and interconnection of solution cavities will have very high groundwater recharge rates whereas, igneous and metamorphic rocks because they are usually very poorly fractured will have very low groundwater recharge rates. Nicholson et al. (1996) in a study of the aquifer systems in Long Valley determined that the recharge rate to the carbonate rock aquifer system was as much as 22 inches per year or 44 percent of incident precipitation. Whereas, with the Precambrian igneous and metamorphic rocks beneath the ridges (a.k.a. uplands) on either side of the valley, Nicholson (1996) determined that very little incident precipitation was capable of infiltrating because of the shallow nature of the fracture systems in these rocks. These researchers concluded the following:

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

Based on the computer simulations of Long Valley, Nicholson et al. (1996) defined the natural boundary for the aquifer systems within the valley at the contact between the highly recharged carbonate rocks and the very poorly recharged Precambrian rocks. These researchers identified this contact between the rock-types as a no flow boundary and then proceeded to prepare a simple water balance to develop approximations of evapotranspiration, surface-water runoff and groundwater runoff.

A similar condition was defined by Lewis-Brown (1995) in the evaluation of the Triassic-Jurassic rocks beneath the Stony Brook, Beden Brook, and Jacobs Creek basins in Mercer and southern Somerset Counties. These researchers determined that very little incident precipitation infiltrated the diabase, which because of its dense, hard, and poorly fractured nature is found beneath the higher elevations much like the basalt beneath Bernards Township. Precipitation quickly ran off the diabase surface to nearby streams with some infiltrating into the sedimentary Passaic and Stockton Formations at lower elevations. Lewis-Brown (1995) determined from computer modeling that uphill of the Hopewell Fault, precipitation quickly ran off the ground surface and infiltrated within the highly fractured zone along the fault trace.

Beneath Bernards Township, given the poorly fractured nature and higher elevations of the areas underlain by Precambrian igneous and metamorphic rocks and the Preakness and Hook Mountain Basalts, it is very likely that much of incident precipitation will runoff the ground surface or at very shallow depths along the bedrock surface and not infiltrate to the aquifer systems in these rocks. Within the lower elevations underlain by the Towaco and Boonton Formations, and especially, near faults zones, a much higher percentage of incident precipitation is likely to infiltrate into the bedrock aquifers of these sedimentary units.

PRECIPITATION

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

Bedrock aquifers are replenished by incident precipitation that infiltrates through soils into fractures and other openings in the rock. Rough estimates have been developed that 10 to 25 percent of incident precipitation infiltrates through soils and recharges groundwater in fractured bedrock aquifers (Kasabach 1966). The research in Long Valley shows that in some rock types, recharge will far exceed the 25 percent limit, whereas, in other rocks it is well below the 10 percent limit suggested by Kasabach. The Lewis-Brown (1995) study indicates that within areas underlain by Triassic-Jurassic igneous, metamorphic, and sedimentary rocks similar to those mapped beneath Bernards Township, groundwater runoff rates will range between 7 and 18 percent of precipitation. Studies by Hordon (1984, 1987, 1995) and Posten (1984) indicate that the recharge component of groundwater runoff is likely to be approximately 4 percent of precipitation in areas underlain by Jurassic igneous and metamorphic rocks.

Although recharge rates are highly dependent on bedrock type, a water balance can provide general approximations for an area that can serve to test assumptions made to indirectly determine hydrologic parameters such as aquifer recharge that are not as easily measured as precipitation.

Based on historical precipitation measurements collected by the National Climatic Data Center (NCDC) for the past 40 years at the Pottersville 2NNW station and 122 years at the Somerville 4NW station, Bernards Township receives approximately 50.5 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 rainfall than average and April, May, June, July, August, and September receiving slightly more than average precipitation.

The Pottersville 2NNW station is located approximately 9.8 miles west-northwest, and the Somerville 4NW station is located approximately 8.2 miles southwest of the center of Basking Ridge. The data from these stations indicate that the northern portion of Bernards Township likely receives more precipitation than the southern portion. The precipitation data for the two NCDC stations and as averaged for Bernards Township from these stations are summarized as follows in Table 5:

Table 5: Normal Precipitation Calculated for Bernards Township From NCDC Normals for Somerville and Pottersville.

Month	Pottersville 2NNW (inches)	Somerville 4NW (inches)	Bernards Township (inches)
January	4.22	4.01	4.12
February	2.90	2.85	2.88
March	4.02	3.93	3.98
April	4.61	4.00	4.31
May	5.21	4.34	4.78
June	4.97	3.98	4.48
July	5.29	4.63	4.96
August	4.42	4.39	4.41
September	5.03	4.58	4.81
October	4.02	3.69	3.86
November	4.51	3.70	4.11
December	4.08	3.61	3.85
Totals:	53.28	47.71	50.50

Using the water balance of the hydrologic cycle, precipitation equals the sum of groundwater runoff, evapotranspiration, and surface runoff. If an area has one or more large water bodies with respect to total surface area, direct precipitation to this body and the resulting evaporation from this body, should also be included in the water balance. However, for Bernards Township, water bodies encompass approximately 44 acres or less than 0.3 percent of the township (see Table 2) and therefore, precipitation to and evaporation from these water bodies are not considered significant with respect to the township's overall water resources.

The water balance is often described by the following equation:

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

Where:

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

SURFACE-WATER RUNOFF

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

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

In areas of Bernards Township, with dense, hard, poorly weathered bedrock; few fractures; hilly terrains; and steep slopes; stream channels will start at high elevations. In these areas, the slopes provide sufficient gradient to induce surface-water runoff and the low permeability of the bedrock limits the infiltration capacity. As a result, groundwater in the underlying bedrock aquifer systems is not significantly recharged and the water quickly runs off the land surface or throughflows immediately below the ground surface often along the top of bedrock to the nearest stream channel.

Based on soils mapping completed by USDA-NRCS, approximately 27 percent of the township has slopes less than 2 percent and much of these areas contain wetlands or can be flooded and therefore, are not significant groundwater recharge zones. Slopes beneath approximately 33 percent of the township are equal to or exceed 6 percent, which is sufficient to promote surface-water runoff in lieu of groundwater recharge. Furthermore, nearly 73 percent of the soils beneath Bernards Township are considered to have a hydrologic soil group code of C or D. These types of soils have very low infiltration rates and therefore, would have high rates of surface-water runoff. Soils and slopes beneath much of Bernards Township promote surface-water runoff in lieu of groundwater recharge.

The study completed by the USGS in Long Valley (Nicholson 1996) included areas underlain by Precambrian igneous and metamorphic rocks. Nicholson et al. (1996) indicated that groundwater recharge to the Precambrian rocks was “negligible” and therefore, most incident precipitation ran off to local streams. In a separate USGS study (Lewis-Brown 1995) within the Piedmont Physiographic Province, in areas underlain by Jurassic igneous and metamorphic rocks, the results indicate surface-water runoff rates of nearly 36 percent of annual precipitation. In the lowland areas underlain by unmetamorphosed Triassic-Jurassic sedimentary rocks, surface-water runoff rates of 24 percent of annual precipitation were calculated (Lewis-Brown 1995).

Based on the geologic and hydrogeologic conditions beneath Bernards Township, a rate of 36 percent of annual precipitation or 18.2 inches per year is most likely an underestimate of surface-water runoff from the Precambrian and Jurassic igneous and metamorphic rocks. A rate of 24 percent or 12.3 inches per year is likely in areas underlain by Towaco and Boonton Formations.

EVAPOTRANSPIRATION

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

Evapotranspiration is greatest during summer months because of higher temperatures and active growth of plants and trees. During the winter months, evapotranspiration in northern New Jersey is usually negligible. Evapotranspiration is the largest component of the water balance and may account for the return to the atmosphere of approximately 50 to 67 percent of annual precipitation in New Jersey.

In the USGS (Nicholson 1996) study of Long Valley, a potential evapotranspiration rate of 25 inches per year or 50 percent of annual precipitation was determined. In the Mercer/southern Somerset County study, evapotranspiration was approximately 27 inches per year or 60 percent of annual precipitation (Lewis-Brown 1995). In both of these studies, 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 evapotranspiration for New Jersey.

Mean temperature data are not available for the Pottersville 2NNW climatic data station. Temperature data from the Somerville 4NW station have been collected by NCDC for the past 119 years and were used by this agency to determine normal temperatures. Based on the Somerville 4NW station, monthly and annual normal temperatures for Bernard Township are summarized as follows:

Table 6: Normal Temperature and Potential Evapotranspiration for Bernards Township, Somerset County.

Month	Somerville 4NW (degrees Fahrenheit)	Potential Evapotranspiration (inches)
January	28.0	0.0
February	30.2	0.0
March	38.8	0.5
April	48.9	1.6
May	59.1	3.3
June	67.9	4.7
July	73.2	5.6
August	71.5	4.9
September	63.9	3.3
October	52.2	1.8
November	42.9	0.7
December	33.3	0.0
Annual:	50.8	26.4

Based on the normal temperatures as determined by the NCDC for the Somerville 4NW station and using the Thornthwaite Method, approximately 26.4 inches of annual precipitation can be returned to the atmosphere by vegetation within Bernards Township. Potential evapotranspiration as determined with the Thornthwaite Method will overestimate actual evapotranspiration as the method assumes water is always available within the root zone. During dry weather, water may not always be available within the root zone to permit evapotranspiration.

GROUNDWATER RUNOFF

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

Equation 1 can be rearranged to develop estimates of groundwater runoff for Bernards Township. In Equation 1, P equals 50.5 inches per year; SW equals 18.2 inches per year in areas of steep slopes and hard, dense bedrock and 12.3 inches per year in areas underlain by the Towaco and Boonton Formations; and ET equals 26.4 inches per year. Based on these values, GW, or groundwater runoff parameter is approximately 5.9 inches per year in areas underlain by igneous and metamorphic rocks and closer to 11.8 inches per year in areas underlain by unmetamorphosed Jurassic sedimentary rocks.

Some portion of the water included in the groundwater runoff parameter in the water-balance equation includes water captured and stored in wetlands systems, flood plain soils, stream banks and other shallow sources that are distinct from the bedrock aquifers used as groundwater-supply resources for township residents. Further detailed analyses of hydrogeologic data are necessary to determine how much groundwater runoff provides groundwater recharge to the aquifer systems beneath the township.

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

Groundwater Recharge Methods

GROUNDWATER

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

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

Water must enter a fully and perennially saturated zone also known as an aquifer system to be available as a water resource exploitable with wells. In New Jersey, steel casing must be installed to a minimum depth of 50 feet below ground surface to prevent shallow water from entering a 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 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 rates with respect to Bernards Township because if the water does not enter a saturated aquifer system, it cannot be used for water supply by residents.

BASEFLOW

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

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

These 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.

Streamflow data are separated into "quick flow" or water draining an area shortly after a precipitation event from "delayed flow" or water draining the area on a more-regular basis. Although the rate of delayed flow is significantly dependent on the rate of quick flow in this method, the author assumed that delayed flow is equal to baseflow.

Posten (1984) developed this method to reduce the number of "personal judgments" and therefore, reduce potential overestimates of groundwater recharge. A study of groundwater recharge rates in New Jersey conducted by Canace et al. (1992) indicates that the Posten (1984) Method does result in lower recharge rates than 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.

7Q10/MA7CD10

Baseflow can be determined from streamflow records during periods of prolonged dry weather when shallow water sources such as floodplain soils, wetlands, stream banks and perched zones have dried and are either minimally, or no longer significantly contributing to streamflow. During these periods, stream flows will approach an asymptote as groundwater discharging from the underlying aquifer systems becomes the primary or only source of water in the stream channel. The asymptote is the equilibrium rate of groundwater recharge that was achieved in prior years.

One method that can be applied to determine the baseflow asymptote is to graphically depict streamflow data and determine the mean lowest flow rate for 7 consecutive days during a 10 year period. The method used to determine the seven consecutive days of lowest flow that may be expected to occur once during a ten-year interval is referred to in New Jersey as the MA7CD10 and by the USGS and others as 7Q10 or M7_10. In the 1996 document entitled "Vital Resource, New Jersey Statewide Water Supply Plan", the NJDEP states the following:

> "From a regulatory perspective, low stream flow, or base flow (the groundwater contribution to a stream), serves as the primary criterion for managing New Jersey's water resources. The most common stream discharge employed for this purpose is the MA7CD10, or the seven consecutive days of lowest flow that may be expected to occur once during a ten-year interval."

The USGS indicates that there is a ten-percent chance the 7Q10 streamflow will occur in any one year. With respect to floods, planning is based on a 1 percent chance in any one year or a recurrence interval of 1 in 100 years. In planning for water supply, using a recurrence interval of 1 in 10 years is reasonable but not conservative. Based on data compiled by the NCDC, New Jersey experienced four droughts of several years in length in the past 100 years and experienced at least one short-term drought every decade since 1900.

Using the 7Q10 to identify the groundwater discharge asymptote and therefore, assess water-supply resources may be considered conservative by some because the lowest flow occurs during periods of extensive dry weather. However, it is highly likely that this method will provide the most reliable approach for ensuring adequate and safe water supplies because it is the least biased measure of groundwater discharge. During extensive periods of dry weather, water contributions from shallow resources such as bank-storage, wetlands, and floodplains have been significantly reduced or eliminated and therefore, it can be reasonably assumed that all or nearly all flow in the stream under these conditions is derived from the underlying aquifer systems and baseflow can be primarily attributed to groundwater discharge.

NJGS MODIFIED METHOD

AQUIFER VERSUS "GROUNDWATER" RECHARGE

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

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

Based on traditional hydrogeologic definitions, the results of the NJGS method should be referred to as soil recharge rates as opposed to groundwater or aquifer recharge rates. As indicated in the textbook Groundwater (Freeze & Cherry 1979) "(t)he term groundwater is usually reserved for the subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated." In Bernards Township and elsewhere in Somerset County, 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 or aquifer upon which residents are reliant for water supply. With the exception of few references to groundwater recharge within quotation marks in this section of the report, the terms aquifer recharge and groundwater recharge have the same definition and refer to water that infiltrates to an aquifer system. The term soil recharge will be used in reference to rates determined with the NJGS Modified Method.

Soil Recharge Rates

Although the soil recharge rates calculated with the NJGS method are not appropriate for evaluating groundwater recharge or water-supply availability for Bernards Township, they are summarized in Table 7 for comparison purposes to other methods and because they are sometimes presented to Township Planning Boards as supporting evidence that adequate groundwater is available. The soil recharge rates summarized in Table 7 were calculated with the NJGS method using a Microsoft Excel Workbook (Hoffman 2002) for the soils mapped in Bernards Township and assuming the current antidegradation standard for the target concentration of nitrate.

Table 7: Soil Recharge and Nitrate Dilution Calculations Made with NJDEP Model DGS02-06 for Soil Types in Bernards Township, Somerset County, New Jersey.

Soil Type	Soil Recharge Rate (inches per year)	Recharge Area per Septic System (acres)
Amwell	13.3	2.1
Birdsboro	14.9	1.9
Bowmansville	Hydric soil, method not applicable	
Califon	12.7	2.2
Croton	Hydric soil, method not applicable	
Fluvaquents	Hydric soil, method not applicable	
Klinesville	14.6	1.9
Lansdowne	12.9	2.1
Mount Lucas	12.4	2.2
Neshaminy	15.2	1.8
Neshaminy variant	12.6	2.2
Norton	13.1	2.1
Parker	15.2	1.9
Parsippany	Hydric soil, method not applicable	
Parsippany variant	Hydric soil, method not applicable	
Penn	12.9	2.2
Quarry	Method not applicable	
Raritan	12.8	2.2
Reaville	12.9	2.2
Riverhead	15.1	1.9
Rowland	12.3	2.2
Udifluvents	12.3	2.2
Watchung	Hydric soil, method not applicable	
Whippany	13.0	2.1

Based on the soil types and climatic conditions of Bernards Township, soil recharge rates ranging from 12.3 to 15.2 inches per year were calculated with the NJGS method for the general soils where this method can be applied. Some of the highest rates of soil recharge were calculated for areas underlain by the poorly fractured Preakness Basalt and local streamflow data clearly show these rates are not substantiated. Other highly recharged soils are located near rock outcrops and steep sloping areas, where it would be expected that because of impervious materials and steep gradients associated with the rock and/or steep slopes, surface-water runoff rates would be highest and recharge rates lowest. The NJGS method cannot be used to calculate soil recharge rates for several soils associated with wetlands, open water, hydric soils, or for the quarry.

Based on the poor to very poor aquifer characteristics, steep slopes, low infiltration rates for soils beneath the township, and 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 groundwater resources beneath Bernards Township. Based on geologic conditions of the township, the soil recharge rates calculated with the NJGS method are not reliable for assessing groundwater resources.

Groundwater Recharge Rates

PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCKS

The USGS (Nicholson 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 some residential wells completed in these rocks.

To assess recharge rates to the Precambrian igneous and metamorphic rocks in Bernards Township, the 7Q10 flow rates of streams primarily or entirely underlain by Precambrian rocks and flowing through Bernards Township or nearby municipalities were evaluated. In addition, streamflow data for two streams underlain entirely by Precambrian rocks as well as data from one stream flowing through Bernards Township underlain primarily by Precambrian rocks were evaluated using the Posten (1984) Method to determine an upper limit to the groundwater recharge range.

There are no streams flowing in or immediately adjacent to Bernards Township monitored by USGS that are completely underlain by Precambrian rocks. USGS Station No. 01378690 (Passaic River near Bernardsville) is located in Bernards Township at the point at which, the Passaic River flows beneath US Highway 202 approximately 1.8 miles northeast of Bernardsville. Upgradient of the stream gauge, approximately 0.4 mi^2 of the 8.83 mi^2 basin is underlain by the Jurassic Boonton and Hook Mountain Basalt and the remainder is underlain by Precambrian igneous and metamorphic rocks. The USGS also indicates a number of ponds along this stream system. Based on USGS topographic maps, ponds encompassing at least 38.4 acres are present within the basin with many of these ponds located within the channel.

The streamflow data compiled by USGS indicate that the 7Q10 for the Passaic River near Bernardsville is 1.4 cubic feet per second (cfs), which is equivalent to 102,500 gallons per day per square mile (gpd/mi^2) or 160 gpd/acre. This measurement is likely skewed high by the presence of the ponds, which can maintain flows in the streams during short-term dry weather periods either through discharges to the stream or to shallow groundwater as water levels in the underlying aquifer decline.

Near Bernards Township the USGS has determined 7Q10 values for Spruce Run at Glen Gardner and Upper Cold Brook near Pottersville. The data for Spruce Run and Upper Cold Brook were selected because both of these drainage basins upgradient of the USGS measuring station are entirely underlain by Precambrian rocks. The size and the 7Q10 flow rates as determined by the USGS (2005) for these two basins and the Passaic River near Bernardsville station are summarized as follows:

Stream Station	Basin Size (mi^2)	7Q10 (cfs)	Potential Recharge (gpd/mi^2)	(gpd/acre)	(inpy)
Passaic River near Bernardsville	8.83	1.4	102,500	160	2.15
Spruce Run at Glen Gardner	11.3	1.5	85,800	134	1.8
Upper Cold Brook near Pottersville	2.18	0.2	59,300	93	1.25

If the flows during the dry weather conditions represented by the 7Q10 measurements were entirely derived from groundwater discharging from underlying aquifers, then potential groundwater recharge rates ranging from 1.25 to 2.15 inches per year (inpy) are calculated. These data indicate that groundwater in Precambrian rocks in northern Hunterdon and Somerset Counties is recharged at a median rate of 1.8 inches per year.

The Posten (1984) Method was used 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. Although there is significant storage in ponds to alter results upstream of the gauging station and the Passaic River near Bernardsville is not entirely underlain by Precambrian rocks, data for water years 1968 to 1976 for this gauge were analyzed with the Posten (1984) Method.

The Posten (1984) Method was used to separate quickflow from "delayed flow", which was then graphically plotted on arithmetic probability paper to determine the "safe yield" of the aquifer as defined by Posten (1984). The delayed flow rate from the arithmetic probability graph at the 99th percentile of exceedence probability is assumed by Posten (1984) to equal to the "safe yield" of the aquifer. Posten (1984) assumed that water withdrawn at a rate equal to the "safe yield" would not result in long- or short-term impacts to an aquifer system. Posten (1984) developed his method to determine the volume of water that could be "rationally exploited" from an aquifer without causing undesirable effects to the aquifer.

The Posten (1984) Method uses a fundamental hydrograph separation method to separate the quickflow and "delayed flow" components of streamflow records. Although Posten (1984) attempted to reduce potential errors with his approach, since it continues to rely on a simple hydrograph separation, the method continues to be susceptible to errors resulting from observer and method bias and from discharges other than from the underlying aquifer system. The resulting delayed flow rates and the potential "safe yield" are in most probability overestimates of the volume of water that can be safely withdrawn after entering a groundwater system.

In accordance with the method outlined by Posten (1984) the "safe yields" for the Precambrian igneous and metamorphic rocks as determined for Passaic River near Bernardsville, Spruce Run at Glen Gardner, and Upper Cold Brook near Pottersville are as follows:

Stream Station	Basin Size (mi^2)	Posten (1984) Method Safe Yield (mgd/mi^2)	(gpd/acre)	(inpy)
Passaic River near Bernardsville	8.83	0.120	188	2.5
Spruce Run at Glen Gardner	11.3	0.145	226	3.0
Upper Cold Brook near Pottersville	2.18	0.162	254	3.4

The results from the Posten (1984) Method analyses of the streamflow data for the Passaic River near Bernardsville indicate a safe yield that is nearly equal to the potential groundwater recharge rate determined from the 7Q10 parameter for this same stream (2.5 versus 2.15 inches per year). Whereas, the safe yields calculated for Spruce Run at Glen Gardner and Upper Cold Brook near Pottersville with the Posten (1984) Method are 66 to 172 percent greater than the potential recharge rates calculated with the 7Q10 values (3.0 versus 1.8 inches per year and 3.4 versus 1.25 inches per year, respectively). The results of the Posten (1984) Method analyses of the flow data for these streams is provided in Appendix C.

As indicated by Halford (2000), Posten (1984), and Sloto et al. (1996), hydrograph separation methods can result in significant overestimates of groundwater recharge because of the inherent difficulties of separating surface-water runoff and shallow subsurface system discharges from actual groundwater discharges. And, the Posten (1984) Method is a very simple hydrograph separation technique. The 7Q10 measurements are likely more reliable since the measured discharges are essentially entirely derived from the bedrock aquifer systems since short-term dry weather conditions associated with these measurements have reduced if not eliminated discharges from shallow and surface sources.

JURASSIC IGNEOUS AND METAMORPHIC ROCKS

There are no streams in Bernards Township entirely underlain by Jurassic basalts or related metamorphosed rocks for which the USGS has streamflow data. Harrisons Brook at Liberty Corner and the Dead River near Millington, New Jersey are evaluated by USGS but these streams are underlain by the Preakness and Hook Mountain Basalts and the Towaco and Boonton Formations to varying extents and there is no way to separate contributions to streamflow from areas underlain by the basalts and metamorphosed rocks from those made in areas underlain by sedimentary rocks.

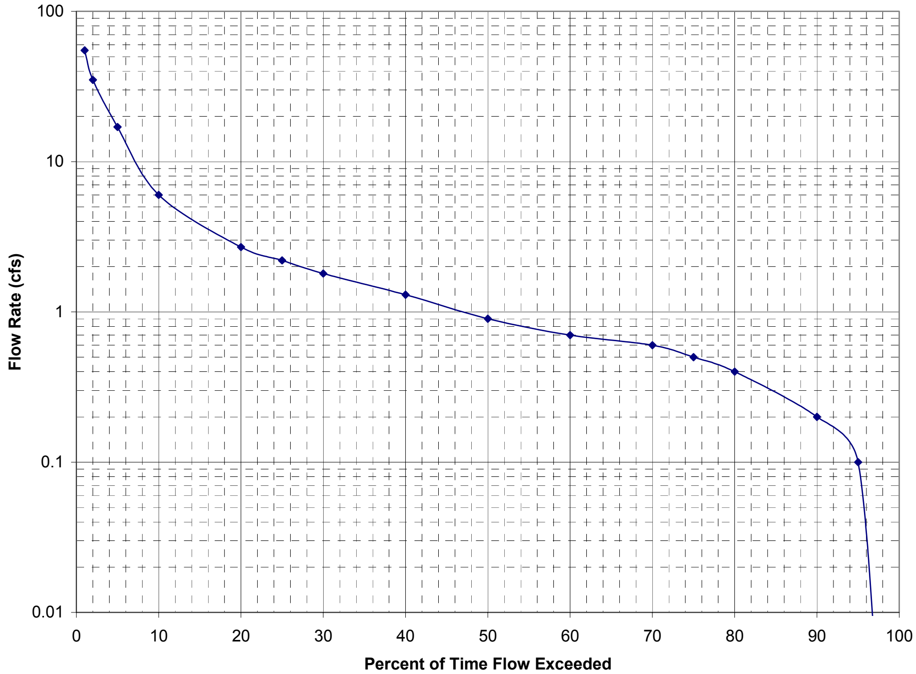
The nearest streams underlain by basalts and likely metamorphosed sedimentary rocks are the East and West Branches of Middle Brook in the Martinsville section of Bridgewater Township. The drainage areas to these streams are underlain by the Orange Mountain Basalt, Feltville Formation, and Preakness Basalt. The Orange Mountain Basalt forms the core of First Watchung Mountain and the saddle between this mountain and Second Watchung Mountain in Bernards Township is primarily underlain by the Feltville Formation. The core of the Second Watchung Mountain is underlain by Preakness Basalt. The Orange Mountain Basalt and Feltville Formation were emplaced in the Jurassic prior to the Preakness Basalt and younger rocks mapped beneath Bernards Township.

In addition to data from the two branches of Middle Brook, the USGS (Lewis-Brown 1995) and others (Hordon 1984, 1987, 1995 and Posten 1984) conducted groundwater resource evaluations in areas underlain by geochemically similar rocks (diabase versus basalt) in other areas of Somerset County and northern Mercer County, and western Hunterdon County. Given the very similar characteristics of the Jurassic igneous rocks in these areas, the data from these studies can be used to further evaluate recharge to the basalts and metamorphic rocks beneath Bernards Township. It should be noted that given the high relief and therefore, steep gradients of areas underlain by diabase or basalt, there are very few, if any, streams monitored by USGS that are entirely underlain by these rocks. As a result, it is necessary to use data from streams that are partially underlain by these igneous rocks as well as those that have been metamorphosed as a result of their emplacement and in most cases, sedimentary rocks that have been unaffected by the igneous rocks.

The USGS (2005) reports 7Q10 values for the West and East Branches of Middle Brook as 0.0 and 0.20 cfs, respectively. The drainage area to the West Branch gauge is 1.99 mi^2 and to the East Branch is 8.45 mi^2. The 7Q10 measurement for the East Branch indicates an annual groundwater recharge rate of 0.32 inches per year. The data for the West Branch indicates that the stream has very limited storage and that the bedrock aquifer systems in the underlying basalts and metamorphosed Feltville Formation are quickly depleted in dry weather every year, to elevations below the stream gauge. These data indicate that groundwater resources of the basalts can be quickly depleted.

The limited storage of bedrock systems beneath the West Branch of Middle Brook drainage basin is apparent on Figure 11, which is a flow duration curve developed from USGS (2005) streamflow statistics. A rapid decline in flow rate is apparent on the right-hand side of the graph indicating very limited groundwater discharges. These streamflow data indicate that as shallow and near ground surface sources of water deplete and water levels are lowered in the underlying aquifers, discharges to the stream decline rapidly. Aquifers with poor storage and transmission capability can be quickly mined or dewatered when pumped at rates exceeding recharge. It should be noted that the USGS data indicate that the recurrence interval for no flow in the West Branch is once per year, which is further indication of the limited storage capability of basalt aquifers near Bernards Township.

Figure 11: Flow Duration Curve for West Branch of Middle Brook



The USGS has daily discharge data for the West Branch of Middle Brook near Martinsville for water years 1980 through 2007. These data were evaluated with the Posten (1984) Method to determine the "safe yield" of the basalts and associated metamorphosed rocks near Bernards Township. The results of the Posten (1984) Method analyses indicate a safe yield of 0.044 mgd/mi^2 or 69 gpd/acre or 0.93 inches per year. The result of the Posten (1984) Method analyses are provided in Appendix C.

The local streamflow data indicate that the basalts within the Watchung Mountains and the related metamorphosed rocks are very poorly recharged and have limited storage capacity. As discussed above in the section on local well data for the Hook Mountain and Preakness Basalts, these rocks have very limited ability to transmit water, which indicates that these rocks are not extensively fractured and those fractures that do exist, are not widely connected to other fractures.

In addition to the local data from the West Branch of Middle Brook, data from the USGS studies of the Stony Brook, Beden Brook and Jacobs Creek indicate that diabase, which is a contemporaneous and geochemically similar rock to the basalts is very poorly recharged. The USGS (Lewis-Brown 1995) determined that the groundwater runoff rate within areas underlain by diabase was 37.5 percent of the groundwater runoff rate in areas of unmetamorphosed Triassic-Jurassic sedimentary rocks. The data from the Lewis-Brown (1995) study indicates that groundwater runoff rates in drier weather range from 0.25 to 2.29 inches per year in streams underlain by diabase. The median groundwater runoff rate of the three streams monitored is 1.31 inches per year. Groundwater recharge rates would be lower.

Hordon (1984 and 1987) conducted studies in Sourland Mountain, which is located in Somerset, Mercer, and Hunterdon Counties, and in Delaware Township in Hunterdon County. These studies were conducted in areas underlain by Jurassic diabase and Triassic Lockatong Formation, which is a poorly recharged sedimentary rock slightly older than those mapped beneath Bernards Township. Posten (1984) also conducted a study in a part of Hunterdon County underlain by diabase and Lockatong Formation when he was developing his analytical method for determining safe yields.

In some portions of the areas studied by Hordon (1984 and 1987) and Posten (1984), the sedimentary beds of the Lockatong Formation have been altered to hornfels by the diabase intrusions. The primary difference between diabase and basalt is that diabase is intruded or injected into fractures or openings in the subsurface whereas, basalts are magmatic flows discharged from volcanoes that migrate over the land surface. One is an intrusive and the other an extrusive magma. Both rocks are considered igneous since they originate as magmas or molten rock and both essentially, have very similar mineralogy. Because diabase is intruded into the subsurface, the magma cools much slower and therefore, may have a wider radiated extent of metamorphism. Whereas, basalts, which flow overland and often into bodies of water, are cooled more rapidly but will have a metamorphic effect as a result of the heat, on sedimentary rocks that the flows contact.

Hordon's (1984) report on groundwater management for Sourland Mountain indicates the safe yield for diabase ranging from 0.84 to 1.7 inches per year. In his study in Delaware Township, Hordon (1987) did not separate recharge to the diabase from the Lockatong Formation since these two rock-types are adjacent and within the same drainage basin much like the basalts and Feltville Formation are adjacent and in the same drainage basin beneath Bernards Township and the West and East Branches of Middle Brook. Based on the Hordon (1987) study, the safe yield of the Jurassic diabase and nearby metamorphosed rock is approximately 1.7 inches per year. Posten (1984) determined from his study of streamflow data for Walnut Brook near Flemington, New Jersey that the safe yield for the diabase and metamorphosed Lockatong Formation rocks beneath this drainage basin was 0.092 mgd/mi^2 or 1.9 inches per year.

Summarizing, local streamflow data, and the analyses completed by Posten (1984) for Walnut Brook and Hordon (1987) for Delaware Township indicate the following potential safe yields:

Data Source	Basin Size (mi^2)	Safe Yield (mgd/mi^2)	(gpd/acre)	(inpy)
West Branch Middle Brook (Posten (1984) Method analysis)	1.99	0.044	69	0.93
East Branch Middle Brook (7Q10)	8.45	0.015	24	0.32
Posten (1984) Walnut Brook	11.3	0.092	144	1.94
Hordon (1987)		0.080	125	1.68

It must be noted that all of these study areas include significant portions of sedimentary rocks, some of which may have been metamorphosed but likely not all. For example, the areas studied by both Posten (1984) and Hordon (1987) (Walnut Brook and Lockatong Creek, respectively) are primarily underlain by Lockatong Formation and the diabase is present in only a small area. Data from streams such as Royce Brook tributary near Frankfort or Belle Mead, or Honey Branch near Pennington, and Baldwins Creek at Baldwins Lake near Pennington show that sedimentary rocks near Jurassic igneous rocks have very limited storage for groundwater. These data indicate that water-bearing zones within Jurassic igneous and metamorphic rocks must be very poorly recharged.

Given the limited groundwater transmission capability, especially of the Preakness Basalt but also of the Hook Mountain Basalt as evidenced by local well data, and the poor storage capacity of aquifers in Triassic-Jurassic igneous and metamorphic rocks, groundwater resources within the basalts beneath Bernards Township are in most probability, severely limited. To prevent mining and long-term adverse impacts to these highly limited resources, withdrawals should be measured with respect to some percentage of groundwater recharge. The local data from the two branches of Middle Brook should be the gauge used in these measurements and these data indicate that safe yields likely range between 0.32 and 0.93 inches per year or 24 to 69 gallons per day per acre.

JURASSIC SEDIMENTARY ROCKS

The USGS does not have any continuous streamflow monitoring stations within Bernards Township in areas that would not be affected by discharges from the Great Swamp and the thick glacial deposits beneath and to the northeast of this national wildlife refuge. The USGS has two low-flow partial record stations with one on Harrisons Brook near Liberty Corner (bridge on Lyons Road) and the second on the Dead River near Millington (bridge on King George Road).

The drainage basin for Harrisons Brook upstream of the Liberty Corner measuring station is underlain by Preakness and Hook Mountain Basalt, and the Feltville, Towaco and Boonton Formations. The drainage basin for Dead River near Millington is located downstream of the Harrison Brook station and therefore, is underlain by the same rocks beneath the Harrison Brook basin but is primarily underlain by Preakness Basalt and Towaco Formation in the southern and western parts of the basin. The drainage areas, 7Q10 measurements, and potential groundwater recharge rates calculated from the 7Q10 measurements are as follows:

Stream Station	Basin Size (mi^2)	7Q10 (cfs)	Potential Recharge (gpd/mi^2)	Potential Recharge (gpd/acre)	Potential Recharge (inpy)
Harrisons Brook at Liberty Corner	3.74	0.1	17,300	27	0.36
Dead River near Millington	20.8	1.3	40,400	63	0.85

While there are no daily streamflow data for either of these locations to further evaluate hydrogeologic conditions within the drainage basins, the low-flow data (USGS 2005) are indicative of limited storage capacity and discharge from underlying aquifer systems. The streamflow statistics for both of these gauges are significantly lower than the three listed above that are underlain by Precambrian rocks or the East Branch of Middle Brook. Dry weather flows, which are essentially entirely derived from groundwater discharges, in the Dead River and Harrisons Brook in Bernards Township are very small. Since groundwater discharges are equal to groundwater recharge, it must be assumed that very little water infiltrates into the bedrock aquifers beneath the township.

While local streamflow data would provide the best data for an evaluation of recharge rates to the Towaco and Boonton Formations rocks beneath Bernards Township, there are not sufficient data from Harrisons Brook or Dead River to separate contributions from these sedimentary rocks from those provided by the lower permeability basalts and metamorphic rocks. Therefore, it may be necessary to use studies completed by the USGS in other areas of the Newark Basin to evaluate recharge rates and safe yields for the Jurassic sedimentary rocks beneath Bernards Township. However, these rates should be used cautiously with respect to Bernards Township given that the available streamflow data indicate very limited groundwater recharge and discharge volumes.

The USGS has conducted two extensive studies of the Stony Brook, Beden Brook, and Jacobs Creek drainage basins (Jacobsen 1993 and Lewis-Brown 1995) located in southern Somerset and Hunterdon Counties and northern Mercer County. These stream basins are underlain by the Triassic-Jurassic Passaic Formation, Triassic Stockton and Lockatong Formations, and Jurassic diabase. Data from the Jacobsen (1993) study were used to prepare a computer model during the Lewis-Brown (1995) study. This model was calibrated to simulate hydrogeologic conditions within the three basins and the results indicated that during years of normal precipitation, groundwater runoff within the three basins averaged 8.58 inches per year. Recharge rates are much lower and the USGS model indicated rates of 0.5 inches per year (6 percent of the total runoff) infiltrated to deeper water-bearing zones typically used for water supply purposes. The remaining 94 percent of the groundwater runoff remained in shallow layers and flowed to the nearest streams.

The computer model was used to better define groundwater runoff rates to the Stony Brook, Beden Brook, and Jacobs Creek basins and indicated that these rates are approximately 8.25, 9.11, and 8.11 inches per year, respectively. The computer model determined that the Beden Brook basin had the highest rate of groundwater runoff because of the Hopewell Fault near Hopewell Borough. Groundwater runoff in the less fractured Stony Brook and Jacob’s Creek basins was lower. These rates are averages for the basins, which are underlain by four Triassic-Jurassic rock types with the Passaic Formation as the predominant rock type beneath all three basins. All groundwater runoff rates determined with the USGS model were based on normal-year precipitation. And, since these are groundwater runoff rates, they include discharges from shallow sources in addition to the discharges from aquifers.

The average groundwater runoff rate to all three basins would not be appropriate for Bernards Township because the stream discharge data indicate that an area of high intensity faulting similar to the Hopewell Fault near Hopewell Borough is not encountered beneath Bernards Township. A groundwater runoff rate ranging from 8.11 to 8.25 inches per year for the Passaic Formation rocks may serve as upper limits to the range for the sedimentary rocks beneath Bernards Township. This range is similar to the results of a second USGS study of hydrogeologic conditions within the Newark Basin, which indicate a groundwater runoff rate of 8.3 inches per year to an area underlain by Triassic Lockatong Formation and Triassic-Jurassic Passaic Formation (Senior 1999). The groundwater runoff rates determined from these two USGS studies are for sedimentary rocks deposited before the extensive volcanism observed in Bernards Township. The metamorphic effects of this volcanism on the sedimentary rocks within the township must be extensive based on the very limited discharges to streams originating and flowing through the central corridor of the municipality.

In summary, local streamflow data indicate that the Jurassic rocks beneath Bernards Township are poorly recharged. However, there are no local streamflow data that can be used to evaluate recharge specific to the sedimentary rocks of the Towaco and Boonton Formations, which combined underlie nearly 56 percent of the township. Based on local well data, the groundwater resources of the Towaco and Boonton Formations beneath Bernards Township are comparable to the Passaic Formation beneath the Stony Brook and Jacobs Creek basins in Mercer and Hunterdon Counties. However, based on streamflow data, these rocks do not discharge much water and therefore, must not be highly recharged.

Based on computer modeling of hydrogeologic conditions beneath the Stony Brook and Jacobs Creek basins completed by USGS, normal year groundwater runoff rates of 8.2 inches per year can be expected. Further based on the USGS model, the recharge component to deep (greater than 50 to 150 feet) portions of these sedimentary bedrock layers is likely 6 percent of the total or 0.5 inches per year.

WATER SUPPLY

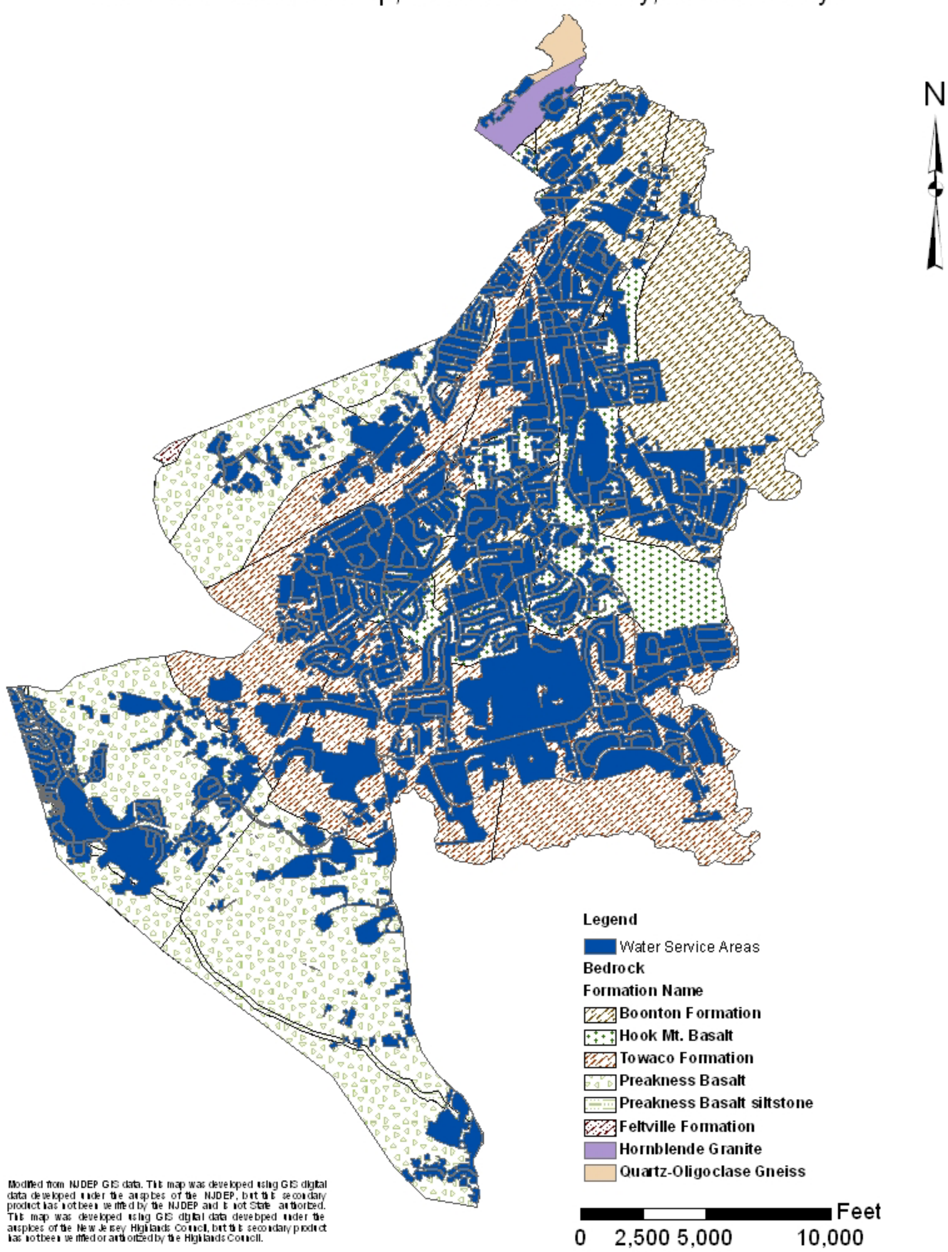
DEMAND

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

Based on US Census data for 2000, Bernards Township has 24,575 residents living in 9,242 dwelling units. These census data indicate a dwelling unit density of 2.7 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, Bernards Township residents currently consume approximately 2.46 million gallons per day or 897 million gallons of water per year.

Based on mapping of water service areas developed by the New Jersey Highlands Council as of March 22, 2007 and provided in GIS format, approximately 38 percent (5,766 acres) of the land area of Bernards Township is provided with potable water by New Jersey American Water Co. (NJAWC). Figure 12 depicts the water service areas within the township as overlain on the bedrock geology.

Figure 12: Water Service Area with respect to Bedrock Geology of Bernards Township, Somerset County, New Jersey.



Based on the mapping of the water service areas within the municipality, large areas of Bernards Township underlain by the Preakness Basalt are currently not provided potable water by NJAWC. Additionally, areas underlain by the Precambrian igneous and metamorphic rocks, Hook Mountain Basalt and the Feltville, Towaco and Boonton Formations are currently not provided water by NJAWC. Large parcels within the area not provided water by NJAWC that is underlain by the Boonton Formation include Lord Stirling Park, Basking Ridge Country Club, and the Verizon office complex.

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-1960's with 1962 to 1966 recording below normal precipitation equal to approximately 82 percent of normal precipitation. In 1965, New Jersey received approximately 30 inches of precipitation, which is two-thirds of normal precipitation and that year was the most severe year of the drought.

Drought Effects and Recharge

Drought conditions can alter the hydrologic water balance for an area depending on the time of year the precipitation shortfall occurs. During the winter months, a precipitation shortfall will adversely impact groundwater recharge and to a lesser degree, surface-water runoff. Evapotranspiration is negligible in winter months so this parameter is generally unaffected by precipitation shortfalls during cold weather. During summer months, precipitation shortages adversely impact evapotranspiration and surface-water runoff. Groundwater recharge is naturally reduced during the summer when most precipitation is rapidly consumed by vegetation and generally, this parameter is not 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.

Based on stream discharge measurements compiled by the USGS in the Passaic River near Millington from December 1, 1903 to September 30, 1979, the median daily flow rate was 47 cfs. After 1979, the USGS indicates that flow was regulated for flooding and the median daily flow rate increased to 53 cfs. This river drains 55.4 mi^2 of varying geology including the Great Swamp Natural Wildlife Refuge and thick glacial aquifers located to the east and northeast. For the water years 1962 through 1966, the median flow rate was 17 cfs or 36 percent of normal flow for the period of record prior to flood control. These streamflow data suggest that if prolonged drought conditions equally affect all water-balance parameters, that groundwater recharge during the “Drought of Record” was reduced by 64 percent to this basin.

Although groundwater in storage within an aquifer is used to buffer short-term drought, if groundwater recharge were reduced 64 percent by a multi-year drought, this limited resource could be quickly depleted resulting in adverse long-term impacts to the aquifer system. Therefore, a reasonable margin of safety is necessary to ensure adequate water supplies in a repeat of the “Drought of Record”.

As discussed above, the 7Q10 Method, as part of determining groundwater recharge rates takes into consideration baseflow derived mostly if not entirely from aquifer systems. Therefore, the recharge rate determined with this method would likely not require reduction to account for lower precipitation to determine a maintainable yield provided that it is understood that the recurrence interval for the dry weather conditions associated with the 7Q10 measurement is 10 years and not 100 years. A drought with a recurrence interval of 100 years like the “Drought of Record” would very likely have a lower recharge rate than calculated with the 7Q10 measurement.

The Posten (1984) Methods as part of the graphical analyses associated with percent exceedence and flow 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 dependable yields.

The computer model used in the study by Lewis-Brown (1995) used normal precipitation conditions when determining groundwater runoff. As a result, adjustments for reduced precipitation during a drought must be made for groundwater runoff rates determined with this model. Local streamflow data for the Dead River and Harrisons Brook clearly indicate that the combined bedrock aquifers beneath the township have very limited storage and are poorly replenished. Therefore, it is not only necessary to account for drought but also the difference between groundwater runoff and actual recharge to water-supply aquifers.

The data for the much larger Passaic River as measured at Millington show that a major drought such as the “Drought of Record” results in a more than 60 percent reduction in daily median flows. It should be noted that the short-term (4 month) Summer drought of 1999 resulted in median daily flows of 6.2 cfs or less than 12 percent of the median daily flow for the period from 1979 through 2007. The local stream flow data are clear indication that short- or long-term droughts have a significant impact on all water resources within the Passaic River basin including the bedrock aquifers beneath Bernards Township. These data show that very little water discharges to the river

Water: A Natural Renewable Resource

systems within the township and upstream municipalities during dry weather which, indicates that very little water recharged the aquifers in the months and years prior.

The water resources of the Passaic River basin are quickly stressed by drought and given the hydrogeologic conditions of Bernards Township, normal year groundwater runoff rates must be reduced by at least 64 percent to account for drought recharge as required by the definition of dependable yield. Based on the USGS computer model, which indicated a groundwater runoff rate for Triassic-Jurassic sedimentary rocks of 8.2 inches per year during periods of normal precipitation, a recharge rate to the shallow portions of this aquifer during drought likely does not exceed 2.95 inches per year.

It is likely that during drought, recharge to the deeper portions of the sedimentary bedrock aquifers would remain 0.5 inches per year as modeled by the USGS, as water from shallower portions would continue to leak to deeper units for some period of time. The thickness of the shallow portion of the aquifer and therefore, the water availability and length of time that the leakage will continue are essentially entirely dependent on the extent and depth of fracturing. In poorly fractured areas, drainage from the shallow zone will stop quickly (days to months) and groundwater will be removed from storage within the deeper aquifer. Once this water is removed, well yields will diminish if not cease and portions of the aquifer may not recover and water quality may diminish. In highly fractured zones near faults, additional water is available in the shallow zone so the rate of depletion will be slower.

Recharge rates developed in consideration of drought conditions for the bedrock aquifers beneath Bernards Township are summarized as follows:

Formation	Area of Township Underlain by Rock Type (acres)	Recharge Rates (inpy)	Recharge Rates (gpd/acre)
Precambrian igneous and metamorphic rocks	224.5	1.8	134
		2.5	188
Preakness and Hook Mountain Basalts (includes	6724.4	0.32	24
Feltville Formation)		0.93	69
Towaco and Boonton Formations -shallow	8534.4	2.95	219
Towaco and Boonton Formations -deep		0.50	37

Planning Threshold

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

Formation	Planning Threshold Dependable Yield (inpy)	(gpd/acre)
Precambrian igneous and metamorphic rocks	0.4	27
	0.5	38
Preakness and Hook Mountain Basalts (includes	0.1	5
Feltville Formation)	0.2	14
Towaco and Boonton Formations -shallow	0.6	44
Towaco and Boonton Formations -deep	0.1	7

Dwelling Unit Densities

Based on US Census data for 2000, Bernards Township has a dwelling unit density of 2.7 persons. Based on this density and water-supply demands listed in N.J.A.C 7:10-12.6, each existing dwelling unit consumes approximately 270 gpd.

To ensure adequate water resources are available to meet the needs of each home, the Planning Threshold dependable yields can be divided into the average daily demand (270 gallons) for each home to determine the recharge area needed per dwelling unit. These calculations are summarized as follows:

Formation	Recharge Area per Dwelling Unit (acres)
Precambrian igneous and metamorphic rocks	10
	7
Preakness and Hook Mountain Basalts (includes	54
Feltville Formation)	19
Towaco and Boonton Formations -shallow	6

Since the deep portion of the Towaco and Boonton Formations is dependent on leakage from the shallow portion, the recharge area needed for a dwelling unit would be dependent on the shallow aquifer system. The data indicate that in the northern portion of the township underlain by Precambrian rocks, recharge areas of 7 to 10 acres are necessary to maintain the water-supply demands of each house. Within the areas of the basalts, given the very poor recharge characteristics much larger areas ranging from 19 to as much as 54 acres are necessary to meet the demands of a single-family home. Within the areas underlain by the sedimentary Towaco and Boonton Formations, 6 acres of recharge area per lot are needed.

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

Recharge to open sections of parcels (those not covered with impervious surfaces) in portions of Bernards Township provided with public water could be included within a dwelling unit recharge area for a parcel requiring a well, provided that the open parcel section is upgradient of the dwelling unit, within the same local watershed, and not separated by a stream or other surface-water discharge point. The property requiring the well should be able to receive groundwater flowing from the parcel using public water. Similarly, preserved open space upgradient of a well could serve as a recharge area to the well provided that the open space is upgradient and in the same local subwatershed, and not separated by a stream or surface-water discharge from the well.

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

Sewer Service Area

The Highlands Council has mapped sewer service areas within in its planning area including Bernards Township. Based on mapping completed on March 22, 2007 and

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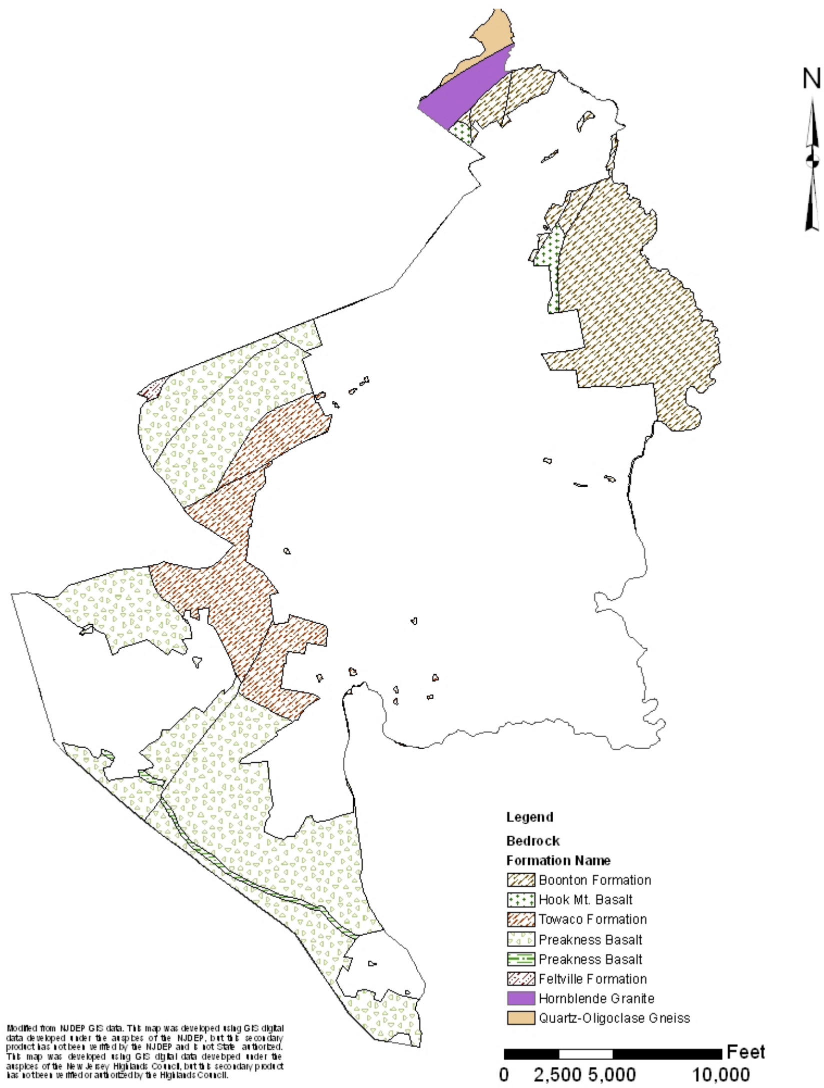
provided through the Council’s GIS database, slightly less than 4200 acres or 27 percent of the township has sewer service. However, mapping prepared by Bernards Township and provided by the Engineering Department indicates that nearly 9800 acres or 63 percent of the land area within the municipal boundaries is within a designated sewer service area under the jurisdiction of the Bernards Township Sewerage Authority.

The bedrock beneath sections of the township that are not located within a designated sewer service area is shown on Figure 13.

Figure 13: Bedrock Geology for Areas Outside Designated Sewer Service Areas of Bernards Township, Somerset County, New Jersey.



The portions of the township underlain by Precambrian rocks to the north are not within a designated sewer service area as are nearly 3000 acres of the township along the western and southern borders that are underlain by Preakness Basalt. Slightly less than 1000 acres or 18 percent of the township that is underlain by the Towaco Formation is outside a designated sewer service area. Approximately 75 acres in the northern portion of the township underlain by Hook Mountain Basalt is outside a sewer service area. Slightly more than 1400 acres underlain by the Boonton Formation is not located within a designated sewer service area and more than 77 percent of this area is Lord Stirling Park and Basking Ridge Country Club.

Properties within the nearly 5700 acres of Bernards Township outside a designated sewer service area primarily rely on septic systems for the disposal of wastewater. The following sections of the report addressing nitrate dilution and recharge area requirements to dilute septic system contaminants are for these properties not currently located within a designated sewer service area or properties within the designated sewer service areas that are not provided sanitary sewer service by one of the local treatment facilities.

NITRATE DILUTION

Nitrate

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

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

Existing Regulations

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

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

The NJGS (Hoffman 2001) summarized analytical data for samples throughout New Jersey and these data indicate that background concentrations of nitrate in groundwater within the Newark Basin range from 0.1 to 7.4 mg/l with a median concentration of 1.6 mg/l. Within the Highlands Province and Precambrian igneous and metamorphic rocks, the NJGS summary indicates nitrate concentrations ranging from less than 0.01 to 4.7 mg/l with a median concentration of 0.76 mg/l.

In the nearly 225 acres underlain by Precambrian rocks, the NJDEP antidegradation standard would permit nitrate concentrations to rise from the current background median concentration of 0.76 mg/l to 5.4 mg/l. In the remaining portions of Bernards Township underlain by Jurassic rocks, the antidegradation policy would permit nitrate concentrations to increase from the current median of 1.6 mg/l to 5.8 mg/l. Under current NJDEP policy, the target concentration for diluting nitrates in septic system discharges is 5.4 mg/l for the Precambrian rocks and 5.8 mg/l for the Jurassic rocks.

Proposed Regulations

On October 4, 2005 NJDEP adopted N.J.A.C 7:9C, which recodified and amended N.J.A.C 7:9-6. These recodified regulations did not change the antidegradation policy, which was listed as N.J.A.C 7:9C-1.8, for Class II-A waters.

On July 2, 2007, NJDEP proposed to repeal and adopt a new rule for N.J.A.C 7:9-1.8. Two months prior, on May 21, 2007, NJDEP proposed to readopt N.J.A.C 7:15 Water Quality Management Planning Rules. Together these two proposed sets of regulations require as part of wastewater management planning, for septic system densities that will limit nitrate concentrations to 2 mg/l. Based on these new regulations, instead of the target concentrations of 5.4 and 5.8 mg/l to ensure adequate dilution, the new target is 2 mg/l for nitrate dilution in a watershed.

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 nearly 30 years when evaluating potential nitrate discharges from septic systems to groundwater and for determining the recharge areas necessary to dilute nitrate concentrations. The model continues to be used by the NJDEP when evaluating septic system impacts.

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

Nitrates 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 nearly all of the township is underlain by soils with severe limitations for septic systems, these soils are unlikely to prevent nitrates or other contaminants from impacting groundwater used for water supply. Therefore, adequate recharge is necessary to dilute the concentration of contaminants to safe drinking conditions.

ASSUMPTIONS

Similar to the water-supply evaluation discussed above, the Trela-Douglas model was applied to Bernards Township to evaluate existing needs based on current demographics of 2.7 persons per dwelling unit. The Trela-Douglas nitrate dilution model is based on several assumptions, which for Bernards Township include the following:

1. The groundwater use rate is 100 gallons per day per person and 2.7 persons occupy each existing residence. These assumptions are the same assumptions used in determining recharge areas for water supply use. Therefore, groundwater use per dwelling unit is 270 gpd.

2. The aquifer recharge ranges for the geologic formations are summarized as follows and were the same as those used in the water-supply evaluation. Drought recharge rates are applied to ensure that nitrate and other septic contaminants are adequately diluted during and extended drought similar to the "Drought of Record".

Formation	Recharge Rates (inpy)	(gpd/acre)
Precambrian igneous and metamorphic rocks	1.8	134
	2.5	188
Preakness and Hook Mountain Basalts (includes	0.32	24
Feltville Formation)	0.93	69
Towaco and Boonton Formations -shallow	2.95	219

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

4. The nitrate concentration at the boundary of the recharge area, which is in accordance with the NJDEP's current antidegradation policy for Class II-A groundwater as adopted October 4, 2005 in N.J.A.C 7:9C. These values are 5.4 mg/l for the Precambrian rocks and 5.8 mg/l for the Jurassic rocks.

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

EQUATION

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

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

Where:

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

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

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

Where:

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

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

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

With the following values for these parameters:

H = 2.7 persons per home.
W_u = 100 gallons per day.
C_e = 40 mg/l.
C_q = 5.4 mg/l for the Precambrian rocks and 5.8 mg/l for the Jurassic rocks.
R = 0.32 to 2.95 inches per year depending on geologic formation.

The results of the analyses for each geologic unit using Equation 5 are summarized as follows:

Formation	Area of Non-Sewered Sections Underlain by Rock Type	Recharge Rates (inpy)	Target Nitrate Concentration (mg/l)	Recharge Area per Dwelling Unit to Dilute Nitrates (acres)
Precambrian igneous and metamorphic rocks	224.5	1.8	5.4	12.9
		2.5	5.4	9.3
Preakness and Hook Mountain Basalts (includes	3033.4	0.32	5.8	66.9
Feltville Formation)		0.93	5.8	23.0
Towaco and Boonton Formations -shallow	2404.9	2.95	5.8	7.3

Within the small portion of the township underlain by Precambrian rocks, recharge areas open to infiltrating precipitation ranging from 9.3 to 12.9 acres are necessary to ensure adequate recharge is available to dilute septic system contaminants that migrate into bedrock aquifers in this area. Given the very low replenishment rate of the Preakness Basalt, if septic system contaminants migrate into the same fractures used for water supply, recharge to the equivalent of 23 to 67 acres will be necessary to adequately dilute the nitrates in these discharges to the current antidegradation level. Within the slightly more than 2400 acres underlain by the Jurassic sedimentary rocks, recharge to 7.3 acres will be necessary for diluting nitrates in septic system discharges to a concentration of 5.8 mg/l.

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

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

CONCLUSIONS

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

1. Bernards Township residents not provided public water by NJAWC use groundwater. Water is supplied to these residents from individual wells completed in fractured bedrock aquifers.

2. USDA-NRCS mapping indicates that soils beneath 98 percent of the township have limitations for the disposal of septic system effluent. Sewage disposal fields may not be permissible beneath 37 percent of the township because of flooding hazards, hydric soil conditions, or steep slopes. Site-specific investigations must be conducted to evaluate limiting conditions and if possible, design disposal fields in accordance with N.J.A.C 7:9A and NJDEP requirements.

3. Approximately 1.5 percent of Bernards Township is located in the Highlands Physiographic Province. Bedrock underlying the Highlands portion of the township is made up of Precambrian igneous and metamorphic rocks some of which exceed 1 billion years in age.

4. In many areas of the Highlands Physiographic Province, Precambrian rocks have not been extensively fractured. The nature of these rocks allows for the attenuation of tectonic deformation within the minerals. These rocks generally behave in a plastic or malleable manner in comparison to more brittle sedimentary rocks such as shale. Because of the nature of the Precambrian igneous and metamorphic rocks, fractures not associated with major faults are often not highly interconnected or closely spaced. Kasabach (1966) indicates that Precambrian rocks are one of the poorest yielding aquifers. The 1996 New Jersey Statewide Water Supply Plan (NJDEP 1996) indicates that the Precambrian rocks are poor aquifers with low yields. In their ranking of bedrock aquifers of New Jersey, the NJGS indicates that Precambrian igneous and metamorphic rocks are poor aquifers with a rank of D. Data compiled by Kasabach (1966) for Hunterdon County as well as data from local well records indicate that the Precambrian rocks beneath Bernards Township are poor aquifers with limited storage and transmission capability.

5. More than 98 percent of Bernards Township is within the Piedmont Physiographic Province. This area is underlain by Jurassic (208 to 145 million years ago) sedimentary, igneous, and metamorphic rocks deposited or extruded as the Newark Basin opened with the rifting or separation of the North American and African plates.

6. The oldest rocks in Bernards Township in the Piedmont Province are part of the Feltville Formation, which encompass less than 17 acres and therefore, are not a significant groundwater resource.

7. The second oldest set of Jurassic rocks in the bedrock sequence beneath Bernards Township is the Preakness Basalt and associated interlayered siltstone. The Preakness Basalt has been separated into three distinct major flows of magma from volcanoes that once formed the Watchung Mountains. These basalts have been mapped beneath approximately 31 percent and the siltstones beneath slightly less than 1 percent of the township or combined, more than 4900 acres of Bernards Township. These rocks are present beneath the northwestern, western, southwestern, and southern portions of the township.

8. Given the limited extent of basalts in New Jersey and their poor aquifer characteristics, these rocks have not been extensively studied. The NJGS mapping of bedrock aquifers indicates that basalt has a ranking of D indicating a poor yielding aquifer system. Local well data indicate that the basalts beneath Bernards Township should be ranked E by NJGS, which is the lowest ranking for aquifers in New Jersey. Diabase, which is geochemically similar to basalt, is ranked E by NJGS.

9. Data from 151 well records obtained for Bernards Township indicate a median well depth of 400 feet below ground surface and a median yield of 12 gpm. These data indicate that in comparison to other rocks beneath the township, a well in the Preakness Basalt must be drilled more than twice as deep to obtain one-half the yield. Data further indicate a median specific capacity of 0.054 gpm/ft or more than one order of magnitude lower than the median specific capacity for any other bedrock unit beneath the township. The well data for Bernards Township clearly indicate that the Preakness Basalt is a very poor groundwater resource. The data further indicate that it is the poorest of the poor aquifers beneath the township.

10. Based on local data, when compared to other areas of New Jersey underlain by geochemically similar diabase, which is regarded as one if not the weakest bedrock aquifer in New Jersey, the basalts beneath the Bernards Township have lower capacities to transmit and store water than diabase. The local data indicate that between diabase and Preakness Basalt, the ability to transmit water differs by an order of magnitude with the Preakness Basalt having much lower capacity. The Preakness Basalt is a very limited groundwater resource.

11. Stratigraphically overlying the Preakness Basalt is the sedimentary Towaco Formation, which was deposited during a period of relative volcanic inactivity in the Jurassic. The Towaco Formation has been mapped beneath nearly 36 percent or 5500 acres of Bernards Township and forms a partial or semi-circular ring separating the older Preakness magmatic flows from the younger Hook Mountain Basalt mapped closer to the center of the township. It is very likely that the later Hook Mountain Basalt flows resulted in metamorphism of the Towaco Formation near the contact between the units.

12. Local well data indicate that the Towaco Formation is perhaps one of the better groundwater resources within the township but one of limited capacity to transmit groundwater. These data indicate a median depth of 190 feet below ground surface and median yield of 22 gpm. The median specific capacity for wells completed in the Towaco Formation is 0.52 gpm/ft or an order of magnitude greater than median specific capacity for the Preakness Basalt. However, the median specific capacity for the Towaco Formation is lower than calculated for the Precambrian rocks in Hunterdon County by Kasabach (1966) and he considered the Precambrian rocks, a poor water-supply resource.

13. The Hook Mountain Basalt is another series of major volcanic magmatic flows resulting from the rifting of the Newark Basin and has been mapped beneath the portion of Bernards Township extending from north of the Veterans Administration hospital to the east of Basking Ridge. Local data obtained from records for wells completed in the Hook Mountain Basalt beneath Bernards Township indicate a median depth of 156 feet below ground surface, a median yield of 15 gpm, and a median specific capacity of 0.14 gpm/ft. The data suggest that the Hook Mountain Basalt may be a slightly better groundwater resource than the older and more-widespread Preakness Basalt but should be considered a poor to very poor aquifer with limited fracture interconnection for storage and transmittal of groundwater.

14. The youngest consolidated rocks beneath Bernards Township is the Lower Jurassic Boonton Formation. These rocks are beneath approximately 20 percent or 3000 acres of Bernards Township, primarily in the eastern portions of the township. Local well data indicate a median depth of 160 feet below ground surface, a median yield of 21 gpm, and a median specific capacity of 0.5 gpm/ft.

15. Based on local well data, the township could be divided into hydrogeologic zones with the Preakness Basalt and adjacent 17 acres underlain by Feltville Formation considered to have very limited groundwater resource capacity. The areas of the township underlain by Hook Mountain Basalt and Precambrian igneous and metamorphic rocks could be considered a second zone with only slightly greater capacity to serve as groundwater resources. The Towaco and Boonton Formations could be considered to be underlain by better bedrock aquifers capable of yielding larger quantities of water, especially near faults.

16. Local streamflow data indicate that the bedrock aquifers beneath Bernards Township discharge very little water. Dry weather flows in the East and West Branches of Middle Brook and in the Dead River and Harrisons Brook in Bernards Township are very small to non-existent. Since groundwater discharges are equal to groundwater recharge, it must be assumed that very little water infiltrates into the bedrock aquifers beneath the township.

17. The data for the Passaic River as measured at Millington show that a major drought such as the “Drought of Record” results in a 64 percent reduction in daily median flows. The more recent but short-term (4 month) Summer drought of 1999 reduced median daily flows by 82 percent when compared to median daily flow for the period from 1979 through 2007. Local streamflow data are clear indication that short- or long-term droughts have significant impact on all water resources within the Passaic River basin including the bedrock aquifers beneath Bernards Township. These data show that very little water discharges to the river systems within the township and upstream municipalities during dry weather which, indicates that very little water recharged the aquifers in the months and years prior to the drought.

18. Recharge rates developed in consideration of drought conditions for the bedrock aquifers beneath Bernards Township are summarized as follows:

Formation	Area of Township Underlain by Rock Type (acres)	Recharge Rates (inpy)	(gpd/acre)
Precambrian igneous and metamorphic rocks	224.5	1.8	134
		2.5	188
Preakness and Hook Mountain Basalts (includes	6724.4	0.32	24
Feltville Formation)		0.93	69
Towaco and Boonton Formations -shallow	8534.4	2.95	219
Towaco and Boonton Formations -deep		0.50	37

19. Dependable yields for the bedrock aquifers beneath Bernards Township after applying the Planning Threshold and in accordance with NJDEP regulations regarding the dependable yield are summarized as follows:

Formation	Planning Threshold Dependable Yield (inpy)	(gpd/acre)
Precambrian igneous and metamorphic rocks	0.4	27
	0.5	38
Preakness and Hook Mountain Basalts (includes	0.1	5
Feltville Formation)	0.2	14
Towaco and Boonton Formations -shallow	0.6	44
Towaco and Boonton Formations -deep	0.1	7

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20. Large areas of the township are not provided water by NJAWC and therefore, reliant on groundwater resources beneath the township, To ensure adequate water resources are available to meet the needs of each home in these areas, the Planning Threshold dependable yields can be divided into the average daily demand (270 gallons) for each home to determine the recharge area needed per dwelling unit. These calculations are summarized as follows:

Formation	Recharge Area per Dwelling Unit (acres)
Precambrian igneous and metamorphic rocks	10
	7
Preakness and Hook Mountain Basalts (includes	54
Feltville Formation)	19
Towaco and Boonton Formations -shallow	6

21. Based on mapping prepared by Bernards Township and provided by the Engineering Department, nearly 9800 acres or 63 percent of the land area within the municipal boundaries is within a designated sewer service area under the jurisdiction of the Bernards Township Sewerage Authority. Areas outside the designated sewer service areas rely on septic system for the disposal of wastewater. To reduce contaminant concentrations in groundwater from these septic system discharges, recharge is necessary for dilution.

22. The Trela-Douglas Model was used to calculate recharge area needs for the areas of the township reliant on septic systems. Within the small portion of the township underlain by Precambrian rocks, recharge areas open to infiltrating precipitation ranging from 9.3 to 12.9 acres are necessary to ensure adequate recharge is available to dilute septic system contaminants that migrate into bedrock aquifers in this area. Given the very low replenishment rate of the Preakness Basalt, if septic system contaminants migrate into the same fractures used for water supply, recharge to the equivalent of 23 to 67 acres will be necessary to adequately dilute the nitrates in these discharges to the current antidegradation level. Within the slightly more than 2400 acres underlain by the Jurassic sedimentary rocks, recharge to 7.3 acres will be necessary for diluting nitrates in septic system discharges to a concentration of 5.8 mg/l.

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APPENDIX A:
USDA-NRCS SEWAGE DISPOSAL REPORT
FOR SOILS MAPPED BENEATH BERNARDS TOWNSHIP,
SOMERSET COUNTY, NEW JERSEY

Sewage Disposal (NJ)

Somerset County, New Jersey

[[The information in this table indicates the dominant soil condition but does not eliminate the need for onsite investigation. The numbers in the value columns range from 0.01 to 1.00. The larger the value, the greater the possible limitation. The table shows only the top five limitations for any given soil. The soil may have additional limitations.]. This report shows only the major soils in each map unit]

Map symbol and soil name	Pct. of map unit	Disposal field (NJ)		Type permitted (NJ)		Suitability class (NJ)	
		Rating class and limiting features	Value	Rating class and limiting features	Value	Rating class and limiting features	Value
AmdB:							
Amwell	85	Very limited					
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIIHr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIISr	1.00
		Depth to perched zone of saturation	0.83	C drain	0.83	IIWp	0.83
AmnrB:							
Amwell, rock substratum	85	Very limited					
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIIHr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIISr	1.00
		Depth to massive bedrock	0.99	M	0.99	IIISr	0.99
				C drain	0.83	IIWp	0.83
		Depth to perched zone of saturation	0.83				
AmnrC:							
Amwell, rock substratum	85	Very limited					
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIIHr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIISr	1.00
		Depth to massive bedrock	0.99	M	0.99	IIISr	0.99
				C drain	0.83	IIWp	0.83
		Depth to perched zone of saturation	0.83				
BhnA:							
Birdsboro	85	Not limited		C		I	
BhnB:							
Birdsboro	85	Not limited		C		I	
BhnC:							
Birdsboro	85	Not limited		C		I	
BoyAt:							
Bowmansville, frequently flooded	85	Very limited					
		Depth to apparent zone of saturation	1.00	Depth to apparent zone of saturation	1.00	Not Permitted - Flooding	1.00
		Not Permitted - Flooding	1.00	Not Permitted - Flooding	1.00	IIIWr	1.00
						Not Permitted - Hydric Soil	1.00
		Not Permitted - Hydric Soil	1.00	Not Permitted - Hydric Soil	1.00		

Sewage Disposal (NJ)

Somerset County, New Jersey

Map symbol and soil name	Pct. of map unit	Disposal field (NJ)		Type permitted (NJ)		Suitability class (NJ)	
		Rating class and limiting features	Value	Rating class and limiting features	Value	Rating class and limiting features	Value
CakB:							
Califon	85	Very limited					
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIIHr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIISr	1.00
		Depth to perched zone of saturation	1.00	C drain	1.00	IIIWp	1.00
CanBb:							
Califon, very stony	85	Very limited					
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIIHr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIISr	1.00
		Depth to perched zone of saturation	1.00	C drain	1.00	IIIWp	1.00
CoxA:							
Croton	85	Very limited					
		Depth to perched zone of saturation	1.00	C drain	1.00	IIIWp	1.00
				Restrictive substratum	1.00	IIIHr	1.00
		Restrictive substratum	1.00	SRB, SRE	1.00	IIISr	1.00
		Restrictive horizon	1.00	Not Permitted - Hydric Soil	1.00	Not Permitted - Hydric Soil	1.00
		Not Permitted - Hydric Soil	1.00	M	0.99	IIISr	0.99
		Depth to massive bedrock	0.99				
CoxB:							
Croton	85	Very limited					
		Depth to perched zone of saturation	1.00	C drain	1.00	IIIWp	1.00
				Restrictive substratum	1.00	IIIHr	1.00
		Restrictive substratum	1.00	SRB, SRE	1.00	IIISr	1.00
		Restrictive horizon	1.00	Not Permitted - Hydric Soil	1.00	Not Permitted - Hydric Soil	1.00
		Not Permitted - Hydric Soil	1.00	M	0.99	IIISr	0.99
		Depth to massive bedrock	0.99				
FmhAt:							
Fluvaquents, loamy, frequently flooded	80	Very limited					
		Depth to apparent zone of saturation	1.00	Depth to apparent zone of saturation	1.00	Not Permitted - Flooding	1.00
		Not Permitted - Flooding	1.00	Not Permitted - Flooding	1.00	IIIWr	1.00
		Not Permitted - Hydric Soil	1.00	Not Permitted - Hydric Soil	1.00	Not Permitted - Hydric Soil	1.00

Sewage Disposal (NJ)

Somerset County, New Jersey

Map symbol and soil name	Pct. of map unit	Disposal field (NJ)		Type permitted (NJ)		Suitability class (NJ)	
		Rating class and limiting features	Value	Rating class and limiting features	Value	Rating class and limiting features	Value
KkoC:							
Klinesville	85	Somewhat limited					
		Excessively coarse substratum	0.99	SRE, M	0.99	IISc	0.99
KkoD:							
Klinesville	85	Somewhat limited					
		Excessively coarse substratum	0.99	SRE, M	0.99	IISc	0.99
LbtA:							
Lansdowne	85	Very limited					
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIIHr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIISr	1.00
		Depth to perched zone of saturation	1.00	C drain	1.00	IIIWp	1.00
				SRE, M	0.99	IISc	0.99
		Excessively coarse substratum	0.99				
LbtB:							
Lansdowne	85	Very limited					
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIIHr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIISr	1.00
		Depth to perched zone of saturation	1.00	C drain	1.00	IIIWp	1.00
				SRE, M	0.99	IISc	0.99
		Excessively coarse substratum	0.99				
MonB:							
Mount Lucas	85	Very limited					
		Depth to perched zone of saturation	1.00	C drain	1.00	IIIWp	1.00
				M	0.86	IISr	0.86
		Depth to massive bedrock	0.86				
MopCb:							
Mount Lucas, very stony	60	Very limited					
		Depth to perched zone of saturation	1.00	C drain	1.00	IIIWp	1.00
				M	0.86	IISr	0.86
		Depth to massive bedrock	0.86				

Sewage Disposal (NJ)

Somerset County, New Jersey

Map symbol and soil name	Pct. of map unit	Disposal field (NJ)		Type permitted (NJ)		Suitability class (NJ)	
		Rating class and limiting features	Value	Rating class and limiting features	Value	Rating class and limiting features	Value
MopCb:							
Watchung, very stony	40	Very limited					
		Depth to apparent zone of saturation	1.00	Depth to apparent zone of saturation	1.00	IIIWr	1.00
						IIIHr	1.00
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIISr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	Not Permitted - Hydric Soil	1.00
		Not Permitted - Hydric Soil	1.00	Not Permitted - Hydric Soil	1.00		
NehB:							
Neshaminy	85	Somewhat limited					
		Depth to massive bedrock	0.20	M	0.20	IISr	0.20
NehC:							
Neshaminy	85	Somewhat limited					
		Depth to massive bedrock	0.20	M	0.20	IISr	0.20
NehEb:							
Neshaminy, very stony	85	Very limited					
		Not Permitted Too Steep	1.00	Not Permitted - Too Steep	1.00	Not Permitted - Too Steep	1.00
		Depth to massive bedrock	0.80	M	0.80	IISr	0.80
NemCb:							
Neshaminy, very stony	55	Somewhat limited					
		Depth to massive bedrock	0.20	M	0.20	IISr	0.20
Mount Lucas, very stony	35	Very limited					
		Depth to perched zone of saturation	1.00	C drain	1.00	IIIWp	1.00
				M	0.86	IISr	0.86
		Depth to massive bedrock	0.86				
NemDb:							
Neshaminy, very stony	60	Somewhat limited					
		Depth to massive bedrock	0.20	M	0.20	IISr	0.20
Mount Lucas, very stony	40	Very limited					
		Depth to perched zone of saturation	1.00	C drain	1.00	IIIWp	1.00
				M	0.86	IISr	0.86
		Depth to massive bedrock	0.86				

Sewage Disposal (NJ)

Somerset County, New Jersey

Map symbol and soil name	Pct. of map unit	Disposal field (NJ)		Type permitted (NJ)		Suitability class (NJ)	
		Rating class and limiting features	Value	Rating class and limiting features	Value	Rating class and limiting features	Value
NeopB:							
Neshaminy variant, fragipan	85	Very limited					
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIISr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIIHr	1.00
		Depth to massive bedrock	1.00	Depth to massive bedrock	1.00	IIISr	1.00
						IIWp	0.83
		Depth to perched zone of saturation	0.83	C drain	0.83		
NeopC:							
Neshaminy variant, fragipan	85	Very limited					
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIISr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIIHr	1.00
		Depth to massive bedrock	1.00	Depth to massive bedrock	1.00	IIISr	1.00
						IIWp	0.83
		Depth to perched zone of saturation	0.83	C drain	0.83		
NotA:							
Norton	85	Very limited					
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIIHr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIISr	1.00
NotB:							
Norton	85	Very limited					
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIIHr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIISr	1.00
NotC:							
Norton	85	Very limited					
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIIHr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIISr	1.00
		Excessively coarse substratum	0.99	SRE, M	0.99	IISc	0.99
PapC:							
Parker	85	Somewhat limited					
		Depth to massive bedrock	0.96	M	0.96	IISr	0.96
PapFg:							
Parker, rocky	85	Very limited					
		Not Permitted Too Steep	1.00	Not Permitted - Too Steep	1.00	Not Permitted - Too Steep	1.00
		Depth to massive bedrock	0.96	M	0.96	IISr	0.96

Sewage Disposal (NJ)

Somerset County, New Jersey

Map symbol and soil name	Pct. of map unit	Disposal field (NJ)		Type permitted (NJ)		Suitability class (NJ)	
		Rating class and limiting features	Value	Rating class and limiting features	Value	Rating class and limiting features	Value
PapFg:							
Rock outcrop	2	Not Rated		Not Rated		Not Rated	
PauDb:							
Parker, very stony	60	Somewhat limited					
		Depth to massive bedrock	0.96	M	0.96	IISr	0.96
Gladstone, very stony	40	Somewhat limited					
		Depth to massive bedrock	0.71	M	0.71	IISr	0.71
PbpAt:							
Parsippany, frequently flooded	90	Very limited					
		Depth to apparent zone of saturation	1.00	Depth to apparent zone of saturation	1.00	Not Permitted - Flooding	1.00
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIIWr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIIHr	1.00
		Not Permitted - Flooding	1.00	Not Permitted - Flooding	1.00	IIISr	1.00
						Not Permitted - Hydric Soil	1.00
		Not Permitted - Hydric Soil	1.00	Not Permitted - Hydric Soil	1.00		
PbtAt:							
Parsippany variant, very poorly drained, frequently flooded	85	Very limited					
		Depth to apparent zone of saturation	1.00	Depth to apparent zone of saturation	1.00	Not Permitted - Flooding	1.00
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIIWr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIIHr	1.00
		Not Permitted - Flooding	1.00	Not Permitted - Flooding	1.00	IIISr	1.00
						Not Permitted - Hydric Soil	1.00
		Not Permitted - Hydric Soil	1.00	Not Permitted - Hydric Soil	1.00		
PenB:							
Penn	85	Somewhat limited					
		Excessively coarse substratum	0.99	SRE, M	0.99	IISc	0.99
PenC:							
Penn	85	Somewhat limited					
		Excessively coarse substratum	0.99	SRE, M	0.99	IISc	0.99

Sewage Disposal (NJ)

Somerset County, New Jersey

Map symbol and soil name	Pct. of map unit	Disposal field (NJ)		Type permitted (NJ)		Suitability class (NJ)	
		Rating class and limiting features	Value	Rating class and limiting features	Value	Rating class and limiting features	Value
PeoB:							
Penn	85	Somewhat limited					
		Excessively coarse substratum	0.99	SRE, M	0.99	IISc	0.99
PeoC:							
Penn	85	Somewhat limited					
		Excessively coarse substratum	0.99	SRE, M	0.99	IISc	0.99
QY:							
Pits, quarry	100	Not Rated		Not Rated		Not Rated	
RarAr:							
Raritan, rarely flooded	85	Very limited					
		Restrictive substratum	1.00	Restrictive substratum	1.00	Not Permitted - Flooding	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIIHr	1.00
		Not Permitted - Flooding	1.00	Not Permitted - Flooding	1.00	IIISr	1.00
		Depth to perched zone of saturation	1.00	C drain	1.00	IIIWp	1.00
RehA:							
Reaville	85	Very limited					
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIIHr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	IIISr	1.00
		Depth to apparent zone of saturation	1.00	Depth to apparent zone of saturation	1.00	IIIWr	1.00
						IISc	0.99
		Excessively coarse substratum	0.99	SRE, M	0.99		
RehB:							
Reaville	85	Very limited					
		Depth to apparent zone of saturation	1.00	Depth to apparent zone of saturation	1.00	IIIWr	1.00
						IISc	0.99
		Excessively coarse substratum	0.99	SRE, M	0.99		
RkrC:							
Riverhead	85	Somewhat limited					
		Excessively coarse horizon	0.99	SRE, M	0.99	IIHc	0.99
				SRE, M	0.99	IISc	0.99
		Excessively coarse substratum	0.99				

Sewage Disposal (NJ)

Somerset County, New Jersey

Map symbol and soil name	Pct. of map unit	Disposal field (NJ)		Type permitted (NJ)		Suitability class (NJ)	
		Rating class and limiting features	Value	Rating class and limiting features	Value	Rating class and limiting features	Value
RorAt:							
Rowland, frequently flooded	85	Very limited					
		Not Permitted - Flooding	1.00	Not Permitted - Flooding	1.00	Not Permitted - Flooding	1.00
		Depth to apparent zone of saturation	0.99	M	0.99	IIWr	0.99
UCFAT:							
Udifluvents, frequently flooded	50	Very limited					
		Not Permitted - Flooding	1.00	Not Permitted - Flooding	1.00	Not Permitted - Flooding	1.00
		Depth to apparent zone of saturation	1.00	Depth to apparent zone of saturation	1.00	IIIWr	1.00
Udepts, frequently flooded	45	Very limited					
		Not Permitted - Flooding	1.00	Not Permitted - Flooding	1.00	Not Permitted - Flooding	1.00
		Depth to apparent zone of saturation	1.00	Depth to apparent zone of saturation	1.00	IIIWr	1.00
WasA:							
Watchung	85	Very limited					
		Depth to apparent zone of saturation	1.00	Depth to apparent zone of saturation	1.00	IIIWr	1.00
						IIIHr	1.00
		Restrictive substratum	1.00	Restrictive substratum	1.00	IIISr	1.00
		Restrictive horizon	1.00	SRB, SRE	1.00	Not Permitted - Hydric Soil	1.00
		Not Permitted - Hydric Soil	1.00	Not Permitted - Hydric Soil	1.00		
WATER:							
Water	100	Not Rated		Not Rated		Not Rated	
WhpA:							
Whippany	85	Very limited					
		Depth to perched zone of saturation	1.00	C drain	1.00	IIIWp	1.00
				Restrictive substratum	1.00	IIISr	1.00
		Restrictive substratum	1.00	Depth to apparent zone of saturation	1.00	IIIWr	1.00
		Depth to apparent zone of saturation	1.00				

Water: A Natural Renewable Resource

APPENDIX B:
SUMMARY OF DATA FROM WELL RECORDS OBTAINED FROM NJDEP FOR BERNARD TOWNSHIP, SOMERSET COUNTY, NEW JERSEY

Summary of Well Records obtained from NJDEP Highview Database and Files for Wells within Bernards Township, Somerset 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)	Specific Capacity (gpm/ft)	Geologic Formation
Hoeckele, Steve	25-22605	2522977	3/10/1982	Mt. Road	189	21	670	50	5	280	0.025	Preakness Basalt
Roper Homes, Inc.	25-20895	2522598	11/29/1979				275	65.5	10	60	0.066667	Towaco Formation
Allen, Derck	25-20381	2523116	12/28/1978	122 Old Farm Road			198	50	15	-2		Precambrian
Crane, Ransford	25-20316	2522396	11/29/1978	Decker Street			198	50	3	17		Preakness Basalt
Cannariato, Thomas	25-20268	2522915	10/16/1978	Somerville Rd	164	13.1	249	50	36	33		Towaco Formation
Meyer, Richard	25-20245	2523494	10/29/1978	210 Stonehouse Rd			199	50	20	18		Towaco Formation
Bocina Development Corp.	25-50440	2522561	4/14/1997	Emily Road	122.01	18	300	60	20	31	0.091324	Preakness Basalt
Bocina Development Corp.	25-50195	2522562	4/8/1997	Chapin Lane	122	19.03	475	58	20	33	0.047962	Preakness Basalt
Bocina Development Corp.	25-50194	2522562	5/5/1997	Mine Brook Rd	122	19.02	225	60	20	100	0.2	Preakness Basalt
Manetta, Robert	25-50105	2522564	1/21/1997	Whiteneck Rd	122	10.02	300	50	50	30	0.294118	Preakness Basalt
Wagner, Cliff	25-50090	2522987	10/20/1997	Hunter's Ridge Rd	187	31.07	700	50	3	20	0.004762	Preakness Basalt
Wagner, Cliff	25-50089	2522979	2/4/1997	Mountain Rd	187	31.01	275	50	12	80	0.025532	Preakness Basalt
Wagner, Cliff	25-50088	2522984	1/24/1997	Hunter's Ridge Rd	187	31.10	400	50	6	40	0.01791	Preakness Basalt
Premier Homes	25-49879	2522892	1/7/1997	Somerville Rd	186	8.02	150	50	20	15		Preakness Basalt
Ventrice, Raymond	25-49706	2522628	1/2/1997	144 Whitenack Rd.	104	19.04	250	51	15	70	0.1875	Towaco Formation
Osborne Associates	25-49193	2522973	8/8/1996	34 Pacer Court	187	18.02	500	50	4	0	0.008333	Preakness Basalt
Bocina Development Corp.	25-49028	2522538	8/28/1996	Emily Road	122	11.01	350	52	20	40	0.148148	Preakness Basalt
Burdi, Gerard	25-48969	2522972	6/13/1996	37 Pacer Court	187	18.04	600	50	4	12	0.007042	Preakness Basalt
Shannon Hills Farms	25-48818	2522951	6/13/1996	Somerville Rd	175	34.25	300	52	10	42	0.166667	Preakness Basalt
Bocina Development Corp.	25-48756	2522563	10/2/1996	55 Emily Rd	122.01	19	600	50	3	58	0.005803	Preakness Basalt
Bocina Development Corp.	25-48696	2522562	10/7/1996	47 Emily Rd	122.01	20	500	50	5	66	0.012225	Preakness Basalt
Bocina Development Corp.	25-48695	2522562	6/4/1996	Emily Road	122	19.06	275	50	15	103	0.102041	Preakness Basalt
Bocina Development Corp.	25-48694	2522565	9/3/1996	463 Mine Brook Rd	122.01	8	500	51	3	15		Preakness Basalt
Bocina Development Corp.	25-48693	2522565	5/30/1996	439 Mine Brook Rd	122.01	11	500	50	8	74		Preakness Basalt
Bocina Development Corp.	25-48692	2523412	8/27/1996	Emily Road	122	11.04	300	52	30	50		Preakness Basalt
Bocina Development Corp.	25-48449	2522562	8/20/1996	111 Emily Rd	122	19.09	325	63	15	40	0.057692	Preakness Basalt
Hill, Tom	25-47987	2522564	10/25/1995	36 Chapin Lane	122.01	15.04	275	60	15	60	0.078947	Preakness Basalt
Bocina Development Corp.	25-47797	2522566	10/23/1995	Emily Road	122	19.14	425	60	15	52	0.043103	Preakness Basalt
Bocina Development Corp.	25-47742	2522621	9/19/1995	50 Meeker Road	104	28.01	325	50	15	2	0.050336	Preakness Basalt
Bocina Development Corp.	25-47741	2522563	11/30/1995	Emily Road	122.01	21	275	50	8	61	0.042328	Preakness Basalt
Dalo, John	25-47679	2523128	9/5/1995	37 Colts Glen Lane	104	30.06	230	50	30	25	0.193548	Preakness Basalt
Crystal Ridge	25-47503	2522537	8/8/1995	Emily Road	122.01	24	400	61	7	50	0.053846	Preakness Basalt
Kelly, Jim	25-47104	2522948	7/11/1995	Parkwood Place	177	20.07	300	52	15	0		Preakness Basalt
Kelly, Jim	25-47183	2522948	8/10/1996	Parkwood Place	177	20.08	75	52	40	20		Preakness Basalt
Bocina Development Corp.	25-47020	2522561	8/1/1995	Emily Road	122	19.13	350	50	18	80	0.073469	Preakness Basalt
Bocina Development Corp.	25-47019	2522562	7/6/1995	Emily Road	122.01	17	300	50	20	40	0.085106	Preakness Basalt

Summary of Well Records obtained from NJDEP Highview Database and Files for Wells within Bernards Township, Somerset 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)	Specific Capacity (gpm/ft)	Geologic Formation
Bocina Development Corp.	25-47018	2522562	6/29/1995	Emily Road	122	19.07	450	50	6	80	0.017391	Preakness Basalt
McCarthy, Mike	25-46932	2522615	5/16/1996	Colts Glen Lane	104	30.14	430	50	6	60	0.02069	Preakness Basalt
Grabel, Neal	25-46753	2522567	7/3/1995	Mine Brook Rd	122.01	15.03	275	61	35	30	0.5	Preakness Basalt
Ravenswood Estates	25-46692	2522618	4/28/1995	Whitenack Rd	104	9.04	1125	61	8	100	0.014545	Preakness Basalt
Bocina Development Corp.	25-64527	2522562	3/14/1965	457 Mine Brook Rd	122	9	600	60	2	35	0.004301	Preakness Basalt
Bocina Development Corp.	25-46526	2522562	4/27/1995	449 Mine Brook Rd	122.01	10	500	59	4	58	0.009592	Preakness Basalt
Bocina Development Corp.	25-46525	2522562	2/17/1995	80 Emily Rd	122	19.12	377	50	30	105	0.122449	Preakness Basalt
Bocina Development Corp.	25-46524	2522562	5/1/1995	108 Emily Rd	122	19.10	400	50	20	60	0.063492	Preakness Basalt
Shannon Hills Farms	25-46390	2522951	6/9/1995	Somerville Rd	175	34.02	375	61	20	40	0.181818	Towaco Formation
Sorge, Joseph	25-46287	2522958	11/7/1995	181 Mountain Rd	187	32.01	590	50	35	150		Preakness Basalt
Wagner, Cliff	25-46268	2522985	7/1/1996		187	31.08	600	50	15	100	0.031579	Preakness Basalt
Wagner, Cliff	25-46266	2522988	11/13/1995	Hunter's Ridge Rd	187	31.06	640	50	3	130	0.006186	Preakness Basalt
Wagner, Cliff	25-46265	2522987	4/22/1996	Hunter's Ridge Rd	187	31.04	480	50	15	100	0.042857	Preakness Basalt
Wagner, Cliff	25-46264	2522987	9/4/1996		187	31.05	640	50	3	120	0.006122	Preakness Basalt
Wagner, Cliff	25-46263	2522987	9/28/1995	Hunter's Ridge Rd	187	31.02	700	50	3	150	0.005714	Preakness Basalt
Wagner, Cliff	25-46262	2522976	11/8/1995	Hunter's Ridge Rd	187	31.12	440	50	10	25	0.025641	Preakness Basalt
Wagner, Cliff	25-46261	2522984	3/6/1995	Hunter's Ridge Rd	187	31.11	620	50	1.5	120	0.003191	Preakness Basalt
Wagner, Cliff	25-46260	2522976	3/3/1995	Hunter's Ridge Rd	187	31.13	580	51	10	120	0.022989	Preakness Basalt
Wagner, Cliff	25-46259	2522976	9/22/1995	Hunter's Ridge Rd	187	31.15	600	50	15	150	0.035294	Preakness Basalt
Wagner, Cliff	25-46258	2522976	9/10/1996		187	31.14	660	50	15	120	0.029412	Preakness Basalt
Bocina Development Corp.	25-46247	2522562	12/23/1994	Mine Brook Rd	122.01	13	263	60	35	55	0.18617	Preakness Basalt
Bocina Development Corp.	25-46246	2522562	12/15/1994	Mine Brook Rd	122.01	12	250	58	35	55	0.212121	Preakness Basalt
Bocina Development Corp.	25-46245	2522562	12/20/1994	Chapin & Emily Road	122.01	16	400	59	40	55	0.128617	Preakness Basalt
Roti, Joseph	25-46052	2522972	11/15/1994	Rickey Lane	187	1	300	50	5	30	0.055556	Preakness Basalt
Holzhauer, Robert	25-45941	2523818	10/11/1994	Sun Road	185	19.03	250	50	10	43	2.5	Towaco Formation
Colonial Ridge Inc.	25-45715	2522619	12/20/1994	Meeker Road	90	6.02	400	50	8	30	0.038095	Preakness Basalt
Bocina Development Corp.	25-45491	2522623	7/27/1994	Meeker Rd	90	6.01	400	55	10	88	0.043478	Preakness Basalt
Bocina Development Corp.	25-45333	2522564	8/10/1994	Chapin Lane	122	19.05	760	50	6	100	0.015	Preakness Basalt
Bocina Development Corp.	25-45332	2522556	8/26/1994	Emily Road	122	19.08	400	50	9	6	0.035019	Preakness Basalt
Bocina Development Corp.	25-45331	2522556	8/16/1994	Emily Road	122	19.11	500	51	8	23	0.195122	Preakness Basalt
Crystal Ridge	25-45262	2522562	7/11/1994	Emily Road	122	11.02	305	60	12	27	0.062176	Preakness Basalt
Bocina Development Corp.	25-45238	2522553	8/22/1994	31 Chapin Lane	122	19.04	400	52	10	70	0.163934	Preakness Basalt
Gollob, Bruce	25-44883	2522654	5/10/1994	Colts Glen Rd	104	30.04	300	61	30	25	0.26087	Preakness Basalt
Stanzione, Robert	25-44824	2522394	11/27/1994	Colts Glen Rd	104	30.05	200	50	20	10	0.181818	Preakness Basalt
Alexander, James	25-20109	2522657	7/28/1978	Queen Anne Dr			148	50	15	42		Towaco Formation
Lavecchia, Richard	25-20039	2522673	7/28/1978	Annin Rd			148	50	22	12		Towaco Formation

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Huber, William	25-19941	2522361	6/21/1978	262 N Maple Rd			160	50				Boonton Formation
Torchia, Leonard	25-44056	2522868	3/1/1994	173 Somerville Rd	177	22	600	52	2	0	0.003478	Preakness Basalt
B. Boice Construction	25-43693	2522561	2/11/1994	Emily Road	122	11.03	300	94	18	35	0.253521	Preakness Basalt
O'Hara, John	25-43648	2522978	12/23/1993	Mountain Rd	187	30	600	52	7.5	200	0.072816	Preakness Basalt
Micholson, Wayne	25-43458	2532216	12/29/1993	17 Long Rd	189	7.05	520	50	8	93	0.085106	Preakness Basalt
J&B Custom Homes	25-43334	2522561	9/29/1993	Emily Road	122	11.05	300	60	15	40	0.1875	Preakness Basalt
Giancaspro, Frank	25-43112	2522816	6/8/1993	Meeker Rd	90	1.03	700	50	8	40	0.022222	Preakness Basalt
Wolklin, Jim	25-43021	2522621	5/26/1993	Meeker Rd	90	1.02	605	50	7	2		Preakness Basalt
B. Boice Construction	25-42158	2522553	6/28/1993	Emily Road	122		305	61	20	26	0.12987	Preakness Basalt
Grillo, Joan	25-42118	2522573	11/3/1992	Meeker Rd	104	30.10	240	50	37	48	0.925	Preakness Basalt
Wojnar, John	25-19350	2532326	8/25/1997	Mountain Rd			620	50	3	90	0.01	Preakness Basalt
Prochaska, Robert	25-19202	2532325	6/2/1977	Mountain Rd			500	50	20	180	0.090909	Preakness Basalt
Paspmare, R.C.	25-10818	2523138	8/17/1962	N. Maple Ave			136	20	25	11	1.315789	Boonton Formation
Wei, Andy	25-41235	2522616	8/18/1992	Meeker Rd	90	6.04	600	51	10	40	0.021739	Preakness Basalt
Regency Homes Const	25-40942	2522613	8/23/1992	Meeker Rd	90	1.01	623	50	16	139		Preakness Basalt
Witte, Carol Ann	25-40777	2522984	3/12/1992	270 Mountain Rd	189	17	500	53	20	120	0.086957	Preakness Basalt
Pedman Associates	25-40158	2522597	12/24/1991	Liberty Corner Rd	172	23.01	398	52	40	24		Towaco Formation
Burket, Louis	25-39983	2523515	11/15/1991	183 Lord Stirling	120	4	170	60	9	6	0.078947	Boonton Formation
LDJ Builders	25-38661	2522869	5/31/1991	Somerville Rd	177	20.01	348	50	20			Preakness Basalt
Piccone, Michael	25-38532	2532319	4/15/1991	Long Rd	189	7.02	405	50	7	80		Preakness Basalt
Koechlein, Harold	25-21761	2522597	12/22/1980	76 Liberty Corner Rd	172	25.01	225	50	7	2		Preakness Basalt
Taupel, Kenneth	25-21880	2522535	3/2/1981	354 Whitenack Rd			85	50	50	5	2	Preakness Basalt
Raven Associates	25-21989	2531363	6/19/1981	Whitenack Rd	122	7	348	50	2	23		Preakness Basalt
Bernards Township	25-21976	2523716	4/9/1981	Valley Rd	155	58	150	50	100	15		Towaco Formation
Dave Jackson Homes, Inc.	25-22465	2522692	12/8/1981	Lyons Rd	106	125	123	50	40	30		Hook Mountain Basalt
Melville, Jean	25-22143	2522638	6/19/1981		186	4	480	50	40	125	0.314961	Preakness Basalt
Shurtleff, Fred	25-23407	2522893	12/5/1982	Mountain Rd	188	12.03	150	58	15	15	0.333333	Preakness Basalt
Ost, Gary	25-37813	2522631	12/20/1990	Whitenack Rd	104	19.02	280	50	20	30	0.266667	Towaco Formation
Murphy, Dennis	25-37596	2522937	11/7/1990	409 King George Rd	182	17	210	52		50		Towaco Formation
Anderson, Ed	25-35441	2522986	2/23/1990	Martinsville Rd	187	51	760	140	7.5	160	0.09375	Preakness Basalt
Meister, Donald	25-34349	2522868	8/22/1989	111 Somerville Rd	187	1.03	150	51	20	50	0.263158	Preakness Basalt
Stafford, Diane	25-34342	2522679	9/14/1989	Mine Brook Rd	172	39.01	98	61	25	12		Towaco Formation
MTS Builders	25-34192	2522974	8/3/1989	Rickey Lane	187	20.02	198	50	11	0		Preakness Basalt
LDJ Builders	25-34151	2522869	8/8/1989	Parkwood Rd	177	20.02	298	50	13			Preakness Basalt
LDJ Builders	25-34150	2522869	8/7/1989	Parkwood Rd	177	20.03	198	50	15			Preakness Basalt
LDJ Builders	25-34149	2522869	8/29/1989	Parkwood Rd	177	20.04	298	61	6			Preakness Basalt

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LDJ Builders	25-34148	2522869	9/12/1989	Parkwood Rd	177	20.05	198	50	15	30		Preakness Basalt
LDJ Builders	25-34145	2522869	9/13/1989	Parkwood Rd	177	20.08	423	61	5			Preakness Basalt
LDJ Builders	25-34144	2522869	8/28/1989	Parkwood Rd	177	20.09	298	51	8	3		Preakness Basalt
LDJ Builders	25-34143	2522869	8/9/1989	Parkwood Rd	177	20.11	248	50	18			Preakness Basalt
LDJ Builders	25-34142	2522869	8/10/1989	Parkwood Rd	177	20.10	248	50	20			Preakness Basalt
Dopp, Paul	25-33984	2523454	9/26/1989	58 Lyons Place	106.04	85	200	50	22	26	0.22	Boonton Formation
Mandoke, Robert	25-33838	2522897	6/27/1989	Liberty Corner	172	23.02	148	61	17	18		Preakness Basalt
Utz, John	25-32828	2522643	4/26/1989	Whitenack Rd	104	19.01	123	51	30	12		Towaco Formation
Polise, Thomas	25-32452	2522539	11/3/1988	Mine Brook Rd	122	20	330	50	10	20	0.05	Feltville Formation
Delesky, Robert	25-31766	2532344	6/10/1989	Sunset Lane	190	8	520	50	20	80	0.2	Preakness Basalt
Bard, Cheryl	25-31085	2523198	6/8/1988	Decker St	92	4.02	900	52	1	30	0.001163	Preakness Basalt
Widmark, Andrew	25-24719	2522664	3/20/1984		106	51.01	250	50	15	60	0.107143	Hook Mountain Basalt
Gottarolo, Lino	25-30177	2523576	8/23/1987	11 Pond Hill Rd	169	5.02	185	60	12	28	0.210526	Towaco Formation
Kotz, Richard	25-29540	2523135	5/19/1987	141 Hardscrabble Rd	4	53	185	50	30	35	0.666667	Precambrian
Stonewood Builders, Inc	25-21447	2522645	11/19/1986	Whitenack Rd	122	3.02	123	50	25	29		Towaco Formation
DeSilva, John	25-28457	2522954	9/10/1986	317 Somerville Rd			600	51		180		Preakness Basalt
Bowers, Jim	25-27773	2532381	8/8/1986		189	34.02	400	50	18	70	0.085714	Preakness Basalt
West Meadow Corp	25-27990	2522897	10/19/1986		188	11	560	50	4	70	0.012121	Preakness Basalt
Steward, Steve	25-27025	2533147	11/20/1985	Sunset Lane	190	19	500	50	20	100	0.133333	Preakness Basalt
Fremont Bldr.	25-27002	2522944	11/10/1985	Stone Ridge Rd			210	60	4	32	0.027027	Preakness Basalt
Knox, W.T.	25-25572	2532318	11/20/1984	Mountain Rd	187	4.01	140	50	20	30	0.4	Preakness Basalt
McKay, Thomas	25-26089	2522869	4/18/1985	61 Circle Dr.	177	21	300	50	7	0	0.026923	Preakness Basalt
Burger, George	25-26007	2522921	4/30/1985		175	23.02	148	50	20	65		Towaco Formation
Sellitto, Matt	25-25752	2522895	12/8/1984		188	12.04	150	50	10	35	0.222222	Preakness Basalt
Waehler, Franl	25-25293	2523191	2/7/1985	287 Childs Rd			50	50	18	12	0.095745	Boonton Formation
United States Golf Assoc.	25-25185	2522585	7/20/1984	Liberty Corner Rd	171	12	480	55	150	10	0.517241	Preakness Basalt
Estes, Simon	2524262	2522974	10/15/1983	1 Deer Ridge Rd	188	12.0	330	50	2	20	0.006667	Preakness Basalt
Fremont Bldr.	25-26755	2522941	10/2/1985	Stone Ridge Rd			100	55	20	28	0.625	Preakness Basalt
Riccardo, Tom	25-26624	2523195	8/26/1985	55 Mt. Airy Rd	120	7	360	50	30	40	0.1875	Boonton Formation
Fremont Bldr.	25-26621	2522944	8/20/1985	Stone Ridge Rd	177	19.03	360	50	2	60	0.006667	Preakness Basalt
Guenot, Eugene	25-26609	2522676	9/19/1985				198	50	30	18		Towaco Formation
Simpson, Rich	25-26561	2523818	8/22/1985	Sun Rd	185	19.02	190	50	10	55	0.4	Towaco Formation
J&H Termarsch	25-25654	2522694	11/20/1984	373 Lyons Rd			150	85	100	26	2.941176	Towaco Formation
Gibson, Robert	25-24203	2523164	10/18/1983	25 Lone Oak Rd	14	1	160	55	30	40	0.5	Boonton Formation
Millington Quarry Inc.	25-24124	2523493	10/4/1983	Stonehouse Rd	164	4	800	50	1	150	0.002222	Hook Mountain Basalt
Millington Quarry Inc.	25-23764	2523556	5/11/1983	Stonehouse Rd	150	20	800	50	7	60	0.01037	Hook Mountain Basalt

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J.C. Development Co.	25-53061	2522613	12/8/1998	Colts Glen Lane	104	30.13	350	51	30	46	0.109489	Preakness Basalt
Van Holten Group	25-53219	2532321	12/11/1998		187	31.09	460	60	10	52	0.027174	Preakness Basalt
Van Holten Group	25-53217	2532321	11/25/1998	Van Holten Rd	187	31.09	400	50	18	40	0.069231	Preakness Basalt
Van Holten Group	25-53121	2532321	12/3/1998	Hunter's Court	187	31.20	760	50	13	10	0.019403	Preakness Basalt
American Homes of NJ	25-53056	2522891	9/30/1998	Somerville Rd	186	1.02	390	51	7	125	0.035897	Preakness Basalt
Van Holten Group	25-52963	2532321	10/6/1998	Hunter's Court	187	31.22	740	50	12	70	0.022642	Preakness Basalt
Van Cleef, J Todd	25-52762	2522677	11/20/1998	Douglas Rd	172	4.02	225	60	35	20	0.194444	Towaco Formation
Dwight, David	25-52706	2522896	7/29/1998	380 Mountain Rd	188	12.05	400	59	12	10	0.104348	Preakness Basalt
Hartvigsen, Harry	25-17399	2522538	4/4/1974	Whitenack Rd	100	6A	350	41	12	40		Preakness Basalt
Tenore, Hugh	25-16486	2522598	8/6/1972	Douglas Rd			97	50	65			Towaco Formation
Bravaco, Rocco	25-16471	2522974	5/26/1972	Mountain Rd			172	50	17	13		Preakness Basalt
Kiederas, J. Thomas	25-16449	2532326	7/20/1972	Mountain Rd			438	50	5	117	0.017668	Preakness Basalt
Humble Oil Co.	25-16029	2523849	8/1/1971	King George Rd			150	72	75	22	1.293103	Towaco Formation
Mahon, James	25-15189	2523122	5/9/1969				203	20	3.5			Boonton Formation
Swenson, Raymond	25-16382	2532673	6/10/1972	Annin Rd			130	50	20	15	0.444444	Towaco Formation
Fellowship Deaconary, Inc	25-15703	2522925	11/16/1970				247	20	15			Towaco Formation
Zervaulis, William	25-15656	2522984	10/9/1970	South Finley Ave			600	50	4.5	20	0.013353	Preakness Basalt
Fellowship Deaconary, Inc	25-13714	2522922	4/27/1966	Valley Rd			246	20	20	48	2.857143	Towaco Formation
J. Bowers & Co.	25-16872	2522974	4/7/1973	Fawn Lane			473	50	8			Preakness Basalt
Dickinson, Gilbert	25-09829	2523197	2/17/1961	Oak St			100	20	25	9	0.78125	Hook Mountain Basalt
Voorhes, Harold	25-16199	2522833	1/15/1972	Liberty Corner Rd			135	47	20	15	0.307692	Preakness Basalt
Bowers, James	25-16690	2522594	11/24/1972	Douglas Rd			98	56	20	42		Preakness Basalt
Bowers, James	25-16689	2522594	11/24/1972	Douglas Rd			98	50	18	14		Preakness Basalt
Dynecki, Cons. Inc.	25-16772	2523418	2/3/1973	Lake Rd			172	50	3	29		Hook Mountain Basalt
Mikalsen, Elinar	25-14970	2522691	5/21/1968	Lyons Rd			148	49	22	79	0.758621	Towaco Formation
Bohnert, Charles	25-15093	2523152	2/4/1969				112	31	15	23	2.142857	Boonton Formation
Van Ness, Roger	25-13595	2523175	2/20/1967	33 North Brook Dr.			380	38.2	6	1	0.015915	Preakness Basalt
Walrafen, George	25-13592	2523123	3/15/1966	Old Army Rd			247	30	6	5	0.027907	Precambrian
Holy Cross Cemetery	25-13577	2522392	1/26/1966	Mt. Airy Rd-Cemetary			95	41	7	8	0.090909	Preakness Basalt
Frelinghuysen, H.O.H	25-13473	2522896	4/10/1966	Mountain Rd			620	25	3	15		Preakness Basalt
Arndt, Lester	25-13428	2522673	11/12/1965	Annin Rd			160	45	30	20	0.3	Towaco Formation
Swenson, Allen	25-12439	2523138	11/20/1964	246 Madisonville Rd			160	35	100	30	1.428571	Boonton Formation
Hayden, M. James	25-12305	2522597	10/6/1964	King George Rd			321	46	4	14	0.01626	Preakness Basalt
Vance, Cyrus Mrs.	25-12304	2522589	9/21/1964	Liberty Corner Rd			166	34	15	18	0.220588	Preakness Basalt
Lee, Charles	25-12184	2522823	8/22/1964	Mt. Prospect Rd			270	21	20	60	0.166667	Preakness Basalt
Pyne, Percy	25-12106	2522821	7/23/1964				167	30	7	9	0.076923	Preakness Basalt

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NJ Power & Light	25-11173	25226	7/17/1963	Mt. Airy Rd			215	57.8	35	11	1.521739	Towaco Formation
Petrucelli, Danial	25-09903	2522538	5/4/1961				212	46	18	40	0.3	Preakness Basalt
Weiss, Dion	25-08880	2523414	11/1/1959	Culberson Road			165	50	17	31	0.586207	Towaco Formation
Morrow, John	25-52379	2522892	5/13/1998	Somerville Rd	186	8.01	123	59.5	28	45		Preakness Basalt
Park, D.	25-12041	2522821	6/14/1964	Liberty Corner Rd			120	43.67	25	8	2.5	Preakness Basalt
Ortman, Howard	25-11888	2522597	3/25/1964	Liberty Corner Rd			421	50	6	7	0.024691	Preakness Basalt
Bernards Twp Sewerage Auth.	25-11357	2522937	7/3/1963				106.5	32	85	3.5	4.722222	Towaco Formation
De Coster, John	25-07283	2523453	11/19/1957	380 S. Finley Ave			140	37	15	23	1.25	Hook Mountain Basalt
Petrella, Angelo	25-03365	2522964	4/6/1954	Martinsville Rd			60	20	3	4	0.053571	Preakness Basalt
Coley, H.J	25-08434	2522896		Mountain Rd			385	30	15	21	0.083799	Preakness Basalt
Hibbert, Arthur	25-08181	2522692	12/30/1958	Lyons Rd			85	32.3				Hook Mountain Basalt
Wojnar, John	25-07805	2532326	1/25/1959	Mountain Rd			400	20	7	5		Preakness Basalt
Braselmann, Arthur	25-07626	2522666	4/7/1959	Sunset Lane			500	40	5	20	0.017857	Preakness Basalt
Stokes, Harold	25-07488	2522866	7/11/1958	Mountain Rd			719	25	5	150	0.055556	Preakness Basalt
Huhn, Concetta	25-07144	2533147	10/3/1957	Mt. Horab			90	18	10	16	0.15625	Preakness Basalt
Durkin, Charles	25-04302	2522613	7/2/1953				106	36.7	30	10	1.25	Preakness Basalt
Hussey, D.	25-00430	2523124	4/22/1949				70	50	20	7	13.33333	Boonton Formation
Abrahamson, Earl	25-00738	2523419	8/28/1950	Lake Rd			102	11.5	7.5	0	0.166667	Hook Mountain Basalt
Walbeck, Ray	25-00310	2523125	10/9/1948	Old Morristown Rd			87	33.8	32	15	1.28	Boonton Formation
Leary, Kevin	25-52131	2522892	3/26/1998	Pacer Court	187	18.04	440	50	4.5	20	0.01125	Preakness Basalt
Leary, Kevin	25-52130	2522519	4/30/1998	Whitenack Rd	104	19.03	300	50	7.5	40	0.03125	Towaco Formation
Van Holten Group	25-52091	2532313	4/7/1998	Hunter's Court	187	31.23	700	50	12	20	0.021429	Preakness Basalt
Henderson, Anna	25-01457	2522857	1/7/1952				396	11	1.5	63	0.017241	Preakness Basalt
Someridge Corp	25-02336	2523181	3/4/1956				259	26.5	60	60	1.276596	Towaco Formation
Wessling, Carl	25-02059	2523127	10/25/1952	Old Farm Rd			190	44.3	20	40	0.333333	Boonton Formation
Brenner, Andrew	25-51917	2513785	3/12/1998	113 Hardscrabble Rd	4	51	360	52	20	0		Precambrian
White, Ken	25-51779	2522695	1/6/1998	Lyons Rd	106	124	198	59.5	20	40		Hook Mountain Basalt
Van Holten Group	25-51654	2532321	12/12/1997	Hunters Court	187	31.21	800	50	10	100	0.015152	Preakness Basalt
Milito, Louis	25-51570	2522943	6/17/1998	91 Milito Way	174.16	32.01	660	50	4	80	0.007692	Preakness Basalt
Dello Rosso, Anthony	25-51458	2522624	3/6/1998	Meeker Road	90	6.06	500	52	12	38	0.107143	Preakness Basalt
Fazio, Peter	25-51352	2522654	11/19/1997	Queen Anne Dr	124	1.02	123	49	20	30		Towaco Formation
Tiger, John	25-51315	2522892	1/7/1998	80 Somerville Rd	186	1	198	59.5	16	40		Preakness Basalt
Van Holten Group	25-50951	2532321	8/1/1997	239 Mountain Rd	187	31.16	620	50	6	70	0.011765	Preakness Basalt
Bernards Township	25-64477	2523474	1/18/2005	Valley Rd-Pleasant Valley Park	155	59	400	60	400	30	1.290323	Towaco Formation

Water: A Natural Renewable Resource

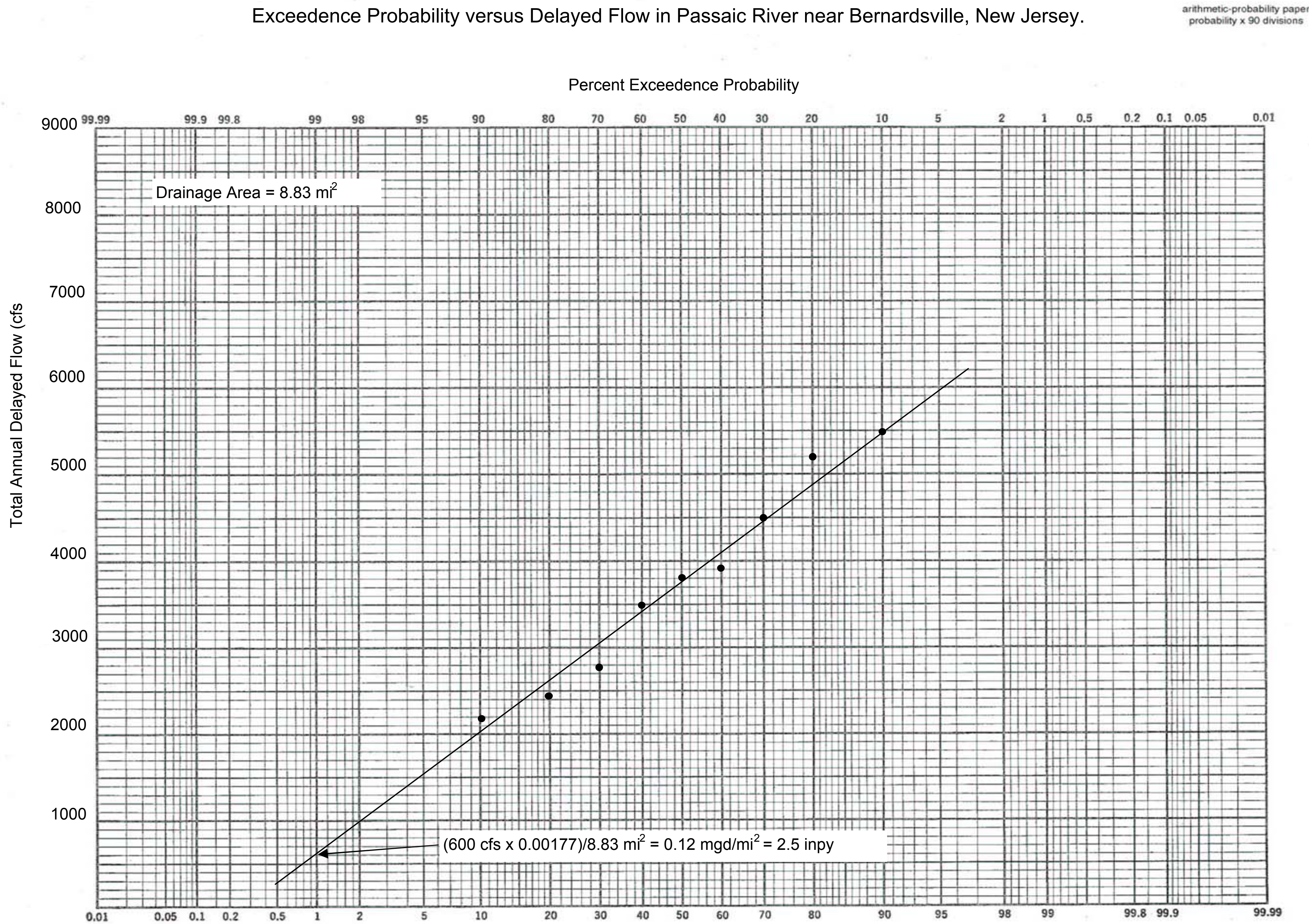
APPENDIX C:
RESULTS OF POSTEN (1984) METHOD ANALYSES FOR STREAMS NEAR BERNARDS TOWNSHIP, SOMERSET COUNTY, NEW JERSEY

USGS 01378690 Passaic River near Bernardsville NJ

Year	Total Annual (cfs)	Total Delayed (cfs)	Percent Delayed
1968	4,847.4	2,398.2	49.5%
1969	4,141.5	2,151.7	52.0%
1970	4,910.9	2,760.5	56.2%
1971	7,374.7	3,493.2	47.4%
1972	9,454.9	5,480.9	58.0%
1973	9,215.7	5,196.1	56.4%
1974	6,661.4	3,907.1	58.7%
1975	8,690.1	4,491.1	51.7%
1976	6,318.7	3,796.6	60.1%

Rank	Year	Total Delayed (cfs)	Exceedance Probability (%) (p=m/(n+1)
1	1972	5480.9	10.0%
2	1973	5196.1	20.0%
3	1975	4491.1	30.0%
4	1974	3907.1	40.0%
5	1976	3796.6	50.0%
6	1971	3493.2	60.0%
7	1970	2760.5	70.0%
8	1968	2398.2	80.0%
9	1969	2151.7	90.0%

Exceedence Probability versus Delayed Flow in Passaic River near Bernardsville, New Jersey.

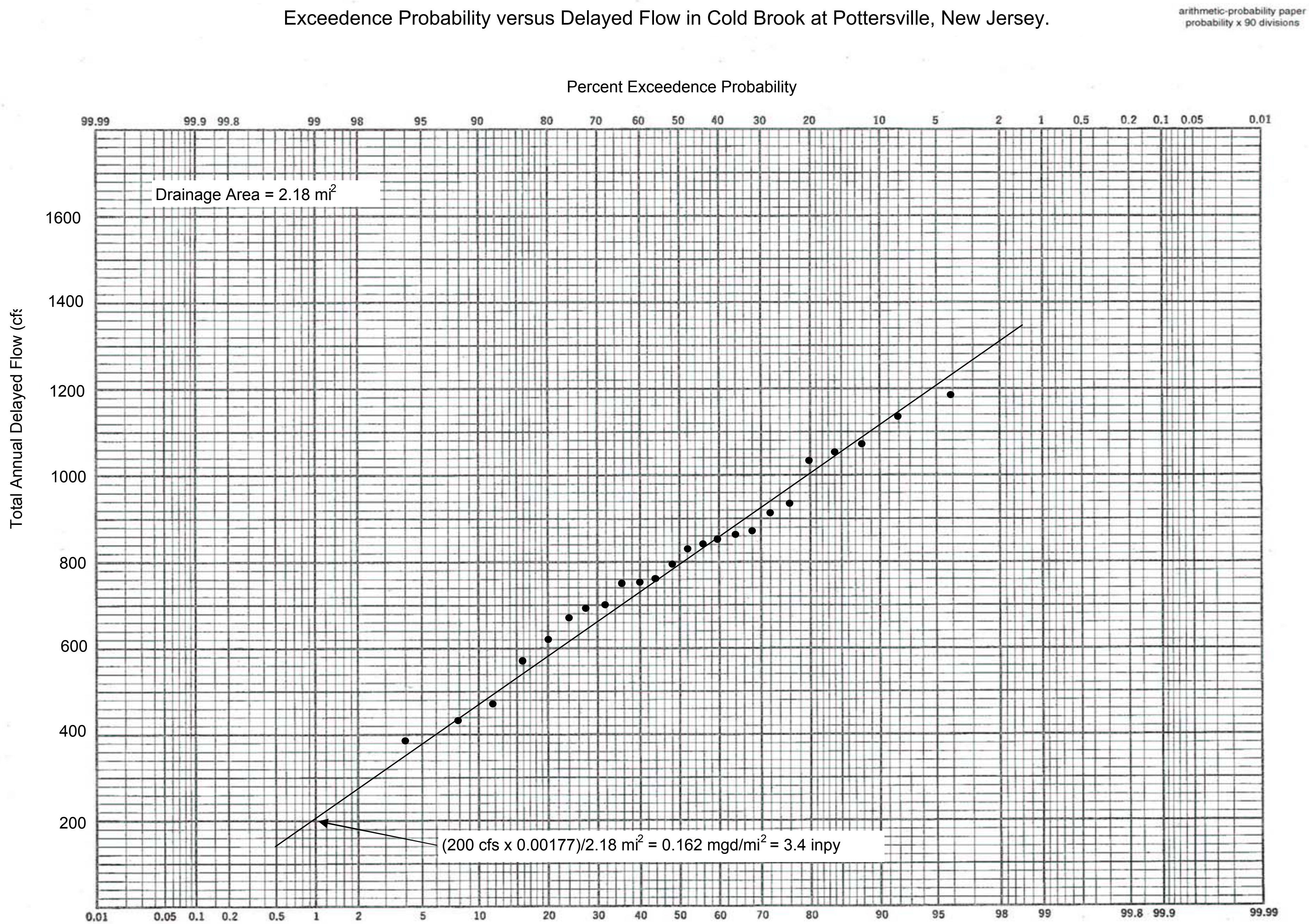


01399510 Upper Cold Brook near Pottersville New Jersey

Year	Total Annual (cfs)	Total Delayed (cfs)	Percent Delayed
1973	1,899.2	1,053.0	55.4%
1974	1,312.4	761.5	58.0%
1975	1,760.1	928.6	52.8%
1976	1,144.1	618.8	54.1%
1977	961.8	466.9	48.5%
1978	1,712.0	906.5	53.0%
1979	1,636.4	695.1	42.5%
1980	1,363.8	788.6	57.8%
1981	748.2	382.2	51.1%
1982	1,151.0	665.6	57.8%
1983	1,507.3	857.9	56.9%
1984	2,588.8	1,182.4	45.7%
1985	636.7	435.7	68.4%
1986	1,200.5	687.8	57.3%
1987	1,427.9	838.0	58.7%
1988	1,246.7	750.8	60.2%
1989	1,523.8	833.7	54.7%
1990	1,400.3	868.2	62.0%
1991	1,630.0	1,066.5	65.4%
1992	1,151.7	745.8	64.8%
1993	1,759.8	1,034.9	58.8%
1994	1,681.8	849.5	50.5%
1995	855.3	568.8	66.5%
1996	1,954.8	1,131.3	57.9%

Rank	Year	Total Delayed (cfs)	Exceedance Probability (%) (p=m/(n+1)
1	1984	1,182.4	4.0%
2	1996	1,131.3	8.0%
3	1991	1,066.5	12.0%
4	1973	1,053.0	16.0%
5	1993	1,034.9	20.0%
6	1975	928.6	24.0%
7	1978	906.5	28.0%
8	1990	868.2	32.0%
9	1983	857.9	36.0%
10	1994	849.5	40.0%
11	1987	838.0	44.0%
12	1989	833.7	48.0%
13	1980	788.6	52.0%
14	1974	761.5	56.0%
15	1988	750.8	60.0%
16	1992	745.8	64.0%
17	1979	695.1	68.0%
18	1986	687.8	72.0%
19	1982	665.6	76.0%
20	1976	618.8	80.0%
21	1995	568.8	84.0%
22	1977	466.9	88.0%
23	1985	435.7	92.0%
24	1981	382.2	96.0%

Exceedence Probability versus Delayed Flow in Cold Brook at Pottersville, New Jersey.

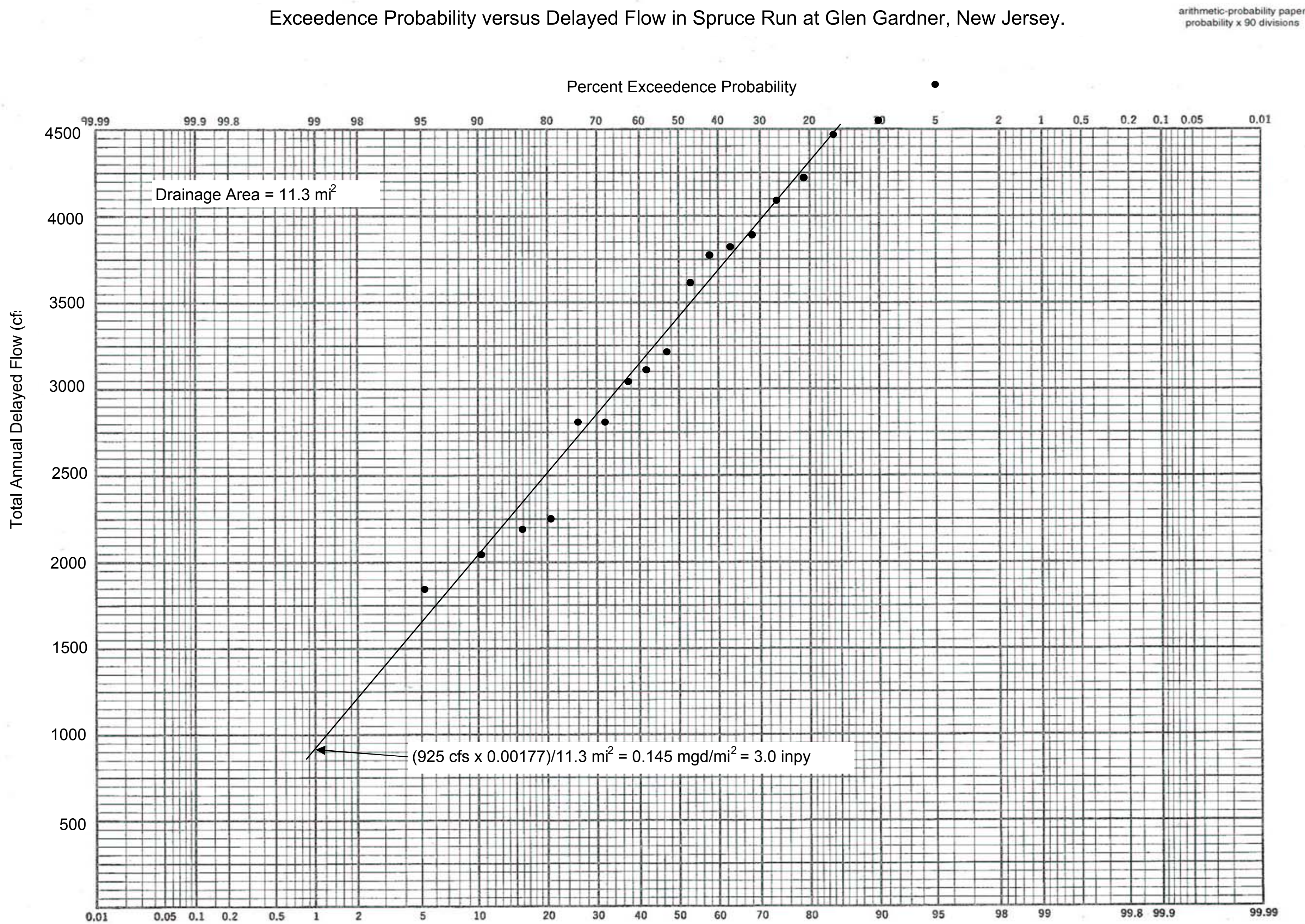


01396580 SPRUCE RUN AT GLEN GARDNER New Jersey

Year	Total Annual (cfs)	Total Delayed (cfs)	Percent Delayed
1979	10,283.5	3,605.6	35.1%
1980	7,598.3	4,223.3	55.6%
1981	4,817.8	2,185.0	45.4%
1982	6,073.8	2,806.4	46.2%
1983	7,210.8	2,816.3	39.1%
1984	12,170.0	4,462.0	36.7%
1985	4,861.8	2,031.3	41.8%
1986	7,753.0	4,080.1	52.6%
1987	8,082.3	3,767.7	46.6%
1988	6,629.2	3,211.5	48.4%
1993	8,074.3	3,892.3	48.2%
1994	9,816.6	3,824.7	39.0%
1995	4,116.7	2,248.7	54.6%
1996	10,279.8	4,861.9	47.3%
1997	9,971.8	4,536.0	45.5%
1998	6,636.4	3,039.8	45.8%
1999	4,703.2	1,838.0	39.1%
2000	7,107.1	3,108.1	43.7%

Rank	Year	Total Delayed (cfs)	Exceedance Probability (%) (p=m/(n+1)
1	1996	4,861.9	5.3%
2	1997	4,536.0	10.5%
3	1984	4,462.0	15.8%
4	1980	4,223.3	21.1%
5	1986	4,080.1	26.3%
6	1993	3,892.3	31.6%
7	1994	3,824.7	36.8%
8	1987	3,767.7	42.1%
9	1979	3,605.6	47.4%
10	1988	3,211.5	52.6%
11	2000	3,108.1	57.9%
12	1998	3,039.8	63.2%
13	1983	2,816.3	68.4%
14	1982	2,806.4	73.7%
15	1995	2,248.7	78.9%
16	1981	2,185.0	84.2%
17	1985	2,031.3	89.5%
18	1999	1,838.0	94.7%

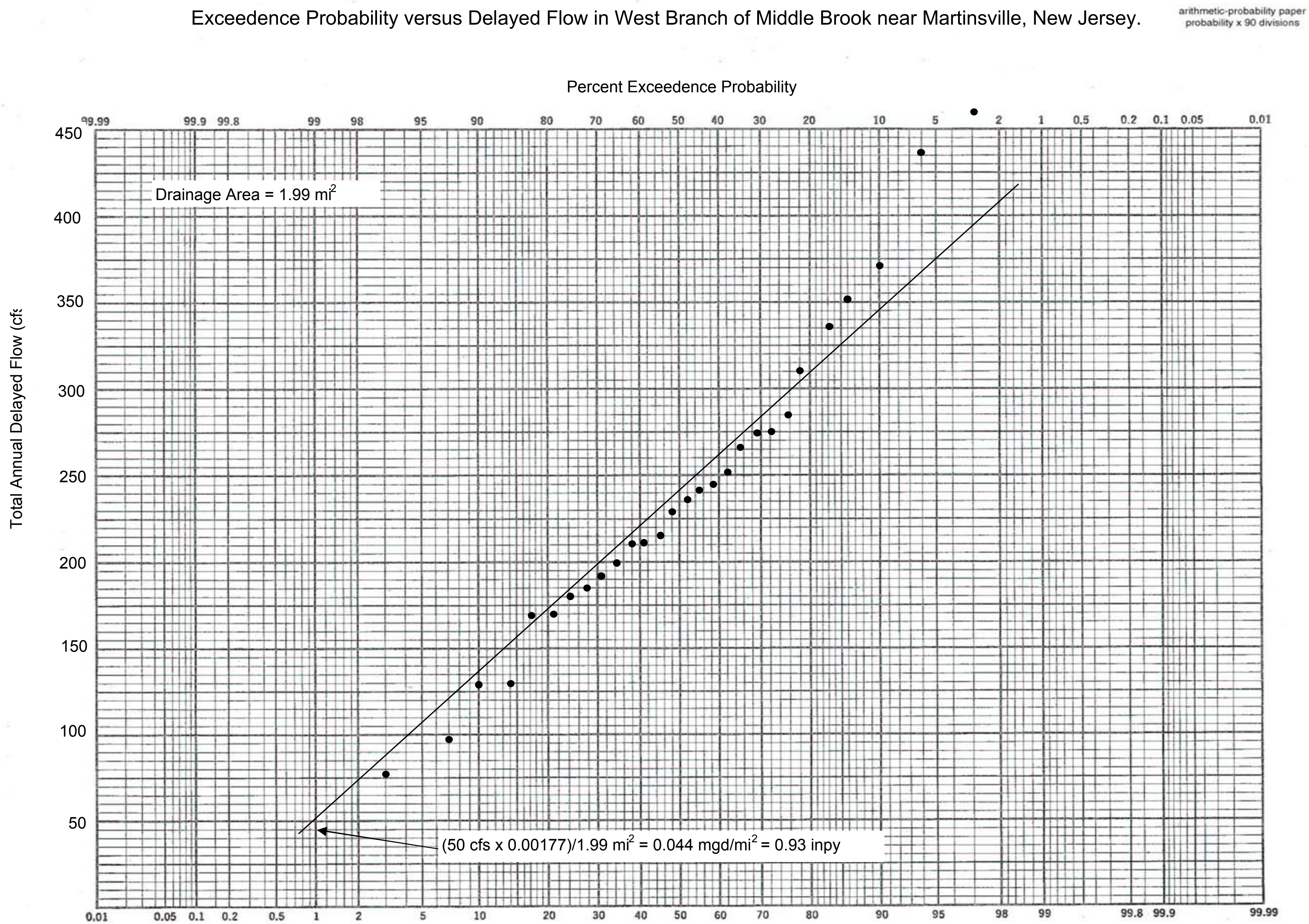
Exceedence Probability versus Delayed Flow in Spruce Run at Glen Gardner, New Jersey.



01403150 West Branch Middle Brook near Martinsville, NJ

Year	Total Annual (cfs)	Total Delayed (cfs)	Percent Delayed
1980	939.7	284.9	30.3%
1981	685.9	97.2	14.2%
1982	1,157.7	178.7	15.4%
1983	1,181.2	274.2	23.2%
1984	1,848.8	243.9	13.2%
1985	782.9	128.0	16.4%
1986	1,258.0	213.2	16.9%
1987	1,499.7	235.2	15.7%
1988	1,149.0	183.8	16.0%
1989	2,001.0	251.1	12.5%
1990	1,859.4	239.7	12.9%
1991	1,857.3	274.8	14.8%
1992	875.0	215.2	24.6%
1993	1,647.9	213.0	12.9%
1994	1,710.0	192.6	11.3%
1995	793.6	197.6	24.9%
1996	1,814.1	437.6	24.1%
1997	1,488.6	308.6	20.7%
1998	1,088.8	168.3	15.5%
1999	1,048.3	129.1	12.3%
2000	869.1	228.4	26.3%
2001	787.0	168.3	21.4%
2002	279.9	77.3	27.6%
2003	1,231.0	266.2	21.6%
2004	1,426.9	334.1	23.4%
2005	1,018.5	351.9	34.5%
2006	1,283.8	371.0	28.9%
2007	1,521.1	461.4	30.3%

Ranking	Year	Total Delayed (cfs)	Exceedance Probability (%) (p=m/(n+1)
1	2007	461.4	3.4%
2	1996	437.6	6.9%
3	2006	371.0	10.3%
4	2005	351.9	13.8%
5	2004	334.1	17.2%
6	1997	308.6	20.7%
7	1980	284.9	24.1%
8	1991	274.8	27.6%
9	1983	274.2	31.0%
10	2003	266.2	34.5%
11	1989	251.1	37.9%
12	1984	243.9	41.4%
13	1990	239.7	44.8%
14	1987	235.2	48.3%
15	2000	228.4	51.7%
16	1992	215.2	55.2%
17	1986	213.2	58.6%
18	1993	213.0	62.1%
19	1995	197.6	65.5%
20	1994	192.6	69.0%
21	1988	183.8	72.4%
22	1982	178.7	75.9%
23	1998	168.3	79.3%
24	2001	168.3	82.8%
25	1999	129.1	86.2%
26	1985	128.0	89.7%
27	1981	97.2	93.1%
28	2002	77.3	96.6%



Exceedence Probability versus Delayed Flow in West Branch of Middle Brook near Martinsville, New Jersey.
arithmetic-probability paper
probability x 90 divisions
Percent Exceedence Probability
Total Annual Delayed Flow (cfs
Drainage Area = 1.99 mi^2
(50 cfs x 0.00177)/1.99 mi^2 = 0.044 mgd/mi^2 = 0.93 inpy