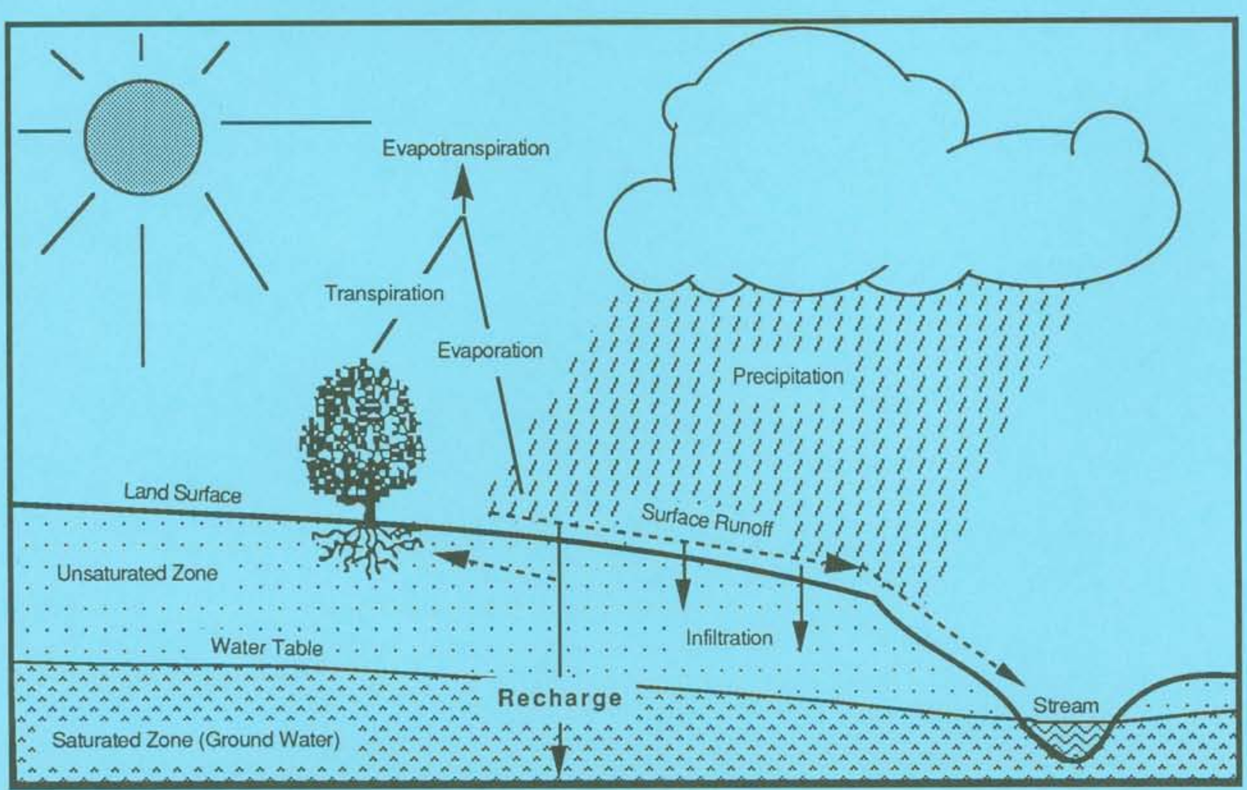
New Jersey Geological Survey
Geological Survey Report GSR-32

A METHOD FOR EVALUATING GROUND-WATER-RECHARGE AREAS IN NEW JERSEY



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Cover illustration: The hydrologic cycle. Precipitation runs off to surface water, evaporates, or infiltrates into the ground. Some of the water which infiltrates into the ground is returned to the atmosphere by evaporation from the soil and transpiration by plants. The rest recharges ground water by percolating downwards to the saturated zone.

New Jersey Geological Survey
Geological Survey Report GSR-32

A Method for Evaluating Ground-Water-Recharge Areas in New Jersey

by
Emmanuel G. Charles, Cyrus Behroozi,
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New Jersey Department of Environmental Protection and Energy
Division of Science and Research
Geological Survey
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CONVERSION FACTORS

For the convenience of the reader, units used in this report may be obtained or converted using the following factors:

Multiply	by	to obtain
inch (in.)	0.08333	foot (ft.)
inch (in.)	2.540	centimeter (cm)
acre	43,560	square feet ($ft.^2$)
square inch ($in.^2$) on 1:24,000 scale map	91.83	acres
square mile ($mi.^2$)	640	acres
cubic inch ($in.^3$)	0.0005787	cubic foot ($ft.^3$)
cubic foot ($ft.^3$)	7.481	gallons
area (acres) x recharge (inches/year)	27,156	gallons/year
map ($in.^2$) x recharge (inches/year)	2,493,667	gallons/year
degrees Fahrenheit (°F)	°C = (°F - 32) x 0.5555	degrees Celsius (°C)
degrees Celsius (°C)	°F = 1.8 x °C + 32	degrees Fahrenheit(°F)

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Jeanne M. Fox
Commissioner

Haig F. Kasabach
State Geologist

Dear User:

The purpose of "A Method for Evaluating Ground-Water-Recharge Areas in New Jersey" is to provide municipalities in New Jersey a means to assess ground-water-recharge areas and rank their importance as required by N.J.S.A. 58:11 A, 12-16 et seq. The maps produced using the methodology show land areas of similar recharge characteristics and their relative contribution to the overall amount of recharge. The quantity and quality of ground-water recharge can be managed largely by wise use of the land through which it is replenished. Thus the effect of present or future land uses on recharge in the study area can be evaluated and considered in land-use planning.

We have attempted to make the procedures and explanations in this methodology as clear and user friendly as possible. This is part of the New Jersey Geological Survey's continuing effort to provide the best possible assistance on ground-water issues to government and the public.

Haig F. Kasabach
State Geologist

ABSTRACT

The purpose of this method is to provide municipal planners with a means to make ground-water-recharge maps that can be used in their planning decisions. Awareness of ground-water-recharge areas is important because land use and land cover have a large effect on the recharge that is necessary for most water supplies, wetlands and surface-water bodies. The recharge maps can be used to help decide where, how, and to what extent to develop land.

The method estimates ground-water recharge rather than aquifer recharge. Ground-water recharge includes, but does not distinguish between, recharge to aquifers and non-aquifers. Application of this method does not require specialized equipment or specialized training in hydrology or mapping.

Because in New Jersey recharge occurs throughout much of the land area, soil-water budgets were used to simulate recharge for all combinations of soil, land use/land cover, and climate based on the equation:

recharge = precipitation - surface runoff - evapotranspiration - soil-moisture deficit

These simulations showed that estimates of long-term recharge could be made using factors developed for climate, soil, and land-use/land-cover. The method utilizes tables of climate factors, recharge factors, basin factors, and recharge constants in a simple recharge formula that can be applied to any combination of soil, climate, and land-use/land-cover:

recharge = (recharge-factor x climate-factor x basin-factor) - recharge-constant

To prepare a recharge map, the study area is divided into parcels using county soil surveys and land-use/land-cover mapped according to categories developed for use in estimating recharge. Then the appropriate recharge-factor and recharge-constant are read from the tables and assigned to each parcel. Finally, recharge (inches/year) is calculated by using the recharge factor, recharge constant, basin factor, and a municipal climate-factor in the recharge formula. Recharge (or discharge) from surface-water bodies, wetlands and hydric soils are not evaluated using the method. These areas are eliminated from the assessment.

The basin factor is used to calibrate calculated volumetric recharge against basin-wide stream baseflow estimates. The basin factor that results in the most satisfactory calibration for the basins tested is 1.3. Further research may define separate basin factors for different watersheds.

Instructions are given for ranking the ground-water-recharge areas. The recommended procedure is based on the actual quantity of ground-water recharge within the study area. The ranking scheme (for example, high, moderate, low) is designed to adapt to any study area and any set of ground-water protection practices.

A METHOD FOR EVALUATING GROUND-WATER-RECHARGE AREAS IN NEW JERSEY

I. BACKGROUND

Introduction

State legislation (NJSA 58:11A,12-16, *et. seq.)* requires the Department of Environmental Protection and Energy (DEPE) to publish a methodology to map and rank aquifer-recharge areas. In addition, the legislation (appendix 1) requires the DEPE to publish ground-water protection practices designed to encourage ecologically sound development in aquifer-recharge areas. DEPE must also publish and periodically update aquifer-recharge maps of the state.

The New Jersey Geological Survey (NJGS) has undertaken two tasks in response to the legislation. The first, presented in this report, is to develop and publish a methodology that will enable municipalities to map and rank land areas according to their ability to transmit water to the subsurface. The second is to produce aquifer-recharge maps of the entire state.

The procedures in this report are for estimating ground-water recharge (the volume of water transmitted to the subsurface through soils) rather than aquifer recharge (recharge to geologic formations which can yield economically significant quantities of water to wells or springs). Ground-water recharge is critical to aquifers, wetlands, streams, and lakes. The method is thus useful for evaluating the effect of present and future land uses on these resources. In addition, ground-water recharge values are being used in conjunction with maps of the water-transmitting characteristics of geologic formations to prepare aquifer-recharge maps.

The procedure developed by the NJGS is designed for application by municipalities as part of their land-use planning. A primary consideration was that the method should not require advanced knowledge of hydrology or mapping, but still provide a reliable assessment of recharge. The method is designed for use by environmental planners, environmental scientists, and engineers. The ground-water-recharge maps that result are to be used at the discretion of municipalities and as one of many considerations in land-use planning. Because the quantity and quality of ground-water recharge can be managed largely by wise use of the land through which it occurs, the recharge maps should be used in conjunction with ecologically sound land-use regulations or ground-water protection practices.

This background section presents an overview of ground-water-recharge concepts, reviews the requirements for the method, and then describes the method chosen. Instructions for estimating recharge and producing ground-water-recharge-area maps follow in Section II. Guidance for classifying and ranking the recharge areas on the map is given in Section III. Section IV discusses the limitations of the methodology that should be considered when using the recharge maps. Understanding and applying sections I through IV do not require an advanced knowledge of hydrology and mapping. A glossary is included to explain the necessary terminology. The appendixes contain data required in the mapping procedure and additional technical documentation.

Acknowledgements

We gratefully acknowledge the exceptional assistance that Daryl Lund, Jack Tibbetts, and Paul Welle of the Soil Conservation Service provided throughout the development of this method. Rich Volkert of NJGS also provided valuable technical assistance. This document benefited from reviews by Suzanne Hess and Caroline Swartz of the Hunterdon County Planning Board, Richard Guilick of the Randolph Township (Morris County) Planning Office, Ken Lechner of Franklin Township (Gloucester County) Department of Planning and Zoning, Glenn Carter of the Plainsboro Township (Middlesex County) Department of Community Development, and Otto Zapecza and Gregory McCabe, Jr., of the United States Geological Survey.

We acknowledge valuable conceptual discussions with William Alley, Scott Andres, Jim Boyle, Robert Canace, Fred Charles, Rick Clawges, Wayne Hutchinson, Laura Nicholson, Ron Taylor and Ron Witte. Valuable assistance with developing the application methodology came from Gail Carter, Mark French, Bill Graff, Evelyn Hall, Ron Pristas and Terry Romagna. Special thanks to Dan van Abs, Jim Gaffney, and the Cook College Office of Continuing Education for oportunity to test and refine the application through a short course. Useful literature for the project was suggested or supplied by Maria Baratta, Dorothy McLaughlin Alibrando, George Blyskun and Don Cramer. Editing by Butch Grossman greatly clarified the document.

Ground-water-recharge concepts

The principal processes that affect ground-water recharge can be summarized by tracing the path that water from precipitation would take (fig. 1). The potential for natural ground-water recharge begins with precipitation (rain, snow, hail, sleet). Some of the precipitation never seeps into the soil, but instead leaves the system as surface runoff. The water that seeps into the soil is infiltration. Part of the water that does infiltrate is returned to the atmosphere through evapotranspiration. Evapotranspiration refers to water that is returned to the atmosphere from vegetated areas by evaporation from the soil and plant surfaces (dew and rain) and soil water that is taken up by plant roots and transpired through leaves or needles. Infiltrated water that is not returned to the atmosphere by evapotranspiration moves vertically downward and, upon reaching the saturated zone, becomes ground water. This ground water could be in geologic material that is either an aquifer or non-aquifer, depending on whether it can yield satisfactory quantities of water to wells.

Many climate, soil, and vegetation factors influence the processes that control ground-water recharge. The most important climatic factors are the amount, intensity, and form of precipitation. Climate also influences recharge through the effect of wind, humidity, and air temperature on evapotranspiration. Soil properties are decisive factors in the recharge process. These properties exert strong control on permeability, water-holding capacity, water content prior to a precipitation event, and depth of plant roots (Balek, 1988). In addition, land use and land cover affect the surface condition of the soil, which can enhance or reduce infiltration. Under conditions prevalent in New Jersey, slope of the land surface does not have a significant affect on the total volume of surface runoff and infiltration, but does affect the rate of surface runoff and peak discharge (Paul Welle, U.S. Department of Agriculture, Soil Conservation Service, oral communication, July 26, 1990). The type of vegetation influences recharge through its effects on evapotranspiration, interception of precipitation, and surface runoff.

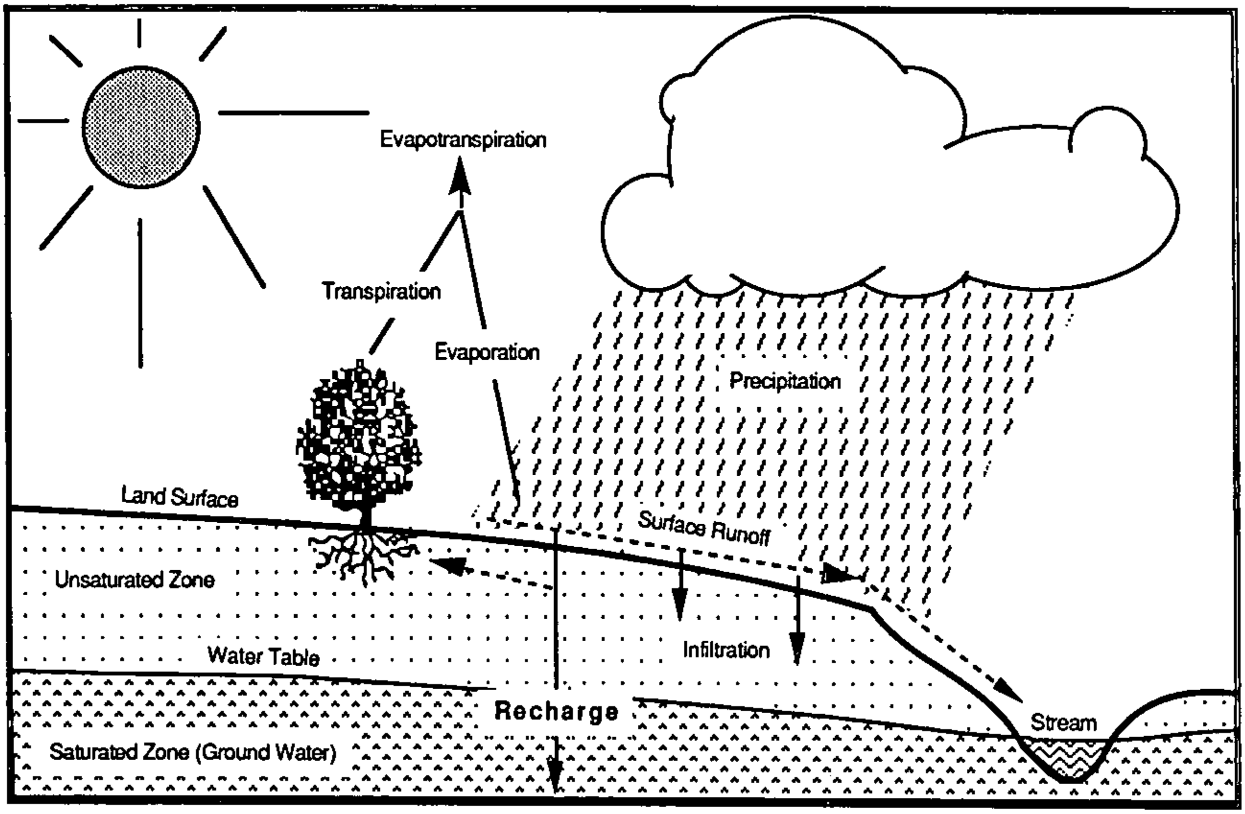


Figure 1. Ground-water recharge in the hydrologic cycle.

Development of the method

A primary consideration in developing the method was that it provide a reliable estimate of ground-water recharge without requiring an advanced knowledge of hydrology or mapping. In addition, the approach was to use readily available equipment and data. Maps produced by the method should be at a large enough scale to clearly delineate a few acres, and also should indicate areas of similar recharge characteristics and their relative contribution to long-term recharge. This is because the method may be used to help decide between alternative development plans, and because land development is long-lasting and maintenance of recharge is a long-term concern.

These requirements were met using a soil-water budget as the basis for recharge calculations. 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:

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

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 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/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 office. These data were used in the surface runoff and evapotranspiration calculations.

Land-use/land-cover is an important consideration that was used in both surface runoff and evapotranspiration calculations. A land-use/land-cover classification of 14 categories (appendix 2) was designed specifically for this method. The classification system was derived largely from a system used in the Soil Conservation Service (SCS) 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 (appendix 7). 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 (see appendix 7).

The simulations showed that average annual recharge could be estimated on the basis of climate, soil characteristics and land-use/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):

annual ground-water recharge = (R-factor x C-factor x B-factor) - R-constant (2)

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

Climate factors were developed for every municipality (appendix 6). Recharge factors and recharge constants (appendixes 4, 5 and 6) were developed for every possible combination of soil characteristics and land use/land cover found in New Jersey.

A user can conveniently carry out the procedure either manually or with a Geographic Information System (GIS). The procedures are designed to be applied at the 1:24,000 scale. First, maps are prepared showing land-use/land-cover according to the categories in appendix 2 and soil units based on SCS data. These two maps are combined to show the distinct areas for which recharge is to be calculated. R-factors and R-constants are then looked up in appendix 4 (by recharge soil group) or appendix 5 (by soil unit). Finally the climate factor for the municipality is found in appendix 6 and ground-water recharge calculated.

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 (appendix 8). Incorporating these complexities was beyond the resources of this study.

II. MAPPING GROUND-WATER-RECHARGE AREAS

The step-by-step directions below enable one to produce ground-water-recharge maps. This section specifies what data to acquire, how to prepare overlays and combine them in order to calculate recharge, and how to produce a ground-water-recharge map. The mapping may be done manually or with a computerized Geographic Information System (GIS). The directions that follow assume application to a municipality using the manual method, but the steps are easily adapted to GIS application.

The procedure involves mapping land-use/land-cover, combining the land-use/land-cover maps with soil maps to delineate areas with distinct recharge characteristics, and then calculating ground-water recharge using the map information and tables developed for New Jersey soils and climate. It is recommended that you read and thoroughly understand the procedure before performing any of the steps. This will enable you to consider options that yield greater accuracy and detail.

The entire procedure is outlined below and on a flow chart on page 17 (fig. 12). Following the flow chart is a series of full-page figures that are referred to throughout the mapping procedure explanation. Copy figures 15, 17, 20, and 21 onto 8 1/2 x 11 inch transparencies and simulate the method by following the procedure in the document. The actual workings of the method will seem straightforward after working through the example.

Included in the outline below is the estimated time required to complete each step using the manual method. The estimates assume that a microcomputer spreadsheet is used for the calculations and approximately 4 hours of field checking is made for land-use/land-cover verification. The low numbers of the ranges correspond to small municipalities (study areas less than 2 square miles) and the high ones correspond to large municipalities (greater than 20 square miles).

Step	Description	Approximate Staff Hours
1.	Acquire source data	2 - 6
2.	Prepare composite maps and mylar templates	6 - 8
3a.	Prepare land-use/land-cover (LULC) overlay	8 - 96
3b.	Prepare soil group overlay	4 - 40
4.	Prepare coded LULC/soil group combination map	4 - 12
5.	Prepare spreadsheet and calculate recharge	16 - 56
6.	Prepare recharge base map	6 - 20
	total staff hours:	46 - 238

Overall time requirements might be significantly reduced if a GIS were used. Staff hour estimates would be somewhat higher for steps 3a and 3b (preparing the overlays), but much lower for later steps. Steps 3a and 3b would require more time with a GIS because the overlays would need to be compiled and drafted manually and then drafted again digitally (or scanned) on the computer. Once computerized, however, steps 4, 5, and 6 would be a matter of a few keystrokes with a GIS. If using a GIS, a separate spreadsheet would not be required for step 5. Also, depending on which classification scheme were chosen, time requirements for portions of the classification (section III) would be greatly reduced by using a GIS. In summary, the initial time spent on computerizing the overlay maps would be more than offset by the time saved in subsequent tasks.

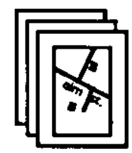
The advantage of the manual procedure is that it requires no special equipment or GIS expertise; the disadvantage is that it does not offer the time savings and flexibility of a GIS. However, when using the manual method in anything other than a small study area, using a microcomputer spreadsheet for calculations can save time. Also, a light table is strongly recommended, but not essential, for use in both manual and GIS applications.

The mapping procedure uses materials readily available statewide. Source documents and map scales are consistent throughout the state. This uniformity simplified development of the methodology and allows the results of one study to be easily compared to those of another. A user who develops an understanding of the methodology may decide to use locally available maps or information which is not discussed here. Substitutions are certainly recommended where they save time and money, as long as the overall accuracy of the maps and the final calculations are not compromised.

1. Acquire source data

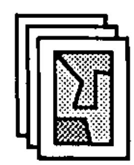
Before beginning the mapping, acquire the following documents:

USGS quads - U.S. Geological Survey 1:24,000-scale topographic quadrangle maps (USGS quads) will be used to produce a base map. These maps can be purchased from the DEPE Maps and Publications Sales Office (609-777-1038), directly from the USGS (USGS Map Sales DFC; Box 25286 MS 306; Denver, CO 80225; (303-236-7477), or at many retail map stores. Purchase all of the USGS quads needed to cover the area of interest.



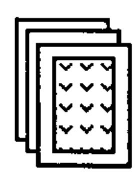
USGS Quads

Photoquads - The DEPE has produced orthophotographic quadrangles (photoquads) from March 1986 aerial photography. These register to the 1:24,000-scale USGS topographic quadrangles. The photoquads are used as a base on which land-use/land-cover will be delineated. Photoquads are preferable to conventional aerial photography because they provide a high quality, high resolution, uniform, easy to use interpretive tool and because the distortion inherent in aerial photography has been removed. The photoquads are available from MARKHURD (the manufacturer, 800-627-4873). Alternatively, variable quality and lower resolution paper diazo prints are available from the DEPE Maps and Publications Sales Office (609-777-1038). At the time of publication, more recent photoquads (photographed in 1991) were being prepared. These more recent photoquads are preferable and should be used if available. Order the photoquads corresponding to the USGS quads for the area of interest.



Photoquads

NWI quads - The U.S. Fish and Wildlife Service has produced 1:24,000-scale National Wetlands Inventory quadrangles (NWI quads) for all of New Jersey. These maps show the extent and types of freshwater wetlands and surface water (together referred to as "wet areas") as of the aerial photography date (1976). NWI quads are available at the DEPE Map and Publication Sales Office and many map stores.



NWI Quads

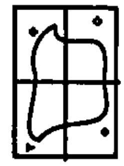
Soil surveys - The U.S. Department of Agriculture, Soil Conservation Service (SCS) has published a soil survey for each county in the state except Essex and Hudson. The county soil maps are compiled as soft-cover books containing soil descriptions and properties in text and tables. Also included are soil map sheets, which are aerial photographs overprinted with soil boundaries and symbols. They are used to delineate soils with distinct properties.

Soil Survey

To acquire a soil survey for any county, contact the local SCS Field Office (addresses and phone numbers are given in appendix 9). For GIS applications, inquire into whether digitized soil coverage is available. If you are in one of the two counties, Essex and Hudson, that lack soil surveys, contact the SCS office about available information.

2. Prepare composites and mylar templates

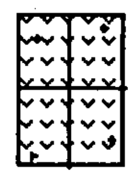
USGS quad composite - Use a blade and straightedge to remove the USGS quad borders to facilitate edgematching the sheets. Carefully edgematch and firmly join the sheets covering your study area to produce a USGS quad composite. The quads will not edgematch perfectly. Try to distribute the error evenly along the quad edges. Delineate the study-area boundary on the USGS quad composite. If the study area is a municipality, the boundary is probably already marked as a dashed line on the quadrangle. Use caution with municipal boundaries on older quads because some are reputed to be inaccurate. In any case, highlight the study area boundary and municipal boundaries (if present) within it.


USGS Quad Composite

Choose at least four tick mark locations near the corners of the composite. Marks should be made on features, such as road intersections, which are clearly identifiable on the USGS quads, photoquads, NWI quads, and soil survey maps. Make a well defined "+" to serve as a tick mark at each location (fig. 13). Highlight the tick marks with a marker.

The product of this step is a composite map of those USGS quads which cover the study area. The composite includes a highlighted study area boundary and tick marks.

NWI quad composite - The method omits wetland areas and surface-water bodies in calculating ground-water recharge. The NWI quad composite is prepared so that these wet areas can be eliminated from the recharge evaluation.


NWI Quad composite

Use a blade and straightedge to remove the NWI quad borders. Do not edgematch the NWI quads. Instead, carefully overlay and register each NWI quad to the underlying USGS quad composite independently. Since the NWI quad base comes directly from the USGS quad, there will be many features to use for registration (for example road intersections, topographic contours, etc.).

The NWI quads will probably not match the USGS quad composite perfectly due to printing distortions. Distribute the error evenly throughout each map sheet. The NWI quads may overlap slightly or have gaps between them in some places, but the final NWI quad composite should register well with the USGS quad composite. After the NWI quads are registered and temporarily attached to the USGS quad composite, firmly join them into one large composite. Transfer the tick marks and study-area boundary from the underlying USGS composite onto the NWI quad composite (fig. 2).

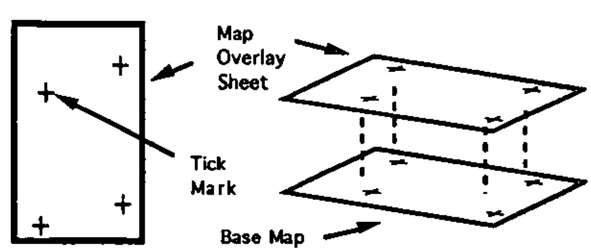


Figure 2. Registration.

The product of this step is a composite map of those NWI quads that cover the study area (fig. 14). The composite includes the highlighted study-area boundary and tick marks.

Mylar templates - Overlay a continuous blank sheet of mylar on the NWI quad composite. Transfer the tick marks and study-area boundary onto the template. Outline the boundaries of all wet areas (wetlands and surface water bodies) with a dark pencil or marker and shade everything inside the wet area boundaries (fig. 3 and 15).

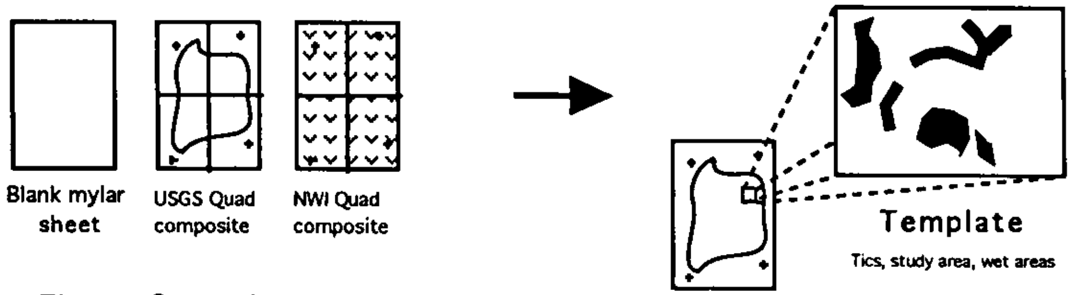
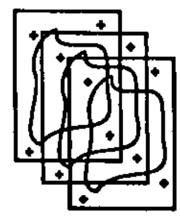


Figure 3. Producing a mylar template.

Verify surface-water bodies from the NWI quad composite using the USGS quad composite. Overlay the mylar template on the USGS quad composite. Any surface water bodies which were not mapped from the NWI composite will show in light blue (or purple, if added to the USGS quads during a recent photorevision). Be careful because not all purple photorevision will be wet areas. For example, it could be easy to mistake the shape of a disturbed area for a surface water body. Trace any remaining surface-water boundaries (excluding small streams) onto the mylar, and complete the shading of wet areas.

Produce two additional copies of the completed template. This can be done manually by tracing the original template, or photographically by a professional reproduction company. Professional reproduction is preferred because manual tracing introduces more error.



Three mylar templates

The products of this step are three duplicate mylar templates containing the ticks, study-area boundary, and shaded wet areas.

3a. Prepare land-use/land-cover (LULC) overlay

When preparing the overlays discussed below, use a different colored pencil for each separate overlay so they are distinct and recognizable. This will simplify the mapping procedure.

The land-use/land-cover map to be prepared in this step is very specific in terms of the land classification scheme and accuracy standards. It is not the same as a land-use map that might be found in a municipal master plan, and municipal land-use maps can not be substituted for the land-use/land-cover maps specified in this procedure. Municipal land-use maps can, however, be used as a reference in preparing the map.

Municipal land-use maps commonly show only land use (not land cover) and generally only on a lot-by-lot basis. For example, a school might have large tracts of lawn or forest within the property boundary. On a municipal land-use map, the entire property might be classified as "public," "quasi-public," or "institutional." On the land-use/land-cover map required for recharge mapping, the forest, lawn, and impervious areas need to be classified separately if such tracts are larger than 5 acres.

1:24,000-scale photoquads are to be used as a base for delineating land-use/land-cover (LULC). Use a blade and straightedge to remove the photoquad borders. Notice that the photo image extends beyond the line representing the USGS quad edge. Trim the borders of the photoquads to the line which represents the USGS quad edge. Do not edgematch the photoquads. Instead, carefully register each photoquad to the USGS quad composite independently.

The photoquads will not match the USGS quads perfectly. Distribute the error evenly throughout each map sheet. The photoquads may overlap slightly or have gaps between them in some places, but the final photoquad composite should register well with the USGS quad composite. After each photoquad is registered and temporarily attached to the USGS quad composite, firmly join the photoquads into one large composite. Transfer the tick marks and study-area boundary to the photoquad composite (fig. 16).

Use the LULC categories in appendix 2 to delineate LULC polygons directly on the photoquad composite (a red pencil shows up best on a grey-tone photoquad). Use the codes given in the appendix to label each distinct LULC area. If you will be estimating recharge for a specific percent impervious cover instead of the ranges shown in appendix 2, note such areas on the map with your own symbol. Tests performed by NJGS show that the easiest LULC delineation sequence from start to finish is:

land use/land cover	LULC code
agricultural	8
wooded areas	9
landscaped open space	0
landscaped commercial	5
unlandscaped commercial	6
unvegetated	7
residential 1/8 acre lots	1
residential 1/8 to 1/2 acre lots	2
residential 1/2 to 1 acre lots	3
residential 1 to 2 acre lots	4

At the 1:24,000 scale of the maps, areas of less than 5 acres should not be mapped (a 5-acre parcel is 470 by 470 feet, about the diameter of a pencil eraser at 1:24,000 scale). For example, if a 2-acre residential lot is in the middle of a wooded area, the entire area should be mapped as "wooded area." Most highways will be so narrow (slivers) on a 1:24,000 map that it is appropriate to absorb them into surrounding polygons. Omitting small parcels simplifies the mapping effort and leads to a more readable final map.

LULC delineation is designed to be a tabletop procedure done primarily from existing knowledge and photoquad interpretation. Calculation of average lot size for residential districts is not necessary, but make sure the average lot sizes are consistent with knowledge of the area. Map estimates of lot size can be easily obtained by counting the number of lots (houses) that appear through a one-quarter-inch diameter hole punched in a file card:

Houses/hole	Average lot size	LULC code
10 - 40	1/8 to 1/2 acre	2
5 - 10	1/2 to 1 acre	3
2 - 5	1 to 2 acres	4

Notice that two of the general LULC categories (agricultural and wooded areas) can be subdivided. Use of the subdivided categories (cropland, permanent pasture; brush,woods and orchards) will yield a more accurate final recharge map. If a more general recharge map is adequate, the general LULC distinctions will probably be sufficient. However if a more detailed map is desired, the subdivisions are recommended. This choice is provided because some users may not be able to justify the possible extra work required to distinguish the subdivisions of LULC. If the user is already quite familiar with the LULC in the study area, use of the subdivisions will require little additional effort. Otherwise airphotos, maps, and reports can aid in the mapping process.

Regardless of the level of detail used for LULC delineation, it is essential that a few of your interpretations be field checked to validate your photo interpretations. Questions concerning airphoto interpretation and land-use/land-cover mapping may be resolved by consulting Avery and Berlin (1985).

After the delineation process is complete, overlay, register, and temporarily attach a mylar template to the photoquad composite. Transfer all LULC boundaries and labels to the template, disregarding the shaded wet areas.

The product of this step is a mylar overlay containing ticks, study-area boundary, shaded wet areas, LULC boundaries, and LULC codes (figs. 4 and 17).

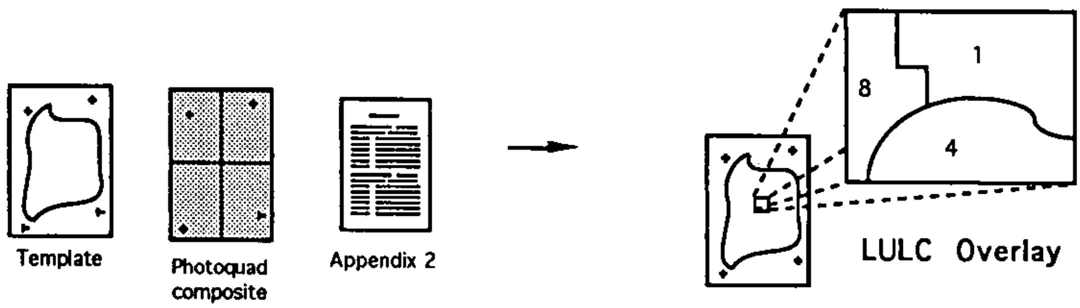


Figure 4. Producing a LULC overlay.

3b. Prepare soil-group overlay

In the SCS county soil survey, find the map sheets covering your study area. These maps are originally at either 1:15,840 or 1:20,000. They must be re-scaled to 1:24,000. County map sheets at 1:15,840 must be reduced to 66 percent of the original size. Sheets at 1:20,000 must be reduced to 83.33 percent of the original size. It is important that the soil-map sheets be accurately reduced. A photocopier introduces some distortion. A professional photographic reduction introduces much less distortion and maintains image quality. Therefore it is preferable to have the sheets professionally reduced.

Use a blade and straightedge to trim the borders from the reduced soil-map sheets. Do not edgematch the soil map sheets. Carefully register each sheet to the USGS quad composite independently. The soil-map sheets were produced using air photo bases containing some distortion, and will therefore not match the USGS quad composite in some places. Distribute the registration error throughout each soil map sheet as evenly as possible before temporarily attaching it to the USGS quad composite. There may be gaps or overlaps between soil-map sheets in the final soil-map composite. After each sheet is registered and temporarily attached to the USGS quad composite, firmly join them into one large composite. Transfer the tick marks to the soil-map composite (fig. 18).

Register and temporarily attach a mylar template to the soil-map composite. Do not trace any soil boundaries yet. Using the soil-group table in appendix 3 (fig. 19 for example), find the recharge soil-group code (A, B, C, etc.). Write this code on the mylar template over the soil symbol. Appendix 3 lists the full name of each soil unit rather than the symbol found on the soil-map sheets because the symbols vary from county to county; symbol-to-unit name translation is given in the county soil survey book.

Some symbols refer to soil complexes (areas with soils of two or more soil series) which are not listed as such in the appendix. The predominant unit in a soil complex is the first name given and should be taken as the soil type. For example, in Mercer County the symbol "SyB" refers to the soil complex "Sassafras-Woodstown," so "Sassafras" would be the unit to look up in Appendix 7.

If the map unit name includes rock outcrop in any form, the full map unit name and associated recharge soil group will be listed in the appendix.

Still other symbols refer to urban land complexes. If the soil survey lists a soil series associated with urban land or urban land complex, use that soil as the map unit to look up in the appendix. For example, in Mercer County, the symbol "Ug" refers to "Urban land, Galestown Material", so "Galestown" would be the unit to look up in the appendix. The Soil Conservation Service should be contacted for advice on urban land or urban land complexes that do not have an associated soil series.

After all the recharge soil group codes have been added, trace the boundaries separating soils of different groups on the mylar template. Eliminate any map unit smaller than 5 acres (pencil eraser size). Smooth out any boundary discontinuities between map sheets. Finally, shade all polygons that contain hydric soils (recharge soil group L).

The product of this step is a mylar overlay containing registration ticks, the study-area boundary, soil-group boundaries, and soil-group codes (fig. 5 and 20).

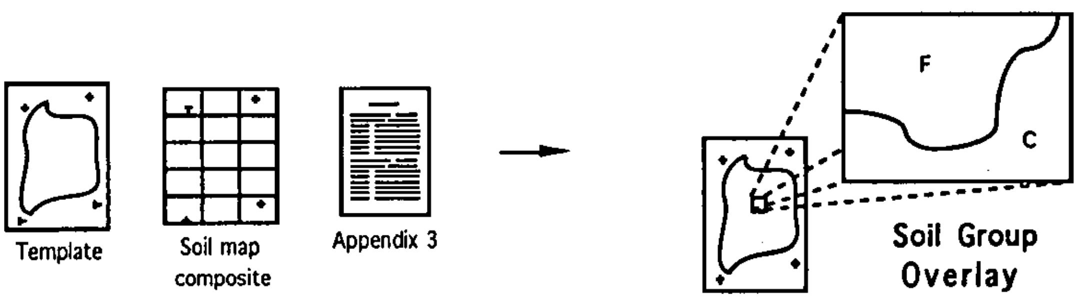


Figure 5. Producing a soil group overlay.

4. **Prepare coded LULC/soil-group combination map**

On a light table, register the LULC overlay with the soil-group overlay. Secure the two maps on the table with drafting tape, then register and tape your third clean mylar template over these. First add the shaded hydric soil areas from the soil-group overlay to the combination map. Then trace the lines over all non-shaded map areas from both underlying maps onto the mylar template to produce a combination LULC/soil-group map. In areas where the combination of soil and LULC boundaries produces slivers or polygons smaller than 5 acres, absorb and smooth the lines into the neighboring polygons, but give preference to the LULC boundaries. Finally, on the combination map, assign each polygon a unique numeric code to give each an identifier (figs. 6 and 21).

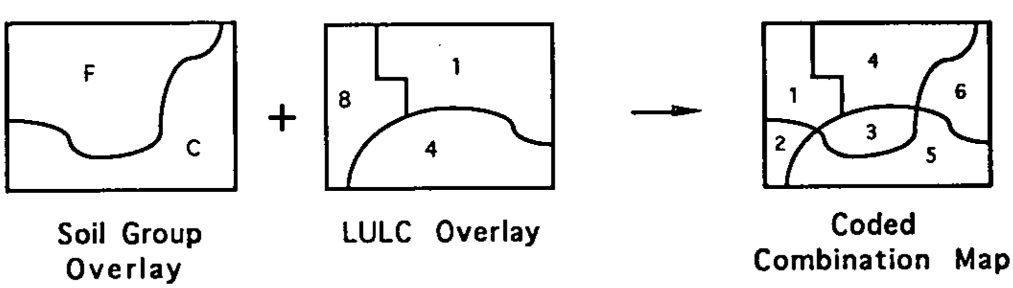


Figure 6. Producing a combination map.

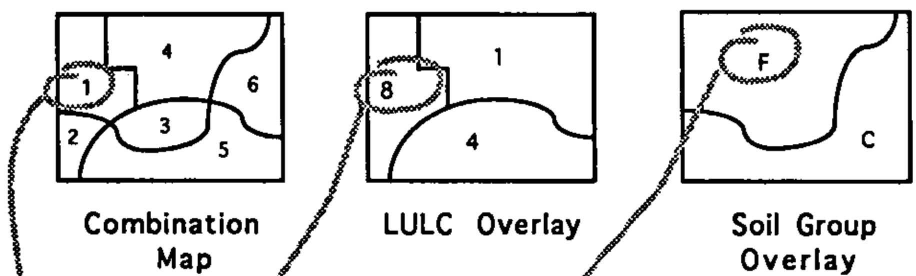
5. Prepare spreadsheet and calculate recharge

Create a computer spreadsheet template (fig. 7) for data needed to calculate ground-water recharge.

Code	LULC	Soil Group	R-Factor	R-Constant	C-Factor	Recharge
1						
2						
3						
etc.						

Figure 7. Spreadsheet format for calculating recharge.

Refer to the two original maps to determine LULC and soil-group codes for each polygon on the combination map, and add these to the spreadsheet (fig. 8):



Code	LULC	Soil Group	R-Factor	R-Constant	C-Factor	Recharge
1	8	F				
2	8	C				
3	4	F				
4	1	F				
5	4	C				
6	1	C				

Figure 8. Adding LULC and soil group codes to the spreadsheet.

Using appendix 4, add recharge factors (R-factors) and recharge constants (R-constants) to the spreadsheet. The example below depicts the look-up procedure for polygon number 1 of figure 9.

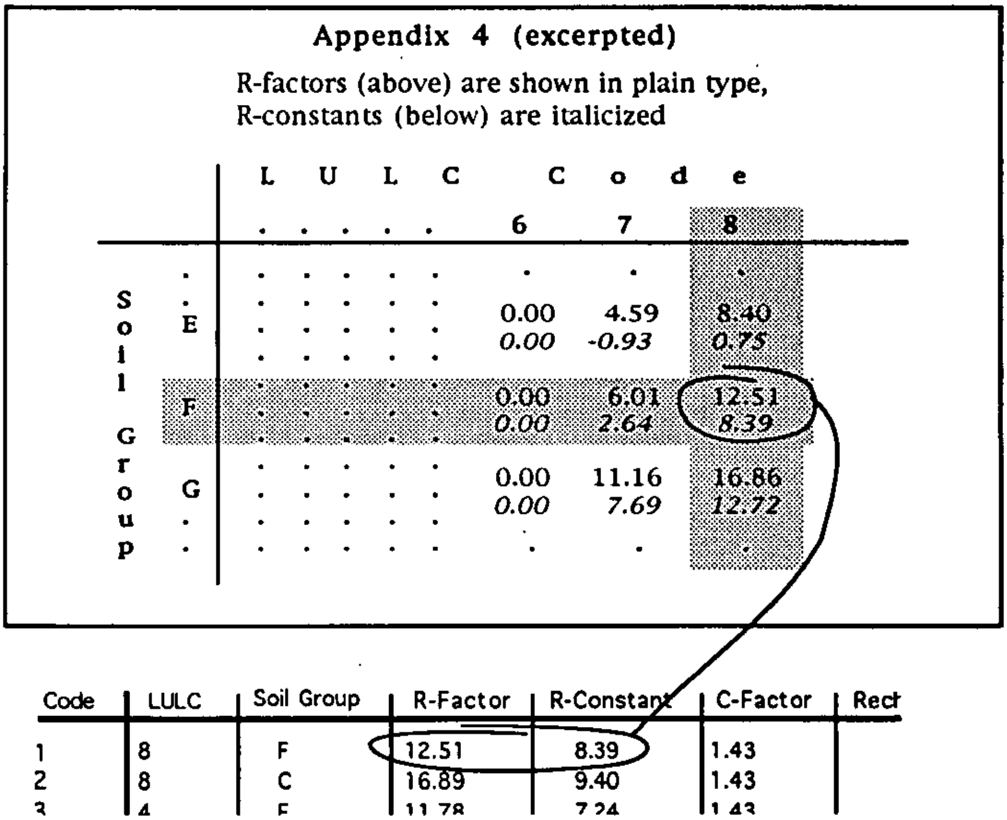


Figure 9. Adding R-factor and R-constant to the spreadsheet.

Using appendix 6, find the climate factor (C-factor) for your municipality and enter it in the spreadsheet. Calculate recharge using the following equation:

$$\text{Recharge} = (\text{R-factor} \times \text{C-factor} \times \text{B-factor}) - \text{R-constant} \quad (3)$$

Round all results to the nearest tenth of an inch (figs. 10 and 23).

Code	LULC	Soil Group	R-Factor	R-Constant	C-Factor	Recharge
1	8	F	12.51	8.39	1.43	14.9
2	8	C	16.89	9.40	1.43	22.0
3	4	F	11.78	7.24	1.43	14.7
4	1	F	4.97	3.05	1.43	6.2
5	4	C	14.75	8.15	1.43	19.3
6	1	C	6.22	3.44	1.43	8.1

Figure 10. Completed spreadsheet with calculated recharge.

Remember, the basin factor is a constant, 1.3. In this example a column is not set up for it. This particular example also has polygons which fall entirely within one municipality. Thus the climate factor is the same for all polygons. A different example might have different climate factors for different pologons.

6. Prepare recharge base map

Each polygon should now have a recharge value expressed in inches per year. Write these values in the polygons on the combination map. The resulting recharge base map includes the combination polygons, their codes, and their recharge values. To distinguish between the codes and the recharge values on the map, make the codes whole numbers, and write the recharge values to the tenths place. In figures 11 and 22, the recharge values are italicized to further distinguish them from the codes.

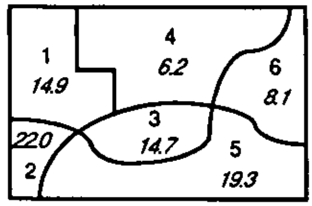


Figure 11. Recharge base map.

The recharge base map is to be used to produce the shaded (ranked) recharge maps described in section III.

7. Mapping by soil unit for more accurate results

More accurate recharge values may be obtained by using soil unit rather than recharge soil group (a group of soil units). R-factors and R-constants for recharge soil groups are generalized values derived from recharge calculated for specific soil units. Results using recharge soil groups may differ by as much as 1 1/2 inches per year from the more accurate values calculated using soil units. Using soil units for recharge calculations is especially applicable for studies of small areas. However, it adds complexity (and accuracy) to larger maps by yielding more polygons. Depending on the size of the study area, this may be a compelling reason to use a GIS. Regardless of the reasons, if a GIS is used, soil units should be incorporated to take advantage of GIS capabilities.

A soil-unit map is made in basically the same way as a soil-group map except for two steps. In step 3b, instead of writing the soil-group code on the mylar template, transfer the first two letters of the soil symbol onto the mylar (the last letter or letter/number combination of the symbol are not needed for this analysis; refer to the county soil-survey book for symbol-to-unit translation). Before proceeding with step 4, shade all soil polygons that contain both a recharge factor and recharge constant of 0.00. Then, in step 5, refer to appendix 5, not appendix 4, for R-factors and R-constants.

8. Recharge estimates for specific percentages of impervious area

For specific development scenarios, it might be desirable to estimate ground-water recharge for a given percentage of impervious cover instead of for the ranges noted in appendix 2. The following calculation can give such estimates for any soil map unit by using a weighted average of the proportion of landscaped open space:

$$\text{Recharge} = (\text{recharge for LULC } 0) \times ((100 - \%\text{ impervious cover})/100) \quad (4)$$

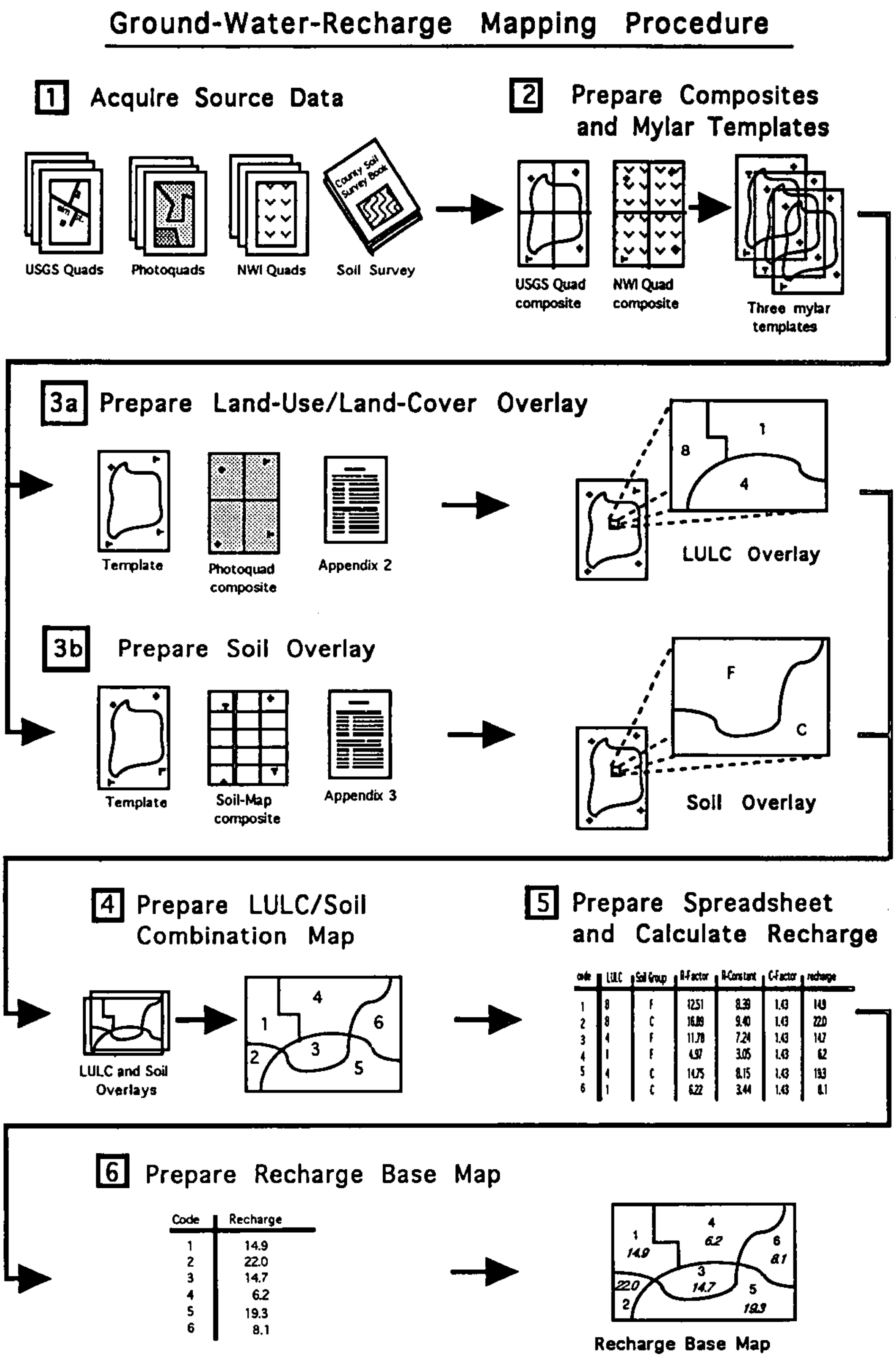


Figure 12. Steps in producing a ground-water-recharge map.

Figure 13. Step 2: USGS quadrangle composite.

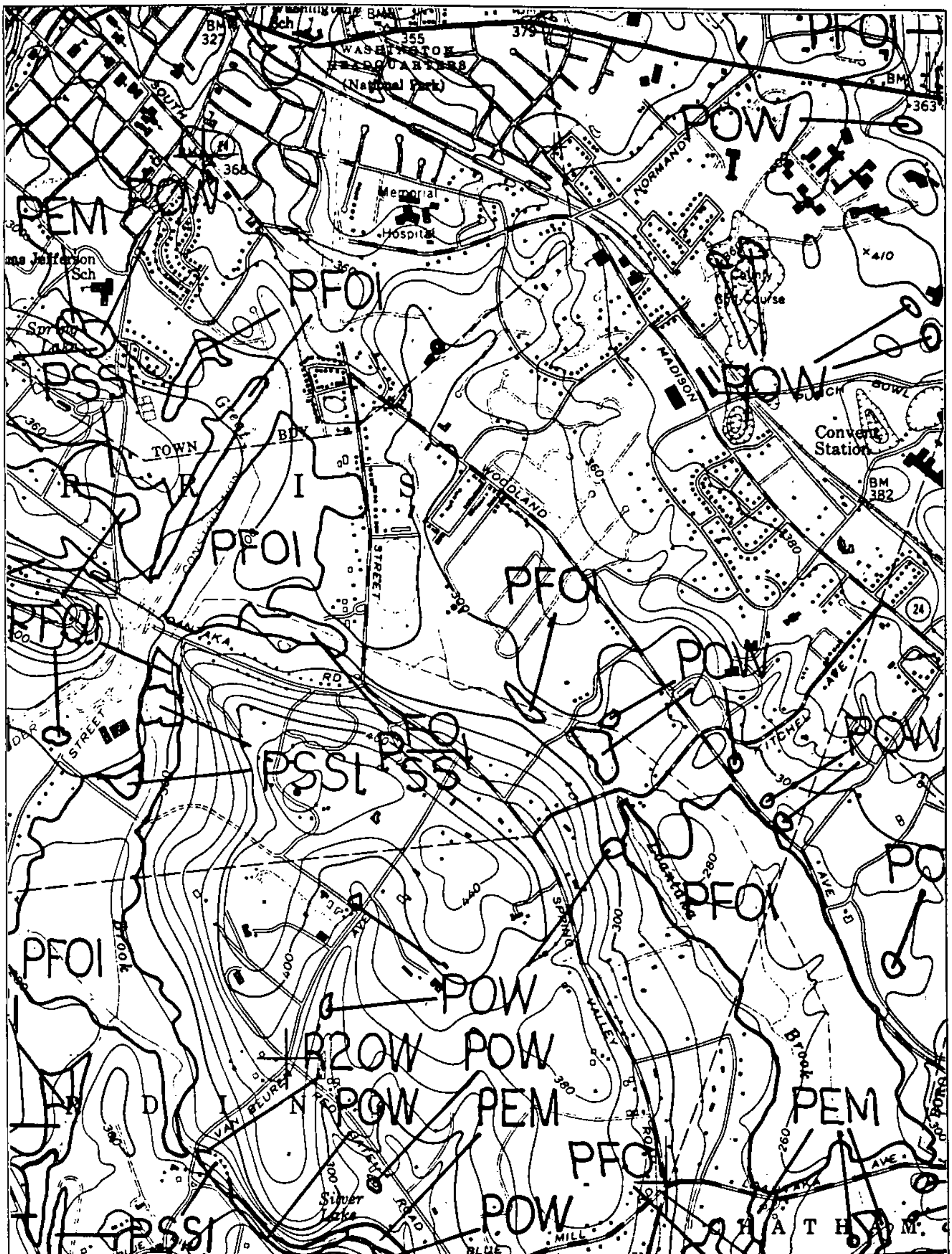


Figure 14. Step 2: NWI quadrangle composite.

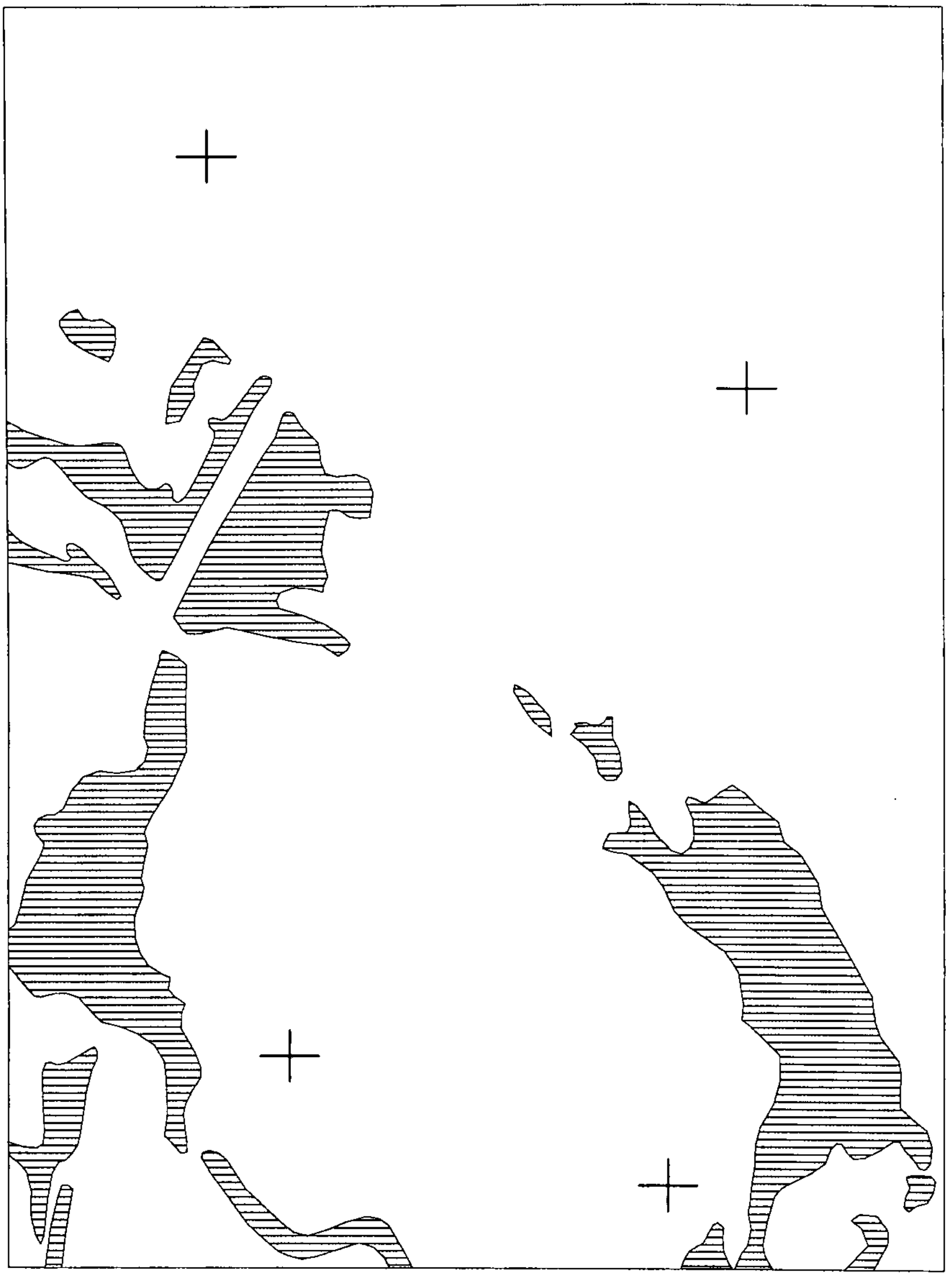


Figure 15. Step 2: Mylar template. Shading indicates surface water and wetlands (> 5 acres).

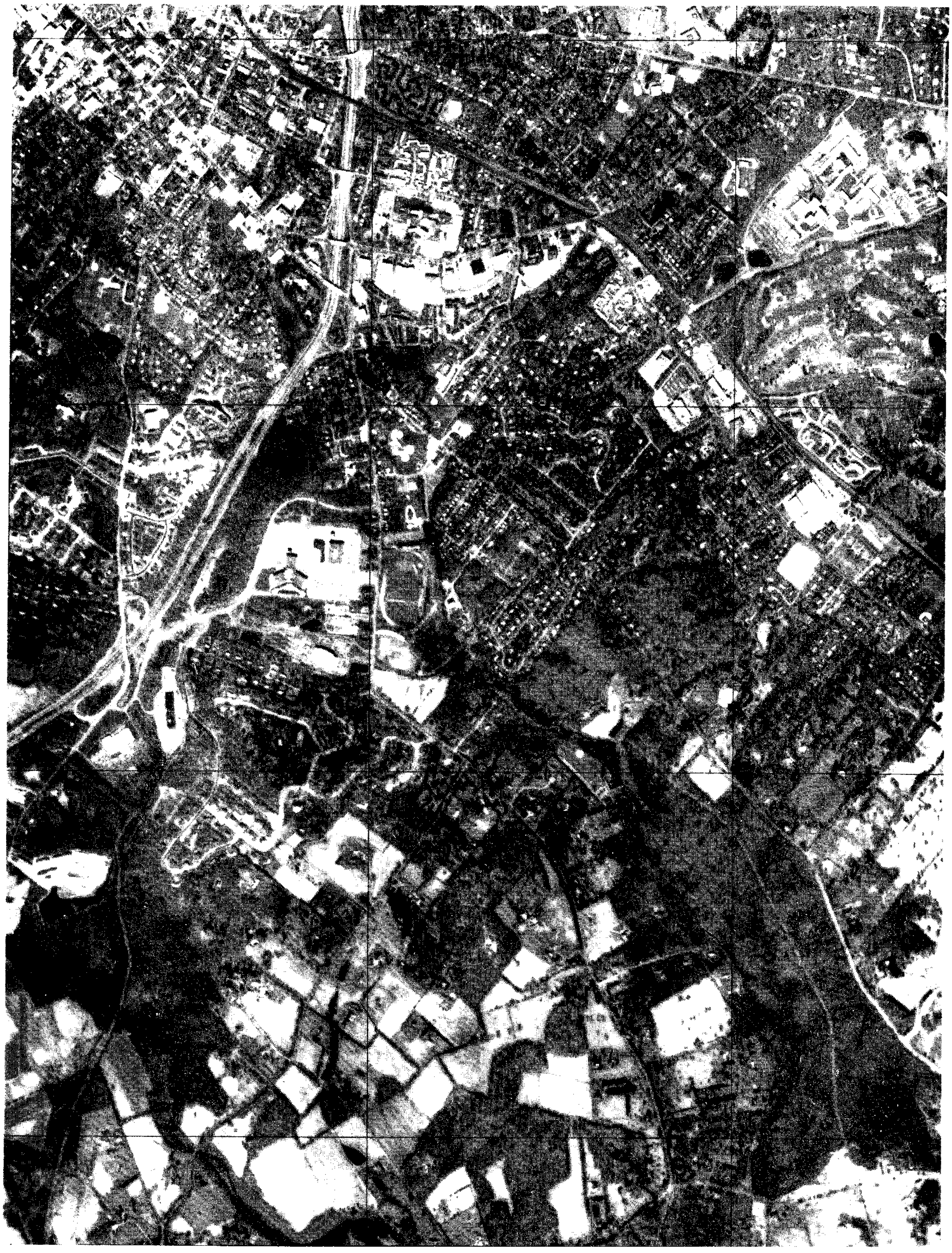


Figure 16. Step 2: mylar orthophotoquad composite

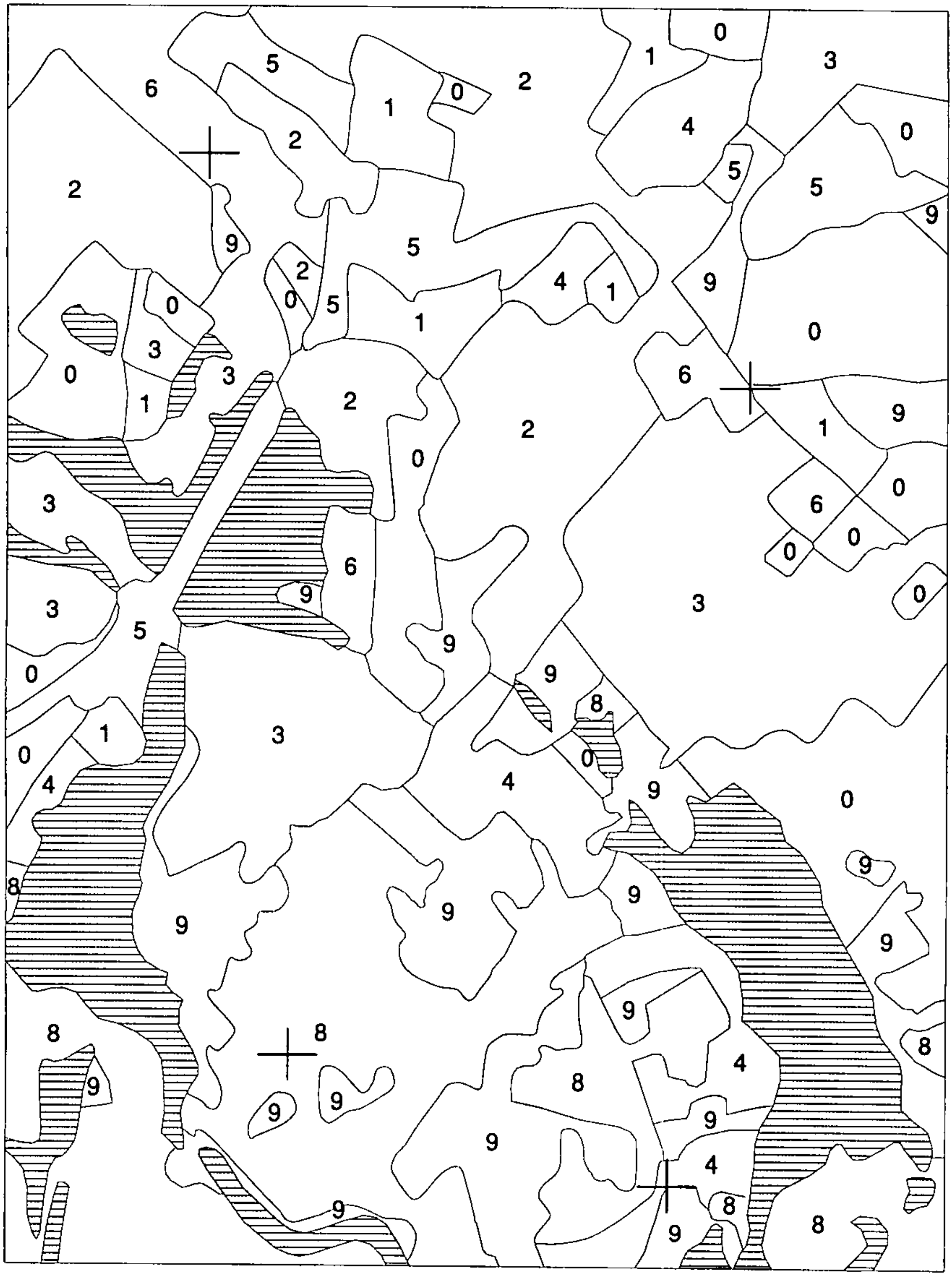


Figure 17. Step 3a: Land-use/land-cover overlay.

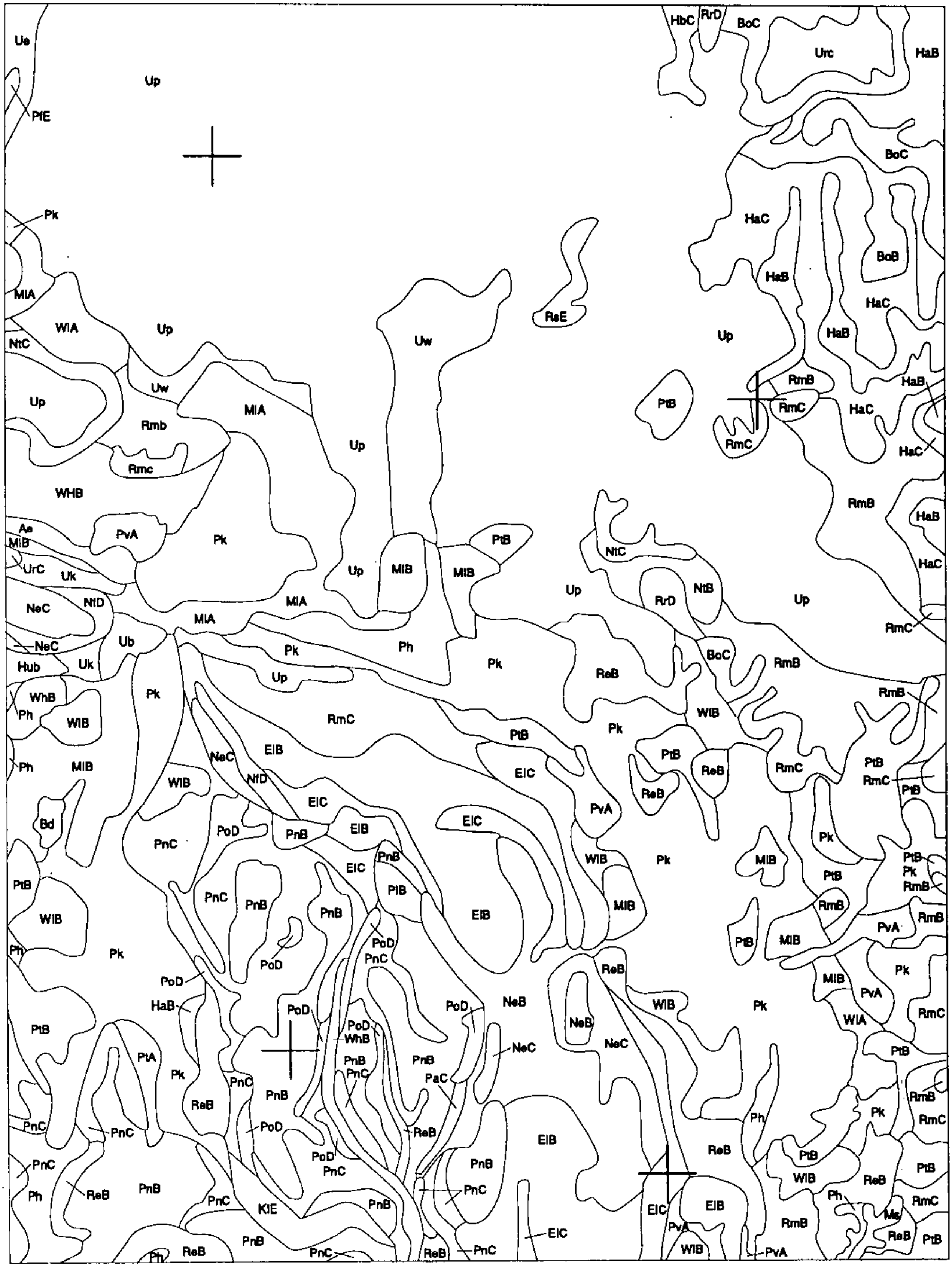


Figure 18. Step 3b: Soil map composite (soils from Eby, 1976).

Map symbol	Recharge soil group	Soil unit
Ae	L	Alluvial land
Bd	L	Biddeford silt loam
BoB	F	Boonton gravely loam, 3 to 8 percent slopes
BoC	F	Boonton gravely loam, 8 to 15 percent slopes
ElB	B	Ellington fine sandy loam, loamy subsoil variant, 3 to 8 percent slopes
ElC	B	Ellington fine sandy loam, loamy subsoil variant, 8 to 15 percent slopes
HaB	F	Haledon silt loam, 3 to 8 percent slopes
HaC	F	Haledon silt loam, 8 to 15 percent slopes
HbC	F	Hibernia stony loam, 3 to 15 percent slopes
MlA	F	Minoa silt loam, 0 to 3 percent slopes
MlB	F	Minoa silt loam, 3 to 8 percent slopes
Ms	L	Muck, shallow over clay
NeB	F	Neshaminy gravely silt loam, 3 to 8 percent slopes
NeC	F	Neshaminy gravely silt loam, 8 to 15 percent slopes
NfD	F	Neshaminy gravely silt loam, 15 to 25 percent slopes
NtB	B	Netcong gravely sandy loam, 3 to 8 percent slopes
NtC	B	Netcong gravely sandy loam, 8 to 15 percent slopes
OtD	C	Otisville gravely loamy sand, 15 to 25 percent slopes
PaC	B	Parker gravely sandy loam, 3 to 15 percent slopes
Ph	L	Parsippany silt loam
Pk	L	Parsippany silt loam, sandy loam substratum
PlC	B	Pattenburg gravely loam, 8 to 15 percent slopes
PnB	F	Penn shaly silt loam, 3 to 8 percent slopes
PnC	F	Penn shaly silt loam, 8 to 15 percent slopes
PoD	F	Penn-Klinesville shaly silt loams, 15 to 25 percent slopes
PtA	B	Pompton sandy loam, 0 to 3 percent slopes
PtB	B	Pompton sandy loam, 3 to 8 percent slopes
PvA	L	Preakness sandy loam, 0 to 4 percent slopes
ReB	F	Reaville shaly silt loam, deep variant, 0 to 5 percent slopes
RmB	D	Riverhead gravely sandy loam, 3 to 8 percent slopes
RmC	D	Riverhead gravely sandy loam, 8 to 15 percent slopes
RrD	E	Rockaway extremely stony sandy loam, 15 to 25 percent slopes
RsE	H	Rockaway-Rock outcrop complex, 25 to 45 percent slopes
Ub	L	Urban land, wet
Ue	B	Urban land-Edneyville complex
Uk	D	Urban land-Neshaminy complex
Up	D	Urban land-Riverhead complex
UrC	E	Urban land-Rockaway complex, gently sloping and sloping
Uw	F	Urban land-Whippany complex
WhB	F	Whippany silt loam, 3 to 8 percent slopes
WlA	F	Whippany silt loam, sandy loam substratum, 0 to 3 percent slopes
WlB	F	Whippany silt loam, sandy loam substratum, 3 to 8 percent slopes

Figure 19. Soil legend for example study area (map symbol from Eby, 1976).

Figure 20. Step 3b: Soil group overlay showing soil-group symbols, boundaries and shaded hydric soils.

Figure 21. Step 4: LULC-soil combination map. Numbers indicate polygon code, lighter fill represents wetlands and dark fill represents hydric soils (L).

Polygon Code	LULC Code	Soil Group	R-factor	R-constant	C-factor	Est. Recharge
1	6	B	0.00	0.00	1.73	0.0
2	6	D	0.00	0.00	1.73	0.0
3	5	D	2.57	1.60	1.73	4.2
4	2	D	11.49	7.14	1.73	18.7
5	1	D	6.00	3.73	1.73	9.8
6	0	F	14.19	8.72	1.73	23.2
7	0	E	10.10	1.66	1.73	21.1
8	0	F	14.19	8.72	1.73	23.2
9	3	E	7.78	1.28	1.73	16.2
10	3	F	10.92	6.71	1.73	17.8
11	2	D	11.49	7.14	1.73	18.7
12	2	D	11.49	7.14	1.73	18.7
13	1	D	6.00	3.73	1.73	9.8
14	0	D	17.15	10.65	1.73	27.9
15	1	F	4.97	3.05	1.73	8.1
16	4	D	14.23	8.84	1.73	23.2
17	0	D	17.15	10.65	1.73	27.9
19	0	F	14.19	8.72	1.73	23.2
20	2	F	9.51	5.85	1.73	15.5
21	9	D	19.84	14.47	1.73	30.2
22	2	D	11.49	7.14	1.73	18.7
23	5	D	2.57	1.60	1.73	4.2
24	2	D	11.49	7.14	1.73	18.7
25	5	F	2.13	1.31	1.73	3.5
26	9	F	16.67	11.80	1.73	25.7
27	5	F	2.13	1.31	1.73	3.5
28	9	F	16.67	11.80	1.73	25.7
29	0	F	14.19	8.72	1.73	23.2
30	9	F	16.67	11.80	1.73	25.7
31	3	D	13.21	8.20	1.73	21.5
32	0	D	17.15	10.65	1.73	27.9
33	0	D	17.15	10.65	1.73	27.9
34	1	D	6.00	3.73	1.73	9.8
35	1	F	4.97	3.05	1.73	8.1
36	4	D	14.23	8.84	1.73	23.2
37	4	H	7.51	1.81	1.73	15.1
38	4	D	14.23	8.84	1.73	23.2
39	1	D	6.00	3.73	1.73	9.8
40	9	D	19.84	14.47	1.73	30.2
41	0	D	17.15	10.65	1.73	27.9
42	0	F	14.19	8.72	1.73	23.2
43	2	B	12.77	9.41	1.73	19.3
44	2	D	11.49	7.14	1.73	18.7
45	0	B	19.06	14.04	1.73	28.8
46	0	D	17.15	10.65	1.73	27.9
47	1	F	4.97	3.05	1.73	8.1
48	1	D	6.00	3.73	1.73	9.8
49	0	D	17.15	10.65	1.73	27.9
50	3	F	10.92	6.71	1.73	17.8
51	5	F	2.13	1.31	1.73	3.5
52	2	F	9.51	5.85	1.73	15.5
53	2	D	11.49	7.14	1.73	18.7
54	2	F	9.51	5.85	1.73	15.5
55	0	F	14.19	8.72	1.73	23.2
56	0	D	17.15	10.65	1.73	27.9
57	4	D	14.23	8.84	1.73	23.2
58	6	D	0.00	0.00	1.73	0.0
59	6	B	0.00	0.00	1.73	0.0
60	0	D	17.15	10.65	1.73	27.9
61	9	F	16.67	11.80	1.73	25.7
62	9	D	19.84	14.47	1.73	30.2
63	9	F	16.67	11.80	1.73	25.7
64	3	F	10.92	6.71	1.73	17.8
65	3	D	13.21	8.20	1.73	21.5
66	6	F	0.00	0.00	1.73	0.0
67	6	D	0.00	0.00	1.73	0.0
68	9	F	16.67	11.80	1.73	25.7
69	6	F	0.00	0.00	1.73	0.0
70	9	F	16.67	11.80	1.73	25.7
71	9	F	16.67	11.80	1.73	25.7
72	9	B	20.73	16.12	1.73	30.5
73	3	D	13.21	8.20	1.73	21.5
74	3	B	14.67	10.81	1.73	22.2
75	3	D	13.21	8.20	1.73	21.5
76	1	D	6.00	3.73	1.73	9.8
77	0	D	17.15	10.65	1.73	27.9
78	6	D	0.00	0.00	1.73	0.0
79	0	D	17.15	10.65	1.73	27.9
80	0	D	17.15	10.65	1.73	27.9
81	0	F	14.19	8.72	1.73	23.2
82	3	D	13.21	8.20	1.73	21.5
83	5	F	2.13	1.31	1.73	3.5
84	3	F	10.92	6.71	1.73	17.8
85	3	E	7.78	1.28	1.73	16.2
86	3	F	10.92	6.71	1.73	17.8
87	0	D	17.15	10.65	1.73	27.9
88	0	F	14.19	8.72	1.73	23.2
89	3	F	10.92	6.71	1.73	17.8
90	0	F	14.19	8.72	1.73	23.2
91	5	F	2.13	1.31	1.73	3.5
92	3	F	10.92	6.71	1.73	17.8
93	3	B	14.67	10.81	1.73	22.2
94	3	D	13.21	8.20	1.73	21.5
95	4	B	15.82	11.65	1.73	23.9
96	9	B	20.73	16.12	1.73	30.5
97	9	F	16.67	11.80	1.73	25.7
98	3	F	10.92	6.71	1.73	17.8
99	0	D	17.15	10.65	1.73	27.9
100	0	D	17.15	10.65	1.73	27.9
101	0	F	14.19	8.72	1.73	23.2
102	1	F	4.97	3.05	1.73	8.1
103	4	F	11.78	7.24	1.73	19.3
104	8	B	16.54	11.93	1.73	25.3
105	9	F	16.67	11.80	1.73	25.7
106	8	F	12.51	8.39	1.73	19.7
107	8	B	16.54	11.93	1.73	25.3
108	9	B	20.73	16.12	1.73	30.5
109	8	F	12.51	8.39	1.73	19.7
110	9	B	20.73	16.12	1.73	30.5
111	4	B	15.82	11.65	1.73	23.0
112	9	F	16.67	11.80	1.73	25.7
113	8	B	16.54	11.93	1.73	25.3
114	4	F	11.78	7.24	1.73	19.3
115	9	F	16.67	11.80	1.73	25.7
116	8	F	12.51	8.39	1.73	19.7
117	3	B	14.67	10.81	1.73	22.2
118	0	F	14.19	8.72	1.73	23.2
119	0	B	19.06	14.04	1.73	28.8
120	0	D	17.15	10.65	1.73	27.9
121	9	B	20.73	16.12	1.73	30.5
122	8	B	16.54	11.93	1.73	25.3
123	9	F	16.67	11.80	1.73	25.7
124	9	F	16.67	11.80	1.73	25.7
125	9	F	16.67	11.80	1.73	25.7
126	9	B	20.73	16.12	1.73	30.5
127	9	B	20.73	16.12	1.73	30.5
128	4	F	11.78	7.24	1.73	19.3
129	8	F	12.51	8.39	1.73	19.7
130	9	F	16.67	11.80	1.73	25.7
131	8	F	12.51	8.39	1.73	19.7
132	4	B	15.82	11.65	1.73	23.9
133	4	F	11.78	7.24	1.73	19.3
134	8	B	16.54	11.93	1.73	25.3
135	9	D	19.84	14.47	1.73	30.2
136	8	B	16.54	11.93	1.73	25.3
137	8	F	12.51	8.39	1.73	19.7
138	9	F	16.67	11.80	1.73	25.7
139	8	F	12.51	8.39	1.73	19.7
140	9	F	16.67	11.80	1.73	25.7
141	8	B	16.54	11.93	1.73	25.3
142	9	B	20.73	16.12	1.73	30.5
143	8	B	16.54	11.93	1.73	25.3
144	9	F	16.67	11.80	1.73	25.7
145	8	F	12.51	8.39	1.73	19.7
146	4	B	15.82	11.65	1.73	23.9
147	9	F	16.67	11.80	1.73	25.7
148	4	F	11.78	7.24	1.73	19.3
149	9	B	20.73	16.12	1.73	30.5
150	4	B	15.82	11.65	1.73	23.9
151	8	B	16.54	11.93	1.73	25.3
152	8	D	14.93	8.97	1.73	24.6
153	8	F	12.51	8.39	1.73	19.7
154	8	D	14.93	8.97	1.73	24.6
155	8	B	16.54	11.93	1.73	25.3
156	8	F	12.51	8.39	1.73	19.7

Figure 22. Step 5: Prepare spreadsheet and calculate recharge.

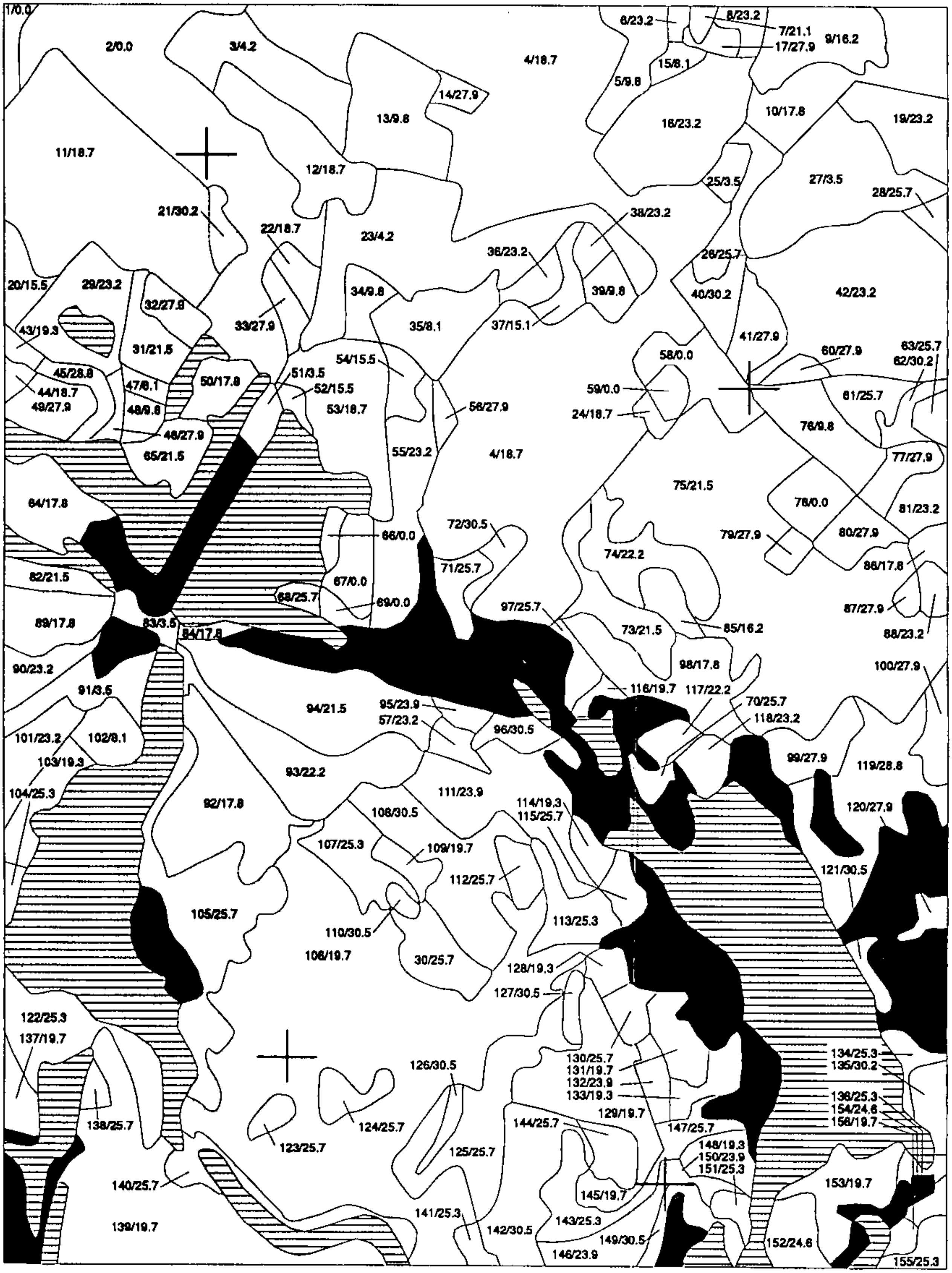


Figure 23. Step 6: Recharge base map. Number at left of slash is polygon code. Number at right of slash is recharge (in.yr). Shaded areas are the same as in figure 21.

III. CLASSIFYING AND RANKING GROUND-WATER-RECHARGE AREAS

Ground-water-recharge areas are classified and ranked in order to group areas of similar recharge properties for later analysis. Most of the work in ranking recharge areas is in setting up the classification system. The ranks (for example, high, medium and low) correspond to recharge rates and are relative. Classification should primarily reflect the future importance of the quantity and quality of ground-water. It should also be consistent with the different levels of land-use regulation and ground-water protection practices that are attainable.

The actual ranks are assigned to the recharge areas only after the user develops the classification. The polygons on the recharge base map are shaded after the ranks are assigned. The shaded recharge-area map (fig. 24) is the final product.

Code	Recharge	Rank
1	14.9	moderate
2	22.0	high
3	14.7	moderate
4	6.2	low
5	19.3	high
6	8.1	low

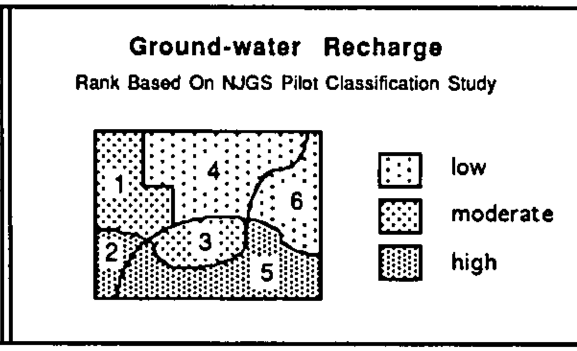


Figure 24. Example ranking with shaded-recharge map.

This section describes two ways to generate a study-area-specific ranking system for ground-water-recharge values: (1) the frequency-weighted method (frequency method) and (2) the volumetric-recharge method (volumetric method). The volumetric method is more meaningful and should be easier to defend in a regulatory context because it is based on direct calculations of the volume of ground-water recharge. Do not choose the frequency method without first understanding the resulting loss of accuracy. Even if you choose the frequency method, recharge volume of any parcel can be compared to other parcels by using the procedure outlined at the end of this section. The examples used to illustrate both classification methods are from a NJGS test study of a quadrangle that yielded over 3,000 recharge polygons. The example study from Section II was not used to illustrate the classification methods because it contained a low number (156) of polygons.

Frequency-weighted classification

The frequency-weighted method (frequency method) is a time-saving approach for classification of recharge values. It is presented here as an option for situations that meet the following criteria: (1) The recharge base map was produced manually. (2) The recharge base map consists of more than approximately 500 polygons. (3) The user is willing to accept a classification that is less accurate than can be generated with the volumetric method.

The advantage of the frequency method is that it does not require calculation of polygon areas. Its disadvantages are: (1) It does not account for the actual volume of ground-water recharge. (2) Its results deviate significantly from those of the volumetric method when applied to study areas of less than about 500 polygons.

The procedure for the frequency method is:

1. Create a spreadsheet with columns labeled recharge group, polygon frequency, and frequency-weighted value (fig. 25).

2. List recharge values in progressively larger order for all the recharge groups that occur in the study area. A recharge group consists of all polygons having the same recharge value.

3. Enter number of polygons (frequency) in each recharge group.

4. Fill in the frequency-weighted values by multiplying recharge group by polygon frequency (fig 26). Round off the frequency-weighted values to whole numbers as shown in figure 26. Print the completed frequency weighted table.

5. Determine the number of classes that seem reasonable for a first-cut classification. If you do not have a good sense for what seems reasonable, try four classes to begin with. For the final classification, the number should be the maximum that represents useful distinctions in the study area. The number of recharge classes chosen is user- and area-specific. It is highly dependent on the future importance of the quantity and quality of ground-water in the study area. It should also be consistent with the levels of ground-water protection practices and land-use regulations you wish to implement. For example, if you expect that the maximum number of levels of ground-water protection practices that you would require is three, a logical number of recharge classes would be three.

Recharge group	Polygon frequency	Frequency weighted value
0.0	375	
0.2	1	
0.6	1	
0.9	7	
1.1	2	
1.3	1	
.	.	
{ rows not shown }		
.	.	
15.2	77	
15.7	219	
16.0	2	
16.1	63	
16.6	147	
17.0	12	

Figure 25. Partial spreadsheet after steps 1, 2, and 3 of frequency method.

Recharge group	Polygon frequency	Frequency weighted value
0.0	375	0
0.2	1	0
0.6	1	1
0.9	7	6
1.1	2	2
1.3	1	1
.		.
.	{ rows not shown }	.
.	.	.
15.2	77	1170
15.7	219	3438
16.0	2	32
16.1	63	1014
16.6	147	2443
17.0	12	204

Figure 26. Partial spreadsheet after step 4 of frequency method.

6. Create class-interval boundaries by first marking the zero-inches-per-year recharge group as a separate class.

Next mark (circle) additional class-interval boundaries to make the total number of boundaries the same as the desired number of recharge classes. Mark these additional class boundaries by working downward from the highest frequency-weighted value.

Define the class-interval boundaries by drawing a horizontal line above the circled value. Figure 27 shows six class intervals.

	Recharge group	Polygon frequency	Frequency weighted value
0.0	0.0	375	0
0.1 to 11.6	0.2	1	0
	0.6	1	1
	0.9	7	6
	1.1	2	2
	1.3	1	1
	1.5	15	22
	1.8	105	185
	2.2	19	43
	3.7	2	7
	4.6	10	46
	5.0	29	145
	5.4	258	1383
	5.5	11	61
	5.8	18	105
	5.9	47	277
	6.3	258	1615
	6.7	23	155
	7.7	3	23
	8.1	13	105
	8.5	88	749
	9.0	18	162
	9.4	43	406
	9.5	1	9
	9.9	223	2208
	10.3	78	804
	10.8	26	281
	11.2	72	807
11.7 to 13.4	11.7	410	4785
	11.9	1	12
	12.1	37	448
	12.6	6	75
	13.0	40	520
13.5 to 15.6	13.5	208	2808
	13.9	32	445
	14.4	24	345
	14.8	22	326
	15.2	77	1170
15.7 to 16.5	15.7	219	3438
	16.0	2	32
	16.1	63	1014
16.6 to 17.0	16.6	147	2443
	17.0	12	204

Figure 27. Full spreadsheet after step 7 of frequency method.

7. Make a table of the class intervals (fig. 28). The class intervals consist of values between the horizontal lines drawn on the frequency-weighted table. Classification examples (data from fig. 27) for 2 to 6 classes are shown below. Note that the 0.1-inch recharge groups that mark the breaks are included in the higher class intervals.

Two Classes	Three Classes	Four Classes	Five Classes	Six Classes
0.0	0.0	0.0	0.0	0.0
0.1-17.0	0.1-11.6	0.1-11.6	0.1-11.6	0.1-11.6
	11.7-17.01	1.7-15.6	11.7-13.4	11.7-13.4
		15.7-17.0	13.5-15.6	13.5-15.6
			15.7-17.0	15.7-16.5
				16.6-17.0

Figure 28. Examples of frequency-method classifications using sample data.

8. Apply ranking labels (for example high, medium, low) to each of the recharge classes that you have defined. The ranking labels should indicate the value judgment you chose for each recharge class in your study area and how they relate to ground-water needs and planning objectives. The polygons on the recharge base map can then be shaded according to their rank to produce the final product, a shaded recharge map.

Volumetric-recharge classification

The most rigorous and meaningful basis for classifying recharge within a study area is by volumetric recharge (the volumetric method). The defensible, quantitative results which this technique yields are worth much more than the effort required to obtain them. The only disadvantage of this method is in manual applications where the time required to measure the area of each polygon may be impractical.

This classification procedure will probably be intimidating the first time you look at it. Keep in mind as you read this procedure that except for measuring the areas of polygons, the entire procedure can be easily accomplished on one spreadsheet. If you are familiar with a microcomputer spreadsheet, you will find the steps quite manageable. If you are not familiar with spreadsheets, be assured that this procedure only involves the most basic of spreadsheet operations. The steps in the volumetric method are:

1. Measure the map area of each polygon.
2. Sum the total polygon areas by 0.1-inch and by 1.0-inch groups.
3. Calculate recharge volume for each group.
4. Graph and examine the 1.0-inch-grouped data.
5. Classify the 0.1-inch-grouped data by natural breaks and priorities.
6. Apply ranking labels and shade polygons.

These steps are detailed below. The example shown uses a map scale of 1:24,000.

1. Measure the map area of each polygon.

Measure, in square inches on the map, the area of each polygon on the coded LULC/soil-group combination map. This can be done 1) with a planimeter; 2) by overlaying the base map on a grid, counting the number of squares within each polygon, and multiplying that number by the area of one square; or 3) with a GIS. Create a spreadsheet with columns labeled for polygon codes, recharge group and square inches on map (fig 29). Enter the polygon areas (square inches on map). Each polygon code now has a recharge value and an associated square-inch value.

2. Group the data by 0.1 inch and by 1.0 inch.

First make a new copy of the spreadsheet to be used for the rest of the calculations. This is to make certain that an original unsorted and ungrouped data set is preserved. The new spreadsheet will be used to sort the entire data set, group the sorted data two different ways, and then make calculations.

Sort the entire data set by recharge in progressively larger order.

Next, create a separate section for 0.1-inch recharge groups within the spreadsheet and label the far left column "recharge group." Label the rows in progressively larger order, with only the 0.1-inch recharge groups that occur in the study area. Label the second column from the left "square inches on map." Sum the square inches for the polygons corresponding to each recharge group and enter the values in this column (Fig. 30).

Create another section within the spreadsheet for the 1.0-inch recharge groups. Label the columns as for the 0.1-inch groups. Label the rows with consecutive whole numbers, for example 0 (meaning 0.0 to 0.9), 1 (meaning 1.0 to 1.9), etc.) in progressively larger order. For the "square inches on map" sum the square inches from the corresponding 0.1-inch groups (fig. 31).

In the test evaluations performed by NJGS, it was found that 1.0-inch groups produced approximately 15 to 20 recharge groups and led to easily interpretable graphs. If the range of recharge rates in the study area is small (perhaps 12 inches or less), 0.5-inch groups will make more meaningful graphs. In any case, the grouping should be chosen to facilitate readability of graphs by creating a uniform x-axis (recharge group) and by lessening the number of data points to give a smoother trend.

Polygon code	Recharge	Square inches on map
847	15.2	0.4
333	11.9	2.9
4	6.3	0.3
721	9.5	0.5
.	{ rows not shown }	.
22	10.3	0.1
1044	11.9	0.2
45	0.0	0.6
146	5.4	0.7

Figure 29. Partial spreadsheet after step 1 of volumetric method

Recharge group	Square inches on map
0.0	38.4
0.2	0.0
0.6	0.1
0.9	1.6
{ rows not shown }	
16.0	0.0
16.1	5.2
16.6	9.6
17.0	0.4

Figure 30. Partial spreadsheet after step 2 of volumetric method.

0.1-in. recharge group	Square inchs on map
0.0	38.4
0.2	0.0
0.6	0.1
0.9	1.6
{ rows not shown }	
16.0	0.0
16.1	5.2
16.6	9.6
17.0	0.4

1.0-in. Recharge group	Square inchs on map
0	40.1
1	6.5
2	0.6
3	0.7
{ rows not shown }	
14	4.0
15	36.7
16	14.8
17	0.4

Figure 31. Converting 0.1-inch to 1.0-inch grouped data.

3. Calculate recharge for each group.

Calculate recharge for each group in both grouping schemes. First add an "area" column to both the 0.1-inch grouping and the 1.0-inch grouping. Use the following formula to convert square inches on map into acres for each row of grouped data:

acres = square inches on map x 91.83

The 91.83 acres/square inches on map conversion value is obtained as follows:

1 inch x 1 inch on map = 2000 feet x 2000 feet on land
2000 feet x 2000 feet on land = 4,000,000 square feet on land
4,000,000 square feet/43,560 square feet per acre = 91.83 acres/square inch

For many study areas you may find it more space efficient to simply divide each entry by 1000 and label the area column with "acres x 1000" as shown in figure 32.

0.1-in. recharge group	Square inches on map	Area (acres X 1000)	Cum. area (acres X 1000)
0.0	38.4	3.5	36.6
0.2	0.0	0.0	33.1
0.6	0.1	0.0	33.1
0.9	1.6	0.1	33.1
.	.	.	.
.	{ rows not shown }		.
.	.	.	.
16.0	0.0	0.0	1.4
16.1	5.2	0.5	1.4
16.6	9.6	0.9	0.9
17.0	0.4	0.0	0.0

Figure 32. Partial spreadsheet showing cumulative area (step 3 of volumetric method) for 0.1-inch recharge group.

Add another column and label it "cumulative area (acres)." Calculate the value for each row by summing the acres represented by the current row (value in cell to the left) with the cumulative sum of the rows below it (value of one cell below). This results in a list of cumulative sums, from highest to lowest recharge rate.

Next, add a column for percentage (%) of total area for each recharge group (fig. 33). Calculate percentage total area by dividing the acre value for each recharge group by the total acres of the study area, then multiplying by 100.

Add a column that shows the cumulative percentage of total area (fig. 33). Start the cumulative sums at the bottom of the table, working from highest to lowest recharge rates in a manner similar to that for cumulative area. The decision to sum from the highest to lowest recharge is based on the assumption that, for management of recharge, areas of highest recharge should always be considered first, regardless of the percentage area they represent.

0.1-in. recharge group	Square inches on map	Area (acres X 1000)	Cum. area (acres X 1000)	% of total area	Cum. % of total area
0.0	38.4	3.5	36.6	9.6	100.0
0.2	0.0	0.0	33.1	0.0	90.4
0.6	0.1	0.0	33.1	0.0	90.4
0.9	1.6	0.1	33.1	0.4	90.3
.	.	.	.	.	.
.	.	{ rows not shown }		.	.
.	.	.	.	.	.
16.0	0.0	0.0	1.4	0.0	3.8
16.1	5.2	0.5	1.4	1.3	3.8
16.6	9.6	0.9	0.9	2.4	2.5
17.0	0.4	0.0	0.0	0.1	0.1

Figure 33. Partial spreadsheet showing percentage and cumulative percentage (step 3 of volumetric method) for 0.1-inch recharge groups.

Add a column for volume of recharge to both the 0.1 and 1.0-inch groupings (fig 34). Calculate gallons of recharge for each recharge group with the following formula:

volume (gallons) = area (acres) x recharge (inches) x 27,156

The 27,156 conversion value is obtained as follows:

1 acre = 43,560 square feet
1 inch/year of recharge = 0.08333 foot/year of recharge
1 foot of recharge x 1 square foot of area = 1 cubic foot of recharge
1 cubic foot of recharge = 7.481 gallons

therefore:

43,560 square feet x 0.0833 foot/year = 3,630 cubic feet/year/acre
3,630 cubic feet/year/acre x 7.481 gallons/cubic foot = 27,156 gallons/inch/acre

0.1-in. recharge group	Square inches on map	Area (acres X 1000)	Cum. area (acres X 1000)	% of total area	Cum. % of total area	Volume (gallon X 1 million
0.0	38.4	3.5	36.6	9.6	100.0	10.0
0.2	0.0	0.0	33.1	0.0	90.4	0.0
0.6	0.1	0.0	33.1	0.0	90.4	0.2
0.9	1.6	0.1	33.1	0.4	90.3	3.5
.	.	.	.	.	.	.
.	.	. { rows not shown }		.	.	.
.	.	.	.	.	.	.
16.0	0.0	0.0	1.4	0.0	3.8	1.9
16.1	5.2	0.5	1.4	1.3	3.8	209.8
16.6	9.6	0.9	0.9	2.4	2.5	396.1
17.0	0.4	0.0	0.0	0.1	0.1	17.9

Figure 34. Partial spreadsheet showing cumulative volume (step 3 of volumetric method) for 0.1-inch recharge groups.

Create three more columns and enter cumulative volume (gallons), percentage of total volume and cumulative percentage of total volume. Calculate these values as you did for the area columns. The resulting spreadsheet should look like this (fig. 35):

1.0-in. recharge group	Square inches on map	Area (acres X 1000)	Cum. area (acres X 1000)	% of total area	Cum. % of total area	Volume (gallons x 1 million)	Cum. vol. (gallons x 1 million)	% of total volume	Cum. % of total volume
0	40.1	3.7	36.6	10.1	100.0	3.7	9023.9	0.0	100.0
1	6.5	0.6	32.9	1.6	89.9	28.5	9020.2	0.3	100.0
2	0.6	0.1	32.3	0.1	88.3	3.2	8991.7	0.0	99.6
3	0.7	0.1	32.3	0.2	88.2	6.9	8988.5	0.1	99.6
4	0.0	0.0	32.2	0.0	88.0	0.2	8981.6	0.0	99.5
5	79.9	7.3	32.2	20.1	88.0	1088.1	8981.4	12.1	99.5
6	21.6	2.0	24.8	5.4	67.9	341.2	7893.3	3.8	87.5
7	0.0	0.0	22.9	0.0	62.5	0.1	7552.0	0.0	83.7
8	8.2	0.7	22.9	2.0	62.5	172.3	7551.9	1.9	83.7
9	55.9	5.1	22.1	14.0	60.4	1368.3	7379.6	15.2	81.8
10	6.8	0.6	17.0	1.7	46.4	178.3	6011.3	2.0	66.6
11	94.0	8.6	16.4	23.6	44.7	2702.7	5833.0	30.0	64.6
12	4.8	0.4	7.7	1.2	21.1	146.3	3130.3	1.6	34.7
13	23.4	2.2	7.3	5.9	19.9	786.2	2984.0	8.7	33.1
14	4.0	0.4	5.1	1.0	14.0	143.3	2197.8	1.6	24.4
15	36.7	3.4	4.8	9.2	13.0	1428.8	2054.5	15.8	22.8
16	14.8	1.4	1.4	3.7	3.8	607.8	625.7	6.7	6.9
17	0.4	0.0	0.0	0.1	0.1	17.9	17.9	0.2	0.2

Figure 35. Full spreadsheet completed (step 3 of volumetric method) for 1.0-inch recharge groups.

4. Graph and examine the whole-inch-grouped data.

With the calculations complete, the next step is to illustrate how recharge rates, area, and the total quantity of recharge are related in the study area. This is best illustrated by creating two bar graphs and three line graphs from the 1.0-inch grouped data. By visualizing these study-area specific attributes through graphs, the user can make a more informed final classification.

The two bar graphs are "area versus recharge group" and "volume versus recharge group." Plot these graphs as shown on figures 36 and 37. On both of these graphs it is useful to show the percentage total area or volume.

"Area versus recharge group" (fig. 36) shows the distribution of area among the recharge groups. The example shows that most of the land recharges at rates of 5 to 15 inches per year. A relatively small part of the total land has recharge values of less than 5 inches. The areally largest recharge group is the 11-inch group, consisting of roughly 24 percent of the study area or approximately 8,600 acres.

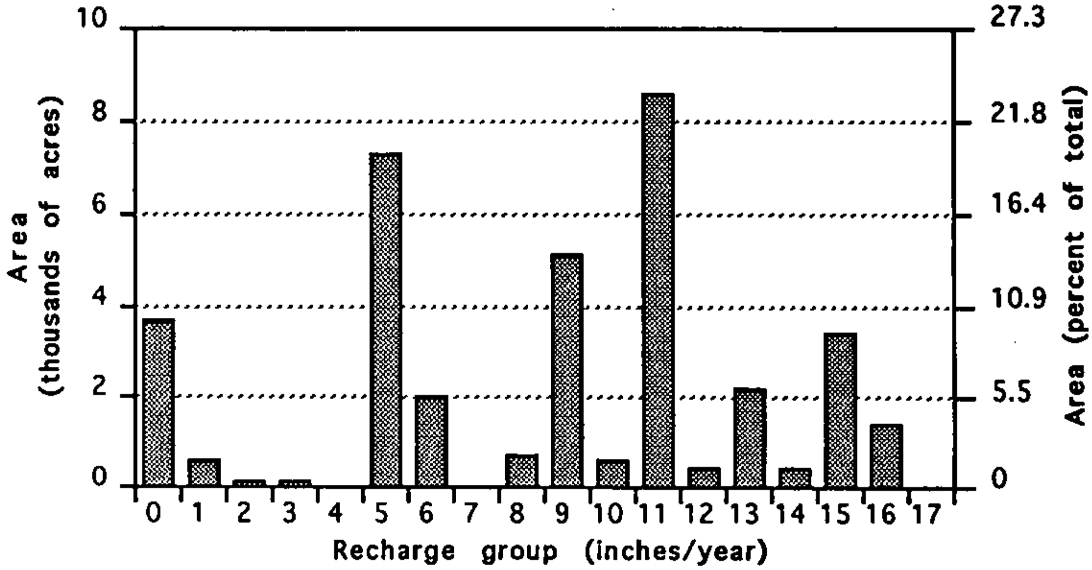


Figure 36. Area vs. recharge group, NJGS test case.

"Volume versus recharge group" (fig. 37) shows the distribution of the volume of recharge among the recharge groups. The example shows that for the study area, most of the recharge occurs in areas which have values of 9 inches or greater. Areas with recharge values of less than 9 inches contribute a relatively small fraction of the overall volume of recharge. For example, the 11-inch group contributes 30 percent of the overall volume of ground-water recharge in the study area or approximately 2,700 million gallons per year.

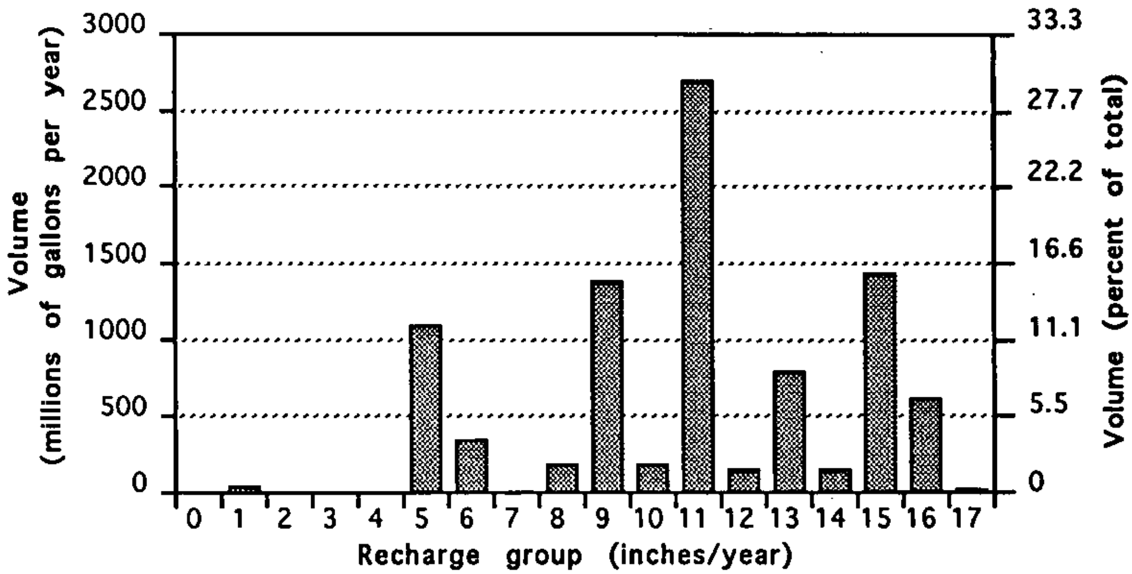


Figure 37. Volume vs. recharge group, NJGS test case.

The three line graphs are "cumulative area versus recharge group," "cumulative volume versus recharge group," and "cumulative percent area and volume versus recharge group." Plot these graphs as shown in figures 38, 39, and 40. In the "cumulative area versus recharge group" (fig. 38), polygons which receive 12 inches of ground-water recharge or more make up 7,700 acres, or approximately 21 percent of the total.

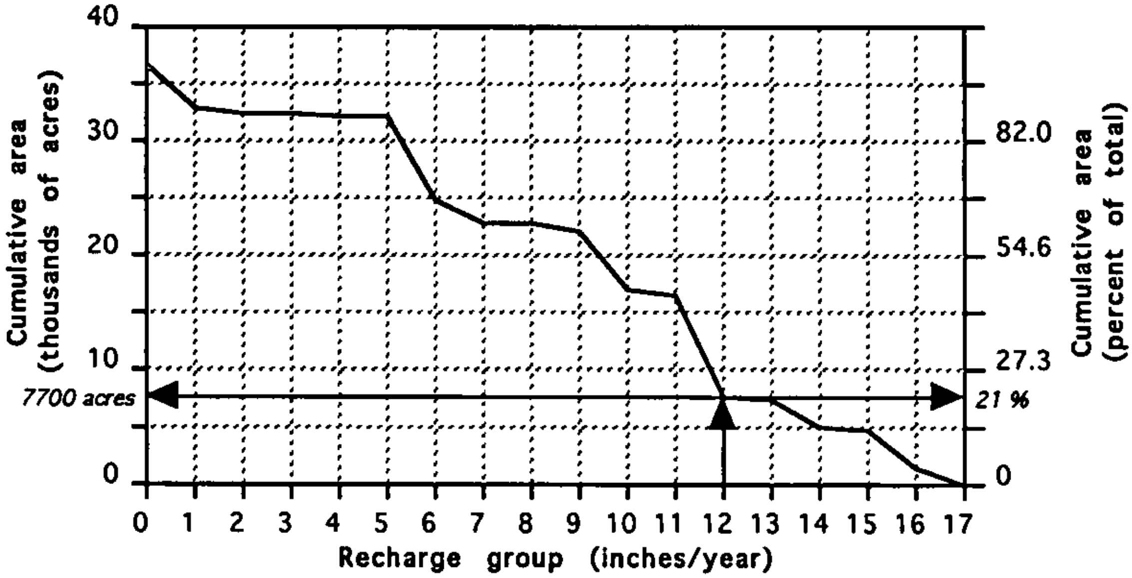


Figure 38. Cumulative area vs. recharge group, NJGS test case.

On the "cumulative volume versus recharge group" graph (fig. 39), notice that the trend is similar to that of the cumulative area graph (fig. 38). Because volume is the product of recharge times area, trends in area are strongly reflected in volume. The volumetric line plot from the example shows that the volume contribution of the recharge groups levels off somewhat below 9 inches. In fact, the graph shows that 82 percent of the total volume of recharge, or approximately 7,380 million gallons, comes from recharge areas that receive 9 inches of ground-water recharge per year or more.

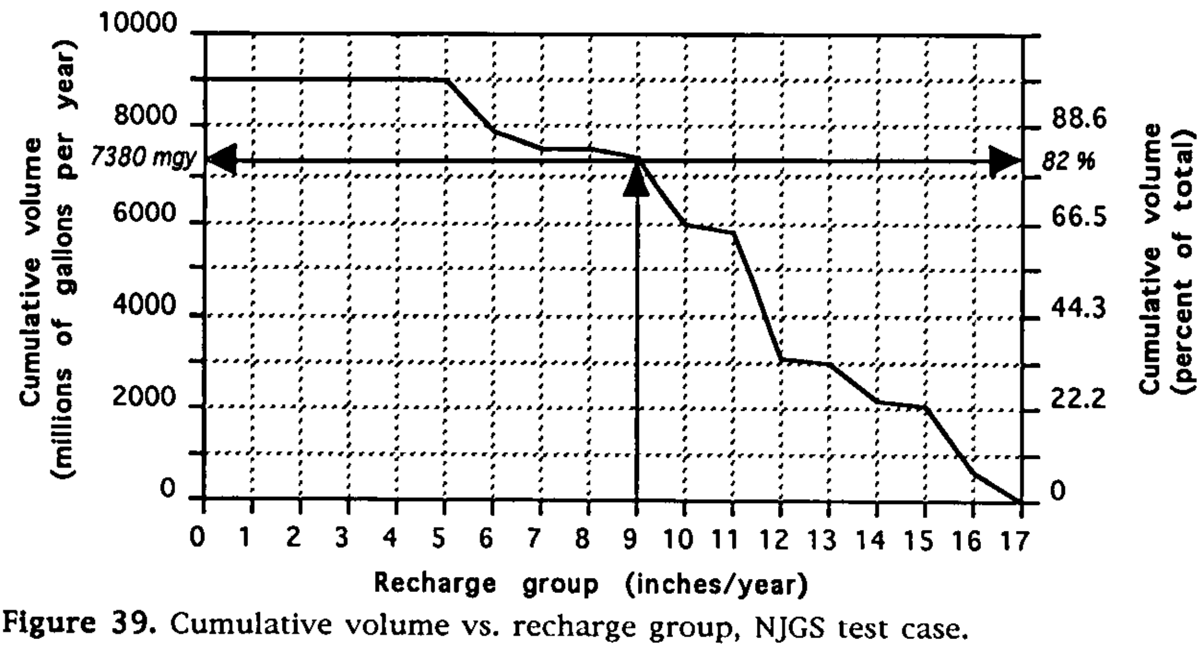


Figure 39. Cumulative volume vs. recharge group, NJGS test case.

The final graph, "cumulative percentage volume and area versus recharge group" (fig. 40), illustrates how the relationship between cumulative volume and the proportion of the total area that contributes to that volume. For example, this graph shows that approximately 60 percent of the study area contributes 82 percent of the recharge volume. The line graphs and the bar graphs are recommended only to graphically illustrate the characteristics of recharge in the study area. Classification of recharge rates by cumulative volume and area is determined by tabular analysis of the 0.1-inch-grouped data as described in the following section.

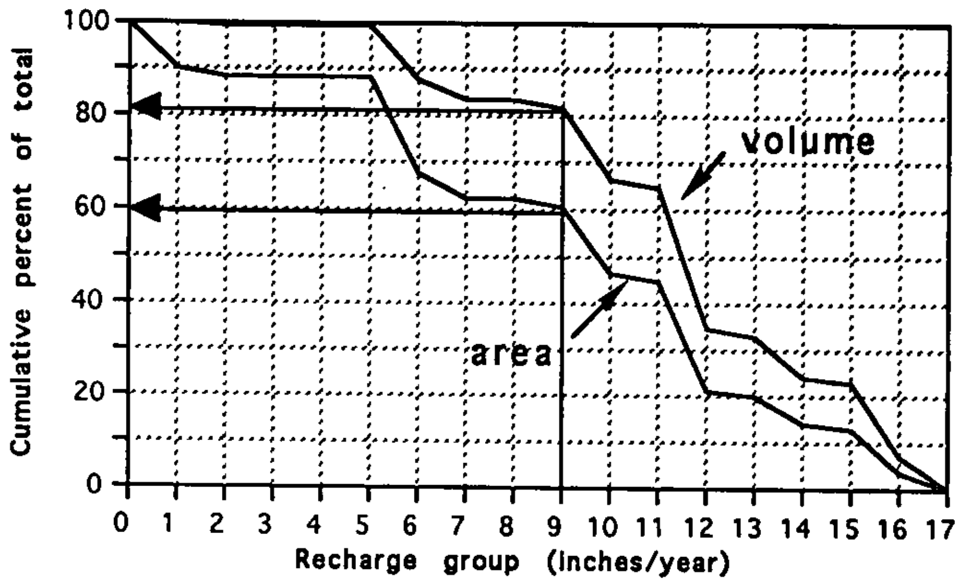


Figure 40. Cumulative volume and area vs. recharge group, NJGS test case.

5. Classify the one-tenth-of-an-inch grouped data

Custom design a classification scheme that is suitable to your planning needs by examining the tabulated 0.1-inch-grouped data. Many classification approaches were tested in order to insure that a single scheme would be valid and universally applicable. The following recommended system was shown to effectively classify recharge groups according to the most significant natural breaks in volumetric recharge (fig. 41).

	Recharge group	Square inches on map	Area (acres x 1000)	Cum. area (acres x 1000)	% of total area	Cum. % of total area	Volume (million gal./year)	Cum. vol. (million gal./year	% of total volume	Cum. % of total volume
0.0 to 5.3	0.0	38.4	3.5	36.6	9.6	100.0	0.0	9023.9	0.0	100.0
	0.2	0.0	0.0	33.1	0.0	90.4	0.0	9023.9	0.0	100.0
	0.6	0.1	0.0	33.1	0.0	90.4	0.2	9023.9	0.0	100.0
	0.9	1.6	0.1	33.1	0.4	90.3	3.5	9023.7	0.0	100.0
	1.1	0.0	0.0	32.9	0.0	89.9	0.1	9020.2	0.0	100.0
	1.3	0.1	0.0	32.9	0.0	89.9	0.4	9020.1	0.0	100.0
	1.5	0.9	0.1	32.9	0.2	89.9	3.3	9019.7	0.0	100.0
	1.8	5.5	0.5	32.8	1.4	89.7	24.7	9016.4	0.3	99.9
	2.2	0.6	0.1	32.3	0.1	88.3	3.2	8991.7	0.0	99.6
	3.7	0.7	0.1	32.3	0.2	88.2	6.9	8988.5	0.1	99.6
	4.6	0.0	0.0	32.2	0.0	88.0	0.2	8981.6	0.0	99.5
	5.0	4.9	0.4	32.2	1.2	88.0	60.9	8981.4	0.7	99.5
5.4 to 6.2	5.4	59.9	5.5	31.7	15.0	86.7	806.7	8920.5	8.9	98.9
	5.5	1.5	0.1	26.2	0.4	71.7	20.8	8113.8	0.2	89.9
	5.8	1.8	0.2	26.1	0.4	71.3	25.5	8092.9	0.3	89.7
	5.9	11.8	1.1	25.9	3.0	70.9	174.2	8067.5	1.9	89.4
6.3 to 9.8	6.3	19.0	1.7	24.8	4.8	67.9	298.2	7893.3	3.3	87.5
	6.7	2.6	0.2	23.1	0.6	63.1	43.0	7595.1	0.5	84.2
	7.7	0.0	0.0	22.9	0.0	62.5	0.1	7552.0	0.0	83.7
	8.1	0.6	0.1	22.9	0.2	62.5	12.8	7551.9	0.1	83.7
	8.5	7.5	0.7	22.8	1.9	62.3	159.5	7539.1	1.8	83.5
	9.0	1.0	0.1	22.1	0.3	60.4	22.7	7379.6	0.3	81.8
	9.4	6.9	0.6	22.0	1.7	60.2	161.2	7356.9	1.8	81.5
	9.5	0.0	0.0	21.4	0.0	58.5	0.0	7195.6	0.0	79.7
9.9 to 11.1	9.9	48.0	4.4	21.4	12.0	58.5	1184.3	7195.6	13.1	79.7
	10.3	3.6	0.3	17.0	0.9	46.4	91.2	6011.3	1.0	66.6
	10.8	3.2	0.3	16.7	0.8	45.5	87.1	5920.1	1.0	65.6
11.2 to 11.6	11.2	31.8	2.9	16.4	8.0	44.7	887.9	5833.0	9.8	64.6
11.7 to 13.4	11.7	62.2	5.7	13.4	15.6	36.7	1814.7	4945.1	20.1	54.8
	11.9	0.0	0.0	7.7	0.0	21.1	0.0	3130.4	0.0	34.7
	12.1	4.8	0.4	7.7	1.2	21.1	144.9	3130.3	1.6	34.7
	12.6	0.0	0.0	7.3	0.0	19.9	1.5	2985.5	0.0	33.1
	13.0	4.1	0.4	7.3	1.0	19.9	132.8	2984.0	1.5	33.1
13.5 to 15.6	13.5	17.1	1.6	6.9	4.3	18.9	576.1	2851.2	6.4	31.6
	13.9	2.2	0.2	5.3	0.6	14.6	77.2	2275.1	0.9	25.2
	14.4	3.0	0.3	5.1	0.8	14.0	107.6	2197.8	1.2	24.4
	14.8	1.0	0.1	4.9	0.2	13.3	35.7	2090.2	0.4	23.2
	15.2	6.0	0.5	4.8	1.5	13.0	226.5	2054.5	2.5	22.8
15.7 to 16.5	15.7	30.7	2.8	4.2	7.7	11.5	1202.3	1828.0	13.3	20.3
	16.0	0.0	0.0	1.4	0.0	3.8	1.9	625.7	0.0	6.9
	16.1	5.2	0.5	1.4	1.3	3.8	209.8	623.8	2.3	6.9
16.6 to 17.0	16.6	9.6	0.9	0.9	2.4	2.5	396.1	414.0	4.4	4.6
	17.0	0.4	0.0	0.0	0.1	0.1	17.9	17.9	0.2	0.2

Figure 41. Full spreadsheet showing step 5 of volumetric method for 0.1-inch grouped data.

Circle the recharge group below which no significant volumetric recharge occurs. The best way to find the zero recharge break is to examine the "cumulative percent of total volume" column. Circle the recharge group at which it is clear that all lesser recharge values contribute no significant additional volume. In the example below, recharge volume is insignificant (see the trend in the cumulative % of total volume column) for recharge values less than 5.4 inches. Thus a circle is drawn around the 5.4-inch recharge group as shown in figure 41.

Mark 7 to 10 additional natural breaks in volumetric recharge. Identify these breaks by examining the "percentage of total volume" column and circling 7 to 10 of the highest values in it.

For each marked value, define a class-interval boundary by drawing a line between the circled value and the next lowest recharge value. In the example (fig. 41), 7 additional boundaries were chosen, starting with 20.1-percent of total volume and ending with 3.3-percent of total volume. Note that the 8.9 value is the same boundary as determined for the no-significant-recharge volume.

Make a table which summarizes, in ascending order, the significant class intervals and their associated percentage of volumetric recharge. To make the class intervals include all possible recharge values, extend the upper limit of each class interval boundary to the lower limit of the class interval above it. In the example (fig. 42), the interval 0.0-5.0 becomes 0.0-5.3, and the interval 5.4-5.9 becomes 5.4-6.2. The percent-volume summary column is filled in by simply summing the percentage-of-total-volume values associated with each class interval.

Class interval	% Volume
0.0 - 5.3	1.1
5.4 - 6.2	11.3
6.3 - 9.8	7.8
9.9 - 11.1	15.1
11.2 - 11.6	9.8
11.7 - 13.4	23.2
13.5 - 15.6	11.4
15.7 - 16.5	15.6
16.6 - 7.0	4.6
	99.9

Figure 42. Significant class intervals and percent volume for volumetric method sample data.

Group the class intervals of the summary list into the number of classes that will be useful for ground-water priorities in the study area. Keep in mind the volume percentage that each class interval represents. In general, the classes desired should be the maximum number that represent useful distinctions in the study area. This step of the classification is very user- and area-specific and involves considerable trial and error and examination of ground-water priorities. Examples of 2- through 6-class interval groupings are shown (fig. 43) for illustration purposes.

CLASSES									
Two		Three		Four		Five		Six	
Interval	% vol.	Interval	% vol.	Interval	% vol.	Interval	% vol.	Interval	% vol.
0.0 - 5.3	1.1	0.0 - 5.3	1.1	0.0 - 5.3	1.1	0.0 - 5.3	1.1	0.0 - 5.3	1.1
5.4 - 7.0	98.8	5.4 - 11.6	44.0	5.4 - 11.1	34.2	5.4 - 9.8	19.1	5.4 - 9.8	19.1
		11.7 - 17.0	54.8	11.2 - 13.4	33.0	9.9 - 11.6	24.9	9.9 - 11.6	24.9
				13.5 - 17.0	31.6	11.7 - 15.6	34.6	11.7 - 13.4	23.2
						15.7 - 17.0	20.2	13.5 - 16.5	27.0
								16.6 - 17.0	4.6

Figure 43. Example classifications of volumetric method sample data.

For the test case shown, NJGS grouped the intervals such that volume contributions are as even as possible. Because of differences in study areas and ground-water priorities, it is likely that the final classification of most users will differ considerably from what is shown here.

Depending on your priorities, you may choose to consider other factors for making the final classification. The proportion of contribution by area, based on the cumulative volumetric percentage of recharge, is important. The "cumulative percent of total area" column could be a factor used. Still other methods could be used to classify the data if defining natural breaks in volume and area tabulations is not consistent with the priorities in a study area. For example, breaks could be made at equal increments (0 to 20 percent, 20 to 40 percent, etc.) rather than at natural breaks.

Before a final classification is selected and areas are ranked, the sorted ungrouped data should be reviewed to see if any of the cumulative-volumetric-classification breaks are the result of a single extremely large polygon. This may modify the decision as to where a classification break is made.

6. Apply ranking labels and shade polygons

Apply ranking labels (for example high, medium, low) to each of the final recharge classes. The ranking labels should reflect the planning priorities and ground-water management practices that the user intends for each recharge class. The polygons on the recharge map can then be shaded according to their rank. The final ranked map can be used to indicate the relative effect of land areas and land uses on the quantity of recharge to ground-water supplies, wetlands, streams, and lakes.

Comparing recharge volume on a parcel-specific basis

In the land planning process it might be necessary to compare the ground-water-recharge volume of two or more parcels of land. A simple calculation allows a comparison of the recharge volume of specific parcels. The calculations below refer to figure 44. To fully understand these calculations, a review of the volumetric-classification method, discussed earlier in this section, may be necessary.

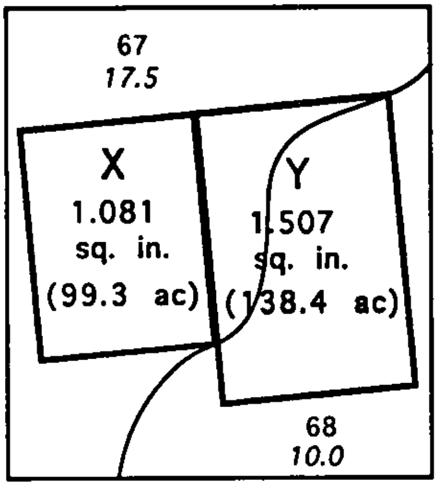


Figure 44. Recharge map with parcels used in volume comparison.

Ground-water recharge through parcel X:

(1.081 sq. in.) x (17.5 recharge in.) x (2,493,667) = 47,173,945 gallons of recharge/year

(Note: 2,493,667 is a conversion factor that is the product of 91.83 square map inches per acre of land and 27,156 gallons of recharge per inch of recharge per acre)

Ground-water recharge through parcel Y:

Portion of parcel Y in polygon no. 67:
(0.467 sq. in.) x (17.5 recharge in.) x (2,493,667) = 20,379,493 gallons of recharge/year
Portion of parcel Y in polygon no. 68:
(1.040 sq. in.) x (10.0 recharge in.) x (2,493,667) = 25,934,136 gallons of recharge/year

Total recharge for parcel X = 47,173,945 gallons/year
Total recharge for parcel Y = 46,313,629 gallons/year

Even though parcel X is substantially smaller than parcel Y, the total recharge in gallons that parcel X contributes is slightly more than that of parcel Y.

IV. LIMITATIONS OF THE GROUND-WATER-RECHARGE MAP

The ground-water-recharge map shows, for distinct land parcels, the recharge estimated based on the combined effects of precipitation, surface runoff, evapotranspiration, land-use/land-cover, and soils. The maps show ground-water recharge rather than aquifer recharge. Aquifer recharge is the recharge that replenishes those geologic formations that can yield economically significant quantities of water to wells. Ground-water recharge does not differentiate recharge to aquifers and non-aquifers, but includes both. An advantage to including recharge to non-aquifers is that in many cases this recharge is necessary for maintenance of streams, lakes and wetlands.

The mapping procedure was designed and tested for application to municipalities at a scale of 1:24,000. Like all maps, however, it has limitations. Some of the limitations are inherent in the soil-water budget and in generalizing the results; others result from the source materials and methods used. Analyses which utilize recharge maps must consider accuracy limitations of the method.

Recharge-value accuracy

Recharge values generated by the method have limitations which stem from techniques for measuring precipitation, estimating runoff and evapotranspiration, classifying land-use/land-cover, and generalizing soil characteristics. In addition, limitations in accuracy stem from generalizing the recharge results of the soil-water budget and from defining recharge soil groups on the basis of these generalized recharge results. Specifically the recharge values are limited by the following assumptions:

- All water which infiltrates below the root zone recharges ground water.
- There is no artificial or induced recharge such as caused by pumping wells and irrigation.
- There is no addition (recharge) or subtraction (discharge) of ground water from surface-water bodies and wet areas.
- The 30-year period of record from the 32 selected climate stations accurately represents statewide temperatures and precipitation.
- Adjustment of the SCS curve-number method based on rainfall and runoff observed from small to moderate sized storms in central New Jersey is applicable to the entire state.
- The 14 land-use/land-covers used in the method represent significant differences in their effect on long-term recharge.
- The soil data generalized from the SCS database are reasonably accurate for all of New Jersey with respect to their effect on ground-water recharge.
- Rooting depths provided by Thornthwaite and Mather (1957) for different combinations of vegetation and soil texture are appropriate for New Jersey.
- The inability of the Thornthwaite method to account for differences in potential evapotranspiration other than as a result of root depth introduces no significant errors.

- Adjustment of the Thornthwaite-derived potential-evapotranspiration values from an open site with no sprinkle irrigation (Seabrook, New Jersey) to observed values is an appropriate adjustment for calculating potential evapotranspiration for the range of statewide natural conditions.

- The difference between runoff from snowmelt or rain on frozen ground to that from rain on unfrozen ground is not significant with respect to the total quantity of long-term ground-water recharge in New Jersey.

- The equations used to generalize the results of the soil-water-budget simulation maintain sufficient accuracy for planning purposes with respect to ground-water recharge.

- The aggregation of soil units into twelve recharge soil groups based on similar recharge characteristics maintains sufficient accuracy with respect to ground-water recharge for planning purposes.

- The generalization of outcrop portions of soil-rock complexes into four categories of relative infiltration potential is sufficiently accurate with respect to ground-water recharge for planning purposes.

Map accuracy

The graphic or spatial accuracy of the resulting map is limited in the following ways:

- The USGS quads, NWI quads, and photoquads have an accuracy of approximately 100 feet.

- Boundaries between soil types in the real world are not distinct because the types grade into one another.

- Some error along the seam of two edgematched maps (quads, photoquads, soil-survey maps) is inevitable. The amount and location of error depend on the error-distribution techniques of the mapper.

- Reduced soil-survey maps, especially those made on a photocopier, are likely to have some error toward the outer edges.

- The LULC, soil, and LULC/soil-group combination maps each have a minimum-sized mapping unit of 5 acres (at 1:24,000-scale).

- Transference of boundaries and other line work to mylar templates is inexact, subject to the interpretive and motor abilities of the mapper. Even a small shift in the position of a boundary may significantly change the area, and thereby the recharge for a polygon.

- The percentage of impervious coverage for a particular polygon may vary significantly depending on the site configuration, and the delineation technique of the mapper.

Classification accuracy

Map accuracy is limited by how the data are classified as well. Classifying and ranking is a way of generalizing data, therefore the resulting map is only a representation of the raw recharge values. The degree of generalization is determined by the number of class intervals and the ranges chosen.

Keep in mind that for classification, what is right for one map user may not be for another. For example, suppose ground-water-recharge data were classified using two different schemes. Ten inches of recharge may be classified as "low" in one scheme, but "high" in the other; this illustrates two very different, but equally correct, interpretations. The choice is based on the needs of the map user. This is an important consideration when determining the kinds of analyses for which the map will be used.

Basin-wide baseflow adjustment

Calibration of calculated volumetric recharge to estimated stream baseflows for test basins indicated the need to modify recharge. The basin factor was added to the recharge equation to meet this goal. Baseflow is a measure of ground-water discharge to streams, and, over the long term, a viable estimate for ground-water recharge.

The calibration process indicated that a constant of 1.3 resulted in basin-wide recharge volumes in line with observed stream baseflows. More detailed analyses may show that different basins may require different basin factors. The accuracy of this adjustment depends on the exact relationship between stream baseflows and the distribution of ground-water recharge.

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GLOSSARY

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.

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 R-factor and R-constant, to yield an estimate of average annual ground-water recharge.

Curve-number method - method of determining surface runoff from a storm by considering land-use/land-cover and soil properties.

Curve number - an index used in the curve-number method presented in U.S. Department of Agriculture, 1985. The number is derived from land-use/land-cover and soil properties. It is used to quantify surface runoff.

Drainage basin - the tract of land that gathers water originating as precipitation and contributes it to a particular stream channel or system of channels.

Edgematch - to align the edges of two or more geographically adjacent map sheets, using recognizable features such as roads, to create one continuous map.

Evaporation - the process by which liquid water is converted to water vapor.

Evapotranspiration - loss of water from a land area through transpiration from plants and evaporation from the soil.

Frequency method - a recharge classification method, developed by NJGS, that categorizes recharge rates according to how many polygons in the study area are represented by each rate.

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 - that part of the 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.

Hydrologic soil group - a four-category (A,B,C,D) classification scheme developed by the Soil Conservation Service that groups soils according to similar runoff potential under similar storm and cover conditions.

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

Initial abstraction - water retained on land areas before surface runoff begins. Initial abstraction results from surface depressions, vegetation interception, evaporation and infiltration.

Interception - the process by which above-ground elements, especially vegetation, block precipitation from reaching the land surface.

Lysimeter - a soil-water collection device or container over which vegetation is maintained for the purpose of studying various soil-water-plant relationships. Evapotranspiration is commonly determined from container-type lysimeters by the measured difference between the inflow and outflow of liquid water.

Mylar template - translucent drafting film which contains registration ticks, study area boundaries and wetland delineations for precise overlay and data transfer.

Permeability - commonly used in place of saturated hydraulic conductivity; a measure of the ease with which a water-bearing material (soil or geologic formation) can transmit water.

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

Precipitation - any form of water (rain, hail, sleet, snow) falling from the atmosphere.

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 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 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," etc.

Recharge soil group - an eight-category (A through H) classification scheme developed by the New Jersey Geological Survey that describes the ground-water-recharge potential of soil units mapped in New Jersey.

Registration - alignment of two or more maps of the same area and scale by the matching and exact overlay of common features.

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.

Sliver - a very narrow polygon, about 1/16 inch in width or less at a map scale of 1:24,000.

Soil complex - a soil-map unit of two or more kinds of soil in such a small or intricate pattern that it is not practical to map them separately at the selected scale of mapping.

Soil group - same as recharge soil group

Soil series - soils identified by a common name that have profiles similar in major horizons, composition, thickness, and arrangement.

Soil symbol - the map abbreviation or code for a soil-map unit.

Soil unit/soil-map unit - a named map area with distinct soil properties. A soil unit is either a soil series, a complex of soil series, or a mapped soil/non-soil area that is named but not necessarily associated with a soil series.

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.

Surface runoff - water that flows over the land surface to bodies of water rather than entering the soil.

Thiessen polygon - a polygon which describes an area of nearest proximity to a given point in a distribution of points.

Transpiration - the process by which water is discharged as water vapor through plant leaves and needles.

Volumetric method - a recharge classification method, developed by NJGS, that categorizes recharge areas according to the proportion of total recharge represented by each recharge-rate category

APPENDIX 1

Legislation

Environmental Protection - Aquifer Recharge Areas

CHAPTER 41
ASSEMBLY NO. 1340

AN ACT concerning the mapping of aquifer recharge areas, supplementing Title 58 of the Revised Statutes, and making an appropriation.

Be it enacted by the Senate and the General Assembly of the State of New Jersey:

1.[1] As used in this act, "aquifer recharge area" means an area which may be composed of sand or gravel, may be located at points of substantial fracturing in geological formations, may extend to the ground surface in certain locations, and which transmits water to an aquifer under the influence of vertical head differentials and refills or "recharges" primarily by infiltration of precipitation through the ground surface.

2.[2] The Department of Environmental Protection, within two years of the effective date of this act, shall prepare and publish a methodology which shall allow the user to define, rank, and map aquifer recharge areas. In conjunction with this methodology, the Department shall prepare and publish model land use regulations or best management practices designed to encourage ecologically sound development in aquifer recharge areas and to restrict therein those activities known to cause ground-water contamination.

3.[3] The Department of Environmental Protection, within four years of the effective date of this act, shall prepare and publish a map of the aquifer recharge areas in the state, using, to the greatest extent possible, the revised state geologic map (scale 1:100,000), and any local and regional mapping efforts already completed or underway which the department shall verify. Periodically thereafter, as appropriate, the Department shall update these maps.

4.[4] The map of aquifer recharge areas prepared pursuant to section 3 of this act and the suggested land use regulations prepared pursuant to section 2 of this act are to be used solely at the discretion of a municipality, and are to be considered guidance as to how orderly development may proceed in conjunction with the sound protection and management of ground-water quality.

5.[5] The Department shall adopt, pursuant to the "Administrative Procedure Act", P.L. 1968, c. 410 (C. 52:14B-1 et seq.), any rules and regulation necessary to implement the provisions of this act.

6. There is appropriated from the General Fund to the Department of Environmental Protection $1,000,000.00 to implement the provisions of this act.

7. This act shall take effect immediately.

Approved June 22, 1988
Effective June 22, 1988

[1] N.J.S.A. 58:11A-12
[2] N.J.S.A. 58:11A-13
[3] N.J.S.A. 58:11A-14
[4] N.J.S.A. 58:11A-15
[5] N.J.S.A. 58:11A-16

APPENDIX 2

Land-use/land-cover Definitions by LULC Code

(for specifics on using this table, see Section II-3a of main text, "Preparing LULC overlay")

LULC Code	LULC descriptions
	----- **Urban/Suburban Features** -----
0	Landscaped open space (0% impervious) - includes lawns, parks, athletic fields, golf courses, cemeteries, and their associated structures.
1	Residential (65% impervious), 1/8 acre lots - usually multi-family dwelling units.
2	Residential (33% impervious), greater than 1/8 acre up to and including 1/2 acre lots
3	Residential (23% impervious), greater than 1/2 acre up to and including 1 acre lots
4	Residential (17% impervious), greater than 1 acre up to and including 2 acre lots
5	Landscaped Commercial/Industrial/Institutional/Mixed-Use Areas - that contain some vegetated areas (approximately 15% of the total area is vegetated or 85% impervious). Use this category for highways that are wide enough to be mapped <u>and</u> contain exceptionally wide medial strips. Also use for large parking lots with substantial vegetated medians or "islands". Remember to separate landscaped open space and other undeveloped areas of five acres or more.
6	Unlandscaped Commercial/Industrial/Institutional/Mixed-Use Areas - that lack vegetated areas and are entirely impervious. Use for highways that are wide enough to be mapped but <u>lack</u> exceptionally wide medial strips. Also use for parking lots and developed areas that lack substantial vegetated medians or "islands".
7	Permanently unvegetated or sparsely vegetated areas (0% impervious-includes areas such as unpaved parking lots (for example at a fairground) and unvegetated pits.
	----- **Rural/Agricultural Features** -----
8	Agricultural land -- includes all cropland, permanent pasture, meadows, and their associated structures
10	Agricultural land -- cropland, legumes
11	Agricultural land -- permanent pasture, meadow; regardless of whether grazed or mowed for hay.
9	Wooded areas -- includes woods, brush, orchards, shrub, tree nurseries, and their associated structures
12	Brush -- uncultivated areas of low to medium height shrubs, weeds, and grass.
13	Woods, orchards, shrubs, and tree nurseries

(1 through 5 assume that pervious portions of lots are fully vegetated with either grass, woods, or mixed. For large developments, remember to separate landscaped open space and other undeveloped areas of five acres or more.)

Appendix 3

Recharge Soil Group by Soil Unit

Derived from NJGS recharge simulations, see Appendix 7 for details.
Asterisk (*) denotes variable soil properties, consult county SCS office for site-specific details (except for quarry).

Soil Unit	Recharge Group
ABBOTTSTOWN	F
ADELPHIA	G
ADELPHIA VARIANT	G
ADRIAN	L
ALBIA	F
ALLUVIAL LAND	L
ALLUVIAL LAND-WET	L
AMWELL	F
ANNANDALE	F
AQUENTS	L
ARENDTSVILLE	B
ATHERTON	L
ATHOL	B
ATSION	L
AURA	D
BARCLAY	I
BARTLEY	F
BATH	F
BAYBORO	L
BEDINGTON	B
BERKS	F
BERRYLAND	L
BERRYLAND VARIANT	L
BERTIE	D
BIBB	L
BIDDEFORD	L
BIRDSBORO	B
BOONTON	F
BOONTON-ROCK OUTCROP	E
BOWMANSVILLE	L
BRACEVILLE	F
BUCKS	B
CALIFON	F
CARLISLE	L
CHALFONT	F
CHENANGO	A
CHILLUM	F
CHIPPEWA	L
CLAY PITS	F
CLAYEY LAND	F
COASTAL BEACH	C
COKESBURY	L
COLEMANTOWN	L
COLLINGTON	G
COLONIE	A
COLTS NECK	G
CROTON	L
CUT AND FILL LAND	*
DONLONTON	I
DOWNER	D
DOYLESTOWN	L
DRAGSTON	F
DUFFIELD	B
DUNE LAND	C
DUNELLEN	B
DUNELLEN VARIANT	B
EDNEYVILLE	B
EDNEYVILLE MATERIAL	B
EDNEYVILLE-PARKER-ROCK OUTCROP	F
ELKTON	L
ELLINGTON (MIDDLESEX)	G
ELLINGTON (MORRIS)	B
EVESBORO	C
FALLSINGTON	L
FALLSINGTON VARIANT	L
FILL LAND	*
FLUVAQUENTS	L
FORT MOTT	C
FREDON	L
FREEHOLD	G
FRESH WATER MARSH	L
FRIPP	C
GALESTOWN	C
GLADSTONE	B
GRAVEL PITS	C
HALEDON	F
HALEDON, WET VARIANT	L
HALSEY	L
HAMMONTON	D
HASBROUCK	L
HAZEN	B
HAZLETON	B
HERO	B
HIBERNIA	F
HOLMDEL	I
HOLYOKE	E
HOLYOKE-ROCK OUTCROP (MORRIS)	J
HOLYOKE-ROCK OUTCROP (PASSAIC)	E
HOOKSAN	D
HOOKSAN VARIANT	L
HOOSIC	A
HOWELL	F
HUMAQUEPTS	L
KEANSBURG	L
KEYPORT	F
KEYPORT SOILS	F
KLEJ	C
KLINESVILLE	E
KRESSON	F
LACKAWANNA	F
LAKEHURST	C
LAKELAND	C
LAKEWOOD	C
LAMINGTON	L
LANSDALE	B
LANSDOWNE	F
LANSDOWNE VARIANT	F
LAWRENCEVILLE	F
LEGORE	B
LEHIGH	F
LENOIR	L
LEON	L
LIVINGSTON	L
LOAMY ALLUVIAL LAND	L
LYONS	L
MADE LAND	*
MANAHAWKIN	L
MARLTON	F
MARSH	L
MATAPEAKE	G

Soil Unit	Recharge Group
MATAWAN	F
MATLOCK	L
MATTAPEX	I
MECKESVILLE	F
MIDDLEBURY	B
MINOA	F
MODERATELY WET LAND	L
MOUNT LUCAS	F
MUCK	L
MUCK, SHALLOW OVER CLAY	L
MUCK, SHALLOW OVER LOAM	L
MULLICA	L
NASSAU	F
NASSAU-ROCK OUTCROP (SUSSEX)	F
NASSAU-ROCK OUTCROP (WARREN)	E
NESHAMINY	D
NESHAMINY VARIANT	F
NETCONG	B
NIXON	D
NIXON VARIANT	D
NIXONTON	G
NORTON	F
NORWICH	L
OCHREPTS	B
OQUAGA	F
OQUAGA-ROCK OUTCROP	F
OQUAGA-SWARTSWOOD ROCK OUTCROP	F
OTHELLO	L
OTISVILLE	C
PALMYRA	B
PARKER	B
PARKER-ROCK OUTCROP	F
PARSIPPANY	L
PARSIPPANY VARIANT	L
PASCACK	F
PASQUOTANK	L
PASSAIC	L
PATTENBURG	B
PEAT	L
PEMBERTON	D
PENN	F
PHALANX	D
PITS, MUCK	L
PLUMMER	L
POCOMOKE	L
POMPTON	B
POPE	B
PORTSMOUTH	L
PREAKNESS	L
PSAMMENTS	*
QUAKERTOWN	F
QUARRY	*
RARITAN	F
RAYNHAMN	L
READINGTON	F
REAVILLE	F
REAVILLE VARIANT	L
RIDGEBURY	L
RIVERHEAD	D
RIVERHEAD VARIANT	B
ROCK LAND, EDNEYVILLE MATERIAL	E
ROCK OUTCROP (GREEN POND CONGLOMERATE. MORRIS)	K
ROCK OUTCROP-HOLYOKE	J
ROCK OUTCROP-NASSAU	E
ROCK OUTCROP-OQUAGA (SUSSEX)	J
ROCK OUTCROP-OQUAGA (WARREN)	F
ROCK OUTCROP-PARKER-EDNEYVILLE	F
ROCK OUTCROP-ROCKAWAY (MORRIS)	K
ROCK OUTCROP-ROCKAWAY (PASSAIC)	J
ROCK OUTCROP-ROCKAWAY (SUSSEX)	K
ROCK OUTCROP-ROCKAWAY-PARKER	H
ROCK OUTCROP-SWARTSWOOD	J
ROCK OUTCROP-WASSAIC	F
ROCKAWAY	E
ROCKAWAY-ROCK OUTCROP (BERGEN)	H
ROCKAWAY-ROCK OUTCROP (MORRIS)	H
ROCKAWAY-ROCK OUTCROP (PASSAIC)	H
ROCKAWAY-ROCK OUTCROP (SUSSEX)	H
ROUGH BROKEN LAND, SHALE	E
ROWLAND	F
ROYCE	F
SAND PITS	C
SANDY ALLUVIAL LAND	L
SANDY AND CLAYEY LAND	D
SANDY AND SILTY LAND	B
SANDY LAND (BURLINGTON)	D
SANDY LAND (SALEM)	D
SANDY PITS	C
SASSAFRAS	G
SHREWSBURY	L
SHREWSBURY VARIANT	L
SLOAN	L
ST. JOHNS	L
STEEP STONY LAND, PARKER	B
STEINSBURG	F
SULFAHEMISTS	L
SULFAQUENTS	L
SWAMP	L
SWARTSWOOD	F
SWARTSWOOD-ROCK OUTCROP	H
TIDAL MARSH	L
TINTON	C
TIOGA	D
TUNKHANNOCK	C
TURBOTVILLE	F
UDIFLUVENTS	F
UDORTHENTS	*
UNADILLA	A
URBAN LAND	*
URBAN LAND, WET	*
VALOIS	A
VENANGO	F
VERY STONY LAND, MOUNT LUCAS	J
VERY STONY LAND, NESHAMINY	J
VERY STONY LAND, WATCHUNG	L
WALLKILL	L
WASHINGTON	D
WASSAIC	B
WASSAIC-ROCK OUTCROP (SUSSEX)	G
WASSAIC-ROCK OUTCROP (WARREN)	G
WATCHUNG	L
WAYLAND	L
WEEKSVILLE	L
WESTPHALIA	G
WETHERSFIELD	F
WETHERSFIELD-ROCK OUTCROP	H
WHIPPANY	F
WHITMAN	L
WOODMANSIE	D
WOODSTOWN	F
WOOSTER	F
WURTSBORO	F

Appendix 4

Recharge Constants and Factors by Recharge Soil Group

Recharge factors are shown in plain text
Recharge constants are shown in italicized text.

RECHARGE SOIL GROUP	LULC Code 0	1	2	3	4	5	6	7	8	9	10	11	12	13
A	23.88	8.36	16.00	18.39	19.82	3.58	0.00	11.75	20.54	25.27	18.00	24.36	25.67	25.06
	21.60	*7.56*	*14.47*	*16.63*	*17.92*	*3.24*	*0.00*	*6.19*	*17.33*	*23.64*	*14.01*	*22.32*	*24.15*	*23.39*
B	19.06	6.67	12.77	14.67	15.82	2.86	0.00	9.23	16.54	20.73	14.51	19.59	21.06	20.57
	14.04	*4.91*	*9.41*	*10.81*	*11.65*	*2.11*	*0.00*	*4.47*	*11.93*	*16.12*	*10.06*	*14.73*	*16.19*	*16.09*
C	17.77	6.22	11.90	13.68	14.75	2.66	0.00	12.57	16.89	19.90	15.76	18.60	18.69	20.50
	9.82	*3.44*	*6.58*	*7.56*	*8.15*	*1.47*	*0.00*	*4.83*	*9.40*	*13.47*	*8.16*	*11.25*	*11.31*	*14.55*
D	17.15	6.00	11.49	13.21	14.23	2.57	0.00	8.67	14.93	19.84	13.01	17.83	19.30	20.11
	10.65	*3.73*	*7.14*	*8.20*	*8.84*	*1.60*	*0.00*	*2.80*	*8.97*	*14.47*	*7.20*	*11.62*	*13.11*	*15.15*
E	10.10	3.53	6.77	7.78	8.38	1.51	0.00	4.59	8.40	11.41	7.02	10.47	12.50	10.86
	1.66	*0.58*	*1.11*	*1.28*	*1.38*	*0.25*	*0.00*	*-0.93*	*0.75*	*2.92*	*-0.09*	*2.01*	*4.02*	*2.37*
F	14.19	4.97	9.51	10.92	11.78	2.13	0.00	6.01	12.51	16.67	10.77	15.13	17.09	16.46
	8.72	*3.05*	*5.85*	*6.71*	*7.24*	*1.31*	*0.00*	*2.64*	*8.39*	*11.80*	*7.33*	*9.99*	*11.56*	*11.93*
G	18.20	6.37	12.24	14.02	15.11	2.73	0.00	11.16	16.86	19.98	15.77	18.49	19.41	20.27
	13.04	*4.56*	*8.80*	*10.04*	*10.82*	*1.96*	*0.00*	*7.69*	*12.72*	*15.26*	*12.32*	*13.31*	*13.91*	*15.93*
H	9.04	3.17	6.06	6.96	7.51	1.36	0.00	4.53	7.77	10.31	6.63	9.48	10.97	9.99
	2.18	*0.76*	*1.45*	*1.68*	*1.81*	*0.33*	*0.00*	*0.11*	*1.73*	*3.52*	*1.10*	*2.68*	*3.95*	*3.30*
I	16.71	5.85	11.19	12.86	13.87	2.51	0.00	7.74	14.29	19.24	12.17	17.47	19.55	19.08
	13.20	*4.62*	*8.85*	*10.17*	*10.96*	*1.98*	*0.00*	*6.07*	*12.10*	*16.26*	*10.75*	*14.12*	*15.64*	*16.57*
J	6.63	2.32	4.39	5.11	5.51	1.00	0.00	-0.07	4.75	7.99	3.17	7.11	8.95	7.52
	-1.24	*-0.44*	*-0.97*	*-0.96*	*-1.03*	*-0.19*	*0.00*	*-8.32*	*-3.15*	*0.43*	*-4.84*	*-0.63*	*1.54*	*-0.12*
K	3.47	1.22	2.33	2.67	2.88	0.52	0.00	1.95	2.99	3.81	2.60	3.57	4.10	3.67
	-2.19	*-0.77*	*-1.51*	*-1.69*	*-1.82*	*-0.33*	*0.00*	*-3.53*	*-2.64*	*-1.80*	*-3.01*	*-2.08*	*-1.47*	*-1.97*
L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*

Appendix 5

Recharge Factors and Constants by Soil Series

R-factors are shown in plain text.

R-constants are shown in italicized text.

Asterisk(*) denotes variable soil properties, consult county SCS office for site-specific details.

	LULC Code													
Soil Unit	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
ABBOTTSTOWN	14.70	5.14	9.85	11.32	12.20	2.20	0	6.68	12.15	16.37	10.13	15.19	17.75	15.68
	9.38	*3.28*	*6.28*	*7.22*	*7.79*	*1.41*	*0*	*4.53*	*7.65*	*11.00*	*6.18*	*9.85*	*12.37*	*10.32*
ADELPHIA	20.73	7.26	13.89	15.96	17.21	3.11	0	10.53	18.26	23.14	16.40	21.06	22.56	23.43
	16.52	*5.78*	*11.07*	*12.72*	*13.71*	*2.48*	*0*	*6.80*	*14.65*	*19.64*	*13.19*	*16.83*	*18.24*	*20.35*
ADELPHIA VARIANT	20.97	7.34	14.05	16.15	17.40	3.15	0	9.97	18.17	23.57	16.06	21.35	23.03	23.84
	16.96	*5.94*	*11.36*	*13.06*	*14.08*	*2.54*	*0*	*6.23*	*14.64*	*20.31*	*12.86*	*17.32*	*18.97*	*20.97*
ADRIAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
ALBIA	15.96	5.59	10.69	12.29	13.25	2.39	0	5.15	12.25	18.40	9.30	16.66	20.48	17.36
	11.65	*4.08*	*7.81*	*8.97*	*9.67*	*1.75*	*0*	*0.94*	*7.54*	*14.72*	*4.23*	*12.52*	*17.40*	*13.38*
ALLUVIAL LAND	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
ALLUVIAL LAND-WET	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
AMWELL	13.30	4.65	8.91	10.24	11.04	1.99	0	6.05	11.00	14.83	9.17	13.75	16.11	14.20
	6.93	*2.43*	*4.64*	*5.34*	*5.75*	*1.04*	*0*	*3.10*	*5.53*	*8.34*	*4.33*	*7.34*	*9.55*	*7.74*
ANNANDALE	14.16	4.96	9.49	10.91	11.76	2.12	0	5.10	11.53	15.89	9.43	14.67	17.33	15.17
	8.86	*3.10*	*5.93*	*6.82*	*7.35*	*1.33*	*0*	*0.92*	*7.05*	*10.52*	*5.52*	*9.33*	*11.95*	*9.81*
AQUENTS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
ARENDTSVILLE	19.45	6.81	13.03	14.97	16.14	2.92	0	9.76	17.06	21.31	14.96	20.20	21.52	21.21
	14.46	*5.06*	*9.69*	*11.14*	*12.01*	*2.17*	*0*	*5.27*	*12.61*	*16.91*	*10.63*	*15.58*	*16.74*	*16.99*
ATHERTON	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
ATHOL	20.74	7.26	13.89	15.97	17.21	3.11	0	10.83	18.62	22.33	16.75	21.41	22.66	22.17
	16.85	*5.90*	*11.29*	*12.97*	*13.99*	*2.53*	*0*	*7.83*	*15.51*	*18.82*	*13.98*	*17.81*	*18.91*	*18.77*
ATSION	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
AURA	19.61	6.86	13.14	15.10	16.27	2.94	0	10.74	17.40	21.94	15.72	19.91	21.26	22.29
	14.60	*5.11*	*9.78*	*11.24*	*12.12*	*2.19*	*0*	*6.41*	*12.96*	*17.70*	*11.69*	*14.87*	*16.13*	*18.49*
BARCLAY	16.66	5.83	11.16	12.82	13.82	2.50	0	7.42	13.78	19.29	11.54	17.13	19.55	19.16
	13.06	*4.57*	*8.75*	*10.06*	*10.84*	*1.96*	*0*	*5.67*	*11.21*	*16.15*	*9.73*	*13.44*	*15.44*	*16.50*
BARTLEY	14.54	5.09	9.74	11.19	12.07	2.18	0	5.65	12.00	16.26	9.96	15.05	17.70	15.55
	9.48	*3.32*	*6.35*	*7.30*	*7.86*	*1.42*	*0*	*1.98*	*7.82*	*11.14*	*6.41*	*9.95*	*12.56*	*10.43*
BATH	15.08	5.28	10.10	11.61	12.52	2.26	0	5.48	11.95	17.20	9.45	15.70	18.98	16.31
	10.33	*3.62*	*6.92*	*7.95*	*8.57*	*1.55*	*0*	*2.13*	*7.50*	*12.77*	*5.14*	*11.02*	*14.87*	*11.72*
BAYBORO	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
BEDINGTON	20.30	7.11	13.60	15.63	16.85	3.05	0	10.31	18.10	21.92	16.14	21.03	22.34	21.70
	16.06	*5.62*	*10.76*	*12.36*	*13.33*	*2.41*	*0*	*6.64*	*14.53*	*18.06*	*12.80*	*17.12*	*18.34*	*17.93*

	LULC Code													
Soil Unit	0	1	2	3	4	5	6	7	8	9	10	11	12	13
BERKS	14.59	5.11	9.77	11.23	12.11	2.19	0	6.28	11.99	16.23	9.93	15.08	17.56	15.56
	9.00	3.15	6.03	6.93	7.47	1.35	0	2.85	7.13	10.62	5.56	9.48	11.95	9.95
BERRYLAND	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BERRYLAND VARIANT	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BERTIE	21.00	7.35	14.07	16.17	17.43	3.15	0	12.87	19.32	22.88	18.00	21.29	22.74	22.95
	16.54	5.79	11.08	12.74	13.73	2.48	0	8.72	15.54	19.05	14.69	16.81	18.28	19.43
BIBB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BIDDEFORD	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BIRDSBORO	19.41	6.80	13.01	14.95	16.11	2.91	0	9.69	17.18	21.33	15.21	20.14	21.53	21.22
	14.63	5.12	9.80	11.26	12.14	2.19	0	5.86	13.10	17.07	11.41	15.64	16.92	17.14
BOONTON	13.43	4.70	9.00	10.34	11.15	2.01	0	6.09	11.17	14.93	9.37	13.87	16.18	14.31
	7.48	2.62	5.01	5.76	6.21	1.12	0	3.32	6.16	8.81	5.03	7.86	9.95	8.24
BOONTON- ROCK OUTCROP	10.66	3.73	7.14	8.20	8.84	1.60	0	4.74	8.80	11.82	7.33	10.99	12.80	11.33
	3.75	1.31	2.50	2.89	3.11	0.56	0	0.52	2.67	4.70	1.77	4.01	5.55	4.28
BOWMANSVILLE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BRACEVILLE	14.22	4.98	9.53	10.95	11.80	2.13	0	6.22	11.44	16.01	9.25	14.73	17.55	15.25
	8.54	2.99	5.72	6.57	7.09	1.28	0	2.72	6.10	10.44	4.13	9.05	12.14	9.59
BUCKS	20.29	7.10	13.59	15.62	16.84	3.04	0	10.71	17.92	21.67	15.94	20.87	22.28	21.37
	16.05	5.62	10.75	12.36	13.32	2.41	0	7.76	14.31	17.58	12.62	16.84	18.14	17.30
CALIFON	14.20	4.97	9.52	10.94	11.79	2.13	0	5.55	11.65	15.91	9.61	14.70	17.32	15.20
	8.87	3.11	5.94	6.83	7.36	1.33	0	1.99	7.17	10.50	5.72	9.34	11.90	9.80
CARLISLE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHALFONT	13.83	4.84	9.27	10.65	11.48	2.07	0	6.30	11.42	15.36	9.50	14.28	16.63	14.73
	7.90	2.77	5.29	6.08	6.56	1.19	0	3.71	6.34	9.31	5.03	8.30	10.50	8.71
CHENANGO	22.62	7.92	15.16	17.42	18.78	3.39	0	14.23	20.67	23.16	19.19	22.89	23.02	23.22
	18.61	6.51	12.47	14.33	15.45	2.79	0	8.87	16.38	19.43	14.61	19.02	19.18	19.55
CHILLUM	22.64	7.93	15.17	17.44	18.79	3.40	0	11.61	19.96	24.92	17.61	23.49	25.05	24.86
	19.27	6.74	12.91	14.83	15.99	2.89	0	9.43	17.29	22.03	15.24	20.37	21.80	22.14
CHIPPEWA	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CLAY PITS	13.22	4.63	8.86	10.18	10.97	1.98	0	6.61	11.49	15.88	9.67	14.22	16.21	15.71
	6.69	2.34	4.48	5.15	5.55	1.00	0	2.36	6.33	10.38	5.05	8.26	9.90	10.62
CLAYEY LAND	14.81	5.18	9.92	11.40	12.29	2.22	0	8.55	12.97	17.41	11.13	15.72	17.78	17.23
	8.84	3.09	5.92	6.81	7.34	1.33	0	5.03	8.36	12.45	7.07	10.30	12.00	12.68
COASTAL BEACH	19.61	6.87	13.14	15.10	16.28	2.94	0	15.08	18.66	20.11	17.97	19.70	19.75	20.29
	11.25	3.94	7.54	8.67	9.34	1.69	0	7.25	10.53	12.53	9.86	11.55	11.60	13.00
COKESBURY	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COLEMANTOWN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Soil Unit	LULC Code 0	1	2	3	4	5	6	7	8	9	10	11	12	13
COLLINGTON	20.38	7.13	13.65	15.69	16.91	3.06	0	10.19	17.91	22.76	16.04	20.71	22.21	23.04
	15.99	*5.60*	*10.71*	*12.31*	*13.27*	*2.40*	*0*	*6.15*	*14.09*	*19.07*	*12.62*	*16.30*	*17.71*	*19.75*
COLONIE	26.87	9.41	18.01	20.69	22.31	4.03	0	14.97	23.95	27.81	21.68	27.35	27.62	27.91
	26.21	*9.17*	*17.56*	*20.18*	*21.75*	*3.93*	*0*	*9.83*	*22.21*	*27.77*	*19.01*	*27.00*	*27.40*	*27.96*
COLTS NECK	21.43	7.50	14.36	16.50	17.79	3.21	0	11.18	18.76	24.17	16.77	21.75	23.22	24.64
	17.45	*6.11*	*11.69*	*13.43*	*14.48*	*2.62*	*0*	*7.55*	*15.33*	*21.04*	*13.72*	*17.73*	*19.10*	*22.01*
CROTON	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
CUT AND FILL LAND*														
DONLONTON	16.69	5.84	11.18	12.85	13.85	2.50	0	6.77	14.38	20.07	11.73	18.35	20.84	19.69
	13.17	*4.61*	*8.82*	*10.14*	*10.93*	*1.98*	*0*	*4.17*	*12.43*	*17.57*	*10.27*	*15.67*	*17.69*	*17.50*
DOWNER	16.97	5.94	11.37	13.07	14.08	2.55	0	10.16	15.46	20.15	13.84	17.90	19.29	20.58
	10.08	*3.53*	*6.76*	*7.76*	*8.37*	*1.51*	*0*	*4.96*	*9.41*	*14.78*	*8.01*	*11.51*	*12.89*	*15.73*
DOYLESTOWN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
DRAGSTON	15.80	5.53	10.59	12.17	13.12	2.37	0	8.83	13.62	18.12	11.95	16.13	17.83	18.27
	11.14	*3.90*	*7.46*	*8.58*	*9.24*	*1.67*	*0*	*6.29*	*10.01*	*14.06*	*9.12*	*11.35*	*12.52*	*14.83*
DUFFIELD	20.10	7.03	13.47	15.48	16.68	3.01	0	9.46	17.95	21.96	15.93	20.99	22.31	21.78
	15.68	*5.49*	*10.51*	*12.08*	*13.02*	*2.35*	*0*	*4.65*	*14.25*	*18.14*	*12.39*	*17.05*	*18.28*	*18.07*
DUNE LAND	18.22	6.38	12.21	14.03	15.12	2.73	0	13.96	17.26	18.87	16.53	18.34	18.42	19.09
	9.62	*3.37*	*6.44*	*7.41*	*7.98*	*1.44*	*0*	*5.90*	*8.87*	*11.08*	*8.14*	*9.96*	*10.04*	*11.60*
DUNELLEN	18.67	6.53	12.51	14.38	15.50	2.80	0	8.88	16.16	20.46	14.29	18.98	20.40	20.49
	13.30	*4.65*	*8.91*	*10.24*	*11.04*	*1.99*	*0*	*3.83*	*11.25*	*15.55*	*9.71*	*13.58*	*14.91*	*15.87*
DUNELLEN VARIANT	18.78	6.57	12.58	14.46	15.58	2.82	0	8.99	16.28	20.61	14.41	19.07	20.42	20.71
	13.42	*4.70*	*8.99*	*10.33*	*11.14*	*2.01*	*0*	*3.91*	*11.34*	*15.76*	*9.78*	*13.68*	*14.93*	*16.18*
EDNEYVILLE	18.90	6.61	12.66	14.55	15.69	2.83	0	8.41	16.10	20.34	14.01	19.24	20.86	20.08
	13.80	*4.83*	*9.25*	*10.63*	*11.46*	*2.07*	*0*	*2.94*	*11.24*	*15.42*	*9.31*	*14.14*	*15.81*	*15.23*
EDNEYVILLE MATERIAL	19.80	6.93	13.27	15.25	16.44	2.97	0	9.10	17.20	21.17	15.25	20.12	21.56	20.98
	15.14	*5.30*	*10.15*	*11.66*	*12.57*	*2.27*	*0*	*3.71*	*12.84*	*16.71*	*11.09*	*15.45*	*16.92*	*16.60*
EDNEYVILLE-PARKER-ROCK OUTCROP	18.27	6.39	12.24	14.07	15.16	2.74	0	8.30	15.51	19.59	13.45	18.60	20.15	19.31
	14.58	*5.10*	*9.76*	*11.23*	*12.11*	*2.19*	*0*	*3.25*	*11.62*	*16.23*	*9.38*	*14.97*	*16.84*	*15.93*
ELKTON	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
ELLINGTON (MIDDLESEX)	17.63	6.17	11.81	13.58	14.63	2.64	0	7.23	15.32	18.84	13.55	17.97	19.52	18.50
	12.01	*4.20*	*8.04*	*9.25*	*9.97*	*1.80*	*0*	*1.77*	*10.28*	*13.16*	*8.92*	*12.33*	*13.82*	*12.83*
ELLINGTON (MORRIS)	19.68	6.89	13.18	15.15	16.33	2.95	0	9.28	17.10	21.24	15.19	19.97	21.28	21.23
	15.21	*5.32*	*10.19*	*11.71*	*12.62*	*2.28*	*0*	*4.76*	*13.10*	*17.08*	*11.53*	*15.46*	*16.58*	*17.33*
EVESBORO	18.05	6.32	12.10	13.90	14.98	2.71	0	13.09	17.31	21.32	16.07	19.17	19.28	22.33
	10.39	*3.64*	*6.96*	*8.00*	*8.62*	*1.56*	*0*	*5.47*	*10.13*	*15.77*	*8.70*	*12.28*	*12.40*	*17.45*
FALLSINGTON	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
FALLSINGTON VARIANT	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
FILL LAND *														

	LULC Code													
Soil Unit	0	1	2	3	4	5	6	7	8	9	10	11	12	13
FLUVAQUENTS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
FORT MOTT	18.89	6.61	12.66	14.55	15.68	2.83	0	13.47	18.56	22.43	17.11	20.74	20.85	23.22
	11.80	*4.13*	*7.91*	*9.09*	*9.79*	*1.77*	*0*	*6.08*	*12.26*	*17.59*	*10.52*	*14.88*	*14.99*	*18.89*
FREDON	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
FREEHOLD	20.43	7.15	13.69	15.73	16.95	3.06	0	10.11	17.96	22.88	16.09	20.76	22.26	23.19
	16.07	*5.62*	*10.77*	*12.37*	*13.34*	*2.41*	*0*	*5.90*	*14.18*	*19.27*	*12.71*	*16.38*	*17.79*	*20.00*
FRESH WATER MARSH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
FRIPP	18.37	6.43	12.31	14.14	15.25	2.76	0	13.91	17.30	19.19	16.47	18.55	18.63	19.48
	10.02	*4.18*	*7.38*	*8.26*	*8.75*	*1.86*	*0*	*7.15*	*9.37*	*10.25*	*8.96*	*9.93*	*9.97*	*10.36*
GALESTOWN	18.94	6.63	12.69	14.58	15.72	2.84	0	13.48	18.05	21.64	16.77	19.96	20.07	22.42
	11.81	*4.13*	*7.91*	*9.10*	*9.80*	*1.77*	*0*	*6.18*	*11.31*	*16.22*	*9.84*	*13.52*	*13.64*	*17.52*
GLADSTONE	19.08	6.68	12.78	14.69	15.83	2.86	0	8.96	16.57	20.89	14.42	19.80	21.35	20.66
	14.13	*4.95*	*9.47*	*10.88*	*11.73*	*2.12*	*0*	*4.39*	*12.14*	*16.43*	*10.12*	*15.17*	*16.70*	*16.29*
GRAVEL PITS	15.96	5.59	10.69	12.29	13.25	2.39	0	11.19	14.69	16.88	13.68	16.22	16.34	17.15
	6.33	*2.21*	*4.24*	*4.87*	*5.25*	*0.95*	*0*	*1.89*	*5.13*	*8.07*	*4.01*	*6.82*	*6.96*	*8.62*
HALEDON	14.28	5.00	9.57	11.00	11.85	2.14	0	6.42	11.92	15.75	10.06	14.72	16.96	15.14
	9.11	*3.19*	*6.10*	*7.01*	*7.56*	*1.37*	*0*	*4.40*	*7.75*	*10.34*	*6.60*	*9.46*	*11.40*	*9.81*
HALEDON-WET	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VARIANT	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
HALSEY	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
HAMMONTON	17.59	6.16	11.79	13.55	14.60	2.64	0	9.73	16.01	21.43	14.12	18.84	20.31	21.98
	11.27	*3.94*	*7.55*	*8.68*	*9.35*	*1.69*	*0*	*4.49*	*10.61*	*16.91*	*8.89*	*13.19*	*14.62*	*18.05*
HASBROUCK	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
HAZEN	20.72	7.25	13.88	15.96	17.20	3.11	0	8.76	17.10	22.68	14.38	21.19	23.37	22.34
	17.09	*5.98*	*11.45*	*13.16*	*14.18*	*2.56*	*0*	*3.51*	*12.94*	*19.72*	*9.80*	*17.66*	*20.46*	*19.35*
HAZLETON	18.68	6.54	12.51	14.38	15.50	2.80	0	8.92	16.23	20.47	14.04	19.51	21.04	20.19
	13.08	*4.58*	*8.76*	*10.07*	*10.85*	*1.96*	*0*	*3.25*	*10.97*	*15.44*	*8.72*	*14.34*	*15.97*	*15.17*
HERO	20.93	7.33	14.03	16.12	17.38	3.14	0	9.04	17.37	22.77	14.69	21.39	23.55	22.37
	17.48	*6.12*	*11.71*	*13.46*	*14.51*	*2.62*	*0*	*4.31*	*13.47*	*19.87*	*10.42*	*18.04*	*20.78*	*19.42*
HIBERNIA	13.33	4.67	8.93	10.27	11.07	2.00	0	6.22	11.13	14.92	9.36	13.80	16.26	14.25
	7.12	*2.49*	*4.77*	*5.48*	*5.91*	*1.07*	*0*	*2.92*	*5.80*	*8.63*	*4.63*	*7.55*	*9.95*	*7.97*
HOLMDEL	16.34	5.72	10.95	12.58	13.56	2.45	0	7.16	13.75	18.85	11.76	16.75	18.86	18.84
	12.54	*4.39*	*8.40*	*9.66*	*10.41*	*1.88*	*0*	*4.67*	*11.04*	*15.60*	*9.84*	*12.83*	*14.45*	*16.18*
HOLYOKE	12.23	4.28	8.19	9.41	10.15	1.83	0	5.40	10.01	13.73	8.24	12.66	15.00	13.10
	5.23	*1.83*	*3.50*	*4.03*	*4.34*	*0.78*	*0*	*1.85*	*3.87*	*6.61*	*2.71*	*5.62*	*7.81*	*6.01*
HOLYOKE-ROCK	7.75	2.71	5.20	5.96	6.43	1.16	0	3.82	6.47	8.61	5.45	8.00	9.34	8.25
OUTCROP (MORRIS)	*-0.07*	*-0.02*	*-0.08*	*-0.05*	*-0.06*	*-0.01*	*0*	*-2.02*	*-0.85*	*0.72*	*-1.52*	*0.15*	*1.41*	*0.38*
HOLYOKE-ROCK	9.85	3.45	6.60	7.58	8.17	1.48	0	4.98	8.13	10.92	6.79	10.14	11.87	10.44
OUTCROP (PASSAIC)	*2.24*	*0.78*	*1.48*	*1.72*	*1.86*	*0.34*	*0*	*0.52*	*1.22*	*3.11*	*0.41*	*2.44*	*3.98*	*2.67*
HOOKSAN	22.59	7.91	15.14	17.39	18.75	3.39	0	16.27	21.07	23.50	19.88	22.85	22.96	23.76
	16.49	*5.77*	*11.05*	*12.70*	*13.69*	*2.47*	*0*	*9.62*	*14.92*	*18.27*	*13.52*	*17.02*	*17.15*	*18.84*

Soil Unit	LULC Code 0	1	2	3	4	5	6	7	8	9	10	11	12	13
HOOKSAN VARIANT	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
HOOSIC	26.83	9.39	17.98	20.66	22.27	4.02	0	14.88	23.76	27.53	21.53	27.10	27.37	27.61
	26.12	*9.14*	*17.50*	*20.11*	*21.68*	*3.92*	*0*	*9.63*	*21.84*	*27.24*	*18.72*	*26.53*	*26.93*	*27.39*
HOWELL	14.69	5.14	9.84	11.31	12.19	2.20	0	7.24	12.63	17.96	10.42	15.95	18.27	17.81
	9.36	*3.28*	*6.27*	*7.21*	*7.77*	*1.40*	*0*	*3.92*	*8.70*	*13.82*	*6.97*	*11.28*	*13.24*	*14.11*
HUMAQUEPTS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
KEANSBURG	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
KEYPORT	13.81	4.83	9.25	10.63	11.46	2.07	0	6.48	12.05	16.65	10.09	14.98	17.09	16.43
	7.72	*2.70*	*5.18*	*5.95*	*6.41*	*1.16*	*0*	*2.39*	*7.37*	*11.62*	*5.93*	*9.52*	*11.28*	*11.78*
KEYPORT SOILS	15.34	5.37	10.28	11.81	12.73	2.30	0	8.56	13.40	18.12	11.42	16.37	18.54	17.91
	10.04	*3.51*	*6.73*	*7.73*	*8.33*	*1.51*	*0*	*5.60*	*9.48*	*13.78*	*8.05*	*11.62*	*13.41*	*13.96*
KLEJ	16.65	5.83	11.15	12.82	13.82	2.50	0	10.12	15.33	20.68	13.69	17.79	19.17	21.44
	9.48	*3.32*	*6.35*	*7.30*	*7.87*	*1.42*	*0*	*4.59*	*9.11*	*15.65*	*7.64*	*11.31*	*12.69*	*17.14*
KLINESVILLE	10.54	3.69	7.06	8.12	8.75	1.58	0	5.17	8.94	11.97	7.60	10.94	13.21	11.35
	1.41	*0.49*	*0.95*	*1.09*	*1.17*	*0.21*	*0*	*-0.23*	*0.81*	*2.80*	*0.16*	*1.78*	*4.07*	*2.16*
KRESSON	15.16	5.31	10.16	11.67	12.58	2.27	0	6.87	12.95	18.10	10.71	16.33	18.48	17.90
	10.09	*3.53*	*6.76*	*7.77*	*8.37*	*1.51*	*0*	*3.44*	*9.21*	*14.05*	*7.44*	*11.87*	*13.61*	*14.26*
LACKAWANNA	16.30	5.71	10.92	12.55	13.53	2.45	0	5.15	12.49	18.73	9.48	17.00	20.78	17.70
	12.40	*4.34*	*8.31*	*9.55*	*10.29*	*1.86*	*0*	*0.91*	*8.26*	*15.40*	*4.94*	*13.24*	*18.00*	*14.09*
LAKEHURST	17.41	6.09	11.66	13.40	14.45	2.61	0	11.99	16.51	20.72	15.10	18.63	18.77	21.69
	9.52	*3.33*	*6.38*	*7.33*	*7.90*	*1.43*	*0*	*3.97*	*9.05*	*14.92*	*7.38*	*11.55*	*11.71*	*16.53*
LAKELAND	16.31	5.71	10.93	12.56	13.54	2.45	0	11.16	15.80	20.33	14.52	17.73	17.85	21.57
	8.34	*2.92*	*5.59*	*6.42*	*6.92*	*1.25*	*0*	*3.13*	*8.37*	*14.58*	*6.89*	*10.59*	*10.72*	*16.51*
LAKEWOOD	18.23	6.38	12.22	14.04	15.13	2.74	0	12.76	17.35	21.36	16.00	19.38	19.51	22.28
	10.73	*3.76*	*7.19*	*8.26*	*8.91*	*1.61*	*0*	*5.10*	*10.28*	*15.84*	*8.70*	*12.65*	*12.79*	*17.37*
LAMINGTON	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
LANSDALE	20.09	7.03	13.46	15.47	16.67	3.01	0	10.33	17.85	21.66	15.92	20.76	22.04	21.48
	15.65	*5.48*	*10.49*	*12.05*	*12.99*	*2.35*	*0*	*6.47*	*14.04*	*17.60*	*12.32*	*16.61*	*17.79*	*17.51*
LANSDOWNE	14.24	4.99	9.54	10.97	11.82	2.14	0	5.84	12.20	17.12	10.04	15.45	17.72	16.82
	8.70	*3.04*	*5.83*	*6.70*	*7.22*	*1.30*	*0*	*1.79*	*7.95*	*12.56*	*6.25*	*10.51*	*12.50*	*12.59*
LANSDOWNE VARIANT	15.00	5.25	10.05	11.55	12.45	2.25	0	5.09	12.05	16.29	9.83	15.38	17.35	15.76
	10.36	*3.63*	*6.94*	*7.98*	*8.60*	*1.55*	*0*	*1.72*	*8.29*	*11.30*	*6.72*	*10.63*	*12.10*	*10.90*
LAWRENCEVILLE	15.11	5.29	10.12	11.63	12.54	2.27	0	6.91	12.52	16.75	10.47	15.60	18.10	16.08
	10.17	*3.56*	*6.82*	*7.83*	*8.45*	*1.53*	*0*	*5.26*	*8.44*	*11.73*	*6.99*	*10.63*	*13.03*	*11.07*
LEGORE	20.11	7.04	13.48	15.49	16.69	3.02	0	10.61	17.88	21.49	15.95	20.77	22.05	21.20
	15.70	*5.49*	*10.52*	*12.09*	*13.03*	*2.35*	*0*	*7.13*	*14.08*	*17.28*	*12.38*	*16.63*	*17.81*	*17.01*
LEHIGH	16.30	5.71	10.92	12.55	13.53	2.45	0	6.87	13.98	18.27	11.80	17.24	19.48	17.67
	12.48	*4.37*	*8.36*	*9.61*	*10.35*	*1.87*	*0*	*5.14*	*11.48*	*14.59*	*9.97*	*13.75*	*15.58*	*14.10*
LENOIR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
LEON	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

Soil Unit	LULC Code 0	1	2	3	4	5	6	7	8	9	10	11	12	13
LIVINGSTON	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
LOAMY ALLUVIAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LAND	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
LYONS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
MADE LAND*														
MANAHAWKIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
MARLTON	14.37	5.03	9.63	11.06	11.93	2.16	0	6.99	12.30	16.96	10.29	15.32	17.31	16.78
	8.45	*2.96*	*5.66*	*6.51*	*7.02*	*1.27*	*0*	*3.19*	*7.65*	*11.98*	*6.12*	*9.93*	*11.54*	*12.20*
MARSH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
MATAPEAKE	20.19	7.07	13.53	15.54	16.76	3.03	0	11.50	18.69	22.48	17.06	21.14	22.41	22.52
	15.95	*5.58*	*10.69*	*12.28*	*13.24*	*2.39*	*0*	*9.16*	*15.60*	*18.88*	*14.47*	*17.28*	*18.31*	*19.16*
MATAWAN	15.92	5.57	10.67	12.26	13.22	2.39	0	7.53	13.93	19.43	11.43	17.67	20.15	19.07
	11.40	*3.99*	*7.64*	*8.78*	*9.46*	*1.71*	*0*	*4.25*	*11.05*	*16.20*	*8.96*	*14.19*	*16.26*	*16.17*
MATLOCK	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
MATTAPEX	17.61	6.16	11.80	13.56	14.62	2.64	0	8.36	15.67	20.12	13.64	18.72	20.34	20.02
	14.74	*5.16*	*9.88*	*11.35*	*12.24*	*2.21*	*0*	*8.13*	*14.50*	*17.72*	*13.34*	*16.25*	*17.04*	*18.06*
MECKESVILLE	15.51	5.43	10.39	11.94	12.87	2.33	0	6.71	12.89	17.12	10.83	15.99	18.44	16.46
	10.95	*3.83*	*7.34*	*8.43*	*9.09*	*1.64*	*0*	*4.65*	*9.24*	*12.43*	*7.82*	*11.38*	*13.66*	*11.81*
MIDDLEBURY	21.08	7.38	14.13	16.23	17.50	3.16	0	8.99	17.56	22.94	14.91	21.54	23.67	22.57
	17.76	*6.22*	*11.90*	*13.68*	*14.74*	*2.66*	*0*	*4.15*	*13.85*	*20.19*	*10.87*	*18.31*	*21.01*	*19.78*
MINOA	15.97	5.59	10.70	12.29	13.25	2.39	0	6.33	13.42	18.31	11.43	16.42	18.74	18.09
	12.19	*4.26*	*8.16*	*9.38*	*10.11*	*1.83*	*0*	*3.75*	*10.72*	*15.00*	*9.50*	*12.55*	*14.51*	*15.25*
MODERATELY	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WET LAND	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
MOUNT LUCAS	15.71	5.50	10.52	12.09	13.04	2.36	0	6.35	13.42	17.98	11.26	16.67	18.81	17.57
	11.47	*4.01*	*7.68*	*8.83*	*9.52*	*1.72*	*0*	*4.09*	*10.51*	*14.15*	*8.99*	*12.78*	*14.47*	*13.99*
MUCK	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
MUCK, SHALLOW	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OVER CLAY	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
MUCK, SHALLOW	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OVER LOAM	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
MULLICA	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
NASSAU	13.32	4.66	8.92	10.26	11.05	2.00	0	5.17	10.63	15.51	8.42	13.94	17.38	14.57
	6.73	*2.36*	*4.51*	*5.18*	*5.59*	*1.01*	*0*	*0.24*	*4.26*	*9.42*	*2.11*	*7.48*	*11.77*	*8.24*
NASSAU-ROCK	13.24	4.63	8.87	10.19	10.99	1.99	0	4.76	10.34	15.24	8.03	13.81	16.96	14.38
OUTCROP (SUSSEX)	*7.32*	*2.56*	*4.89*	*5.63*	*6.07*	*1.10*	*0*	*-1.16*	*4.07*	*9.89*	*1.43*	*8.03*	*12.15*	*8.76*
NASSAU-ROCK	12.10	4.23	8.11	9.31	10.04	1.81	0	5.65	9.98	13.84	8.23	12.61	15.28	13.12
OUTCROP (WARREN)	*5.04*	*1.76*	*3.37*	*3.88*	*4.18*	*0.76*	*0*	*0.34*	*3.23*	*7.14*	*1.61*	*5.65*	*8.91*	*6.25*

Soil Unit	LULC Code 0	1	2	3	4	5	6	7	8	9	10	11	12	13
NESHAMINY	17.74	6.21	11.88	13.66	14.72	2.66	0	7.79	15.53	20.03	13.31	18.86	20.37	19.86
	11.78	*4.12*	*7.89*	*9.07*	*9.77*	*1.77*	*0*	*1.60*	*10.23*	*14.95*	*8.03*	*13.54*	*15.03*	*14.91*
NESHAMINY VARIANT	15.73	5.51	10.54	12.12	13.06	2.36	0	6.59	13.48	17.71	11.39	16.62	18.96	17.08
	11.33	*3.97*	*7.59*	*8.72*	*9.40*	*1.70*	*0*	*3.62*	*10.31*	*13.47*	*8.84*	*12.53*	*14.58*	*12.92*
NETCONG	19.33	6.77	12.95	14.89	16.05	2.90	0	8.80	16.62	20.96	14.60	19.64	21.05	20.92
	14.60	*5.11*	*9.78*	*11.24*	*12.12*	*2.19*	*0*	*3.51*	*12.17*	*16.61*	*10.35*	*14.89*	*16.22*	*16.80*
NIXON	15.50	5.42	10.38	11.93	12.86	2.32	0	6.63	14.22	18.72	12.17	17.29	18.86	18.66
	8.48	*2.97*	*5.68*	*6.53*	*7.04*	*1.27*	*0*	*-0.01*	*8.30*	*12.96*	*6.36*	*11.21*	*12.75*	*13.07*
NIXON VARIANT	15.50	5.42	10.38	11.93	12.86	2.32	0	6.63	14.22	18.72	12.17	17.29	18.86	18.66
	8.48	*2.97*	*5.68*	*6.53*	*7.04*	*1.27*	*0*	*-0.01*	*8.30*	*12.96*	*6.36*	*11.21*	*12.75*	*13.07*
NIXONTON	20.34	7.12	13.63	15.66	16.89	3.05	0	9.85	17.91	22.78	15.67	21.26	22.93	22.70
	16.01	*5.60*	*10.72*	*12.33*	*13.29*	*2.40*	*0*	*6.67*	*14.29*	*19.08*	*12.31*	*17.26*	*18.87*	*19.19*
NORTON	14.37	5.03	9.63	11.06	11.93	2.16	0	6.04	12.23	17.17	10.06	15.50	18.02	16.75
	8.74	*3.06*	*5.86*	*6.73*	*7.26*	*1.31*	*0*	*1.87*	*7.77*	*12.52*	*5.99*	*10.44*	*12.88*	*12.33*
NORWICH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
OCHREPTS	19.24	6.73	12.89	14.81	15.97	2.89	0	9.40	16.50	20.73	14.47	19.54	20.93	20.63
	14.08	*4.93*	*9.43*	*10.84*	*11.68*	*2.11*	*0*	*4.31*	*11.54*	*15.84*	*9.68*	*14.35*	*15.67*	*15.92*
OQUAGA	14.04	4.91	9.41	10.81	11.65	2.11	0	5.21	11.12	16.23	8.75	14.67	18.09	15.30
	8.23	*2.88*	*5.51*	*6.34*	*6.83*	*1.23*	*0*	*0.62*	*5.51*	*10.87*	*3.20*	*8.97*	*13.15*	*9.72*
OQUAGA-ROCK OUTCROP	14.00	4.90	9.38	10.78	11.62	2.10	0	4.83	10.86	16.08	8.36	14.60	17.85	15.19
	8.74	*3.06*	*5.85*	*6.73*	*7.26*	*1.31*	*0*	*-0.66*	*5.26*	*11.36*	*2.44*	*9.48*	*13.65*	*10.22*
OQUAGA-SWARTS-WOOD-ROCK OUTCROP	12.85	4.50	8.61	9.89	10.66	1.93	0	5.70	10.50	14.60	8.58	13.37	16.03	13.88
	6.54	*2.29*	*4.37*	*5.04*	*5.43*	*0.98*	*0*	*0.68*	*4.45*	*8.60*	*2.66*	*7.15*	*10.32*	*7.74*
OTHELLO	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
OTISVILLE	15.89	5.56	10.64	12.23	13.18	2.38	0	10.01	14.46	17.05	13.25	16.28	16.42	17.37
	6.57	*2.30*	*4.40*	*5.06*	*5.45*	*0.99*	*0*	*0.62*	*5.17*	*8.57*	*3.80*	*7.23*	*7.39*	*9.16*
PALMYRA	20.44	7.16	13.70	15.74	16.97	3.07	0	8.71	16.77	22.28	14.00	20.91	23.14	21.85
	16.57	*5.80*	*11.10*	*12.76*	*13.75*	*2.48*	*0*	*3.36*	*12.28*	*18.97*	*9.03*	*17.15*	*20.02*	*18.44*
PARKER	18.27	6.39	12.24	14.06	15.16	2.74	0	8.13	15.37	19.74	13.19	18.62	20.31	19.46
	12.62	*4.42*	*8.45*	*9.71*	*10.47*	*1.89*	*0*	*2.14*	*9.80*	*14.32*	*7.68*	*12.99*	*14.80*	*14.08*
PARKER-ROCK OUTCROP	14.60	5.11	9.78	11.24	12.12	2.19	0	6.89	12.43	15.62	10.81	14.85	15.98	15.44
	9.12	*3.19*	*6.10*	*7.02*	*7.57*	*1.37*	*0*	*1.22*	*7.07*	*10.23*	*5.54*	*9.36*	*10.46*	*10.11*
PARSIPPANY	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
PARSIPPANY VARIANT	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
PASCACK	13.70	4.79	9.18	10.55	11.37	2.05	0	5.20	11.27	16.05	9.37	14.12	16.35	15.90
	8.09	*2.83*	*5.42*	*6.23*	*6.71*	*1.21*	*0*	*1.52*	*6.68*	*10.94*	*5.53*	*8.40*	*10.21*	*11.31*
PASQUOTANK	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
PASSAIC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
PATTENBURG	19.21	6.72	12.87	14.79	15.95	2.88	0	9.24	16.71	20.91	14.59	19.89	21.42	20.66
	14.38	*5.03*	*9.64*	*11.07*	*11.94*	*2.16*	*0*	*5.07*	*12.41*	*16.48*	*10.45*	*15.34*	*16.84*	*16.29*

Soil Unit	LULC Code 0	1	2	3	4	5	6	7	8	9	10	11	12	13
PEAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
PEMBERTON	18.64	6.52	12.49	14.35	15.47	2.80	0	9.72	16.36	21.62	14.62	18.97	20.48	22.18
	13.04	*4.56*	*8.74*	*10.04*	*10.82*	*1.96*	*0*	*3.92*	*11.24*	*17.21*	*9.83*	*13.36*	*14.86*	*18.38*
PENN	13.62	4.77	9.13	10.49	11.31	2.04	0	5.78	11.16	15.22	9.21	14.09	16.56	14.56
	7.85	*2.75*	*5.26*	*6.04*	*6.52*	*1.18*	*0*	*3.12*	*6.27*	*9.33*	*4.94*	*8.27*	*10.60*	*8.69*
PHALANX	17.24	6.03	11.55	13.27	14.31	2.59	0	9.29	15.08	19.61	13.43	17.56	19.02	19.91
	10.57	*3.70*	*7.08*	*8.14*	*8.78*	*1.59*	*0*	*3.18*	*8.85*	*13.84*	*7.48*	*10.89*	*12.38*	*14.57*
PITS,MUCK	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
PLUMMER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
POCOMOKE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
POMPTON	19.39	6.79	12.99	14.93	16.10	2.91	0	9.09	16.69	20.93	14.69	19.70	21.09	20.85
	14.71	*5.15*	*9.86*	*11.33*	*12.21*	*2.21*	*0*	*4.26*	*12.31*	*16.56*	*10.52*	*15.00*	*16.31*	*16.68*
POPE	19.06	6.67	12.77	14.68	15.82	2.86	0	8.77	16.50	20.92	14.59	19.37	20.78	20.99
	14.08	*4.93*	*9.43*	*10.84*	*11.69*	*2.11*	*0*	*3.08*	*11.75*	*16.57*	*10.00*	*14.39*	*15.86*	*16.92*
PORTSMOUTH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
PREAKNESS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
PSAMMENTS*														
QUAKERTOWN	16.65	5.83	11.15	12.82	13.82	2.50	0	7.13	14.39	18.80	12.22	17.66	19.82	18.29
	13.14	*4.60*	*8.80*	*10.11*	*10.90*	*1.97*	*0*	*5.93*	*12.34*	*15.58*	*10.87*	*14.55*	*16.21*	*15.26*
QUARRY*														
RARITAN	14.38	5.03	9.63	11.07	11.93	2.16	0	6.44	11.86	15.91	9.87	14.83	17.18	15.28
	9.03	*3.16*	*6.05*	*6.95*	*7.49*	*1.35*	*0*	*4.55*	*7.40*	*10.39*	*6.06*	*9.42*	*11.56*	*9.81*
RAYNHAMN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
READINGTON	15.63	5.47	10.47	12.03	12.97	2.34	0	6.99	13.01	17.23	10.95	16.11	18.54	16.58
	11.18	*3.91*	*7.49*	*8.61*	*9.28*	*1.68*	*0*	*5.51*	*9.49*	*12.63*	*8.08*	*11.61*	*13.85*	*12.03*
REAVILLE	13.61	4.76	9.12	10.48	11.30	2.04	0	5.91	11.16	15.21	9.20	14.08	16.55	14.55
	7.83	*2.74*	*5.25*	*6.03*	*6.50*	*1.17*	*0*	*3.54*	*6.25*	*9.31*	*4.92*	*8.25*	*10.58*	*8.67*
REAVILLE VARIANT	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
RIDGEBURY	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
RIVERHEAD	17.67	6.19	11.84	13.61	14.67	2.65	0	8.43	15.21	19.30	13.37	17.97	19.36	19.27
	11.71	*4.10*	*7.84*	*9.02*	*9.72*	*1.76*	*0*	*2.80*	*9.59*	*13.73*	*7.99*	*11.99*	*13.37*	*13.92*
RIVERHEAD VARIANT	18.45	6.46	12.36	14.21	15.32	2.77	0	8.63	15.60	19.98	13.48	18.78	20.27	19.84
	12.92	*4.52*	*8.65*	*9.95*	*10.72*	*1.94*	*0*	*3.03*	*10.18*	*14.74*	*8.14*	*13.24*	*14.72*	*14.75*
ROCK LAND, EDNEYVILLE MAT.	8.06	2.82	5.42	6.20	6.69	1.21	0	4.84	7.28	8.47	6.69	8.15	8.58	8.41
	-0.78	*-0.27*	*-0.58*	*-0.60*	*-0.65*	*-0.12*	*0*	*-4.21*	*-1.47*	*-0.31*	*-2.00*	*-0.69*	*-0.25*	*-0.34*

Soil Unit	LULC Code 0	1	2	3	4	5	6	7	8	9	10	11	12	13
ROCK OUTCROP	1.08	0.38	0.73	0.83	0.89	0.16	0	1.08	1.08	1.08	1.08	1.08	1.08	1.08
(GREENPOND CON-	*-4.77*	*-1.67*	*-3.24*	*-3.67*	*-3.96*	*-0.72*	*0*	*-4.77*	*-4.77*	*-4.77*	*-4.77*	*-4.77*	*-4.77*	*-4.77*
GLOMERATE,														
MORRIS)														
ROCK OUTCROP-	7.62	2.67	5.11	5.86	6.32	1.14	0	3.97	6.33	8.42	5.32	7.83	9.14	8.06
HOLYOKE	*-0.49*	*-0.17*	*-0.36*	*-0.38*	*-0.41*	*-0.07*	*0*	*-1.77*	*-1.25*	*0.16*	*-1.86*	*-0.34*	*0.82*	*-0.17*
ROCK OUTCROP-	9.93	3.47	6.67	7.64	8.24	1.49	0	4.24	7.99	11.27	6.44	10.31	12.42	10.69
NASSAU	*2.57*	*0.90*	*1.69*	*1.98*	*2.14*	*0.39*	*0*	*-3.12*	*0.40*	*4.30*	*-1.38*	*3.06*	*5.82*	*3.54*
ROCK OUTCROP-	8.13	2.85	5.45	6.26	6.75	1.22	0	2.74	6.28	9.35	4.81	8.48	10.39	8.83
OQUAGA (SUSSEX)	*2.67*	*0.93*	*1.76*	*2.06*	*2.22*	*0.40*	*0*	*-2.86*	*0.62*	*4.21*	*-1.03*	*3.10*	*5.56*	*3.54*
ROCK OUTCROP-	13.42	4.70	8.99	10.33	11.14	2.01	0	5.85	10.93	15.27	8.90	13.97	16.79	14.51
OQUAGA (WARREN)	*7.36*	*2.58*	*4.92*	*5.67*	*6.11*	*1.10*	*0*	*1.15*	*5.15*	*9.54*	*3.24*	*8.00*	*11.36*	*8.63*
ROCK OUTCROP-	14.92	5.22	10.00	11.49	12.39	2.24	0	6.87	12.57	16.05	10.82	15.21	16.54	15.80
PARKER-EDNEYVILLE	*10.56*	*3.70*	*7.06*	*8.13*	*8.77*	*1.58*	*0*	*1.33*	*7.93*	*11.99*	*5.95*	*10.90*	*12.54*	*11.71*
ROCK OUTCROP-	4.66	1.63	3.13	3.59	3.87	0.70	0	2.54	3.99	5.19	3.43	4.81	5.64	4.97
ROCKAWAY(MORRIS)	*-1.42*	*-0.50*	*-0.98*	*-1.09*	*-1.18*	*-0.21*	*0*	*-2.66*	*-1.86*	*-0.86*	*-2.25*	*-1.26*	*-0.38*	*-1.11*
ROCK OUTCROP-	7.15	2.50	4.79	5.51	5.94	1.07	0	3.66	5.93	7.95	4.97	7.37	8.68	7.59
ROCKAWAY	*0.04*	*0.02*	*0.01*	*0.03*	*0.04*	*0.01*	*0*	*-1.23*	*-0.66*	*0.71*	*-1.22*	*0.19*	*1.39*	*0.37*
(PASSAIC)														
ROCK OUTCROP-	3.46	1.21	2.32	2.66	2.87	0.52	0	1.31	2.72	3.95	2.13	3.60	4.37	3.74
ROCKAWAY (SUSSEX)	*-2.65*	*-0.93*	*-1.82*	*-2.04*	*-2.20*	*-0.40*	*0*	*-4.83*	*-3.47*	*-2.03*	*-4.13*	*-2.48*	*-1.49*	*-2.30*
ROCK OUTCROP-	11.90	4.17	7.98	9.16	9.88	1.79	0	5.19	9.69	13.55	7.89	12.39	14.90	12.87
ROCKAWAY-PARKER	*6.27*	*2.19*	*4.19*	*4.83*	*5.20*	*0.94*	*0*	*0.90*	*4.30*	*8.20*	*2.61*	*6.84*	*9.82*	*7.39*
ROCK OUTCROP-	7.62	2.67	5.11	5.87	6.33	1.14	0	3.73	6.30	8.45	5.27	7.85	9.20	8.08
SWARTSWOOD	*0.73*	*0.26*	*0.47*	*0.57*	*0.61*	*0.11*	*0*	*-1.31*	*-0.04*	*1.41*	*-0.66*	*0.89*	*2.10*	*1.07*
ROCK OUTCROP-	15.06	5.27	10.10	11.60	12.50	2.26	0	7.45	12.74	16.07	11.01	15.35	16.65	15.78
WASSAIC	*10.82*	*3.79*	*7.24*	*8.33*	*8.98*	*1.62*	*0*	*2.88*	*8.26*	*12.04*	*6.33*	*11.15*	*12.75*	*11.68*
ROCKAWAY	11.94	4.18	8.00	9.20	9.91	1.79	0	5.42	9.87	13.46	8.20	12.38	14.74	12.82
	4.62	*1.62*	*3.09*	*3.55*	*3.83*	*0.69*	*0*	*1.28*	*3.42*	*6.04*	*2.36*	*5.01*	*7.29*	*5.41*
ROCKAWAY-ROCK	9.00	3.15	6.03	6.93	7.47	1.35	0	4.11	7.44	10.07	6.21	9.30	10.98	9.61
OUTCROP (BERGEN)	*1.80*	*0.63*	*1.19*	*1.38*	*1.49*	*0.27*	*0*	*-0.48*	*0.96*	*2.69*	*0.25*	*2.04*	*3.51*	*2.29*
ROCKAWAY-ROCK	8.50	2.98	5.70	6.55	7.06	1.28	0	3.90	7.02	9.56	5.83	8.81	10.45	9.11
OUTCROP (MORRIS)	*1.47*	*0.51*	*0.97*	*1.13*	*1.22*	*0.22*	*0*	*-0.87*	*0.60*	*2.44*	*-0.16*	*1.74*	*3.30*	*2.01*
ROCKAWAY-ROCK	9.04	3.16	6.06	6.96	7.50	1.36	0	4.56	7.46	10.07	6.23	9.31	11.00	9.60
OUTCROP (PASSAIC)	*1.72*	*0.60*	*1.14*	*1.33*	*1.43*	*0.26*	*0*	*0.09*	*0.83*	*2.58*	*0.10*	*1.92*	*3.45*	*2.15*
ROCKAWAY-ROCK	10.77	3.77	7.22	8.30	8.94	1.62	0	3.55	8.30	12.41	6.33	11.24	13.81	11.71
OUTCROP (SUSSEX)	*5.68*	*1.99*	*3.79*	*4.38*	*4.72*	*0.85*	*0*	*-1.63*	*2.94*	*7.75*	*0.72*	*6.26*	*9.55*	*6.85*
ROUGH BROKEN	9.82	3.44	6.58	7.56	8.15	1.47	0	5.39	8.47	11.01	7.33	10.17	12.01	10.51
LAND - SHALE	*0.70*	*0.25*	*0.46*	*0.54*	*0.58*	*0.11*	*0*	*-0.92*	*0.08*	*1.94*	*-0.57*	*1.06*	*3.02*	*1.41*
ROWLAND	15.99	5.60	10.71	12.31	13.27	2.40	0	6.51	13.75	18.36	11.59	17.01	19.11	17.99
	11.99	*4.19*	*8.03*	*9.23*	*9.95*	*1.80*	*0*	*4.39*	*11.15*	*14.83*	*9.64*	*13.40*	*15.01*	*14.74*
ROYCE	15.65	5.48	10.49	12.05	12.99	2.35	0	6.49	13.51	18.03	11.37	16.72	19.05	17.52
	11.17	*3.91*	*7.48*	*8.60*	*9.27*	*1.67*	*0*	*3.23*	*10.37*	*14.09*	*8.80*	*12.73*	*14.74*	*13.76*
SAND PITS	18.29	6.40	12.26	14.08	15.18	2.74	0	13.96	17.39	19.80	16.60	18.59	18.68	20.36
	9.97	*3.49*	*6.68*	*7.68*	*8.28*	*1.50*	*0*	*6.03*	*9.39*	*12.85*	*8.53*	*10.67*	*10.77*	*13.89*
SANDY ALLUVIAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LAND	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

Soil Unit	0	1	2	3	4	5	6	7	8	9	10	11	12	13
							LULC Code							
SANDY AND	18.29	6.40	12.25	14.08	15.18	2.74	0	10.77	16.03	20.44	14.34	18.56	19.81	20.75
CLAYEY LAND	*12.01*	*4.20*	*8.05*	*9.25*	*9.97*	*1.80*	*0*	*5.28*	*10.18*	*14.97*	*8.79*	*12.27*	*13.48*	*15.72*
SANDY AND	19.99	7.00	13.40	15.39	16.59	3.00	0	12.78	18.49	21.79	17.30	20.28	21.71	21.83
SILTY LAND	*14.58*	*5.10*	*9.77*	*11.23*	*12.10*	*2.19*	*0*	*7.89*	*13.69*	*17.05*	*12.91*	*14.86*	*16.38*	*17.38*
SANDY LAND	17.05	5.97	11.42	13.13	14.15	2.56	0	9.44	14.85	18.23	13.16	17.38	18.88	17.90
(BURLINGTON)	*10.11*	*3.54*	*6.77*	*7.78*	*8.39*	*1.52*	*0*	*4.06*	*8.27*	*11.33*	*6.81*	*10.45*	*12.03*	*10.98*
SANDY LAND (SALEM)	18.01	6.30	12.07	13.87	14.95	2.70	0	10.81	16.12	21.07	14.30	18.85	20.13	21.54
	11.48	*4.02*	*7.69*	*8.84*	*9.53*	*1.72*	*0*	*5.87*	*10.31*	*16.02*	*8.66*	*12.79*	*14.03*	*17.01*
SANDY PITS	16.62	5.82	11.14	12.80	13.80	2.49	0	11.22	15.43	18.57	14.21	17.27	17.39	19.15
	7.77	*2.72*	*5.21*	*5.99*	*6.45*	*1.17*	*0*	*2.28*	*6.78*	*11.23*	*5.34*	*8.93*	*9.09*	*12.30*
SASSAFRAS	20.01	7.00	13.41	15.41	16.61	3.00	0	10.47	17.78	22.21	16.09	20.32	21.72	22.45
	15.40	*5.39*	*10.31*	*11.85*	*12.78*	*2.31*	*0*	*6.22*	*13.81*	*18.20*	*12.57*	*15.67*	*16.96*	*18.83*
SHREWSBURY	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
SHREWSBURY	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VARIANT	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
SLOAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
ST. JOHNS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
STEEP STONY	18.31	6.41	12.27	14.10	15.20	2.75	0	8.64	15.52	19.83	13.43	18.66	20.29	19.60
LAND, PARKER	*12.40*	*4.34*	*8.31*	*9.55*	*10.29*	*1.86*	*0*	*2.42*	*9.62*	*14.26*	*7.51*	*12.78*	*14.60*	*14.09*
STEINSBURG	15.39	5.39	10.31	11.85	12.77	2.31	0	6.21	12.44	17.40	10.08	15.99	19.04	16.58
	10.61	*3.71*	*7.11*	*8.17*	*8.81*	*1.59*	*0*	*2.48*	*8.01*	*12.90*	*5.82*	*11.29*	*14.81*	*11.95*
SULFAHEMISTS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
SULFAQUENTS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
SWAMP	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
SWARTSWOOD	13.87	4.86	9.30	10.68	11.52	2.08	0	5.64	11.17	15.80	9.00	14.43	17.43	14.99
	7.99	*2.80*	*5.35*	*6.15*	*6.63*	*1.20*	*0*	*1.28*	*5.74*	*10.12*	*3.85*	*8.58*	*11.98*	*9.19*
SWARTSWOOD-	9.35	3.27	6.26	7.20	7.76	1.40	0	4.51	7.71	10.38	6.43	9.63	11.30	9.92
ROCK OUTCROP	*2.34*	*0.82*	*1.55*	*1.80*	*1.94*	*0.35*	*0*	*-0.20*	*1.37*	*3.18*	*0.60*	*2.53*	*4.03*	*2.76*
TIDAL MARSH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
TINTON	19.12	6.69	12.81	14.72	15.87	2.87	0	13.44	18.72	22.99	17.17	21.04	21.16	23.90
	12.13	*4.25*	*8.13*	*9.34*	*10.07*	*1.82*	*0*	*6.09*	*12.50*	*18.46*	*10.61*	*15.34*	*15.46*	*19.96*
TIOGA	21.52	7.53	14.42	16.57	17.86	3.23	0	13.14	19.77	23.32	18.41	21.81	23.24	23.36
	17.50	*6.13*	*11.73*	*13.48*	*14.53*	*2.63*	*0*	*9.97*	*16.50*	*19.85*	*15.65*	*17.77*	*19.18*	*20.18*
TUNKHANNOCK	17.98	6.29	12.04	13.84	14.92	2.70	0	10.44	16.26	19.34	15.00	18.14	18.31	19.85
	10.25	*3.59*	*6.87*	*7.89*	*8.51*	*1.54*	*0*	*1.85*	*8.55*	*12.41*	*7.29*	*10.43*	*10.62*	*13.31*
TURBOTVILLE	14.36	5.03	9.62	11.06	11.92	2.15	0	5.89	11.71	16.07	9.60	14.86	17.49	15.36
	9.23	*3.23*	*6.19*	*7.11*	*7.66*	*1.38*	*0*	*3.79*	*7.44*	*10.86*	*5.93*	*9.70*	*12.25*	*10.16*
UDIFLUVENTS	15.72	5.50	10.54	12.11	13.05	2.36	0	6.37	13.55	18.10	11.43	16.74	18.85	17.72
	11.58	*4.05*	*7.76*	*8.92*	*9.61*	*1.74*	*0*	*4.19*	*10.85*	*14.42*	*9.42*	*13.00*	*14.58*	*14.34*

	LULC Code													
Soil Unit	0	1	2	3	4	5	6	7	8	9	10	11	12	13
UDORTHENTS*														
UNADILLA	23.33	8.17	15.63	17.97	19.37	3.50	0	9.61	19.28	25.41	16.17	23.93	26.52	24.86
	21.78	*7.62*	*14.59*	*16.77*	*18.08*	*3.27*	*0*	*5.82*	*16.98*	*24.58*	*13.25*	*22.58*	*26.06*	*23.84*
URBAN LAND*														
URBAN LAND, WET	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
VALOIS	22.92	8.02	15.35	17.65	19.02	3.44	0	9.17	18.80	25.20	15.58	23.64	26.29	24.66
	20.96	*7.34*	*14.04*	*16.14*	*17.40*	*3.14*	*0*	*4.19*	*15.96*	*24.17*	*11.93*	*22.01*	*25.62*	*23.45*
VENANGO	15.39	5.39	10.31	11.85	12.78	2.31	0	6.48	12.45	17.40	10.08	16.00	19.04	16.58
	10.62	*3.72*	*7.12*	*8.18*	*8.81*	*1.59*	*0*	*3.71*	*8.02*	*12.91*	*5.83*	*11.30*	*14.81*	*11.96*
VERY STONY LAND, MOUNT LUCAS	7.37	2.58	4.95	5.67	6.12	1.11	0	4.67	6.61	7.83	5.98	7.55	8.03	7.73
	0.39	*0.14*	*0.22*	*0.30*	*0.32*	*0.06*	*0*	*-1.67*	*-0.01*	*0.87*	*-0.44*	*0.63*	*0.90*	*0.86*
VERY STONY LAND, NESHAMINY	7.88	2.76	5.30	6.07	6.54	1.18	0	5.48	7.49	8.49	7.04	8.17	8.59	8.44
	0.35	*0.12*	*0.19*	*0.27*	*0.29*	*0.05*	*0*	*-1.88*	*0.27*	*1.18*	*-0.08*	*0.80*	*1.22*	*1.16*
VERY STONY LAND, WATCHUNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
WALLKILL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
WASHINGTON	18.93	6.62	12.68	14.57	15.71	2.84	0	8.15	16.54	20.95	14.32	19.86	21.40	20.72
	13.93	*4.87*	*9.33*	*10.72*	*11.56*	*2.09*	*0*	*2.57*	*12.12*	*16.62*	*9.96*	*15.35*	*16.90*	*16.48*
WASSAIC	20.71	7.25	13.88	15.95	17.19	3.11	0	9.16	17.09	22.39	14.37	21.18	23.37	21.91
	17.07	*5.98*	*11.44*	*13.15*	*14.17*	*2.56*	*0*	*4.64*	*12.93*	*19.18*	*9.78*	*17.65*	*20.44*	*18.55*
WASSAIC-ROCK OUTCROP (SUSSEX)	17.81	6.23	11.95	13.71	14.78	2.67	0	8.05	14.78	19.29	12.48	18.22	20.15	18.86
	13.40	*4.69*	*8.96*	*10.32*	*11.12*	*2.01*	*0*	*1.89*	*9.66*	*15.40*	*6.80*	*13.95*	*16.58*	*14.81*
WASSAIC-ROCK OUTCROP (WARREN)	16.21	5.67	10.87	12.48	13.45	2.43	0	8.38	13.82	17.25	12.04	16.50	17.84	16.95
	10.45	*3.66*	*6.98*	*8.05*	*8.68*	*1.57*	*0*	*2.29*	*7.82*	*11.70*	*5.84*	*10.79*	*12.44*	*11.33*
WATCHUNG	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
WAYLAND	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
WEEKSVILLE	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
WESTPHALIA	20.44	7.16	13.70	15.74	16.97	3.07	0	9.35	17.68	23.17	15.59	20.82	22.50	23.50
	16.17	*5.66*	*10.84*	*12.45*	*13.42*	*2.43*	*0*	*5.37*	*13.92*	*19.71*	*12.18*	*16.54*	*18.18*	*20.48*
WETHERSFIELD	14.05	4.92	9.41	10.82	11.66	2.11	0	5.63	11.94	16.62	9.86	15.05	17.21	16.32
	8.77	*3.07*	*5.88*	*6.75*	*7.28*	*1.32*	*0*	*3.08*	*8.05*	*12.00*	*6.63*	*10.18*	*11.82*	*12.09*
WETHERSFIELD ROCK OUTCROP	11.06	3.87	7.42	8.52	9.18	1.66	0	4.75	9.48	12.99	7.92	11.81	13.44	12.76
	4.95	*1.73*	*3.30*	*3.81*	*4.11*	*0.74*	*0*	*0.69*	*4.41*	*7.38*	*3.35*	*6.01*	*7.24*	*7.44*
WHIPPANY	13.07	4.57	8.76	10.06	10.85	1.96	0	5.29	11.18	15.98	9.13	14.26	16.59	15.67
	6.82	*2.39*	*4.57*	*5.25*	*5.66*	*1.02*	*0*	*0.76*	*6.24*	*10.77*	*4.65*	*8.62*	*10.72*	*10.80*
WHITMAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
WOODMANSIE	18.35	6.42	12.29	14.13	15.23	2.75	0	10.34	16.70	22.37	14.69	19.73	21.21	22.94
	12.23	*4.28*	*8.19*	*9.41*	*10.15*	*1.83*	*0*	*5.14*	*11.50*	*18.31*	*9.52*	*14.46*	*15.94*	*19.50*

Soil Unit	LULC Code 0	1	2	3	4	5	6	7	8	9	10	11	12	13
WOODSTOWN	15.94	5.58	10.68	12.27	13.23	2.39	0	7.83	13.46	18.81	11.56	16.30	18.20	19.12
	11.50	*4.02*	*7.70*	*8.85*	*9.54*	*1.72*	*0*	*5.06*	*10.04*	*15.30*	*8.90*	*11.75*	*13.15*	*16.37*
WOOSTER	15.77	5.52	10.57	12.14	13.09	2.37	0	5.74	12.59	17.82	10.06	16.37	19.52	16.96
	11.69	*4.09*	*7.84*	*9.00*	*9.71*	*1.75*	*0*	*3.19*	*8.94*	*13.95*	*6.68*	*12.34*	*15.89*	*12.98*
WURTSBORO	13.55	4.74	9.08	10.44	11.25	2.03	0	5.72	10.93	15.49	8.81	14.11	17.14	14.67
	7.34	*2.57*	*4.92*	*5.65*	*6.09*	*1.10*	*0*	*1.85*	*5.17*	*9.51*	*3.32*	*7.94*	*11.41*	*8.56*

Appendix 6

Climate Factors (C-factors) by New Jersey Municipality

derived from data of 32 climate stations, see appendix 7 for details

ATLANTIC COUNTY

ABSECON CITY	1.18
ATLANTIC CITY	1.18
BRIGANTINE CITY	1.18
BUENA BORO.	1.35
BUENA VISTA TWP.	1.35
CORBIN CITY	1.33
EGG HARBOR CITY	1.39
EGG HARBOR TWP.	1.20
ESTELL MANOR CITY	1.33
FOLSOM BORO.	1.36
GALLOWAY TWP.	1.27
HAMILTON TWP.	1.32
HAMMONTON TOWN	1.36
LINWOOD CITY	1.18
LONGPORT BORO.	1.18
MARGATE CITY	1.18
MULLICA TWP.	1.36
NORTHFIELD CITY	1.18
PLEASANTVILLE CITY	1.18
PORT REPUBLIC CITY	1.40
SOMERS POINT CITY	1.18
VENTNOR CITY	1.18
WEYMOUTH TWP.	1.33

BERGEN COUNTY

ALLENDALE BORO.	1.59
ALPINE BORO.	1.49
BERGENFIELD BORO.	1.58
BOGOTA BORO.	1.39
CARLSTADT BORO.	1.40
CLIFFSIDE PARK BORO.	1.39
CLOSTER BORO.	1.59
CRESSKILL BORO.	1.51
DEMAREST BORO.	1.57
DUMONT BORO.	1.59
EAST RUTHERFORD BORO.	1.41
EDGEWATER BORO.	1.39
ELMWOOD PARK BORO.	1.59
EMERSON BORO.	1.59
ENGLEWOOD CITY	1.39
ENGLEWOOD CLIFFS BORO.	1.39
FAIR LAWN BORO.	1.59
FAIRVIEW BORO.	1.39
FORT LEE BORO.	1.39
FRANKLIN LAKES BORO.	1.59
GARFIELD CITY	1.59
GLEN ROCK BORO.	1.59
HACKENSACK CITY	1.56
HARRINGTON PARK BORO.	1.59
HASBROUCK HEIGHTS BORO.	1.56
HAWORTH BORO.	1.59
HILLSDALE BORO.	1.59
HOHOKUS BORO.	1.59
LEONIA BORO.	1.39
LITTLE FERRY BORO.	1.39
LODI BORO.	1.59
LYNDHURST TWP.	1.40
MAHWAH TWP.	1.74
MAYWOOD BORO.	1.59

BERGEN COUNTY (cont.)

MIDLAND PARK BORO.	1.59
MONTVALE BORO.	1.59
MOONACHIE BORO.	1.39
NEW MILFORD BORO.	1.59
NORTH ARLINGTON BORO.	1.39
NORTHVALE BORO.	1.59
NORWOOD BORO.	1.59
OAKLAND BORO.	1.72
OLD TAPPAN BORO.	1.59
ORADELL BORO.	1.59
PALISADES PARK BORO.	1.39
PARAMUS BORO.	1.59
PARK RIDGE BORO.	1.59
RAMSEY BORO.	1.59
RIDGEFIELD BORO.	1.39
RIDGEFIELD PARK VILLAGE	1.39
RIDGEWOOD VILLAGE	1.59
RIVER EDGE BORO.	1.59
RIVER VALE TWP.	1.59
ROCHELLE PARK TWP.	1.59
ROCKLEIGH BORO.	1.59
RUTHERFORD BORO.	1.45
SADDLE BROOK TWP.	1.59
SADDLE RIVER BORO.	1.59
SOUTH HACKENSACK TWP.	1.43
TEANECK TWP.	1.45
TENAFLY BORO.	1.41
TETERBORO BORO.	1.40
UPPER SADDLE RIVER BORO.	1.59
WALDWICK BORO.	1.59
WALLINGTON BORO.	1.59
WASHINGTON TWP.	1.59
WESTWOOD BORO.	1.59
WOOD-RIDGE BORO.	1.52
WOODCLIFF LAKE BORO.	1.59
WYCKOFF TWP.	1.59

BURLINGTON COUNTY

BASS RIVER TWP.	1.45
BEVERLY CITY	1.41
BORDENTOWN CITY	1.43
BORDENTOWN TWP.	1.43
BURLINGTON CITY	1.41
BURLINGTON TWP.	1.41
CHESTERFIELD TWP.	1.43
CINNAMINSON TWP.	1.41
DELANCO TWP.	1.41
DELRAN TWP.	1.41
EASTAMPTON TWP.	1.44
EDGEWATER PARK TWP.	1.41
EVESHAM TWP.	1.42
FIELDSBORO BORO.	1.43
FLORENCE TWP.	1.43
HAINESPORT TWP.	1.42
LUMBERTON TWP.	1.44
MANSFIELD TWP.	1.44
MAPLE SHADE TWP.	1.41
MEDFORD LAKES BORO.	1.43
MEDFORD TWP.	1.43

BURLINGTON COUNTY (cont.)

MOORESTOWN TWP.	1.41
MOUNT HOLLY TWP.	1.44
MOUNT LAUREL TWP.	1.41
NEW HANOVER TWP.	1.44
NORTH HANOVER TWP.	1.44
PALMYRA BORO.	1.41
PEMBERTON BORO.	1.44
PEMBERTON TWP.	1.44
RIVERSIDE TWP.	1.41
RIVERTON BORO.	1.41
SHAMONG TWP.	1.43
SOUTHAMPTON TWP.	1.44
SPRINGFIELD TWP.	1.44
TABERNACLE TWP.	1.43
WASHINGTON TWP.	1.41
WESTAMPTON TWP.	1.42
WILLINGBORO TWP.	1.41
WOODLAND TWP.	1.45
WRIGHTSTOWN BORO.	1.44

CAMDEN COUNTY

AUDUBON BORO.	1.36
AUDUBON PARK BORO.	1.36
BARRINGTON BORO.	1.36
BELLMAWR BORO.	1.36
BERLIN BORO.	1.42
BERLIN TWP.	1.42
BROOKLAWN BORO.	1.36
CAMDEN CITY	1.36
CHERRY HILL TWP.	1.39
CHESILHURST BORO.	1.39
CLEMENTON BORO.	1.36
COLLINGSWOOD BORO.	1.36
GIBBSBORO BORO.	1.36
GLOUCESTER CITY	1.36
GLOUCESTER TWP.	1.36
HADDON HEIGHTS BORO.	1.36
HADDON TWP.	1.36
HADDONFIELD BORO.	1.36
HI-NELLA BORO.	1.36
LAUREL SPRINGS BORO.	1.36
LAWNSIDE BORO.	1.36
LINDENWOLD BORO.	1.36
MAGNOLIA BORO.	1.36
MERCHANTVILLE BORO.	1.40
MOUNT EPHRAIM BORO.	1.36
OAKLYN BORO.	1.36
PENNSAUKEN TWP.	1.39
PINE HILL BORO.	1.37
PINE VALLEY BORO.	1.36
RUNNEMEDE BORO.	1.36
SOMERDALE BORO.	1.36
STRATFORD BORO.	1.36
TAVISTOCK BORO.	1.36
VOORHEES TWP.	1.38
WATERFORD TWP.	1.41
WINSLOW TWP.	1.38
WOODLYNNE BORO.	1.36

CAPE MAY COUNTY

AVALON BORO.	1.30
CAPE MAY CITY	1.22
CAPE MAY POINT BORO.	1.22
DENNIS TWP.	1.33
LOWER TWP.	1.22
MIDDLE TWP.	1.27
NORTH WILDWOOD CITY	1.22

CAPE MAY COUNTY (cont.)

OCEAN CITY	1.22
SEA ISLE CITY	1.33
STONE HARBOR BORO.	1.22
UPPER TWP.	1.33
WEST CAPE MAY BORO.	1.22
WEST WILDWOOD BORO.	1.22
WILDWOOD CITY	1.22
WILDWOOD CREST BORO.	1.22
WOODBINE BORO.	1.33

CUMBERLAND COUNTY

BRIDGETON CITY	1.32
COMMERCIAL TWP.	1.32
DEERFIELD TWP.	1.32
DOWNE TWP.	1.32
FAIRFIELD TWP.	1.32
GREENWICH TWP.	1.33
HOPEWELL TWP.	1.33
LAWRENCE TWP.	1.32
MAURICE RIVER TWP.	1.33
MILLVILLE CITY	1.32
SHILOH BORO.	1.35
STOW CREEK TWP.	1.35
UPPER DEERFIELD TWP.	1.33
VINELAND CITY	1.32

ESSEX COUNTY

BELLEVILLE TOWN	1.44
BLOOMFIELD TOWN	1.60
CALDWELL BORO.	1.67
CEDAR GROVE TWP.	1.60
EAST ORANGE CITY	1.39
ESSEX FELLS BORO.	1.67
FAIRFIELD BORO.	1.64
GLEN RIDGE BORO.	1.66
IRVINGTON TOWN	1.31
LIVINGSTON TWP.	1.68
MAPLEWOOD TWP.	1.62
MILLBURN TWP.	1.69
MONTCLAIR TOWN	1.64
NEWARK CITY	1.31
NORTH CALDWELL BORO.	1.61
NUTLEY TOWN	1.59
ORANGE CITY	1.61
ROSELAND BORO.	1.67
SOUTH ORANGE VILLAGE	1.63
VERONA BORO.	1.67
WEST CALDWELL BORO.	1.67
WEST ORANGE TOWN	1.67

GLOUCESTER COUNTY

CLAYTON BORO.	1.35
DEPTFORD TWP.	1.36
EAST GREENWICH TWP.	1.35
ELK TWP.	1.35
FRANKLIN TWP.	1.35
GLASSBORO BORO.	1.35
GREENWICH TWP.	1.36
HARRISON TWP.	1.35
LOGAN TWP.	1.35
MANTUA TWP.	1.36
MONROE TWP.	1.36
NATIONAL PARK BORO.	1.36
NEWFIELD BORO.	1.33
PAULSBORO BORO.	1.36
PITMAN BORO.	1.36
SOUTH HARRISON TWP.	1.35

GLOUCESTER COUNTY (cont.)

SWEDESBORO BORO.	1.35
WASHINGTON TWP.	1.36
WENONAH BORO.	1.36
WEST DEPTFORD TWP.	1.36
WESTVILLE BORO.	1.36
WOODBURY CITY	1.36
WOODBURY HEIGHTS BORO.	1.36
WOOLWICH TWP.	1.35

HUDSON COUNTY

BAYONNE CITY	1.32
EAST NEWARK BORO.	1.31
GUTTENBERG TOWN	1.39
HARRISON TOWN	1.31
HOBOKEN CITY	1.39
JERSEY CITY	1.39
KEARNY TOWN	1.36
NORTH BERGEN TWP.	1.39
SECAUCUS TOWN	1.39
UNION CITY	1.39
WEEHAWKEN TWP.	1.39
WEST NEW YORK TOWN	1.39

HUNTERDON COUNTY

ALEXANDRIA TWP.	1.54
BETHLEHEM TWP.	1.56
BLOOMSBURY BORO.	1.50
CALIFON BORO.	1.83
CLINTON TOWN	1.54
CLINTON TWP.	1.63
DELAWARE TWP.	1.46
EAST AMWELL TWP.	1.52
FLEMINGTON BORO.	1.54
FRANKLIN TWP.	1.54
FRENCHTOWN BORO.	1.54
GLEN GARDNER BORO.	1.83
HAMPTON BORO.	1.66
HIGH BRIDGE BORO.	1.83
HOLLAND TWP.	1.53
KINGWOOD TWP.	1.49
LAMBERTVILLE CITY	1.39
LEBANON BORO.	1.68
LEBANON TWP.	1.83
MILFORD BORO.	1.54
RARITAN TWP.	1.54
READINGTON TWP.	1.52
STOCKTON BORO.	1.39
TEWKSBURY TWP.	1.78
UNION TWP.	1.56
WEST AMWELL TWP.	1.39

MERCER COUNTY

EAST WINDSOR TWP.	1.43
EWING TWP.	1.40
HAMILTON TWP.	1.43
HIGHTSTOWN BORO.	1.43
HOPEWELL BORO.	1.53
HOPEWELL TWP.	1.42
LAWRENCE TWP.	1.43
PENNINGTON BORO.	1.39
PRINCETON BORO.	1.43
PRINCETON TWP.	1.43
TRENTON CITY	1.42
WASHINGTON TWP.	1.43
WEST WINDSOR TWP	1.43

MIDDLESEX COUNTY

CARTERET BORO.	1.39
CRANBURY TWP.	1.43
DUNELLEN BORO.	1.55
EAST BRUNSWICK TWP.	1.48
EDISON TWP.	1.52
HELMETTA BORO.	1.48
HIGHLAND PARK BORO.	1.48
JAMESBURG BORO.	1.47
METUCHEN BORO.	1.55
MIDDLESEX BORO.	1.54
MILLTOWN BORO.	1.48
MONROE TWP.	1.45
NEW BRUNSWICK CITY	1.48
NORTH BRUNSWICK TWP.	1.48
OLD BRIDGE TWP.	1.47
PERTH AMBOY CITY	1.53
PISCATAWAY TWP.	1.52
PLAINSBORO TWP.	1.43
SAYREVILLE BORO.	1.48
SOUTH AMBOY CITY	1.48
SOUTH BRUNSWICK TWP.	1.46
SOUTH PLAINFIELD BORO.	1.55
SOUTH RIVER BORO.	1.48
SPOTSWOOD BORO.	1.48
WOODBRIDGE TWP.	1.54

MONMOUTH COUNTY

ABERDEEN TWP.	1.46
ALLENHURST BORO.	1.55
ALLENTOWN BORO.	1.43
ASBURY PARK CITY	1.55
ATLANTIC HIGHLANDS BORO.	1.55
AVON-BY-THE-SEA BORO.	1.55
BELMAR BORO.	1.55
BRADLEY BEACH BORO.	1.55
BRIELLE BORO.	1.55
COLTS NECK TWP.	1.45
DEAL BORO.	1.55
EATONTOWN BORO.	1.55
ENGLISHTOWN BORO.	1.44
FAIR HAVEN BORO.	1.55
FARMINGDALE BORO.	1.44
FREEHOLD BORO.	1.44
FREEHOLD TWP.	1.44
HAZLET TWP.	1.44
HIGHLANDS BORO.	1.55
HOLMDEL TWP.	1.44
HOWELL TWP.	1.44
INTERLAKEN BORO.	1.55
KEANSBURG BORO.	1.46
KEYPORT BORO.	1.44
LITTLE SILVER BORO.	1.55
LOCH ARBOUR VILLAGE	1.55
LONG BRANCH CITY	1.55
MANALAPAN TWP.	1.44
MANASQUAN BORO.	1.55
MARLBORO TWP.	1.44
MATAWAN BORO.	1.45
MIDDLETOWN TWP.	1.53
MILLSTONE TWP.	1.43
MONMOUTH BEACH BORO.	1.55
NEPTUNE CITY BORO.	1.55
NEPTUNE TWP.	1.55
OCEAN TWP.	1.55
OCEANPORT BORO.	1.55
RED BANK BORO.	1.55

MONMOUTH COUNTY (cont.)

ROOSEVELT BORO.	1.43
RUMSON BORO.	1.55
SEA BRIGHT BORO.	1.55
SEA GIRT BORO.	1.55
SHREWSBURY BORO.	1.55
SHREWSBURY TWP.	1.55
SOUTH BELMAR BORO.	1.55
SPRING LAKE BORO.	1.55
SPRING LAKE HEIGHTS BORO.	1.55
TINTON FALLS BORO.	1.55
UNION BEACH BORO.	1.44
UPPER FREEHOLD TWP.	1.43
WALL TWP.	1.53
WEST LONG BRANCH BORO.	1.55

MORRIS COUNTY

BOONTON TOWN	1.67
BOONTON TWP.	1.67
BUTLER BORO.	1.83
CHATHAM BORO.	1.69
CHATHAM TWP.	1.69
CHESTER BORO.	1.83
CHESTER TWP.	1.82
DENVILLE TWP.	1.70
DOVER TOWN	1.73
EAST HANOVER TWP.	1.68
FLORHAM PARK BORO.	1.69
HANOVER TWP.	1.72
HARDING TWP.	1.72
JEFFERSON TWP.	1.80
KINNELON BORO.	1.78
LINCOLN PARK BORO.	1.62
MADISON BORO.	1.69
MENDHAM BORO.	1.73
MENDHAM TWP.	1.75
MINE HILL TWP.	1.73
MONTVILLE TWP.	1.67
MORRIS PLAINS BORO.	1.73
MORRIS TWP.	1.73
MORRISTOWN TOWN	1.73
MOUNT ARLINGTON BORO.	1.73
MOUNT OLIVE TWP.	1.82
MOUNTAIN LAKES BORO.	1.67
NETCONG BORO.	1.83
PARSIPPANY-TROY HILLS TWP.	1.69
PASSAIC TWP.	1.58
PEQUANNOCK TWP.	1.64
RANDOLPH TWP.	1.73
RIVERDALE BORO.	1.83
ROCKAWAY BORO.	1.73
ROCKAWAY TWP.	1.77
ROXBURY TWP.	1.77
VICTORY GARDENS BORO.	1.73
WASHINGTON TWP.	1.83
WHARTON BORO.	1.73

OCEAN COUNTY

BARNEGAT LIGHT BORO.	1.54
BARNEGAT TWP.	1.48
BAY HEAD BORO.	1.54
BEACH HAVEN BORO.	1.45
BEACHWOOD BORO.	1.54
BERKELEY TWP.	1.54
BRICK TWP.	1.54
DOVER TWP.	1.54
EAGLESWOOD TWP.	1.45
HARVEY CEDARS BORO.	1.45

OCEAN COUNTY (cont.)

ISLAND HEIGHTS BORO.	1.54
JACKSON TWP.	1.49
LACEY TWP.	1.54
LAKEHURST BORO.	1.54
LAKEWOOD TWP.	1.54
LAVALLETTE BORO.	1.54
LITTLE EGG HARBOR TWP.	1.45
LONG BEACH TWP.	1.47
MANCHESTER TWP.	1.53
MANTOLOKING BORO.	1.54
OCEAN GATE BORO.	1.54
OCEAN TWP.	1.54
PNE BEACH BORO.	1.54
PLUMSTED TWP.	1.46
POINT PLEASANT BEACH BORO.	1.55
POINT PLEASANT BORO.	1.54
SEASIDE HEIGHTS BORO.	1.54
SEASIDE PARK BORO.	1.54
SHIP BOTTOM BORO.	1.45
SOUTH TOMS RIVER BORO.	1.54
STAFFORD TWP.	1.45
SURF CITY BORO.	1.45
TUCKERTON BORO.	1.45

PASSAIC COUNTY

BLOOMINGDALE BORO.	1.83
CLIFTON CITY	1.59
HALEDON BORO.	1.59
HAWTHORNE BORO.	1.59
LITTLE FALLS TWP.	1.59
NORTH HALEDON BORO.	1.59
PASSAIC CITY	1.59
PATERSON CITY	1.59
POMPTON LAKES BORO.	1.77
PROSPECT PARK BORO.	1.59
RINGWOOD BORO.	1.83
TOTOWA BORO.	1.59
WANAQUE BORO.	1.83
WAYNE TWP.	1.59
WEST MILFORD TWP.	1.83
WEST PATERSON BORO.	1.59

SALEM COUNTY

ALLOWAY TWP.	1.35
CARNEYS POINT TWP.	1.35
ELMER BORO.	1.35
ELSINBORO TWP.	1.35
LOWER ALLOWAYS CREEK TWP.	1.35
MANNINGTON TWP.	1.35
OLDMANS TWP.	1.35
PENNS GROVE BORO.	1.35
PENNSVILLE TWP.	1.35
PILESGROVE TWP.	1.35
PITTSGROVE TWP.	1.34
QUINTON TWP.	1.35
SALEM CITY	1.35
UPPER PITTSGROVE TWP.	1.35
WOODSTOWN BORO.	1.35

SOMERSET COUNTY

BEDMINSTER TWP.	1.55
BERNARDS TWP.	1.52
BERNARDSVILLE BORO.	1.63
BOUND BROOK BORO.	1.49
BRANCHBURG TWP.	1.50
BRIDGEWATER TWP.	1.49
FAR HILLS BORO.	1.49

SOMERSET COUNTY (cont.)	
FRANKLIN TWP.	1.48
GREEN BROOK TWP.	1.55
HILLSBOROUGH TWP.	1.50
MANVILLE BORO.	1.49
MILLSTONE BORO.	1.49
MONTGOMERY TWP.	1.50
NORTH PLAINFIELD BORO.	1.55
PEAPACK-GLADSTONE BORO.	1.67
RARITAN BORO.	1.49
ROCKY HILL BORO.	1.43
SOMERVILLE BORO.	1.49
SOUTH BOUND BROOK BORO.	1.49
WARREN TWP.	1.52
WATCHUNG BORO.	1.55
SUSSEX COUNTY	
ANDOVER BORO.	1.60
ANDOVER TWP.	1.60
BRANCHVILLE BORO.	1.60
BYRAM TWP.	1.60
FRANKFORD TWP.	1.64
FRANKLIN BORO.	1.66
FREDON TWP.	1.60
GREEN TWP.	1.60
HAMBURG BORO.	1.66
HAMPTON TWP.	1.60
HARDYSTON TWP.	1.71
HOPATCONG BORO.	1.61
LAFAYETTE TWP.	1.64
MONTAGUE TWP.	1.66
NEWTON TOWN	1.60
OGDENSBURG BORO.	1.70
SANDYSTON TWP.	1.64
SPARTA TWP.	1.69
STANHOPE BORO.	1.68
STILLWATER TWP.	1.60
SUSSEX BORO.	1.66
VERNON TWP.	1.68
WALPACK TWP.	1.60
WANTAGE TWP.	1.66
UNION COUNTY	
BERKELEY HEIGHTS TWP.	1.59
CLARK TWP.	1.55
CRANFORD TWP.	1.59
ELIZABETH CITY	1.31
FANWOOD BORO.	1.55
GARWOOD BORO.	1.55
HILLSIDE TWP.	1.31
KENILWORTH BORO.	1.59
LINDEN CITY	1.34
MOUNTAINSIDE BORO.	1.66
NEW PROVIDENCE BORO.	1.69
PLAINFIELD CITY	1.55
RAHWAY CITY	1.55
ROSELLE BORO.	1.31
ROSELLE PARK BORO.	1.31
SCOTCH PLAINS TWP.	1.55
SPRINGFIELD TWP.	1.69
SUMMIT CITY	1.69
UNION TWP.	1.49
WESTFIELD TOWN	1.57
WINFIELD TWP.	1.55
WARREN COUNTY	
ALLAMUCHY TWP.	1.66
ALPHA BORO.	1.50

WARREN COUNTY (cont.)	
BELVIDERE TOWN	1.50
BLAIRSTOWN TWP.	1.55
FRANKLIN TWP.	1.50
FRELINGHUYSEN TWP.	1.60
GREENWICH TWP.	1.50
HACKETTSTOWN TOWN	1.83
HARDWICK TWP.	1.60
HARMONY TWP.	1.50
HOPE TWP.	1.50
INDEPENDENCE TWP.	1.77
KNOWLTON TWP.	1.50
LIBERTY TWP.	1.50
LOPATCONG TWP.	1.50
MANSFIELD TWP.	1.74
OXFORD TWP.	1.50
PAHAQUARRY TWP.	1.55
PHILLIPSBURG TOWN	1.50
POHATCONG TWP.	1.50
WASHINGTON BORO.	1.50
WASHINGTON TWP.	1.53
WHITE TWP.	1.50

APPENDIX 7

Development and Application of the Soil-Water Budget to the Method

Introduction

This appendix documents the development of the N.J. Geological Survey (NJGS) soil-water budget simulation and its application to the ground-water-recharge method. A soil-water budget calculates water left after surface runoff, evapotranspiration and any soil-moisture deficit are subtracted from precipitation as available for ground-water recharge:

recharge = precipitation - surface runoff - evapotranspiration - soil-moisture deficit (1)

Forms of the soil-water budget equation have been used for daily, weekly, monthly and annual estimates of recharge.

Commonly, this available recharge water moves downward until it reaches the ground-water system. In other cases, horizontal layers of low permeability cause a perched water table in which water may move a significant horizontal distance before recharging the principal ground-water system. In certain situations, infiltrating water that descends beyond the base of the root zone never recharges the regional ground-water system, but instead discharges directly into a surface-water body or a wetland. The NJGS method assumes that all infiltrated water that moves below the bottom of the root zone contributes to the ground-water system.

The factors that control recharge are complex and interrelated. Surface runoff and evapotranspiration are interdependent. Soil texture and land-use/land-cover characteristics both affect runoff. Evapotranspiration is highly dependent on the amount of available soil water, available radiant energy, and wind. The NJGS soil-water budget simulation is intended to incorporate factors that affect ground-water recharge into one model. The final goal is to translate the main relationships demonstrated by the simulation model into an easy-to-use formula for mean annual ground-water recharge.

The next section in this appendix discusses the development for the five types of data used in the simulation: precipitation, runoff, evapotranspiration, land-use/land-cover and soil. A third section builds on the second one by explaining how the basic data were incorporated into the simulation. The final section explains how the results were summarized into a single ground-water-recharge equation.

Basic Data Considerations

Precipitation

Daily precipitation data are available for 126 National Oceanic and Atmospheric Administration (NOAA) climate-recording stations in New Jersey. Raw data for precipitation were selected from 32 of these (table 1).

The 32 stations were selected because each has a nearly continuous daily record since 1957, and each has no more than 10 percent of its data missing. The 32 stations are rather evenly distributed, with an average of 233 square miles per station. This is well within the 230- to 350-square-miles-per-station density recommended by the World Meteorological Organization (1976) for non-mountainous temperate regions. It is important to note that the NOAA data are not corrected for possible measurement deficiencies that could result from the effects of wind on the gauge. Wind is probably the most significant factor affecting precipitation measurement and has been shown to cause undermeasurement by as much as 20 percent for some storms (Larson and Peck, 1974).

Thirty years is the standard length of climate record for comparison purposes (Linsley, Kohler, and Paulhus, 1982); it was used as the time basis of the soil-water budget. Daily records from 1957 through 1986 were used because they constituted the most recent 30-year record available at NJGS at the time of the simulation.

Table 1. Climate recording stations used for NJGS simulations

32 Climate recording stations used for NJGS simulations	
Atlantic City WSO AP	Little Falls Water Co.
Audubon	Long Branch Oakhurst
Belleplain	Long Valley
Belvidere	Millville FAA Airport
Boonton 2 SE	Moorestown
Canoe Brook	Morris Plains 1 W
Cape May 3 W	Newark WSO Airport
Charlotteburg	New Brunswick 3 SE
Essex Fells Sewage Plant	Newton St. Pauls Abbey
Flemington 5 NNW	Pemberton 3
Freehold	Plainfield
Hightstown 2 W	Somerville
Hammonton 2 NNE	Sussex
Indian Mills 2 W	Toms River
Jersey City	Tuckerton 1 S
Lambertville	Woodstown 2 NW

Surface runoff

Surface runoff was assessed by the empirical curve-number method of the U.S. Soil Conservation Service (U.S. Department of Agriculture, 1986). This method can be used for large storms to calculate surface-runoff volume, peak discharge, stream hydrographs, and detention-structure size based on the magnitude of 24-hour rainfall. For purposes of the soil-water budget, only part of this technique, one that addresses surface-runoff volume was used. The data required to calculate runoff volume are 24-hour rainfall records, Soil Conservation Service (SCS) soil maps, and field-determined information regarding type of land cover and land treatment. The curve-number method is a widely accepted method for estimating runoff from large storms and has proven useful for many combinations of climate, land use, and soils.

For calculation of the volume of surface runoff, the curve-number method takes into consideration: (1) the rainfall retained before surface runoff begins, (2) impervious areas, (3) hydrologic condition of the soil, (4) land cover according to an SCS classification, and (5) the capacity of the soil to absorb rainfall.

To calculate surface-runoff volume, first the soil series is determined from SCS soil maps, generally available as County Soil Surveys. SCS has assigned a qualitative value, hydrologic soil group (HSG), to represent the capacity of a soil series to absorb rainfall (infiltration). SCS's classification includes four levels of infiltration capacity; high (HSG A), moderate (HSG B), low (HSG C) and very low (HSG D). The HSG of the soil series is determined using a SCS manual (TR-55). The next step is to determine the cover type, hydrologic condition and land treatment. On the basis of these factors a unique curve number, from 30 to 98, is assigned using the SCS runoff-curve-number table. The curve number is then used, along with 24-hour-precipitation records, in an empirical formula that calculates the volume or depth of 24-hour surface runoff.

Whether runoff occurs and the amount, if it occurs, are partly dependent on the capacity of the cover and soil to retain water. In the curve-number method, this capacity is known as retention factor (S, inches), and is a function of curve number (CN):

$$S = \frac{1000}{CN} - 10 \qquad (2)$$

The precipitation amount below which runoff will not occur is determined by initial abstraction, a term that is defined as all rainwater retained before surface runoff actually begins. Surface-depression storage, vegetation interception, evaporation, and initial infiltration all contribute to initial abstraction (I_a, inches). SCS established a general empirical relationship for I_a as a function of S:

$$I_a = 0.2S \tag{3}$$

For storms that are large enough to generate runoff, surface runoff (Q, inches) is calculated by SCS's empirical equation which relates Q to S and 24-hour rainfall (P, inches).

$$Q = \frac{(P - 0.2S)^2}{(P + 0.08S)} \tag{4}$$

Test simulations of the soil-water budget show that small storms are most important for the long-term quantity of recharge. For example, one simulation showed that approximately 80 percent of the annual infiltration came entirely from storms with 24-hour precipitation totals of less than 1.25 inches. Because the curve-number method is designed for predicting runoff from the largest annual storms, application of the curve-number method to the NJGS simulations is completely different than the originally intended application. Additionally, SCS has recognized that in different parts of the country, factors affecting curve number vary (Paul Welle, U.S. Department of Agriculture, Soil Conservation Service, oral communication, January 7, 1991). These two issues make a strong case for adjusting the predicted (computed) curve-number results so they more closely match the amount of runoff observed from small storms in New Jersey.

This necessary adjustment was made for the soil-water budget simulations and is applicable only to this method. It was accomplished by utilizing data from Campbell, (1987) for storm events observed from 1979 to 1984 for eight drainage basins in Somerset County.

The first step was to map soil and land use/land cover (LULC) for each of the eight Somerset County drainage basins. Curve numbers were assigned to each soil-LULC combination in accordance with the guidance in TR-55. Each of the resulting maps contained many polygons with a curve number assigned to each polygon. For example, the largest basin contained 705 separate curve-number polygons which represented 27 possible curve numbers ranging from 48 to 95.

The next step was to compute a basin curve number. SCS provides two different calculations for basin curve number (U.S. Department of Agriculture, 1985). The volume weighted calculation was used because it is more accurate for basins containing large differences in curve number and small precipitation events. This method was used to compute a curve number (CN_c) for each storm event in each basin:

$$CN_c = \frac{1000}{S + 10} \tag{5}$$

In equation (5), S is defined as:

$$S = \frac{0.4P + 0.8Q_c - \sqrt{0.8PQ_c + 0.64Q_c^2}}{0.8} \qquad (6)$$

In equation (6) the variables P and Q_c are defined as:

P = observed basin precipitation (inches)
Q_c = computed basin runoff (inches) which is defined as:

$$Q_c = \frac{\sum_{i=1}^{n} V_i}{\sum_{i=1}^{n} A_i} \qquad (7)$$

In equation (7), the variables A_i and V_i are defined as:

A_i= area of polygon i
V_i = runoff volume from land represented by polygon i, which is defined as:

$$V_i = \frac{A_i(P - 0.2S_i)^2}{P + 0.8S_i} \qquad (8)$$

In equation (8), S_i is defined as:

$$S_i = \frac{1000}{CN_i} - 10 \qquad (9)$$

where:
CN_i = curve number of polygon i.

Conversion of all computed curve numbers to whole numbers resulted in a total of 22 values among all eight basins; they ranged in value from 65 to 86.

Observed rainfall and runoff were tabulated for each basin based on all reported rainfall events from late 1979 to mid-1984. An observed basin-curve number (CN_o) was then calculated for each rainfall-runoff event, using equations 5 and 6, by substituting observed basin runoff for computed basin runoff (Q_c).

The 22 computed curve numbers (for large storms) were compared with the average observed curve number (from small and moderate storms). A least-squares linear regression was used to correct for the difference between computed and observed curve numbers (fig. 45). For example, a computed curve number of 75 becomes 81 when adjusted for runoff observed from small storms in central New Jersey.

The adjusted curve numbers were used in calculating surface runoff for all simulations. No adjustments were made to the actual SCS runoff equation. The adjusted curve numbers were used with the assurance that they account for small storms and any regional effects. This adjustment is applicable only to the recharge estimation method in this document. It is not appropriate for typical applications (runoff from large annual storms) of the curve-number method.

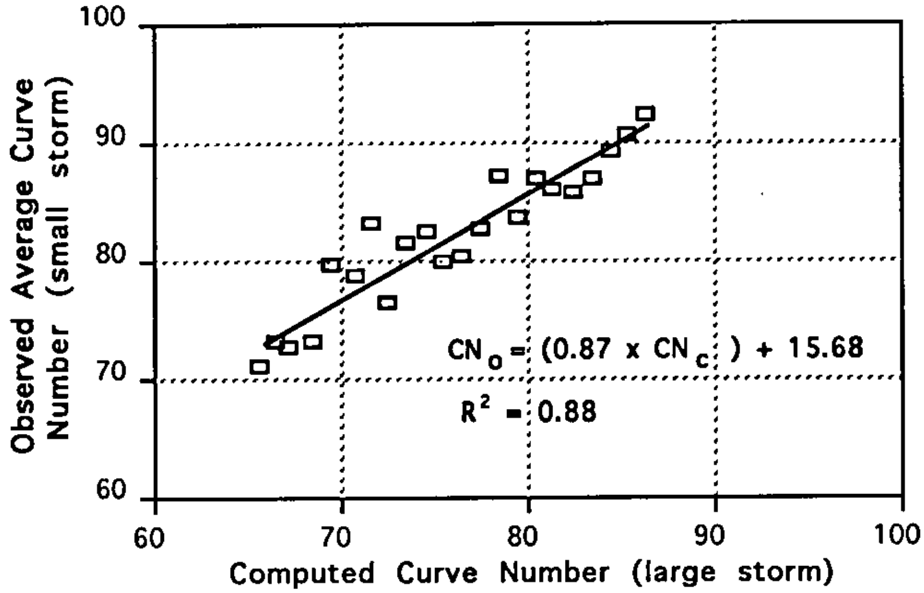

Figure 45. Observed (small storm) vs. computed (large storm) curve numbers (22 whole numbers from 65 to 86).

Evapotranspiration

A wide variety of methods is available to assess evapotranspiration for a soil-water budget. Data requirements of different methods vary considerably (Jensen, Burman, and Allen, 1990). The Thornthwaite method (Thornthwaite and Mather, 1957) for estimating potential evapotranspiration was chosen primarily because it was developed and tested in New Jersey. In addition to a bias toward the humid climate of New Jersey, this method is widely accepted and the required data are readily available. The results are reported as centimeters of potential evapotranspiration (ET_p) per month.

Briefly, this method uses mean monthly air temperature as an index of the energy available for evapotranspiration. According to Thornthwaite and Mather

$$ET_{p,i} = 1.6\left(\frac{10T_i}{I}\right)^a \qquad (10)$$

where:

$ET_{p,i}$ = potential evapotranspiration (cm/month) for month i

T_i = mean monthly air temperature (°C) for month i

I = annual heat index, which is defined as a function of the 12 monthly mean monthly air temperatures:

$$I = \sum_{i=1}^{12}\left(\frac{T_i}{5}\right)1.514 \qquad (11)$$

a = empirically derived coefficient defined as:

$$a = 6.75x10^{-7}I^3 - 7.7x10^{-5}I^2 + 1.79x10^{-2}I + 0.49 \qquad (12)$$

The result for this empirical equation is for a 30-day month with days of 12 hours of daylight. In application, adjustments are made for the length of daylight and the number of days in the month.

This method produces values of potential evapotranspiration because it assumes, at all times, a fully vegetated surface covering moist soil. In reality, land cover affects evapotranspiration indirectly through its influence on infiltration and thus the soil moisture available for evapotranspiration. In addition, the type of vegetation may have a large effect on the amount of evapotranspiration. Additionally, heat and air movement at the land or plant surfaces vary with land cover and exert a significant influence on evapotranspiration. To account for some of the evapotranspiration differences between types of vegetation, Thornthwaite and Mather (1957) outlined a procedure that provides an adjustment for vegetation cover (root depths) and soil moisture deficits.

Where lysimeters are available, they can provide a reliable adjustment for an empirical estimation method such as that of Thornthwaite. Yoshioka and Mather (1967) reported data from lysimeters in southern New Jersey: three from Centerton and three from Seabrook. The Centerton site was not as open as the Seabrook site and was representative of a wind-protected microclimate. Adjustment of evapotranspiration to Seabrook, the open site, is favored for the NJGS method because if the areas to be evaluated have to be generally characterized they would be considered open rather than protected.

Some of the Seabrook lysimeters were watered daily by sprinkling from above and are assumed to be a good estimate of potential evapotranspiration under the microclimate of sprinkle irrigation conditions. Other lysimeters were watered by maintaining a constant water table approximately 14 inches below the land surface. The Seabrook lysimeters, watered by maintaining a constant water table, were chosen by NJGS as the adjustment lysimeter ($ET_{L,S}$) for the Thornthwaite estimation method. These lysimeters were believed to best represent the microclimate and potential evapotranspiration under natural (non-irrigated) but unlimited soil-moisture conditions in New Jersey. NJGS followed Yoshioka and Mather's (1967) example in which predicted evapotranspiration at site j ($ET_{c,j}$) is equal to the calculated Thornthwaite potential evapotranspiration at that site ($ET_{p,j}$) multiplied by the ratio of observed monthly Seabrook lysimeter evapotranspiration ($ET_{L,S}$) to calculated Thornthwaite potential evapotranspiration at Seabrook ($ET_{p,S}$) (fig. 46):

$$ET_{c,j} = \left(\frac{ET_{L,S}}{ET_{p,S}}\right) \times ET_{p,j} \tag{13}$$

where:

$ET_{c,j}$ = predicted Thornthwaite potential evapotranspiration at site j
$ET_{L,S}$ = observed lysimeter evapotranspiration measured at Seabrook
$ET_{p,S}$ = calculated potential Thornthwaite evapotranspiration at Seabrook
$ET_{p,j}$ = calculated potential Thornthwaite evapotranspiration at site j

The NJGS simulated potential evapotranspiration for each month by using the lysimeter-calibrated Thornthwaite method for the 30 years of record at each of the 32 selected stations in the state.

The predicted Thornthwaite potential evapotranspiration values were used in calculating the amount of water lost to evapotranspiration each month.

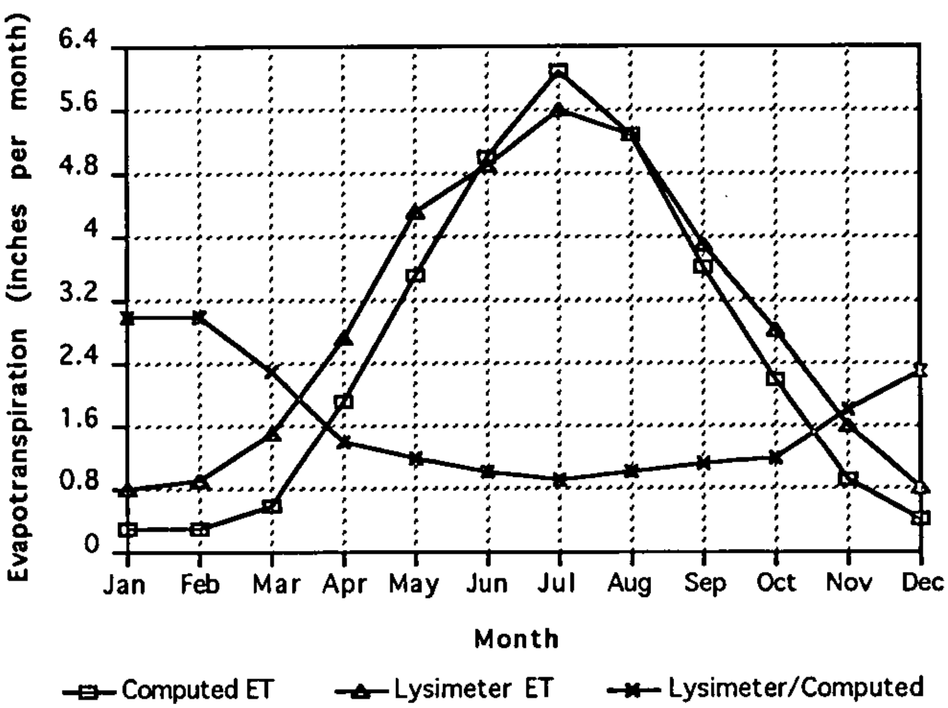

Figure 46. Computed and observed evapotranspiration, Seabrook, NJ.

Land-use/land-cover

Land-use/land-cover (LULC) has a significant effect on runoff (and infiltration) as well as evapotranspiration. A LULC classification for the purposes of ground-water recharge should be sensitive to long-term runoff and evapotranspiration characteristics. The scale on which a LULC classification can be applied should be large enough to make distinctions down to a few acres, because planners and engineers would use the method at such a scale. Additionally, it is desirable to minimize the time and material requirements for LULC mapping. Based on these method requirements, the principal LULC categories are designed to be mapped largely by 1:24,000 orthophotoquad interpretation with little field validation.

The SCS has designated 64 different categories that represent different combinations of LULC and hydrologic condition for use of the curve-number method in humid-temperate areas. These 64 categories were reduced to 43 by elimination of the variants of hydrologic condition (good, fair, poor). This is justified for this method because for a long-term analysis of ground-water recharge, the hydrologic condition of most importance is the average observed condition. The average observed condition for New Jersey was determined empirically by adjustment of the curve-number method to low to moderate-size storms as described in the "Surface runoff" section above.

Delineation of land-use/land-cover for the pilot studies indicated that in New Jersey the SCS designations of "commercial and business" and "industrial" cover types were sufficiently similar in their percentage of impervious cover to be lumped into one class. This resulting class has an average impervious cover of 85 percent. In commercial and industrial parks that contain significant open space, the 85-percent assumption is valid as applied in this method because any landscaped open space of 5 acres or more is handled as a separate LULC map unit. Unlandscaped commercial or industrial districts are grouped under one category which assumes approximately 100-percent impervious cover. Most paved streets or roads, whether curbed or uncurbed, were eliminated as a category because at the scale (1:24,000) NJGS recommends for recharge-area mapping, they are not mappable. SCS's 6-part residential district classification was reduced to 4 classes on the basis that this was the highest level of detail realistically distinguishable on orthophotoquads (1:24,000 scale).

The SCS categories of "newly graded areas" and "fallow" covers were eliminated because they were considered transient in terms of long-term land-use/land-cover. All agricultural categories were fit into either "cropland-legumes" or "pasture-meadow." This was justified on the grounds that cultivated agricultural areas typically have a variety of crop types over the long-term. The pilot studies showed that if one is not otherwise experienced with land use in an area, making distinctions between cropland-legumes versus pasture-meadow, and brush versus woods-orchard-nursery is generally not possible from photoquads alone. To accommodate this limitation, two additional lumped categories were created, "agricultural land," and "wooded areas," respectively. This extensive reduction of the original 64-part SCS classification is designed only for this recharge method. It results in a total of 14 LULC categories (appendix 2) that are useful for NJGS recharge calculations.

Another land-cover classification used in simulations during development of this method is that developed by Thornthwaite and Mather (1957). They provide a table that consists of five categories of typical vegetation-root depths for five different soil types (table 2). This vegetation-cover classification is part of their system for making vegetation and soil-moisture-sensitive estimates of actual evapotranspiration.

Table 2. Maximum mature root depth (feet)

Vegetation Type	Fine Sand	Fine Sandy Loam	Silt Loam	Clay Loam	Clay
Shallow-rooted (spinach, peas, beans,carrots)	1.67	1.67	2.08	1.33	0.83
Moderately Deep-rooted (corn, small grain, lawn turf)	2.50	3.33	3.33	2.67	1.67
Deep-rooted (alfalfa, pasture/meadow, shrubs	3.33	3.33	4.17	3.33	2.22
Orchard	5.00	5.55	5.00	3.33	2.22
Mature Forest	8.33	6.66	6.66	5.33	3.90

Wetlands and surface water are deleted from the analysis of land-use/land-cover. Determining if wetlands and surface water bodies are recharge or discharge areas, or neither, is beyond the scope of this method (see appendix 8).

Soil

The basic soil data necessary for estimating ground-water recharge was largely obtained from a New Jersey soils database maintained by SCS. The portion of the database used by NJGS contained approximately 600 records of unique soil-map units. Many of these units had more than one full-profile description. This is because a typical soil series generally varies slightly between counties, therefore more than one entry may appear under the same name. For such multiple entries of a given series, NJGS averaged all entries in that series.

A soil complex is a mappable unit that consists of more than one soil series. Many soil complexes were mapped by the SCS and are included in their database. Some of these complexes consist of soils only and others consist of soil and rock outcrop. To keep the mapping procedure from becoming too cumbersome for the user, all soil complexes were eliminated from the database, and ultimately from the soil list contained in the NJGS method. Instead users are instructed to calculate recharge for any soil complex as if it were the same as the first listed soil series of that complex. For urban land complexes, the user simply calculates recharge using the principal soil map unit associated with the urban land or urban land complex. These steps reduced the database size from roughly 400 to 252 records.

Each of the 33 soil/rock-outcrop complexes was excluded from the soils database because recharge for them was not simulated using the standard soil water-budget approach. This left 219 soil records in the database.

Hydric soils are those that are nearly saturated or have a very shallow water table (commonly less than one foot below land surface) most of the year. In many cases such soils are in wetlands and have undetermined recharge potential according to the NJGS method. Development of generally applicable criteria to distinguish between those hydric soils that act as net recharge or discharge areas is beyond the scope of this method. These hydric soils were assigned a recharge value of zero for use in the application (appendixes 3, 4, and 5). Elimination of the 75 hydric soils from the list of those slated for recharge analysis left 144 soils.

Seven map units are too variable to justify generalizing by simulation. These are: "cut and fill land," "fill land," "made land," "psamments," "quarry," "udorthents," and "urban land." These were eliminated from the simulations. The user is advised to obtain a site-specific field determination from SCS for such units except in the case of "quarry," which is indeterminate without an in-depth site-specific study. This left 137 soil units in the database.

The appropriate hydrologic soil group (A, B, C or D) was assigned, as discussed in the section "Surface runoff," to each of the 137 soil units in the NJGS database.

Water capacity of the root zone (RWC) is a necessary input for calculating actual evapotranspiration as a function of the amount of soil water available to the plant. Calculation of RWC is the product of the available water capacity (AWC) and root depth:

$$RWC = (\text{mature root depth}) \times (AWC) \qquad (14)$$

In a humid-temperate climate such as that of New Jersey, root depth is highly dependent on the type of soil. Thornthwaite and Mather (1957) provide guidelines for typical mature vegetation root depths for different soil types (table 2, above). Accordingly each of the 137 soil units was assigned a characteristic soil type (fine sand, fine sandy loam, silt loam, clay loam, or clay) from those listed by Thornthwaite and Mather. This categorization was carried out with the assistance of SCS and was based on the general texture of the entire soil profile.

A root barrier (bedrock or fragipan) is a complicating factor for calculating RWC because it may make it impossible for plants to attain their optimal root depth. To correct for this, the depth of the root barrier was determined for each of the 137 soil units. For database reference, bedrock root barriers were coded "B" and fragipan root barriers were coded "F."

Eleven of the 137 soil units had incomplete SCS-soil-database records. To complete the NJGS recharge calculations, data for similar types of soils were substituted as shown in table 3. As a result, there remained 126 unique soil records in the NJGS database that were actually used in the soil-water-budget simulations.

Table 3. Map units lacking complete data and their surrogates.

Soil map unit with no data	Similar to:	HSG	Soil type	Max. rooting depth (inches)	Root barrier bedrock or fragipan
Clayey land	Clay pits	C	C	none	0
Coastal beach	Hooksan	A	PS	none	0
Dune land	Hooksan	A	PS	none	0
Fripp	Hooksan	A	PS	none	0
Lakeland	Lakewood	A	PS	none	0
Ochrepts	Riverhead	C	PSL	none	0
Sandy and clayey land	Phalanx	B	PSL	none	0
Sandy and silty land	Phalanx	B	PSL	none	0
Sandy land (Salem)	Downer	B	PS	none	0
Sandy pits	Sand pits	A	PS	none	0
Udifluvents	Rowland	C	SIL	none	0

PS = fine sand PSL = fine sandy loam SIL = silt loam C = clay

The SCS soils database includes available water capacities (AWC) and depths for each of the soil horizons of each soil-unit record. Each soil record typically contained three to four separately-described horizons. The AWC was given as a range (high and low value) for each horizon included in the soil series description. For NJGS purposes, the average of the high and low value of AWC was used in the calculations.

Based on the soil data described above, soil-unit-specific RWCs were calculated for all five categories of mature-vegetation root depth. These RWC values are sensitive to the AWC profile of the specific soil profiles, the type of soil, and the root barrier, if present. The results are summarized in table 4, which shows the soil-unit name followed by five RWCs, one for each vegetation type. This 126-by-5 matrix was one of the essential elements used in the soil-water-budget simulation.

In summary, the complete NJGS soils database contained five types of data for each of the 126 unique soil units; 1) hydrologic soil group (HSG for runoff), 2) general type of soil (for typical root depths), 3) maximum-root depth where barrier-restricted, 4) type of root barrier (B or F) where present, and 5) available water capacity for specific horizons of a soil series. Table 4 lists all of the basic data used in the NJGS soil-water budget simulations.

Table 4. Root zone water capacity by soil unit

Soil Unit	Hydrologic Soil Group	Soil Type	Root Barrier Depth (in.)	Root Barrier Type	Root zone water capacity (RWC, in.) Shallow	Moderate	Deep	Orchard	Mature Forest
Abbotstown	C	SIL	22	F	3.94	3.94	3.94	3.94	3.94
Adelphia	B	FSL	none		3.35	6.08	6.08	8.83	10.48
Adelphia Var.	B	FSL	none		3.38	6.03	6.03	8.78	10.43
Albia	C	SIL	16	F	2.64	2.64	2.64	2.64	2.64
Amwell	C	SIL	24	F	3.35	3.35	3.35	3.35	3.35
Annandale	C	CL	30	F	2.49	4.65	4.65	4.65	4.65
Arendtsville	B	SIL	96	B	3.10	4.60	5.60	6.60	8.60
Athol	B	SIL	75	B	5.15	8.30	10.35	11.95	14.35
Aura	B	FSL	none		2.54	4.59	4.59	6.75	7.88
Barclay	C	FSL	none		3.43	5.89	5.89	7.76	8.89
Bartley	C	CL	30	F	2.62	4.57	4.57	4.57	4.57
Bath	C	SIL	30	F	3.43	4.00	4.00	4.00	4.00
Bedington	B	SIL	60	B	4.35	6.75	8.35	9.50	9.50
Berks	C	SIL	34	B	2.85	3.66	3.66	3.66	3.66
Bertie	B	FSL	none		2.10	4.39	4.39	6.64	7.99
Birdsboro	B	SIL	none		4.39	6.45	7.49	8.72	10.84
Boonton	C	SIL	30	F	3.33	3.69	3.69	3.69	3.69
Braceville	C	SIL	27	F	2.48	2.64	2.64	2.64	2.64
Bucks	B	SIL	51	B	5.04	6.85	7.88	7.98	7.98
Califon	C	CL	25	F	2.83	4.35	4.35	4.35	4.35
Chalfont	C	SIL	22	F	3.63	3.63	3.63	3.63	3.63
Chenango	A	SIL	none		3.05	3.53	3.83	4.13	4.73
Chillum	B	SIL	none		5.06	7.25	8.00	8.75	10.25
Clay Pits	C	C	none		1.30	2.65	3.33	3.33	6.03
Collington	B	FSL	none		3.09	5.68	5.68	8.18	9.68
Colonie	A	FS	none		1.75	2.45	3.15	4.55	6.75
Colts Neck	B	FSL	none		3.30	6.25	6.25	9.75	11.85
Donlonton	C	CL	none		2.67	5.82	7.76	7.76	12.01
Downer	B	FS	none		1.91	2.63	3.15	4.29	6.64
Dragston	C	FSL	none		2.19	4.06	4.06	5.81	6.86
Duffield	B	CL	66	B	3.18	6.18	8.18	8.18	12.68
Dunellen	B	FSL	none		2.97	5.19	5.19	7.06	8.19
Dunellen Var.	B	FSL	none		2.94	4.98	4.98	6.86	7.98
Ednyville	B	FSL	47	B	2.70	5.07	5.07	5.84	5.84
Ednyville Mat.	B	FSL	47	B	2.67	5.47	5.47	6.45	6.45
Ellington(Morris)	B	FSL	none		3.18	6.16	6.16	9.41	11.36
Ellington(Middlesex)	B	FSL	36	B	3.36	6.56	6.56	7.84	7.84
Evesboro	A	FS	none		1.30	1.96	2.65	4.18	7.35
Fort Mott	A	FS	none		1.50	2.54	3.94	5.64	8.64
Freehold	B	FSL	none		2.92	5.74	5.74	8.49	10.14
Galestown	A	FS	none		1.40	2.10	2.75	3.86	6.26
Gladstone	B	SIL	65	B	3.55	5.48	6.58	7.68	8.22
Gravel Pits	A	FS	none		0.30	0.45	0.60	0.90	1.50
Haledon	C	SIL	30	F	4.06	4.62	4.62	4.62	4.62
Hammonton	B	FS	none		2.06	3.37	4.19	5.94	9.94
Hazen	B	FSL	none		2.80	4.36	4.36	5.61	6.36
Hazleton	B	SIL	54	B	2.42	3.62	4.32	4.60	4.60
Hero	B	FSL	none		3.38	5.00	5.00	5.90	6.42
Hibernia	C	FSL	24	F	2.60	3.02	3.02	3.02	3.02
Holmdel	C	FSL	none		2.84	5.73	5.73	8.35	9.93
Holyoke	C	SIL	17	B	2.97	2.97	2.97	2.97	2.97
Hooksan	A	FS	none		0.53	0.73	0.93	1.33	2.13
Hoosic	A	FSL	none		1.64	2.33	2.33	3.08	3.54
Howell	C	C	none		1.85	3.55	4.45	3.87	8.38
Keyport	C	C	none		1.63	3.12	3.87	6.12	6.87
Keyport Soils	C	C	none		1.86	3.36	4.11	4.11	7.11
Klej	B	FS	none		1.60	2.37	3.05	4.90	8.80
Klinesville	C	SIL	18	B	1.14	1.14	1.14	1.14	1.14
Kresson	C	C	none		1.92	3.72	4.62	4.62	8.22
Lackawanna	C	FSL	26	F	2.60	3.38	3.38	3.38	3.38
Lakehurst	A	FS	none		1.32	2.02	2.72	4.21	7.20

Table 4 (cont.)--Root zone water capacity by soil unit

Soil Unit	Hydrologic Soil Group	Soil Type	Root Barrier Depth (in.)	Root Barrier Type	Root zone water capacity (RWC, in.) Shallow	Moderate	Deep	Orchard	Mature Forest
Lakewood	A	FS	none		1.35	2.05	2.75	4.15	6.95
Lansdale	B	SIL	60	B	3.82	5.81	6.90	8.00	8.00
Lansdowne	C	C	60	B	2.24	4.06	4.96	4.96	8.55
Landsdowne Var.	C	CL	30	B	3.24	5.64	5.64	5.64	5.64
Lawrenceville	C	SIL	25	F	4.45	4.45	4.45	4.45	4.45
Legore	B	SIL	50	B	4.22	5.88	6.94	6.94	6.94
Lehigh	C	SIL	50	B	4.36	6.44	7.60	7.60	7.60
Marlton	C	C	none		1.51	2.81	3.46	3.46	6.07
Matapeake	B	SIL	none		5.41	7.82	9.12	10.47	13.07
Matawan	C	CL	none		1.78	4.27	5.97	5.97	9.22
Mattapex	C	SIL	none		5.43	8.30	9.90	11.50	13.75
Mecksville	C	SIL	33	F	4.02	5.02	5.02	5.02	5.02
Middlebury	B	FSL	none		3.26	5.55	5.55	6.93	7.75
Minoa	C	FSL	none		3.33	6.33	6.33	9.71	11.73
Mt. Lucas	C	SIL	66	B	4.05	6.17	7.16	8.05	8.58
Nassau	C	SIL	18	B	1.81	1.81	1.81	1.81	1.81
Neshaminy	B	CL	60	B	2.28	4.22	5.51	5.51	8.21
Neshaminy Var.	C	CL	36	F	2.93	5.03	5.71	5.71	5.71
Netcong	B	FSL	none		2.54	5.14	5.14	7.39	8.73
Nixon	B	CL	none		2.24	4.04	5.24	5.35	7.23
Nixon Var.	B	CL	none		2.40	4.24	5.35	6.85	8.35
Nixonton	B	SIL	none		4.38	6.00	6.75	7.50	9.00
Norton	C	C	90	B	2.01	3.57	4.32	4.32	7.28
Oquaga	C	SIL	30	B	2.14	2.54	2.54	2.54	2.54
Otisville	A	FS	none		0.95	1.11	1.26	1.56	2.16
Palmyra	B	FSL	none		2.70	3.69	3.69	4.07	4.29
Parker	B	FSL	48	B	2.24	3.92	3.92	4.40	4.40
Pascack	C	FSL	none		2.80	4.70	4.70	6.33	7.30
Pattenburg	B	SIL	60	B	3.98	5.82	6.88	7.94	7.94
Pemberton	B	FSL	none		1.40	3.83	3.83	6.58	8.23
Penn	C	SIL	30	B	3.77	4.07	4.07	4.07	4.07
Phalanx	B	FSL	none		1.36	2.89	2.89	4.14	4.89
Pompton	B	FSL	none		2.94	5.28	5.28	7.15	8.28
Pope	B	FSL	none		2.42	4.82	4.82	7.32	8.82
Quakertown	C	SIL	56	B	4.93	7.23	8.90	9.74	9.74
Raritan	C	SIL	25	F	4.48	4.48	4.48	4.48	4.48
Readington	C	SIL	30	F&B	4.62	5.21	5.21	5.21	5.21
Reaville	C	SIL	25	B	4.06	4.06	4.06	4.06	4.06
Riverhead	B	FSL	none		2.58	4.24	4.24	5.34	5.79
Riverhead Var.	B	FSL	none		2.25	3.65	3.65	4.40	4.85
Rockaway	C	FSL	24	F	2.29	2.54	2.54	2.54	2.54
Rowland	C	SIL	none		4.10	6.45	7.62	8.43	10.88
Royce	C	CL	57	B	2.65	4.90	5.90	5.90	7.60
Sandy Land (Burlington)	B	FS	24	F	1.73	2.13	2.13	2.13	2.13
Sand Pits	A	FS	none		0.65	1.00	1.35	2.05	3.45
Sassafras	B	FSL	none		2.83	5.60	5.60	7.72	9.00
Steep Stony Land; Parker	B	FSL	48	B	1.96	3.20	3.20	3.68	3.68
Steinsburg	C	FSL	36	B	2.46	3.42	3.42	3.42	3.42
Swartswood	C	FSL	30	F	2.00	2.89	2.89	2.89	2.89
Tinton	A	FS	none		1.40	2.29	3.73	5.87	9.47
Tioga	B	FSL	none		3.10	5.41	5.41	8.16	9.80
Tunkhannock	A	FSL	none		2.05	3.39	3.39	4.64	5.39
Turbotville	C	SIL	28	F	4.53	4.94	4.94	4.94	4.94
Unadilla	B	SIL	none		4.71	7.49	8.04	8.59	9.69
Valois	B	SIL	90	B	2.73	4.23	5.07	5.67	6.87
Venango	C	SIL	20	F	3.43	3.43	3.43	3.43	3.43
Washington	B	CL	78	B	2.85	5.57	7.33	7.33	11.30
Wassaic	B	SIL	30	B	3.64	4.34	4.34	4.34	4.34
Westphalia	B	FSL	none		3.50	6.13	6.13	9.13	10.93
Wethersfield	C	SIL	none		3.88	5.16	6.00	6.86	8.55

Table 4 (cont.)--Root zone water capacity by soil unit

Soil Unit	Hydrologic Soil Group	Soil Type	Root Barrier Depth (in.)	Root Barrier Type	Root zone water capacity (RWC, in.) Shallow	Moderate	Deep	Orchard	Mature Forest
Whippany	C	C	90	B	1.97	3.61	4.41	4.41	7.75
Woodmansie	B	FS	none		1.63	2.72	3.72	5.71	9.71
Woodstown	C	FSL	none		2.32	4.61	4.61	7.48	9.19
Wooster	C	SIL	32	F	4.36	5.48	5.48	5.48	5.48
Wurtsboro	C	FSL	21	F	2.46	2.57	2.57	2.57	2.57

Simulation of the soil-water budget

The discussion to this point explains the development of the basic data used in the soil-water budget simulation. These data enable one to estimate recharge for each of the possible combinations of land-use/land-cover (14 possibilities), soil (126 units), and climate condition (32 stations) in the state. The following discussion explains how the basic data were used.

The curve-number method gives results in terms of inches of infiltration per day. However, because of the monthly result given by the evapotranspiration-estimation technique, the smallest time interval for simulation of the soil-water budget is a month. Therefore all infiltration results were lumped into sets of mean monthly infiltration values based on a 30-year record.

Mean monthly infiltration was estimated for each soil unit for all possible land-use/land-covers, but only for those climate areas of the state in which a given soil occurs. These calculations are dependent on precipitation, the hydrologic soil group of the soil unit and the land-use/land-cover (LULC). Infiltration for all LULCs that contained impervious cover were calculated as if they were 100-percent pervious cover of landscaped-open space in good hydrologic condition. This was done as an interim step to avoid an area-weighted value of infiltration that would invalidate the results of the soil-water-storage and actual evapotranspiration calculations. Adjustments for the percentage of impervious cover were made after recharge was calculated and are explained following equation 17.

Next, each of the vegetation-root-depth categories was paired with the appropriate LULC category (table 5). For every combination of LULC and soil, a value for root zone water capacity (RWC) was assigned from table 2.

Table 5. LULC and associated vegetation root-depth categories

Land-use/land cover (LULC)	Vegetation root depth category
Landscaped open space applies to vegetated portion of all developed areas)	moderate
Unpaved parking areas	shallow
Annual crops	moderate
Legumes or rotation meadow	deep
Pasture or meadow	deep
Brush	deep
Woods and grass combination	orchard
Woods	mature forest

With all this in place, monthly ground-water-recharge estimates sensitive to LULC, soil, and climate were made. Table 6 and equations 15 through 17 illustrate how mean monthly recharge was calculated from the infiltration and potential evapotranspiration values.

Table 6. Example of values used to calculate monthly recharge

Month	Potential evapotranspiration (ETp)	Infilitration (INF)	Water in root zone (Si)	Recharge
January	0.00	3.17	3.94	3.17
February	0.00	2.80	3.94	2.80
March	1.27	3.45	3.94	2.18
April	2.39	3.85	3.94	1.47
May	4.26	3.69	3.41	0.00
June	4.68	3.26	2.37	0.00
July	5.25	4.15	1.79	0.00
August	5.09	3.61	1.23	0.00
September	3.66	3.52	1.19	0.00
October	2.37	2.93	1.74	0.00
November	1.27	3.45	3.92	0.00
December	0.06	3.54	3.94	3.47

All values in inches

Somerville climate station
Soil unit = Abbottstown
LULC = woods
CN(SCS) = 77

Vegetation type = forest
Root zone water capacity (RWC) = 3.94

Equations 15 through 17 are modified from Alley's (1984) summary of analytical solutions for calculation of Thornthwaite's monthly soil-water budget. The method assumes that before any ground-water recharge can occur the water capacity of the root zone (RWC) must be filled. Infiltration during a month which occurs after the RWC is satisfied then becomes ground-water recharge.

The amount of water stored in the soil at the end of month i (S_i) must be calculated assuming two different situations. The first is when the infiltration is less than the potential evapotranspiration. The second is when infiltration during a month is greater than or equal to the potential evapotranspiration.

If infiltration for the month is less than the potential evapotranspiration ($INF_i < PET_i$), then soil moisture is at less than its full capacity and the evapotranspiration rate will be at some value less than the potential. In this case the amount of water in the soil at the end of month i is assumed to be expressed as:

$$S_i = (S_i - 1)e^{\left\{\frac{-(ET_{p,i} - INF_i)}{RWC}\right\}} \qquad (15)$$

where:

S_i = amount of water in soil at end of month i
S_{i-1} = amount of water in soil at end of month i-1
INF_i = infiltration during month i
$ET_{p,i}$ = potential evapotranspiration during month i
RWC = water capacity of the root zone

If infiltration for the month is greater than or equal to potential evapotranspiration for that month ($INF_i \geq ET_{p,i}$) then the additional water is available either for replenishing soil moisture or for ground-water recharge. The volume of water in the soil at the end of month i is the sum of this additional water and the amount of water that was in the soil at the end of the previous month. This calculation is qualified, however, by the fact that the amount of water can not exceed the water capacity of the root zone. This is expressed as:

$$S_i = \min\{(INF_i - ET_{p,i})+S_{i-1},RWC\} \quad (16)$$

Ground-water recharge can occur during month i only when two conditions are satisfied: (1) infiltration exceeds potential evapotranspiration for month i ($INF_i > ET_{p,i}$); and (2) the soil moisture of the root zone is at full capacity at the end of month i (S_i = RWC). When these conditions are satisfied, the excess of water becomes ground-water recharge:

$$\text{monthly ground-water recharge} = (INF_i-ET_{p,i}) - (RWC-S_{i-1}) \quad (17)$$

In equation (17) the term ($RWC-S_{i-1}$) represents the amount of soil-water deficit at the end of the previous month. This value can range from 0 (which indicates the root zone's soil moisture capacity was full at the end of the previous month) to RWC (which indicates there was no water at all in the root zone).

For LULCs in developed areas (those that contained impervious cover), all precipitation that fell on impervious areas was considered directly connected to the local surface-water system. This assumption is consistent with SCS guidance for the curve-number method (U.S. Department of Agriculture, 1986). Recharge calculation for such areas was based on the assumption that all of the pervious areas consisted of landscaped open space in good hydrologic condition. Thus for recharge estimates on any LULC that contained impervious area, an area-weighted average was calculated:

$$\text{ground-water recharge} = RE_{os} \times \frac{(100 - \text{percent impervious cover})}{100} \quad (18)$$

where:

RE_{os} = recharge through landscaped open space

There were 33 map units in the state that were listed as either "rock outcrop," "rock outcrop complex," "rock outcrop association" or had some proportion of associated rock outcrop. Recharge estimates for these map units were simulated separately from the soils. Table 7 shows a summary of these map units with the outcrop proportions reported as the average of the range listed in the county soil surveys.

Table 7. Summary of SCS map units with reported proportions of rock outcrops.

County	Soil Unit	Symbol	Percent Outcrop	Principal Geologic Unit(s)	Infiltration Potential
Bergen	Boonton-Rock Outcrop	Bs*	0.20	Jurassic Basalts	Low
Bergen	Rockaway-Rock Outcrop	Rr*	0.25	Proterozoic Basement	Very Low
Bergen	Wethersfield-Rock Outcrop	Ws*	0.20	Diabase	Low
Hunterdon	Rock Land; Edneyville Mat.	Rk	0.70	Passaic Formation	Moderate
Hunterdon	Rough Broken Land; Shale (Klinesville Assoc.)	RlF	0.20	Passaic Formation	Moderate
Mercer	Very Stony Land; Mt. Lucas & Neshaminy Mat.	VmC	0.70	Diabase	Low
Mercer	Very Stony Land; Neshaminy Mat.	VnE	0.70	Diabase	Low
Morris	Holyoke-Rock Outcrop	HrE	0.43	Hook Mtn. Basalt	Low
Morris	Parker-Rock Outcrop	PfE	0.23	Proterozoic Basement	Very Low
Morris	Rockaway-Rock Outcrop	Rs*	0.30	Proterozoic Basement	Very Low
Morris	Rock Outcrop	Rt	1.00	Green Pond Congl.	Very Low
Morris	Rock Outcrop-Rockaway	RvF	0.70	Proterozoic Basement	Very Low
Passaic	Holyoke-Rock Outcrop	HrC	0.20	Jurassic Basalts	Low
Passaic	Rockaway-Rock Outcrop	RsC	0.23	Proterozoic Basement	Very Low
Passaic	Rock Outcrop-Holyoke	RwE	0.40	Jurassic Basalts	Low
Passaic	Rock Outcrop-Rockaway	RxE	0.40	Proterozoic Basement	Very Low
Passaic	Rock Outcrop-Swartswood	RyE	0.38	Skunnemunk Congl.	Very Low
Passaic	Swartswood-Rock Outcrop	SrC	0.23	Skunnemunk Congl.	Very Low
Sussex	Nassau-Rock Outcrop	Nf*	0.18	Martinsburg Formation	Moderate
Sussex	Oquaga-Rock Outcrop	OrD	0.15	Bellvale Sandstone	Moderate
Sussex	Rockaway-Rock Outcrop	RrD	0.33	Proterozoic Basement	Very Low
Sussex	Rock Outcrop-Nassau	RsF	0.45	Martinsburg Formation	Moderate
Sussex	Rock Outcrop-Oquaga	RtE	0.50	Shawangunk Formation	Very Low
Sussex	Rock Outcrop-Rockaway	RvE	0.80	Proterozoic Basement	Very Low
Sussex	Wassaic-Rock Outcrop	WnD	0.28	Paleozoic Carbonates	High
Warren	Edneyville-Parker-Rock Outcrop	EPD	0.15	Proterozoic Basement	Very Low
Warren	Nassau-Rock Outcrop	NF*	0.15	Martinsburg Formation	Moderate
Warren	Oquaga-Swartswood-Rock Outcrop	ORD	0.10	Bloomsburg Formation	Moderate
Warren	Rock Outcrop-Oquaga	ROF	0.30	Shawangunk Formation	Very Low
Warren	Rock Outcrop-Parker-Edneyville	RPF	0.20	Proterozoic Basement	Very Low
Warren	Rock Outcrop-Rockaway-Parker	RRE	0.30	Proterozoic Basement	Very Low
Warren	Rock Outcrop-Wassaic	RW*	0.28	Paleozoic Carbonates	High
Warren	Wassaic-Rock Outcrop	WO*	0.23	Paleozoic Carbonates	High

* Represents average of two or more slope variants.

Comparison of the areal distribution of these soil map units with published and unpublished geologic mapping showed that some soil map units occur over geologic units that in outcrop may vary considerably in their ability to absorb precipitation. However it was felt that the need for some kind of broad relative scale of outcrop infiltration potential outweighed the importance of variations of outcrop within some soil map units. The latest geologic mapping data and judgment of NJGS mappers was thus used to assign a relative infiltration potential value to the outcrop associated with each soil-rock complex or association. This infiltration potential of exposed outcrop was ranked on a scale of 1 (lowest) to 4 (highest). The main considerations included in this qualitative ranking included (1) surface retention characteristics, and (2) typical fracture density and orientation. For purposes of simulating infiltration, curve numbers were assigned to the four classes: rank 1 = curve number 99, 2 = 98, 3 = 97, 4 = 96.

Simulation of recharge for the four categories of outcrop utilized the following modification of the curve number technique. This modification is applicable only to the NJGS recharge estimation method. It was assumed that outcrop portions are relatively unvegetated and overall transpiration from plants over such areas would therefore be insignificant. Evaporation from rock outcrop would consist principally of that precipitation retained on the outcrop surface and evaporated after a precipitation event. Therefore ground-water recharge through rock outcrop can be estimated as the amount of water left from precipitation (P) after surface runoff (Q) and surface retention (calculated in the same manner as initial abstraction, I_a) are subtracted:

$$\text{Recharge} = P - Q - I_a \qquad (19)$$

This recharge simulation was calculated on a daily basis for the 30-year period of record for the relevant climate stations of each of the 33 rock outcrop types. The results were summarized as annual averages.

To apply the outcrop estimates to the soil-rock complexes or associations, an area-weighted average of the soil and outcrop portions were used to calculate an average annual estimate of recharge for the entire complex:

Recharge = (soil proportion of complex) x (soil recharge rate) + (outcrop proportion of complex) x (outcrop recharge rate) (20)

For developed areas over rock-outcrop complexes, equation 18 was applied directly to the recharge results for the soil-rock outcrop complex and landscaped-open space combination. It is assumed that neither outcrop nor soil portions of a site are selectively developed.

Application of the Simulation Results for Recharge Calculation

A primary objective of the method is to have it readily applicable by engineers and planners. Accordingly, it was necessary to summarize the results of the soil water-budget simulation in a simple yet reasonably accurate way. For all 159 soil units simulated (126 soil series and 33 soil/rock complexes), recharge values were annualized for each of the 14 land-use/land-covers at all the appropriate climate stations. The result was a large matrix of 30-year mean-annual-recharge estimates covering every reasonable combination of soil, land-use/land-cover and climate in New Jersey. Additionally, precipitation and potential evapotranspiration were converted to mean annual values for each of the climate stations relevant to a specific map unit.

Tests by NJGS showed that the ratio of precipitation over potential evapotranspiration, or climate factor (C-factor), could serve as a reliable climate-sensitive index of simulated recharge, given a fixed combination of soil and land-use/land-cover. Based on C-factor as the independent variable and recharge as the dependent variable, least-squares linear regressions were calculated for all simulated combinations of soil and land-use/land-cover that occur in New Jersey. As an example, a graphical representation of the regression for Keyport soils with a woods LULC is shown in figure 47. A slope (R-factor) and y-intercept (R-constant) were calculated to describe the recharge relationship of every combination of soil and land-use/land-cover with climate factor.

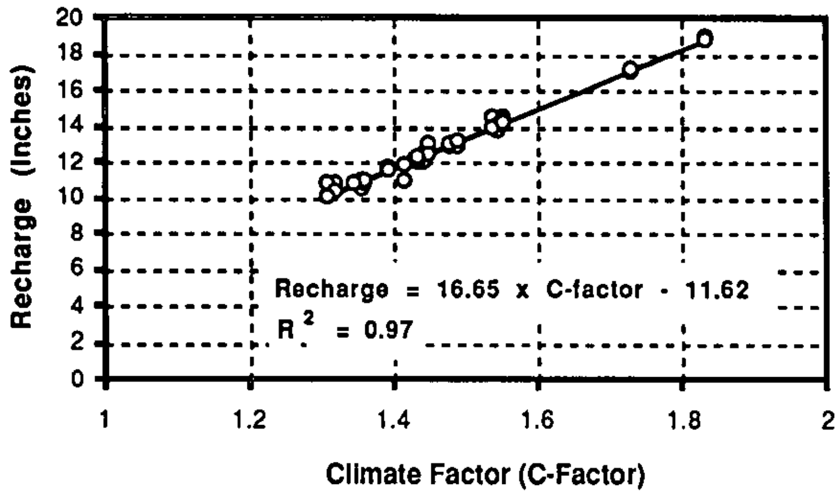

Figure 47. Recharge vs. climate factor (soil = Keyport, LULC = woods).

This allows a general linear equation for ground-water recharge for a given soil and land-use/land-cover combination:

annual ground-water recharge = (R-factor x C-factor x B-factor) - R-constant (19)

R-factors and R-constants were thus entered in appendix 5 according to the appropriate LULC for the 159 soil units simulated. Appendix 5 also includes the 11 sets of surrogate R-factors and R-constants for the soil units that lacked a complete SCS database. To include all 252 soil units in appendix 5, R-factor and R-constant values that yield zero-recharge were also included in appendix 5 for hydric soils (75). The seven soil map units that require site specific determination were also listed. The final result was a 14-by-252 matrix (3,528 pairs) of R-factors and R-constants: one pair for each combination of soil unit and LULC possible in the state. This list is as comprehensive as possible.

The basin factor (B-factor) was derived by calibrating calculated volumetric ground-water recharge to stream baseflows. Test areas in the Maurice, Musconetcong and Passaic River Basins were used to represent different geologic settings. The calibration process showed a constant basin factor of 1.3 brought calculated values acceptably close to baseflows. More detailed investigations of different basins may show the need for different basin factors for different basins. For the purposes of this report, however, a constant value of 1.3 provides acceptably accurate ground-water recharge values.

To make the recharge equation more relevant for local planning, it was necessary to convert climate factors for the 32 stations to municipal level values. The NJGS utilized a Geographic Information System (GIS) to assign mean-annual-climate factors to New Jersey's 567 municipalities. A GIS is a computer-based combined spatial and tabular database. Each map layer, or coverage, has spatial features that may include polygons, lines, and points. These features are linked to a tabular database (Environmental Systems Resources Institute, Inc., 1987). For example, one of the coverages used to assign mean annual climate factor to municipalities was the climate recording-station point coverage. The spatial component is the "x,y" or longitude/latitude coordinates, the points that are actually seen on the map. The tabular part of the database contains a climate factor for each station.

To arrive at a representative climate factor for each municipality, the Thiessen polygon method was used (Linsley, Kohler, and Paulhus, 1982). A Thiessen polygon describes an

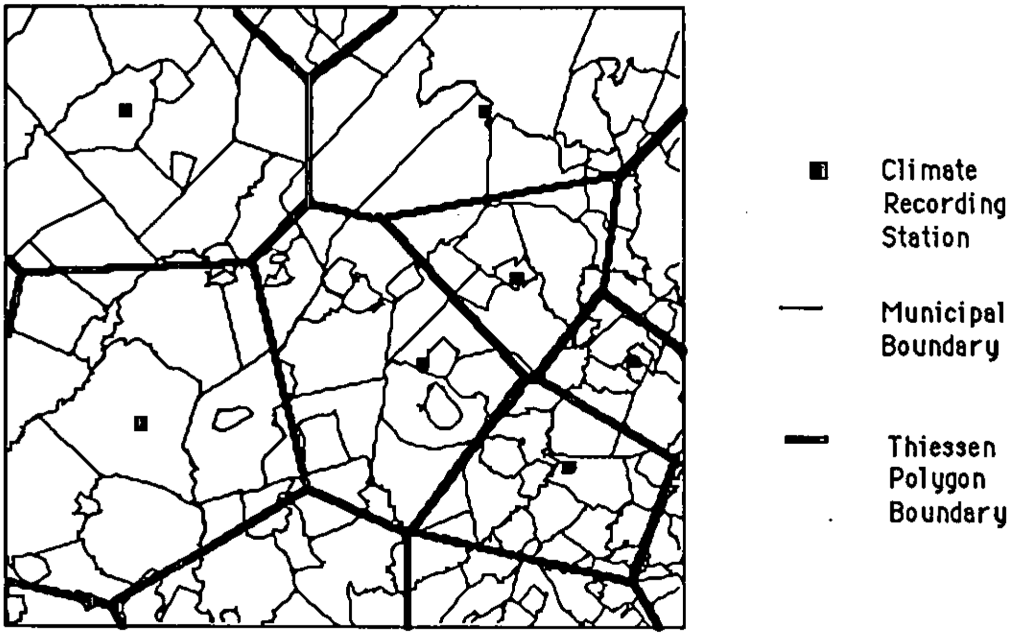

Figure 48. Thiessen polygons, climate stations and municipal boundaries. for eastern Morris County.

area closest to a given point within a distribution of points. These polygons were generated, using the GIS, for the 32 points in the climate-station coverage. Overlaying the Thiessen polygon coverage on New Jersey's municipal boundaries, another polygon coverage, made it possible to identify which municipality fell into what Thiessen polygon. Those that fell entirely within one Thiessen polygon were assigned its station's climate factor. Those that fell into two or more polygons were assigned an area-weighted average of the associated climate factors. Using this method, an average annual climate factor was assigned to each municipality in the state. Figure 48 shows Thiessen polygons, climate stations, and municipal boundaries in the Morris County area.

Manual application of the method using R-factors and R-constants associated with the 252 discrete soil units was impractical for large areas, based on pilot tests performed by NJGS. The main reason was that it required excessive detail for manual labeling and reading. To avoid this, the soil units were lumped into groups with similar recharge characteristics (similar R-factors and R-constants).

The first step in making the method more amenable to manual applications, was to sort the soil units by similar recharge factor and constant. Further sorting and exchanging was then performed in an effort to minimize the relative analytical error between recharge estimates using the soil unit factor and constant versus using the group average factor and constant. This clustering resulted in twelve recharge soil groups (A through L) which typically can estimate recharge within ten percent of the value calculated from the individual recharge factors and constants for that soil unit (appendix 5). The simplicity of manual application that results from this grouping is intended to encourage use of the method by all planning entities. However if the planning area is small or if a GIS is used, the greater accuracy obtained by use of discrete soil units is recommended.

APPENDIX 8
Wetlands and Streams as Zones of Ground-Water Discharge and Recharge

Whether a wetland or surface-water body recharges ground water or receives discharge from ground water depends on the relative levels of the water table and the surface water and on the degree of interconnection between them.

The following examples illustrate the four possible recharge/discharge relationships involving streams and wetlands. The first shows ground water discharging to a wetland and a stream. The second shows a water-table aquifer being recharged by surface water. The third shows a wetland which is both a discharge area and a recharge source. The fourth shows a wetland isolated from the aquifer beneath the site.

1. A wetland and stream in a ground-water-discharge area (fig. 49)

Small wetlands commonly border streams. This case, similar to many in New Jersey Coastal Plain valleys, shows such a stream bordered by wetlands at the foot of a hill. The wetlands are above the level of the stream and are fed almost entirely by ground-water discharge which has come from infiltration upland of the stream.

Under the conditions shown here, both the wetlands and stream are ground-water-discharge areas. During high-water times, however, raised surface-water levels may reverse the vertical gradient and temporarily change the wetland area from a discharge area to a recharge area. Characterization of a wetland or water body as a discharge or recharge area must thus account for seasonal variations and the direction of net annual vertical leakage.

2. A stream in a ground-water-recharge area (fig. 50)

This case, illustrating a glacial valley-fill situation common in northern New Jersey, shows a stream discharging to ground water. Wells in many of the valley-fill aquifers are largely supplied by water which moves from nearby streams to the aquifer by moving through the stream bed. The situation here is the result of ground-water removal through a production well, but similar streambed leakage occurs under natural conditions as well. The stream bed is acting as a recharge area to the underlying water-table aquifer. Wetlands located along the streams probably contribute recharge as well.

3. A wetland which includes both ground-water-recharge and ground-water-discharge zones (fig. 51)

A shallow water table may intersect an irregular topography at several places. A deep surface depression will extend below the water table and be a pond. A shallower depression will intersect the water table and be a wetland. The water surface of these bodies is normally at the water table. Ground water may discharge to the upgradient side of the pond or wetlands, while the downgradient side may, in turn, recharge the ground-water system. During drier seasons, when the water table drops, these surface water bodies may provide recharge to the underlying aquifer throughout their extent.

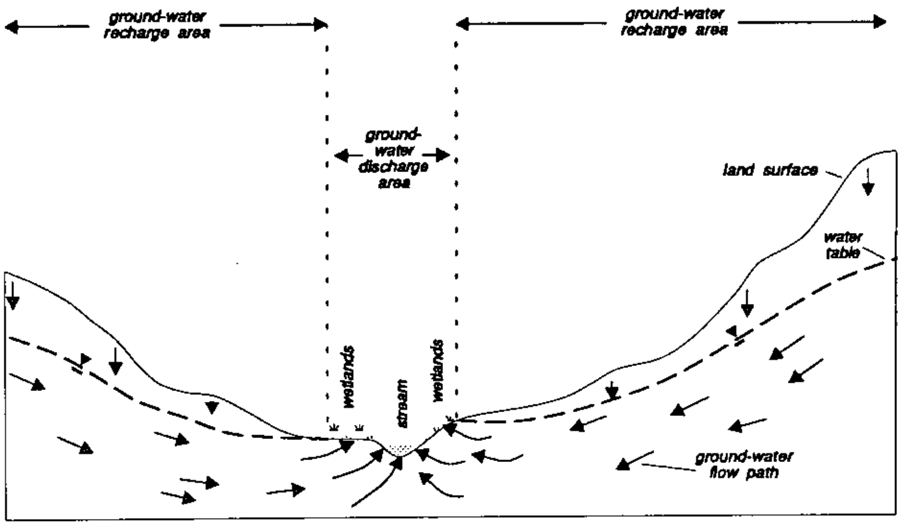

Figure 49. Example of ground-water discharge to a stream and wetlands.

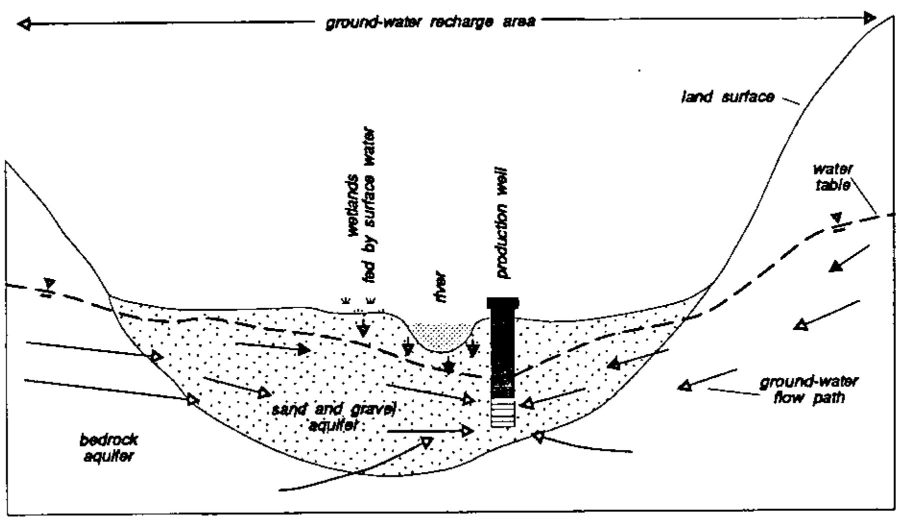

Figure 50. Example of a stream as a source of ground-water recharge.

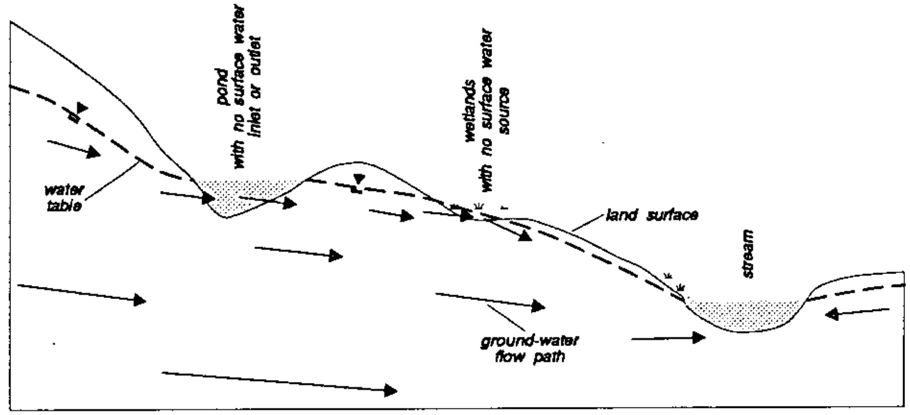

Figure 51. Example of ground-water recharging to and discharging from a wetland.

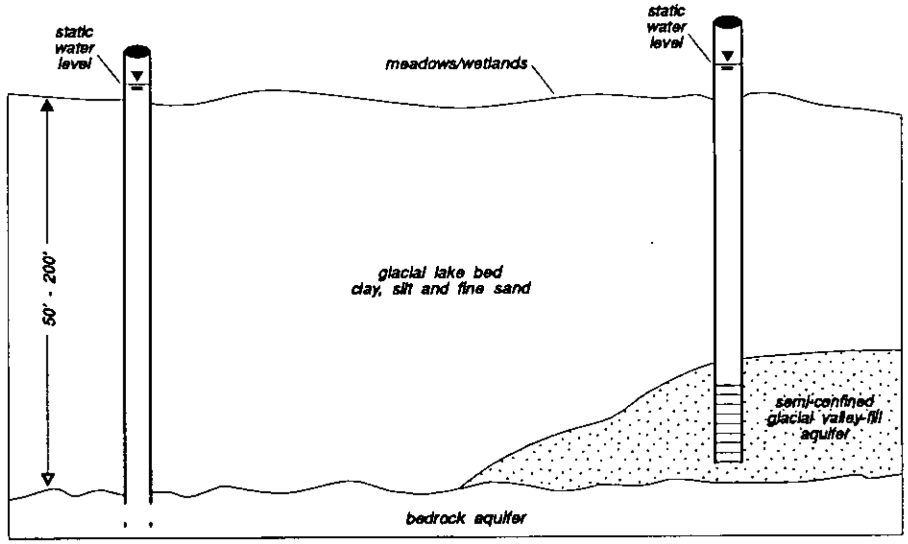

Figure 52. Example of a wetlands that is neither a significant ground-water recharge nor discharge area.

4. **Ground-water not significantly affected by surface water (fig. 52)**

This example illustrates a situation common in northern New Jersey where many valleys contain wetlands which have formed on fine-grained lake-bed sediments deposited in glacial lakes during the last Ice Age. These silts and clays can be up to 200 feet thick and have extremely low permeability, on the order of 10^{-8} centimeters per second. The wetlands are fed by stream flow from nearby topographic highs onto the low lying former-lake beds. The thick glacial lake-bed sediments prevent any significant vertical movement of water to underlying aquifers. While the static water level in the aquifer under the clay may be above or below land surface, the thick clay layer prevents these wetlands from acting as either significant recharge or discharge areas.

These four examples show that the role of wetlands and streams in the hydrologic cycle changes depending on topography, water levels and geology. One cannot make the statement that wetlands are always recharge or discharge areas. There are some principles, though, which can be applied to make a preliminary evaluation.

Wetlands need a continual source of water to exist or they dry up. Wetlands which do not have a surface-water source must be fed by ground water and thus are probably ground-water-discharge areas. Wetlands next to streams but uphill and not subject to frequent flooding are probably discharge areas. Wetlands next to streams that receive frequent additions of surface water may be either a discharge or recharge area or may not significantly interact with the aquifer. In most cases, however, a field investigation will be required to precisely determine the interaction between any particular wetland and the ground-water system.

From the standpoint of a soil-water balance model used in this report, the fact that the recharge or discharge status of the wetlands does not depend on the factors used in the recharge simulations precludes the use of the model to quantify any recharge they may supply. Other modeling methods exist that can simulate recharge from surface water.

APPENDIX 9

Soil Conservation Service Field Offices

ATLANTIC & CAPE MAY
Mays Landing SCS Field Office
1200 Harding Highway
Mays Landing, NJ 08330
(609) 625-9400

BURLINGTON
Mount Holly SCS Field Office
1632 Route 38, Cramer Building
Mount Holly, NJ 08060
(609) 267-0811

GLOUCESTER & CAMDEN
Pitman SCS Field Office
Kandle Center
77 E. Holly Avenue, Suite 1-A
Pitman, NJ 08071
(609) 582-9027

HUNTERDON
Flemington SCS Field Office
Hunterdon County Extension Center
8 Gauntt Place
Flemington, NJ 08822
(908) 782-3915

MERCER
Trenton SCS Field Office
508 Hughes Drive
Hamilton Square, NJ 08690
(609) 584-8337

MIDDLESEX & MONMOUTH
Freehold SCS Field Office
Opatut Professional Center
Suite B-11
77-55 Schanck Road
Freehold, NJ 07728
(908) 462-1079

MORRIS, BERGEN, HUDSON, ESSEX & PASSAIC
Morristown SCS Field Office
Court House
Morristown, NJ 07960
(201) 538-1552

OCEAN
Forked River SCS Field Office
714 Lacey Road
Forked River, NJ 08731
(609) 971-3316

SALEM & CUMBERLAND
Deerfield SCS Field Office
P.O. Box 144 (Route77)
Deerfield, NJ 08313
(609) 451-2144

SOMERSET & UNION
Bridgewater SCS Field Office
Somerset County 4-H Center
308 Milltown Road
Bridgewater, NJ 08807
(908) 725-3848

SUSSEX
Newton SCS Field Office
330 Route 206 South
Newton, NJ 07860
(201) 383-0529

WARREN
Hackettstown SCS Field Office
Hackettstown Commerce Park
101 Bilby Road, Bldg. #1-H
Hackettstown, NJ 07840
(908) 852-5450

A METHOD FOR EVALUATING GROUND-WATER-RECHARGE AREAS IN NEW JERSEY
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