Prepared in cooperation with the
MISSISSIPPI DEPARTMENT OF ENVIRONMENTAL QUALITY
OFFICE OF POLLUTION CONTROL and the
MISSISSIPPI DEPARTMENT OF AGRICULTURE AND COMMERCE
BUREAU OF PLANT INDUSTRY

FACTORS AFFECTING THE RELATIVE SUSCEPTIBILITY OF GROUND WATER TO SURFACE AND SHALLOW SOURCES OF CONTAMINATION IN MISSISSIPPI

The relative susceptibility of ground water in major aquifers to surface and shallow sources of contamination in Mississippi was evaluated based on the combination of selected factors (of cultural and hydrologic significance) that contribute to the likelihood that contaminants from surface and shallow sources will follow the path of aquifer recharge and reach the water table. The selected contributing factors, in the form of GIS spatial data layers, are provided in the following list:

- Hydraulic Conductance (*C*)- the product of hydraulic conductivity (*K*) and cross-sectional area (*A*) of flow divided by the length (*L*) of the flow path (McDonald and Harbaugh, 1988). Hydraulic conductance represents the transmitting capability of a block of earth material (Franke and others, 1990) and is used in this investigation as a measurement of the capacity of the materials in the soil zone and the unsaturated zone overlying the unconfined aquifer to transmit water (with or without contaminants) from the land surface to the water table. Hydraulic conductance (*C*) can be most simply expressed in a formula as follows:

$$C = (K \times A) / L \qquad (1)$$

- Land-Surface Slope - the inclination or slope of the land surface, expressed in percent, provides data about the likelihood that surface water or precipitation will run off or pond due to land-surface slope, and
- Land Use/Land Cover - the classification of the type of cover or use of the land surface provides data about the likelihood that land use or land cover will influence the infiltration and/or generation of potential contaminants.

The selected contributing factors were derived from individual GIS spatial data layers or from the analytical combination of more than one GIS layer. Land-surface slope and land use/land cover were each derived from individual GIS spatial data layers, whereas, hydraulic conductance was derived from the analytical combination of GIS spatial data layers about soil permeability and thickness, aquifer outcrop area and conductivity, and the depth to the water table (used as the total thickness of the unsaturated zone). A detailed description of the statewide determination of relative vertical hydraulic conductance and a map of relative vertical hydraulic conductance are on sheet 3.

In evaluating relative ground-water susceptibility, hydraulic conductance, land-surface slope, and land use/land cover are each treated as contributing factors and rated on a scale of 1 to 10. A rating of 1 is the lowest ground-water susceptibility rating for a given factor and 10 is the highest ground-water susceptibility rating for a factor. The assignment of rating values for each factor is detailed in tables 2 and 3. The rated factors are assigned weights of 3 for hydraulic conductance, 1 for land-surface slope, and 1 for land use/land cover. Hydraulic conductance is given a weight of 3 because data are combined from many sources to determine relative vertical hydraulic conductance. After the factors are rated and weighted, they are combined, resulting in a relative susceptibility value. Finally, relative susceptibility values are divided into five categories. A detailed description of the statewide determination of the relative susceptibility of ground water to contamination from surface and shallow sources along with the map of evaluated relative susceptibility is given on sheet 4.

Soil Permeability and Thickness

The soil layer generally is the uppermost part of the unsaturated zone and is characterized by significant biological activity. Permeability of soils is a measure of the ease with which fluids can move through the soil zone and is an important factor in evaluating the susceptibility of ground water to contamination. Values for soil permeability used in this investigation are saturated soil permeability rates measured in inches per hour and converted to feet per day for use in the determination of vertical hydraulic conductance.

The U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS) State Soil Geographic Data Base (STATSGO) was the primary source of data for the determination of area-weighted harmonic mean soil permeability and soil thickness. STATSGO provides information about soils and individual layers within soils, but does not provide a mapped boundary for each individual soil. The NRCS developed STATSGO to be used primarily as a guide for regional resource planning, management, and monitoring. Soil permeability and thickness information was extracted from STATSGO at the layer level, combined by component, and statistically expanded to cover the entire map unit. STATSGO soil map units are not homogeneous and continuous; each soil map unit is normally composed of soils of highly different permeabilities, and the area-weighted harmonic mean permeabilities generated by this study for each soil map unit do not reflect local permeability conditions related to a site-specific soil. Furthermore, the total depth of soil layers as provided in the STATSGO data base is variable; most of the soil samples that were used to develop STATSGO were collected from approximately the uppermost 64 inches of the soil profile. Because most water-table aquifers in Mississippi occur at a depth below land surface greater than 64 inches, STATSGO provides an indication of the permeability of only the upper part of the unsaturated zone.

The permeability values used for soils in the susceptibility evaluation are the area-weighted harmonic mean of the permeabilities of a vertical succession of horizontally oriented soil layers in a given area (O'Hara, 1994). The permeability values used provide a representative vertical soil permeability for a given area. The permeability values generated were subdivided into permeability ranges to generate the color-shaded permeability range map (fig. 4). The resultant permeability ranges are considered a representative average permeability for the entire vertical succession (total thickness) of soil layers for a given area. The permeability map illustrates well the relation between soils and the underlying lithology of the parent material that have given rise to them. Areas of relatively low soil permeability tend to overlie geologic units that have a fine-grained characteristic lithology as can be seen in the generally low permeabilities for soils that overlie the Yazoo Clay of the Jackson Group, the Quaternary alluvium in the Delta, and in the outcrops of the Porters Creek Formation and the Arcola Limestone, Mooreville Chalk, and Demopolis Chalk members of the Selma Group. Generally, areas of high soil permeability tend to overlie geologic units that have coarsely-grained characteristic lithologies.

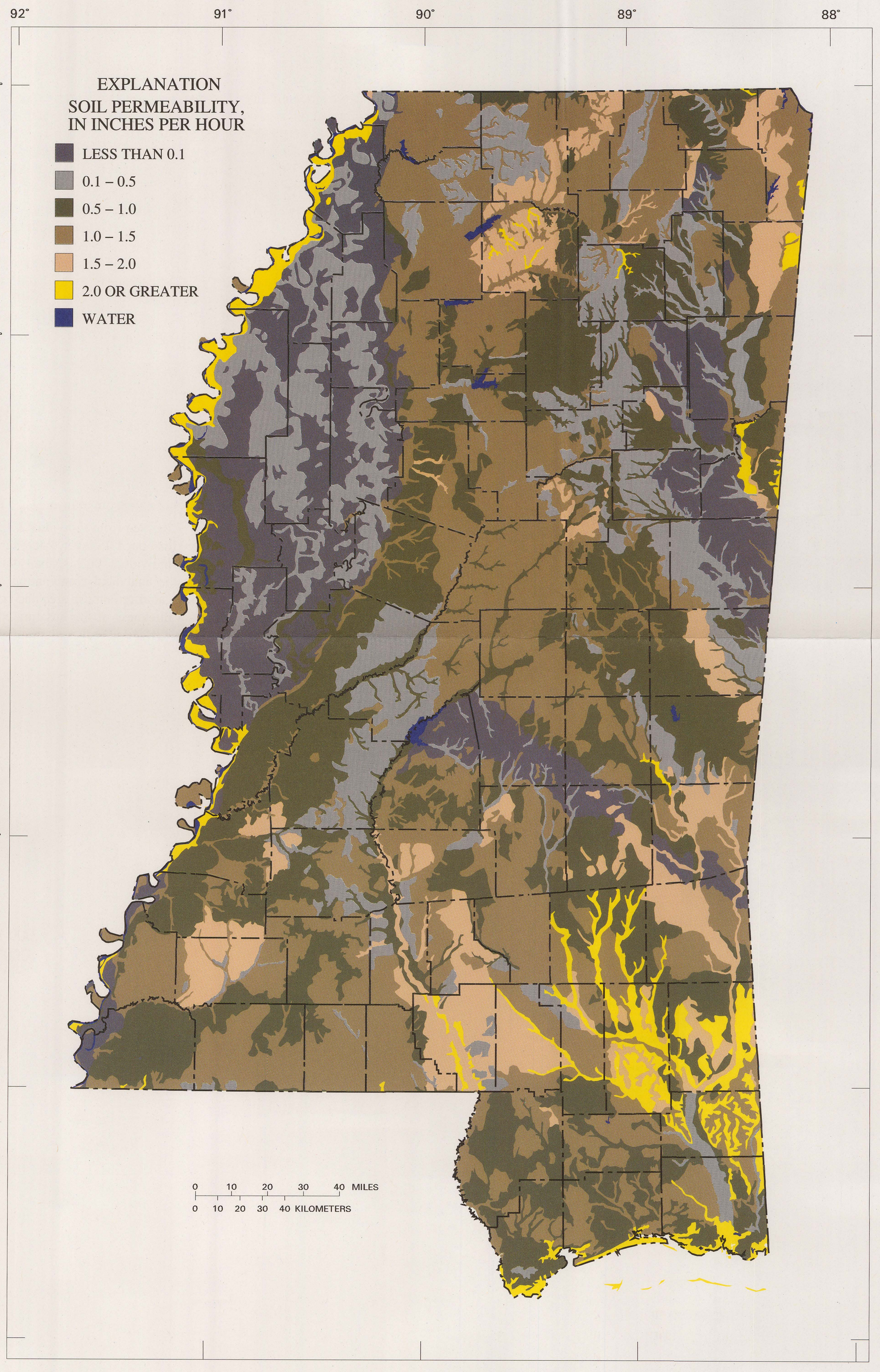

Figure 4. Soil permeability in Mississippi.

Table 2. Contamination susceptibility factors

[modified from Aller and others, 1985]

Factor	Weight	Divisions	Contamination potential rating (CPR)
Conductance (feet-squared per day)	3	Less than or equal to 500	1
		Greater than 500 to less than or equal to 1,000	2
		Greater than 1,000 to less than or equal to 2,000	3
		Greater than 2,000 to less than or equal to 4,000	4
		Greater than 4,000 to less than or equal to 8,000	5
		Greater than 8,000 to less than or equal to 16,000	6
		Greater than 16,000 to less than or equal to 32,000	7
		Greater than 32,000 to less than or equal to 64,000	8
		Greater than 64,000 to less than or equal to 128,000	9
		Greater than 128,000	10
Slope (percent)	1	Less than or equal to 2	10
		Greater than 2 to less than or equal to 6	9
		Greater than 6 to less than or equal to 12	5
		Greater than 12 to less than or equal to 18	3
		Greater than 18	1

Unsaturated Zone and Aquifer Media

The "Geologic Map of Mississippi," compiled by Alvin R. Bicker, Jr. (1969), was modified for use as the geology base map for this investigation (fig. 2). The geology map was generalized and modified to determine the general boundaries of aquifer recharge areas. The boundaries of the recharge areas were based on the outcrop areas of the geologic units that generally host the aquifers and aquifer systems in Mississippi (fig. 3) and are generally referred to [in this report] as aquifer outcrop areas. The GIS spatial data layer for aquifer outcrop areas was used to facilitate many tasks in this investigation including the following:

- Selection of wells that occur in the outcrop for the determination of DTW,
- The generation of an outcrop zone grid with grid cells measuring 300 feet on a side to discretize aquifer outcrop areas in the State,
- The determination of the mean altitude above sea level for each aquifer outcrop,
- To designate areas where aquifer-specific characteristics, such as hydraulic conductivity should be used in the determination of vertical hydraulic conductance,
- To supervise the transformation of the statewide land-surface altitude model into the statewide DTW model, and
- To identify aquifer outcrop areas in the evaluation of the susceptibility of ground water to contamination from surface and shallow sources.

For the purposes of this investigation, the hydraulic conductivity used for the unsaturated zone is an averaged lateral hydraulic conductivity representing saturated flow conditions. The lateral hydraulic conductivity values, as provided in table 1 for the 14 major aquifers and aquifer systems in Mississippi, were derived from results published by Slack and Darden (1991).

In some areas, such as the outcrop area of the Mississippi River alluvial aquifer, the thickness values for the hardpan clay in the upper part of the aquifer were used to further define the nature of the materials overlying the aquifer (Arthur, 1994). The availability of thickness maps for the upper clay unit allowed this information to be used (along with a clay hydraulic conductivity value of less than 0.01 feet per day (J.K. Arthur, USGS, oral commun., 1995) in the determination of vertical hydraulic conductance for the outcrop area of the Mississippi River alluvial aquifer.

Depth to Water Table

The depth-to-water-table (DTW) is the distance from the land surface to the water table and is a measure of the vertical distance a potential contaminant would travel from the land surface to reach the water table. The vertical distance between the land surface and water table was used in this investigation to approximate the length of the total flow path through the unsaturated zone, from the land surface to the unconfined water table, in the determination of hydraulic conductance.

As early as 1899, F.H. King recognized that the surface of the unconfined water table surface is generally a subdued replica of the land surface above it. Mississippi's land surface generally has little to moderate relief and topographic variability. Therefore, a statewide altitude model was transformed to estimate the depth to the water table (O'Hara, 1995). The transformation was based upon a statistical relation between the land-surface altitude and the water-table altitude. However, for the area of northwestern Mississippi commonly called the "Delta" (corresponding generally to the outcrop of the Mississippi River alluvial aquifer), measurements made in the spring of 1995 at 450 wells were used to determine the depth to the water table for the outcrop area of the Mississippi River alluvial aquifer. The decision to use measured data for the Delta, rather than a transformation of the land surface, was made because of the following reasons:

- extensive pumpage from the area [more than 2,000 million gallons per day (Arthur, 1995)] has caused water-level declines throughout the Delta;
- the presence of an extensive, non-continuous upper confining "hard-pan" clay unit; and
- the availability of adequate data about ground-water levels for the area.

The use of water-level measurements to map the depth to the water table in the Delta makes apparent the areas of drawdown, particularly at locations of extensive use of ground water.

On the accompanying map (fig. 5), showing depth to the water table, increasing intensity of blue indicates an increase in the depth to water. Areas shown in brown as "outcrop of confining units" represent units that consist of materials such as massive clays and chalks and are not considered aquifer outcrop areas. The mapped values for depth to the water table (DWT) in figure 5 show estimated shallow water-table conditions along the coast, in bottom-land areas where the topography is extensively dissected by stream drainage, and in the Delta. Deep water-table conditions are shown in hill-crest areas and upland areas of aquifer outcrop. In areas other than the Delta, the values for DTW shown on the map are from a statistical relation of water-table altitudes during unpumped conditions to land-surface altitudes at the well head. Accordingly, DTW values displayed (in areas other than the Delta) do not show the localized effects of drawdown. In any specific location, the actual depth to the water table may be greater or less than indicated on the map due to local factors which could not be considered at the scale used for this investigation. In parts of the State, areas of outcrop contain hardpan or noncontinuous clay sediments that locally confine ground water. Areas of local confinement in the areas of outcrop were treated as unconfined for this study.

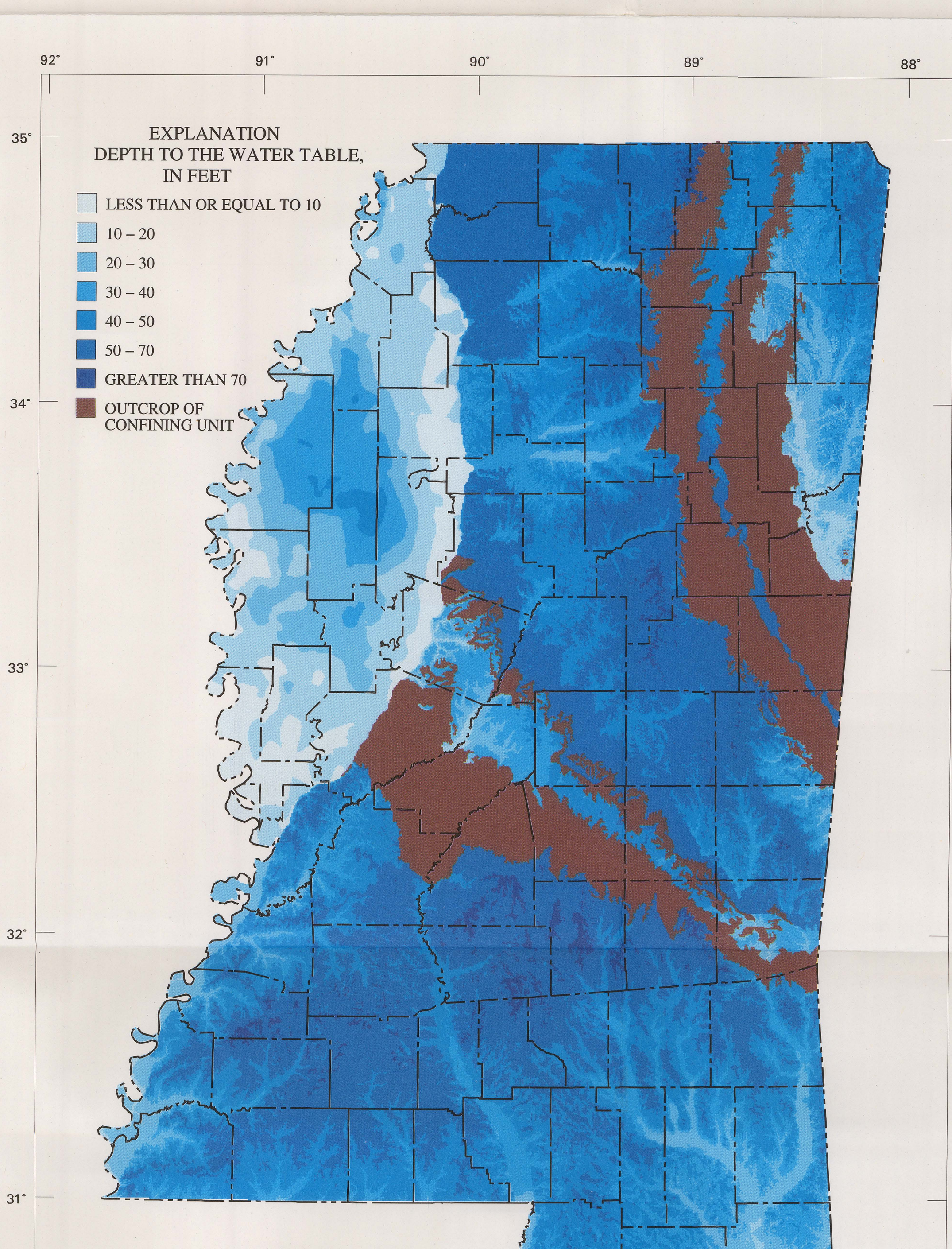

Figure 5. Depth to the water table in Mississippi.

Slope of the Land Surface

The use of slope as a contributing factor in the evaluation of the relative susceptibility of ground water to contamination is based on the assumption that runoff decreases and infiltration increases in areas of low slopes. Areas with steeper slopes have increased runoff and decreased infiltration of water. Therefore, in the evaluation of the relative susceptibility of ground water to contamination, areas with gentle slopes were given a high rating and areas with steep slopes were given a low rating (table 2).

Mississippi's topography generally is characterized by little to moderate relief and variability. The altitude of the land surface in the State ranges from 0 to about 800 feet above sea level. The average altitude statewide is about 290 feet. The highest elevation in is 806 feet at Woodall Mountain in Tishomingo County. The percent slope of the land surface was determined from a statewide-altitude model. This model (grid) was created by combining all of the U.S. Geological Survey, 1:250,000 scale digital elevation models (DEM's) for Mississippi. The 1:250,000 DEM's provided the best available source of digital altitude data and are based on 1:250,000 quadrangle maps with a contour interval of 50 feet. Altitudes at this scale are interpolated at a 3-arc-second interval which was resampled to an even 300-foot interval in the construction of the statewide altitude model.

The mapped slope of the land surface in Mississippi (fig. 6) provides a picture of how and where land surface features change. In boundary areas between hilly and flat regions, the map shows distinctly where land-surface features are in transition. This aspect of the slope map makes possible the visual examination of land-surface features and physiographic districts and, to a lesser extent, provides insight to soil and geologic unit distribution (surficially) throughout the State.

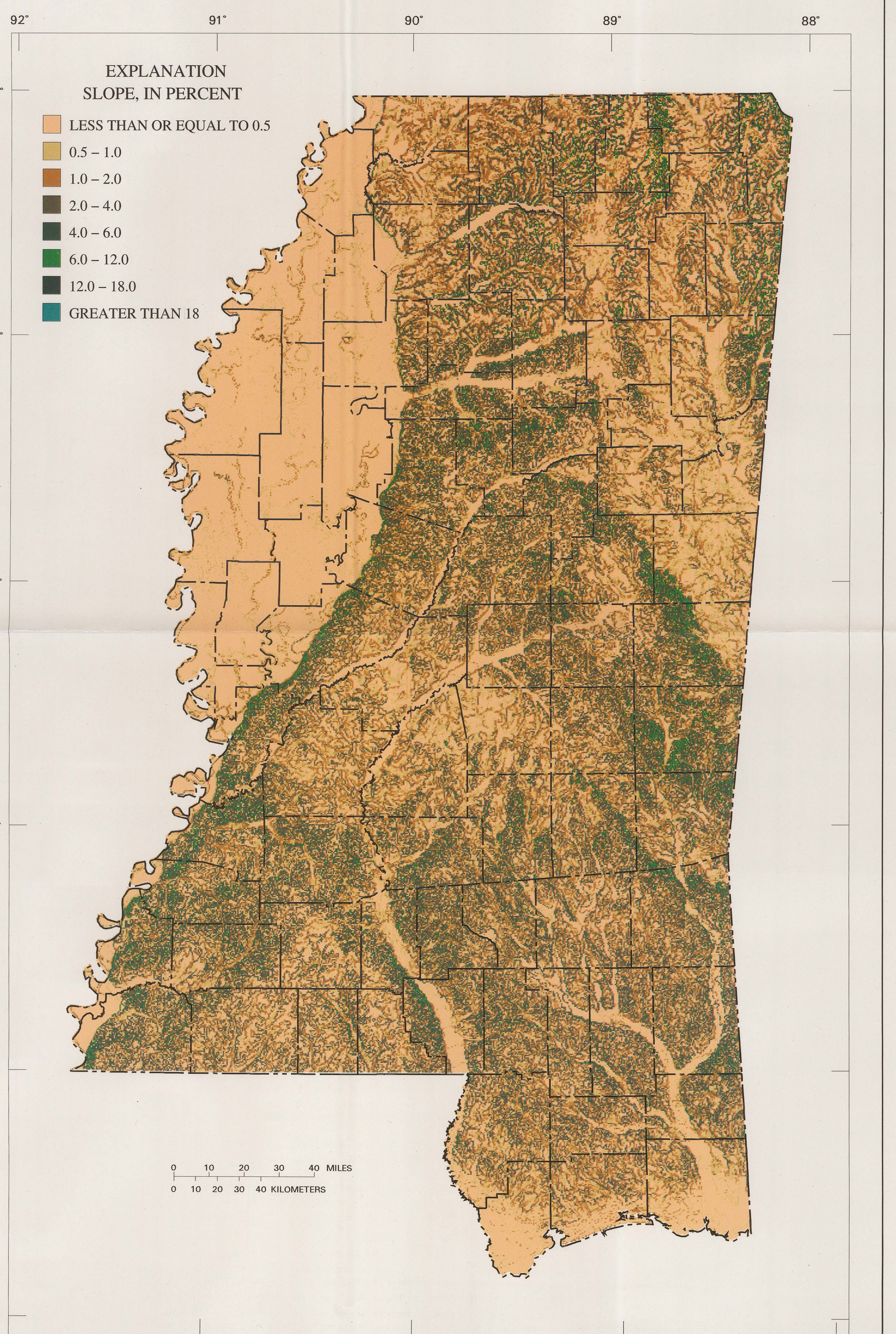

Figure 6. Slope of the land surface in Mississippi.

Table 3. Land use/land cover categories and ratings

[--, indicates areas were merged with adjacent areas; CPR, contamination potential rating; modified from Anderson and others, 1976]

Land use categories: Level I	Land use categories: Level II	General description or example	CPR
Urban or built-up land	Residential	High and low density residential areas	6
	Commercial and services	Land used for the sale of goods and services	7
	Industrial	Land used for the manufacture of products	10
	Transportation, communications and utilities	Roads, railways, utility lines, airports, docks	7
	Mixed urban or built-up land	More than one-third intermixture of two or more urban/built-up level II categories	--
	Other urban or built-up land	Parks, cemeteries, zoos, levees	4
Agricultural land	Cropland and pasture	Land used to cultivate crops and livestock	10
	Orchards, groves, vineyards, nurseries, and ornamental horticultural areas	Land used to cultivate fruits, nuts, trees	--
	Confined feeding operations	Stock yards, feed lots, chicken houses	10
	Other agricultural land	Ponds, field roads, out buildings	--
Forest land	Deciduous forest land	Predominately deciduous trees present	4
	Evergreen forest land	Predominately evergreen trees present	4
	Mixed forest land	More or less equal numbers of deciduous and evergreen trees present	4
Water	Streams and canals	Streams, canals, unimpounded linear water bodies	8
	Lakes	Natural impoundments	8
	Reservoirs	Artificial impoundments	8
Wetlands	Forested wetland	Wetlands dominated by woody vegetation	8-10
	Nonforested wetland	Wetlands dominated by herbaceous vegetation or nonvegetated	8-10
Barren land	Sandy areas other than beaches	Sand bars usually in rivers and streams	--
	Strip mines, quarries, and gravel pits	Lands undergoing surface mineral extraction	8
	Transitional areas	Areas changing from one category to another	--
	Mixed barren land	Mixture of barren land categories; no category occupies more than two-thirds total area	--

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Land Use/Land Cover

In the evaluation of the relative susceptibility of ground water to contamination, ratings for each land-use area are based on how the land use/land cover type influences runoff, the relative contamination risk of anthropogenic and natural activities occurring in that area, as well as hydrologic properties particular to each area. Because land cover and land-use activities substantially influence ground-water contamination risk, this factor was included in the evaluation. Whenever possible, documented cases of the relation between ground-water contamination potential and land-use practice were used to support or modify the rating assigned to each category.

Land-use maps were created from Geographic Information Retrieval and Analysis System (GIRAS) data sets (U.S. Geological Survey, 1978a, 1978b, 1980a, 1980b). These data sets generally are compiled at a scale of 1:250,000 (U.S. Geological Survey, 1986) and are based on the land use and land cover classification system developed by Anderson and others (1976). The classification system is multi-level, wherein each successive level is a more detailed characterization of land use and land cover than the previous level (table 3). Level II categories were used for the susceptibility evaluations, but because of the detailed nature of level II categories, only level I categories are mapped in figure 7. The level I categories mapped in figure 7 include the following with definitions as provided in Anderson and others, 1976:

- Urban or built-up land: The urban or built-up land category consists of any land that is intensively used, much of which is covered by structures. Included in this category are the residential; commercial and services; industrial; transportation, communications, and utilities; mixed urban or built-up land; and other urban or built-up land level II categories (table 3).
- Agricultural land: The agricultural land-use category consists of any land used for the production of food or fiber. Included in this category are cropland and pasture; confined feeding operations, orchards, groves, vineyards, nurseries, and ornamental horticulture operations; and other agricultural land level II categories.
- Range land: The rangeland category includes any land where the potential natural vegetation is predominantly grasses, grasslike plants, forbs, or shrubs and where natural herbivory was an important influence in its pre-civilization state. This category includes herbaceous rangeland, shrub and brush rangeland, and mixed rangeland.
- Forest land: The forest land category includes any land with a tree-crown areal density of 10 percent or more, which is stocked with trees capable of producing timber or other wood products, which influence the climate or water regime. Included in the forest land category are the deciduous forest land, evergreen forest land, and mixed forest land level II categories.
- Water: The water category includes any land that is continually covered by water. To be included, if these areas are linear they must be at least 1/8-mile wide and, if extended, they must cover at least 40 acres (Anderson and others, 1976). Many of the water bodies in Mississippi do not meet this requirement and were mapped with the dominant surrounding land-use category. Included in the water category are streams and canals; lakes; reservoirs; and bays and estuaries level II categories.
- Bays and estuaries: The bays and estuaries category includes inlets or arms of the sea that extend inland and are considered inland waters and, as such, are part of the total area of the United States.
- Wetland: The wetland category includes any land where the water table is at, near, or above the land surface for a significant part of most years. Aquatic or hydrophytic vegetation usually is established, although some areas may not be vegetated. Included in the wetlands category are the forested and nonforested wetland level II categories.
- Barren land: The barren land category consists of any land with limited ability to support life and in which less than one-third of the area has vegetation or other cover. Level II categories included in the barren land category are sandy areas other than beaches; strip mines, quarries, and gravel pits; transitional areas; and mixed barren land.

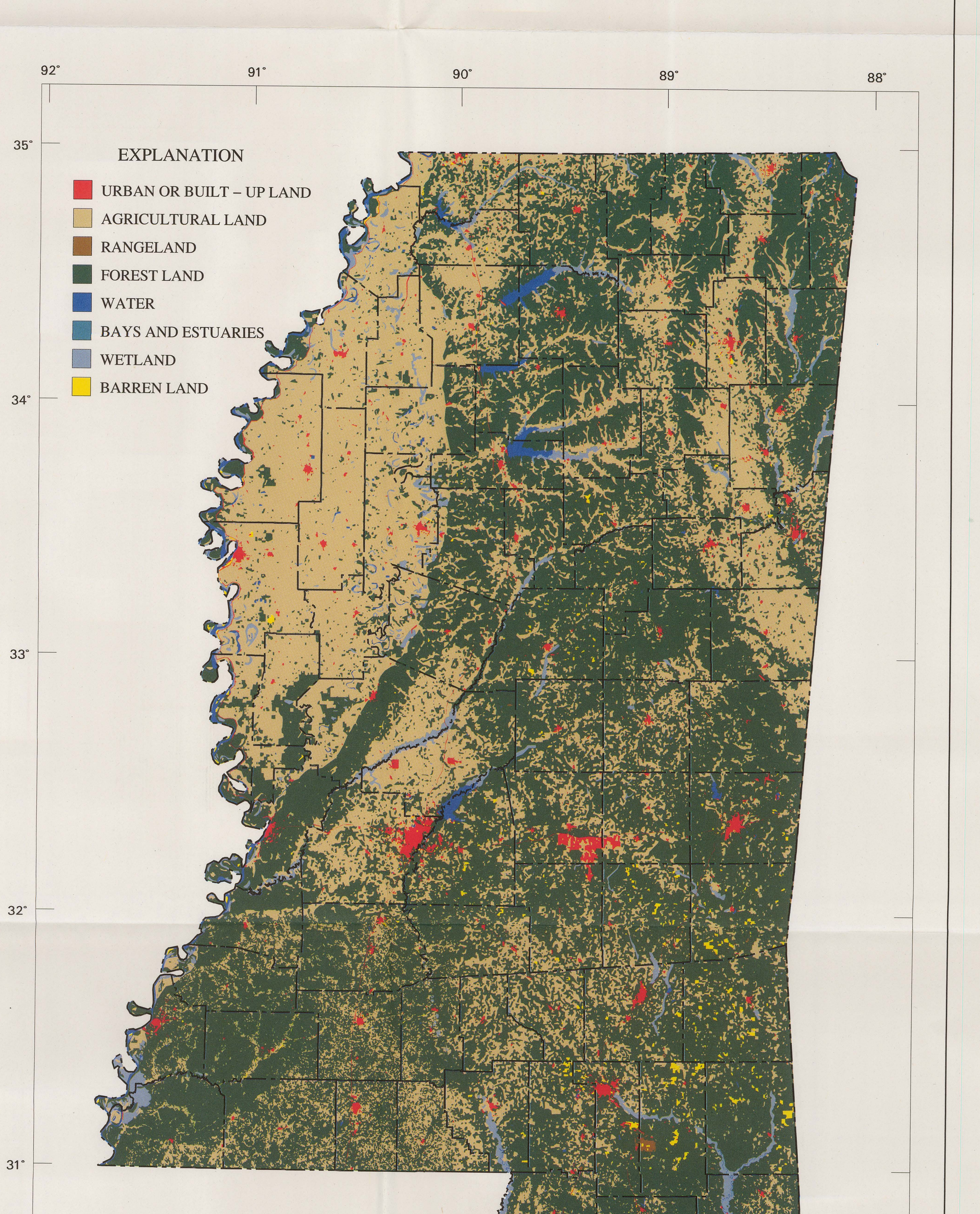

Figure 7. Land use/land cover in Mississippi.

For additional information write to:
U.S. Geological Survey
308 South Airport Road
Pearl, Mississippi 39208-6649

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By
Charles G. O'Hara
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