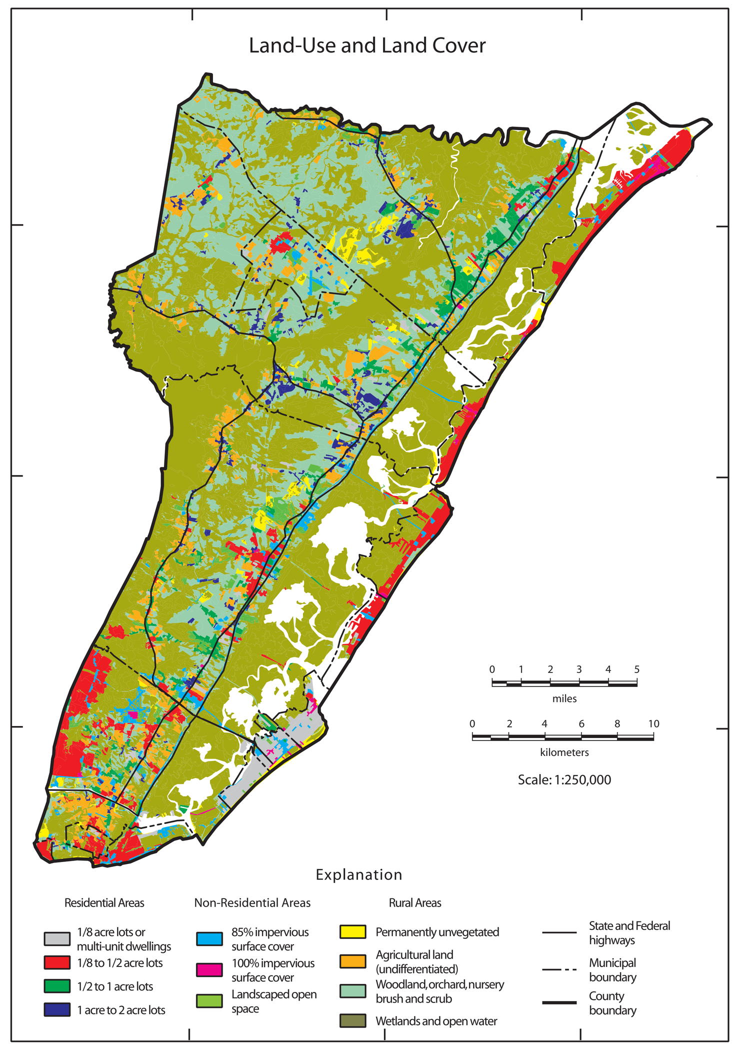

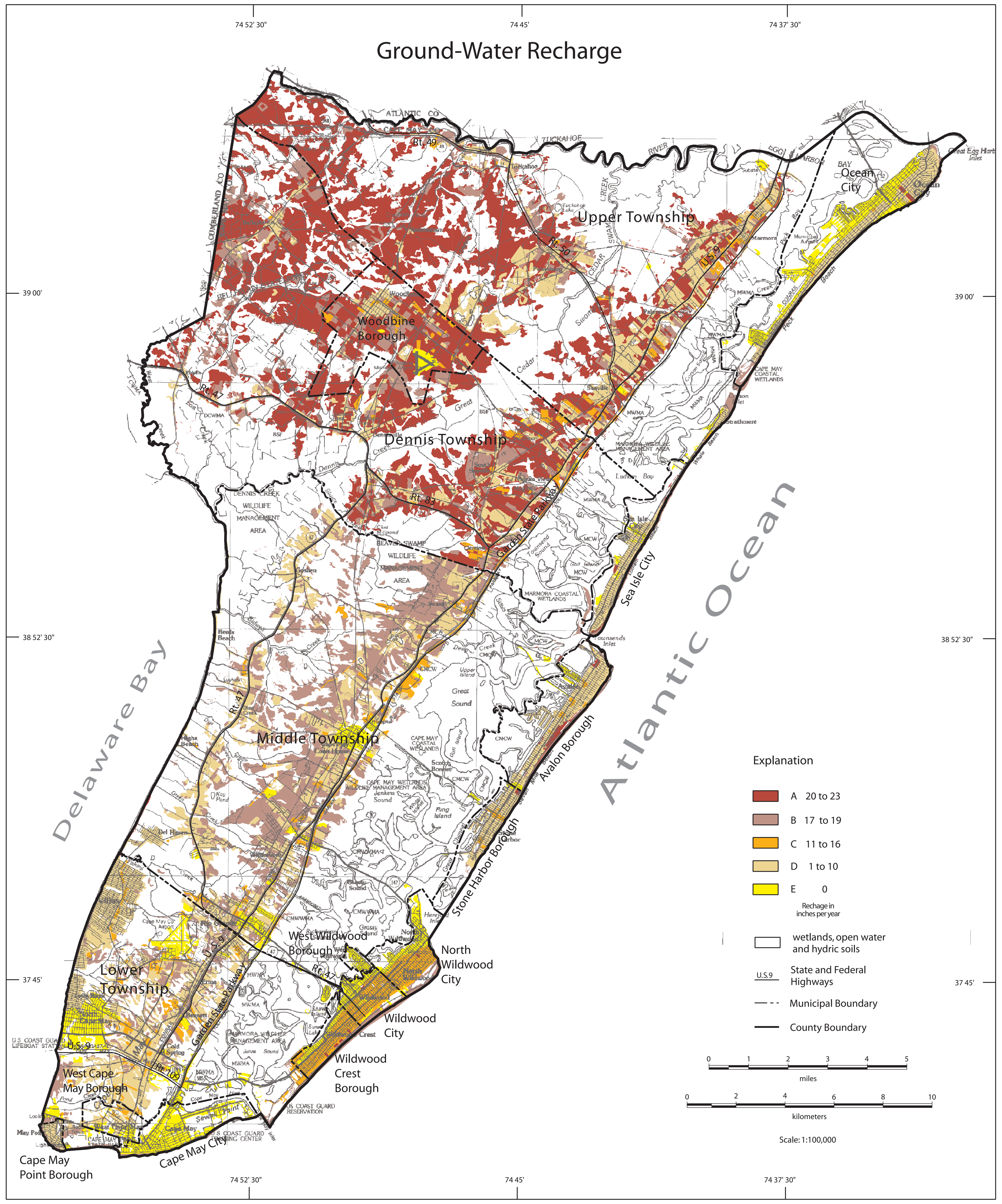

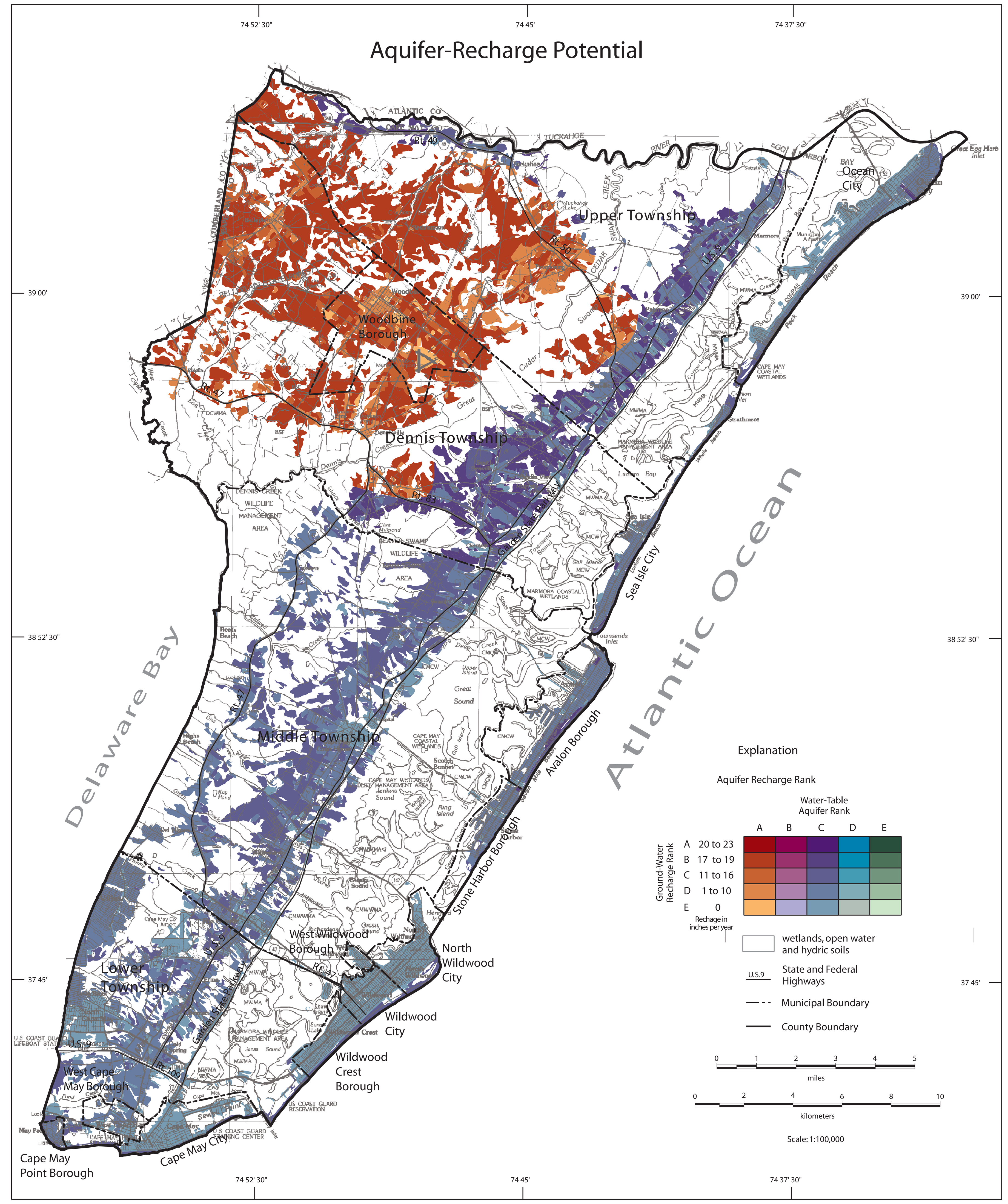

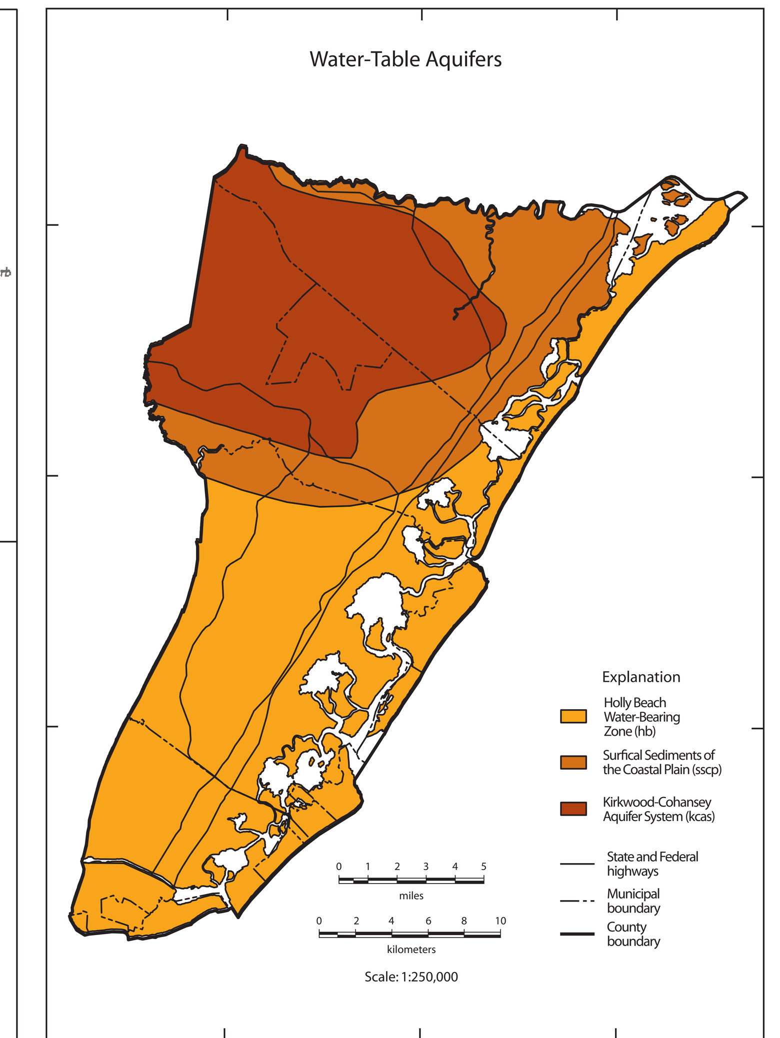

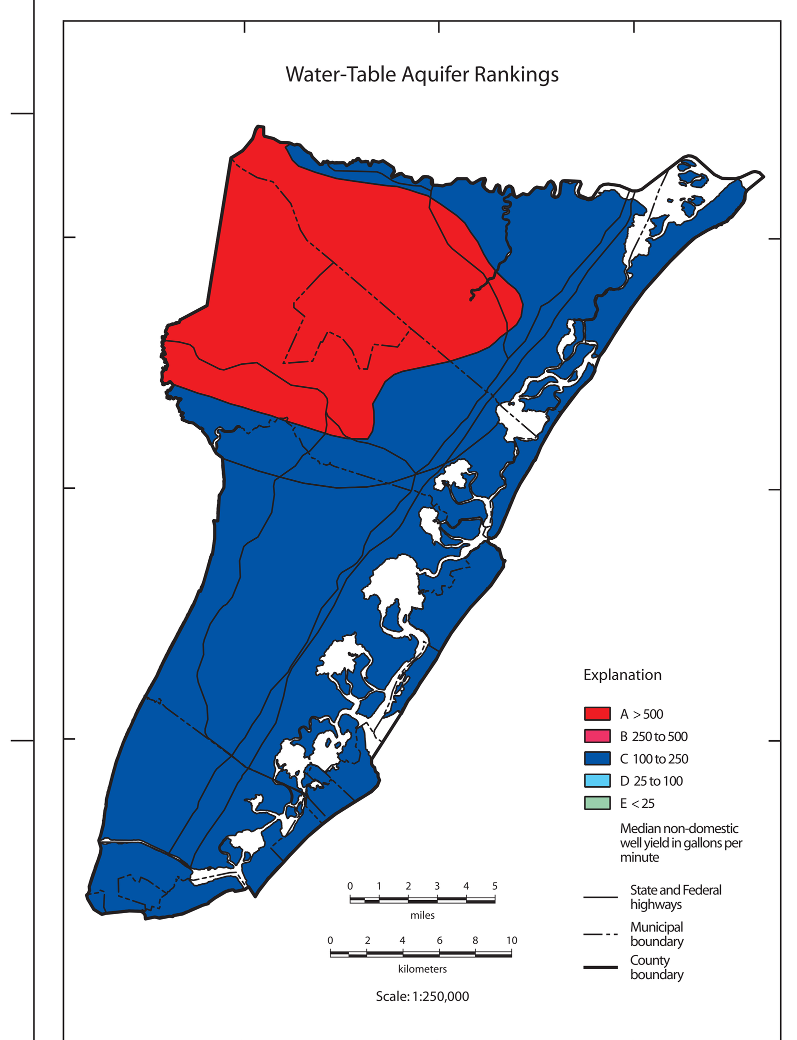

Ground-Water Recharge and Aquifer Recharge Potential for Cape May County, New Jersey

by

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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 classification 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). This system 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). The method uses a modification of the SCS approach that reduces the original 64 land use and land cover categories to 14 catagories. 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. Ten of the 14 categories of the NJGS system were used to classify the land use and land cover in Cape May County. The land use and land cover map was produced using the methodology outlined in Charles and others (1993) and modified for implementation on a geographic information system (GIS).

Land use and land cover are also components of the 1993 Cape May County integrated terrain unit (ITU) GIS coverage, produced for the New Jersey Department of Environmental Protection (NJDEP) by Environmental Systems Research Institute, Inc. The land use and land cover coverage extracted from the integrated terrain unit uses a modified U. S. Geological Survey (USGS) land use and land cover classification system (Anderson, and others, 1976), and reflects field conditions from 1986. This classification system is generally different than the one used by the NJGS. Many of the USGS categories correlate to NJGS categories which allows a partial translation between the two schemes.

The residential, industrial, commercial, institutional, and mixed use areas did not correlate between the two systems. The residential areas in the USGS system were mapped to a single category (Residential) while the industrial, commercial, institutional, and mixed use areas were mapped to multiple categories (Commercial and Service, Industrial, Transportation, Communication and Utilities, Industrial and Commercial Complexes, Mixed Urban or Built Up, Other Urban or Built Up). The NJGS scheme required the following four residential categories: 65% impervious cover (1/8 acre lots or multi-family dwelling units); 33% impervious cover (greater than 1/8 acre up to and including 1/2 acre lots); 23% impervious (greater than 1/2 acre up to and including 1 acre lots); and 17% impervious (greater than 1 acre up to and including 2 acre lots). The industrial, commercial, institutional, and mixed use areas only required 2 categories: Landscaped commercial/industrial/institutional/mixed-use areas (approximately 85% impervious); and Unlandscaped commercial/industrial/ institutional/ mixed-use areas (approximately 100% impervious). Without direct correlation between the two systems, it was necessary to translate these areas to two polygons with generic codes.

Mylar overlay maps were produced at 1:24,000 scale for each USGS 7.5 minute quadrangle of Cape May County. NJGS staff remapped the residential areas and industrial, commercial, institutional, and mixed use areas to the NJGS system using the 1991 orthophotoquadrangles. All other areas were checked against the same orthophotoquads. As advised in Charles and others (1993), only areas of five acres and greater were mapped. Areas were field checked when land use and land cover was unable to be determined from the photoquads. The changes were then digitized for each quadrangle and compiled to produce the land use and land cover coverage.

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 method 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 basin factor (B-factor) and a recharge constant (R-constant):

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

"The basin factor (B-factor), a constant of 1.3[2], was assigned by calibrating predicted volumetric ground-water recharge to reported basin wide stream baseflow values.

*"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 combined-coverage 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 this data was 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.

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

[2] Subsequent studies by the NJGS inidicate that the baseflow calibration factor or basin factor (b-factor) is too high. A basin factor of 1.0 should be used. This new b-factor was used to produce ground-water-recharge estimates for this map. This change is explained in NJGS Technical Memorandum TM99-1 "Basin Calibration for Ground-Water-Recharge Estimation (Addendum to Charles et. al., 1993, "A Method for Evaluating Ground-Water-Recharge areas in New Jersey)".

Glossary of selected terms

Aquifer: a geologic formation, part of a formation or group of formations that can supply economic 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: loss of water from a land area through transpiration from plants and evaporation from the soil.

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 recharge.

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 the 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 Gill (1962), Herman and others (1998), Owens and others (1995), Stanford (1997), based upon Newell and others (1995).

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 Cape May 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 Cape May county's aquifers:

Cape May County Aquifer Data Summary

Aquifer	Med. Well Yield (gpm)	No. of Values	Avg. Well Yield (gpm)	Aquifer Rank
Holly Beach Water-Bearing Zone[1]	100	10	110	C
Estuarine Sand	250	12	360	C
Kirkwood-Cohansey[1, 2]	500	50	514	A
Rio Grande Water-Bearing Zone (Upper Kirkwood Sand)	300	5	460	B
Atlantic City 800 Ft. Sand (Lower Kirkwood Sand)	700	40	579	A

[1] water-table aquifers
[2] also a confined aquifer in places

The Coastal Plain surficial sediments 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. 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 Holly Beach water-bearing zone is a water-table aquifer composed of sand and gravel, with minor silt and clay deposits. It includes alluvium, beach, dune, deltaic, and marine sands. The Holly Beach is underlain by the Estuarine Clay confining unit and the Estuarine Sand aquifer in the southern part of the county and by the Kirkwood-Cohansey aquifer in the north. Water is available from primary intergranular porosity and permeability. The reported yield from non-domestic wells completed in the aquifer ranges from 15 to 302 gpm with a median value of 100 gpm and an average yield of 110 gpm (Herman and others, 1998).

The Kirkwood-Cohansey water-table aquifer in Cape May County is composed of sand and gravel with lenses of silt and clay. The aquifer is the primary water-table aquifer in northern Cape May County. This aquifer is confined in southern Cape May County by the overlaying Estuarine Clay unit. It is underlain by the confined Kirkwood aquifers; the Rio Grande water-bearing zone and the Atlantic City 800-foot sand. Water is available from primary intergranular porosity and permeability. The reported non-domestic yield of the aquifer ranges from 10 to 1500 gpm with a median yield of 500 gpm and an average yield of 514 gpm (Herman and others, 1998).

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

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