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U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with
ORANGE COUNTY

OPEN FILE-REPORT 99-179
Terziotti and Eimers, 1999, Susceptibility of ground water to surface and shallow sources of contamination, Orange County, North Carolina

Abstract

In 1998, the relative susceptibility of ground water in Orange County, North Carolina, to contamination from surface and shallow sources was evaluated. A geographic information system was used to build three county-wide data layers—soil permeability, land use/land cover, and land-surface slope. The harmonic mean permeability of soil layers was used to estimate a location's capacity to transmit water through the soil.

Values for each of these three factors were categorized and ranked from 1 to 10 according to relative potential for contamination. Each factor was weighted to reflect its relative potential contribution to ground-water contamination, then the factors were combined to create a relative susceptibility index. The relative susceptibility index was categorized to reflect lowest, low, moderate, high, and highest potential for ground-water contamination.

The relative susceptibility index for about 12 percent of the area in Orange County was categorized as high or highest. The high and highest range areas have highly permeable soils, land cover or land-use activities that have a high contamination potential, and low to moderate slopes. Most of the county is within the moderate category of relative susceptibility to ground-water contamination. About 21 percent of the county is ranked as low or lowest relative susceptibility to ground-water contamination.

Introduction

Growth in population and light industry in Orange County, North Carolina, has resulted in increased demand for water resources. In 1990, approximately 41 percent of the population in Orange County depended on ground water as a drinking-water supply (U.S. Bureau of the Census, 1992). It is estimated that the county's population increased by 17 percent between 1990 and 1998 (U.S. Bureau of the Census, 1999). Historically, the pattern throughout the Piedmont has been that the number of ground-water users in the county has increased as the population has increased (Daniel, 1996). Planners and managers will be better able to keep up with increasing demands for potable water by relying on computerized mapping tools for protecting water sources for the growing population.

In 1998, the U.S. Geological Survey (USGS), in cooperation with Orange County, conducted an investigation to evaluate the susceptibility of ground water to contamination from surface and shallow sources. A geographic information system (GIS) was used to develop and analyze county-wide spatial data layers that contain geologic, hydrologic, topographic, and cultural information. A relative susceptibility index was developed and was based on a combination of factors that contribute to the likelihood that contaminants from surface and shallow sources reach the water table by following the path of aquifer recharge. The selected contributing factors, represented here in the form of GIS spatial data layers, include the following:

- Soil permeability—The harmonic mean permeability of soil layers provides a single value for the capacity of the entire sequence of soil layers to transmit water (with or without contaminants) from the land surface through the soil.
- Land use/land cover—The uses of the land surface and the types of land cover affect the likelihood of infiltration and the generation of contaminants.
- Land-surface slope—The inclination or slope of the land surface, expressed in percent, affects the likelihood that surface water or precipitation will run off rather than pond or infiltrate soils.

Modular programming techniques and data structures were used to develop the susceptibility index. A modular framework allows planning tools, such as a relative susceptibility index, to be more easily refined as data with better resolution or accuracy become available. The best available data were used for this study, but as contaminant inventories, updated data, or other pertinent data become available, the index can be recalculated. Thus, the index can be used to reflect change over time or change based on more accurate data.

Purpose and Scope

This report describes the factors and methods of classification that were used to compute the relative susceptibility to ground-water contamination index for Orange County, North Carolina. Results of the analysis are presented as figures and tables summarizing the areal extent of each index category.

Factors Affecting the Susceptibility of Ground Water to Contamination

Three factors were used to compute the relative susceptibility index—soil permeability, land use/land cover, and land-surface slope. Each contributing factor was derived from individual GIS spatial data layers, or from the analytical combination of more than one GIS layer. A detailed description of the methods that were used to derive each contributing factor is included below.

Soil Permeability

In the absence of county-wide information about the vertical conductance of subsurface materials, the authors considered soil permeability the primary factor in determining the capacity of the entire sequence of materials that overlie the saturated zone to transmit water. No estimate was made of the vertical hydraulic conductance of unsaturated material other than soil. The areal distribution of the permeability of soils in Orange County is shown in figure 1.

Soil types, by county, were identified in the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) Soil Survey Geographic Data Base (SSURGO). The NRCS developed the SSURGO data base at a scale of 1:24,000 primarily for use in the natural-resource management and planning of farms and ranches, land uses, townships, and counties. Information about soil permeability and thickness was obtained from the Map Unit Interpretations Record (MUIR) attribute data base that is linked to the SSURGO soil-unit delineation. MUIR contains information about soils and individual layers within soils. The SSURGO data base provides information about multiple layers for each soil.

Up to four layers of soil type are defined in Orange County. Soil permeability and layer thickness were calculated for each soil layer, *i*. Depths to the upper and lower soil-layer boundaries, recorded in inches, are stored as $deph_i$ and $depl_i$ in the NRCS soils data base (U.S. Department of Agriculture, 1995). The maximum and minimum values for the permeability of a given soil layer, *i*, expressed in inches per hour, are stored in the NRCS data base as $permh_i$ and $perml_i$. The accepted way for obtaining the estimate of the central value for permeability of the entire soil is to calculate the harmonic mean soil permeability (HMP) of the series of soil layers (Sharp, 1998).

Permeability is distributed lognormally. Therefore, the log mean permeability, P_i, is used to estimate the central value of the maximum and minimum permeability for a given layer, *i*.

$$P_i = \left\{\frac{\log(permh_i) + \log(perml_i)}{2}\right\}$$

To estimate the central value for permeability of a series of soil layers, P_1, P_2, P_3, and P_4, the HMP is used (Sharp, 1998).

$$\text{HMP} = \frac{\sum_{i=1}^{i=4} |deph_i - depl_i|}{\sum_{i=1}^{i=4} \frac{|deph_i - depl_i|}{P_i}}$$

This analytical technique was performed in an ARC/Info[1] GIS environment for each soil type in the SSURGO data base for Orange County. Harmonic mean permeabilities were subdivided into six permeability classes to generate the color-shaded map shown in figure 1. The resulting mapped permeability classes provide a representative permeability for the entire vertical succession of soil layers.

Land Use / Land Cover

Land use/land cover are contributing factors to the susceptibility of ground-water contamination because activities on the land, as well as the physical properties of the land cover, can substantially influence the potential for ground-water contamination. The areal distribution of land use/land cover categories in Orange County is shown in figure 2. The land-use/land-cover categories were rated to reflect the potential of anthropogenic and natural activities to generate contaminants, as well as hydrologic properties inherent in a particular land-cover type, notably the ability for precipitation to infiltrate into the subsurface.

Land cover was determined from the Multi-Resolution Land Characterization (MRLC) data base. The primary source for this data base is Landsat satellite imagery, collected between 1990 and 1993 and stored at a 30-meter resolution. Supplementary land-use information was provided by the North Carolina Division of Waste Management, and includes geographic data on (a) active municipal solid-waste landfills at a scale of 1:24,000, updated in March 1994; (b) uncontrolled and unregulated hazardous-waste sites, including sites on the State and national priority list, at a scale of 1:24,000, updated in June 1995; and (c) hazardous-waste treatment, storage, and disposal facilities regulated under the Resource Conservation and Recovery Act (RCRA) at a scale of 1:24,000, updated in March 1991.

Land-Surface Slope

Slope is used as an indicator of runoff or infiltration of precipitation. Relative susceptibility to ground-water contamination at a given point is greater when infiltration is high and runoff is low. Flat terrain (low-percent slope) indicates areas of low runoff and high infiltration potential. The areal distribution of land-surface slope in Orange County is shown in figure 3.

Slope of the land surface throughout Orange County was determined from analysis of a digital elevation model (DEM) generated by the USGS for the county. The 30-meter resolution DEM was generated from the 1:100,000-scale USGS Digital Line Graph (DLG) hypsography (surface-elevation contour line) data and the 1:100,000-scale U.S. Environmental Protection Agency River Reach stream files using the ARC/Info "topogrid" process (Environmental Systems Research Institute, Inc., 1994), modeled after Cederstrand and Rea (1996). A slope map was derived from the DEM by using ARC/Info GIS software.

Methods

Soil permeability, land-surface slope, and land use/land cover are each treated as contributing factors in evaluating relative ground-water contamination susceptibility. The values of each of these three factors were categorized and assigned a contamination-potential rating (CPR) on a scale of 1 to 10. The description of each factor and assignment of CPR values are detailed in tables 1, 2, and 3. A rating of 1 reflects the lowest ground-water CPR for a given factor and 10 reflects the highest CPR for a factor. For example, the land-use/land-cover category of "hazardous-waste disposal site" has a high CPR (10) due to the high potential for ground-water contamination from a known contaminant source, whereas the category of "deciduous forest" was assigned a CPR of 4 because it does not pose as great an inherent risk. Similarly, the CPR for slope is low (1) in areas of high slope (greater than 18 percent), and high (10) in areas of low slope (0 to 2 percent) because of increased infiltration potential in flatter terrain. The CPR's were modified from O'Hara (1996); the land-cover/land-use categories reflect residential land-use characteristics, agricultural practices, and wetland characteristics in Orange County.

[1]The use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Table 1. Soil permeability[1] ratings
[<, less than]

Permeability values (inches per hour)	Area in county (percent)	Contamination-potential rating (CPR)
Less than 0.2	5	1
Greater than or equal to 0.2 to less than 0.4	17	2
Greater than or equal to 0.4 to less than 0.8	<1	4
Greater than or equal to 0.8 to less than 1.6	65	6
Greater than or equal to 1.6 to less than 3.2	10	8
Greater than or equal to 3.2	3	10

[1]Permeability refers to harmonic mean soil permeability (HMP).

Table 2. Land-use/land-cover categories and ratings
[<, less than]

Land-use categories	General description or example	Area in county (percent)	Contamination-potential rating (CPR)
Low-intensity development	Residential development. Structures account for 30 to 80 percent of the total area. Most commonly, single-family housing areas, especially suburban neighborhoods.	4	6
High-intensity residential	Residential development. Densely built urban centers, apartment complexes and row houses. Vegetation occupies less than 20 percent of the landscape. Structures account for 80 to 100 percent of the total area.	1	7
Commercial/ industrial	Land used for the manufacture of products or sale of goods. Includes all highly developed lands not classified as residential, most of which are commercial, industrial, or transportation.	< 1	8
Hazardous-waste disposal sites	Uncontrolled and unregulated hazardous-waste sites, including superfund sites.	< 1	10
Hazardous-waste facilities	Treatment, storage, and disposal facilities regulated under the Resource Conservation and Recovery Act. Originally stored as point locations, a circle with a 30-foot radius was generated around each site to define the extent.	< 1	10
Landfills	Active municipal solid-waste landfills. Originally stored as point locations, a circle with a 30-foot radius was generated around each site to define the extent.	< 1	10
Hay/pasture	Areas dominated by vegetation, which are planted and(or) maintained for the production of food or feed. Grasses, legumes, or mixtures planted for livestock grazing.	9	3
Row crops	Areas dominated by vegetation that is planted; areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.	11	5
Other grass	Vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, and golf courses.	< 1	5
Deciduous forest	Areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously.	44	4
Mixed forest	Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present.	10	4
Evergreen forest	Areas dominated by trees where 75 percent or more of the tree species retain their foliage all year. Canopy is never without green foliage.	19	4
Woody wetland	Areas of forested or shrubland vegetation where the soil or substrate is periodically saturated or covered with water.	1	1
Emergent wetland	Non-woody, vascular, perennial vegetation where the soil or substrate is periodically saturated or covered with water.	< 1	1
Water	All areas of open water, generally with less than 25-percent cover of vegetation.	1	8
Barren land	Bare rock, sand, silt, gravel, or other earthen material with little or no vegetation, regardless of its inherent ability to support life.	< 1	8

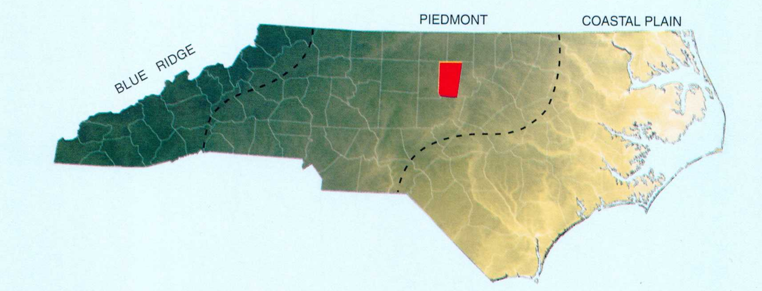
Table 3. Slope ratings

Slope values (percent)	Area in county (percent)	Contamination-potential rating (CPR)
Less than or equal to 2	25	10
Greater than 2 to less than or equal to 6	49	9
Greater than 6 to less than or equal to 12	22	5
Greater than 12 to less than or equal to 18	4	3
Greater than 18	1	1

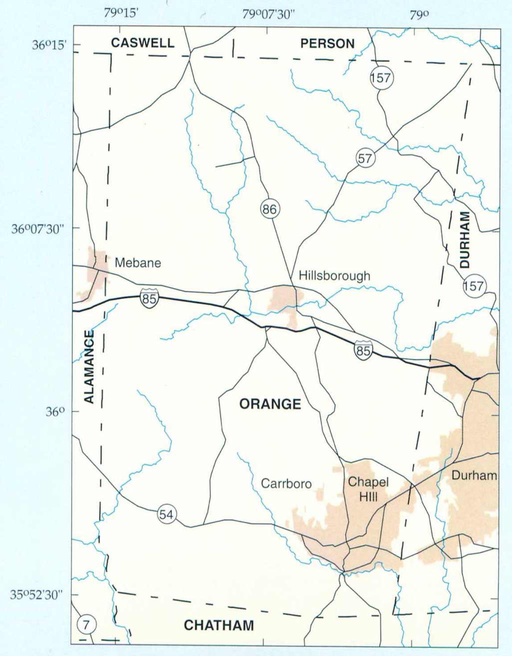
The three contributing factors—soil permeability, land use/land cover, and land-surface slope—also are weighted. The weights are subjective measures that reflect confidence in the information as well as relative importance in determining susceptibility to ground-water contamination. Permeability of soils has a weight of 6, land use/land cover has a weight of 3, and land-surface slope has a weight of 1. The rated and weighted factors were combined, resulting in a relative susceptibility value ranging from 10 to 100 (table 4). Finally, relative susceptibility values were divided into five relative susceptibility categories (table 5).

Table 4. Example calculation of relative susceptibility value

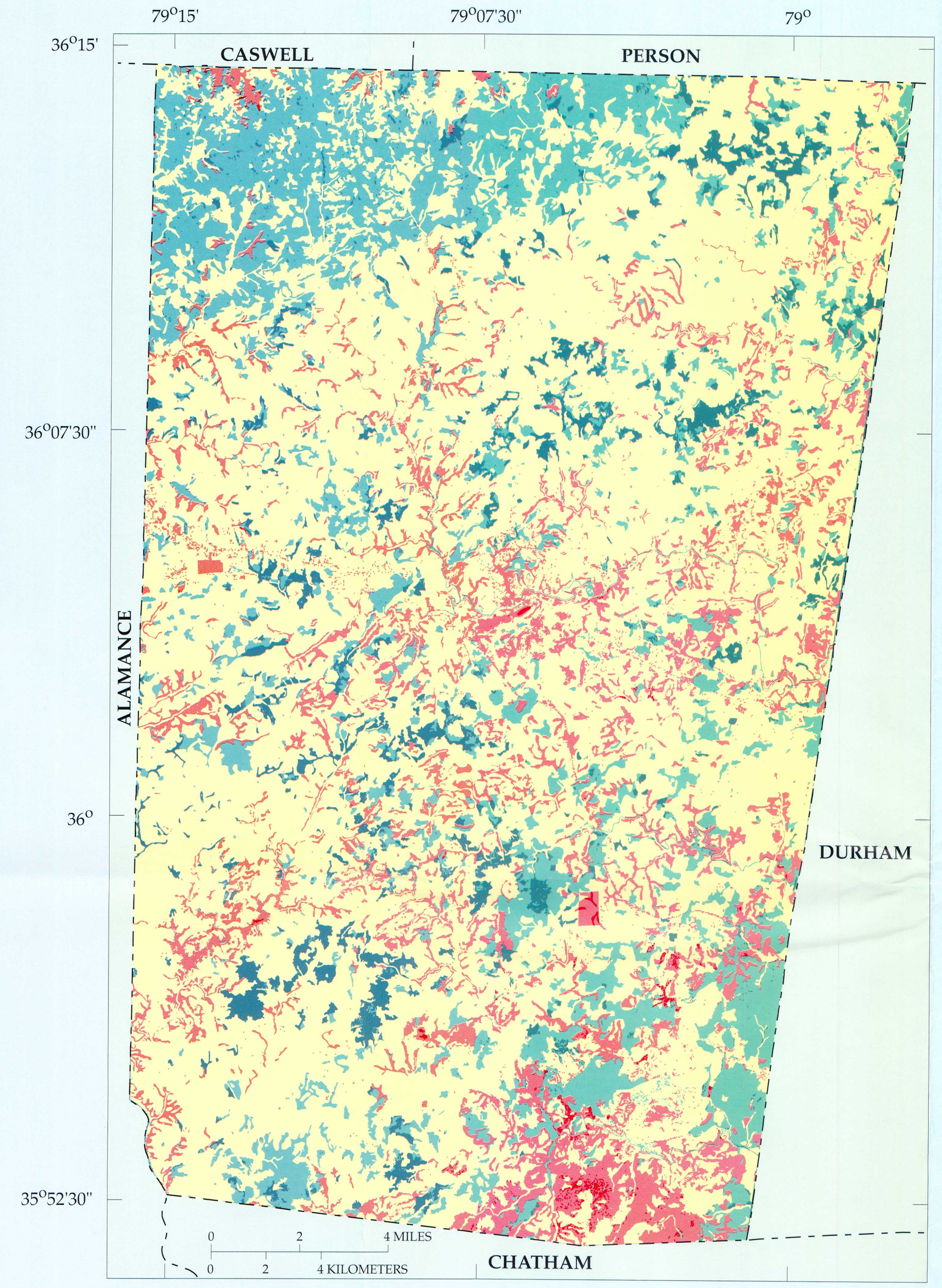
Factor	Data value (from GIS)	Assigned contamination-potential rating (CPR)	Weight (W)	Total (T) ($T_i = CPR_i \times W_i$)
Permeability (inches per hour)	0.7	4	6	24
Land use/land cover	Low-intensity development	6	3	18
Slope (percent)	5	9	1	9
	relative susceptibility value = $T_1 + T_2 + T_3$			51



LOCATION OF ORANGE COUNTY AND PHYSIOGRAPHIC PROVINCE LINES IN NORTH CAROLINA

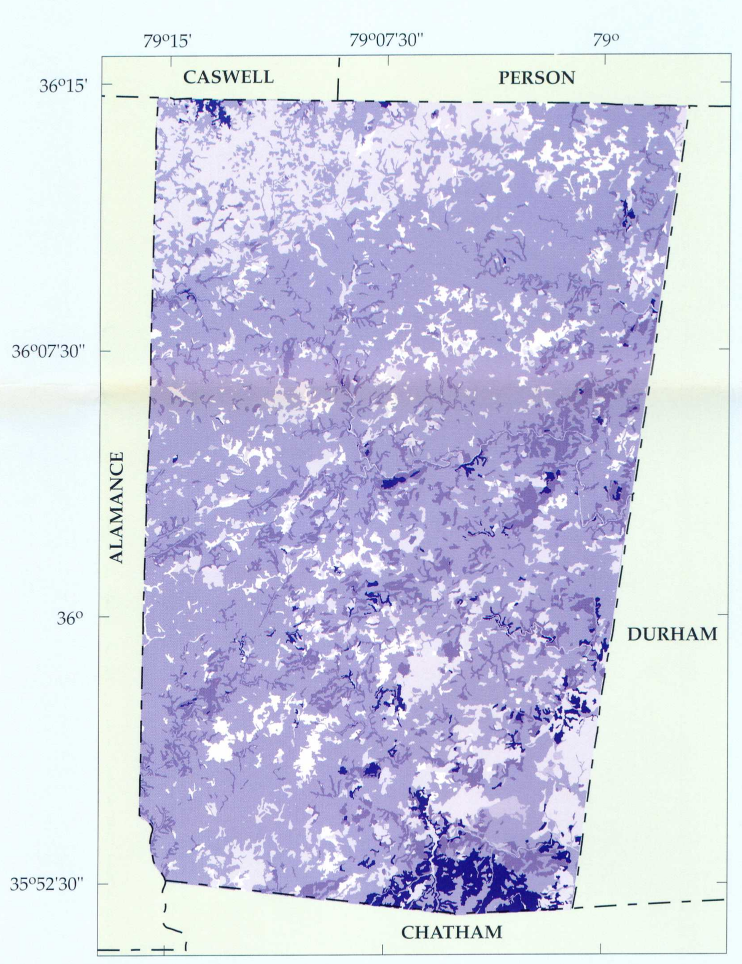


ORANGE COUNTY, NORTH CAROLINA



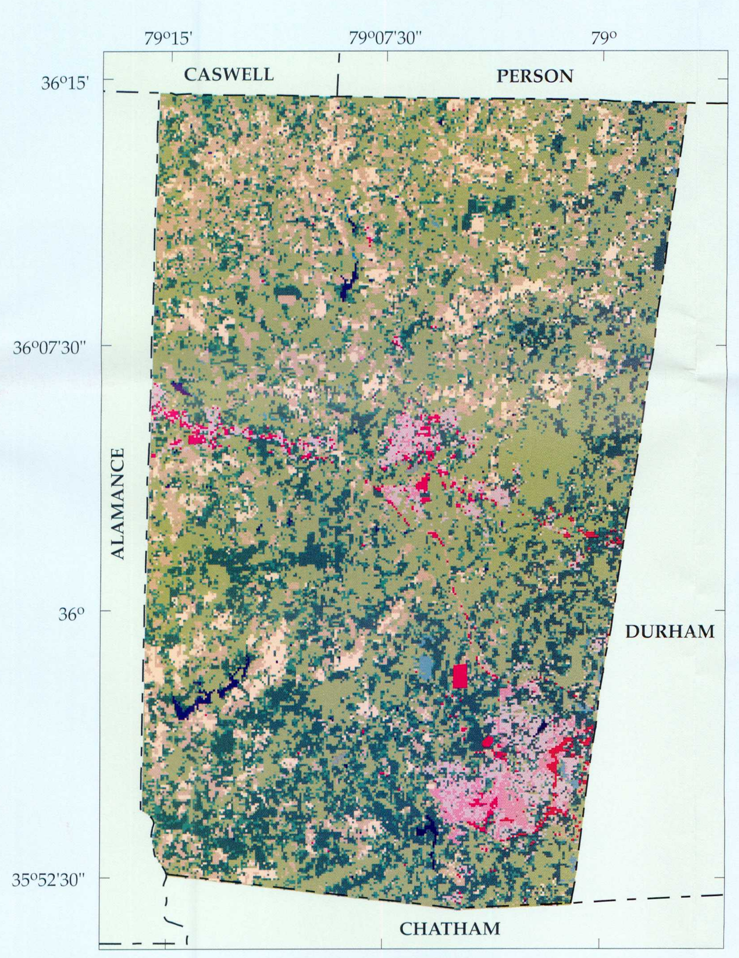
EXPLANATION
RELATIVE SUSCEPTIBILITY CATEGORIES
- LOWEST
- LOW
- MODERATE
- HIGH
- HIGHEST

Figure 4. Relative susceptibility of ground water to contamination in Orange County, North Carolina.



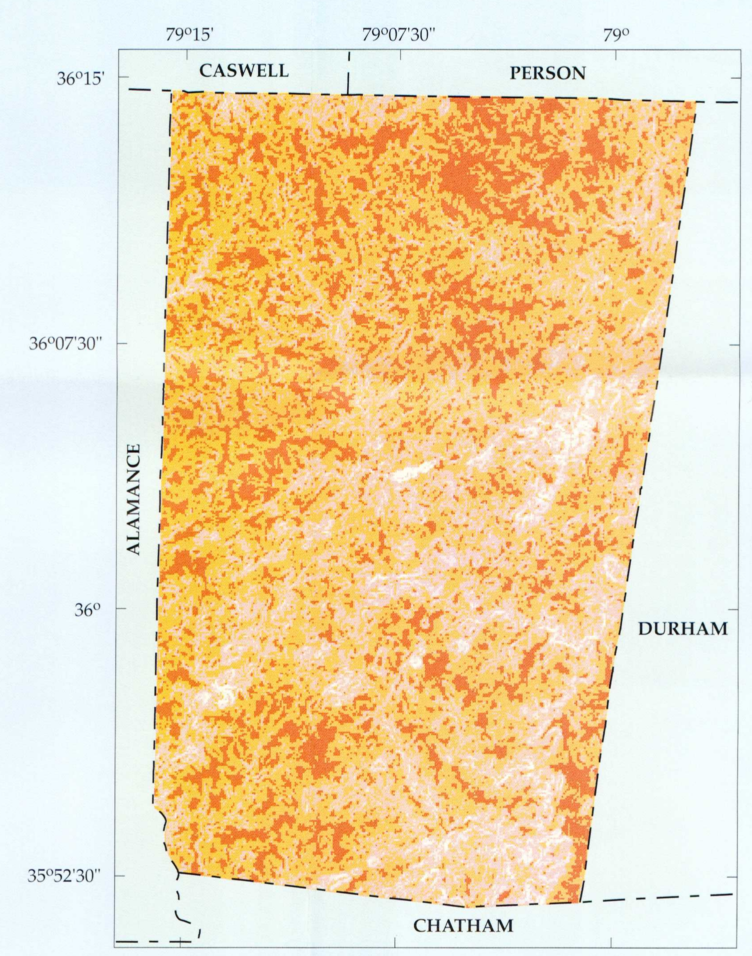
EXPLANATION
SOIL PERMEABILITY, IN INCHES PER HOUR
- LESS THAN 0.2
- 0.2 to 0.4
- 0.4 to 0.8
- 0.8 to 1.6
- 1.6 to 3.2
- GREATER THAN 3.2

Figure 1. Soil permeability.



EXPLANATION
LAND USE/LAND COVER CATEGORIES
- WATER
- LOW INTENSITY DEVELOPED
- HIGH INTENSITY RESIDENTIAL
- HIGH INTENSITY COMMERCIAL/ INDUSTRIAL/HAZARDOUS DISPOSAL SITES
- HAY/PASTURE
- ROW CROPS
- OTHER GRASS (lawns, city parks, golf courses)
- EVERGREEN FOREST
- MIXED FOREST
- DECIDUOUS FOREST
- WOODY WETLAND
- EMERGENT HERBACEOUS WETLAND
- BARE QUARRIES, STRIP MINES, SAND PITS

Figure 2. Land use/land cover categories.



EXPLANATION
LAND-SURFACE SLOPE, IN PERCENT
- 0 to 2
- 2 to 6
- 6 to 12
- 12 to 18
- GREATER THAN 18

Figure 3. Land-surface slope.

Table 5. Relative susceptibility percentile ranges and categories

Relative susceptibility value range (percent)	Area in county (percent)	Relative susceptibility category
10 to 28	5	lowest
29 to 46	17	low
47 to 64	67	moderate
65 to 82	11	high
83 to 100	< 1	highest

Results

Five categories of relative susceptibility of ground water to contamination from surface and shallow sources were mapped (fig. 4). Areas with the combination of highly permeable soils, low slopes, and land uses with known or suspected contaminant sources have the highest relative-susceptibility rating. Areas of the county that contain soils with low permeability, high slopes, and land cover with little potential for contamination have low susceptibility ratings. The lowest relative susceptibility category encompasses about 5 percent of the county area. Seventeen percent of the county is in the low relative susceptibility category. The majority (67 percent of the county) is in the moderate relative susceptibility category. Eleven percent of the area of the county is in the high susceptibility category. Less than 1 percent of the area in the county is highest in relative susceptibility to contamination.

The relative susceptibility index is intended to serve as a guide in planning and decision making in Orange County. Because the data used to determine the relative susceptibility index were created at different times and are available at different spatial scales, the resulting map has limitations. Numerical values derived from the application of the rating system, although based on quantitative data, provide only a relative comparison of contamination risks over broad areas. They are valid only at the county-wide spatial scale presented and within the context of the land-use data set.

Summary and Application

A relative susceptibility index of ground-water contamination from surface and shallow sources was generated for Orange County, North Carolina. The index was constructed by using a GIS to build, classify, and categorize three factors that contribute to the susceptibility of ground-water contamination—soil permeability, land use/land cover, and land-surface slope. The factors were weighted and combined to create relative susceptibility values for all of Orange County. The relative susceptibility values were categorized and classified to reflect lowest to highest contamination potential throughout the county. Most of the county has a moderate susceptibility to contamination, and less than 1 percent of the county is in the highest category of susceptibility to ground-water contamination.

The relative susceptibility index can be a valuable planning tool for Orange County. Using a modular GIS approach to construct the susceptibility index insures that as more detailed contamination-source information or more detailed land-use information becomes available, the index can be refined to reflect the more accurate components.

The relative susceptibility index is not a measure of actual contamination but an evaluation of potential for ground-water contamination on a county-wide basis, based on the physical properties of the earth and land use in 1994. County officials can use this information to help guide development when ground-water use is involved in the planning decisions. Individual homeowners cannot use this information to evaluate a single piece of property because of the scale at which the data are available. However, homeowners can use this information to evaluate the susceptibility of their general area to determine how vigilant they must be in protecting the ground-water resources.

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Susceptibility of Ground Water to Surface and Shallow Sources of Contamination, Orange County, North Carolina

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1999