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SOURLAND MOUNTAIN GROUND WATER MANAGEMENT REPORT

Prepared for

The New Jersey Department of Environmental Protection
Division of Water Resources

by the

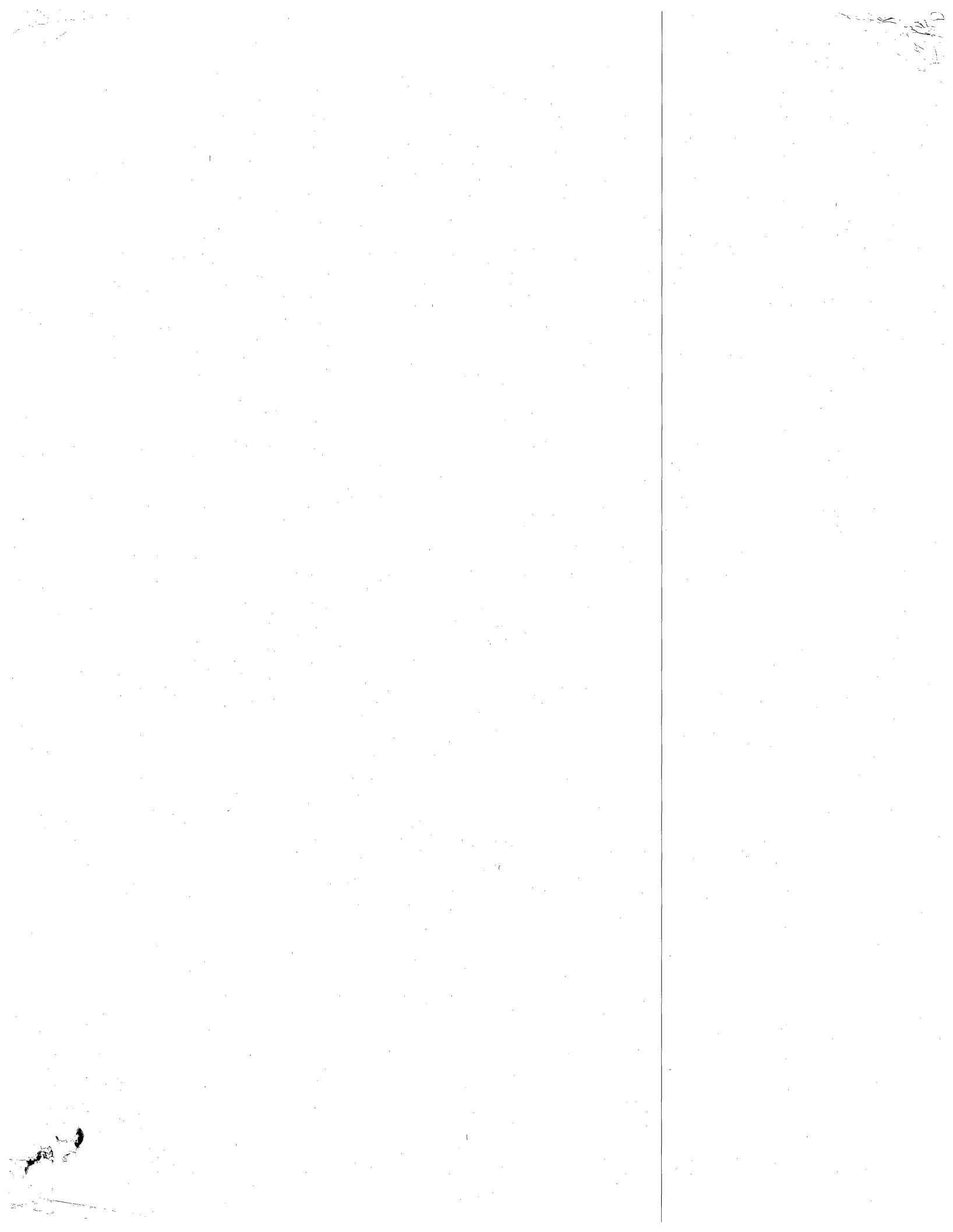
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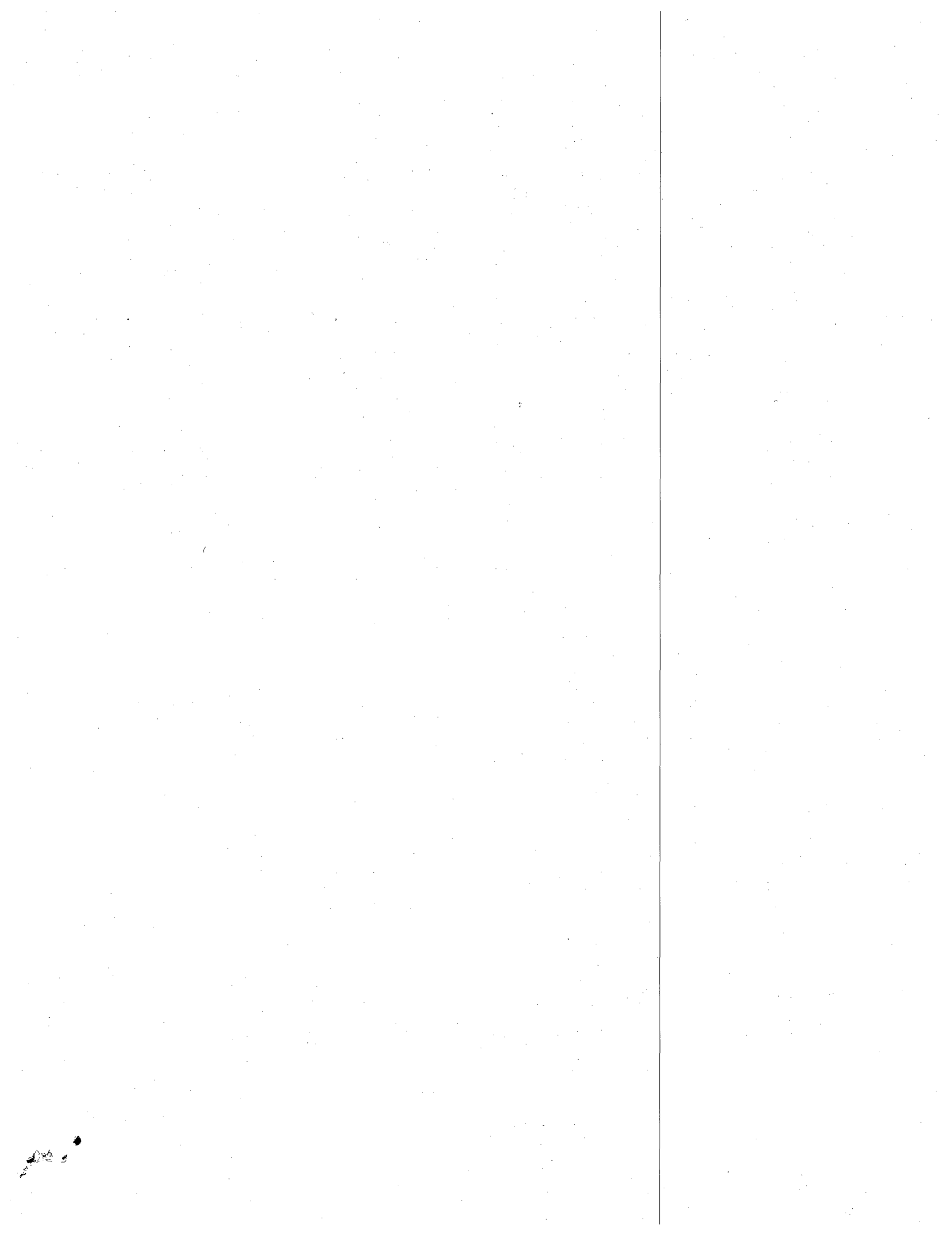
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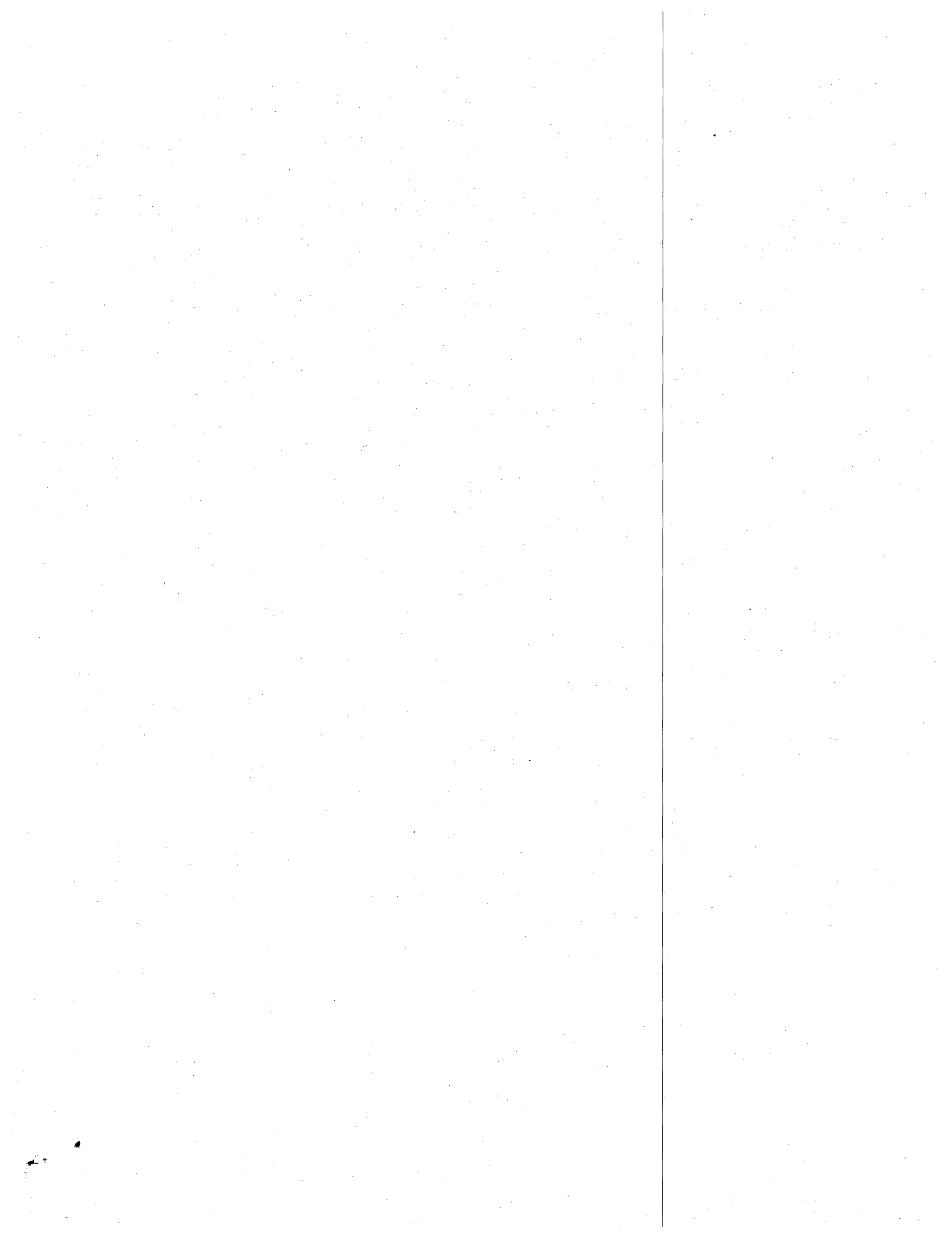
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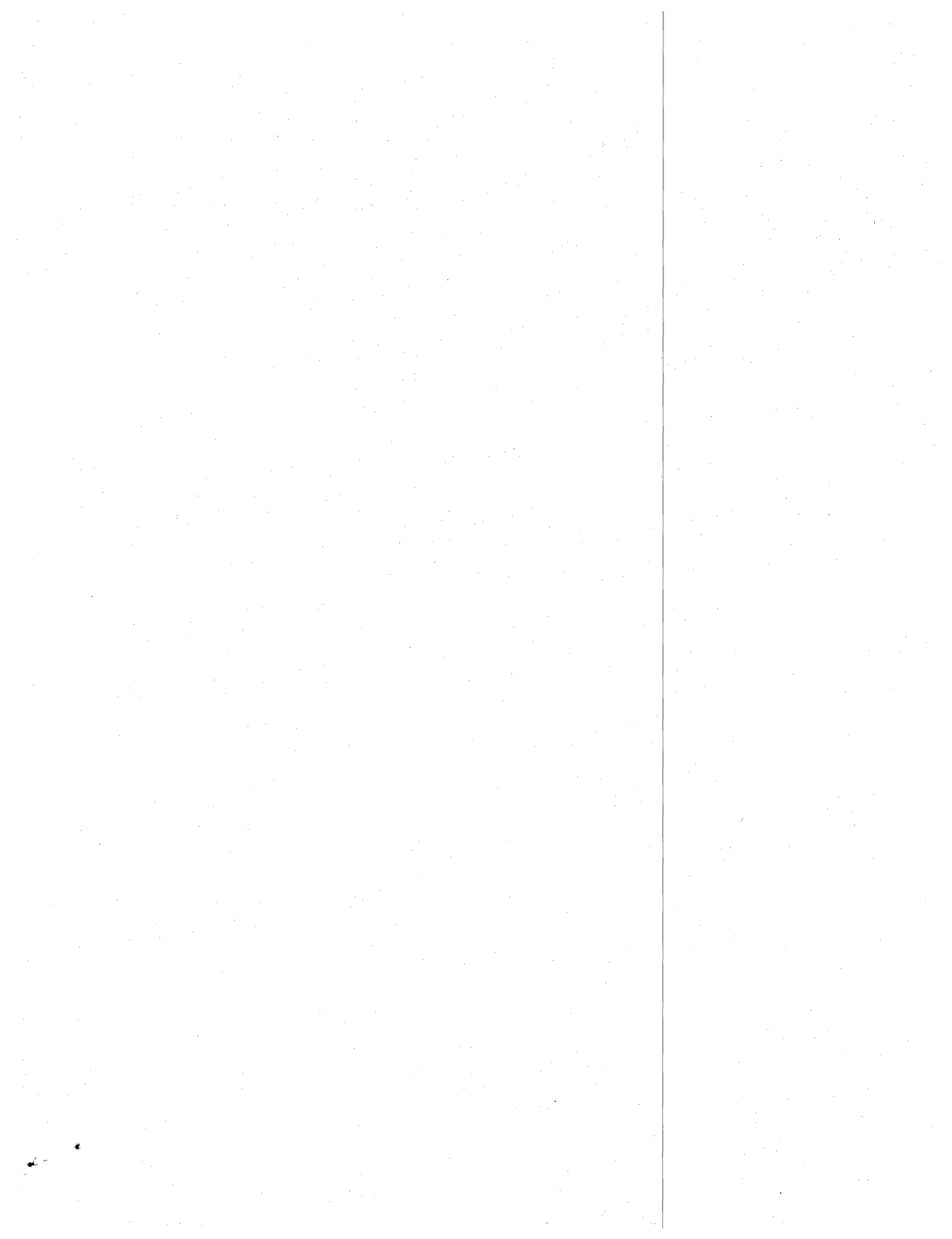
This report was submitted to the New Jersey Department of Environmental Protection by the MSM Regional Study Council, Inc. based on technical analysis by Robert M. Hordon, Ph.D., Water Resources Consultant, Kendall Park, and legal analysis by Lewis Goldshore, Esq. and Marsha Wolf, Esq., Trenton.

The idea of a regional basis for ground water resource management in the Sourland Mountain area was first proposed in 1979 by William Queale, planning consultant to several municipalities that share the Sourland Mountain area. Van Zandt Williams, then Chairman of the Hillsborough Township Planning Board, and Thomas Peterson, then Hillsborough Township Planning Director, were instrumental in defining the project and securing Hillsborough Township's support. Thanks are also due to B. Budd Chavooshian of the Department of Environmental Resources, Cook College, Rutgers University, who was also instrumental in developing the project.

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MSM Regional Study Council staff responsible for preparation of this report were Samuel M. Hamill, Jr., Executive Director (Project Director); Elizabeth Lyons, Research Assistant; Sylvia Macirowski, Research Assistant; and Jeff Murphree, Cartographer. The report was typed by Iris Barr and Barbara Thomsen.



SOURLAND MOUNTAIN GROUND WATER MANAGEMENT REPORT

I. INTRODUCTION AND SUMMARY

New Jersey's ground water supply has, in past years, been taken pretty much for granted. But recently public attention has begun to focus on this invisible but vital resource because of the threat and reality of contamination in many parts of the state. Some protective changes in public policy have resulted.

Now, in many parts of New Jersey, there exists a new set of circumstances that shows signs of stressing the very supply of water in the ground, rather than its quality. The circumstances result from the fact that exurban growth is occurring over areas underlain by hard rock, where there is very little ground water. And, this development is occurring at densities far too low to allow the economic provision of public water service.

In central New Jersey there has been significant growth in employment along the major suburban highway corridors - Route 287, Route 22, Route 1, for example. With growing employment has come a corresponding demand for housing in outlying rural townships. Rural residential developments are generally served by on-site wells and septic systems.

Such an area is the vicinity of the Sourland Mountain in Somerset, Mercer, and Hunterdon Counties. Here, residential development has been accompanied by a growing number of documented instances of well failure - a cause for serious public concern if one considers the expense of drilling a well and building a home only to find that the well is not adequate and public water unavailable.

A shift in the type of agricultural production toward more intensive cultivation of fruits and vegetables may also compound the ground water supply problem in the future. These crops require irrigation, and a new "trickle" irrigation technology has made intensive production feasible in locations where it would not have been before, assuming a water supply is available.

In Bucks and Montgomery Counties, Pennsylvania, where exurban development has proceeded farther than it has in central New Jersey, ground water withdrawal already exceeds the capability of the aquifer to replenish itself.¹ Public supply wells are in some cases threatened, and stream flows have diminished. This is particularly significant because geologic conditions in these counties are very similar to those in central New Jersey.

Before turning to the specifics of this study, a review of some important characteristics of the ground water system is in order. First, ground and surface water are connected as elements of what we have come to know as the natural water cycle (see Figure 1). While there may be a large amount of water in storage in the ground, this "reservoir" is replenished only by some fraction of the rainfall that makes its way down through the soil. If "recharge" is not maintained, the ground water reservoir will diminish. Likewise, the reservoir will diminish if an excessive amount is withdrawn through wells.

Second, ground water feeds streams. In the summer months, the flow of ground water is virtually the only source of stream flow. Thus, surface water and ground water are intimately interrelated, though the latter may be invisible.

The Sourland Mountain study area is underlain by hard rocks, with very little

¹R. E. Wright Associates, Inc. Special Ground Water Study of the Middle Delaware River Basin, Study Area II, for the Delaware River Basin Commission. See Volume IV, plate 22.

room for storage of water except in areas where the rock may be fractured. Ground water availability, while low overall, is highly variable from place to place. Also, while geological maps may appear to delineate areas of varying rock types very precisely, these areas are for the most part poorly differentiated - blending into one another gradually. From a ground water supply standpoint, some areas may be very much better off than the map would indicate while other areas may be very much worse off.

Thus, the challenge for public policy is to evolve effective means of regulating ground water withdrawal under circumstances where very little is accurately known about the limits of the natural system.

In 1981, the New Jersey Legislature declared that ". . . the water resources of the state are public assets of the State held in trust for its citizens . . ." and ". . . that ownership of these assets is in the state as trustee of the people;"² Our ground water supply cries out for responsible governmental management. With so limited a supply, at least in the area of this study and similar areas, and with a growing demand, the time has come for the various levels of government to exercise their responsibility. The risk that overdevelopment may not be evident for many years in the future underscores the need for effective action now.

Fortunately, as this report points out, the powers of government under existing statutes are for the most part equal to the task. While state government has authority under the Water Supply Management Act of 1981 to regulate ground water withdrawals, local government has similar powers. Because the use of ground water is so intimately related to land development, which at present falls under

². Water Supply Management Act of 1981, N.J.S.A. 53:1:01 et seq.

the purview of local government administration in New Jersey, the greater burden of ground water regulation appropriately falls on municipal shoulders.

This report was initiated as a result of documented instances of well depletion in Hillsborough and Hopewell Townships. While the problems occurred in the area known as the Sourland Mountain, a somewhat larger area was included in the study in order to obtain a basis for comparison. Further, the New Jersey Department of Environmental Protection asked for a methodology that would be of general applicability to areas elsewhere in New Jersey where similar problems have occurred or are likely to occur.

This report commences with a general description of the ground water system. It then reviews the various data available regarding the water resources of the study area. Section II concludes with recommendations regarding the amount of water that can be withdrawn from the ground on a unit area basis.

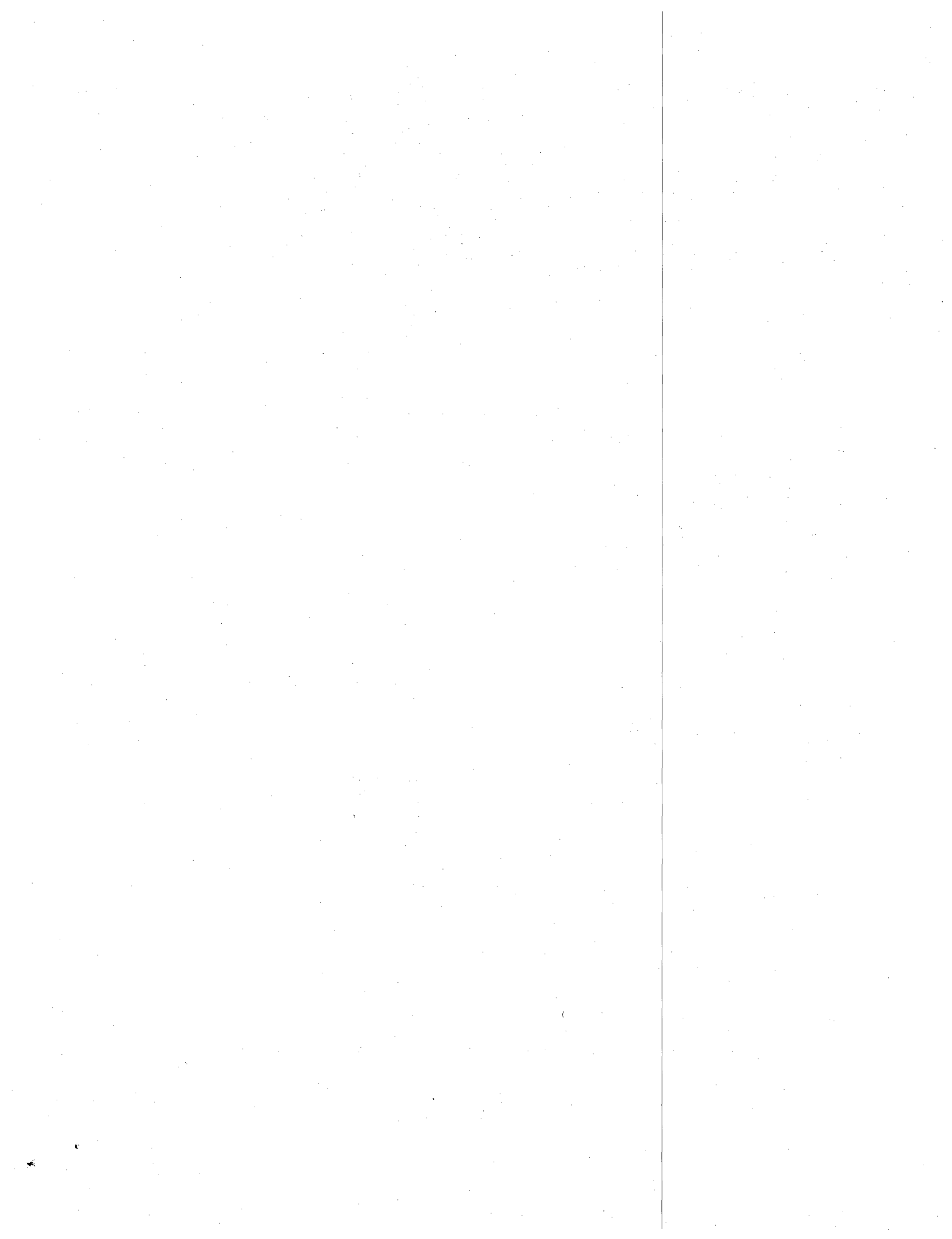
Section III is a discussion of the state and local government authority for the regulation of ground water resources. Section IV presents elements of a model ordinance that would designate special ground water protection areas and specify local government procedures for regulating withdrawal of ground water within them.

The principal findings and recommendations of this report are summarized below.

- The vicinity of the Sourland Mountain area in Somerset, Mercer, and Hunterdon Counties has one of the poorest ground water supplies in New Jersey.
- With instances of well depletion in Hillsborough and Hopewell Townships and reports of diminished stream flows in some areas, there is evidence that over-development is beginning to stress the ground water supply.

- There is considerable variability in study area rock types, and delineation of formations is not always as precise as may appear on a map.
- Areas underlain by diabase and argillite have significantly lower ground water yields than areas underlain by other rock types. These yields are lower than had previously been estimated. These areas should be designated "low ground water yield areas" by the municipalities.
- Within "low ground water yield areas" low average development densities should be adopted in municipal planning and zoning regulations. Because these broad averages do not adequately reflect the considerable variability of natural conditions, special review procedures for development applications should be adopted by the municipalities.
- The New Jersey Department of Environmental Protection should adopt an administrative procedure for making its technical resources available to the municipalities in the review of development applications on a timely basis.
- Regulatory procedures providing for the designation of special ground water protection areas and the application of special development review procedures within them in the event of municipal failure to protect the ground water resource, should be adopted by the Department of Environmental Protection.

It should be emphasized that there is very little data available regarding ground water in the Sourlands study area and that little is known about the effect of land development upon this critical resource. Even the measures recommended in this report may not prove adequate to protect the resource from irreparable harm caused by overdevelopment. Only cautious policies by municipal and state regulatory agencies, a commitment to increased monitoring and data collection, and increased attention by policy-makers will lead to effective public policy in the area of ground water management.



II. GROUND WATER HYDROLOGY

A. Ground Water Hydrology: An Introduction

Ground water is that fraction of the precipitation on the land surface that has worked its way downward by gravity through the soil and into the underlying bedrock. The source of ground water in the study area is the precipitation that falls within the confines of the area. It is presumed that the ground water divides are the same as the surface water divides; therefore, the amount of water entering the area from outside the study area boundaries may be considered to be almost zero.

Precipitation is part of the hydrologic cycle (see Figure 1). The distribution of precipitation in the hydrologic cycle can be explained by the hydrologic budget equation, as follows:

$$P + E + R + \Delta S$$

where P = precipitation

E = evapotranspiration

R = total runoff or streamflow

ΔS = change in ground-water storage

The zone of saturation consists of rock fractures and pores filled with ground water (see Figure 2). The zone of aeration, in which water does not

Note: This section was researched and written by Robert M. Hordon, PhD.

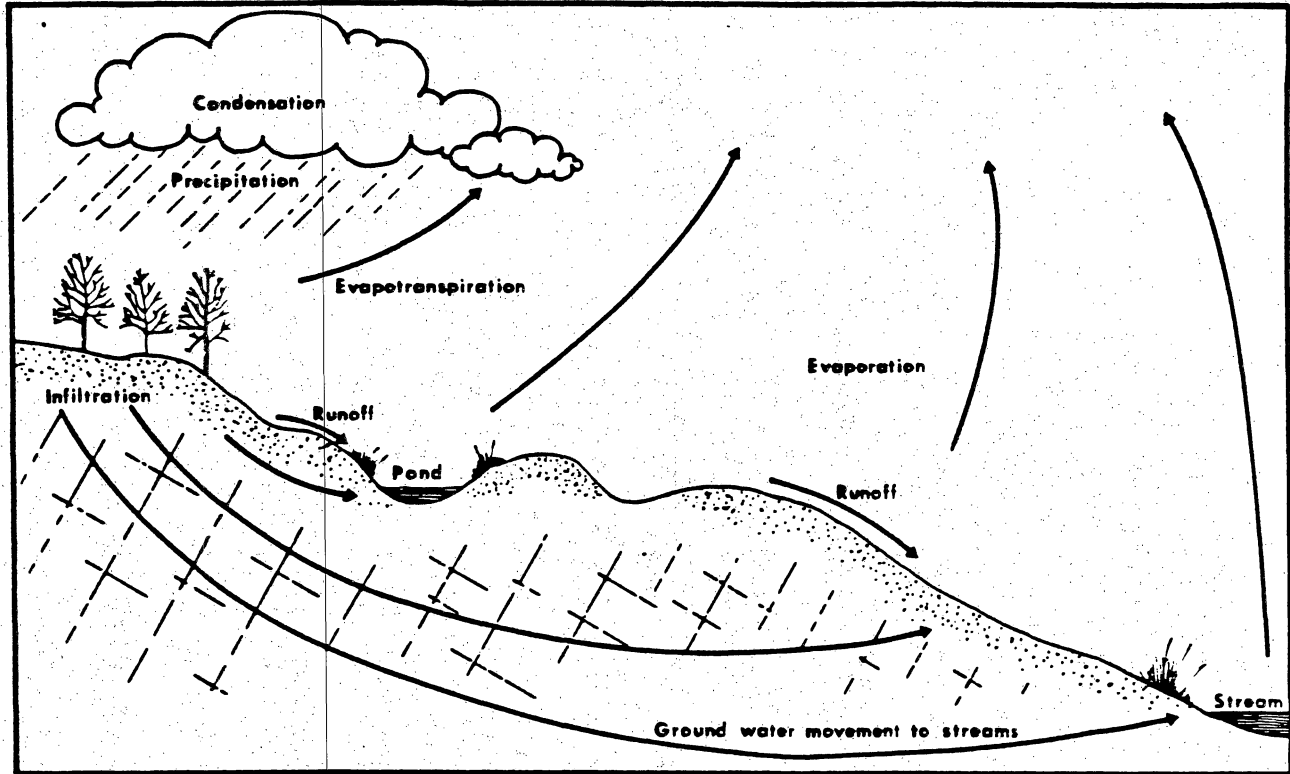


Figure 1. Hydrologic Cycle.

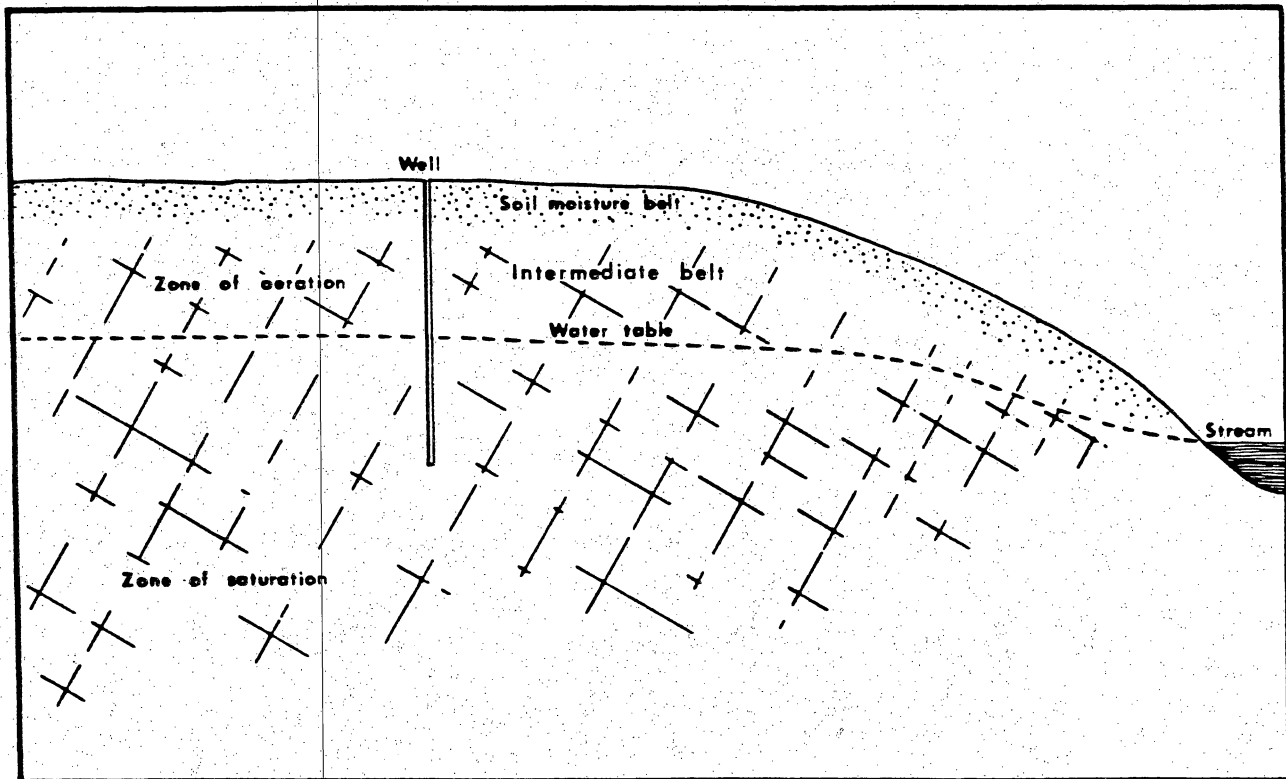


Figure 2. Subsurface Water Zones.

fully saturate the pores, lies above the zone of saturation. Water is held in the soil-moisture belt by capillary force in tiny films adhering to the soil particles. The same condition occurs in the intermediate belt within the zone of aeration. The reason for distinguishing these two belts is that the soil-moisture belt is usable by plants whereas the intermediate belt is too deep for capillary water to be returned to the atmosphere by evapotranspiration (Strahler, 1975).

The zone of aeration may be very shallow or even missing in swampy areas, or it can be several hundred feet thick in hilly regions where the water table is far below the surface.

The subsurface part of the hydrologic cycle is completed when the ground water seeps out along lines or zones where the ground surface is intersected by the water table, as in stream channels and lake floors. Over time, the ground water must leave the area to balance the new inputs of water which is percolating through the zone of aeration.

The theoretical paths of ground water flow are shown in Figure 3. Ground water follows paths which are curved concavely upward. Water that enters the slope midway between the divide at the top of the hill and the stream flows towards the stream valley. The most rapid flow occurs close to the line of discharge in the stream, where the arrows converge (see Figure 3).

The water table marks the upper boundary of the zone of saturation and conforms to the surface topography (see Figure 4). The water table will rise after recharge during a wet period and decline during a long drought.

Unconfined ground water in contact with the atmosphere occurs under water-

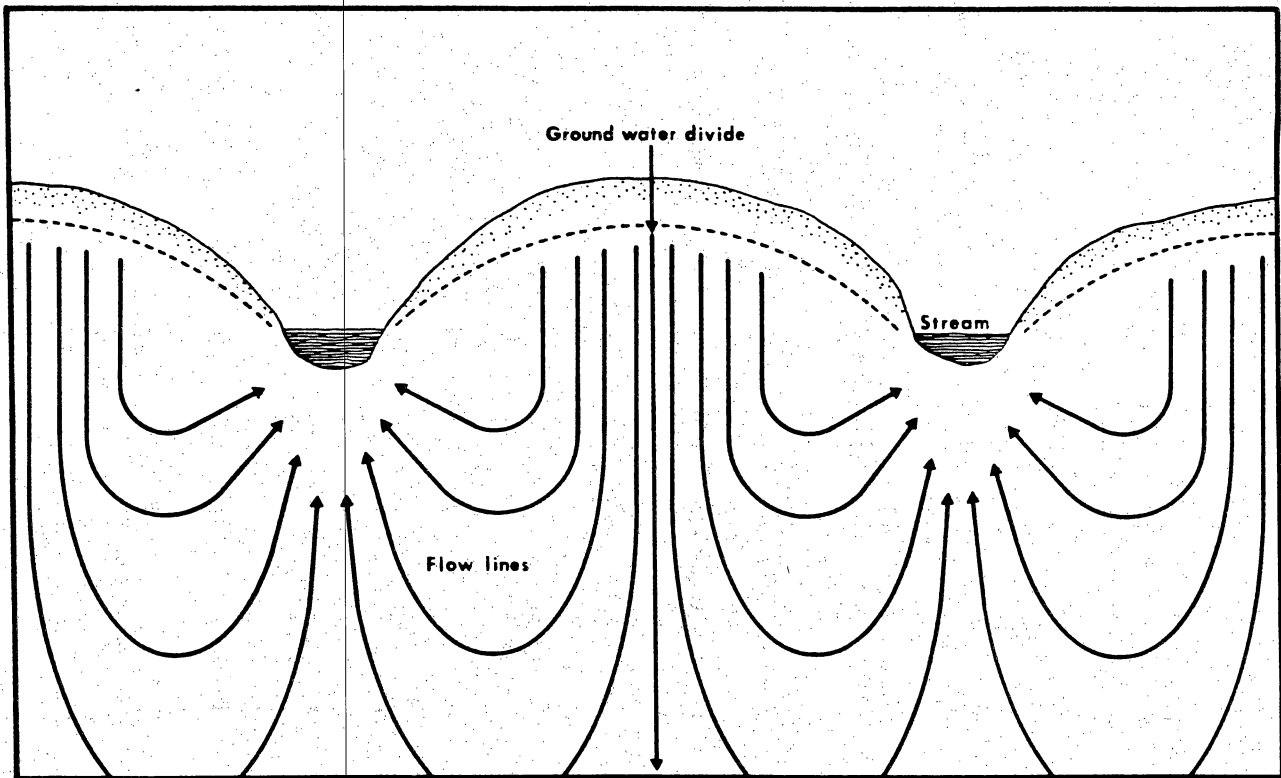


Figure 3. Theoretical Paths of Ground Water Flow.

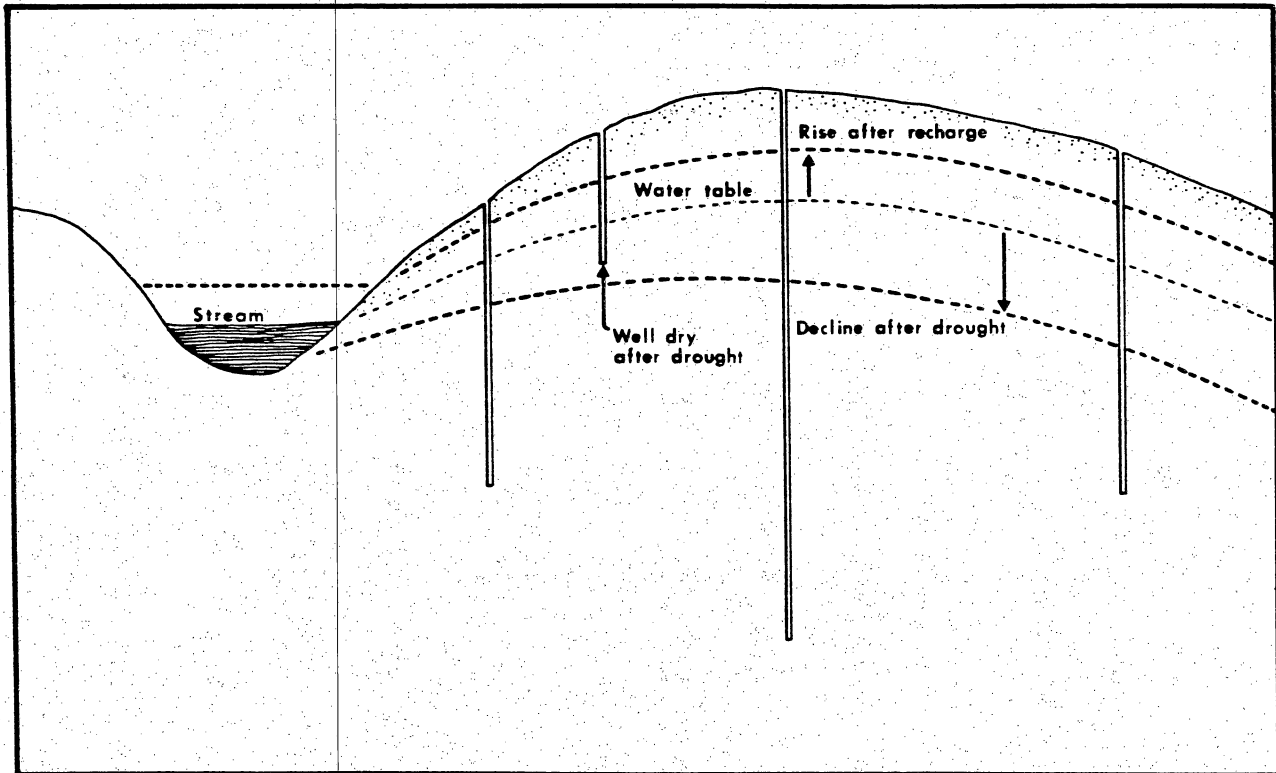


Figure 4. Water Table Fluctuations.

table conditions. Variations in precipitation, evapotranspiration, and pumping will cause water level fluctuations in a water-table well.

Ground water can also be confined under pressure beneath a relatively impermeable zone or formation (aquiclude), resulting in artesian conditions. The piezometric surface is the level to which the water would rise in a well tapping an artesian or confined aquifer.

In fractured rock systems, water in the lower fractures may be partially confined. This situation creates semi-artesian (or semi-confined) conditions. Thus, ground water can exist in an area in a combination of unconfined, semi-confined and confined conditions. This results in increased difficulty for predicting ground-water movement.

Porosity and permeability are important properties of rocks that relate directly to the occurrence and movement of ground-water. Porosity is the percentage of open space in a rock and is therefore related to the amount of water that can be stored therein. Permeability refers to the ease of water transfer through a given earth material based upon the interconnection of the open spaces in the material.

Consolidated rock formations have generally low porosities as compared to unconsolidated coastal plain or glacial outwash deposits. Most of the water in consolidated formations is contained in the cracks and fractures within the rock (which is called "secondary porosity"). Because most of the cracks and fractures are small and poorly interconnected within these formations, permeability is low.

Ground water generally moves vertically downward in the zone of aeration.

Below the water table in the zone of saturation, it moves laterally to natural discharge points along the stream valleys.

As water is pumped from a well, the water level in the well drops and the adjacent water table is lowered in the shape of a conical surface which is called the cone of depression (see Figure 5). The height of the cone of depression is called the drawdown. Wells that are too close can result in intersecting cones of depression which can lower the regional water table.

A well can interfere with another well by affecting its water level (see Figure 6). The extent of the interference is difficult to predict in fractured rock formations, since the degree of interconnection and the alignment of fractures is generally now known in sufficient detail. For example, Kasabach (1966) refers to a pumping test in weathered precambrian crystalline rocks in Tewksbury Township in Hunterdon County where a well 450 feet away from a pumped well was affected (i.e., water level decline).

B. Geology and Hydrology Of The Study Area

Physiographically, New Jersey may be divided into four distinct "provinces": 1) the Coastal Plain, 2) the Piedmont Plain, 3) the Highlands, and 4) the Appalachian Ridge and Valley Section (see Figure 7).

The Piedmont Plain borders the Coastal Plain on the northwest and forms the continuation from the southern Atlantic states of a dissected plateau area, although in New Jersey it bears a closer resemblance to a plain than a plateau.

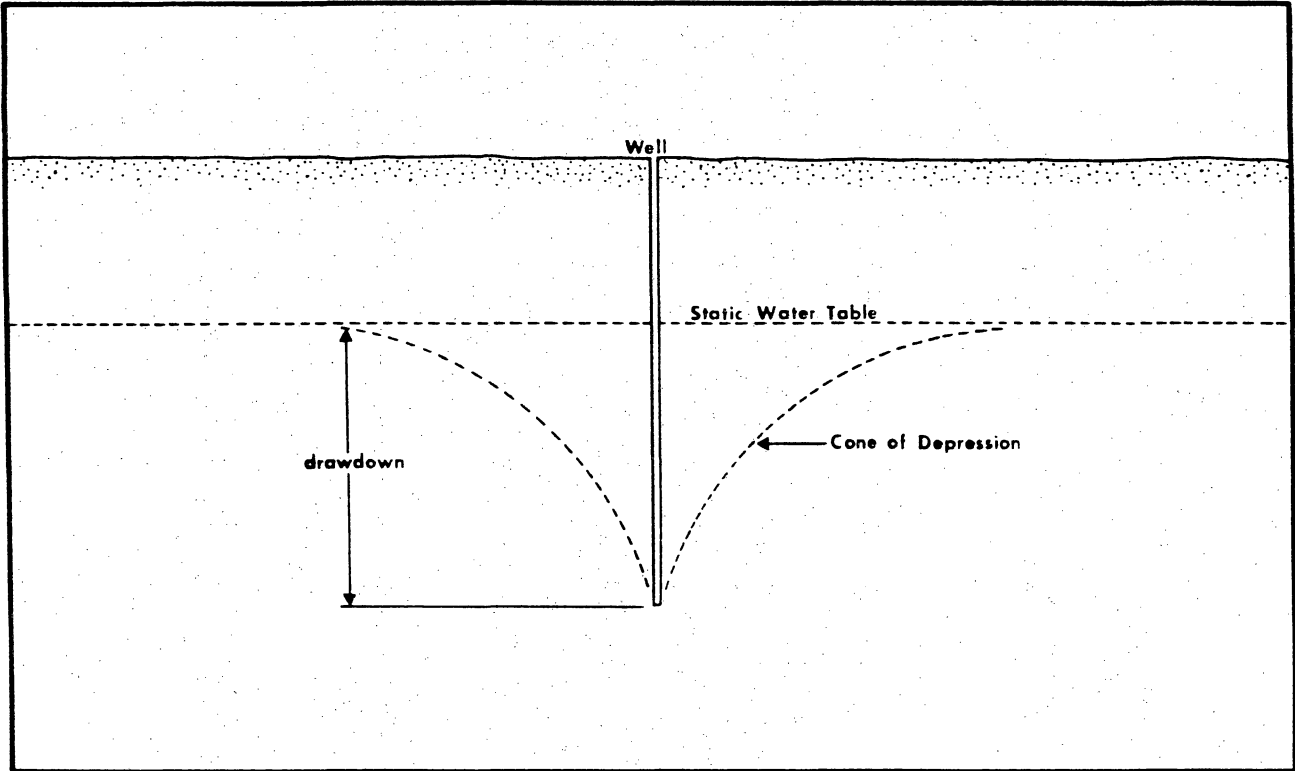


Figure 5. Drawdown and Cone of Depression in a Pumped Well.

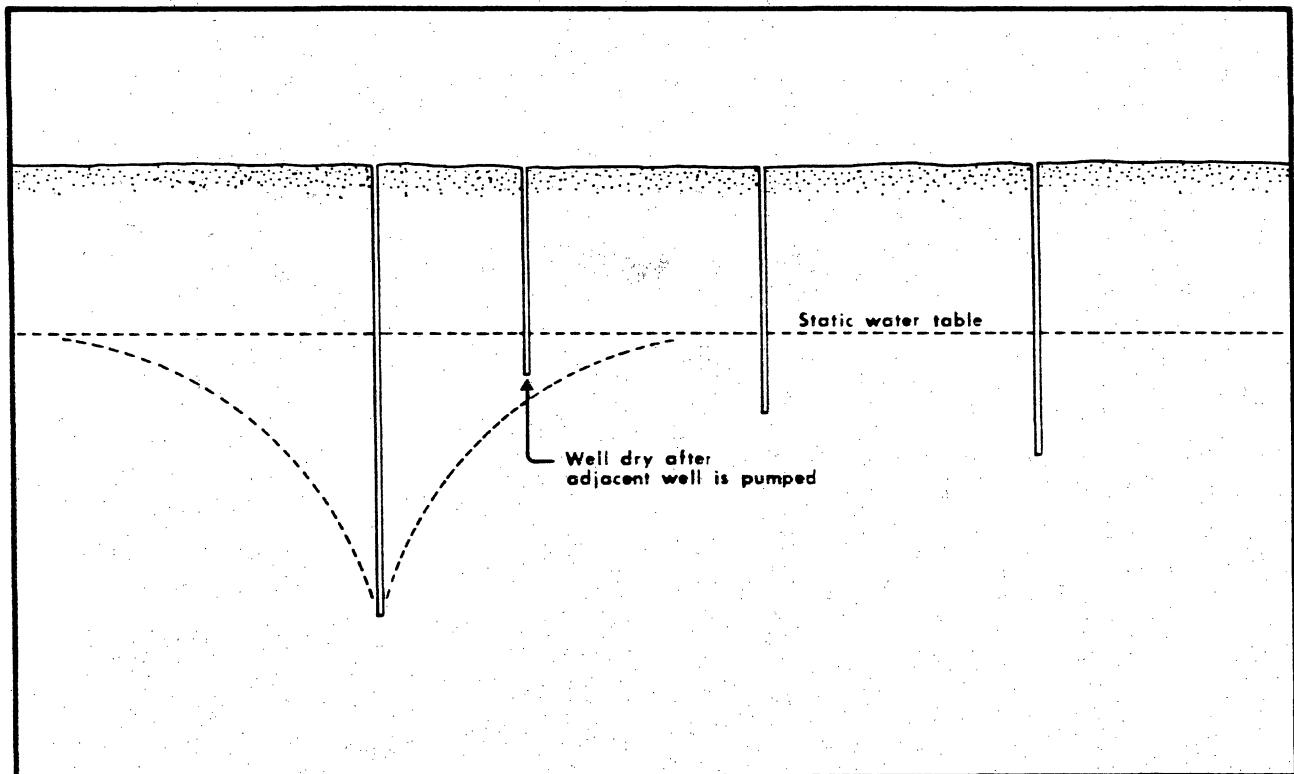


Figure 6. Interference Between Pumped Wells.

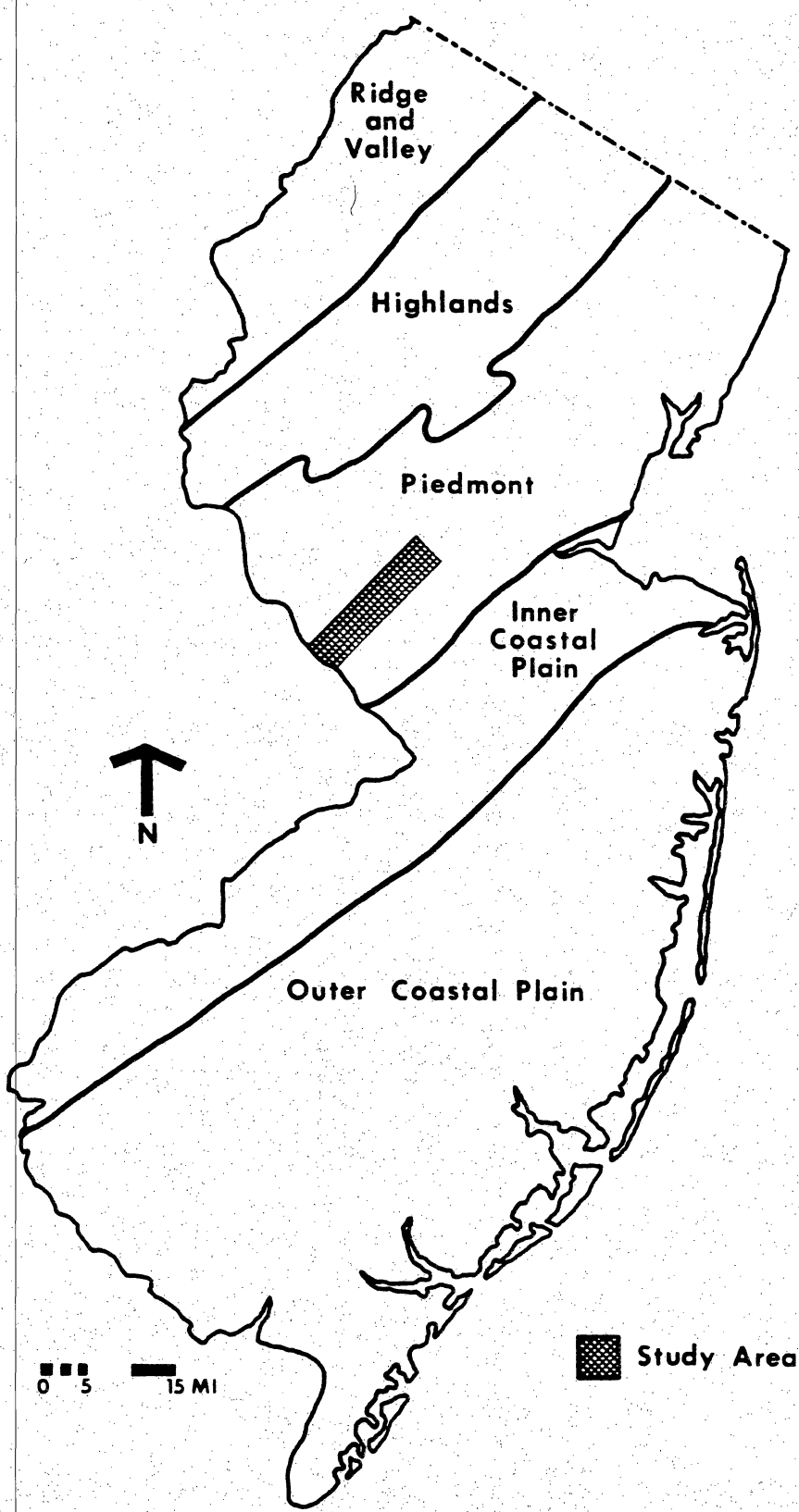


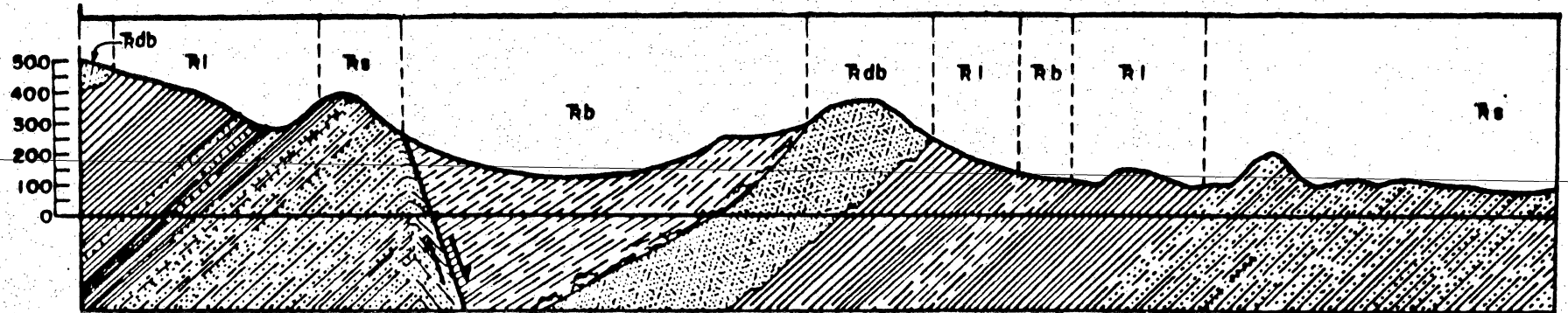
Figure 7. Physiographic Provinces of New Jersey.

The rocks of this area are harder than those of the Coastal Plain, and were deposited in a horizontal position, but now dip to the northwest (see Figure 8). They consist of interbedded red sandstones and shales which are cut by belts of harder trap rock - the latter constituting the present ridges, such as the Watchungs, Palisades, and the Sourland Mountains. These rocks are of Triassic age.

The Sourland Mountains extend from the Delaware River to Hillsborough Township in Somerset County (see Figure 9). They are composed of diabase and argillite which are extremely resistant to erosion, thereby forming low but prominent ridges. Diabase is an igneous intrusive rock which has been quarried for years to construct seawalls and jetties along the coast. Its resistance to mechanical wear also makes diabase very useful as crushed stone or gravel-sized aggregate in highway construction (Wolfe, 1977). Most of the Diabase in the Sourland Mountains is in Hunterdon County, with smaller areas in Somerset and Mercer Counties.

The Lockatong Formation consists of argillite which interfingers extensively with the Stockton Sandstone and Brunswick Shale formations (Kasabach, 1966). The argillite is much more resistant to weathering and erosion than the sandstone and shale formations. Like diabase, the argillite is a ridge former. The Lockatong Formation underlies most of the Hunterdon Plateau and Sourland Mountain.

The Sourlands study area (see Figure 9) covers nearly 817 square miles of which nearly 38 percent consists of diabase and argillite (see Table 1). For purposes of geohydrologic comparison, adjoining areas underlain by Brunswick Shale and Stockton Sandstone Formations were included in the analysis. The topography of the Sourlands is shown in Figure 10.



HORIZONTAL SCALE 1"=1mile VERTICAL SCALE 1"=500'
 VERTICAL EXAGGERATION 10
 Thin mantle of Pleistocene not shown

Rdb - Diabase (intrusive)
 Rb - Brunswick Shale
 Rl - Lockatong Argillite
 Rs - Stockton Sandstone

Source: Geology of the Ground Water Resources of Mercer County,
 Kemble Widner, 1965

Figure 8. Geologic Profile of Study Area.

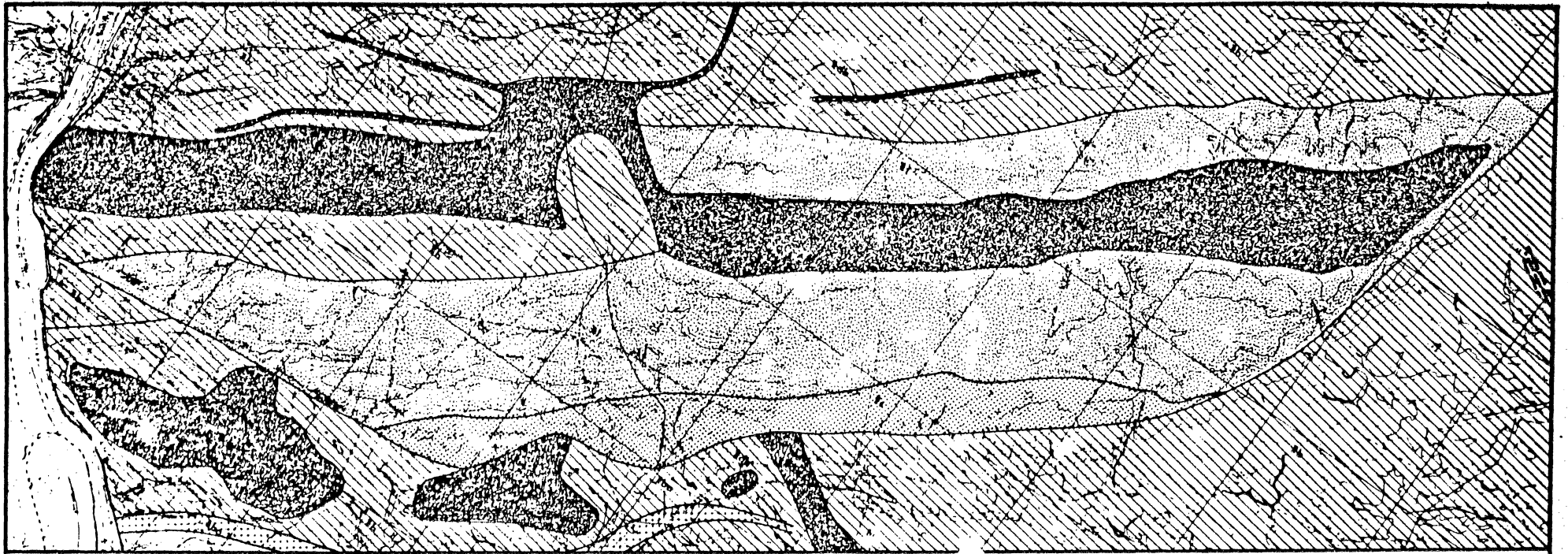





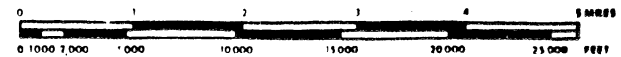
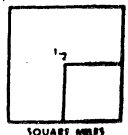


Figure 9. Geology.

-  Sb Bed. Similar to Lockatong Formation
-  Ss Stockton Formation
-  Sd Dis. ...
-  Sb Somerset Formation
-  Tl Lockatong Formation

SOURLAND MOUNTAIN REGIONAL PLANNING PROJECT
HUNTERDON, MERCER AND SOMERSET COUNTIES, N.J.

BASE MAP PREPARED BY M. S. M. REGIONAL STUDY COUNCIL, INC. FROM U.S.G.S. HOPWELL, LAMBERTVILLE, PENNINGTON, RARITAN, ROCKY HILL AND STOCKTON QUADRANGLES, 7.5 MINUTE SERIES 1970



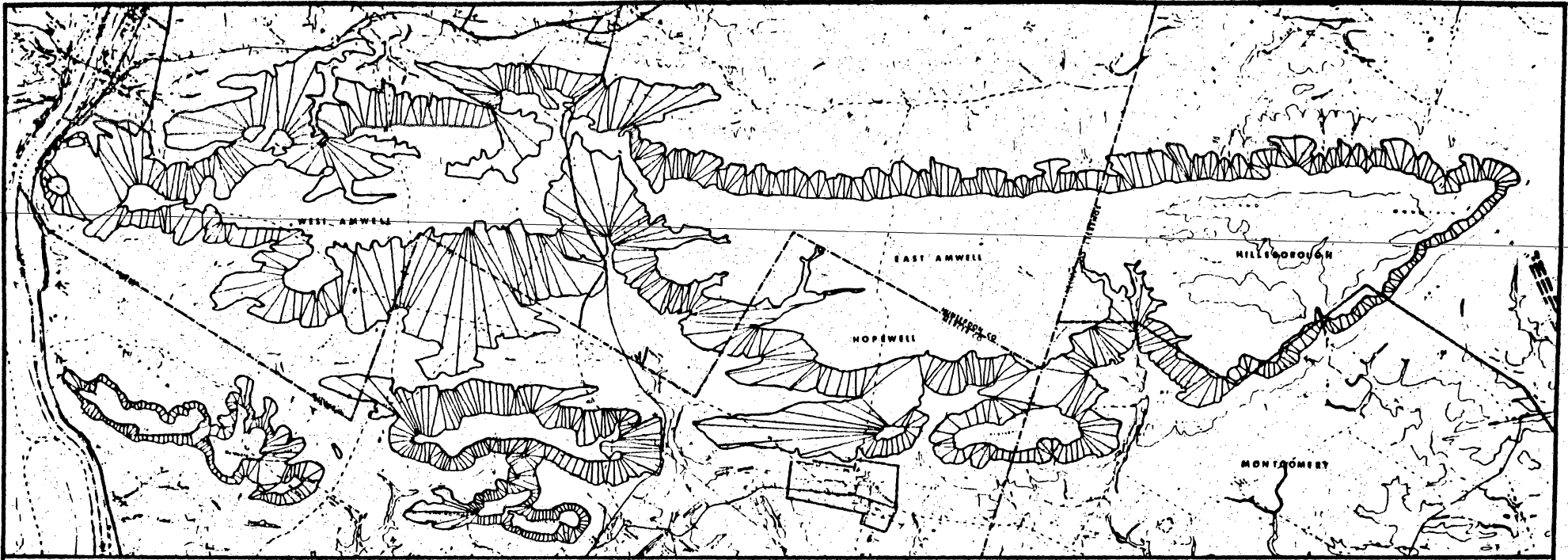


Figure 10. Topography.

**SOURLAND MOUNTAIN REGIONAL PLANNING PROJECT
HUNTERDON, MERCER AND SOMERSET COUNTIES, N.J.**

BASE MAP PREPARED BY M. E. M. REGIONAL STUDY COUNCIL, INC. FROM U.S.G.S. HOPWELL, LAMBERTVILLE, PENNINGTON, BARTAM, ROCKY HILL AND STOCKTON QUADRANGLES, 7.5 MINUTE SERIES, 1970

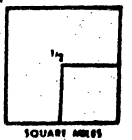
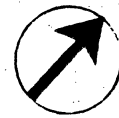


Table 1
EXTENT OF GEOLOGICAL FORMATIONS IN STUDY AREA

Geologic Formations	Symbol	Area (mi. ²)	Percent of Total
Brunswick Shale	Trb	468.81	57.4
Lockatong Argillite	Trl	186.35	22.8
Diabase	Trdb	122.68	15.0
Stockton Sandstone	Trs	32.45	4.0
Baked Shale	Trba	<u>6.37</u>	<u>0.8</u>
		816.66	100.0

NOTE: areas planimetered on base map at a scale of 1" = 2000' from NJDEP geologic overlay maps at a scale of 1" = 1 mile.

Table 2
TOTAL NUMBER OF WELLS IN
THE SOURLAND MOUNTAIN AREA

Geologic Formations	Total Number of Wells	Number of Domestic Wells	Domestic Wells as a Percent of the total
Stockton Sandstone	106	97	91.5
Brunswick Shale	327	308	94.2
Lockatong Argillite	950	927	97.6
Diabase	<u>215</u>	<u>213</u>	<u>99.1</u>
Total	1598	1545	96.7

Source: Calculated by R. M. Hordon from records obtained from NJDEP, Trenton.

Argillite and diabase have practically no primary porosity. What little ground water is contained in the formations is available only within the relatively few fractures and joints which tend to be widely spaced. Both formations have been found to be among the worst in the entire state in terms of ground water yield (Kasabach, 1966). Better yielding wells are invariably associated with faults or with an overlying weathered zone. Most of the ground water occurs under water-table (unconfined) conditions.

Although the Brunswick Shale has about the same primary porosity as the Lockatong argillite, it is much more fractured and therefore has a higher secondary porosity. Well yields in the shale can be expected to be higher on the average than wells drilled in the argillite and diabase. However, the Brunswick Shale formation which extends from the Delaware River through Central New Jersey to Bergen County and beyond into New York State varies in composition from southwest to northeast. The formation has more sandstone in the northeastern part of the state than in the area around the Sourlands; consequently, the groundwater yield would tend to be higher in those portions which have more sandstone. The northern portion of the Brunswick Shale also benefits from glacial deposits which act as a "sponge" and allow more water to infiltrate into the formation. Thus, the Brunswick Shale in the vicinity of the Sourlands is a worse aquifer than the same formation further north in the state.

The Stockton Sandstone formation is one of the better aquifers in the area. Both primary and secondary porosity are higher than in adjoining formations. Ground water usually occurs under water-table conditions (Kasabach, 1966).

Since groundwater in all four formations (sandstone, shale, diabase and argillite) occurs mostly in the void space of the fractured rock, well yields

can be highly variable as the "internal plumbing" of the bedrock is not homogeneous. This means that yields will be much higher for wells located on or near fractures. An even better location for wells would be at the intersection of a set of interconnected fractures.

In fractured formations, groundwater movement is controlled by the distribution, degree of interconnection, and orientation of joints, faults and bedding planes. These fractured aquifers are strongly heterogeneous and anisotropic, that is, groundwater flow is structurally controlled and includes the following aspects (Meiser and Earl, 1982):

- a) Cones of depression are irregular and elongate.
- b) Wells can interfere dramatically with one another when they are located in the same fracture system.
- c) Groundwater flow rates in well-developed fracture zones can be several orders of magnitude greater than flow in poorly jointed, dense bedrock.
- d) Groundwater usually flows in a direction orthogonal to water-table contours. However, the actual path may be much more complex in fractured rocks when one considers the orientation of bedding planes.

The location of fracture traces within an aquifer would be very useful information to a community. Presumably, wells located near a fracture zone would have higher yields. Pendleton (1969) prepared a fracture trace map of the Triassic rocks in Mercer County. His objective was to delineate areas of potential high groundwater productivity. In a study of groundwater conditions within the middle portion of the Delaware River basin, Wright (1982) delineated earth lineaments in the bedrock formations by using satellite imagery at a scale of 1:250,000. In the Wright study, earth-fracture traces were delineated for two study basins in Pennsylvania by oblique-angle examination of black and white aerial photographs at a scale of 1" = 2000' (Little Neshaminy Creek basin)

and 1" = 1670' (Little Lehigh Creek basin). Both Pendleton (1969) and Wright (1982) found that well yields were substantially better in the vicinity of fracture zones.

Fracture traces of a portion of Sourland Mountain were also delineated as part of this study. Black and white aerial photographs at a scale of 1:40,000 (1" = 3333') were used. The fracture traces were then transferred to a 1:24,000 (1" = 2000') base map of the Sourlands (see Figure 11). Well locations were initially plotted on a 1:63,360 (1" = 1 mile) map and then transferred to the 1:24,000 base map.

An examination of the relationship between well performance parameters and distance to a fracture trace was inconclusive, partly because well locations were not recorded exactly and domestic well records with limited reliability had to be used. Also, many fracture traces were identified in portions of the study area where there were simply no well records available within a reasonable distance. The delineation of fracture traces and the locating of wells at different scales also presented a problem in interpretation.

However, fracture trace information developed as a part of this project and that developed by Pendleton (1969) for Mercer County are available as an important point of departure for site analysis as recommended in Section III (c) of this report.

The hydrologic soil groups for the Sourlands are shown in Figure 12 which indicates the infiltration characteristics of the various soils in the area.

C. Well Record Analysis

In a U. S. Geological Survey study of evaluating well yields in consolidated



Figure 11. Fracture Traces.

TRIASSIC

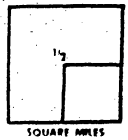
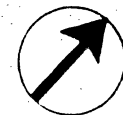
Sedimentary Rocks

- 1b Brunswick Formation
- 1ba Beds Similar to Lockatong Formation
- 1l Lockatong Formation
- 1s Stockton Formation

Igneous Rocks

- 1db Diabase

Source: U.S. State Geologic Overlay Maps 24, 25, 27, 28.



**SOURLAND MOUNTAIN REGIONAL PLANNING PROJECT
HUNTERDON, MERCER AND SOMERSET COUNTIES, N.J.**

BASE MAP PREPARED BY M. S. M. REGIONAL STUDY COUNCIL, INC. FROM U.S.G.S., HOPEWELL, LAMBERTVILLE, PENNINGTON, BARITAN, ROCKY HILL AND STOCKTON QUADRANGLES, 7.5 MINUTE SERIES 1970.

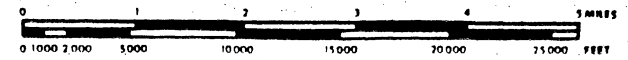


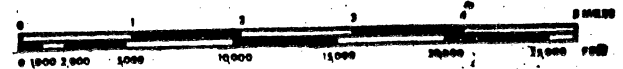
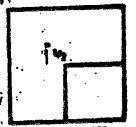


Figure 12. Hydrologic Soil Groups.

- High
- ↑ Infiltration
- ▨ ↓
- ▬ Low
- Unclassified

SOURLAND MOUNTAIN REGIONAL PLANNING PROJECT
HUNTERDON, MERCER AND SOMERSET COUNTIES, N. J.

BASE MAP PREPARED BY N. J. M. REGIONAL STUDY COUNCIL, INC., FROM N. J. S. S. C. S. SOIL SURVEY OF HUNTERDON, MERCER AND SOMERSET COUNTIES, 1974.



rocks from Virginia to Maine, Cederstrom (1972) states that industrial and municipal well yields are the most reliable indicators of the water-yielding potential of these formations. These nondomestic wells are drilled to develop a maximum supply of water. They are generally deeper than domestic wells and may therefore intersect several water-bearing zones in the consolidated rock formations. In addition, the non-domestic wells are often 8" or more in diameter which allows a greater drawdown and consequently a higher potential yield.

In contrast, domestic wells are drilled to the depth where enough water to satisfy a typical residential family is obtained. The wells are 6" in diameter and are often not located in the best position with regard to geologic structure (e.g., fracture traces). In addition, domestic well records as recorded by well drillers often contain only depth and yield information and may not even be properly located on large-scale maps. Pumping tests, if they are reported, are often only 1 or 2 hours long which obviously affects the reliability of yield data.

It would be very nice to follow Cederstrom's advice and use only non-domestic well records to evaluate the groundwater potential of the Sourland Mountain area. However, the vast majority of the well records (nearly 97 percent; see Table 2) in the study area are domestic and are the only ones available for use. However, as discussed in this section, attention will be given to those wells for which pumping tests of 4 hours or more are available on the grounds that those records are generally more reliable to work with. In addition, published well records for similar geologic formations in Hunterdon and Mercer Counties which have more reliable information will be used in the ground water evaluation process.

Nearly 1600 well records from the Sourland Mountain area were obtained from the files in NJDEP, Trenton, as background data for this project (see Figures 13, 14, & 15). Specific capacity was calculated only in those instances where pumping tests

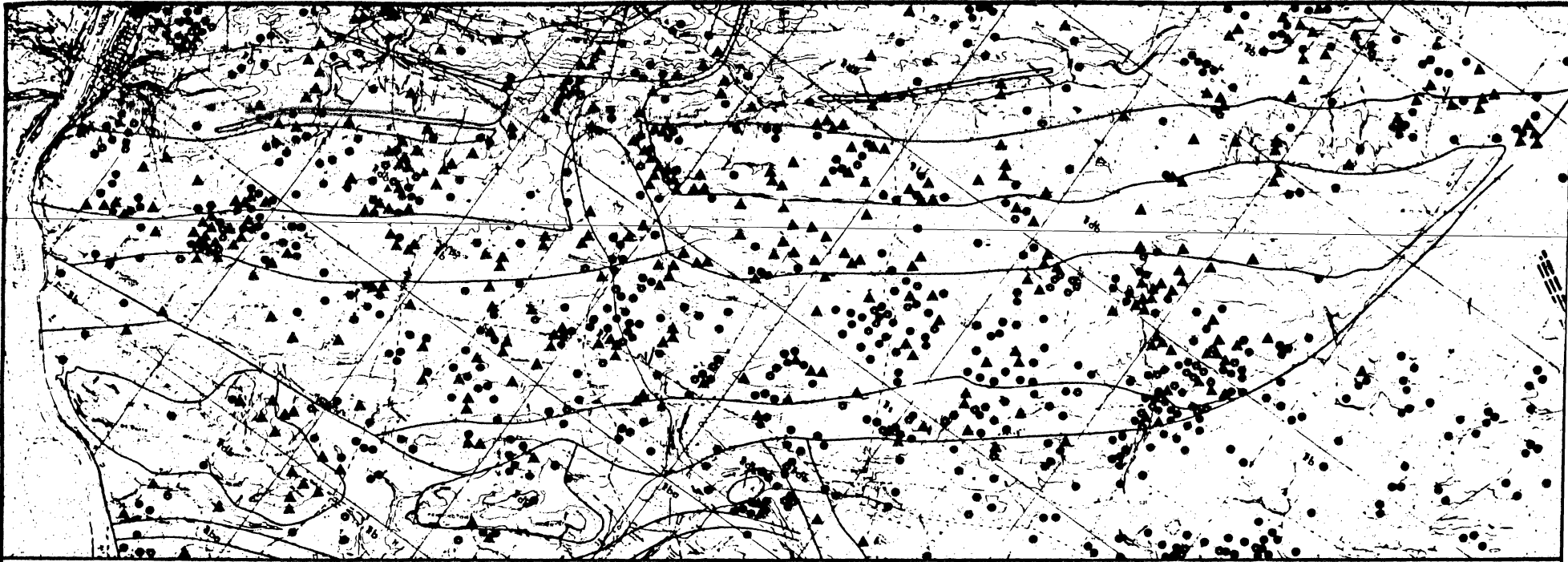


Figure 13. Well Locations: Yield.

(GPM)

- ▲ 1 - 4
- 5 - 9
- ≥ 10

TRIASSIC

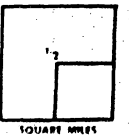
Sedimentary Rocks

- 1b Brunswick Formation
- 1ba Beds Similar to Leebatong Formation
- 1l Leebatong Formation
- 1s Stockton Formation

Igneous Rocks

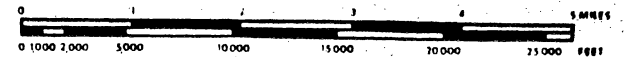
- 1db Diabase

Source: H. J. Stone, Geologic Overview Sheets 50 25 27 28



**SOURLAND MOUNTAIN REGIONAL PLANNING PROJECT
HUNTERDON, MERCER AND SOMERSET COUNTIES, N. J.**

BASE MAP PREPARED BY M. S. M. REGIONAL STUDY COUNCIL, INC. FROM U.S.G.S. HOPEWELL, LAMBERTVILLE, PENNINGTON, BARITAN, ROCKY HILL AND STOCKTON QUADRANGLES, 7.5 MINUTE SERIES 1970.



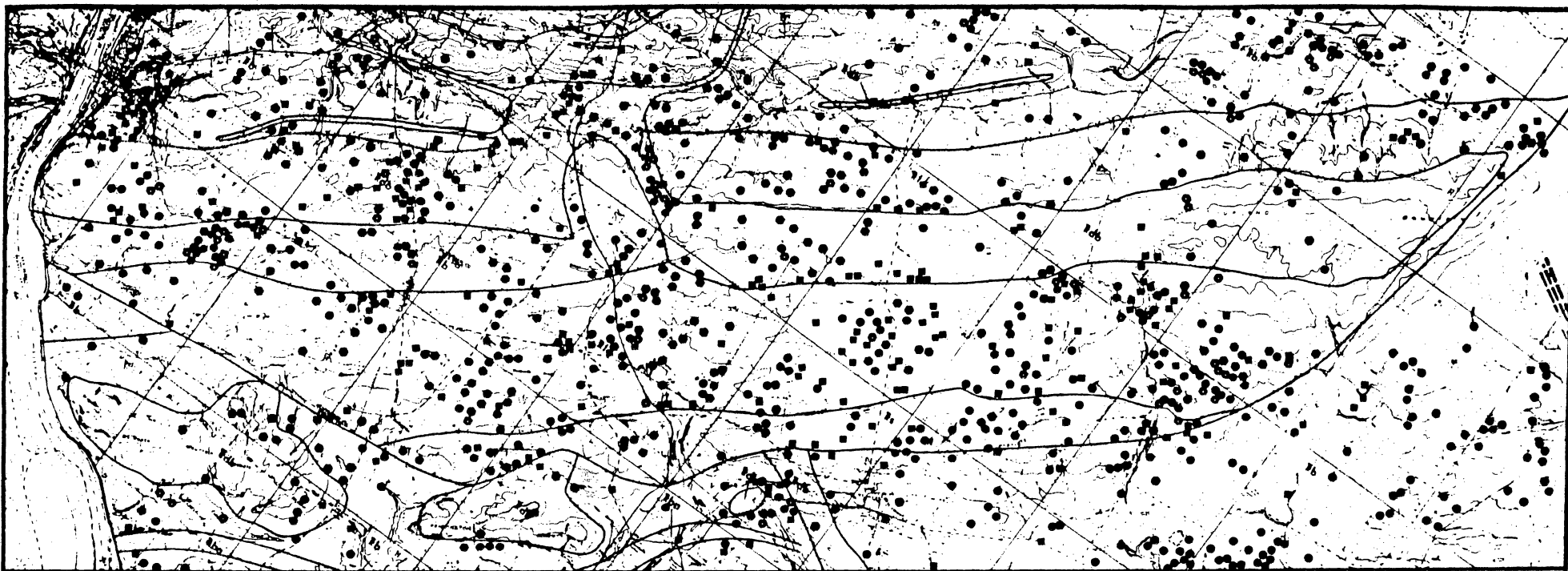


Figure 14. Well Locations: Depth.

(FEET)

- 0-100
- 101-200
- ≥ 201

TRIASSIC

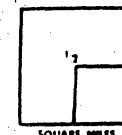
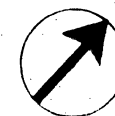
Sedimentary Rocks

- Bb Brunswick Formation
- Bba Beds Similar to Lockatong Formation
- S1 Lockatong Formation
- S2 Stockton Formation

Igneous Rocks

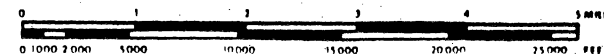
- Ddb Diabase

Source: N.J. State Geologic Overview Sheets 30 25 27 28



**SOURLAND MOUNTAIN REGIONAL PLANNING PROJECT
HUNTERDON, MERCER AND SOMERSET COUNTIES, N.J.**

BASE MAP PREPARED BY M S M REGIONAL STUDY COUNCIL, INC. FROM U.S.G.S. HOPSWELL, LAMBERTVILLE PENNINGTON BABYAN ROCKY HILL AND STOCKTON QUADRANGLES 7.5 MINUTE SERIES 1970



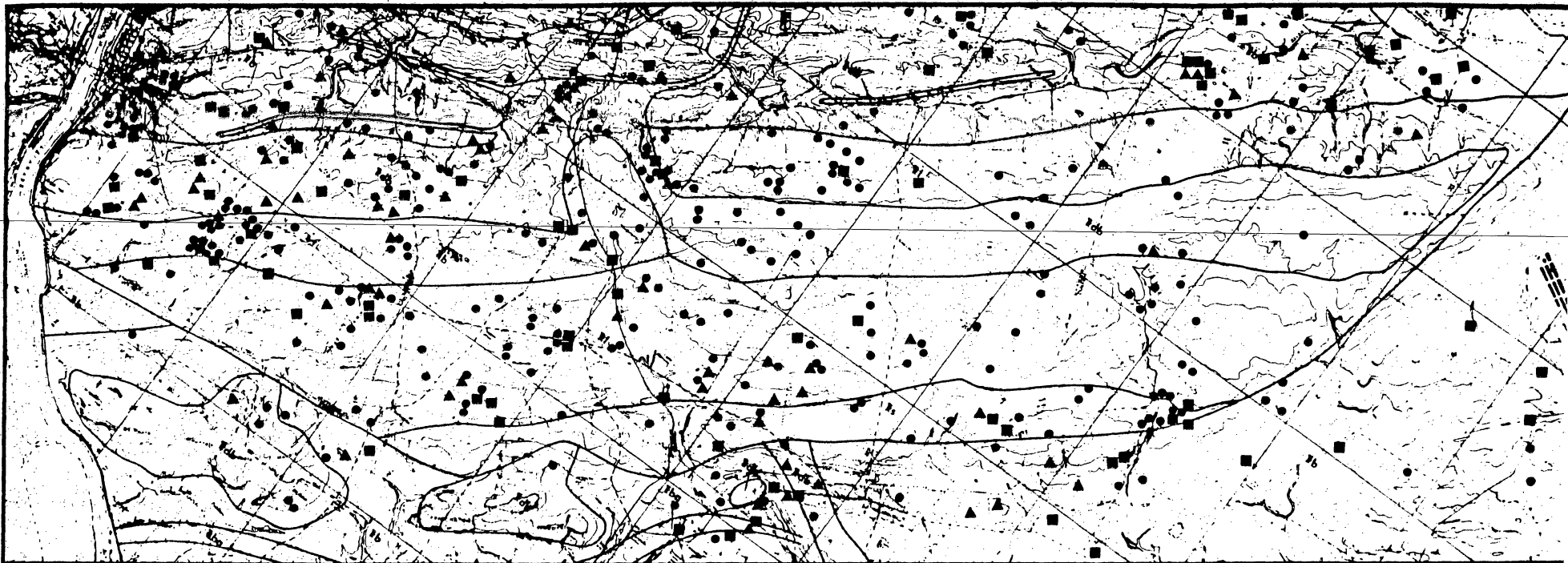


Figure 15. Well Locations: Specific Capacity.

(GPM/FT)

- 0.01 - 0.10
- ▲ 0.11 - 0.25
- ≥ 0.26

TRIASSIC

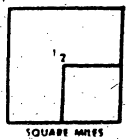
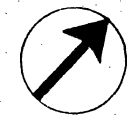
Sedimentary Rocks

- Tb Brunswick Formation
- Tba Beds Similar to Lockatong Formation
- Tl Lockatong Formation
- Ts Stockton Formation

Igneous Rocks

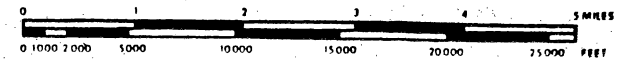
- Mb Diabase

Source: N. J. State Geologic Overlay Sheets 26 25 27 28



**SOURLAND MOUNTAIN REGIONAL PLANNING PROJECT
HUNTERDON, MERCER AND SOMERSET COUNTIES, N. J.**

BASE MAP PREPARED BY M. S. M. REGIONAL STUDY COUNCIL, INC. FROM U.S.G.S. HOPEWELL, LAMBERTVILLE, PENNINGTON, RARITAN, ROCKY HILL AND STOCKTON QUADRANGLES, 7.5-MINUTE SERIES, 1970.



were reported for 4 hours or more.

Analysis of the well records results in the following major conclusions:

- a) The bulk of the wells were drilled in argillite (nearly 60 percent), but the other formations are fairly well represented (see Table 2).
- b) Median yields ranged from a low of 5 and 7 gpm for the diabase and argillite formations, respectively, to 12 and 20 gpm for the shale and sandstone, respectively (see Table 3 and Figure 16).
- c) Median well depths ranged from 125 feet (diabase and sandstone) to 175 feet for argillite (see Table 3).
- d) Median specific capacity values ranged over nearly an order of magnitude, from 0.055 gpm/foot for the argillite to a high of 0.343 gpm/foot for the sandstone (see Table 3 and Figure 17).
- e) Well yields were always greater for the sandstone and shale formations as compared to the diabase and argillite for all levels of exceedence probability when plotted on logarithmic probability paper (see Figure 18).
- f) The differences among the formations in terms of well depths when plotted on logarithmic probability paper were relatively small (see Figure 19).
- g) Wells drilled in the sandstone and shale formations had higher specific capacity values for all exceedence probability levels when plotted on logarithmic probability paper as compared to the diabase and argillite (see Figure 20).

In short, it is apparent from analysis of the well records that the groundwater potential for the argillite and diabase formations is substantially less than the sandstone and shale formations. This difference in aquifer characteristics is of course attributable to the extremely low primary and secondary porosity of the very dense and hard argillite and diabase.

As indicated before, published well records for similar formations in Hunterdon and Mercer Counties were also analyzed in order to provide a better data base. As shown in Table 4, the bulk of the wells in Hunterdon County from the

Table 3

MEDIAN YIELD, DEPTH AND SPECIFIC CAPACITY
VALUES FOR WELLS IN THE SOURLAND MOUNTAIN AREA

Geological Formation	Median Yield (gpm)	Median Depth (Feet)	Median Specific Capacity (gpm/foot)
Stockton Sandstone	20 (N=105)	125 (N=106)	0.343 (N=54)
Brunswick Shale	12 (N=323)	150 (N=327)	0.238 (N=112)
Lockatong Argillite	7 (N=949)	175 (N=950)	0.055 (N=426)
Diabase	5 (N=213)	125 (N=215)	0.067 (N=91)
Total Number of Wells	1590	1598	683

Source: Calculated by R. M. Hordon from records obtained from NJDEP, Trenton. Median specific capacity values pertain only to those domestic wells which had reported pumping tests of 4 hours or more.

Table 4

TOTAL NUMBER OF WELLS IN SELECTED
FORMATIONS IN HUNTERDON COUNTY, N. J.

Geological Formation	Total Number of Wells	Number of Domestic Wells	Domestic Wells as a Percent of the total
Stockton Sandstone	124	123	99.2
Brunswick Shale	471	442	93.8
Lockatong Argillite	119	115	96.6
Diabase	<u>35</u>	<u>32</u>	<u>91.4</u>
Total	749	712	95.1

Source: Kasabach (1966). Numbers pertain only to those domestic and non-domestic wells which had reported pumping tests of 4 hours or more. (Calculations by R. M. Hordon).

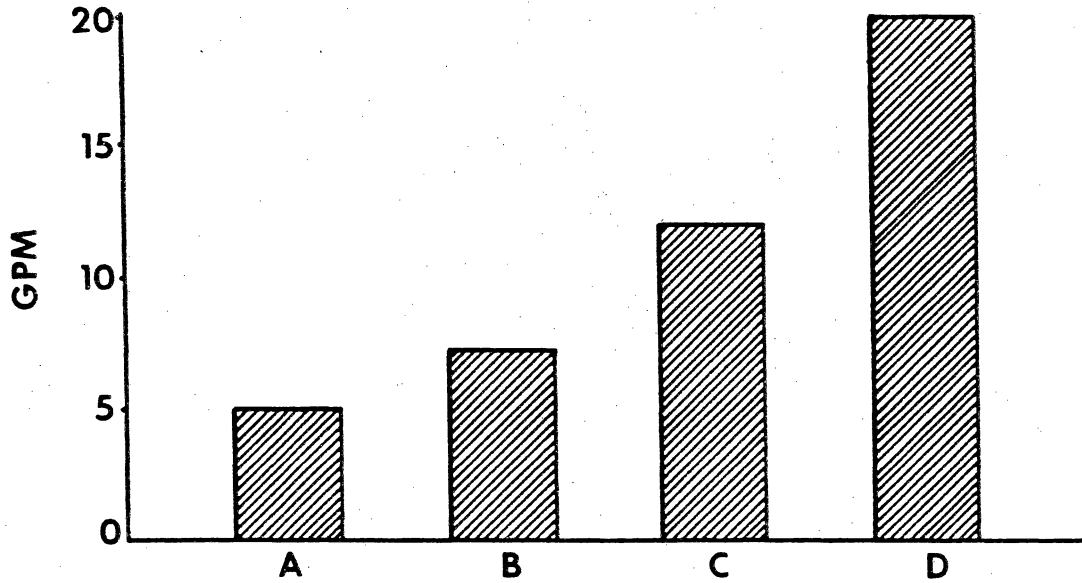


Figure 16. Median Yields.

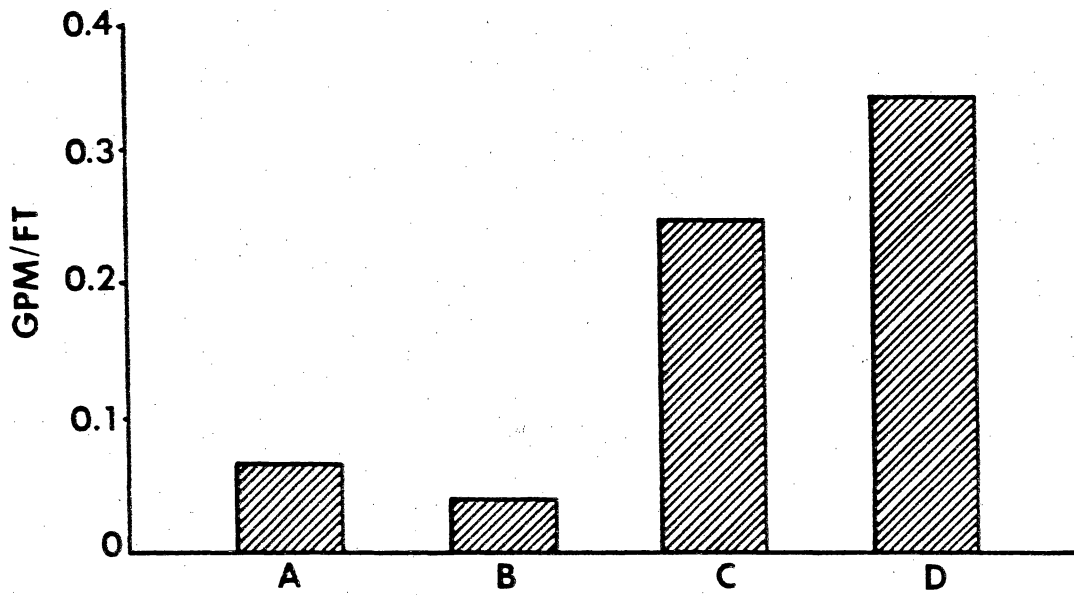


Figure 17. Median Specific Capacity.

- A - Diabase (Trdb)
- B - Lockatong Argillite (Trl)
- C - Brunswick Shale (Trb)
- D - Stockton Sandstone (Trs)

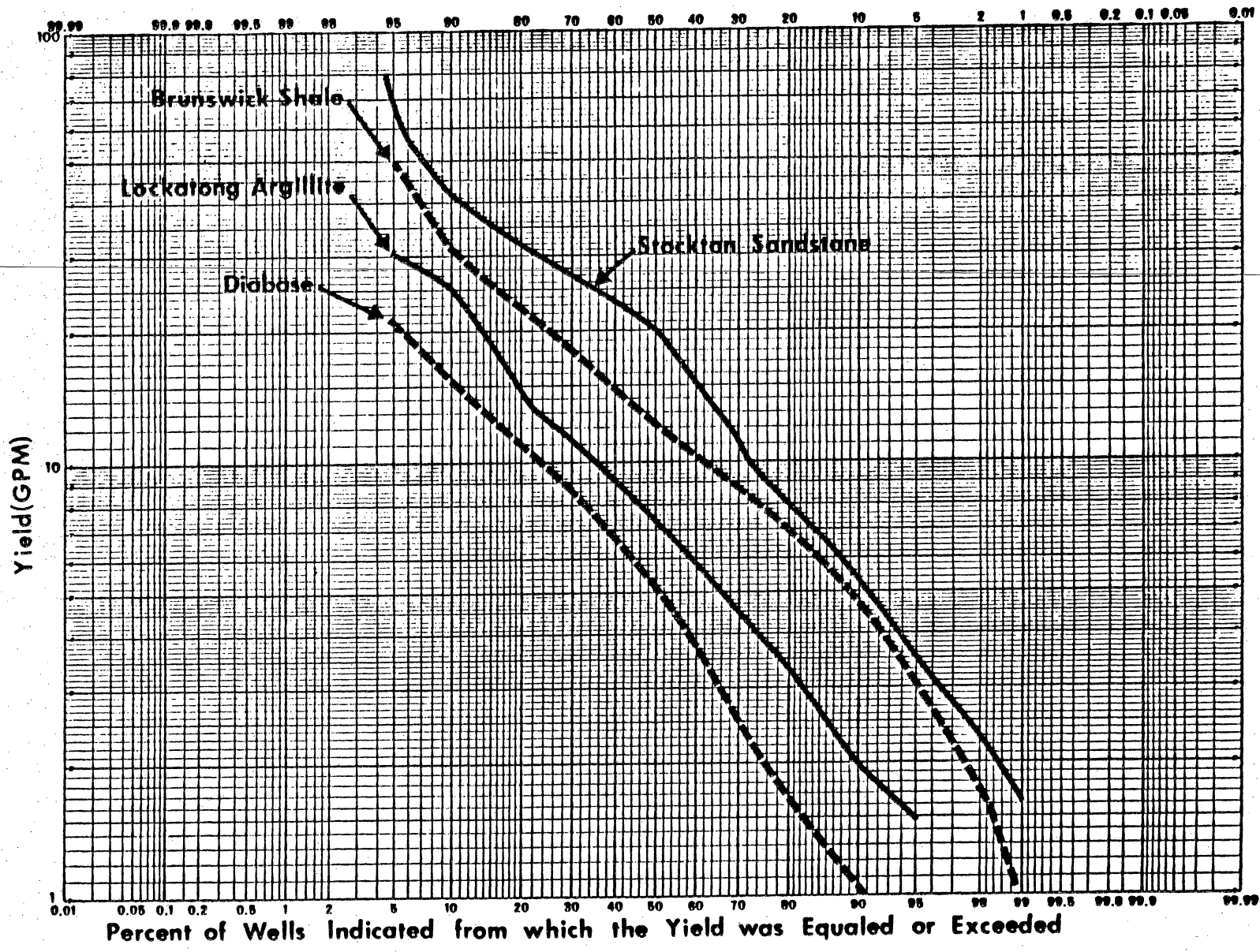


Figure 18. Frequency Distribution of Well Yields.

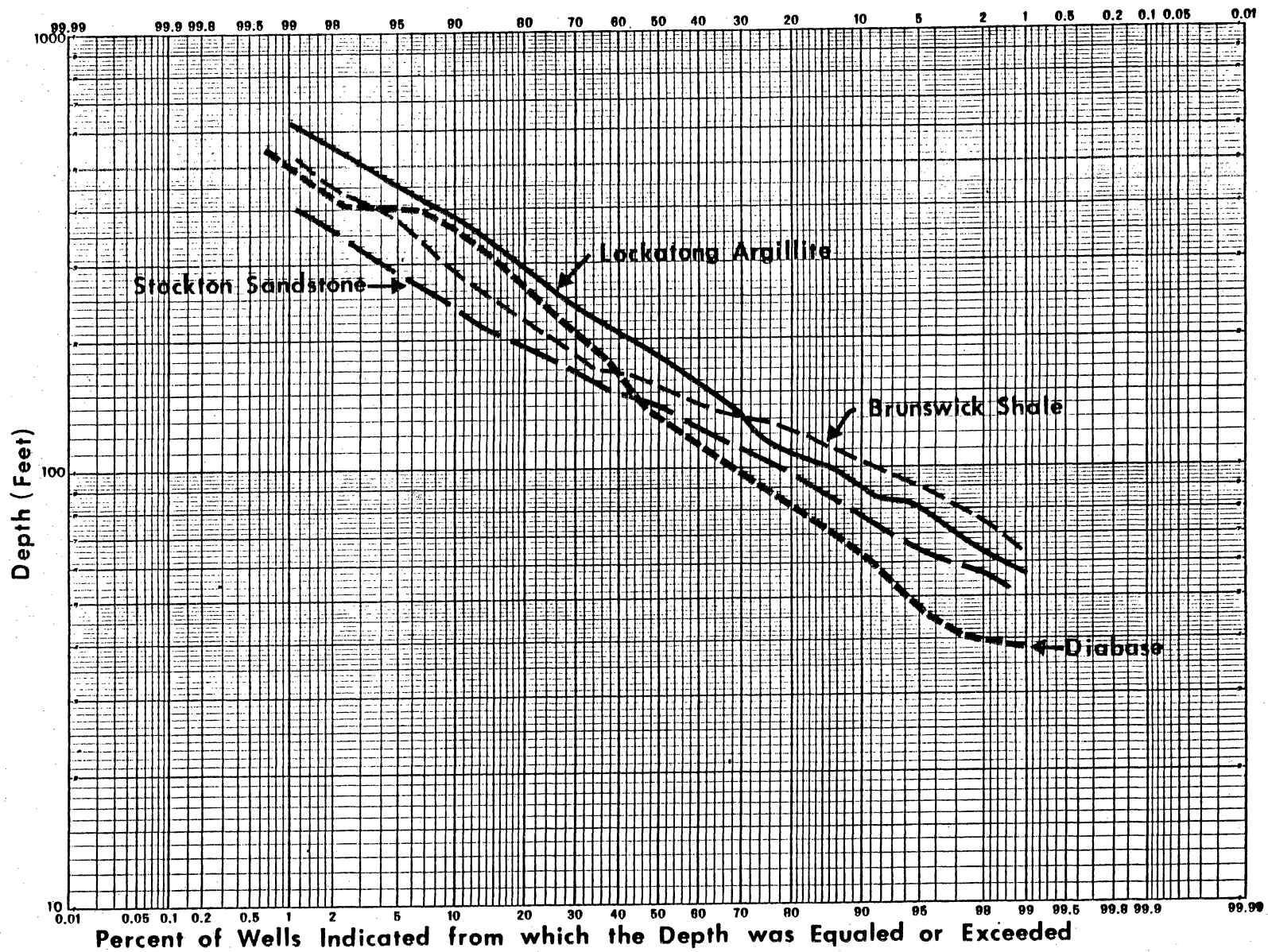
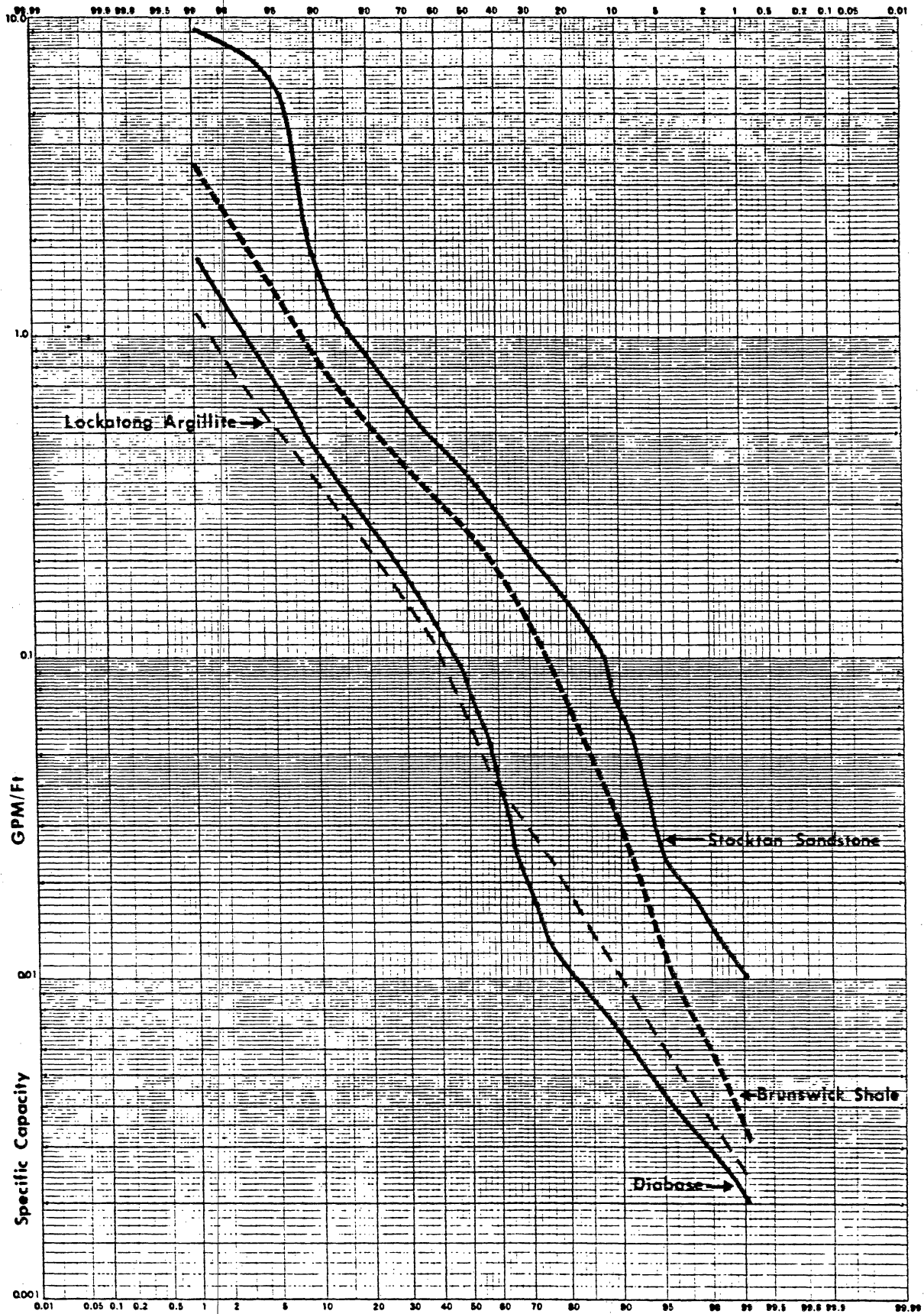


Figure 19. Frequency Distribution of Well Depths.



Percent of Wells Indicated from which the Specific Capacity was Equaled or Exceeded

Figure 20. Frequency Distribution of Specific Capacity of wells.

same formations as in the Sourland Mountain area are domestic (95 percent). Note that there is some overlap between the Sourland Mountain area wells and those in Hunterdon County, since some wells may be on both lists.

Median yield, depth and specific capacity information for selected wells in Hunterdon County, N.J. are shown in Table 5. Again, the wells in the argillite and diabase show substantially poorer yields than those drilled in the shale and sandstone.

A similar analysis of domestic and non-domestic wells in Mercer County which had reported pump tests of 4 hours or more revealed that although the bulk of the wells are domestic (76.4 percent), a larger proportion of the wells in the sandstone are non-domestic as compared to Hunterdon County (see Tables 4 and 6); 60.4 percent in Mercer vs. 99.2 percent in Hunterdon. Non-domestic wells are generally 8" in diameter or greater and consequently have higher yield and specific capacity values. Note the median yield and specific capacity of 30 gpm and 1.109 gpm/foot, respectively, for the sandstone wells in Mercer County (see Table 7) as compared to 16 gpm and 0.40 gpm/foot, respectively, for the sandstone wells in Hunterdon County (see Table 5). The difference in well performance is partially attributed to the inclusion of more non-domestic wells in Mercer County as compared to Hunterdon County.

Comment was made earlier about the possible overlap among the data sets of the Sourland Mountain area, Hunterdon and Mercer Counties. This overlap is conceded, but the Sourland Mountain area data set was recently obtained from the files of NJDEP in Trenton whereas the Mercer and Hunterdon County ground water reports were published in 1965 and 1966, respectively. Therefore, the Sourland Mountain area data set has more than a decade and a half of new inform-

Table 5
 MEDIAN YIELD, DEPTH AND SPECIFIC
 INFORMATION FOR SELECTED WELLS IN HUNTERDON COUNTY NJ

Geologic Formation	Median Yield (gpm)	Median Depth (feet)	Median Specific Capacity (gpm/foot)
Stockton Sandstone (N=124)	16	125	0.40
Brunswick Shale (N=124)	18	150	0.74
Lockatong Argillite (N=471)	9	153	0.111
Diabase (N=35)	5	116	0.08

Source: Kasabach (1966). Numbers pertain only to those domestic and non-domestic wells which had reported pumping tests of 4 hours or more. (Calculations by R. M. Hordon).

Table 6
 TOTAL NUMBER OF WELLS IN
 SELECTED FORMATIONS IN MERCER COUNTY, NJ

Geologic Formation	Total Number of Wells	Number of Domestic Wells	Domestic Wells as a Percent of the total
Stockton Sandstone	101	61	60.4
Brunswick Shale	90	76	84.4
Lockatong Argillite	48	43	89.6
Diabase	<u>11</u>	<u>11</u>	<u>100.0</u>
Total	250	191	76.4

Source: Widmer (1965). Numbers pertain only to those domestic and non-domestic wells which had reported pumping tests of 4 hours or more. (Calculations by R. M. Hordon).

Table 7

MEDIAN YIELD, DEPTH AND SPECIFIC CAPACITY
INFORMATION FOR SELECTED WELLS IN MERCER COUNTY, NJ

Geologic Formation	Median Yield (gpm)	Median Depth (Feet)	Median Specific Capacity (gpm/foot)
Stockton Sandstone (N=101)	30	150	1.109
Brunswick Shale (N=90)	17	175	0.30
Lockatong Argillite (N=48)	10	155	0.117
Diabase (N=11)	6	100	0.143

Source: Widmer (1965). Numbers pertain only to those domestic and non-domestic wells which had reported pumping tests of 4 hours or more. (Calculations by R. M. Hordon).

ation that has been analyzed.

With the exception of median yield and depth information for the Sourland Mountain area, all of the other values in Tables 3 to 7 pertain only to domestic and non-domestic well records which had reported pump tests of 4 hours or more. Although there is nothing magical about a 4-hour pump test, it is generally agreed that the longer the pump test, the more reliable the yield and drawdown data. Four hours is a compromise threshold which at least screens out some of the lesser reliable domestic well records.

In sum, analysis of selected domestic and non-domestic wells in the Sourland Mountain area, Hunterdon and Mercer Counties indicates that the median yield and specific capacity of wells drilled in the diabase and argillite are substantially lower than those wells drilled in the shale and sandstone. This information is not only of importance itself, but it can be used to quantify aquifer characteristics by comparing well ratios by formation. This procedure will be employed in a later section of this report as another means of estimating ground water yields on an areal basis (gpd/mi.²).

D. Hydrograph Separation Analysis

A stream hydrograph is a plot of stream discharge (in ft³/sec or mgd/mi²) against time at a gaging station within a watershed. Following a precipitation event, the hydrograph will typically show a steep rising limb (period before the peak) and a more gently sloping falling limb (period after the peak). A daily stream hydrograph would have each day on the abscissa (X-axis) and mean daily discharge on the ordinate (Y-axis) (see Figure 21).

A hydrograph can theoretically be divided into a number of components, such as channel precipitation, overland flow, interflow through the unsaturated

zone, and baseflow from the saturated zone. These procedures can be simplified by separating the hydrograph into direct runoff or stormflow (which lumps together channel precipitation, overland flow and interflow) and baseflow (Ward, 1975).

One reason for separating the hydrograph into only stormflow and baseflow is the enormous difficulty in estimating the other components of hydrograph. Indeed, there is so much difficulty in estimating baseflow from the hydrograph so that expending time in estimating interflow (that flow in the soil column above the water table) may not be warranted. Another reason is that we are only interested in the baseflow portion of the hydrograph for purposes of groundwater yield estimation.

Dunne and Leopold (1978) note that all of the hydrograph separation techniques are judgemental and may be related in varying degrees to the physical processes generating the hydrograph. However, they concluded that so long as one method is employed consistently, reasonable results can be obtained.

Three methods of hydrograph separation are shown schematically in Figure 21 (Dunne and Leopold, 1978).

- a) The pre-storm baseflow is projected under the peak of the hydrograph (Figure 21-A). A separation line is drawn from a point beneath the peak to a point on the recession limb that is N days after the peak in accordance with the following formula suggested by Linsley, Kohler and Paulhus (1958):

$$N = A^{0.2}$$

where N = number of days after the storm peak

A = area of watershed in square miles

- b) The hydrograph is plotted on semi-logarithmic paper with discharge on the logarithmic scale (Y-axis). A straight line is fitted to the lower part of the recession limb and projected backwards to a point under the peak. A rising limb for the baseflow is drawn to meet the projected

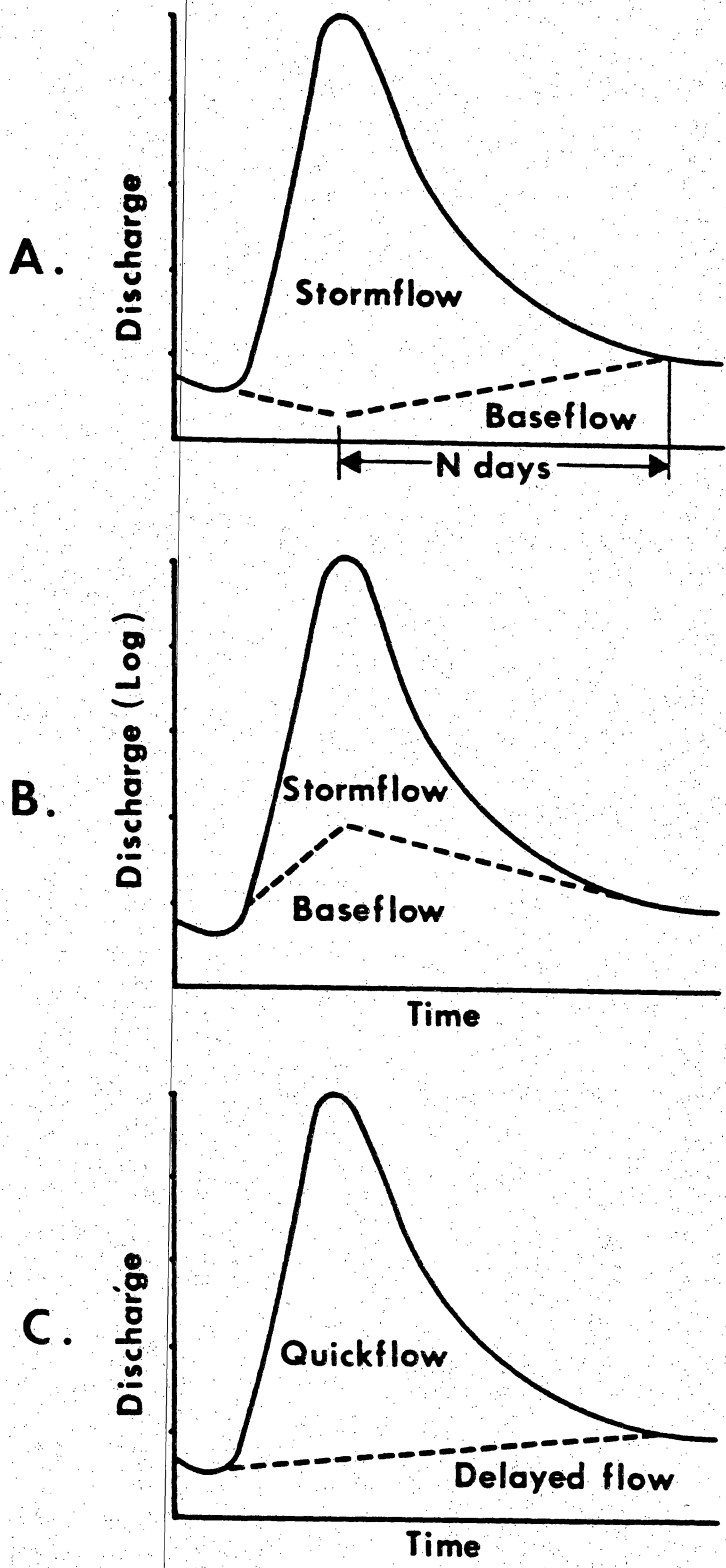


Figure 21. Methods of Hydrograph Separation.

separation line (Figure 21-B).

- c) A separation line is drawn from the point of initial rise to the recession limb. This separation line should rise at the rate of 0.05 cfs/mi²/hour and is appropriate for watersheds smaller than 20 square miles (Figure 21-c).

A modified form of the hydrograph separation procedures shown in Figures 21 A and B was employed in this study. The actual steps, using the Stony Brook at Princeton as an example, were as follows:

- a) The average discharge for each year during the period of record is ranked in descending order as shown in Table 8.
- b) The exceedence probability in percent for each ranked year is calculated by the following equation:

$$p = m/n+1 (100)$$

where p = exceedence probability in percent

m = rank 1 through n

n = number of years in the study period

- c) The calculated exceedence probability values from Table 8 are then plotted on arithmetic probability paper (Figure 22). Note that the annual discharge values are close to a straight line, indicating a normal distribution.
- d) The year which is closest to the 90 percent point (or 1 year in 10) is selected for hydrograph separation. In the case of the Stony Brook at Princeton, 1959 came closest to the 90 percent point (see Table 8 and Fig. 22).
- e) The same procedure was followed for the Royce Brook Tributary near Belle Mead (underlain by Brunswick shale) and the Stony Brook at Glenmoore (71 percent argillite and diabase). Note that a synthetic hydrograph had to be developed for the Stony Brook at Glenmoore since it is only a partial-record station. The estimating equations used by the U. S. Geological Survey for this and other partial-record stations were obtained from the District Office in Trenton.

The mean daily discharge values for the years selected were plotted on semi-logarithmic paper and baseflow was estimated for each day by using a modified form of the hydrograph separation procedures shown in Figure 21 A and B. The

Table 8

STONY BROOK AT PRINCETON: PROBABILITY PLOTTING DATA

Rank (m)	Calendar Year	Average Discharge (cfs)	Exceedence probability in Percent
			$p = \frac{m (100)}{n + 1}$
1	1979	115	3.6
2	75	111	7.1
3	73	98.1	10.7
4	71	96.1	14.3
5	72	95	17.9
6	67	82	21.4
7	58	77.8	25.0
8	61	77.5	28.6
9	78	69.8	32.1
10	74	69.6	35.7
11	60	65.3	39.3
12	69	63.3	42.9
13	77	62.9	46.4
14	55	62.4	50.0
15	62	60.8	53.6
16	56	59.2	57.1
17	70	58.9	60.7
18	68	50.6	64.3
19	64	48.4	67.9
20	80	47.6	71.4
21	54	44.7	75.0
22	66	43.6	78.6
23	57	42.9	82.1
24	76	41.7	85.7
25	59	40.4	89.3
26	63	32.8	92.9
27	65	27.7	96.4
Mean		64.6	
Standard Deviation		23.3	
Coefficient of Variation (Percent)		36.0	

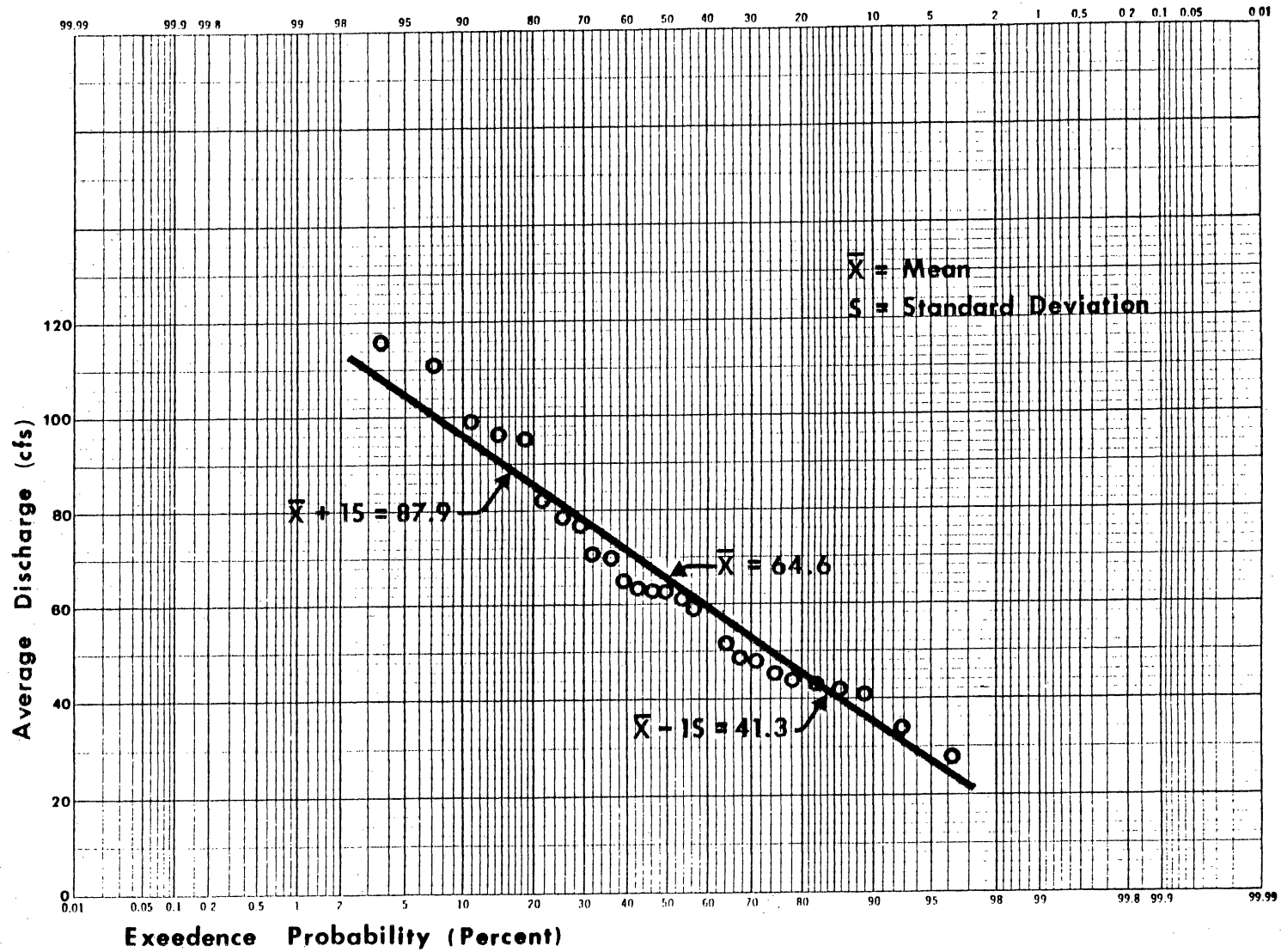


Figure 22. Frequency Distribution of Discharge for Stony Brook at Princeton.

daily baseflow values were then cumulated and an average value for the year was calculated. The results are shown in Table 9 where the baseflow for the Stony Brook at Princeton is estimated to be 0.119 mgd/mi^2 for a recurrence interval of 1 year in 10. Note that the corresponding points on the flow-duration curve are all about 69-70 percent for the three watersheds.

A much more elaborate hydrograph separation analysis of watersheds draining consolidated rock formations in New Jersey was made by Posten (1982). In brief, his methodology was as follows:

- a) Select only those watersheds draining consolidated rock formations which are underlain entirely by one formation, have a continuous daily discharge record for at least 10 years, and are not substantially regulated. Surprisingly, only three watersheds in New Jersey (two Precambrian basins in Passaic County and one basin underlain by argillite in Hunterdon County) met these criteria.
- b) Rank the annual discharge values in the same manner as discussed previously and plot the exceedence levels on arithmetic probability paper. Select several years of low, medium and high flows for hydrograph analysis.
- c) Posten used a modified form of hydrograph separation similar to that discussed earlier. The mean daily discharge for each of the selected years was separated into quickflow (direct runoff or stormflow) and delayed flow (baseflow).
- d) The average baseflow value for each year for each watershed was then ranked and the exceedence levels in percent were plotted on arithmetic probability paper. The mean and one standard deviation above and below the mean were plotted on the graph and connected by a straight line.
- e) The discharge at the 99 percent exceedence probability level of the cumulative frequency distribution of estimated annual delayed flows was selected as an estimate of the ground water yield for that basin.

The estimated yield for Walnut Creek near Flemington which is underlain entirely by argillite by Posten's method is $92,000 \text{ gpd/mi}^2$. This value comes out to 72 percent on the flow-duration curve.

Table 9

ESTIMATED BASEFLOW FOR SELECTED WATERSHEDS IN CENTRAL NEW JERSEY

	Stony Brook at Princeton	Stony Brook at Glenmoore*	Royce Brook Trib. near Belle Mead
USGS ID No.	4010	4009	4026
Area (sq. mi.)	44.5	17.0	1.20
Major Geologic Formations (Percent of Watershed)	Argillite (37%) Shale (35%) Diabase (18%)	Argillite (51%) Diabase (20%) Shale (19%)	Shale (100%)
Year Selected	1959	1959	1981 (Water Year)
Baseflow (mgd/mi. ²)	0.119	0.088	0.125
Corresponding Point on Flow-Duration Curve (Percent)	69	70	69

*Partial-record station and synthetic hydrograph.

Table 10

ESTIMATED BASEFLOW FOR SELECTED
WATERSHEDS/AQUIFERS BY HYDROGRAPH SEPARATION
(gpd/mi.²)

Watershed/Aquifer	Yield	Recurrence Interval	Reference
Stony Brook at Princeton	119,000	1 year in 10	This study
Stony Brook at Glenmoore	88,000	1 year in 10	This study
Royce Brook tributary near Belle Mead (all shale)	125,000	1 year in 10	This study
Walnut Brook near Flemington (all argillite)	92,000	*	Posten (1982)
Neshaminy Creek, Pa.	200,000	1 year in 10	Wright (1982)
Neshaminy Creek, Pa.	146,000	1 year in 50	Wright (1982)
Shale & Siltstone (in Pa.)	220,000	1 year in 2	Wright (1982)
Shale & Siltstone (in Pa.)	53,000	1 year in 10	Wright (1982)

* 99 percent exceedence level

Hydrograph separation procedures were also employed by Wright Associates (1982) in their groundwater study of the middle Delaware River basin for the Delaware River Basin Commission. The estimated annual baseflow rate for the Neshaminy Creek basin with a 1 year in 10 recurrence interval is 200,000 gpd/mi.² The baseflow estimate for the driest year on record for the Neshaminy is 146,000 gpd/mi² (1 year in 50 recurrence interval).

The geologic formations in the Neshaminy basin are as follows (Wright, 1982):

<u>Formation</u>	<u>Percent of Watershed</u>
Stockton Sandstone (sandy members)	42
" " (shale member)	7
Lockatong Argillite	31
Brunswick Shale	14
Igneous and Metamorphic	<u>6</u>
	100

The Wright (1982) study provided an estimate of baseflow for aquifer types. The baseflow for shale and siltstone aquifers with a 1 year in 10 recurrence interval is 53,000 gpd/mi² based on Q30-10/Q30-2 ratios. It is believed that the shale and siltstone aquifers in the middle Delaware River basin are similar to the shale and argillite formations in the Sourland Mountain area.

In sum, a hydrograph can be separated into several components of runoff, such as stormflow, interflow, and baseflow. Even if all of the various forms of runoff are grouped into only two categories: direct runoff (quickflow) and baseflow (delayed flow), the hydrograph separation procedures are judgemental and the results may vary from investigator to investigator. The fact that there are so many legitimate hydrograph separation procedures which can yield varying baseflow estimates is an inherent problem with hydrograph analysis. One thing that must

be noted is that if the same separation methodology is applied to different watersheds, the procedure (like any other procedure) will be judgemental but consistent.

The various hydrograph separation procedures discussed in this section result in baseflow or ground water yield estimates ranging from 53,000 to 220,000 gpd/mi² (see Table 10). The variation in the yield estimates is mostly attributed to the particular separation procedure adopted and the recurrence interval selected.

E. Flow-Duration Curves

The flow-duration curve is a cumulative frequency plot that shows the percent of time during which specified stream discharges were equaled or exceeded within a given period of time (Searcy, 1959). For example, the daily mean discharge of the Stony Brook at Princeton was at least 0.108 mgd/mi² during 70 percent of the 1954-75 time period (see Table 11 and Figure 23).

Although the flow-duration curve does not show the chronological sequence of flows (which a hydrograph does), it does provide a convenient means for studying the flow characteristics of streams. The shape of the flow-duration curve is determined by the hydrologic and geologic characteristics of the watershed. Consequently, the curve can be used to compare the characteristics of one basin with that of another. For example, a curve with a steep slope indicates a "flashy" stream where the flow is largely from direct runoff.

The distribution of low flows in a watershed is governed primarily by the geology of the basin. Thus, the lower end of the flow-duration curve

Table 11

FLOW-DURATION DISCHARGE DATA FOR STONY BROOK AT PRINCETON, N.J., 1954-75
AND SOUTH BRANCH RARITAN RIVER NEAR HIGH BRIDGE, 1919-75

Percent of Time	Discharge Which Was Exceeded for Indicated Percent of Time (mgd/mi. ²)	
	<u>Stony Brook</u>	<u>South Branch</u>
2	6.881	4.778
5	3.557	3.215
10	1.974	2.315
20	1.067	1.642
30	0.701	1.286
40	0.473	1.039
50	0.316	0.832
60	0.200	0.672
70	0.108	0.545
80	0.055	0.432
90	0.023	0.334
95	0.012	0.281
98	0.005	0.235
99	0.003	0.214
99.5	0.002	0.198
Q ₇₋₁₀	0.001	0.208

Source: Gillespie and Schoop (1982).

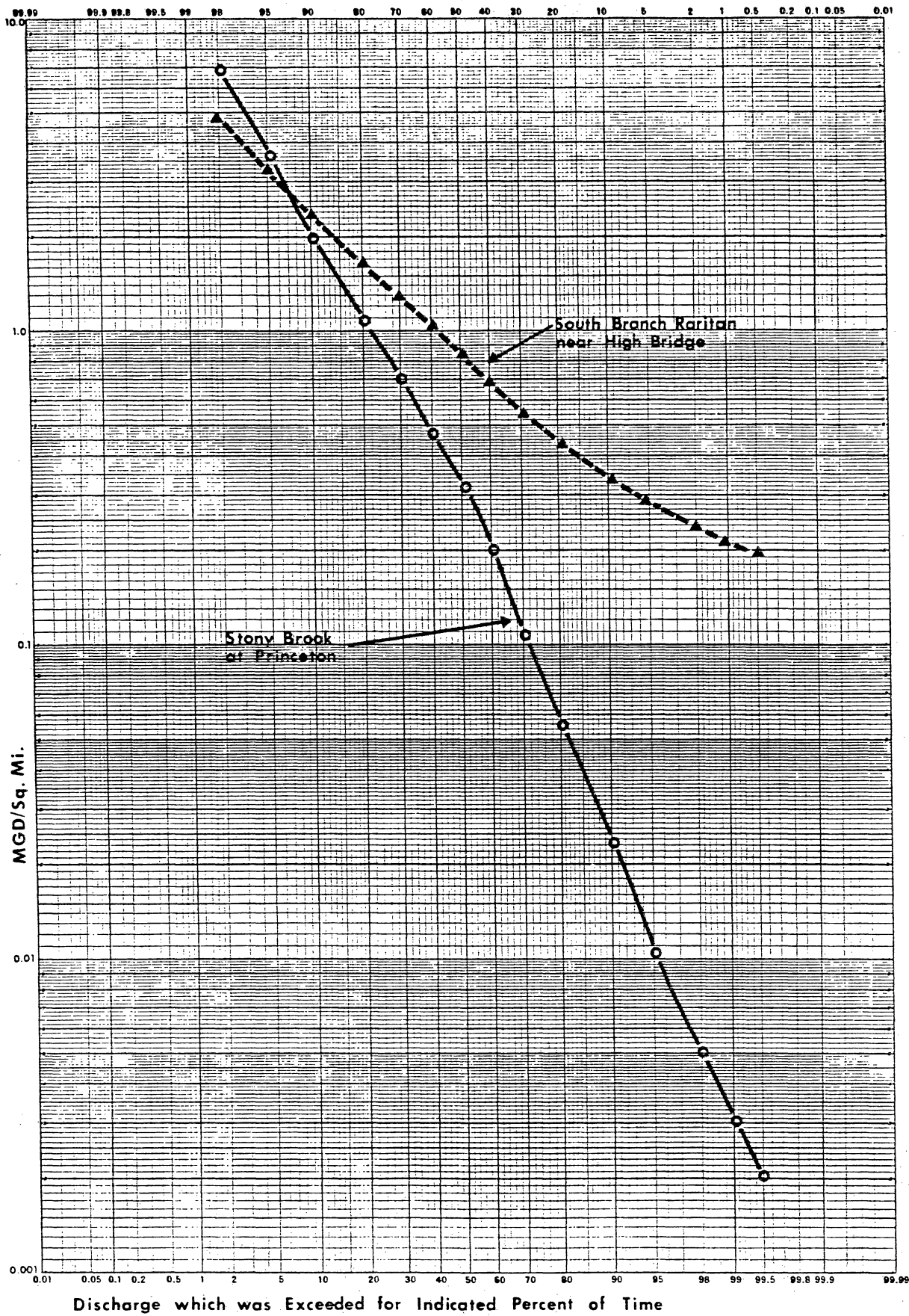


Figure 23. Flow-Duration Curves; Stony Brook at Princeton, 1954-1975; South Branch Raritan near High Bridge, 1919-1975.

provides valuable information on the effects of geology on the ground water runoff to the stream. For example, a steep slope at the lower end of the duration curve indicates a minimal amount of ground water storage in the basin (Searcy, 1959).

The flow-duration curves shown in Figure 23 represent watersheds draining very different types of geologic formations. Over 55 percent of the Stony Brook at Princeton watershed consists of the diabase and argillite of the Sourland Mountain area, whereas the South Branch Raritan at High Bridge drains mostly weathered precambrian and limestone bedrock. Note the very steep slope of the Stony Brook as compared to the gentler slope of the South Branch Raritan at the low-flow end of the graph.

It is generally assumed that streamflow at the lower end of the flow-duration curve is almost entirely derived from ground water sources. For example, Wyrick and Lloyd (1968) suggest that streamflow from ground water sources can be estimated at some point between the 60-percent and 90-percent values on the flow-duration curve. The 60-percent point pertains more to areas underlain by thick glacio-fluvial deposits and to coastal plain formations, whereas the 90-percent point is more appropriate to use for areas underlain by clayey soils of the southern Piedmont and areas covered with glacial till. Wyrick and Lloyd's study area covered the Appalachian region.

In their study of the Swatara Creek basin in southeastern Pennsylvania, Stuart, Schnieder and Crooks (1967) state that the ground water discharge is represented at the 75-percent flow-duration point. Frimpter (1972, p. 37) indicates in his study of the ground water resources of Orange and Ulster

Counties in New York that ". . . streamflow at the 90-percent duration discharge is derived entirely from ground water discharge." In another study of the Black River basin in north-central New York State, Waller and Ayer (1975) indicate that ground water discharge is represented by that portion of the flow-duration curve between the 90-percent and 99.5-percent points. Finally, in a study of New Jersey streams, Miller (1966) states that "The streamflow per square mile at the 90-percent duration point may be used as an arbitrary index of dry-weather flow, since the streamflow at such times is almost entirely from ground water sources."

In sum, it is apparent that the magnitude of ground water discharge to a stream can be reasonably estimated by examining the low-flow end of a flow-duration curve. If we further assume that the long-term ground water yield in a basin can be approximated by the ground water discharge to a stream, then the flow-duration curve provides an excellent means for readily obtaining yield estimates for many watersheds. All it requires then for this initial estimate of the ground water yield of a basin is what point on the flow-duration curve to pick. In this study, the 80-percent point is selected for consolidated rock formations in central and northern New Jersey. For purposes of comparison, discharge values at the 70-percent and the 90-percent points will also be included as well as the Q7-10 value (the average annual minimum discharge for 7 consecutive days with a recurrence interval of 10 years). The Q7-10 value, which is used in water quality studies as a standard for determining the assimilative capacity of surface waters, is exceeded at least 99 percent of the time and is therefore an extremely low number (see Table 11).

Table 12
DISCHARGE AT THE 80-PERCENT POINT ON FLOW-DURATION CURVES
FOR SELECTED STREAMS IN NEW JERSEY

Rank	Stream	Gage No.	Area (mi. ²)	Q80 (mgd/mi. ²)
1	Passaic River near Bernardsville	37869	8.83	0.470
2	Hohokus Brook at Hohokus	3910	16.4	0.453
3	South Branch Raritan near High Bridge	3965	65.3	0.432
4	Whippany River at Morristown	3815	29.4	0.402
5	Weasel Brook near Clifton	3920	4.45	0.401
6	Lamington River near Pottersville	3995	32.8	0.396
7	Elizabeth River at Irvington	3930	2.90	0.370
8	Second River at Belleville	3925	11.6	0.364
9	North Branch Raritan near Far Hills(*)	3985	26.2	0.358
10	South Branch Raritan at Stanton (**)	3970	147	0.338
11	Pequest River at Pequest	4455	108	0.294
12	Ramapo River near Mahwah	3875	118	0.267
13	Flat Brook near Flatbrookville	4400	65.1	0.258
14	Paulins Kill at Blairstown	4435	126	0.256
15	North Branch Raritan near Raritan	4000	190	0.255
16	Ramapo River at Pompton Lakes	3880	160	0.245
17	Mahwah River near Suffern	38745	12.3	0.241
18	Pequest River at Huntsville	4450	31.4	0.226
19	Beaver Brook near Belvidere	4460	36.2	0.209
20	West Brook near Wanaque	3860	11.8	0.203
21	Wallkill River near Unionville	3680	140	0.197
22	Pochuck Creek near Pine Island	3690	98.0	0.189
23	Ringwood Creek near Wanaque	3845	19.1	0.166
24	Pohatcong Creek at New Village	4552	33.4	0.121
25	Blue Mine Brook near Wanaque	3865	1.71	0.089
26	Cupsaw Brook near Wanaque	3850	4.38	0.072
27	Royce Brook Tributary near Belle Mead	4026	1.20	0.066
28	Neshanic River at Reaville	3980	25.7	0.061
29	Stony Brook at Princeton	4010	44.5	0.055
30	Walnut Brook near Flemington	3975	2.24	0.052

Source: Gillespie & Schopp (1982)

* 1904-63 period; prior to Spruce Run Reservoir

** occasional regulation at low flow

Another way to assess the variety of geologic formations in the state is to select flow-duration curve values at the 80-percent point for a mix of watersheds in the consolidated rock areas of central and northern New Jersey. In Table 12, 30 streams with continuous discharge records were ranked in descending order. Note the immediate disparity in Table 12 between the South Branch Raritan near High Bridge (rank No. 3) and the Stony Brook at Princeton (rank No. 29). Further, Walnut Brook near Flemington, which is entirely underlain by argillite, is at the bottom of the table (rank No. 30). Thus, those watersheds which drain diabase and argillite have the least groundwater storage and represent some of the worst areas in the state in terms of ground water yield.

The major geologic formations of 17 watersheds in the Sourland Mountain area are shown in Table 13. Minor formations are not included in the list, so the percent of watershed values may not total 100 percent. Note that only 5 of the 17 streams have continuous discharge records.

Based on regression equations obtained by the U. S. Geological Survey for the 12 partial-record stations listed in Table 13, estimated discharges at the 70, 80, and 90-percent flow-duration points are listed in Table 13 along with the Q7-10 value. The flow-duration values for the 5 continuous record stations were obtained from Gillespie and Schopp (1982). Note that the Q7-10 values for 8 watersheds in Table 13 are zero, and the remaining values are exceedingly low, indicating the minimal amount of ground water storage in the basins.

Table 13

LOW-FLOW CHARACTERISTICS OF SELECTED STREAMS IN CENTRAL NEW JERSEY

Stream	Gage No.	Station Record	Area (Sq. Mi.) ¹	Dominant Formation(s)	Percent of Watershed	MGD / Sq. Mi. At Exceedence Probability (Percent)			Q7-10 ²
						70	80	90	
1. Walnut Brook near Flemington	3975	Continuous	2.24	Argillite	100	0.112	0.052	0.021	0.0
2. Woodville Brook at Woodville	40085	Partial	1.78	Argillite	93	0.065	0.029	0.011	0.0
3. Stony Brook at Glenmoore	4009	Partial	17.0	Argillite Diabase Shale	51 20 19	0.085	0.042	0.017	0.004
4. Baldwin Creek at Pennington	40093	Partial	1.99	Baked Shale Shale	46 42	0.083	0.041	0.018	0.0
5. Baldwin Creek at Baldwin Lake	400932	Continuous	2.52	Shale Baked Shale	46 45	0.049	0.004	0.002	0.0
6. Stony Brook at Pennington	400947	Partial	26.7	Shale Argillite Diabase	35 35 16	0.093	0.041	0.016	0.002
7. Honey Branch near Pennington	400953	Continuous	0.70	Shale Diabase	89 11	0.070	0.029	0.006	-
8. Honey Branch near Rosedale	40097	Partial	3.83	Shale Diabase	60 35	0.056	0.028	0.012	0.0
9. Stony Brook at Princeton	4010	Continuous	44.5	Argillite Shale Diabase	37 35 18	0.108	0.055	0.023	0.001
10. Stony Brook at Clarkeville	4011	Partial	46.5	Argillite Shale Diabase	36 33 18	0.122	0.067	0.033	0.003
11. Bedens Brook near Hopevell	40152	Partial	6.67	Shale Argillite Sandstone	48 29 21	0.128	0.070	0.033	0.010
12. Rock Brook at Blawenburg	40159	Partial	8.02	Shale Argillite	50 42	0.078	0.030	0.010	0.0
13. Bedens Brook near Rocky Hill	4016	Partial	27.0	Shale Argillite	67 20	0.125	0.070	0.035	0.007
14. Royce Brook Tributary near Belle Mead	4026	Continuous	1.20	Shale	100	0.122	0.066	0.024	0.0
15. Jacobs Creek at Somerset	4628	Partial	13.3	Argillite Baked Shale	57 28	0.082	0.038	0.017	0.005
16. Shipetaukin Creek at Lawrenceville	46365	Partial	4.48	Argillite Sandstone	63 37	0.318	0.153	0.059	0.0
17. Shabakunk Creek at Ewingville	46375	Partial	5.0	Sandstone Argillite	60 36	0.245	0.136	0.064	0.013

Source: Gillespie, B. D. & Schopp, R. D. 1982. Low-Flow Characteristics & Flow Duration of New Jersey Streams. U. S. Geological Survey Open-File Report 81-1110.

Note 1. Areas of geologic formations planimetered by the MSM Regional Study Council.

Note 2. Q7-10 = average annual minimum discharge for 7 consecutive days with a recurrence interval of 10 years.

In conclusion, the Q80 (80-percent point on the flow-duration curve) for 17 streams in the Sourland Mountain area ranges from 0.004 to 0.153 mgd/mi². If we assume that the Stony Brook at Princeton is a watershed representative of the area and is also more reliable because of its larger size (44.5 sq. mi.) and length of continuous record (21 years), then the estimated baseflow yield at the Q80 point is 0.055 mgd/sq. mi.

F. Ground Water Yields

Estimating the "safe yield" of an aquifer is fraught with much greater uncertainty than estimating the safe yield of a surface water reservoir system, because the ground water portion of the hydrologic cycle is more complex, less well understood, and not visible to the observer. The term "safe yield" of an aquifer was first introduced by Meinzer (1932) who defined it as ". . .the practicable rate of withdrawing water from it (the aquifer) perennially for human use." Todd (1959) defined safe yield as ". . .the amount of water which can be withdrawn from (the ground water basin) annually without producing an undesired result."

For a particular basin, the amount of discharge must be balanced by a comparable amount of recharge over a period of time, less any change in storage. This balance can be expressed quantitatively by an equation of hydrologic equilibrium. Thus, the calculation of safe yield involves the collection of data on:

- a) surface water inflow and outflow;
- b) water imports and exports;
- c) precipitation;
- d) consumptive use (evapotranspiration);

- e) changes in ground and surface water storage;
- f) subsurface water inflow and outflow.

A number of these items are difficult to measure: subsurface inflow and outflow discharges cannot be directly gauged, and ground water storage changes require detailed information about the existence of ground water in the basin. Adequately measuring ground water storage would require the delineation of aquifers and an analysis of all well logs.

The concept of safe yield has come under criticism, partly because it is often misinterpreted by laymen as implying a fixed underground water supply. Kazmann (1972) considers safe yield to be a pseudo-hydrologic term, inasmuch as it may depend more on the particular well location rather than on general aquifer characteristics. A similar criticism is made in the revised edition of the Glossary of Geology (Bates and Jackson, 1980), wherein usage of the term is discouraged because feasible withdrawal rates depend on the relationship between aquifer boundaries and well locations. Finally, in a recent ground water study of the middle Delaware River basin, Wright (1982) recommends that the term be discontinued and that emphasis should be placed on those components of the hydrologic cycle (such as infiltration or ground water recharge) that have a direct impact on the ground water system.

Subject to the foregoing criticisms, it is still essential to have some estimate of the magnitude of the ground water resource. In his revised edition of Groundwater Hydrology, Todd (1980) suggests that the term "perennial yield" be used in place of safe yield. He defines perennial yield as ". . .the rate at which water can be withdrawn perennially. . .without producing an undesired result." A maximum perennial yield would reflect a

situation where ground water extractions would not exceed ground water recharge. Thus, perennial yield implies a rate at which ground water can be withdrawn from a basin over a time period such that there will be no significant change in ground water storage (Todd, 1980).

In this report, the term "ground water yield" will be used to indicate the rate (in gpd/mi^2) at which water can be withdrawn from an aquifer or basin without causing a long-term decline in the water table or a substantial loss in ground water storage. Furthermore, recognition is given to the importance of maintaining a long-term balance between ground water recharge (defined as that portion of the water infiltrating through the ground surface which can reach the saturated zone of the aquifer) and ground water withdrawal. If these conditions are met, withdrawal of water from the aquifer should not either (a) diminish streamflow, (b) result in interference among wells, or (c) result in an area-wide drawdown of the water table.

G. Well Ratio Method

Well ratios provide a means of relating ground water yields for different aquifers on an areal basis (gpd/mi^2). The presumption is made that if the yield or specific capacity values or ratios of a set of wells from formation A is twice as good as those calculated for formation B, then the ground water yield from formation A is correspondingly twice as good. Although there is a deterministic element in the ratio method, there is a reasonable hydrologic underpinning to the procedure. High yield and specific capacity values do reflect favorable aquifer properties, and therefore one could anticipate better overall yields on an areal basis from such an aquifer.

Other investigators might assert that the ratio method is overly simplistic and that only more complex procedures would give better results. But given all of the uncertainties in hydrologic estimation, a simpler method will provide results that are not only meaningful but practical to obtain.

Now that we have mentioned at least some of the philosophical aspects of hydrologic estimation, we can turn our attention to the procedure itself. As stated in Section IIC, specific capacities were calculated only for those wells in the study area where pump tests were reported for 4 hours or more. The same threshold was applied to yield data for the wells in Hunterdon and Mercer Counties. In the case of the study area, all of the well records were analyzed for yield. While some of the domestic well information in the study area may not be too reliable, the large number of wells (nearly 1,600) provides a reasonable degree of confidence. Note that the total number of wells in the study area is not a sample but rather the population of all of the well records that were available in the files of NJDEP in Trenton.

The well ratio method can be applied to either yield or specific capacity values. However, specific capacity is a better figure to use in determining aquifer efficiency, as both yield and drawdown are factors in the calculation, as follows:

$$\text{Specific Capacity} = \frac{\text{yield (GPM)}}{\text{drawdown (feet)}}$$

Specific capacity values can vary by several orders of magnitude and indeed can even reach infinity when drawdown is zero. When one is comparing the median specific capacity of one formation to another, the resulting ratio

may be unusually large, given the nature of the distribution. Therefore, it is suggested that the Q3-Q1 (75 percent-25 percent) value that is derived from the cumulative frequency distribution of specific capacities for each formation be used to assess aquifer performance. For example, the Q3-Q1 values for the sandstone and argillite formations in the study area are 0.492 and 0.148, respectively (see Table 14), resulting in a sandstone/argillite ratio of 3.32 (see Table 15). The average sandstone/argillite ratio based on the three areas is 3.31 (see Table 15). The average ratios may then be used to estimate ground water yields for each formation.

The next step in the procedure is to select the aquifer which has the best yield information. Since Walnut Creek near Flemington is underlain entirely by argillite and has had a continuous gauging station operating in the watershed from 1936-61 (24 complete years of record), it has been selected as the baseline aquifer. This means that the other formations in the study area will be compared to the argillite formation. Posten (1982) also selected Walnut Brook for his hydrograph separation analysis.

Royce Brook tributary near Belle Mead in Hillsborough Township is underlain entirely by shale. However, the watershed is smaller than Walnut Brook (1.20 vs. 2.24 mi²) and had a continuous gauging station for a smaller time period (10/66-9/74; reactivated in 1/80). Therefore, Walnut Brook appeared to be the better choice. It would have been desirable to select a larger watershed with a longer period of record such as the Stony Brook at Princeton (44.5 mi²; discharge records begin 10/53), but the watershed is underlain by several formations (see Table 13).

Table 14

SPECIFIC CAPACITY Q3-Q1 VALUES OF SELECTED FORMATIONS

Area	Stockton Sandstone	Brunswick Shale	Lockatong Argillite	Diabase
A. Study Area				
Q3-Q1 *	0.492	0.339	0.148	0.118
Sample Size	54	112	426	91
B. Hunterdon County				
Q3-Q1	0.572	1.335	0.337	0.342
Sample Size	124	471	119	35
C. Mercer County				
Q3-Q1	1.950	0.510	0.398	0.358
Sample Size	101	90	48	11

* Q3 : 75 percent; Q1 : 25 percent

Note: Specific capacities were calculated only for those domestic and non-domestic wells where pump tests were reported for 4 hours or more.

Table 15

RATIOS OF SELECTED FORMATIONS BASED ON SPECIFIC CAPACITY Q3-Q1 VALUES

Geologic Formation	Sourland Mountain Area Wells (1)	Hunterdon County Wells (1)	Mercer County Wells (1)	Average of Three Areas
Sandstone/Argillite	3.32	1.70	4.90	3.31
Shale/Argillite	2.29	3.96	1.28	2.51
Diabase/Argillite	0.80	1.01	0.90	0.90

Trs: Stockton Sandstone

Trdb: Diabase

Trb: Brunswick Shale

Trl: Lockatong Argillite

(1) See Table 14.

H. Discussion and Conclusions

It is readily apparent from the previous sections that there are a variety of methods which can be brought to bear on estimates of baseflow and hence ground water yield. Other methods, such as the ground water stage-discharge rating curve procedure and well/aquifer tests are possible in theory, but the lack of observation wells in the area precluded their use in this study.

Hydrograph analysis is a valuable empirical method for estimating baseflow. Hydrographs with continuous records are available for thousands of gaging stations in the U. S. Indeed, New Jersey has the highest number of gaging stations per unit area of any state - about five times the national average. However, hydrograph analysis is laborious, as it involves the separation of numerous years of mean daily discharge into stormflow (or quickflow) and baseflow (or delayed flow). There are many separation procedures, and their selection and use is fraught with a high degree of professional judgment. Different investigators can come up with varying results using unimpeachable but different techniques on the same hydrograph.

Be that as it may, there is a strong hydrologic rationale to hydrograph separation. In addition the procedure can be programmed for a computer which will of course enable one to process many years of record for many stations. (This procedure was beyond the scope of this project.) However, one is still faced with the problem of dealing with watersheds underlain by two or more rock formations. The suggested procedure for estimating ground water yield on an areal basis ($\text{gpd}/\text{mi.}^2$) for each formation based upon hydrograph

separation analysis is as follows:

- a) Collect all available well data within the study area.
- b) Calculate the specific capacity of all wells where pump tests were reported for 4 hours or more. Non-domestic well records are preferred, but if the sample size is too small within the study area, include domestic wells as long as the 4-hour pump test criterion is met.
- c) Perform a frequency distribution analysis of all of the well data. Obtain the Q3-Q1 (75-25 percent) points on the cumulative frequency distribution of specific capacity for each formation.
- d) Select one formation as the baseline aquifer with which the other aquifers will be compared. Presumably, the aquifer selected would have the best estimate of yield available.
- e) Prepare a Q3-Q1 specific capacity ratio for all of the formations in the study area and use the ratios for ground water yield estimation.

Flow-duration curves are a reliable and straightforward basis for baseflow estimates. As indicated earlier, the low-flow end of a flow-duration curve provides excellent information about the geology and ground water storage of a watershed. Flow-duration curves which are steeply sloping indicate minimal amount of ground water in storage and consequently low baseflow.

Flow-duration data are available for many gaging stations and have been recently published for New Jersey (Gillespie and Schopp, 1982). They can be used as baseflow estimators. However, as noted above, the problem is the selection of the low-flow portion of the curve as the baseflow indicator. A review of the literature (see Section IIE) indicates that baseflow can be estimated somewhere between the 60-percent and 99-percent points on the curve.

Posten (1982) found that his yield estimates for three bedrock basins in New Jersey based on hydrograph separation corresponded to the following points on the flow-duration curve for each watershed:

<u>Watershed</u>	<u>Geology</u>	<u>Percent on Flow-Duration Curve</u>
Walnut Brook near Flemington	Argillite	72
Blue Mine Brook	Precambrian	75
West Brook	"	83

Wright (1982) regrettably did not include any comparison with flow-duration data for his study of watersheds in Pennsylvania. Stuart, Schneider and Crooks (1967) estimated that the baseflow in the Swatara Creek basin in southeastern Pennsylvania corresponded to 75-percent on the flow-duration curve. Other estimates (Frimpter, 1972; Miller, 1966) suggest the 90-percent point but did not include hydrograph separation in their estimates. It is reasonable to conclude that the baseflow is probably represented by a value on flow-duration curves in bedrock areas of New Jersey somewhere between 70-percent and 90-percent. In this study, the 80-percent value was selected as the most reasonable value to work with. The base flow for the formations in the study area are shown in Table 16. As indicated before, the 80-percent point on the flow-duration curve for Walnut Brook at Flemington (which is entirely underlain by argillite) in conjunction with the average well ratio from Table 15 was selected as the best estimator of base flow. The other estimates in Table 16 are included for purposes of comparison.

In non-sewered residential areas, it is recognized that most of the water coming into the house will be returned to the ground via septic disposal fields.

Table 16

ESTIMATED BASE FLOW FOR SELECTED FORMATIONS IN THE SOURLANDS STUDY AREA

Formation	Base Flow (gpd/mi. ²)			
	Hydrograph Separation Method (a)	Q70 (b)	Q80 (c)	Q90 (d)
Stockton Sandstone	305,000	371,000	172,000	70,000
Brunswick Shale	231,000	281,000	131,000	53,000
Lokatong Argillite	92,000	112,000	52,000	21,000
Diabase	83,000	101,000	47,000	19,000

(a) Based on hydrograph separation for Walnut Brook at Flemington (all argillite) and the average well ratio shown in Table 15.

(b) Based on the 70-percent flow-duration point (Q70) for Walnut Brook at Flemington and the average well ratio shown in Table 15.

(c) Based on the 80-percent flow-duration point (Q80) for Walnut Brook at Flemington and the average well ratio shown in Table 15.

(d) Based on the 90-percent flow-duration point (Q90) for Walnut Brook at Flemington and the average well ratio shown in Table 15.

Thus, this water will be recycled as it recharges the local aquifer. On the other hand, that fraction of the household water that is used for watering shrubbery and lawns represents a consumptive use which will not return to the local aquifer. This "loss" to evapotranspiration will of course vary from house to house, but the important thing is that the amount that is used will not be available to recharge the aquifer.

Estimates of the amount of water that is used within the house and that will become spent water that is discharged to either sewers or septic tanks varies from 60-96 percent. For example, Fair, Geyer and Okun (1966) estimate that 60-70 percent of the total water supplied becomes wastewater which is in the same range as the Linsley and Franzini (1972) estimate of 60-75 percent. Note that the latter two estimates pertain to communities with public water and sewer. In terms of the water used by an average household, Durfor and Becker (1962) estimate that 96 percent of the water coming into the house is used within the house. New Jersey Department of Environmental Protection estimates that the depletive use of water for residential areas is about 10 percent, which means that 90 percent of the incoming water winds up as wastewater (Ross, telephone interview, December 21, 1983).

If we assume that the Sourland Mountain area will remain in low-density housing, then it is reasonable to presume a somewhat greater depletive use of water to account for larger lawn/vegetated areas. For purposes of this study then, a depletive use of 15 percent is adopted which means that 85 percent of the water coming into the house will be released back to the aquifer.

We can now make operational definitions for two terms in common usage:

- 1) base flow is the amount of ground water that will sustain stream flow at

Table 17

GROUND WATER YIELD ESTIMATES FOR SELECTED STUDY AREA FORMATIONS

Formation	Ground Water Yield (gpd/mi. ²)
Stockton Sandstone	145,000
Brunswick Shale	110,000
Lockatong Argillite	45,000
Diabase	40,000

Note: the values in this table are 85 percent of the Q80 values shown in Table 16. All estimates have been rounded to the nearest 5,000 gpd/mi.²

given exceedence probability levels; and 2) ground water yield is equal to the base flow minus the depletive use component. Thus, the procedure for obtaining ground water yield estimates is as follows:

- 1) obtain the base flow for a formation or watershed by hydrograph analysis or by selecting an appropriate exceedence level on the flow-duration curve (the Q80 value is recommended for the Sourland area);
- 2) multiply the base flow estimate by the specific capacity well ratio method in order to obtain values for other formations;
- 3) multiply the base flow values by 0.85 (or 15 percent depletive use) to obtain ground water yield estimates.

The underlying presumption in all of this is that continued pumping on an areal basis ($\text{gpd}/\text{mi.}^2$) at the ground water yield estimate level will not have any deleterious impacts on the ground water resources of the study area. If a sewerage system is introduced whereby the wastewater will be collected and disposed of outside the study area, then the depletive use component rises dramatically and the ground water yield estimate would have to be revised downward.

For the Sourland Mountain area, a set of base flow estimates for each formation are shown in Table 16. If we select the Q80 base flow estimate and use a multiplier of 0.85, the resulting ground water yield estimates for each formation are shown in Table 17.

The average residential development density based on groundwater yield on either a watershed or formation basis can be estimated by the following equation (Pizor, et al., 1982):

$$Dws = \frac{Y}{640 Qs P}$$

where Dws = average development density in DU/acre based on water supply

Y = ground water yield in gpd/mi.²

Qs = per capita consumption in gals/person/day (GPCD)

P = number of people/DU

DU = dwelling unit

For convenience, it is useful to use the reciprocal of DU/acre which is acre/DU. This is shown on the ordinate of Figure 24.

If you hold Qs and P constant, the equation plots as a straight line on log-log graph paper (see Fig. 24). Note the inverse relationship between groundwater yield and average development requirements: as the groundwater yield increases, the acres required per DU decreases.

Table 18 lists average development densities for a variety of yield assumptions. For example, if we assume a yield for the diabase and argillite of about 50,000 gpd/mi.² and a household consumption of 350 GPCD, then application of the equation results in average development density of about 4.5 acres/DU.

It is important to stress that water quality considerations (viz, wastewater disposal) were not included in the Dws equation and are known to be much more constraining (Pizor, et al, 1982). For example, average minimum residential lot size recommendations for consolidated rock areas in central New Jersey are approximately doubled when onsite wastewater disposal is considered. Thus, the 4.5 acre/DU estimate is on the low side and the development density should be decreased to allow more acreage (and thus more recharge) per DU. Water quality considerations, it should be noted, were beyond the scope of this report.

Table 18

AVERAGE DEVELOPMENT DENSITY BASED ON GROUND WATER YIELD

Ground Water Yield (GPD/sq. mil.)	Average Development Density (Acres/DU) Qs = 100 GPD; P = 3.5/DU
25,000	9.0
50,000	4.5
100,000	2.2
150,000	1.5
200,000	1.1
250,000	0.9
300,000	0.7

Equation: $Dws = \frac{Y}{640 Qs P}$

where Dws = development density in DU/acre based on water supply

Y = Ground water yield in gpd/sq. mi.

Qs = Per Capita consumption (gpd)

P = Number of people/DU

DU = Dwelling unit

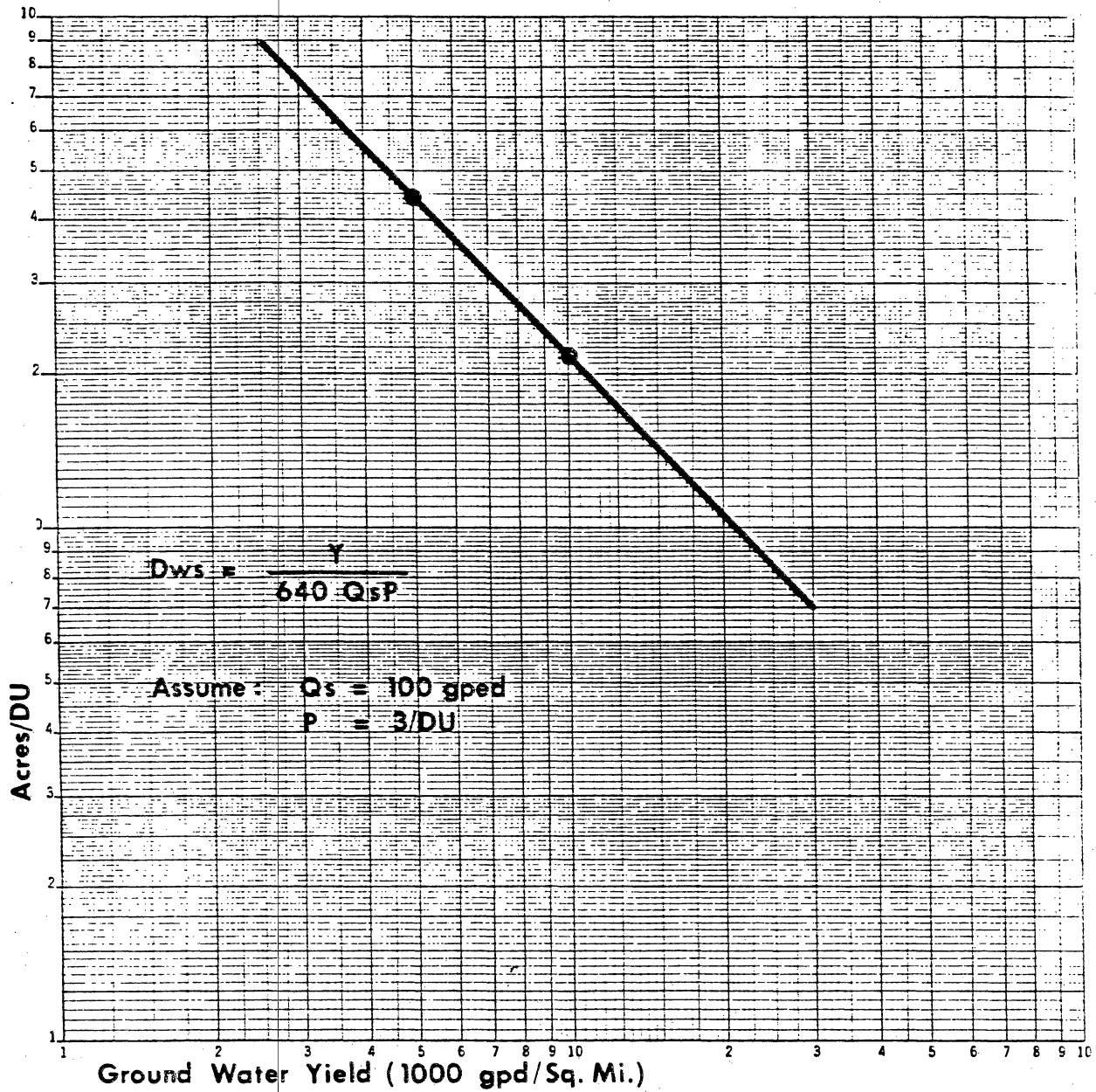


Figure 24. Development Density Based on Groundwater Yield.

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III. LEGAL AND INSTITUTIONAL ANALYSIS

A. The State's Role in Groundwater Management

In 1981, the Legislature adopted a series of water supply statutes that thoroughly revised and modernized the State's approach to water resource management. The most significant was the Water Supply Management Act, N.J.S.A. 58:1A-1 et seq. In reviewing the particular provisions of that statute, it is helpful to consider the statement of legislative findings and declarations intended to assist in the interpretation and implementation of the law. It provides in pertinent part:

. . . (T)he water resources of the State are public assets of the State held in trust for its citizens and are essential to the health, safety, economic welfare, recreational and aesthetic enjoyment, and general welfare, of the people of New Jersey; that ownership of these assets is in the State as trustee of the people; that because some areas within the State do not have enough water to meet their current needs and provide an adequate margin of safety, the water resources of the State and any water brought into the State must be planned for and managed as a common resource from which the requirements of the several regions and localities in the State shall be met; . . . that it is necessary to insure that within each basin there exists adequate water supplies to accommodate present and future needs; . . . (N.J.S.A. 58:1A-2) (emphasis added)

To fulfill the hortatory objectives of this statute, the DEP is vested with broad regulatory powers. The agency may adopt rules and regulations "to control, conserve and manage the water supply . . . and the diversions of that water supply to assure the citizens of the State an adequate supply of water . . ."

N.J.S.A. 58:1A-5. While the administrative rules may be applicable throughout the State, they may be particularized to address local conditions. There appears to be implicit legislative recognition that the rules in water-deficient regions may be substantially more restrictive than in water-abundant areas. N.J.S.A.

Note: This section was written and researched by Lewis Goldshore, Esq. and Marsha Wolf, Esq.

58:1A-5. Pursuant to this enabling authority, the DEP may be empowered to adopt a broad array of regulations limiting, conditioning and controlling ground water withdrawals in the Sourland Mountain region.

The essential control mechanism in the Water Supply Management Act is a permit system for diversions, statutorily defined to include ground water withdrawals. N.J.S.A. 58:1A-3, -5 to -8. Such diversion permits are statutorily required to include provisions fixing maximum allowable diversions, identifying and limiting the use of the water, permitting inspection and monitoring by the DEP. N.J.S.A. 58:1A-8. While the presumptive threshold that necessitates a diversion permit is 100,000 gallons per day, it appears that the DEP could justify similar controls over smaller diversions, particularly in areas characterized by limited subsurface water supply.

The current water diversion/allocation administrative rules adopted by the DEP and generally applicable to persons desiring to divert more than 100,000 gallons per day are compiled at N.J.A.C. 7:19-1 et seq. Incorporated within the existing rule-making is a concern with maintaining adequate water supplies, with preventing interference respecting existing water resources and with recognizing the rights of other water users. An applicant for a water diversion permit is thus required to provide all information to establish, among other things:

1. That the plans proposed are in the public interest and provide for the proper and safe construction of all works connected therewith;
2. That diversion of the quantity of water requested shall not unduly interfere with other existing supplies;
3. That diversion normally shall not exceed the natural replenishment or safe yield of the water resources or threaten to exhaust such waters or to render them unfit for use from any cause;

4. That the plans for the proposed diversions are just and equitable to the other water users affected thereby;

. . .

6. In the case of ground water only, that the proposed diversion does not lie within a cone of depression where the aquifer to be utilized is over stressed or threatened by saline intrusion, and that the location relative to hazardous waste disposal site or other major source of pollution is not such as to be likely to result in groundwater contamination;

7. That there are adequate sewerage facilities for disposal of sewage from areas to be served;

. . .

(N.J.A.C. 7:19-2.2).

These regulations provide an appropriate framework for the formulation of requirements that could be applied to applicants for smaller diversions in water-deficient regions.

Another element of the water supply law that might be applicable under extreme circumstances concerns water supply emergencies. In the event that a water supply shortage is so severe as to endanger public health, safety or welfare, the State is vested with extraordinary remedial powers. Following a DEP determination of exigent conditions, the Governor is authorized to proclaim by Executive Order a state of water emergency and appropriate actions may be taken, including the DEP issuance of orders to reduce water use or distribution, emergency interconnections and the imposition of a surcharge on water use. N.J.S.A. 58:1A-4. It is presumed that these measures would be of a temporary duration. Thus, where the conditions are of a chronic nature, such as in the Sourland Mountains, the preferable practice would be to rely on other provisions of the statute for possible relief.

An additional statute enacted as part of the 1981 water supply legislative package that might have applicability in the instant situation concerns small water companies. A "small water company" is defined to include any private company, purveyor or entity, that supplies water to less than 1,000 customer connections. N.J.S.A. 58:11-59 et seq.

This statute would be applicable in the event that such small water companies operate in the area in question and fail to comply with a DEP order concerning water quality or water supply. Following a joint public hearing conducted by the DEP and the BPU, an order could be issued directing the acquisition of the small water company by the most suitable public, including municipal, or private entity. Relief under this statute would only be available in those situations where there was a preexisting small water company in operation. Thus, this statute is likely to be of limited assistance with respect to the Sourland Mountain Region.

The water supply measures adopted in 1981 were preceded by substantial legislative involvement in water resource law. As early as 1954 the State recognized that subdivisions not served by State approved water supply or sewerage systems could result in future problems. In an effort to address this situation, The Realty Improvement Sewerage and Facilities Act (1954), N.J.S.A. 58:11-23 et seq., commonly referred to as "Chapter 199", was enacted.

The realty improvement law authorized the DEP to adopt minimum standards for the construction of individual and small non-community water supply and sewerage facilities, basically individual wells and septic tanks, and to assure that these systems were constructed in a safe, adequate and proper manner. N.J.S.A. 58:11-36. Such standards have been adopted and are compiled at N.J.A.C. 7:9-2.1

et seq. (standards for individual subsurface sewage disposal systems) and N.J.A.C. 7:10-12.1 et seq. (standards for public non-community and non-public water systems). The authority to adopt more stringent standards at the local level is expressly recognized in the law. N.J.S.A. 58:11-25 provides that no building permit shall be issued for a realty improvement until compliance with State standards or more restrictive local standards has been determined.

Except in unusual circumstances, that is, where more than 50 units are submitted for approval, the authority to determine compliance with the standards is generally assigned to the local board of health. N.J.S.A. 58:11-26. It should be noted that in some municipalities the powers of the board of health are assigned to another municipal agency or are provided under contract with a regional health agency. Even where larger developments have been constructed, developers have been able to avoid State level-DEP approval by phasing the development. N.J.S.A. 58:11-25.1.

It appears that there is sufficient statutory authority to upgrade State-level water supply regulations in water-deficient areas. N.J.S.A. 58:11-36. In such event, however, the enforcement of those standards for all practical purposes would remain at the municipal level. An argument can be advanced for an increased State role in this process, particularly in those communities that have experienced serious problems with private wells or where local officials lack adequate training or interest to assure compliance with the standards. This realignment of administrative responsibility could be effectuated in a number of ways including the amendment of the realty improvement statute to expressly enable the DEP to designate critical areas for water supply purposes and limit the types of water supply facilities that could be constructed thereafter.

In this regard, it should be noted that a procedure for designating critical areas for sewerage facilities has been in place since 1966 and has been utilized in low-lying areas along the coast and in the pinelands. See N.J.S.A. 58:11-43 et seq.; Ocean Acres, Inc. v. State, 168 N. J. Super. 597 (App. Div. 1979), certif. den. 81 N.J. 352 (1979) (rejecting challenge to DEP's designation of central pine barrens as a "critical area" for sewerage and water quality standards and to validity of DEP regulations requiring developer to obtain permits to install septic systems on the property); N.J. Bldrs. v. Dept. of Environmental Protec., 169 N.J. Super. 76 (App. Div. 1979), certif. den. 81 N.J. 402 (1979). It appears that even in the absence of the enactment of legislation expressly addressing these issues, it could be argued that there is sufficient existing general statutory authority to remedy the situation.

In addition to the authority vested in the DEP, the Board of Public Utilities (BPU) has substantial powers concerning investor-owned water utilities. Such entities are designated public utilities and subject to the jurisdiction and control of the BPU. N.J.S.A. 48:2-13; 48:19-5 et seq. Additionally, the BPU is authorized to direct private water companies to provide service in an environmentally acceptable manner. N.J.S.A. 48:2-23. While it is conceivable that the BPU could become involved in remedying problems in water-deficient areas, as a result of the prevalence of individual private wells, rather than small water companies, in the Sourland Mountains region, the BPU's participation is unlikely.

B. Municipal Government's Role in Ground Water Management

Pursuant to the police power, as well as the zoning power, local government can have a very substantial role in water supply management. While there are some limitations on the exercise of these powers, a concerned local government situated in a water-deficient region can have a very important part in preventing and controlling water supply problems.

The State Constitution

In applying grants of municipal power it is helpful to refer to pertinent provisions of the State Constitution. Unlike some other states that have enacted systems of constitutional home rule, the New Jersey Legislature, subject to specified limitations, may freely adopt, amend and repeal statutes pertaining to municipal government. N. J. Const. (1947) Art. 4, section 7, par. 9. At the same time, however, the State Constitution mandates that where authority has been granted to local government either by the Constitution or by statute, these powers are to be broadly and liberally construed and are to encompass not only those powers which are expressly granted but those that can be reasonably implied.

The provisions of this Constitution and of any law concerning municipal corporations formed for local government, or concerning counties, shall be liberally construed in their favor. The powers of counties and such municipal corporations shall include not only those granted in express terms but also those of necessary or fair implication, or incident to the powers expressly conferred, or essential thereto, and not inconsistent with or prohibited by this Constitution or by law. N.J. Const. (1947), Art. 4, section 7, par. 11.

Statutory authority for local involvement in the water supply management area includes the general police power, the zoning power, the statutory authority of local boards of health, and may additionally be implied from statutes concerning water supply management. Where such powers are exercised, the Constitution instructs that they are to be liberally construed in favor of the municipal entity.

General Police Power

Pursuant to the Home Rule Act, N.J.S.A. 40:48-1 et seq., adopted in 1917, the governing body of every municipality is vested with broad general police powers. In addition to enumerating the specific areas as to which ordinances may be enacted and enforced by municipal government, the Home Rule Act provides a broad grant of authority to enable a municipality to adopt any ordinance it deems necessary and proper to promote the public health, safety and welfare.

This provision provides in its entirety:

Any municipality may make, amend, repeal and enforce such other ordinances, regulations, rules and by-laws not contrary to the laws of this state or of the United States, as it may deem necessary and proper for the good government, order and protection of persons and property, and for the preservation of the public health, safety and welfare of the municipality and its inhabitants, and as may be necessary to carry into effect the powers and duties conferred and imposed by this subtitle, or by any law. (N.J.S.A. 40:48-2).

This general grant of police power has been broadly construed by the courts to expressly delegate State police powers to local governing bodies and is regarded as additional to, not merely ancillary to, the detailed authorizations for municipal action set forth in the statutes. Hudson Circle Servicer, Inc. v. Kearny, 70 N.J. 289, 298 (1976). Furthermore, the constitutional provision providing that "any law concerning municipal corporations . . . shall be

liberally construed in their favor", gives further weight to the express delegation of police power to a municipality. N. J. Const. (1947) Art. IV, section 7, par. 11; Id.; Quick Chek Food Stores v. Springfield Tp., 83 N.J. 438, 447 (1980).

Accordingly, a municipality is empowered to enact regulatory ordinances concerning any subject matter of local concern that is reasonably related to a legitimate object of the public health, safety or welfare, as long as the field has not otherwise been preempted. Quick Chek Food Stores v. Springfield Tp., supra, 83 N.J. at 448. A presumption of validity and reasonableness attaches to ordinances, with the burden of proof to establish otherwise on the challenging party. Id. at 447. Only a clear showing that the ordinance is arbitrary or unreasonable can overcome this strong presumption of validity. Id. Further, the underlying policy and wisdom of ordinances are regarded as within the domain of the governing body and an ordinance will not be set aside if any state of facts may reasonably be conceived to justify it. Id.

The broad delegation of police power set forth in N.J.S.A. 40:48-2 has accordingly been interpreted to authorize the enactment of municipal ordinances concerning an expansive range of subject matter. For example, in the context of environmental protection and safeguarding the health and safety of the community, extensive local regulation of quarry operations was upheld. See Dock Watch Hollow Quarry Pit v. Tp. of Warren, 142 N. J. Super. 103 (App. Div. 1976), aff'd o.b. 74 N.J. 312 (1977). In reaching this conclusion the court observed:

. . . The Supreme Court has recognized that the protection of public health through the preservation of the environment is a valid, and indeed primary, objective of the police power. Huron Portland Cement Co. v. Detroit, 362 U.S. 440, 442, 80 S. Ct. 813, 815, 4 L. Ed. 2d 852, 855 (1960). Today it cannot possibly be questioned that the preservation

of the environment and the protection of ecological values are, without more, sufficient to warrant an exercise of this power . . . (142 N. J. Super. at 116, citations omitted).

Indeed, it has been recognized by the courts that local government may be accorded the discretion to devise measures tailored to meet local needs. See Inganamort, et al. v. Bor. of Fort Lee, et al, 62 N.J. 521, 528 (1973) (upholds a rent control ordinance in the absence of express enabling authority). Clearly, a problem, such as an inadequate water supply, existing in some municipalities may be non-existent in others. Accordingly, municipalities may choose to act in a manner which will best serve the local need. Id. at 529. For additional examples of ordinances held to be within the broad purview of the municipal police power see, e.g., Quick Chek Food Stores v. Springfield Tp., supra (restriction of business hours of commercial establishment); Hudson Circle Servicenter, Inc. v. Kearny, 70 N.J. 289 (1976) (regulation of parking lots operated in conjunction with "truck stops"); Lehrhaupt v. Flynn, 140 N. J. Super 250 (App. Div. 1976) aff'd o.b. 75 N.J. 459 (1978) (requiring certain municipal officials to make full financial disclosure).

In respect of the enforcement of local police power ordinances and penalties for violating such ordinances, a governing body may prescribe penalties for violation of such ordinances by imprisonment for a term not exceeding 90 days, or by a fine not exceeding \$500.00, or both. N.J.S.A. 40:49-5. See also N.J.S.A. 40:69A-29(b) authorizing Faulkner Act municipalities to adopt and enforce local police ordinances of all kinds and authorizing similar sanctions.

The regulatory powers of the local boards of health should also be considered. While these agencies exist in many communities, in some municipalities the board's responsibilities are assigned to another entity, generally to the governing body.

Moreover, there is a growing trend for the functions of the local boards to be assigned to a regional health agency.

In those municipalities in which there is a local board of health, that entity has independent statutory authority to adopt local public health ordinances for enumerated purposes. N.J.S.A. 26:3-31; 26:3-64. Monetary penalties of up to \$500 may be imposed for the violation of a local health ordinance. N.J.S.A. 26:3-70.

It appears that local boards of health could enact ordinances pertaining to water supply, but the precise scope of the regulatory authority is not clear. N.J.S.A. 26:3-31.a. To avoid jurisdictional questions, it may be more appropriate for a municipality desirous of enacting controls in this area to rely on the general grant of the police power pursuant to N.J.S.A. 40:48-2, rather than the powers granted to the local board of health.

Furthermore, it should be noted that pursuant to the Environmental Rights Act, N.J.S.A. 2A:35A-1 et seq., a local governing body or any other political subdivision of the State, is authorized to maintain a court action against any other person to enforce or to restrain the violation of, any statute, regulation or ordinance designed to prevent or minimize pollution, impairment or environmental destruction. N.J.S.A. 2A:35A-4. Thus in the event that a municipality determined that a State water supply management statute was being violated, it could commence a lawsuit to directly enforce the applicable provision of law.

Municipal Land Use Controls

Municipal land use controls constitute another source of authority for the municipal regulation of water supply. In this regard, the State Constitution

expressly authorizes the process of local zoning:

2. Zoning laws. The Legislature may enact general laws under which municipalities, other than counties, may adopt zoning ordinances limiting and restricting to specified districts and regulating therein, buildings and structures, according to their construction, and the nature and extent of their use, and the nature and extent of the uses of land, and the exercise of such authority shall be deemed within the police power of the State. Such laws shall be subject to repeal or alteration by the Legislature. (N.J. Const. (1947) Art. IV, section VI, par. 2).

Through the adoption of the Municipal Land Use Law, N.J.S.A. 40:5D-1 et seq., the Legislature has implemented the constitutional zoning enabling provision. Several provisions of the Municipal Land Use Law are applicable to the municipal regulation of water supply. Included in the intent and purpose of the act, for example is:

- a. To encourage municipal action to guide the appropriate use or development of all lands in this State, in a manner which will promote the public health, safety, morals and general welfare;
- b. To secure safety from fire, flood, panic and other natural and man-made disasters;
-
- e. To promote the establishment of appropriate population densities and concentrations that will contribute to the well-being of persons, neighborhoods, communities and regions and preservation of the environment;
-
- g. To provide sufficient space in appropriate locations for a variety of agricultural, residential, recreational, commercial and industrial uses and open space, both public and private, according to their respective environmental requirements in order to meet the needs of all New Jersey citizens;
-
- j. To promote the conservation of open space and valuable natural resources and to prevent urban sprawl and degradation of the environment through improper use of land;
-

Implicit in the development of sound zoning regulation is that municipalities consider the State's public policy of preserving the environment; local zoning decisions may thus be properly influenced by the concern with protecting the environment from pollution, impairment and destruction. Lusardi v. Curtis Point Prop. Owners Ass'n. 86 N.J. 217, 229 n.3 (1981); N.J.S.A. 40:55D-2(e), (g), (i), (j); N.J.S.A. 2A:35A-2. Moreover, as a practical matter, the adequacy and reliability of an area's water supply are major factors in determining its rate of growth and development.

Any doubt concerning the importance of integrating environmental factors in the landuse process was removed by the Supreme Court in its recent decision in So. Burlington Cty. N.A.A.C.P. v. Mount Laurel Tp., 92 N.J. 158 (1983), commonly referred to as Mount Laurel II. In this regard, particularly in areas designated as "limited growth", "agriculture" or "conservation" areas by the State Development Guide Plan, environmental considerations limit such municipalities' housing obligation to its indigenously generated present need. In those municipalities containing growth areas, however, environmental impact must be shown to be substantial before it may be used to restrict the construction of affordable housing. Accordingly, under the rationale of the Mount Laurel II decision, concern for protection of the environment remains strong. Of further relevance to local concern with water supply issues, is the Court's statement that as long as a community satisfies its fair share obligation, other measures, including large-lot and open area zoning, will not be restricted by the Mount Laurel doctrine. Thus, low density limitations which may be a useful approach in water-deficient areas, are not necessarily violative of Mount Laurel obligations as long as such obligations are otherwise satisfied.

Of particular relevance to the integration of water supply concerns in

the local land use process, is the provision in the Municipal Land Use Law providing for the realization of the statute's objectives by the adoption of a master plan "to guide the use of lands within the municipality in a manner which protects public health and safety and promotes the general welfare". N.J.S.A. 40:55D-28a. The most essential element in the plan, the land use plan element, provides the rationale for the zoning ordinance, and is expressly required to take into account water supply issues:

(2) A land use plan element (a) taking into account the other master plan elements and natural conditions, including, but not necessarily limited to, topography, soil conditions, water supply, drainage, flood plain areas, marshes and woodlands. . . . (N.J.S.A. 40:55D-28b.(2) (emphasis added).

Other optional elements of the master plan involve water supply considerations. The utility service plan element should analyze the need for and indicate the future general location of water supply and distribution facilities, as well as drainage and flood control facilities, sewerage and waste treatment, solid waste disposal and other related utilities. N.J.S.A. 40:55D-28b. (5) The master plan may also include a conservation plan element which provides for the preservation, conservation and utilization of natural resources which include to the extent appropriate, open space, water, and soil. N.J.S.A. 40:55D-28b.(8). The master plan may thus be quite detailed and comprehensive and should properly incorporate water supply issues. Experience indicates that few municipal master plans reflect these statutory goals.

The subdivision and site plan review processes provide additional opportunities for municipalities to deal responsibly with water supply needs. N.J.S.A. 40:55D-37 and -38. These ordinances must include provisions ensuring, among other things, "adequate water supply, drainage, shade trees, sewerage facilities

and other utilities necessary for essential services to residents and occupants". N.J.S.A. 40:55D-38b.(3). As a discretionary provision, the governing body may include in an ordinance requiring planning board approval of either subdivisions or site plans or both, "provisions for off-tract water, sewer, drainage, and street improvements which are necessitated by a subdivision or land development . . ." N.J.S.A. 40:55D-39a. Additionally, a governing body by ordinance may adopt regulations requiring a developer as a condition for subdivision or site plan approval to pay a pro-rata share of the cost of providing reasonable and necessary street improvements and water, sewerage and drainage facilities, as well as easements for such facilities, which are located outside the subdivision's property limit but are necessitated by virtue of the construction or improvements within the subdivision or development. N.J.S.A. 40:55D-42.

Another important grant of authority to local government pursuant to the Municipal Land Use Law, from which the power to address water supply concerns may be derived, is through the governing body's adoption or amendment of zoning ordinances relating to the nature and extent of the uses of land and of the buildings and structures thereon. N.J.S.A. 40:55D-62. It is through the adoption of such zoning provisions that the municipality exercises its ultimate responsibility to establish the essential land use character of the community. In order to fulfill the underlying purposes of the land use statute, including the appropriate use or development of lands in accordance with the public health, safety and welfare and to respect environmental considerations, the law requires that zoning ordinances "shall be drawn with reasonable consideration to the character of each district and its peculiar suitability for particular uses and to encourage the most appropriate use of land". N.J.S.A. 40:55D-62a. Thus, muni-

cipal officials are encouraged to regulate land use in water-deficient regions in a manner that respects and is compatible with the environmental limitations of development. To the extent that objective scientific information concerning water supply limitations is available to assist local planners in determining appropriate densities or other restrictions, such information should be utilized in formulating the regulations.

C. Limitations On The Exercise Of Local Authority

In considering water supply management powers of municipalities, it is also necessary to recognize the limitations on the exercise of that authority. Local government must act in accordance with authority delegated to it by the State Constitution and by statute; there is no inherent jurisdiction as such, to enact laws or adopt regulations. Dome Realty, Inc. v. Paterson, 83 N.J. 212, 225 (1980). Municipalities may accordingly enact ordinances pursuant to their general police power and pursuant to their zoning power.

In determining whether police power delegated to municipalities encompasses the power to address a given matter, the Court has set forth a three-prong test involving the inquiry whether the State Constitution prohibits the delegation of the power at issue; if the grant of power is permissible, whether the Legislature has, in fact, done so; and if the statutes vesting such police power in municipalities include the area under consideration, whether the existence of other statutes dealing with the subject matter preempt or bar the exercise of local initiative. Inganamort, et al. v. Bor. of Fort Lee, et al., 62 N.J. 521, 527 (1973).

Additionally, all enactments are subject to constitutional limitations that

they not be unreasonable, arbitrary or capricious and that the means have a real and substantial relation to the purposes sought to be attained.

In general, there is a presumption that action has been taken on the basis of adequate factual support and in the absence of a sufficient showing to the contrary, it is assumed that such enactments are grounded on a rational basis. This presumption may be overcome only by proofs precluding the possibility that there could have been any set of facts known to the legislative body which would rationally support the conclusion that the enactment is in accordance with the public interest. Dome Realty, Inc. v. Paterson, 83 N.J. 212, 235 (1980).

Additionally, while municipal ordinances, including zoning ordinances, are generally entitled to a presumption of validity that may be overcome only by an affirmative showing of the arbitrary or unreasonable nature of the ordinance, ordinances adopted pursuant to the Municipal Land Use Law must also be consistent with the standards set forth therein. Lusardi v. Curtis Point Prop. Owners Ass'n., supra, 86 N.J. at 226.

It is also axiomatic that all ordinances are constitutionally required to contain reasonably explicit standards to accord a person of ordinary intelligence fair notice of the nature of the prohibited conduct. See, e.g., Belmar v. Buckley, 187 N.J. Super. 107, 112 (App. Div. 1982). Arbitrary and indiscriminant application of the law can be avoided by means of the requirement that the terms be reasonably definite and certain. See, e.g., Morristown Rd. Assoc. v. Mayor of Bernardsville, 163 N.J. Super. 58, 63 (Law Div. 1978) (invalidating amendment to a zoning ordinance establishing review of site plans by design review committee based on the criteria of harmony of architectural design on the grounds that such standards were unduly broad and vague, the absence of guidelines vested

the reviewing bodies with unlimited discretion and would preclude conformance with the requirements of the ordinance by the applicant and would permit the arbitrary and capricious application of the ordinance). Thus, zoning or police power regulations that limit development because of water supply limitations must be based on a firm factual foundation and be reasonably understandable.

Another important issue to be addressed with respect to local regulation of water supply through the land use process is that of State preemption or preclusion of local regulation. This doctrine is predicated upon the principle that municipalities, as agents of the State and as entities possessing delegated powers, are precluded from acting in a manner contrary to the State and may not contradict a policy established by the Legislature. Sumner v. Teaneck, 53 N. J. 548, 554-555 (1969). To determine whether or not the exercise of local initiative is in conflict with the preemption doctrine, it is necessary to determine if the legislative enactment is intended to exclusively occupy the area, if the municipal ordinance conflicts with the statute, if the particular subject requires uniformity of regulation throughout the State, or if the State law is so pervasive or comprehensive as to preclude coexisting municipal regulation. Overlook Ter. Manage. v. Rent Control Bd. of W. New York, 71 N.J. 451,461-462 (1976); Dome Realty Inc. v. Paterson, 83 N.J. 212 (1980). The Court has identified a number of considerations relevant to a determination of preemption:

1. Does the ordinance conflict with the state law, either because of conflicting policies or operational effect, (that is, does the ordinance forbid what the Legislature has permitted or does the ordinance permit what the Legislature has forbidden)? . . .
2. Was the state law intended expressly or impliedly to be exclusive in the field? . . .

3. Does the subject matter reflect a need for uniformity? . . .
4. Is the state scheme so pervasive or comprehensive that it precludes coexistence of municipal regulation? . . .
5. Does the ordinance stand 'as an obstacle to the accomplishment and execution of the full purposes and objectives' of the Legislature? . . .

(Overlook Ter. Manage. v. Rent Control Bd. of W. New York, supra, 71 N.J. at 461-62) (citations omitted).

As a result of the application of these criteria, the courts have on occasion invalidated local ordinances. See, e.g., Little Falls Tp. v. Bardin, 173 N. J. Super 397 (App. Div. 1979), certif. den. 82 N.J. 286 (1980) (township ordinance precluding the operation of a sanitary landfill within the geographical boundaries of the municipality was held to be preempted by the Solid Waste Management Act); Brunetti v. Milford, 68 N. J. 576 (1975) (State legislation concerning landlord/tenant relations preempted the eviction provisions of a local rent control ordinance since the State statute provided "a complete system of law"); State v. Crawley, 90 N. J. 241 (1982) (New Jersey Code of Criminal Justice, N.J.S.A. 2C:1-1 et seq., determined to preempt a municipal loitering ordinance). In other instances, objections to local ordinances on preemption grounds have been unsuccessful. Accordingly, a municipal ordinance requiring substantial compliance with the standards of habitability contained in its housing code before a new tenant could take possession of rented residential premises was held to be valid despite the challenge of preemption. Dome Realty, Inc. v. Paterson, 83 N. J. 212 (1980). For other instances in which the Legislature was held not to have intended to preempt municipal action to address local concerns in a given area see, e.g., Summer v. Teaneck, 53 N.J. 548 (1969) (upholding ordinance preventing blockbusting); Belmar v. Buckley, 187 N.J. Super. 107 (App. Div. 1982) (the New Jersey Code of Criminal Justice did not

preempt local enactment prohibiting public nudity of a character not rising to the level of lewdness). It appears that the preemption doctrine should not pose serious impediments to thoughtfully prepared local ordinances concerning water supply.

One other aspect of water supply law could potentially have an impact on remedial initiatives by municipal government. In addition to the regulatory system consisting of State water supply statutes and pertinent municipal ordinances, there are a number of common law rules derived from judicial decisions that define and control water rights issues between competing public and private users of the resource. It should additionally be noted that as a result of the relative abundance of New Jersey's water supply as compared to the arid West, water rights issues in New Jersey are not as well developed as in other jurisdictions.

In general, the common law system enables a landowner to make reasonable withdrawals of subsurface water for uses in connection with the overlying property. See Meeker v. East Orange, 77 N.J.L. 623 (E & A 1909) which enunciated the now classic statement of the "reasonable user" doctrine and Woodsum v. Pemberton Tp., 172 N.J. Super 489 (Law Div. 1980), aff'd 177 N. J. Super. 639 (App. Div. 1981), for a recent application of the principles concerning the relative rights of a private person and public entity in underground waters used by both. Special provisions concerning priorities may apply in times of drought. It appears logical that an analogous system of priorities would be applied by the courts in water-deficient areas.

Ordinarily, a conflict between the regulatory system and common law rules

defining rights between competing users will not arise. In the event that a conflict did develop, it is likely that the regulatory approach, if reasonable, would prevail. To assure that there was no such inconsistency, a municipality proposing to directly control or limit subsurface withdrawals should devote thoughtful consideration to the reasonableness of its approach as well as to water rights issues.

In conclusion, a review of the applicable statutory provisions and case law decisions indicates that the State, as well as municipal governments, have a substantial residuum of presently unutilized authority concerning water supply management. The State's powers are expansive and are not limited to diversions exceeding 100,000 gallons a day, particularly in areas where the resource is limited or threatened. If conditions were considered to be serious in water-deficient areas, the State DEP would clearly be justified in taking remedial action.

The unmet challenge, however, concerning water supply management is clearly at the municipal level. Local government has the potential through the reasonable exercise of the zoning power and police power to have a significant role in the water supply management process. Zoning and subdivision regulations may be adopted that are protective of existing and prospective water supply conditions. Limitations should be based on technical supporting information, recognizing that sound judgment, rather than absolute precision, should suffice as the controlling standard.

The police power provides a broad range of possibilities for municipalities in water-deficient areas. At a minimum, local governments should consider developing procedures to assure that existing State standards are, in fact, being

strictly adhered to and maintained. Furthermore, where justified, it appears that municipalities are empowered to adopt requirements adequate to protect the ground water resource, even if these requirements are more restrictive than those set forth in State provisions.

IV. PUBLIC POLICY MEASURES FOR GROUND WATER CONSERVATION

A. An Intergovernmental Process

Section III of this report concludes that the State and municipal governments each have "a substantial residuum of presently unutilized authority concerning water supply management."

As noted, ground water supplies in the Sourland Mountain vicinity are even now being stressed in some areas and these pressures will certainly increase in the future. Thus, the question is not whether government can respond but, rather what the appropriate governmental response should be. How can each level of government most effectively deploy its authority to protect the sustained, perennial yield of the ground water resource? While the details of such a policy are beyond the scope of this report, a preliminary discussion is appropriate.

First, it should not be assumed that centralized water distribution by public or private purveyors will be feasible throughout areas such as the vicinity of the Sourlands. Here, as in other suburban fringe areas similarly situated, the density of residential development is likely to be so low that, even as development continues, the installation of a water distribution system may prove prohibitively expensive. In the overall suburban development mix there will of course be concentrations of higher density residential and non-residential development, principally along highway corridors, that can economically be served by centralized systems. However, in outlying areas, residential development can be expected to be at far lower average densities than New Jersey has been accustomed to. This is a departure from the traditional pattern of suburban growth, where the den-

sity of development was typically high enough to support centralized water supply when it became necessary.

The New Jersey Statewide Water Supply Master Plan, adopted in 1982, states:

Ultimately, we must all realize that the continued availability of adequate and safe water supplies for future generations will require implementation and enforcement of sound land use policies.¹

This document also notes that "... the active assistance of counties and municipalities as they apply their land use powers in urban and urbanizing areas" will be indispensable to the success of aquifer protection programs.

A subsequent "Update" to the Water Supply Master Plan (August, 1983)² states NJDEP's intention to adopt regulations authorizing the Department to delineate "water supply critical areas" when, among other conditions, there is a shortage of ground water. It is understood that regulations implementing this concept have now been drafted and are presently under review.

At the present, only the State Department of Environmental Protection has the technical resources to evaluate ground water resources and withdrawal proposals. This is largely because of the absence of adequate data. Evaluation under these circumstances becomes a question of professional experience and judgment. In addition, ground water is characteristically a resource of regional dimensions, requiring regional management. The interests of one municipality may conflict with its neighbors who may share the same ground water resource. These

1. N.J. Department of Environmental Protection, New Jersey Statewide Water Supply Master Plan, April, 1982, p. 62

2. N. J. Department of Environmental Protection, Statewide Water Supply Master Plan Update, August, 1983. p.2.

are strong arguments for a state role.

On the other hand, municipalities review land development proposals routinely, and are charged by law with the protection of the water supply as well as other resources. In the past decade, water supply considerations have become very much a part of municipal master plans and zoning ordinances. It is not likely that local governments will choose to turn this responsibility over to the state. Further, many withdrawals of water, such as those through domestic wells are very small. With the proper policy framework, it would be more efficient to have applications for such withdrawals reviewed locally.

Given the appropriateness and legitimacy of both municipal and state involvement in ground water management, care should be given to a clearly stated inter-governmental procedure giving both municipalities and the State explicit responsibilities. The draft "Elements of a Ground Water Conservation Ordinance" provided below outlines municipal responsibilities. The Department of Environmental Protection, with its draft water supply management regulations, has begun to define a state role. As the state drafting and review process continues, it is expected that the responsibilities of the various levels of government will be more explicitly defined.

This discussion would not be complete without mention of the potential county role in ground water management. Counties are a regional level of government, intermediate between the state and the municipalities. Counties are more capable financially of supporting a technical staff. Indeed, several New Jersey counties already employ environmentally-trained specialists. Counties could effectively re-

gulate ground water withdrawals under overall policy guidance from the State. Indeed, among "watershed and aquifer protection" programs elements listed in the State Water Supply Master Plan is a demonstration county level water resource management program, in the context of the County Environmental Health Act (N.J.S.A. 26: 3A2-21) which already provides certain authority for such activity.

Clearly, the development and adoption of a well-balanced intergovernmental process for ground water regulation will require time and thought. In the meantime, municipalities in the Sourlands area and throughout the state are revising master plans and zoning ordinances. It is important that these local initiatives incorporate the best thinking available. In other states where ground water supply and quality are becoming public concerns, local governments are acting on their own initiative as well.¹ With this trend in mind, the following "Elements of a Ground Water Conservation Ordinance" is presented.

B. Recommended Municipal Ground Water Conservation Measures

Three means are available to local government to manage and conserve ground water resources responsibly in accord with the findings of this report.

First, the municipal master plan and zoning ordinance should be reviewed and amended to reflect the recommendations of Section II-H with respect to average development density based upon ground water yield.

Second, the municipality should establish "low ground water yield areas". These are areas where scientific analysis has concluded that withdrawal of ground water through agricultural, domestic, or commercial wells may adversely affect the long-term equilibrium of the ground and surface waters; may result in interference

¹ See American Planning Association Local Groundwater Protection Programs. PAS Memo 83-8, August, 1983.

between existing and prospective wells; and may adversely affect the natural flow of streams.

Third, special review procedures designed to protect the ground water supply for present as well as future users should be applied within "low ground water yield areas". A draft presentation of elements of a ground water conservation ordinance appropriate for such areas follows. Both the underlying minimum average development densities and the special review requirements are required because of the variability of hydrogeological conditions in the study area. It is difficult to generalize about conditions at a particular development site. The proposal that follows is intended to reveal conditions at the specific development site.

ELEMENTS OF A GROUND WATER CONSERVATION ORDINANCE

1.0 Purposes

The purposes of this ordinance are to maintain the long-term natural equilibrium of the ground and surface waters of (insert name of municipality); to prevent interference between existing and prospective wells; to maintain the natural flow of streams; and to assure the availability of indigenous natural sources of water for present and future generations.

2.0 Definitions

Agricultural use. The use of land for common farmsite activities including but not limited to: production, harvesting, storage, grading, packaging, processing and the wholesale and retail marketing of crops, plants, animals and other related commodities and the use and application of techniques and methods of soil preparation and management, fertilization, weed, disease and pest control, disposal of farm waste, irrigation, drainage and water management, and grazing;

Applicant. A developer submitting an application for development (MLUL)

Application for Development. The application form and all accompanying documents required by ordinance for approval of a subdivision plat, site plan, planned development, conditional use, zoning variance, or direction of the issuance of a permit pursuant to Section 25 or Section 27 of Ch. 291, Laws of 1975. (MLUL)

Community water supply system. A source and distribution system for potable water that is not connected to any governmentally-owned water supply system. Ground water may be supplied by means of individual wells on individual lots, or by means of a community well or well field.

Low ground water yield areas. Areas designated as such by the Township Committee, where scientific analysis as cited in Section 3.0 of this ordinance shows that withdrawal of excessive amounts of ground water through agricultural, domestic, or commercial wells may contravene the purposes of this ordinance.

Developer. The legal or beneficial owner or owners of a lot or of any land proposed to be included in a proposed development including the holder of an option or contract to purchase, or other person having an enforceable proprietary interest in such land. (MLUL)

Local enforcement officer. The municipal health officer or other technical representative of the municipality as designated by the township committee.
(Note: The person or agency responsible should be so designated in the ordinance.)

Local land use agency. The municipal agency responsible for review and approval of an application for development.

Note: MLUL indicates definition taken from the Municipal Land Use Law, Ch. 291, Laws of 1975.

3.0 Low Ground Water Yield Areas

3.1 Low ground water yield areas within (insert name of municipality) are identified on the map attached hereto and made a part of this ordinance.

3.2 Low ground water yield areas have been designated on the basis of (cite reference to scientific study or studies) which identify these areas and recommend amounts of ground water that may be withdrawn without contravening the purposes of this ordinance.

3.3 The provisions of sections 4.0, 5.0, 6.0 and 7.0 shall be applicable within low ground water yield areas.

4.0 Construction Permits.

4.1 No construction permit for a new home or other structure shall be issued unless the well intended to serve the home(s) or other structure(s) has been drilled, and tested by the applicant, and certified by the local enforcement officer as complying with state standards for the construction of public non-community and non-public water systems (N.J.A.C. 7:10 - 3.20 et seq.), and as being otherwise acceptable as specified in Section 7.0 of this ordinance.

5.0 Agricultural Use

5.1 A person intending to use ground water for agricultural purposes shall be entitled to no more than the amount of ground water calculated on the basis of the following formula:

$$Y_p = \frac{A_p}{I} (Y_c)$$

where: Y_p = Amount to which the property owner is entitled

A_p Area of property ownership

Y_c , Perennial yield of the area in gals(day/mi.²)

5.2 Prior to being pumped for production, an agricultural well shall be tested by the owner and certified by the local enforcement officer in accordance with the applicable provisions of Section 7.0.

6.0 Larger Development Proposals

6.1 The provisions of this Section shall apply to applications for subdivision of 3 or more lots; construction of 3 or more dwelling units; and construction of more than 5,000 square feet of space for non-residential purposes.

6.2 An application shall include a report by a qualified hydrologist on the geohydrology of the proposed development site and its environs. The report shall cover the following:

- (a) A discussion of the geohydrology of the site and its environs including location of any known fractures or faults.
- (b) Location and technical specifications for the proposed well(s).
- (c) Location and technical specifications for disposal.
- (d) Results of the tests described in Section 7.0.

- (e) A full discussion of the effect that the proposed withdrawal will have on the long term equilibrium of the ground and surface waters of (insert name of township): existing and prospective wells; the natural flow of streams; and the availability of indigenous natural sources of water for present and future generations.

6.3 On receipt of the report specified in 6.2 the local enforcement officer shall forward a copy to the State Division of Water Resources for review, comment and recommendation. The Division's comments and recommendations regarding the application shall be attached to the application for development for consideration by the local land use agency.

6.4 The local land use agency shall not approve an application for development unless the applicant's report, the State Division of Water Resources's report and its own analysis conclude that the applicant's plans for water supply will not unreasonably contravene the purposes of this ordinance. The local land use agency may disapprove an applicant's water supply plans with conditions or may require additional surveys or tests before approving the application, or the local land use agency may approve the application when it is satisfied that the requirements of this ordinance have been met.

7.0 Specifications for Well Tests

7.1 Test wells may be required by the local enforcement officer on or near the proposed development site. The wells shall be located geographically by the local enforcement officer in consultation with the applicant and Division of Water Resources staff. The following shall be a guide to the number of test well required:

Subdivisions or Site Plans

<u>No. of Lots or Units</u>	<u>Wells</u>	
	<u>Test</u>	<u>Observation</u>
3 - 10	1	1
11 - 25	1	2
26 - 49	2	2
50 and over	At the enforcement officer's discretion	

Community Systems

1 3

(Additional test wells may be required at the local enforcement officer's discretion.)

7.2 The test wells shall be pumped continuously for 8 hours. In accordance with N.J.A.C. 7:10-3.58, each well shall be tested for yield, drawdown and recovery. The following information about each well will be furnished to the local enforcement officer and recorded on the well record by the driller and transmitted to the Division of Water Resources.

- a) Location: Block and Lot; street address also if possible
- b) Year drilled
- c) Casing diameter
- d) Yield in gpm
- e) Geologic formation (or rock type)
- f) Depth
- g) Depth of casing (should be a minimum of 50 ft.)
- h) Static water level (the elevation of water in a well when no pumping is in progress)
- i) Pumping level (in feet)
- j) Hours pumped (should be a minimum of 8 hours)

- k) Drawdown in feet
- l) Recovery time
- m) Depth to bedrock
- n) Elevation at ground surface
- o) Specific capacity (gpm/foot of drawdown)

7.3 Observation wells and all existing domestic and other wells within 500' of the boundaries of the proposed development site shall be monitored by the applicant continuously during the pumping test and any change in well levels shall be recorded. The local enforcement officer may require monitoring of wells further from the boundaries of the proposed development site if hydrogeologic conditions warrant it.

7.4 If a drawdown exceeding 2' is observed in any observation well or a well on a neighboring property or if in the judgment of the local enforcement officer or the local land use agent there is reason to believe that the purposes of this ordinance may, in any way, be contravened by the proposed withdrawals, additional test pumping may be required by the enforcement officer.

* * * * *

It is important to emphasize that the foregoing is presented as an outline for consideration by municipalities. Before adoption, the outline should be reviewed by the municipal attorney, engineer, and planner and adapted to the particular circumstances and considerations affecting that municipality.

