GROUND WATER STUDY OF THE ARGILLITE FORMATION IN KINGWOOD TOWNSHIP, HUNTERDON COUNTY, NEW JERSEY

Report Prepared for the

Kingwood Township Planning Board

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November 5, 1995

Corneilia Baum
Chair, Kingwood Township Planning Board
2 Oak Grove Road
Baptistown, NJ 08803-1099

Dear Ms. Baum:

Enclosed please find 16 copies of my 51-page report entitled: "Ground Water Study of the Argillite Formation in Kingwood Township, Hunterdon County, New Jersey." The report is submitted pursuant to a Professional Services Agreement which had a starting date of September 5, 1995.

The enclosed document contains an overview of the hydrology of the subject area, a brief introduction to basic ground-water hydrology, an analysis of the available domestic well records, a discussion of the various methodologies regarding ground-water recharge, and a sample application of nutrient dilution models. The report also includes a number of recommendations regarding well records and pump testing.

It is hoped that the enclosed information will be of assistance to the residents of Kingwood Township.

Very truly yours,

Robert M. Hordon

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P.H. # 84-H-349

Robert M. Hordon, Ph.D., P.H.

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GROUND WATER STUDY OF THE ARGILLITE FORMATION IN KINGWOOD TOWNSHIP, HUNTERDON COUNTY, NEW JERSEY

A. BACKGROUND

Kingwood Township in Hunterdon County does not have any public water supply or public wastewater disposal facilities (Zripko and Hasan, 1994). Accordingly, all residents in this rural community depend upon onsite domestic wells and septic systems for their water supply and wastewater disposal needs.

Kingwood is located within the unglaciated portion of the Piedmont Physiographic Province, one of the major landform regions of the state. Consequently, almost all of the ground water that Kingwood depends upon comes from fractures within the consolidated rock formations of the area. The Hunterdon County Planning Board (1967) estimates that the Lockatong argillite (Trl) formation occupies 36.6 percent of the township. This formation has the dubious distinction of ranking among the poorest sources of ground water in the entire state, since the fractures and joints where water may be found are widely spaced, poorly connected and very tight (Kasabach, 1966). The baked shale rock units (Trba) are hydrologically similar to the argillite and are therefore included in the well analysis and discussion. They are estimated to occupy 28.1 percent of Kingwood. Together, the argillite and baked shale units underlie 64.7 percent of the township.

Given this situation of the absence of public water and sewer infrastructure and the presence of a widely acknowledged poor source of ground water, Kingwood Township became interested in undertaking an investigation of the ground water availability and resources in that portion of the community that is underlain by the Lockatong argillite formation. Accordingly, Robert M. Hordon, a water resources specialist at Rutgers University and a professional hydrologist, was retained by the township to look at the water supply and wastewater disposal issues regarding the argillite formation.

B. POPULATION

The population in Kingwood Township increased 20 percent from 2,772 in 1980 to 3,325 in 1990 (New Jersey, Department of Community Affairs, 1992). Based on an area of 35.6 square miles, the population density rose from 78/sq mi in 1980 to 94/sq mi in 1990. By comparison, the 1990 population density in Hunterdon County and New Jersey was 251/sq mi and 1,032/sq mi, respectively. Thus, it is readily apparent that Kingwood Township is a largely rural community with a population density well below that of Hunterdon County and substantially below the entire state.

C. LOCATION AND PHYSICAL FEATURES

Kingwood Township is located in the Piedmont physiographic province which trends in a northeast-southwest direction across New Jersey (see Figure 1 at an approximate scale of 1 inch to 4 miles). As shown in Figure 2 which is a hypsometric map of Hunterdon County at an approximate scale of 1 inch to 4 miles, most of Kingwood has an elevation between 300 and 700 feet. The Hunterdon Plateau, which is underlain by dense argillite and shale, is the dominant landscape feature in the township.

All of Kingwood drains into the Delaware River (see Figure 3 at an approximate scale of 1 inch to 3.3 miles). The largest stream in the township is Lockatong Creek which drains a portion of the Hunterdon Plateau and flows through the central and southern portions of Kingwood (see (Figure 3). The various geologic formations and the location of the wells that were referenced in the Hunterdon County Ground Water Study by Kasabach (1966) are shown in Figure 4 at a scale of 1 inch to 1 mile.

D. ELEMENTS OF GROUND-WATER HYDROLOGY

Ground-water hydrology is part of the science of hydrology that deals with the occurrence, movement, and quality of water that is found below the Earth's surface (Heath, 1983). Ground water is the subsurface component of the hydrologic cycle, that constant movement of water above, on, and below the land surface (see Figure 5). Subsurface water is found within the unsaturated and saturated zones in the earth, although it is only the saturated zone that has water that is available to wells and springs (see Figure 6). The pore space in the soil belt and the intermediate belt contains both air and water and is therefore called the unsaturated zone. In contrast, the pore spaces or fractures in the saturated zone are completely filled with water (or any other contaminants that may be present).

The pore space in unconsolidated materials such as sand and gravel is called primary porosity. There is very limited primary porosity in consolidated rocks such as argillite and baked shale. The only way water can be found in these rocks is in the fractures and fissures that were formed after the rock itself was formed. These voids are referred to as secondary openings or secondary porosity (Heath, 1983; see Figure 7). Consolidated formations such as argillite have practically no primary porosity and very limited secondary porosity as the fractures are both small and poorly connected. Consequently, the ground water yield from argillite ranks among the worst in the consolidated rock formations of New Jersey and surrounding states.

Ground water moves from recharge areas to discharge areas (see Figure 8). Depending upon the amount of precipitation, the hydraulic conductivity of the earth materials, and the hydraulic gradient, among other things, the rate of movement of ground water from the recharge areas to the discharge areas can range from days in shallow systems to thousands of years in the deeper parts of the ground-water system (Heath, 1983; see Figure 8).

The static water table is the level of water in the ground prior to any pumping. As a well is pumped, the water table is lowered in the shape of a cone which is called the cone of depression. The vertical difference in height between the static water level and the base of the cone of depression is called the drawdown (see Figure 9).

Depending upon the rate of pumping and the nature of the aquifer, cones of depression can extend out for several miles from a well (Strahler and Strahler, 1992). Intersecting cones of depression can occur when two or more wells are operating at the same time. This process is called well interference and can occur if any type of well, including domestic wells, is spaced too closely.

E. ANALYSIS OF WELL RECORDS IN KINGWOOD

An examination was made of all of the well records in Kingwood Township that are filed with the Hunterdon County Health Department. All well records are located by block and lot and can potentially include much useful information.

All well drillers are required to fill out a 2-page standard form for every domestic well that is drilled in the state. The current form is DEP Form DWR-138 (as of November, 1985). If completely filled out, the form would list some very useful information about the characteristics of the well. Regrettably, not all of the information is filled out by the well driller even though it is required to be sent to the state as well as to the Hunterdon County Health Department. Accordingly, it is strongly recommended that Kingwood adopt an ordinance that requires each company that drills a domestic well in the township to fill out the form as completely as possible. In particular, the following information is specifically requested and should be stipulated in the ordinance:

1) Owner's name;

2) Street address;

3) Block;

4) Lot;

5) Date of drilling;

6) Depth (feet);

7) Static water level (feet);

8) Hours pumped;

9) Water level at the end of pumping (feet);

10) Yield (gpm) and how measured;

11) Well log information: what types of earth material were encountered and at what depths;

12) Depth(s) at which water was encountered (feet).

Copies of this important but minimal set of information should be sent to the Kingwood Township Board of Health as well as to the county and state.

All of the information in the files was recorded as long as the well driller stated that the rocks were argillite. It turned out that many of the wells that were identified as argillite were located in that portion of Kingwood where the underlying formation was shale. In particular, there were many mis-identified wells in Blocks 1, 1.01, 2, 4, 6, 7-9, and 12-15. It was decided to include only those wells that were located in blocks 17 and higher which are south of Route 12. It is believed that these wells are located in the argillite and baked shale formations. At any rate, the identification of the rock unit in the well logs by the driller is open to question, particularly for those areas of the township along Route 12. As one gets further south of Route 12 in the direction of Delaware Township, the accuracy of the well logs improves as this portion of the township is clearly underlain by argillite.

All of the 143 well records that were found in the files of the Hunterdon County Health Department in blocks 17 and higher are listed in Table 1. The following observations can be made:

1. The well depths ranged from 100 to 800 feet, averaging 399 feet. The median well depth was 390 feet. In contrast, the median depth for 32 and 22 wells drilled in the baked shale and argillite formations in Kingwood as reported by Kasabach (1966) was 158 and 137 feet, respectively. It is hypothesized that the newer wells in the township have to be drilled to deeper depths in order to intercept enough water-bearing layers and furnish sufficient water for a household.

2. The hours pumped ranged from as low as 30 minutes (for 2 wells) to as high as 10 hours (only one well). The majority (101 wells or 70.6%) of the wells were pumped for only one hour or less (see Table 1). Another 7 wells (or 4.9%) were pumped for 2 hours. Although this is somewhat better, it is clearly an insufficient amount of time to obtain meaningful yield and drawdown information. The well should be pumped for at least 4 hours so as to stress the aquifer at a rate that is greater than normal household

requirements. This comment pertains to domestic wells located in dense, compacted consolidated rock units where yield and well interference problems pose distinct possibilities. It should be noted in comparison that wells drilled for public potable water supply purveyors have to be pump-tested for at least 72 consecutive hours under a detailed protocol approved by DEP prior to the actual test.

Out of the 143 wells, 31 (or 21.7%) were pumped for 4 hours or more. These records would therefore be considered to be more reliable. Interestingly, most of the 4-hour pump tests were conducted by the D & L Well Drilling Company of Clinton, New Jersey. No data were available for 4 wells (or 2.8%).

3. The pumping water level refers to the level of water in the well after the end of pumping and is needed to calculate drawdown. Out of the 143 wells, 25 (or 17.5%) had a pumping water level of zero feet which indicates that the well penetrated one or more confining levels. Data were not available for 3 wells (or 2.1%). The remaining wells (115 or 80.4%) had varying pumping levels and were therefore under water-table or unconfined conditions.

4. In most cases, the yield value should really be thought of as an "initial yield" since the duration of the pump test was so short. It is well known that initial yields in poorly fractured formations are generally much higher than long-term yields after a period of years. This statement, although qualitative in nature, means that most of the yields reported in Table 1 would be expected to decrease by some amount over time. The

amount of decrementing would depend on a number of factors, such as housing density, well depth, and local site conditions. Only those wells which have been pump-tested for a sufficient amount of time (say 4 hours or more) would be expected to have long-term yields broadly similar to initial yields.

Given this "initial yield" caveat, the well yields ranged from a low of 0.125 (1 pint) to a high of 100 gpm (see Table 1). The 100 gpm well is unusually high and may have been a typographical error in the well record. The average (arithmetic mean) and median yield was 9 and 5 gpm, respectively. These values are less than the comparable mean and median yields reported in Kasabach (1966) for 32 baked shale (10 and 7 gpm) and 22 argillite wells (15 and 12 gpm), respectively.

The standard deviation of 11 gpm is a measure of the absolute dispersion about the arithmetic mean. The coefficient of variation (CV) is a dimensionless number which measures the relative dispersion about the mean. The CV for yield is 127.4% which indicates that there is considerable variation in the array of yields. As a result, the median is a better statistic to use than the mean when a distribution is skewed (has a high CV). Therefore, when you are talking about initial yields for wells drilled in either argillite or baked shale, the more appropriate measure is the median of 5 gpm rather than the mean of 9 gpm.

5. The drawdown is the vertical difference between the static water level and the pumped water level. It provides some very useful information about the ability of a rock unit to

sustain pumpage. For a given pumping rate, the larger the drawdown, the less the amount of water that can move through the fractures in the aquifer. If the drawdown is substantial and shows no sign of stabilizing after a period of time, the well would have to be considered marginal and a prime candidate for potential well interference.

When the pumping level was higher than the static water level, the drawdowns in Table 1 are negative in sign. This indicates that the well has penetrated one or more confining levels and that the ground water is under some pressure. As mentioned previously, 25 wells are tapping semi-confined or confined aquifers and data were not available for 3 wells. The remaining 115 wells (or 80.4% of the total) had widely varying drawdowns.

The maximum and minimum drawdowns were 0 and 699 feet, respectively (see Table 1). The mean and median drawdowns were 222 and 190 feet, respectively. These are large drawdowns, especially considering the fact that most of the wells were pumped for only a short duration. The large drawdowns provide further evidence that the argillite and baked shale rock units have low transmissibility rates and are therefore poor aquifers. This observation of course is not a surprise but it does indicate that the ground water potential of these formations is limited.

The large coefficient of variation of 78% for the 115 drawdown observations indicates a large relative dispersion about the mean which suggests that the median is the better statistic to use.

Given the importance of drawdown in the evaluation of a well, it is strongly recommended that Kingwood adopt an ordinance that would require minimum pump-test durations when either the yield is low or the drawdown is greater than 100 feet. For example, if the yield is less than 5 gpm, then the well driller would be required to pump for an additional 30-60 minutes. If the water level in the well continues to decline at a rapid rate, then the driller should be required to continue pumping until the water level stabilizes or 4 hours is reaches, whichever comes first. The purpose of the additional pumping is obvious: in marginal wells, herein defined as those with an initial yield less than 5 gpm or with 100 feet of drawdown, the information would provide the owner and the township possible warnings about future water supply problems. It is interesting to note that 84 wells (or 58.7%) in the sample had drawdowns of 100 feet or more even when many of the pump tests were only one hour.

Furthermore, recovery tests should be required for all marginal wells as previously defined. A recovery test simply indicates what the rate of recovery is as the pumped water level returns (slowly or rapidly) to its level prior to pumping which is the static water level. Full or 100% recovery can take hours and even days if the transmissibility in the aquifer is very low. But this is precisely why a recovery test is so important, inasmuch as it provides very useful information about the ability of the water table to recover to its pre-pumped level.

It is therefore recommended that at the least, even partial recovery tests be undertaken by the well driller and reported to the township. Following the completion of drilling and as soon as conditions warrant, probes can be inserted in the well to measure the depth to the water level from the surface. For example, if the drilling stopped at 10:30, then water levels could be measured at 10;45, 11:00, 11:15, 11:30, etc., while equipment is being taken away. It is recognized that these are not the ideal circumstances for a full-scale recovery test, but at least the township and owner will have an approximation of the rapidity (or lack thereof) of the return of the water level to its original level. The duration of the recovery test should be at the discretion of the well driller since additional time will add to the cost of the new well.

The implications of a recovery test, even a partial one, can be substantial. If it takes many hours for a well to recover, then the amount of water that can be transmitted through the aquifer is limited and there could be problems in the future as more wells are drilled in the same area. Well interference could then become a serious possibility even if the homes are on multi-acre lots.

In sum, partial pump test data is recommended for all marginal wells and recovery test data is recommended for all new wells drilled in the township. The information should be sent to the township and the county Board of Health. In this manner, the township and county will at least have some information regarding possible water supply problems in the future.

6. Nitrate-nitrogen values were available for 105 wells or 73.4% of the total. The samples were collected by the Hunterdon County Health Department and analyzed by

private labs. The nitrate values were very low; indeed, many of the samples were close to the detection limit of the lab (0.1 mg/l). The highest value was 6.41 mg/l for block 29, lot 31.05 (see Table 1). The fact that many of the samples had low readings reflects the low ambient concentrations in the aquifer prior to development and the depth of the wells. As the septic disposal system density increases in the township, it is only reasonable to expect an increase in the nitrate levels. The nitrate dilution models discussed later in this report provide a guide for long-term planning densities.

In short, the generally low nitrate readings are obviously favorable. However, they represent pre-development conditions and could increase as housing density increases.

7. Out of curiosity, the relationship between depth and yield was explored. The basic question was: how does depth affect yield? A scatter plot of depth and yield for the 143 wells is shown in Figure 10. There appears to be a slight negative relationship which is borne out by regression analysis. The estimating equation is $Y = 23.3 - 0.036X$, which shows that yield decreases as depth increases. The correlation coefficient is .518 and the r^2 value is .268. The r^2 is also called the coefficient of determination and represents the amount of variation in the data that is explained by the regression. An r^2 of.268 means that only 26.8% of the data is explained; the remaining 73.2% is unexplained. The analysis was re-run by excluding the 100 gpm outlier. The same slight negative relationship is shown in Figure 11. The second estimating equation is $Y = 20.0 - 0.030X$ with a somewhat higher correlation coefficient of .570. The percentage of explanation

increases from 26.8% to 32.5%. However, the relatively low r^2 values in both instances indicate that although there is a slight but measurable negative relationship between depth and yield, the results should be viewed as suggestive and preliminary.

F. GROUND WATER RECHARGE

Ground water recharge is the amount of water that is able to infiltrate through the soil and overburden on the earth's surface and enter the saturated zone. The recharge is that fraction of incoming precipitation that is left over after the processes of runoff and evapotranspiration have occurred. Runoff represents that portion of precipitation that does not seep into the soil but leaves the area as surface flow. Evapotranspiration refers to the combined processes of evaporation and transpiration from vegetation that returns water to the atmosphere. Thus, recharge may be expressed in the form of a simple equation as:

$$R = P - RO - ET$$

where R = ground water recharge

P = precipitation

RO = runoff

ET = evapotranspiration

There are many climate, soil and vegetation factors that influence the processes that control recharge. For example, the key climatic factors are the amount, intensity, and type of precipitation which varies seasonally. Wind, humidity and air temperature have strong effects on evapotranspiration. The permeability of the soil has a pronounced effect on the amount of water that can infiltrate through the soil and reach the water table. For example, the Bowmansville, Croton and Reaville soils have very low infiltration rates (hydrologic soil group D) and therefore allow very little water to reach the ground water. For these soils, the bulk of the precipitation leaves the area by overland flow into the nearest stream. Soils in Kingwood that are in hydrologic soil group B and have favorable infiltration rates include the Birdsboro, Bucks, Hazleton, Neshaminy, Pope and Riverhead series. The remaining soils in Kingwood are in hydrologic soil group C and include the Abbottstown, Chalfont, Klinesville, Lehigh, Mount Lucas, Penn, Quakertown, Readington, Reaville and Rowland series (U.S. Department of Agriculture, 1974).

Although precipitation and surface runoff can be measured with a reasonable degree of accuracy, evapotranspiration is a more difficult parameter to measure. Thus, alternative methods have been employed to estimate the amount of water from precipitation that winds up as ground water which is then available as a source of water supply.

It is recognized that recharge is much higher in sandy areas than in areas covered by bare rock. The highest recharge rates in New Jersey occur in the sandy sections of the outer coastal plain in South Jersey and the stratified drift deposits of glaciated valleys in North Jersey (Ramapo, Pequannock, etc.). In these very permeable areas, recharge rates can approach 50% of the precipitation. If the average annual precipitation is 45 inches, this means that the recharge comes out to be greater than one million gallons/day/sq mi (gpd/sq mi). In less permeable areas overlying dense, poorly fractured consolidated rock formations such as argillite and diabase in Hunterdon County, Kasabach (1966) estimates that only 10-15% of the average precipitation of 45 inches is available as recharge. The 10-15% estimate is 4.5-6.75 inches/year which on an areal basis comes out to be 213,000-319,000 gpd/sq mi.

Recharge estimates for the various bedrock units that form Sourland Mountain in Hunterdon, Mercer and Somerset Counties were prepared by Hordon (1984) for the NJDEP. The estimates were based on two methods of analyzing streamflow data. One method involved the separation of base flow, which is the ground-water component of streamflow, from hydrographs. The supposition was that base flow provides a good indication of the amount of water that is coming from ground-water sources and is therefore useful for predicting aquifer yields.

In brief, the hydrograph separation procedure used by Hordon (1984) was as follows:

1) The average flow for each year of record for the selected stream was ranked in descending order.

2) The exceedence probability for each year was calculated, i.e., the probability that the flow of the selected year would be exceeded.

3) The year closest to the 90% exceedence probability level was selected for hydrograph separation. This level is the flow that is expected one out of every 10 years; the remaining 9 years would have higher streamflows. The 90% level is conservative and represents periods of below normal precipitation.

The procedure was applied to the Stony Brook at Princeton which has a drainage area of 44.5 sq mi. The major geologic formations in the Stony Brook watershed are argillite (37%), shale (35%), and diabase (18%). The estimated base flow was 119,000 gpd/sq mi.

The second method used by Hordon (1984) was flow-duration curve analysis. The flow-duration curve is a cumulative frequency plot on logarithmic probability paper that shows the percent of time when specified stream discharges were equalled or exceeded within a given time period (Searcy, 1959). The major assumption in using flow-duration curves is that streamflow on the lower end of the curve (60-90% exceedence level) is almost entirely derived from ground water and can therefore be used to used to estimate aquifer yields.

In the Sourland Mountain study, the 80% exceedence level (or Q80) was recommended as an estimate of recharge to the bedrock aquifers of central New Jersey. If we select the Q80 level for Walnut Brook, a 2.24 sq mi watershed near Flemington which is underlain entirely by argillite, the estimated recharge is 52,000 gpd/sq mi. In a study of ground-water recharge models for Montgomery Township in Somerset County by Geraghty and Miller (1987), the Q70 level was suggested as a more reasonable approximation of base flow estimation. The Q70 value for Walnut Brook is 112,000 gpd/sq mi.

A more elaborate hydrograph separation analysis of watersheds draining consolidated rock formations in New Jersey was made by Posten (1982). The procedure was as follows:

1) 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. It turned out that only three watersheds in New Jersey (two Precambrian basins in Passaic County and Walnut Creek in Hunterdon County) met these criteria.

2) The annual discharge values were plotted on arithmetic probability paper. Several years of low, medium and high flows were then selected for hydrograph analysis.

3) The mean daily discharge for each of the selected years was separated into quickflow (stormflow) and delayed flow (base flow).

4) The average base flow value for each year was then ranked and the exceedence levels in percent were plotted on arithmetic probability paper.

5) The discharge at the 99% exceedence level of the cumulative frequency distribution of estimated annual base flows was then selected as the ground water yield estimate. Note that this value is a very conservative one as the probability of exceedence is a very high 99%.

The estimated yield for Walnut Creek near Flemington which is underlain entirely by argillite by Posten's Method (1982) is 92,000 gpd/sq mi. This value comes out to 72% on the flow-duration curve for Walnut Creek.

Hydrograph separation techniques were also used by Wright Associates (1982) in their groundwater study of the middle Delaware River basin for the Delaware River Basin Commission. The major geologic formations in the Neshaminy Creek basin in Pennsylvania are sandstone (49%), argillite (31%), and shale (14%). The estimated annual base flow for Neshaminy Creek with a 1 year in 10 recurrence interval is 200,000 gpd/sq mi. The base flow estimate for the driest year on record for Neshaminy Creek is 146,000 gpd/sq mi (1 year in 50 recurrence interval).

In sum, the various estimates, hydrograph separation techniques and flow-duration curve analyses discussed in this section result in ground water yield estimates ranging from 52,000 to 319,000 gpd/sq mi. The variation in the yield estimates is attributed to the particular methodology employed and the recurrence interval selected.

G. DILUTION MODELS

There is a great deal of interest, as well as uncertainty, in determining lot size for rural areas without public water and sewer. A number of attempts have been made that are based on a variety of assumptions. To begin with, Kasabach (1966) recommended a minimum lot size of 2-2.5 acres for those areas in Hunterdon County underlain by argillite and baked shale. The reasoning is based on the comparison between well yields and specific capacities in the shale and argillite formations. Specifically, the yields and specific capacities from wells in the shale are two and three times better than those in the argillite, respectively. Accordingly, residences underlain by argillite and baked shale would need 2-3 times more recharge area than areas underlain by shale.

One useful approach to the problem of estimating minimum lot size is to use a dilution model for nitrates. Nitrates are highly mobile in ground water and can therefore be used as a surrogate for a variety of other mobile contaminants, such as volatile organics. All nitrate dilution models are various types of mass balance approaches for determining the impact on the water quality of regional water tables by residential septic system effluent. The models incorporate a variety of assumptions in the calculated estimate of the nitrate concentration to be expected at the property line.

One parameter that is extremely important for all dilution models is the amount of recharge that is available to dilute the septic effluent. Only a small fraction of the nitrogen in the septic effluent is denitrified into elemental N_2 which can then return to the atmosphere. Nitrogen is a highly mobile ion, which means that once it gets into the ground water, the only way to reduce the concentration is by dilution. Consequently, the amount of precipitation that can infiltrate into the subsurface environment and dilute the nitrogen in the effluent to acceptable standards is a key parameter. Thus, ground water recharge is the most important parameter in any of the dilution models.

1. TRELA-DOUGLAS DILUTION MODEL

The Trela-Douglas (1978) dilution model has been used for many years in New Jersey as an easily applied mass balance approach to nitrogen dilution. It was developed for use in areas in the Pinelands of South Jersey that did not have public water and sewer. The parameters of the model are as follows:

A = area of the subject property (ft^2);

IP = infiltration of precipitation (inches/year; feet/day);

IA = (A) x (IP) = infiltration over the area (in^3/day; ft^3/day);

SD = septic discharge = number of DU x gpcd x people/DU (gpd; ft^3/day);

DF = dilution factor = (SD + IA)/SD (dimensionless)

NO_3-N = nitrate-nitrogen concentration in the septic effluent;

(NO_3-N)/DF = theoretical diluted value of nitrate-nitrogen at the property line (mg/l).

The application of the model to Kingwood Township will use as an example a single family home on a 2-acre lot rather than a subdivision. The Northern Virginia Planning District Commission (1979) estimated that the percent of impervious cover ranges from 9% to 6% for a 2-acre and a 5-acre lot, respectively. If we interpolate for the intermediate lot sizes, then the percent imperviousness for a 3-acre and a 4-acre lot would be 8% and 7%, respectively. Note that these percentages refer to impervious cover which is directly connected to clearly defined drainage ways (New Jersey, 1981). Rooftop areas are not included in the estimates for large lot, low density homes. In addition, the streets associated with a typical subdivision are not included in this example. Since ground-water recharge is diminished as impervious area increases, the recharge will obviously be affected. This factor should be kept in mind as we proceed through the example. What this means is that the recharge estimation is somewhat higher in this example than it would be if applied to a subdivision with impervious streets and connecting roadways.

A 2-acre lot has a gross area of 87,120 sq ft. If we assume 9% imperviousness, the net area (A) is 79,279 sq ft. Recharge is assumed to be occurring over the entire net area.

The infiltration of precipitation (IP) is the amount of precipitation that can infiltrate the soil and enter the ground water zone where it can then dilute the septic system effluent. As previously discussed, the infiltration or recharge estimates for areas underlain by argillite (and baked shale) range from 52,000 to 319,000 gpd/sq mi, respectively. It is suggested that a more reasonable estimate would fall within the 100,000 to 200,000 gpd/sq mi range. If we assume for this example that the recharge is 200,000 gpd/sq mi, then the recharge IP is calculated as follows:

$$IP = 200{,}000 \text{ gpd/sq mi} = 4.229 \text{ in/yr} = 0.3524 \text{ ft/yr}$$
$$= 9.6 \times 10^{-4} \text{ ft/day}$$

The infiltration over the net area (IA) is calculated as follows:

$$IA = (A) \times (IP) = (79{,}279 \text{ sq ft}) \times (9.6\times10^{-4} \text{ ft/day})$$
$$= 76 \text{ ft}^3\text{/day}$$

The septic discharge (SD) is calculated by multiplying the number of dwelling units (DU) by the per capita generation of effluent (gpcd) by the number of people/DU. Since this example is based on one single family home, the number of DU will obviously be one. Per capita effluent generation varies from household to household with estimates ranging from 45 to 100 gallons/capita/day (gpcd). A reasonable mid-value of 75 gpcd will be assumed for this example. The 1990 census indicates a population of 3,325 for Kingwood Township (New Jersey, Department of Community Affairs, 1992). The increase in population in the township since 1990 is estimated to be 100. The current number of DUs in the township is 1,250 (Telecon with Diane Laudenbach, Kingwood Township, November 3, 1995). Therefore, the number of people/DU is calculated as follows: $(3{,}325 + 100)/1{,}250 = 2.74/\text{DU}$

The septic discharge (SD) is calculated as follows:

$$SD = 1\ DU \times 75\ gpcd \times 2.74/DU$$

$$= 205.5\ gpd = 27.5\ ft^3/day$$

The dilution factor (DF), which is dimensionless, is calculated as follows:

$$DF = (SD + IA)/SD$$

$$= (27.5\ ft^3/day + 76\ ft^3/day)/27.5\ ft^3/day$$

$$= 3.78$$

The nitrate-nitrogen (NO_3-N) concentration in the septic effluent is assumed to be 40 mg/l based on an effluent loading of 11.2 gm/capita/day.

Finally, the theoretical diluted value of nitrate-nitrogen at the property line is calculated as follows:

$$(NO_3\text{-}N)/DF = 40/3.78 = 10.6\ mg/l$$

In conclusion, the 10.6 mg/l nitrogen concentration exceeds the drinking water standard of 10 mg/l. Application of the Trela-Douglas model to Kingwood using a variety of recharge assumptions is shown in Table 2. Note that ground water quality standards are contravened whenever the recharge is too low or the lot sizes too small.

2. A MODIFIED DILUTION MODEL

The Trela-Douglas model was modified by Pizor, Nieswand and Hordon (1984) and applied to consolidated rock areas. The dilution model is formulated as follows:

$$A = (640 \times R \times C \times Q \times P) / (I \times Co)$$

where A = the average area/dwelling unit (acres/DU);

640 = conversion factor (acres/sq mi);

R = pollutant renovation factor (decimal fraction);

C = pollutant concentration in septic system effluent (mg/l);

Q = septic system effluent generation (gpcd);

P = unit occupance (persons/DU);

I = recharge rate in gpd/sq mi;

Co = pollutant concentration limit (10 mg/l for nitrate).

The assumptions in the model are as follows for the areas in Kingwood underlain by argillite or baked shale:

1) The pollutant renovation factor (R) assumes that 20% of the effluent is denitrified, leaving 80% of the pollution to be renovated or diluted. Thus, R = 0.80.

2) The concentration (C) in septic system effluent is assumed to be 40 mg/l.

3) The septic effluent generation (Q) is assumed to be 75 gpcd.

4) The unit occupance (P) is calculated a 2.74 persons/DU.

5) The recharge rate (I) is assumed to be 200,000 gpd/sq mi.

6) The pollutant concentration limit for nitrate-nitrogen is 10 mg/l as set by state and federal standards for drinking water.

Substituting the terms in the dilution model equation results in the following:

$$A = (640 \times 0.8 \times 40 \times 75 \times 2.74) / (200{,}000 \times 10)$$

$$A = 2.1 \text{ acres/DU}$$

The comparable minimum lot sizes using the same values as before but varying the recharge estimates results in a value of 2.8 and 4.2 acres/DU for recharge values of 150,000 and 100,000 gpd/sq mi, respectively. As expected, both dilution models have similar results given the fact that many of the assumptions are the same. The main conclusion is that 2-acre zoning on the argillite and baked shale areas in Kingwood appears to be too small for long-term ground water quality protection.

H. SUMMARY AND CONCLUSIONS

1. Kingwood Township has no public water and sewer service and is therefore totally dependent on onsite wells and septic disposal systems.

2. Nearly 65% of the entire township is underlain by argillite and baked shale rock units. The baked shale beds are hydrologically similar to argillite and are therefore included in the discussion. The two formations are dense, poorly fractured, and offer very limited opportunities for ground water to be stored and transmitted. In terms of ground water availability and storage, they rank near the bottom of all of the formations in New Jersey.

3. All well records on file for Kingwood Township in the Hunterdon County Health Department were examined. Out of the array of wells which may have had mis-identified well logs, it was decided to retain only those wells south of Route 12. The wells north of Route 12 are underlain by shale.

4. The well depths for the selected set of 143 wells ranged from 100 to 800 feet (see Table 1). The mean and median well depth was 399 and 390 feet, respectively. These newer wells (post-1978) are considerably deeper than the older set of wells discussed by Kasabach (1966). It is hypothesized that the newer wells are being drilled to deeper depths in order to intercept either better water-bearing zones or simply more of them.

5. Most of the wells (70.6%) were pumped for only one hour or less. This short time period is clearly not enough to provide meaningful data on drawdown and yield. The pumping period should be increased, particularly for potentially marginal wells.

6. The yields reported on the data forms are considered to be "initial yields" which the literature indicates should diminish with time, especially if more wells are tapping the same aquifer. An increase in impervious cover, such as roadways, will reduce the ground water recharge opportunity which will then have an obvious, decrementing impact on yield.

The mean and median yield of the sample of 143 wells was 9 and 5 gpm, respectively. Since the distribution of the yield values was skewed as evidenced by the high coefficient of variation of 127.4%, the median value of 5 gpm is the more appropriate measure of yield. The reported yields are less than the values indicated in Kasabach (1966) for the wells in Kingwood that were drilled prior to 1966.

7. The drawdown is the vertical difference between the static (pre-pumping) water level and the post-pumping water level. Drawdowns could not be calculated for 25 wells (17.5% of the total) since the water levels were affected by semi-confined or confined conditions. The drawdowns ranged from 0 to 699 feet for the remaining water-table or unconfined wells. The mean and median drawdowns were 222 and 190 feet, respectively. These values are large, particularly in light of the short duration of pumping. They clearly indicate the poor storage and transmissibility of the argillite and baked shale formations.

8. Most of the nitrate values were very low; indeed, many of the samples were close to or at the detection limit of 0.1 mg/l for some of the labs. These low readings indicate favorable ambient ground water concentrations which could change as septic tank density increases.

9. Regression analysis indicates that there is a slight but measurable negative relationship between depth and yield. Yields are somewhat less as well depth increases. This relationship is to be expected, as the degree of fracturing diminishes with depth. Thus, the probability of finding sufficient water-bearing zones in consolidated rock formations decreases with depth.

10. Based on various estimates, hydrograph separation techniques and flow-duration curve analysis, ground-water recharge rates for consolidated formations like the argillite and baked shale in Kingwood range from 52,000 to 319,000 gpd/sq mi. These estimates represent 2.4 to 15% of the average annual precipitation of 45 inches. The wide variation in the rates is related to the particular methodology employed and the recurrence interval selected. It is suggested that the recharge rate for the argillite and baked shale area in Kingwood lies within the 100,000-200,000 gpd/sq mi range.

11. Nitrate dilution models are mass balance models that can be used to estimate nitrate-nitrogen concentrations in the ground water at the property line of a subject area. Application of two types of dilution models which have similar assumptions indicate that the recommended minimum lot size for areas which are underlain by argillite or baked

shale ranges from 2.1 to 2.8 to 4.2 acres/DU for recharge rate assumptions of 200,000, 150,000 and 100,000 gpd/sq mi, respectively.

These values indicate that the current zoning of 2 acres is marginal at the high end of the recharge estimates (200,000 gpd/sq mi) and inappropriate at the intermediate and lower range of the estimates (150,000 and 100,000 gpd/sq mi, respectively). The results of the dilution models suggest that 3-4 acre zoning is more appropriate for the subject area, especially in those areas which have Bowmansville, Croton or Reaville Variant soils which have very poor infiltration rates. In addition, the recommended lot sizes would have to be incrementally increased if the unit occupance is greater than 2.74 and if the roadways associated with a subdivision are included.

I. ACKNOWLEDGMENTS

Appreciation is expressed to the Hunterdon County Health Department for all of their active assistance during the course of this study.

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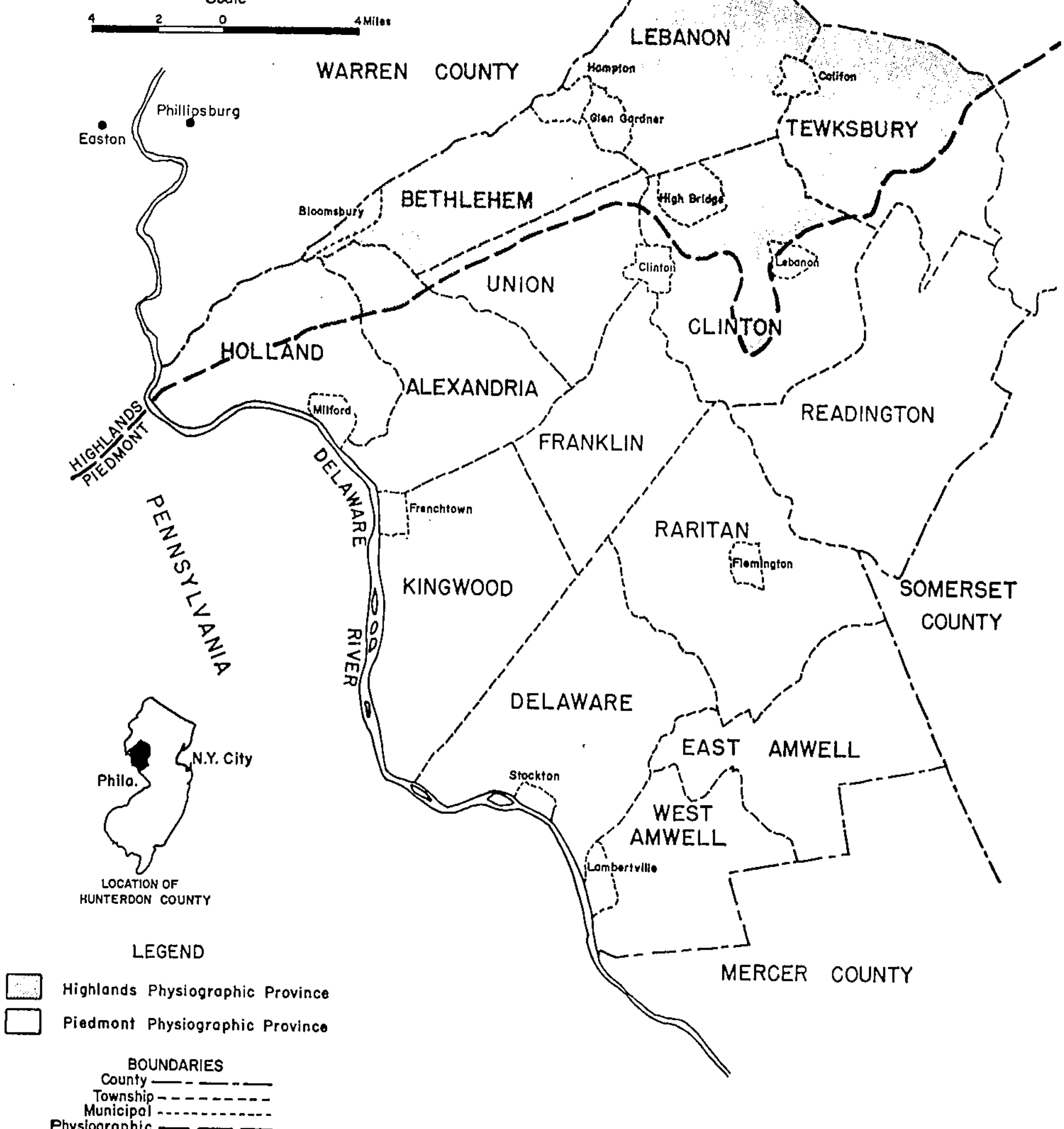
Figure 1.

POLITICAL SUBDIVISIONS AND PHYSIOGRAPHIC PROVINCES OF HUNTERDON COUNTY



Base Map Atlas Sheet NO. 40

Figure 2.

HYPSOMETRIC MAP
OF
HUNTERDON COUNTY
Approx. Scale: 1" = 4 mi.

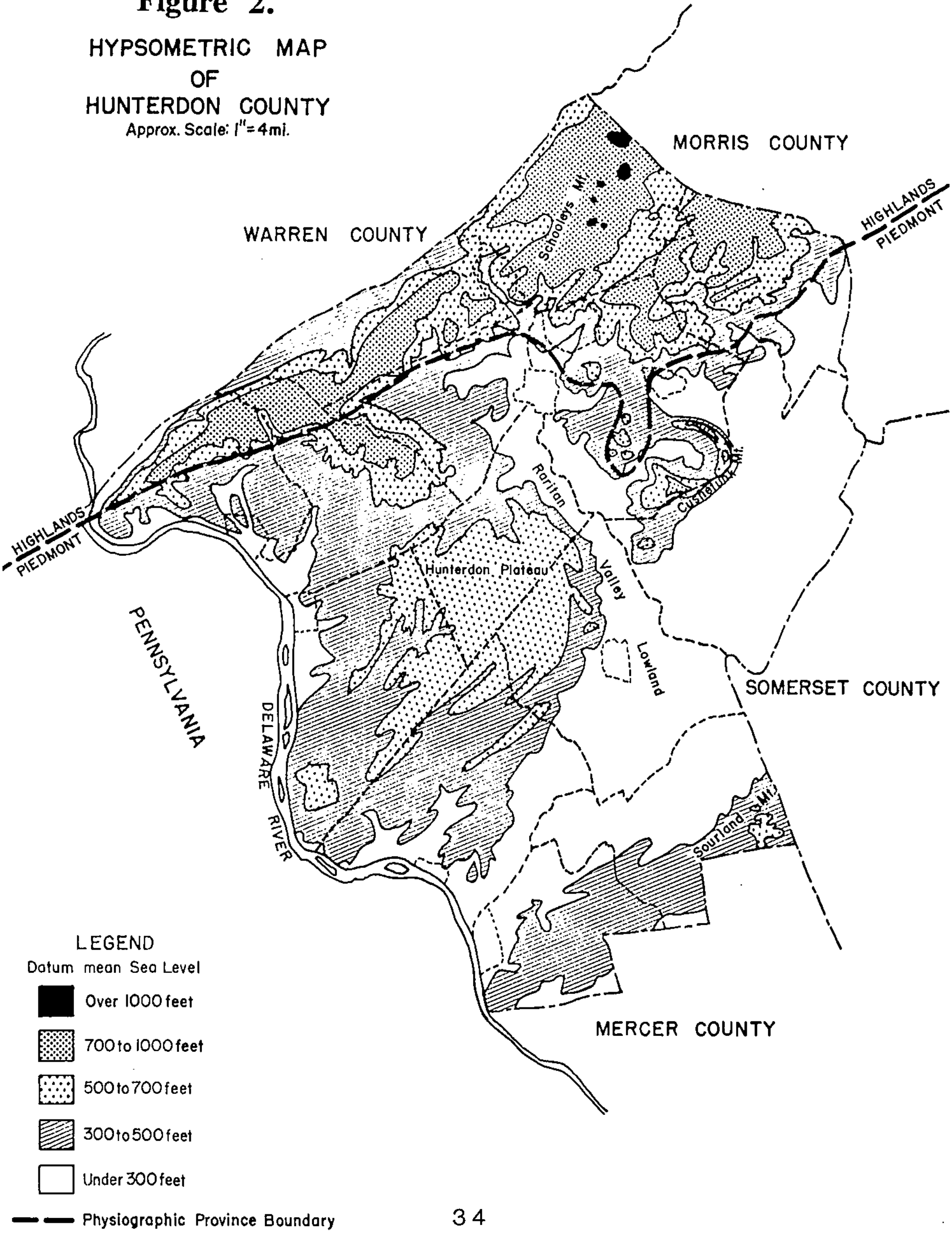
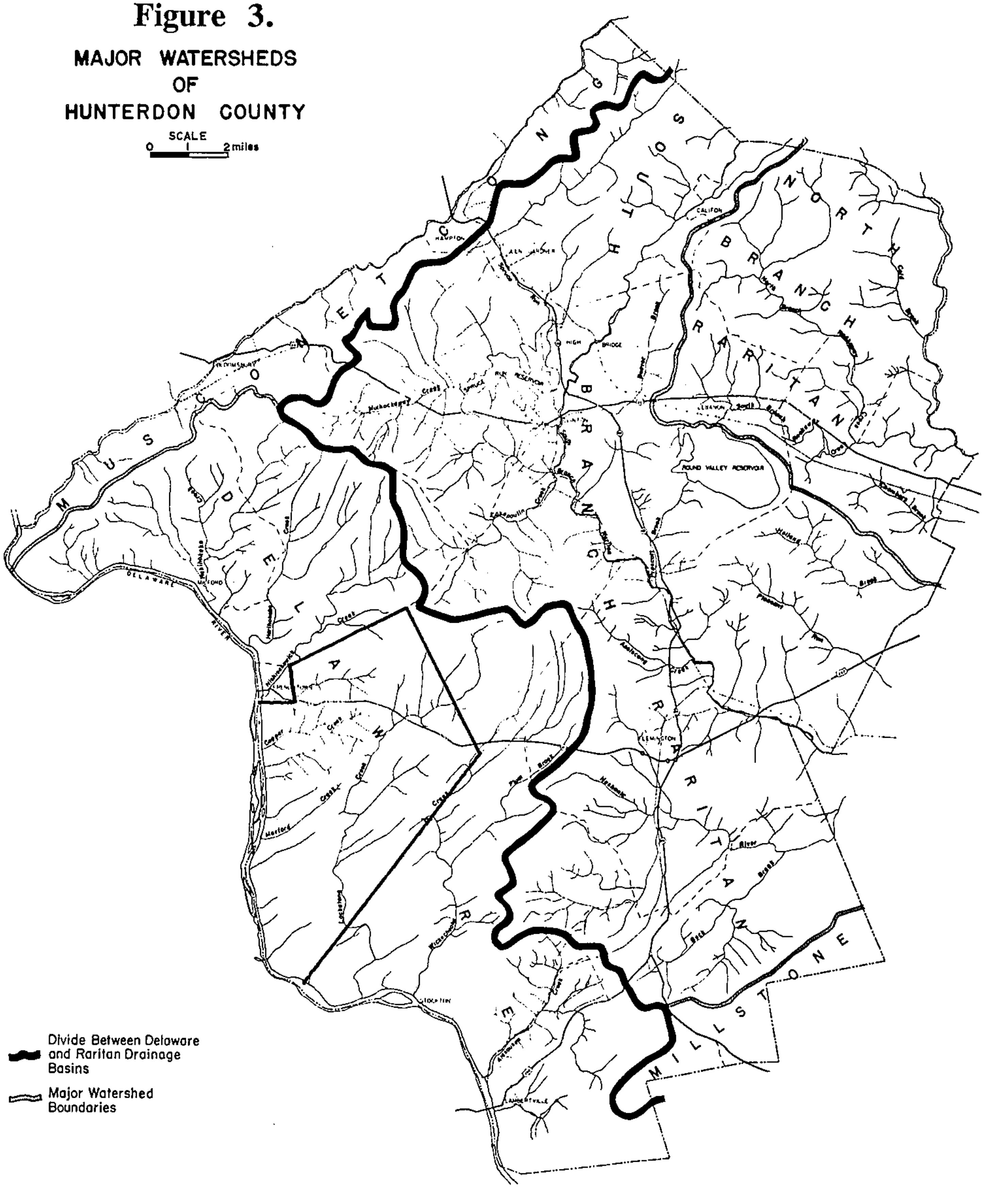


Figure 3.

MAJOR WATERSHEDS OF HUNTERDON COUNTY



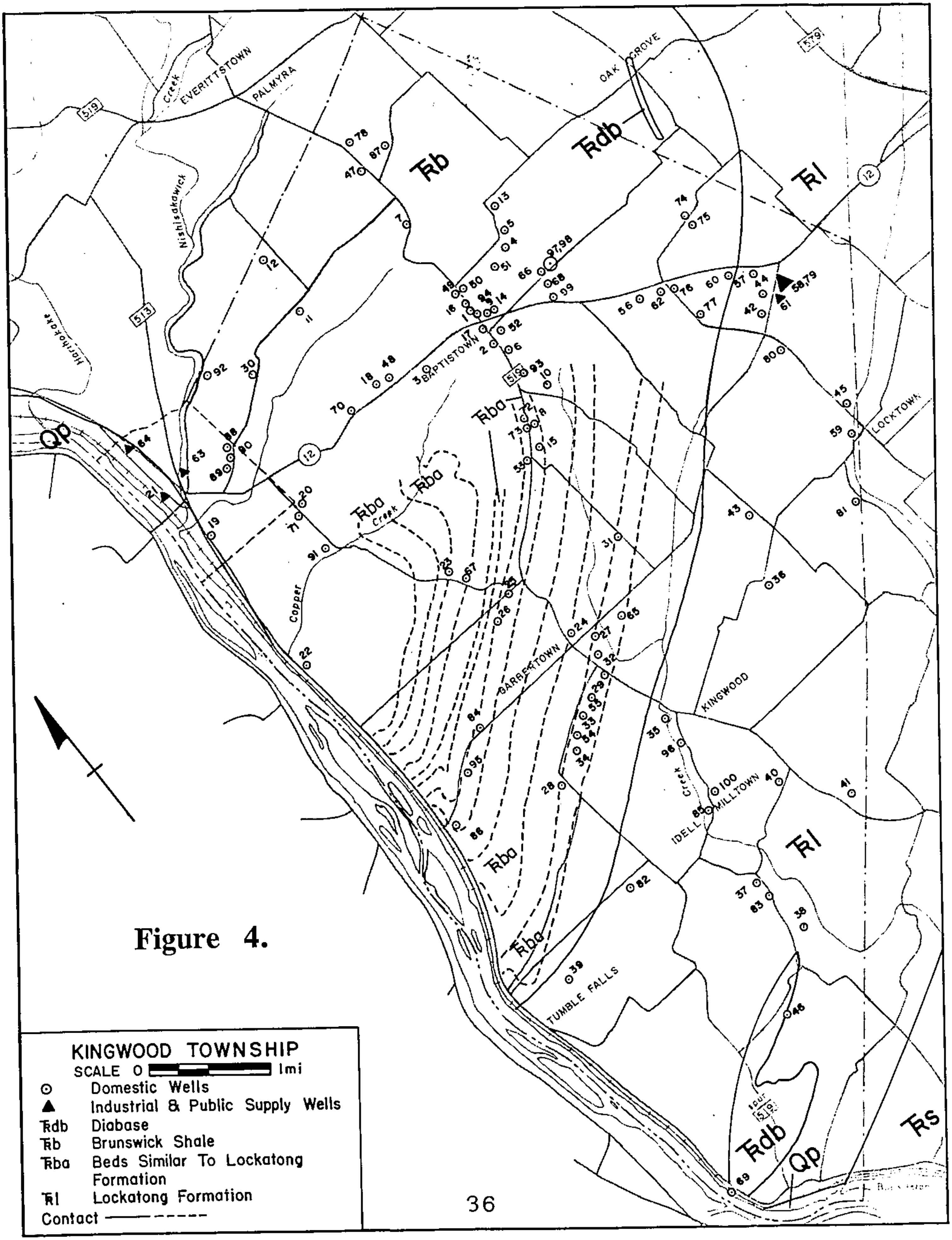

EVERITTSTOWN
PALMYRA
OAK GROVE
Creek
Nishisakawick
Harihokake
BAPTISTOWN
LOCKTOWN
Copper Creek
GARRETTOWN
KINGWOOD
IDELL MILLTOWN
TUMBLE FALLS
Creek
Ꞧdb
Ꞧb
Ꞧl
Ꞧba
Ꞧs
Qp
KINGWOOD TOWNSHIP
SCALE 0 1mi
Domestic Wells
Industrial & Public Supply Wells
Ꞧdb Diabase
Ꞧb Brunswick Shale
Ꞧba Beds Similar To Lockatong Formation
Ꞧl Lockatong Formation
Contact

Figure 4.

HYDROLOGIC CYCLE

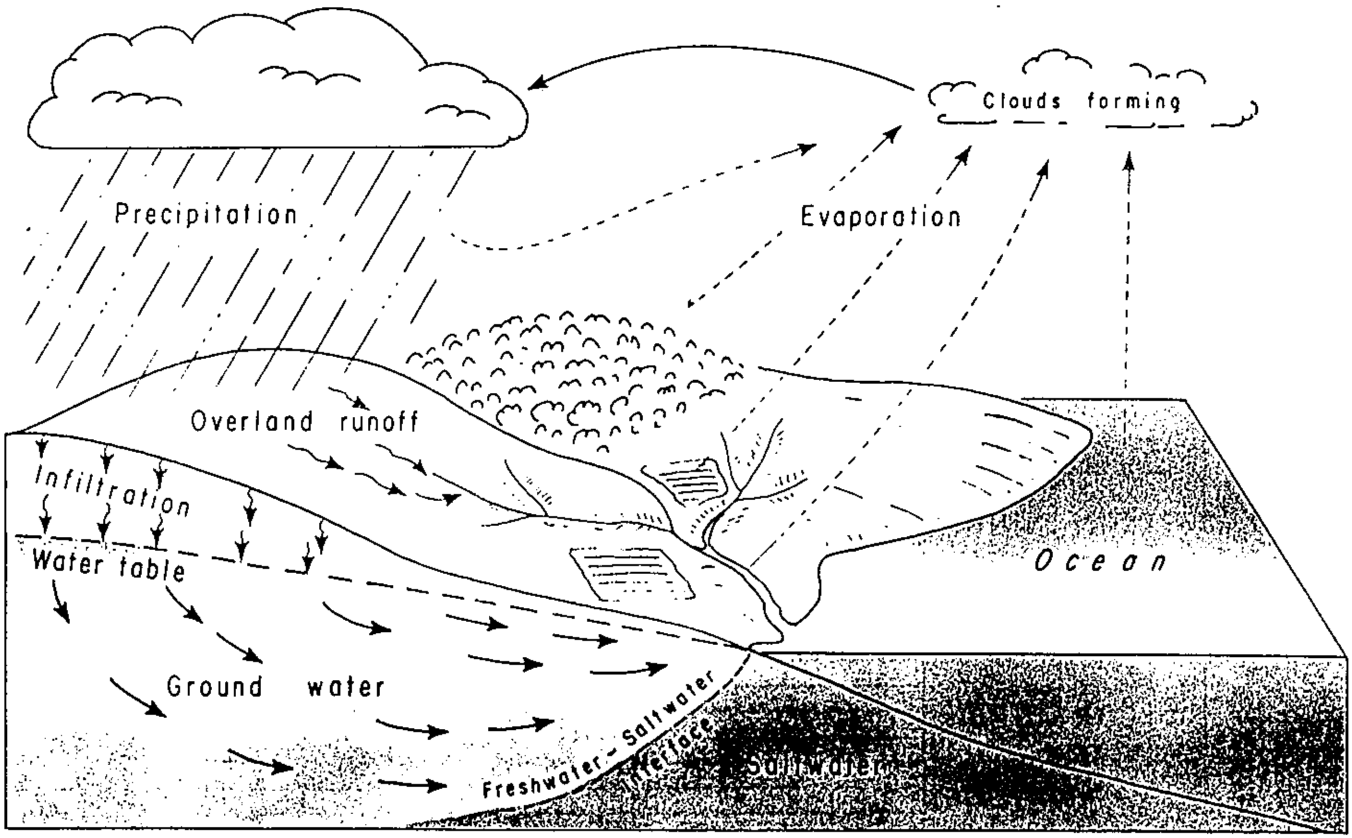
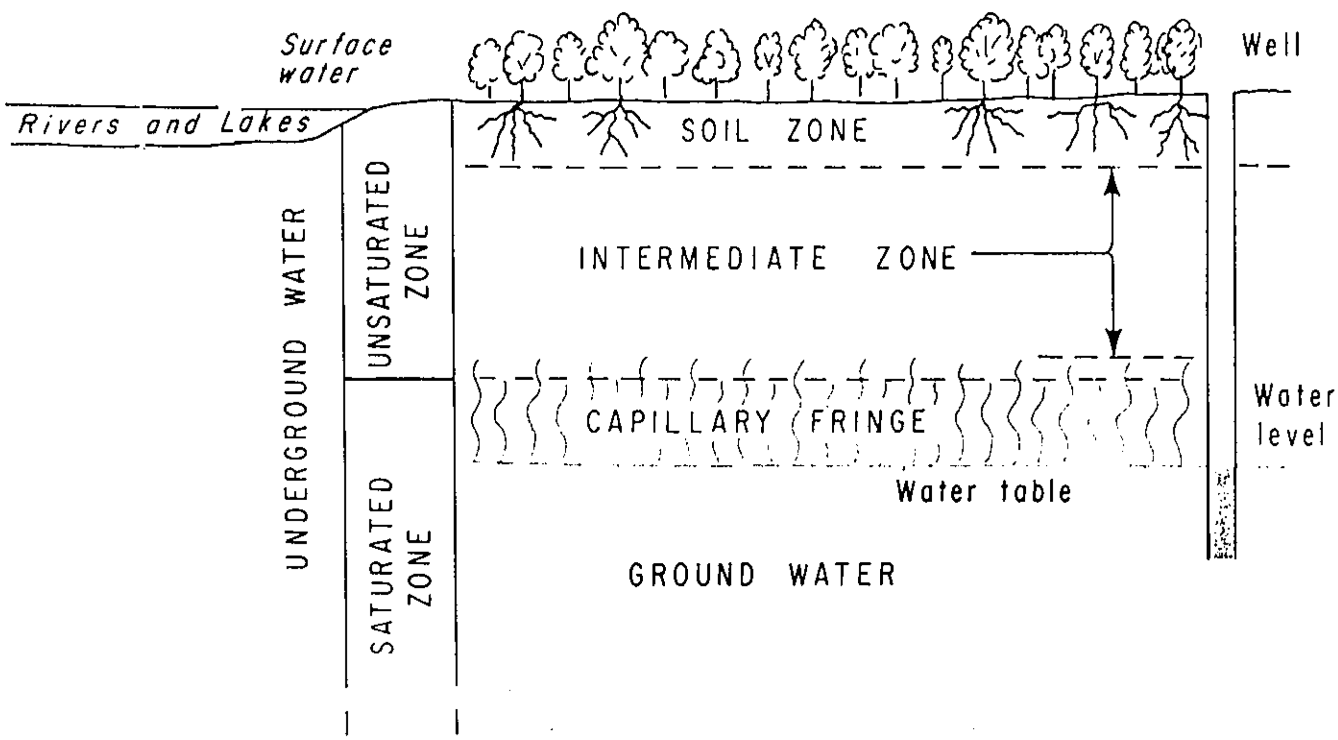


Figure 5.

Figure 6.


Surface water
Rivers and Lakes
SOIL ZONE
INTERMEDIATE ZONE
CAPILLARY FRINGE
Water table
GROUND WATER
UNDERGROUND WATER
UNSATURATED ZONE
SATURATED ZONE
Well
Water level

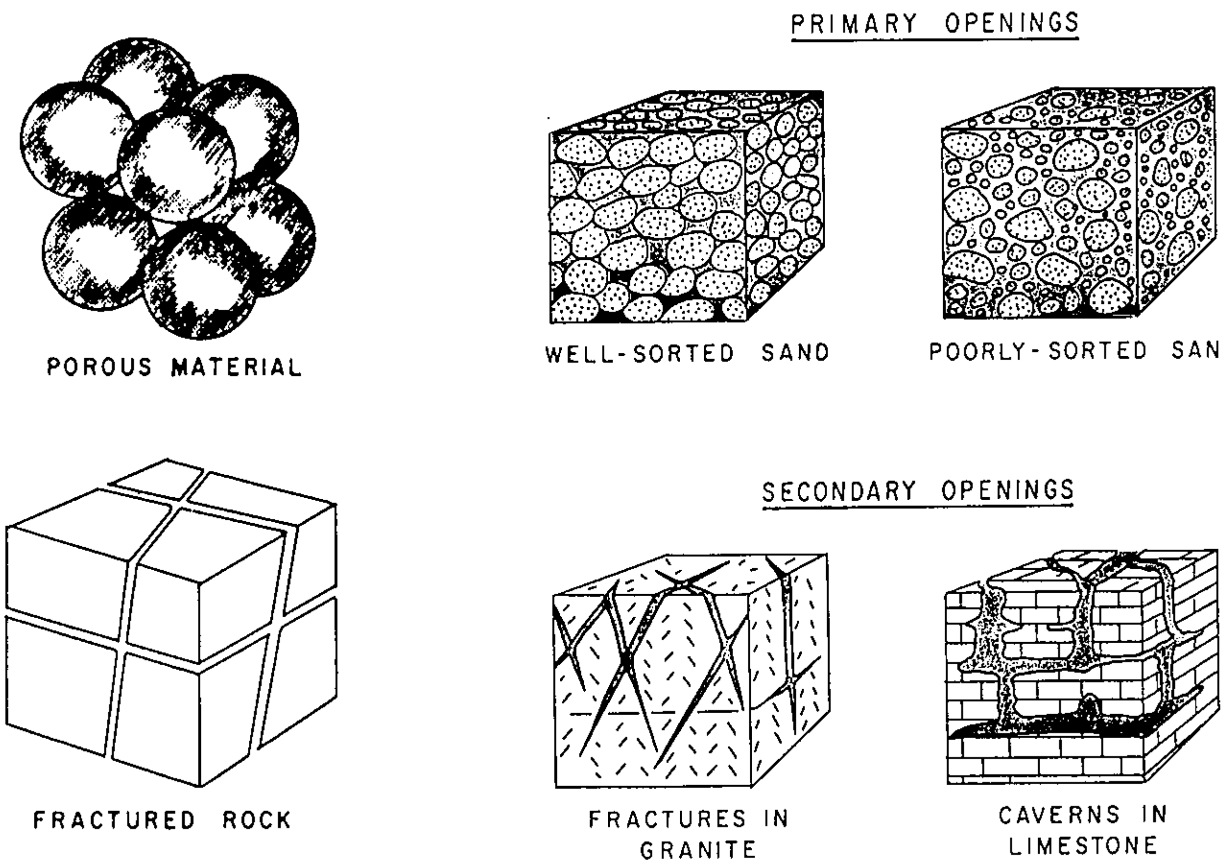

PRIMARY OPENINGS
POROUS MATERIAL
WELL-SORTED SAND
POORLY-SORTED SAND
SECONDARY OPENINGS
FRACTURED ROCK
FRACTURES IN GRANITE
CAVERNS IN LIMESTONE

Figure 7.

FUNCTIONS OF GROUND-WATER SYSTEMS

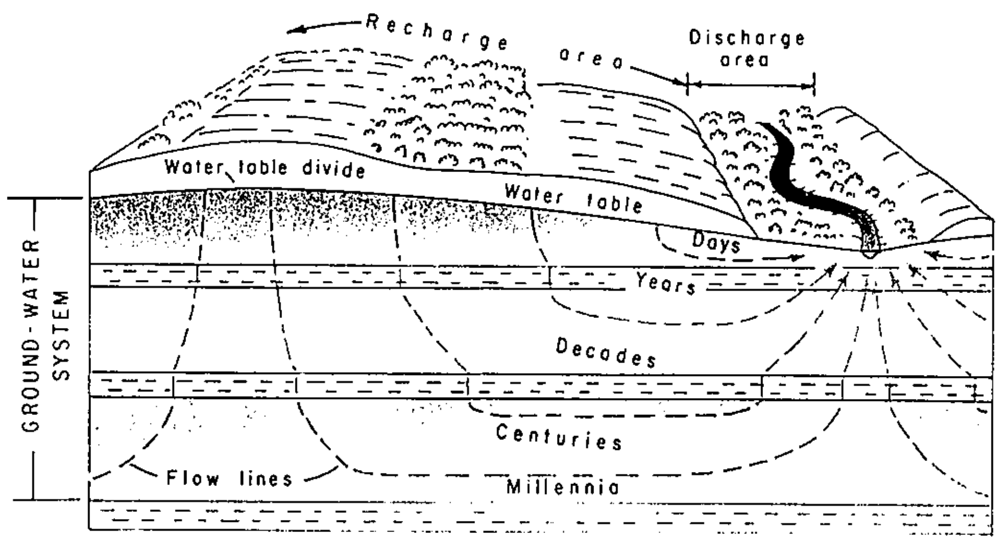


Figure 8.

DRAWDOWN DURING PUMPING TEST

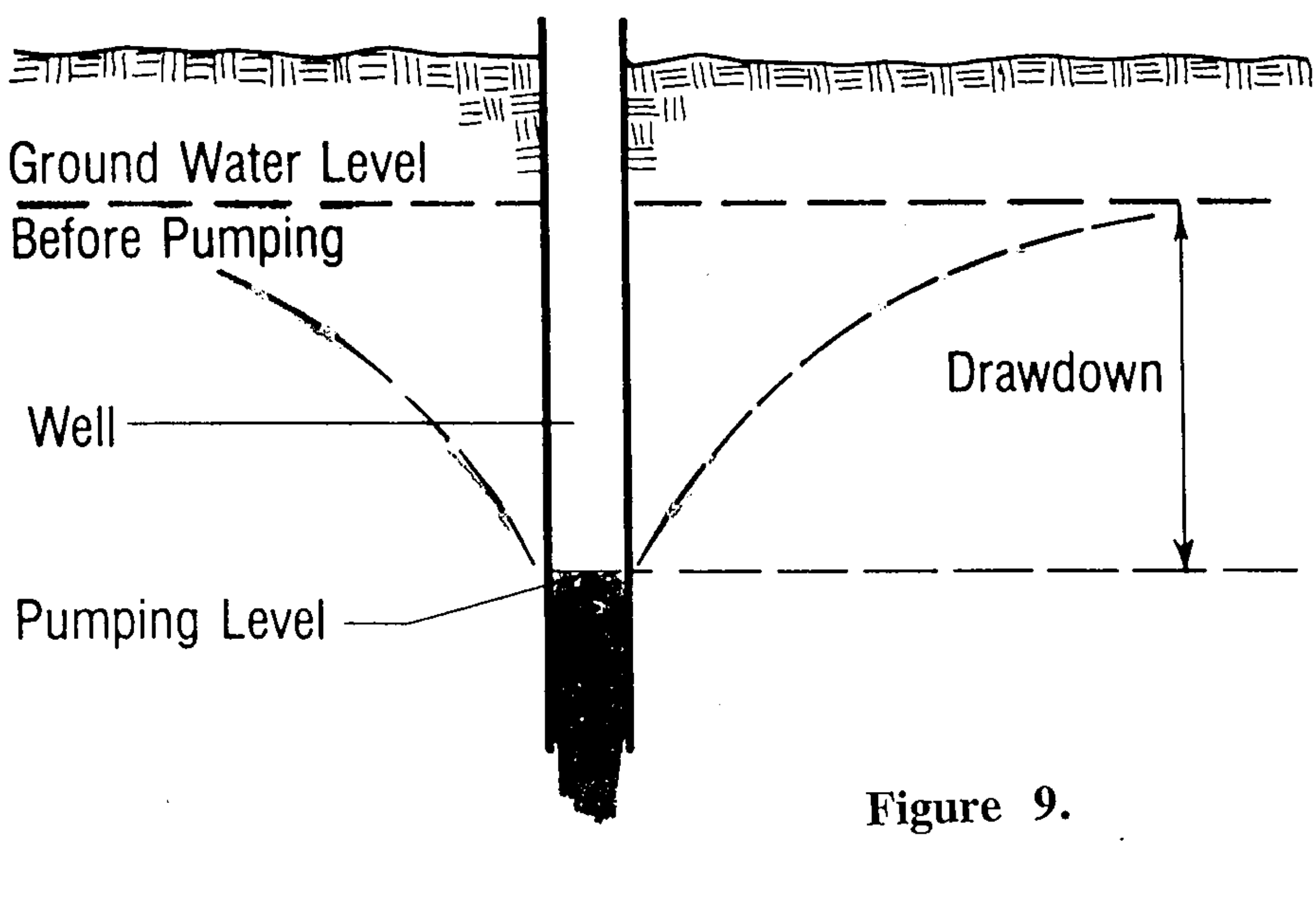
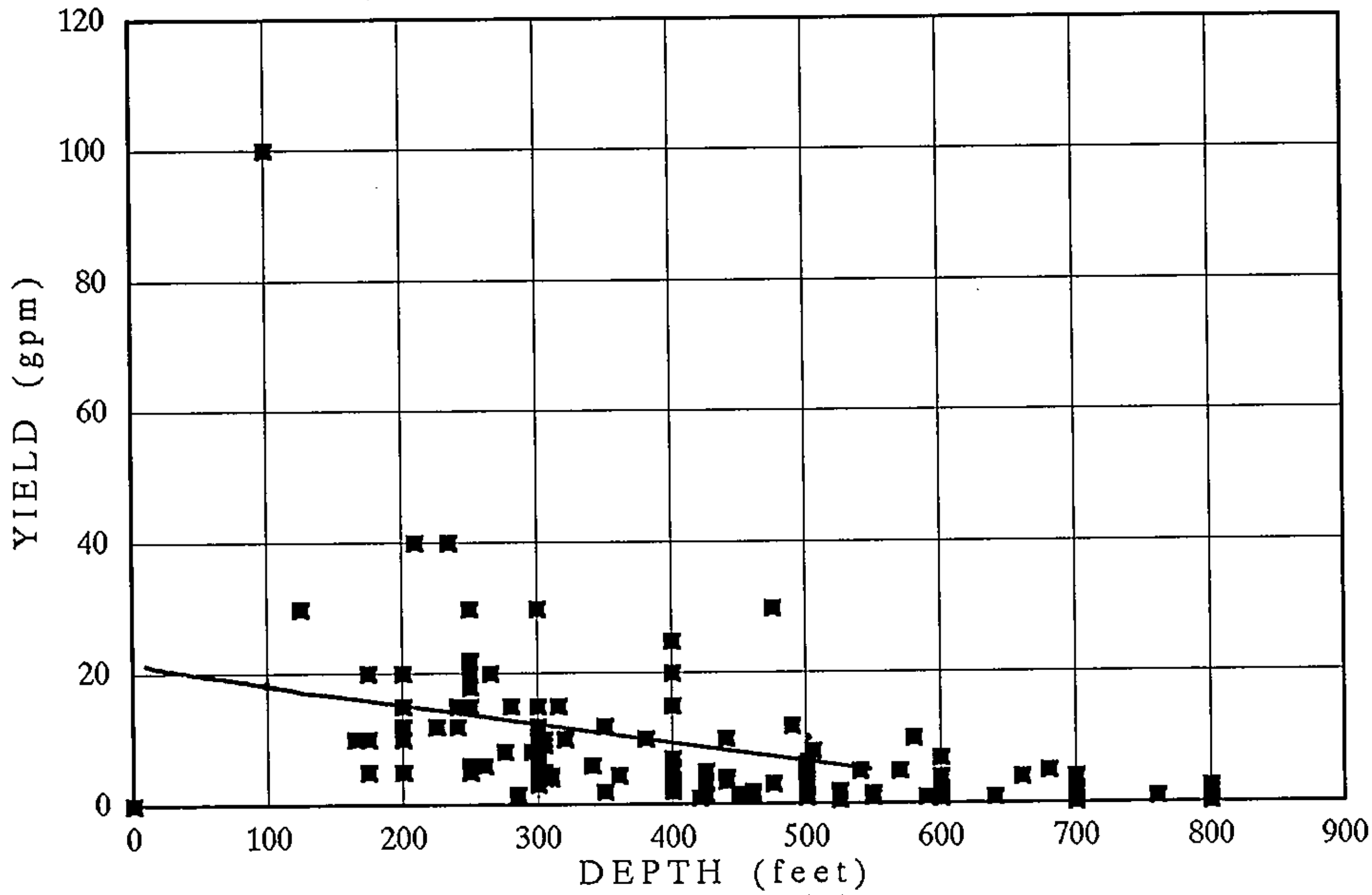


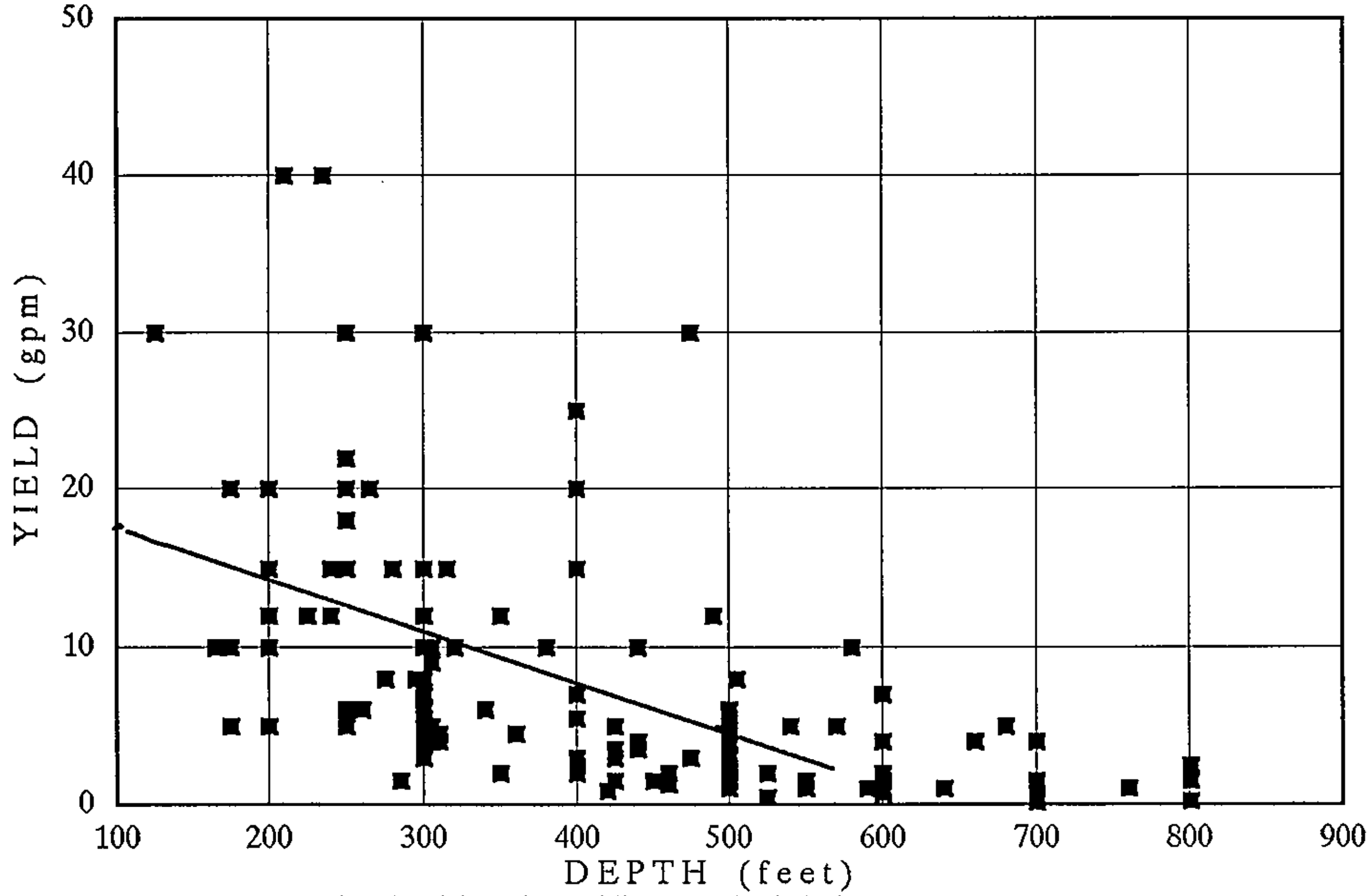
Figure 9.

Figure 10. Relationship between Depth and Yield for Selected Domestic Wells in Kingwood
(N = 143; Y = 23.3 – 0.036 X; r = .518; r^2 = .268)



All wells were reported to be drilled in argillite or baked shale.

Figure 11. Relationship between Depth and Yield for Selected Domestic Wells in Kingwood
(N = 142; Y = 20.0 – 0.030 X; r = .570; r^2 = .325)



All wells were reported to be drilled in argillite or baked shale.

Table 1. Selected Domestic Wells in Kingwood Township, Hunterdon County, New Jersey

	Location					Static		Pumping			Nitrate–Nitrogen		
	Block	Lot	Road	Date	Depth (feet)	Water Level (feet)	Hours Pumped	Water Level (feet)	Yield (gpm)	Drawdown (feet)	(mg/l)	Date	Well Driller
1	17	16.05	Barbertown Road	5/87	200	30	1	0	20	−30	<0.1	12/9/87	Stover
2	18	1.03	Fitzer Road	4/93	250	30	1	195	18	165	<0.5	7/7/93	"
3	"	2.06	Locktown Road	6/92	175	40	1	150	5	110	1.18	7/6/92	"
4	"	8–B	" "	8/84	200	60	4	180	5	120	NA		D & L
5	19	6.02	Fitzer Road	7/88	500	15	4	200	2	185	0.47	8/15/88	Summit
6	"	6.08	" "	10/86	235	40	1	0	40	−40	2.12	10/27/86	Stover
7	"	6.09	" "	10/86	320	50	4	250	10	200	1.49	12/8/86	Somerville
8	"	6.10	" "	4/88	350	50	1	0	12	−50	0.89	8/10/88	Stover
9	"	6.11	" "	8/89	400	30	4	30	7	0	<0.1	10/16/89	D & L
10	"	14.01	Union Road	3/86	240	35	4	150	12	115	"	4/2/86	Stothoff
11	"	14.02	" "	8/86	250	25	1	0	15	−25	0.07	11/2/87	Stover
12	"	14.03	" "	10/91	300	20	1	275	4.5	255	<0.1	12/4/91	"
13	"	17.01	" "	9/89	550	10	1	525	1.5	515	"	6/3/91	"
14	"	18.03	Point Breeze Road	8/88	200	10	1	120	12	110	"	11/30/88	Stothoff
15	"	18.04	" " "	7/90	295	15	4	35	8	20	0.11	9/5/90	Cataluce
16	20	6–C	Thatcher Road	12/86	300	30	1	0	5	−30	NA		Stover
17	"	7.01	Union Road	9/87	260	30	1	220	6	190	<0.1	1/27/88	Stothoff
18	"	7.02	" "	10/93	425	40	1	400	3	360	"	6/29/94	Stover
19	"	7.04	" "	4/90	250	50	1	225	30	175	<0.01	8/29/90	"
20	"	7.06	" "	10/94	300	5	1	175	3	170	1.89	12/19/94	"
21	21	2	Point Breeze Road	9/91	400	5	1	150	3	145	NA		Stothoff
22	"	2	" " "	9/91	250	7	1	50	22	43	"		"
23	"	7	" " "	10/79	305	10	1	10	4	0	"		Stover
24	"	9	Locktown Road	5/79	350	25	4	NA	2	NA	"		B & E
25	22	10.01	" "	1/87	300	80	1	0	3	−80	<0.1	3/16/87	Stover
26	"	11	" "	11/82	175	20	1	135	10	115	NA		Stothoff

Table 1. Selected Domestic Wells in Kingwood Township, Hunterdon County, New Jersey

	Location: Block	Location: Lot	Location: Road	Date	Depth (feet)	Static Water Level (feet)	Hours Pumped	Pumping Water Level (feet)	Yield (gpm)	Drawdown (feet)	Nitrate–Nitrogen (mg/l)	Nitrate–Nitrogen Date	Well Driller
27	22	13–A	Locktown Road	7/84	300	40	10	40	8	0	NA		Stover
28	"	13–B	" "	7/88	285	5	1	5	1.5	0	"		"
29	"	13–C	" "	8/82	600	60	8	500	2	440	"		Somerville
30	"	13–F	" "	8/84	525	NA	1	NA	0.5	NA	"		Stover
31	"	15–A	Hammer Road	5/86	200	20	1	100	20	80	<0.1	6/9/86	"
32	"	19–A	" "	7/85	310	60	1	280	4	220	0.25	9/16/85	"
33	"	19.02	" "	9/90	500	20	1	475	1.5	455	0.09	11/19/90	"
34	"	19–D	Locktown Road	12/86	250	45	4	175	30	130	0.18	2/23/87	Somerville
35	"	19–E	" "	8/83	100	10	1	10	100	0	NA		Stover
36	"	19.06	" "	5/88	300	50	4	250	12	200	0.09	6/29/88	Somerville
37	"	22	" "	10/91	500	30	0.5	100	2.5	70	0.17	11/6/91	Stothoff
38	23	5	Thatcher Road	6/90	305	30	4	30	5	0	0.91	7/16/90	D & L
39	"	5.03	" "	5/88	360	60	1	300	4.5	240	0.15	3/30/92	Stothoff
40	"	5.05	" "	8/89	315	40	2	200	15	160	0.25	10/11/89	"
41	"	6.01	Kingwood Road	7/88	300	40	2	40	5.5	0	0.18	10/31/88	D & L
42	"	22–B	Point Breeze Road	8/83	500	20	1	460	1.5	440	NA		Stothoff
43	"	22–C	" " "	5/80	600	30	5	399	1.5	369	"		Somerville
44	"	25.01	Thatcher Road	12/87	600	60	1	0	1	–60	0.09	5/4/88	Stover
45	"	25–B	Point Breeze Road	10/85	600	30	1	450	1	420	0.09	2/5/86	Stothoff
46	"	25–C	" " "	4/84	600	NA	NA	NA	1	NA	NA		Stover
47	"	25.04	" " "	4/85	400	40	1	40	3	0	"		"
48	24	1.02	Route 519	1/91	680	20	4	300	5	280	0.09	2/25/91	Bryan
49	"	9.03		4/95	200	10	1	175	15	165	1.05	5/10/95	Stover
50	25	8	Locktown Road	1/88	475	10	1	0	30	–10	0.65	8/10/88	"
51	"	9	" "	6/93	525	40	1	500	0.5	460	0.99	8/2/93	"
52	26	6	Route 12	6/86	490	80	1	280	12	200	NA		Stothoff

Table 1. Selected Domestic Wells in Kingwood Township, Hunterdon County, New Jersey

	Location					Static		Pumping			Nitrate–Nitrogen		Well
	Block	Lot	Road	Date	Depth (feet)	Water Level (feet)	Hours Pumped	Water Level (feet)	Yield (gpm)	Drawdown (feet)	(mg/l)	Date	Driller
53	26	10	Featherbed Lane	8/88	500	30	1	30	5.5	0	0.09	11/29/89	D & L
54	"	22	" "	10/78	570	15	1	500	5	485	NA		Stothoff
55	"	25	Hammer Road	6/83	600	60	1	580	1	520	"		"
56	27	2.02	Locktown Road	6/90	300	20	1	275	15	255	0.09	9/26/90	Stover
57	"	2–B	Tumble Road	9/80	460	0	1	440	2	440	NA		Stothoff
58	"	7.01	Wickecheoke	10/87	600	10	1	0	0.75	–10	0.09	3/9/88	Stover
59	28	1	Route 29	5/88	440	110	1	300	10	190	0.14	1/23/89	Stothoff
60	"	3	Fairview Road	11/86	300	80	1	0	6	–80	2.28	7/22/87	Stover
61	"	3.05	" "	5/90	280	40	2	240	15	200	1.53	6/11/90	Interstate
62	"	3.07		10/94	580	40	4	40	10	0	5.03	11/16/94	D & L
63	29	7.01	Kingwood Road	12/92	500	70	1	475	6	405	2.72	1/4/93	Stover
64	"	15–A	Barbertown Road	6/87	500	40	1	400	1	360	0.43	10/5/87	Stothoff
65	"	25.01	" "	10/86	475	20	1	0	3	–20	<0.1	11/24/86	Stover
66	"	25.02	" "	3/87	300	40	1	0	4	–40	2.98	6/687	"
67	"	25.03	" "	NA	200	60	NA	120	10	60	0.57	11/18/91	D & L
68	"	25.04	" "	11/87	400	50	1	0	2	–50	2.25	6/29/88	Stover
69	"	29.02	Warford Road	11/87	550	90	1	0	1	–90	<0.1	1/20/88	"
70	"	31–A	" "	8/83	400	50	1	50	5.5	0	NA		"
71	"	31–B	" "	6/83	425	225	1	225	3.5	0	"		"
72	"	31–C	" "	9/83	550	200	1	200	1	0	"		"
73	"	31–D	" "	10/84	460	2	4	450	2	448	"		D & L
74	"	31.05	" "	8/87	700	NA	1	0	0.125	NA	"		Stover
75	"	31.05	" "	"	800	50	1	0	0.25	–50	6.41	9/23/87	"
76	"	31.06	" "	6/87	600	100	4	100	4	0	1.38	9/28/87	Hawkins
77	"	31.07	" "	11/94	500	50	1	475	4	425	1.63	1/30/95	Stover
78	"	31.08	" "	6/93	300	75	1	275	7	200	<1.0	6/21/93	"

Table 1. Selected Domestic Wells in Kingwood Township, Hunterdon County, New Jersey

	Location			Date	Depth (feet)	Static Water Level (feet)	Hours Pumped	Pumping Water Level (feet)	Yield (gpm)	Drawdown (feet)	Nitrate–Nitrogen		Well Driller
	Block	Lot	Road								(mg/l)	Date	
79	30	9.01	Warsaw Road	3/93	300	70	1	275	12	205	2.50	5/12/93	Stover
80	"	9.02	" "	"	300	20	1	275	12	255	3.01	3/31/93	"
81	31	3	Idell Road	10/87	760	0	1	290	1	290	NA		Stothoff
82	"	3.05	Hill Road	5/88	300	20	2	20	5	0	1.00	6/22/88	D & L
83	"	3.07	Idell Road	11/90	700	30	1	675	0.5	645	0.28	1/7/91	Stover
84	"	3.08	" "	12/87	800	1	1	700	1.5	699	0.18	9/12/88	Stothoff
85	"	3.11	" "	7/91	700	70	1	650	1.5	580	0.16	4/6/92	Stover
86	32	1.03	Warsaw Road	8/94	210	5	1	55	40	50	1.69	11/14/92	J. Liedl
87	"	8.01	Idell Road	12/87	175	30	1	0	20	–30	0.20	6/6/88	Stover
88	33	2.03	" "	5/95	460	50	1	435	1.25	385	0.67	6/21/95	"
89	"	2.05	" "	2/95	425	20	2	200	1.5	180	2.39	3/22/95	"
90	"	2.06	519 Spur	3/95	600	23	4	23	7	0	NA	4/5/95	D & L
91	"	2.07	Barcroft Lane	4/95	450	25	1	425	1.5	400	"	5/31/95	Stover
92	"	2.08	" "	3/95	400	40	1	375	15	335	0.95	"	"
93	"	14.02	519 Spur	4/89	225	15	1	200	12	185	<0.1	5/22/89	"
94	"	14.07	Idell Road	12/90	165	40	4	40	10	0	"	2/4/91	Hawkins
95	34	4.02	Federal Twist Rd	2/94	305	5	4	5	10	0	"	5/19/94	D & L
96	"	8.01	Milltown Road	11/88	265	30	1	0	20	–30	"	12/12/88	Stover
97	"	12	" "	1/88	250	30	1	0	5	–30	"	3/9/88	"
98	34–B	38	Federal Twist Rd	11/84	250	30	4	200	18	170	NA		D & L
99	35	6.01	Kingwood Road	10/87	300	40	2	40	10	0	<0.1	12/9/87	"
100	"	13	519 Spur	3/87	400	20	1	0	2	–20	2.66	7/3/89	Stover
101	"	14–A	Milltown Road	10/88	400	100	1	200	20	100	<0.1	11/23/88	Stothoff
102	37	2.03	519 Spur	1/89	200	10	1	0	10	–10	"	3/8/89	Stover
103	"	3	Federal Twist Rd	6/89	340	120	1	280	6	160	"	5/7/90	"
104	38	5.04	Route 519	11/89	400	30	1	375	2	345	"	12/18/89	"

Table 1. Selected Domestic Wells in Kingwood Township, Hunterdon County, New Jersey

	Location			Date	Depth (feet)	Static Water Level (feet)	Hours Pumped	Pumping Water Level (feet)	Yield (gpm)	Drawdown (feet)	Nitrate–Nitrogen		Well Driller
	Block	Lot	Road								(mg/l)	Date	
105	38	25.03	Federal Twist Rd	10/93	310	50	1	250	4.5	200	<0.1	4/18/94	J. Liedl
106	"	31	" " "	11/87	500	40	8	400	4.5	360	"	2/8/88	Somerville
107	"	31.01	" " "	7/94	400	40	1	375	2.5	335	0.34	8/1/94	Stover
108	"	34.03	" " "	6/86	425	70	0.5	300	5	230	0.70	9/3/86	Stothoff
109	39	2	Idell Rd	3/86	660	200	4	650	4	450	NA		Somerville
110	"	2.01	" "	8/89	600	175	1	575	2	400	0.63	1/24/90	Stover
111	"	2–C	" "	2/86	700	180	4	680	4	500	0.96	4/30/86	Somerville
112	"	4.01	" "	8/94	500	30	1	475	5	445	0.60	9/7/94	Stover
113	"	5	" "	8/86	590	40	1	450	1	410	<0.1	10/29/86	Stothoff
114	"	6	Tumble Falls Rd	10/93	250	90	1	150	20	60	"	5/18/94	J. Liedl
115	"	12.01	Kingwood Road	9/92	400	50	4	375	25	325	"	12/2/92	Somerville
116	"	12.03	519 Spur	6/89	640	45	1	440	1	395	"	7/12/89	Stothoff
117	"	12.04	" "	1/89	380	50	NA	320	10	270	"	1/30/89	"
118	"	13	Kingwood Road	2/81	540	40	1	450	5	410	NA		"
119	"	14	Old Road	8/83	800	80	8	700	2.5	620	"		Somerville
120	"	20	Tumble Falls Rd	3/93	420	30	1	390	0.9	360	<0.1	4/5/93	Stover
121	"	20.05	" " "	8/87	440	70	1	375	3.5	305	2.22	3/23/88	Stothoff
122	"	25.02	" " "	7/88	440	70	1	320	4	250	NA		"
123	"	26	" " "	1/91	700	110	1	300	1.5	190	<0.1	6/19/91	"
124	40	6.05	" " "	5/87	500	40	1	400	3	360	"	11/16/87	"
125	"	6.07	" " "	11/84	300	20	4	280	3	260	NA		D & L
126	"	12.01	Kingwood Road	5/93	305	40	4	75	9	35	<0.1	7/26/93	Bucks Co.
127	"	21.02	Byram Road	9/87	200	40	1	130	20	90	"	3/9/88	Stothoff
128	"	22	" "	3/88	240	40	1	180	15	140	0.2	6/8/88	"
129	"	29.01	" "	11/94	200	30	1	175	20	145	NA		Stover
130	41	3.01	Lockatong Road	5/92	305	10	1	100	10	90	1.19	6/15/92	J. Liedl

Table 1. Selected Domestic Wells in Kingwood Township, Hunterdon County, New Jersey

	Location			Date	Depth (feet)	Static Water Level (feet)	Hours Pumped	Pumping Water Level (feet)	Yield (gpm)	Drawdown (feet)	Nitrate–Nitrogen		Well Driller
	Block	Lot	Road								(mg/l)	Date	
131	41	3.04	Lockatong Road	3/93	305	30	4	30	10	0	<0.1	5/26/93	D & L
132	"	3.05	" "	11/94	350	60	1	180	12	120	1.62	3/22/95	Stothoff
133	"	4	" "	8/92	500	30	1	420	5	390	<0.1	8/31/92	"
134	"	5	" "	8/86	200	40	4	180	15	140	3.20	10/15/86	D & L
135	"	5.02	" "	11/94	425	20	1	400	1.5	380	NA		Stover
136	"	8.12	Federal Twist Rd	10/87	275	30	1	0	8	−30	0.27	12/2/87	"
137	"	8.14	" " "	6/85	250	50	4	220	6	170	NA		D & L
138	"	8.15	" " "	8/87	505	30	2	30	8	0	<0.1	11/30/87	"
139	"	9		8/86	125	30	1	0	30	−30	1.86	10/1/86	Stover
140	"	15.01	Stompf Tavern Rd	4/91	300	20	1	275	10	255	<0.1	10/21/91	"
141	42	5	" " "	9/87	525	120	1	0	2	−120	1.44	10/21/87	"
142	"	5.02	" " "	6/88	250	60	1	0	15	−60	5.50	6/22/88	"
143	52	11.08		4/86	300	30	NA	200	30	170	NA		Stothoff

	Depth (feet)	Yield (gpm)	Drawdown (feet)
Sample size	143	143	115
Maximum	800	100	699
Minimum	100	0.125	0
Average	399	9	222
Median	390	5	190
Standard deviation	159	11	173
Coefficient of variation	39.8%	127.4%	78.0%

Table 1. Selected Domestic Wells in Kingwood Township, Hunterdon County, New Jersey

Source: Hunterdon County Health Department

All wells are reported as being drilled in argillite or baked shale.

NA: data not available.

A negative (–) sign for drawdown indicates that the water in the well is coming from semi–confined or confined layers in the rock.

B & E Well Drilling Co., Flemington.
Bryan Well Drilling Co., Chester.
Bucks County Artesian Well Drilling Co.
D & L Well Drilling Co., Clinton.
Dominick Cataluce, Washington, NJ.
D.J. Hawkins Well Drilling Co., Glen Gardner.
Interstate Well and Pump Co.
J.H. Liedl Well Drilling Co., Somerville.
Samuel Stothoff Co., Flemington.
Somerville Well Drilling Co., Somerville.
Stover's Wells and Pumps, Ringoes.
Summit Well Drilling Co., Bridgewater.

Table 2.

Application of the Trela–Douglas Model to
Kingwood Township, Hunterdon County

Lot size (acres)	2	3	4	5
Impervious area (%)	9	8	7	6
Recharge (gpd/sq mi)	100,000	100,000	100,000	100,000
Nitrate (mg/l)	16.7	12.9	10.4	8.7
Recharge (gpd/sq mi)	150,000	150,000	150,000	150,000
Nitrate (mg/l)	13.0	9.6	7.6	6.3
Recharge (gpd/sq mi)	200,000	200,000	200,000	200,000
Nitrate (mg/l)	10.6	7.7	6.0	4.9

The nitrate level is the estimated concentration at the property line.