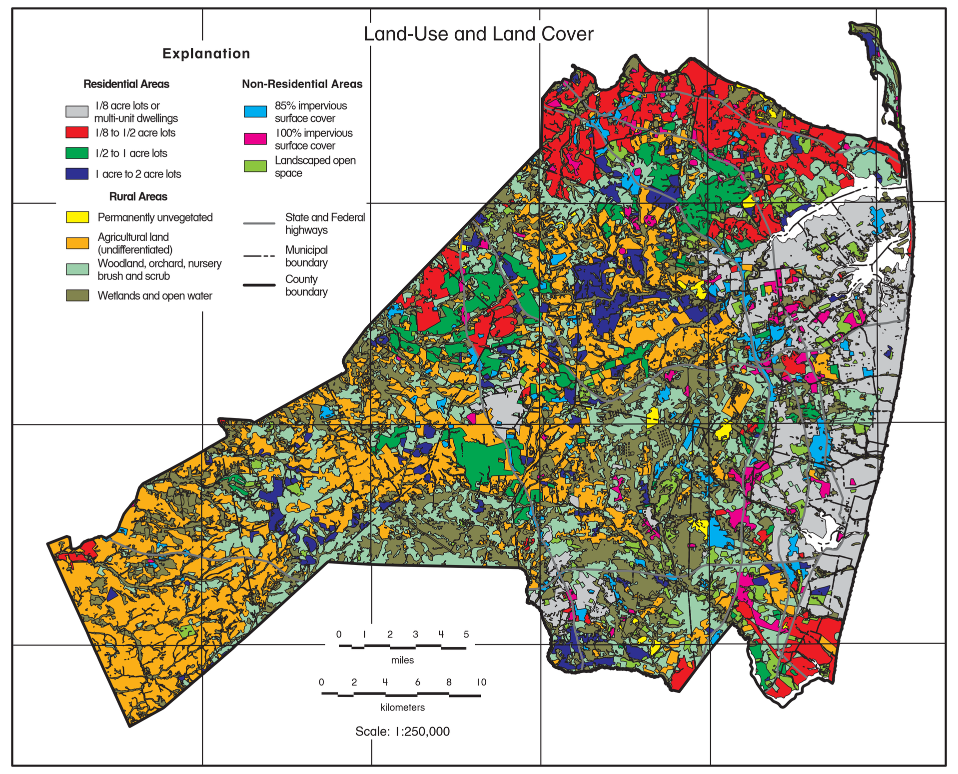
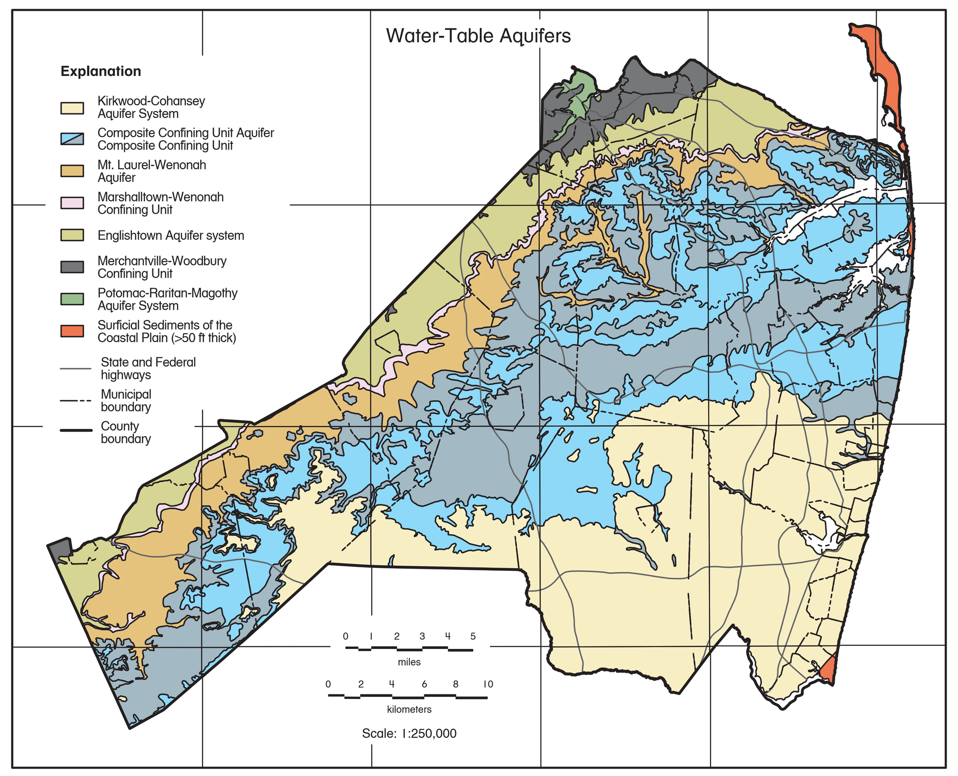
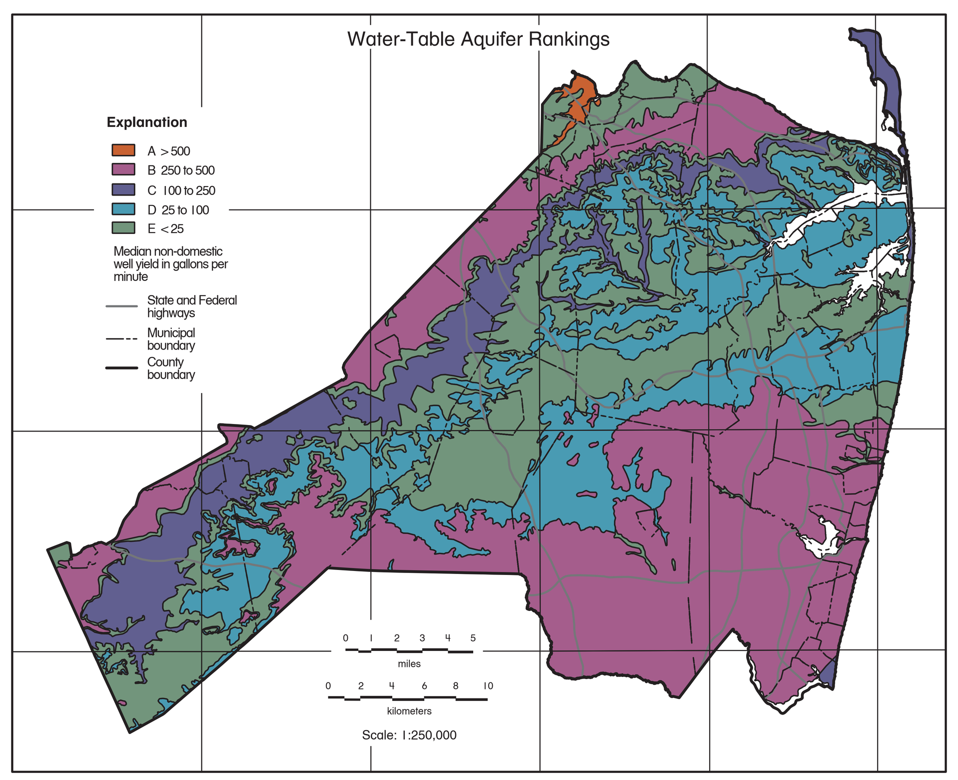
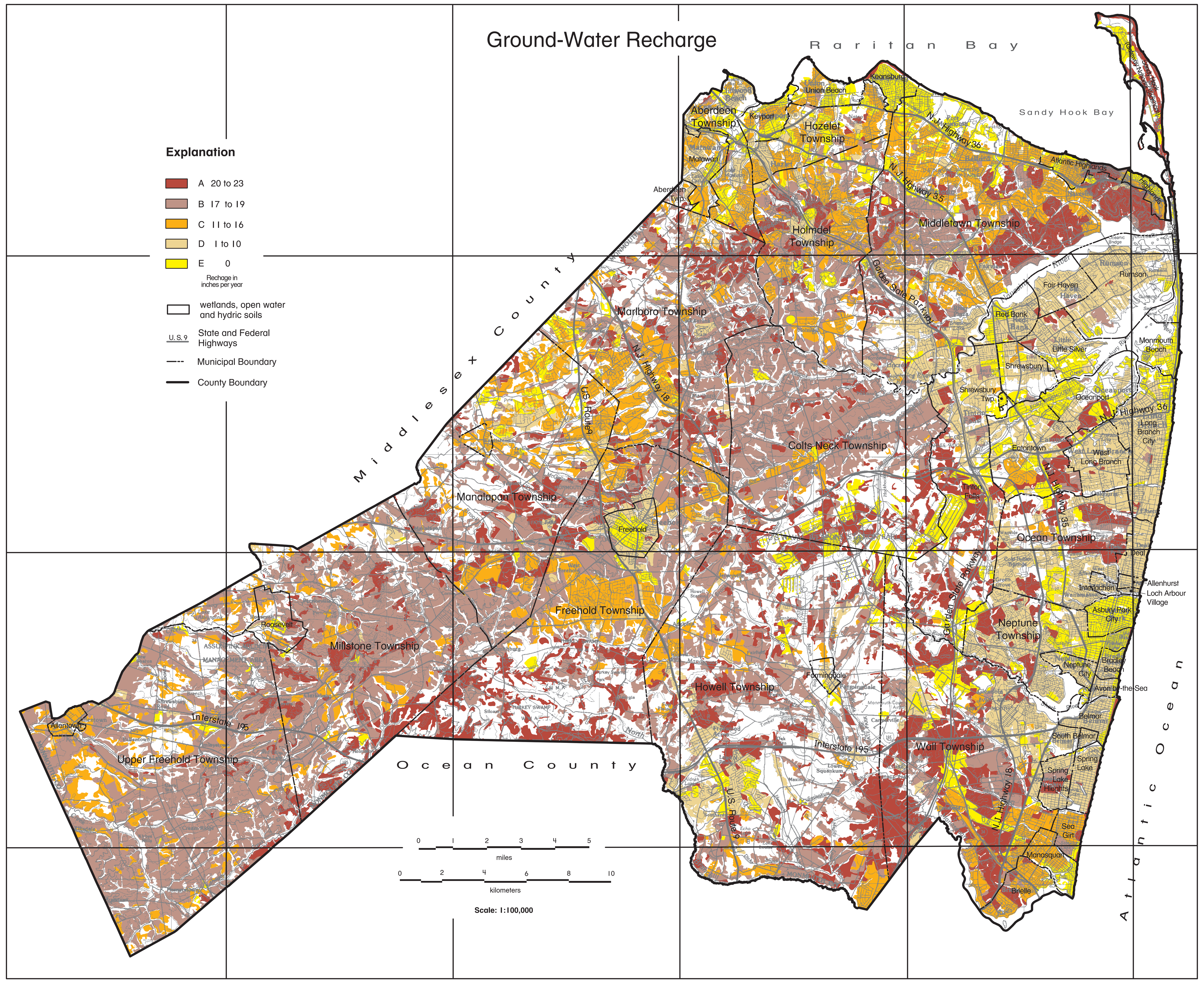
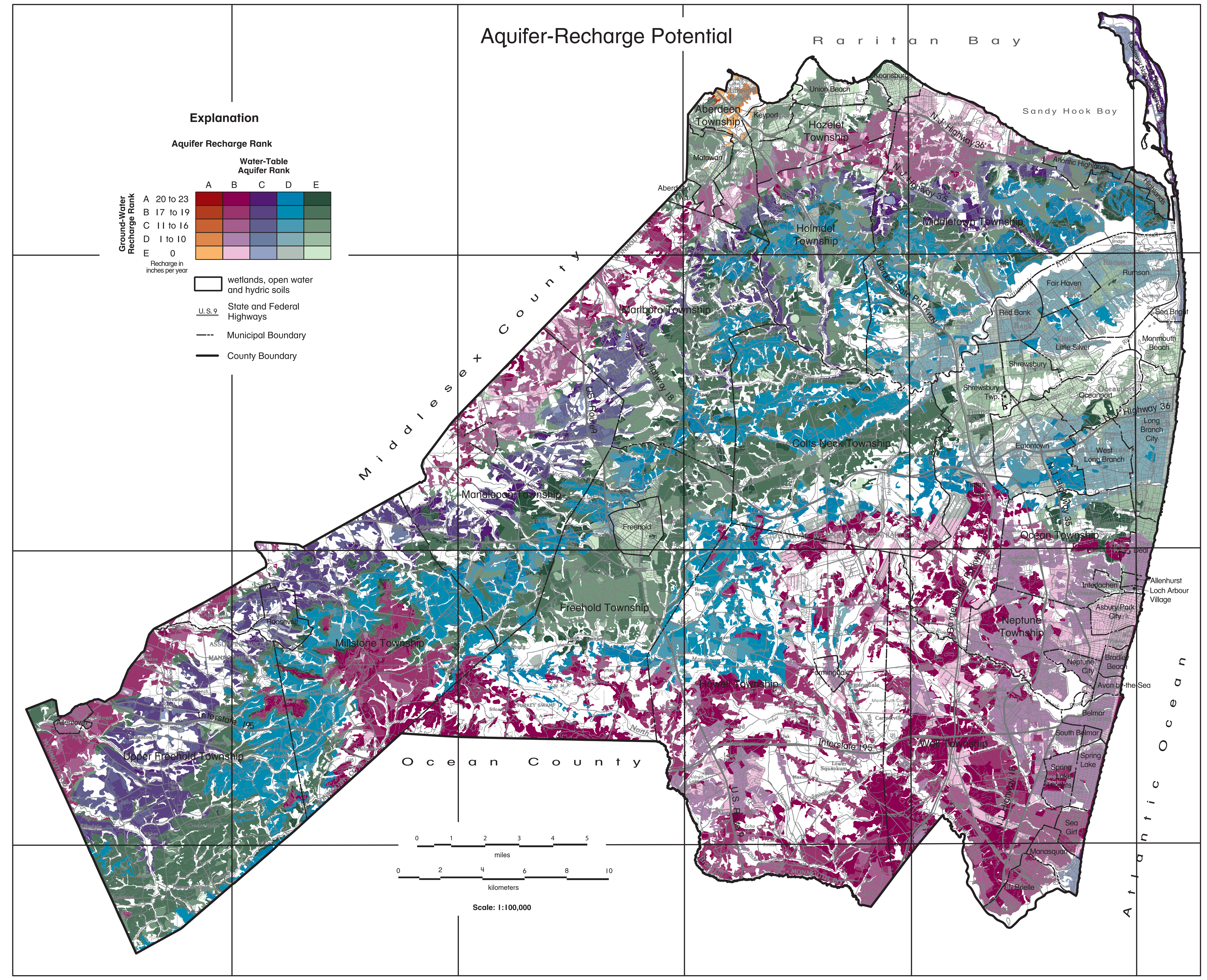




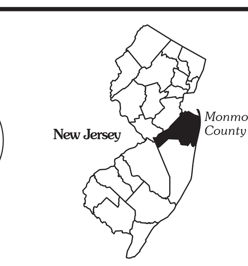






Ground-Water Recharge and Aquifer Recharge Potential for Monmouth County, New Jersey

by
Mark A. French
2003



Land Use and Land Cover Methodology

Land use and land cover (LULC) are important factors influencing ground-water recharge and must be classified in a manner that will be meaningful to ground-water recharge studies. A land use and land cover classification system that is specifically tailored for such studies was developed from a system outlined in the Soil Conservation Service's (SCS)[1] Technical Release 55 (TR-55) "Urban Hydrology for Small Watersheds" (U.S. Department of Agriculture, SCS[1], 1986). It is outlined in New Jersey Geological Survey (NJGS) Report GSR-32, "A Method for Evaluating Ground-Water-Recharge Areas in New Jersey" (Charles and others, 1993). This method uses a modification of the SCS approach that reduces the original 64 land use and land cover categories to 14 categories. This reduction reflects adjustment from transient land use and land cover conditions to average annual land use and land cover conditions, and limitations inherent in mapping from aerial photos with little field verification.

Land use and land cover (LULC) data for this map were produced by the Monmouth County Health Department using 1991, 7.5 minute, 1:24,000 scale orthophotoquads. The LULC data were produced on a geographic information system (GIS) using Mylar originals and digital images, and a combination of manual and heads-up or on-screen digitization. These data were completed in 1995 and reflect ground-conditions from 1991. The coding of LULC polygons was slightly modified from the NJGS scheme. This modification consisted of re-numbering the classification for Landscaped Open Space from "0" to "15" and adding the classification "999" for open water.

This data were then combined with the NJ Dept. of Environmental Protection (NJDEP) freshwater wetlands GIS data. The open water and wetlands areas were coded to classification "101" and the Landscaped Open Spaces were changed back to classification "0". Areas of less than five acres were then eliminated by combining them with adjacent, larger areas.

Ground-Water Recharge Methodology

Ground-water recharge is defined as water which infiltrates into the ground to a depth below the root zone. This definition does not differentiate between recharge to aquifers and recharge to non-aquifers. This methodology of calculating ground-water recharge is based on a monthly soil-water-budget approach. The following is excerpted from Charles and others (1993, p. 4-6) and is provided as background to explain the methodology used to construct the ground-water-recharge map.

"A soil-water budget estimates recharge by subtracting water that is unavailable for recharge (surface runoff and evapotranspiration) from precipitation (the initial budget amount). Any deficit in water storage in the unsaturated zone (soil-moisture deficit) must be made up before ground-water recharge can occur. The resulting equation is:

$$\text{recharge} = \text{precipitation} - \text{surface runoff} - ET - \text{soil-moisture deficit} \quad (1)$$

"Although recharge to ground water is a highly variable and complex process, a soil-water budget can account for the principal mechanisms and provide reasonable recharge estimates. Appendix 7 [in Charles and others, 1993] provides a comprehensive technical explanation of the data and calculations used to develop the method, and how the results were adapted for the mapping procedure. Briefly, the method was developed as follows:

"An expanded form of equation 1 was used to simulate monthly recharge for all reasonable combinations of climate, soil and land use and land cover found in New Jersey. Recharge was based on statewide ranges of precipitation and the principal factors that control surface runoff and evapotranspiration. Data on five environmental factors were necessary for the simulations: precipitation, soil, land-use/land-cover, surface runoff, and evapotranspiration.

"Daily precipitation data were selected from 32 of the 126 National Oceanic and Atmospheric Administration (NOAA) climate stations in New Jersey on the basis of their even geographic distribution and complete record. Thirty years of data were used in the simulations because it is the standard length of climate record for comparison purposes (Linsley, Kohler, and Paulhus, 1982).

"The soil data were hydrologic-soil group, soil type, depth and type of root barriers, and available water capacities. These were developed from a database of New Jersey soils maintained by the state SCS[1] office. These data were used in the surface runoff and evapotranspiration calculations. Land use and land cover is an important consideration that was used in both surface runoff and evapotranspiration calculations.

*"A land use and land cover classification of 14 categories * * * was designed specifically for this method. The classification system was derived largely from a system used in the Soil Conservation Service (SCS)[1] curve-number method for calculating runoff (U.S. Department of Agriculture, 1986). The number of categories was reduced to reflect useful long-term land-use distinctions and limitations inherent in mapping from aerial photos.*

*"Surface runoff was calculated using a modification of the SCS curve-number method. Because the curve-number method is designed for calculating runoff from the largest annual storms, adjustments were made so the results more accurately reflect runoff observed in New Jersey from smaller storms * * *. These adjustments are applicable only to recharge calculations and are important because frequent smaller storms contribute most of the long-term recharge.*

*"Evapotranspiration was computed for each of the 32 climate stations using a method developed by Thornthwaite and Mather (1957). Evapotranspiration calculations incorporated the effects of land-use/land-cover. Adjustments were made to the evapotranspiration results so they would more closely approximate evapotranspiration from naturally-watered, open, vegetated areas in New Jersey * * *.*

"The simulations showed that average annual recharge could be estimated on the basis of climate, soil characteristics and land use and land cover. The results were incorporated in a simple formula which allows one to calculate average annual recharge in inches per year from a climate factor (C-factor), a recharge factor (R-factor), a baseflow calibration factor (B-factor)[2], and a recharge constant (R-constant):

$$\text{annual ground-water recharge} = (\text{R-factor} \times \text{C-factor} \times \text{B-factor}) - \text{R-constant} \quad (2)$$

*"Climate factors were developed for every municipality * * *. Recharge factors and recharge constants * * * were developed for every possible combination of soil characteristics and land use/land cover found in New Jersey.*

*"There are four primary qualifiers of the method. First, the method estimates ground-water recharge (recharge to both aquifers and non-aquifers) rather than aquifer recharge. Second, a fundamental assumption when using a soil-water budget to estimate ground-water recharge is that all water which migrates below the root zone recharges ground water (Rushton, 1988). Third, the method addresses only natural ground-water recharge. Intentional and unintentional artificial recharge, withdrawals of ground water, and natural discharge are not addressed. Fourth, wetlands and water bodies are eliminated from the analysis before recharge mapping is begun. This is because the direction of flow between ground-water and surface water or wetlands depends on site specific factors and can also change seasonally * * *. Incorporating these complexities was beyond the resources of this study."*

This ground-water-recharge map was created using the method presented in Charles and others (1993), and modified for GIS implementation. The method requires information about 4 components: (1) land use and land cover, (2) soils, (3) municipal boundaries, and (4) wetlands and open water. Land use and land cover was mapped as indicated above. Soils were obtained from the 1993 county integrated terrain unit coverage of the county.

Municipal boundaries were taken from the 1987 municipality coverage in the NJDEP GIS database. This coverage was modified to include the municipal C-factors. Finally, wetlands and open-water were obtained from both the 1993 county integrated terrain unit and newly available 1991 freshwater wetlands coverages produced by MARKHURD, Inc. for the NJDEP. All four of these components were combined into one coverage.

The resultant data were then downloaded to a spreadsheet program and the R-factor and R-constant were determined by cross-referencing the soils and land use and land cover coding of each polygon. Recharge in inches per year was then calculated for each polygon using equation 2. The recharge values were ranked using volumetric ranking as described in Charles and others (1993). Each recharge rank represents 20% of the total recharge volume. Once the recharge was ranked these data were then uploaded and joined to the combined coverage. Like-ranked polygons were combined and shading applied. Wetlands, open water, and hydric soil polygons were not shaded.

Wetlands, Open Water and Hydric Soils

The unshaded areas on the map, which include wetlands, open water and hydric soils, were not ranked because their relationship with ground water cannot be determined using this approach. The ground-water-recharge model does not encompass the complexities of these areas. The direction of flow between ground and surface water or wetlands is dependent upon site specific variables which can change seasonally. Furthermore, hydric soils were not ranked because they are generally recognized as ground-water-discharge areas or areas of predominately saturated soils (Charles and others, 1993).

Therefore, wetlands, open water and hydric soils can be either recharge or discharge areas, both or neither, or neutral in relationship with ground water. This relationship depends upon many factors and may change unpredictably over the course of time. Site specific studies are required to determine the relationship to ground water for the areas of interest.

Aquifer Recharge Potential

Aquifer recharge or recharge to water-bearing geologic units is defined by this study as the ground water which reaches the water table in the uppermost geologic unit with a thickness of 50 feet or greater. The water-table aquifer rankings map was combined with the ground-water recharge map to produce a map of aquifer-recharge potential. This produced a composite ranking of 25 possible aquifer-recharge potentials which show the relationship between ground-water-recharge areas and the underlying water-table aquifer.

Ground-water-recharge rates vary independently across the underlying aquifers. High-ranked ground-water-recharge areas can be found on low-ranked aquifers. This indicates infiltration or recharge at higher rates than the aquifer can absorb. This excess recharge provides water to wetlands and for stream baseflow. When high-rank, ground-water-recharge areas are located over high-ranked aquifers, this indicates an area where recharge rates are matched more closely to the aquifer's ability to absorb this water and are indicative of important aquifer-recharge areas.

This map incorporates two additional assumptions besides those outlined in the ground-water-recharge methodology as presented by Charles and others (1993). These assumptions are: (1) Any lateral flow of ground water along boundaries of differing hydraulic conductivity has not been incorporated in this map. (2) The influence of topography on recharge is considered to have been addressed in the ground-water-recharge methodology as presented in Charles and others (1993).

Water Table Aquifer Rankings

For the purposes of this study water-table aquifer is defined as the first water-bearing geologic unit with a thickness of 50 feet or greater and is under unconfined conditions. The aquifers were defined using geologic and hydrogeologic data from Jablonski (1968), Pucci and others (1994), Newell and others (1995), Owens and others (1995), Stanford (1997), and Herman and others (1998).

To create a system to rank these aquifers the NJGS analyzed statewide aquifer and well data that included well yield, hydraulic conductivity, specific capacity, transmissivity, and storativity. Well-yield data from a high-yield subset of non-domestic wells were used because they provided the most comprehensive data and were the most representative of the potential water-yielding ability of the aquifer (Sloto and others, 1990). Well-yield data were obtained from NJGS project databases and from the USGS Ground Water Site Index (GWSI) database (Vowinkel and others, 1982). Statistical analysis showed that the median (a value, in an ordered set of values, below and above which there is an equal number of values) of the well yield could be used to adequately assess the aquifer. The ranges of yields for the rankings are selected based upon natural breaks in the data. These ranges were further refined after discussions with NJGS hydrogeologic staff. The five statewide rankings are as follows:

Aquifer Rank	Range of Median Yields
A	> 500
B	250 to 500
C	100 to 250
D	25 to 100
E	< 25

Discharge in gallons per minute

Once these ranges were established, statewide rankings were determined for each aquifer. If well-yield data were not available for an aquifer, it was ranked based upon its lithologic characteristics compared to the ranked aquifers, and the combined professional judgment of the NJGS geologic and hydrogeologic staff.

The relative rank of the aquifers in Monmouth County was created by retrieving well-yield data from the county and calculating the medians for each aquifer with three or more values. The statewide rankings were then applied to the results. All aquifers which did not have county well data were assigned the statewide rank. The following table contains the data used to rank Monmouth County's aquifers:

Monmouth County Aquifer Data Summary

Aquifer	Med. Well Yield (gpm)	No. of Values	Avg. Well Yield (gpm)	Aquifer Rank
Surficial sediments of the Coastal Plain (sscp)[6]	n/a	n/a	n/a	C
Kirkwood-Cohansey aquifer system (kcas)[4,5]	401	22	510	B
Composite confining unit (ccu)[4,5]	10	3	23	E
Composite confining unit aquifer (ccua)[4,5]	95	9	246	D
Mt. Laurel-Wenonah aquifer (mlwa)[4,5]	124	38	176	C
Marshalltown-Wenonah confining unit (mawc)[6]	n/a	n/a	n/a	E
Englishtown aquifer system (eas)[4,5]	300	85	303	B
Merchantville-Woodbury confining unit (mewcu)[6]	n/a	n/a	n/a	E
Potomac-Raritan-Magothy aquifer system (prma)[4,5]	712	132	737	A

4. water-table aquifers in outcrop area
5. also a confined aquifer
6. statewide data and rank

Aquifer Descriptions

The surficial sediments of the Coastal Plain (sscp) are unconsolidated sediments overlying Coastal Plain aquifers and confining units. These include Pleistocene beach, dune, deltaic, and marine sands, and recent alluvium. The sediments are hydraulically connected to the underlying aquifer and are considered a minor aquifer when they reach a thickness of 50 ft. or greater, or occur atop a confining unit. This unit only reaches sufficient thicknesses in two locations in the county: in the Sandy Hook area and the far southeastern corner. No well-yield data were available therefore, this aquifer was ranked based upon its lithologic characteristics and the judgment of the NJGS (Herman and others, 1998).

The Kirkwood-Cohansey aquifer system is composed of sand and gravel with lenses of silt and clay. The aquifer is the primary water-table aquifer in the southeastern part of the county. This aquifer is overlain by a thin veneer of the younger Coastal Plain surficial sediment. It is underlain by the confined parts of the composite confining unit and aquifers; the Manasquan Formation, Vincentown Formation, Hornerstown Sand, Tinton Sand, Red Bank Sand, and the Navesink Sand. The reported non-domestic yield of the aquifer ranges from 94 to 1200 gpm with a median yield of 401 gpm and an average yield of 510 gpm (Herman and others, 1998, Pucci and others, 1994, Jablonski, 1968).

The composite confining unit and composite confining unit aquifer are made up of silt and clay with localized sand lenses. Confining units include the Shark River, Manasquan, Hornerstown, and Tinton Formations, and the lower part (Sandy Hook Member) of the Red Bank Formation. The localized water-table aquifers, which are composed of massive quartz sand outcrop, include the Vincentown Formation and the upper part (Shrewsbury Member) of the Red Bank Formation. These aquifers grade into confining units southeast in the subsurface where the quartz sands become more glauconitic and silty. The outcrop area of these units runs northeast to southwest through the center of the county. These units dip to the southeastward where they are overlain by the Kirkwood-Cohansey aquifer system, and overlay the Mt. Laurel-Wenonah aquifer. Reported non-domestic median yield for the confining units is 10 gpm and 95 gpm for the aquifers portions. Average yields are 23 gpm and 246 gpm for the confining units and aquifers, respectively. Well yield ranges from 10 to 50 gpm for the confining units and from 20 to 900 gpm for the aquifers (Herman and others, 1998, Pucci and others, 1994, Jablonski, 1968).

The Mount Laurel-Wenonah aquifer is made up of glauconitic sand of the Mt. Laurel Sand overlying coarse-grained and micaceous sand portions of the Wenonah Formation. This aquifer outcrops in a relatively thin band running from the northeast to the southwest near the eastern edge of the county. It dips southeastward under the composite confining unit and aquifer and overlays the Marshalltown-Wenonah confining unit. The median and average well yield is 124 gpm and 176 gpm respectively with a range of 8 to 750 gpm (Herman and others, 1998, Pucci and others, 1994, Jablonski, 1968).

The Marshalltown-Wenonah confining unit is composed of the lower, poorly-sorted, fine-grained silty, glauconitic, and micaceous sand part of the Wenonah Formation and the glauconitic silt and sand of the Marshalltown Formation. This thin confining unit lies between the Mt. Laurel-Wenonah aquifer above and the Englishtown Aquifer below. It dips to the southeast and outcrops in a very thin band in the eastern part of the county running fromt the northeast to the southwest. No well-yield data were available therefore, this unit was ranked based upon its lithologic characteristics and the judgment of the NJGS (Herman and others, 1998, Pucci and others, 1994, Jablonski, 1968).

The Englishtown aquifer system in Monmouth County is made up of an upper and lower fine-to-medium grained, quartzose, well-sorted sand separated by thin, slightly-sandy or silty clay beds in the outcrop area which runs along the eastern edge of the county. It overlays the Merchantville-Woodbury confining unit. Median well yield was 300 gpm. Average well yield was 303 gpm. Maximum and minimum well yields were 1486 gpm and 10 gpm, respectively (Herman and others, 1998, Pucci and others, 1994, Jablonski, 1968).

The Merchantville-Woodbury confining unit is composed of the clayey silt, micaceous clay, and thin beds and lenses of glauconitic sand of the Merchantville Formation; and the micaceous clay of the Woodbury Clay. It may also contain the localized Cliffwood and Morgan beds, and the Amboy Stoneware Member of the upper Magothy Formation. It forms the most massive confining unit of the Coastal Plain. It outcrops in the northwest corner of the county and dips southeastward under the Englishtown aquifer system. It overlies the important Potomac-Raritan-Magothy aquifer system. No well-yield data were available therefore, this unit was ranked based upon its lithologic characteristics and the judgment of the NJGS (Herman and others, 1998, Pucci and others, 1994, Jablonski, 1968).

Potomac-Raritan-Magothy aquifer system is interbedded sand, gravel, silt, and clay separated into lower, middle and upper aquifers. It includes the Raritan confining unit composed of interbedded sand, silt, and clay. The upper aquifer is made up primarily of the Old Bridge Sand Member of the Magothy Formation and includes the Sayreville Sand Member where the intervening South Amboy Fire Clay is thin or absent. This part of the aquifer outcrops in the northwest corner of the county. The middle aquifer is made up of the Farrington Sand Member of the Raritan Formation and is separated from the upper aquifer by the Woodbridge Clay Member. This aquifer overlies either pre-Cretaceous bedrock, or the Raritan Fire Clay Member which makes up the confining unit of the lower aquifer. This lower aquifer is made up of the fine-grained sediments of the Potomac Group. Neither the middle or lower aquifer outcrops in the county, but are present in the subsurface. The entire aquifer system dips southeastward under the overlying aquifers and confining units. Median and average well yields were 712 and 737 gpm, respectively. Minimum yields were 40 gpm and maximum yields were 1760 gpm. (Herman and others, 1998, Pucci and others, 1994, Jablonski, 1968).

Recharge to confined aquifers in Monmouth County occurs either in the outcrop zone or as leakage from overlaying aquifers.

Acknowledgements

The following individuals and organizations are acknowledged for their assistance in the development of this map: Robert Canace, Jeffrey Hoffman, Gregory Herman, Richard Dalton, William Graff, Thomas Seckler, Scott Stanford, Ronald Pristas, Maryann Scott, formerly of the N. J. Geological Survey; Emmanuel Charles of the U. S. Geological Survey; Robert Berardo and the Staff of the Monmouth County Health Dept., and the staff of the NJDEP Bureau of Geographic Information Analysis.

Glossary of selected terms

Aquifer: a geologic formation, part of a formation or group of formations that can supply useable quantities of water to wells.

Aquifer recharge: the process of addition of water to an aquifer through infiltration.

Aquifer-recharge area: the land surface area that allows recharge to an aquifer.

B-Factor: a calibration constant developed by the NJGS to calibrate ground-water-recharge estimates to statewide, stream-baseflow-based recharge estimates. B-factor is used in a formula, in conjunction with C-factor, R-factor, and R-constant, to yield an estimate of average annual ground-water recharge.

Baseflow: that part of stream flow (discharge) derived from ground water seeping into the stream.

C-factor: a climate-sensitive constant developed by NJGS that consists of the ratio of average annual precipitation to the average annual (simulated) potential evapotranspiration. C-factor is used in a formula, in conjunction with B-factor, R-factor and R-constant, to yield an estimate of average annual ground-water recharge.

Evapotranspiration (ET): loss of water from a land area through transpiration from plants and evaporation.

Geographic Information System (GIS): a computer-based, integrated spatial and tabular database used for spatial analysis, data storage and query, and computer-assisted mapping.

Ground water: subsurface water that is in the saturated zone.

Ground-water recharge: the process of addition of water to the saturated zone.

Ground-water-recharge area: the land surface area that allows recharge to the saturated zone.

Infiltration: the downward movement of water into and through soil.

Polygon: an enclosed area on a map which has information associated with it.

R-constant: a land-use/land-cover and soil-group dependent constant developed by NJGS. R-constant is used in a formula, in conjunction with B-factor, C-Factor and R–factor, to yield an estimate of average annual ground-water recharge.

R-factor: a land-use/land-cover and soil-group dependent factor developed by NJGS. R–factor is used in a formula, in conjunction with B-factor, C-Factor and R-constant, to yield an estimate of average annual ground-water recharge.

Rank: a label that establishes a relative position for example "very high," "high," "moderate," "A," "B," "C," etc.

Root zone: the zone from the land surface to the maximum depth penetrated by plant roots.

Saturated zone: a subsurface zone in which all voids are filled with water.

Soil-water budget: an accounting of the water flow in and out of a soil unit by calculation of precipitation, surface runoff, evapotranspiration and changes in soil-moisture. In a soil–water budget the excess of water can be considered available for ground-water and aquifer recharge.

Selected References

Anderson, J. R., Hardy, E. E., Roach, J. T., and Witmer, R. E., 1976, A Land Use and Land Cover Classification System for Use with Remote Sensing Data: U. S. Geological Survey Professional Paper 964.

Charles, E. G., Behroozi, C., Schooley, J., and Hoffman, J. L., 1993, A Method for Evaluating Ground–Water-Recharge Areas in New Jersey: N. J. Geological Survey Report GSR 32, 95 p.

Daniel, C. C., III, 1989, Statistical Analysis Relating Well Yield to Contruction Practices and Siting of Wells in the Piedmont and Blue Ridge Provinces of North Carolina: U. S. Geological Survey Water-Supply Paper 2341, pp. A13-A22.

Herman, G. C., Canace, R., French, M. A., Hoffman, J. L., Mennel, W. J., Pristas, R. S., Sugarman, P. J., and Stanford, S. D., 1998, Aquifers of New Jersey: N. J. Geological Survey Open File Map OFM–24, 1:100,00 map.

Hoffman, J., L., 1999, Basin-Factor Calibration for Ground-Water-Recharge Estimation (Addendum to Charles and others, 1993, A Method for Evaluating Ground-Water Recharge-Areas in New Jersey): N. J. Geological Survey Technical Memorandum TM99-1, 2 p.

Jablonski, L. A., 1968, Ground-Water Resources of Monmouth County N. J.: N. J. Dept. of Conservation and Economic Development Special Report 23, 114 p.

Linsley, R. K., Kohler, M. A., and Paulhus, J. L. H., 1982, Hydrology for Engineers (3rd ed.): New York, McGraw-Hill, 508 p.

Newell, W. L., Powars, D. S., Owens, J. P., Schindler, J.S., 1995, Surficial Geologic Map of New Jersey: Southern Sheet: U. S. Geological Survey Open File Report 95-272, 1:100,000 map.

Owens, J. P., Sugarman, P. J., Sohl, N. F., Parker, R. A., Houghton, H. F., Volkert, R. A., Drake, A. A. Jr., and Orndorff, R. C., 1995, Bedrock Geologic Map of Central New Jersey: U.S. Geological Survey Open-File Report 95-253, 1:100,000 map

Pucci, A. A., Pope, D. A., Gronberg, J. M., 1994 Hydrogeology, Simulation of Regional Ground-Water Flow and Saltwater Intrusion, Potomac-Raritan-Magothy Aquifer System, Northern Coastal Plain of New Jersey: N. J. Geological Survey Report GSR 36, 209 p.

Rushton, K. R., 1988 Numerical and Conceptual Models for Recharge Estimation in Arid and Semi-Arid Zones, in Simmers, I., ed., Estimation of Natural Groundwater Recharge: Boston, D. Reidel Publishing, pp. 223-238

Sloto, R. A., Cecil, L. D., Senior, L. A., 1991, Hydrogeology and Ground-water Flow in the Carbonate Rocks of the Little Lehigh Creek Basin, Lehigh County, Pennsylvannia: U. S. Geological Survey Water–Resouces Investigations Report 90-4076, pg. 15.

Thornthwaite, C. W., and Mather, J. R., 1957, Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance: Publications in Climatology, v. 10, no. 3, pp. 185-311

U. S. Department of Agriculture, Soil Conservation Service[1], 1986, Urban Hydrology for Small Watersheds (2nd ed.): Soil Conservation Service Technical Report 55.

Vowinkel, E. F., Daniels, R., Brown, P. H., and Ryan, J. J., 1982, Ground-Water Site Inventory [GWSI], User's Guide, U.S. Geological Survey Water Resources Division, New Jersey District, Trenton, N.J., 28 p

[1] The Soil Conservation Service (SCS) has been renamed the Natural Resources Conservation Service (NRCS).

[2] Studies by the NJGS indicate that a baseflow calibration factor or basin factor (b-factor) may be required. A basin factor of 1.0 was used for this map. The basin factor is explained in Charles et. al., 1993, "A Method for Evaluating Ground-Water-Recharge Areas in New Jersey" and NJGS Technical Memorandum TM99-1 "Basin Calibration for Ground-Water Recharge Estimation (Addendum to Charles et al., 1993)."