UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREDICTED EFFECTS ON GROUND WATER OF CONSTRUCTION OF DIVIDE CUT SECTION, TENNESSEE-TOMBIGBEE WATERWAY, NORTHEASTERN MISSISSIPPI USING A DIGITAL MODEL

by Mark S. McBride

Open-File Report 81-649

Prepared in cooperation with

U.S. Army, Corps of Engineers
Nashville District

Jackson, Mississippi
1981

UNITED STATES DEPARTMENT OF THE INTERIOR
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ILLUSTRATIONS

TABLE

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ABSTRACT

The Tennessee-Tombigbee Waterway, connecting the Tennessee River in northeastern Mississippi with the Gulf of Mexico, is currently (1980) under construction. The Divide Section, the northernmost 39 miles of the Waterway, will consist, from north to south, of (1) a dredged channel, (2) the Divide Cut, and (3) an artifical lake impounded by the Bay Springs Dam. In all three, water will be at Tennessee River level. A three-dimensional digital model covering 3,273 square miles was constructed to simulate ground-water flow in the Gordo and Eutaw Formations and the Coffee Sand in the vicinity of the Divide Section. The model was calibrated to preconstruction water levels, then used to simulate the effects of stresses imposed by the construction of the Divide Section. The model indicates that the system stabilizes after major changes in conditions within a few months. The Divide Cut acts as a drain, lowering water levels as much as 55 feet. Drawdowns of 5 feet occur as much as 8 miles from the Cut. The 80-foot-high Bay Springs Dam raises ground-water levels by 5 feet as far as 6 miles from its impoundment. Drawdown is not likely to affect public water supplies significantly, but probably will adversely affect a relatively small number of private wells.

INTRODUCTION

The Tennessee-Tombigbee Waterway will connect the Tennessee River at the point where it touches the north-eastern corner of Mississippi, with the Gulf of Mexico at Mobile, Alabama.

The Waterway is 470 miles long and is divided into four sections (fig. 1) from south to north. These sections and their lengths are:

(1) an existing waterway, following the lower Tombigbee River (267 miles),
(2) the River Section following the upper part of the Tombigbee River (118 miles),
(3) the Canal Section following the East Fork of the Tombigbee River (46 miles), and
(4) the Divide Section for the most part following Mackey's and Yellow Creeks (39 miles)

Sections 2, 3, and 4 are currently (1980) under construction.

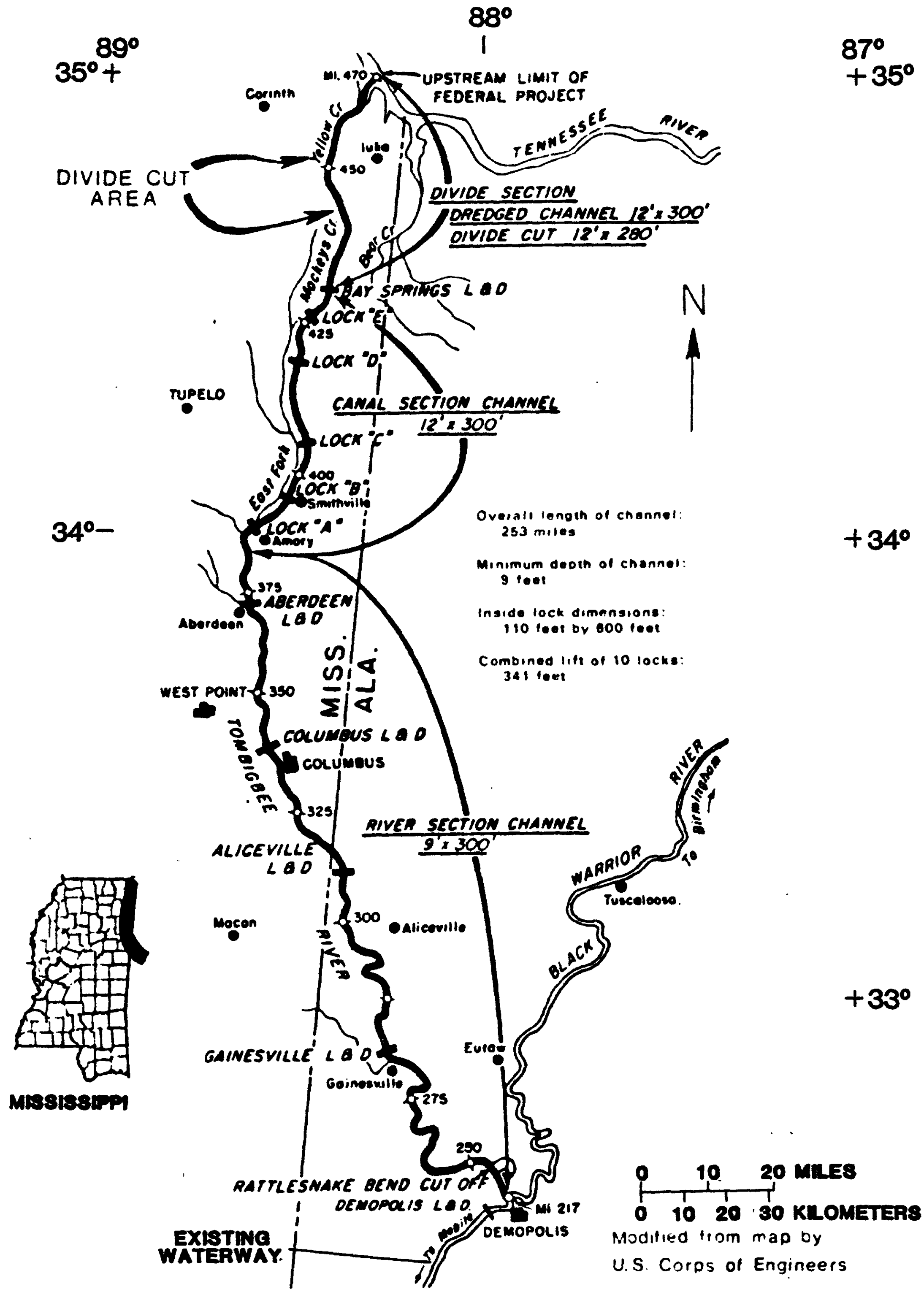

Figure 1.—Location of the Tennessee–Tombigee Waterway and its division into four sections.

This report concerns the hydrologic effects of the Divide Section, and in particular the central part, the Divide Cut. At the south end of the Divide Section a lock and dam at Bay Springs will impound a lake. North of the lake a range of hills forms the topographic divide between the Tombigbee River basin and the Tennessee River basin. A trench will cut north through the hills toward the Tennessee River; this is the Divide Cut. A channel dredged through the lowlands to the mouth of Yellow Creek will connect the Divide Cut with the Tennessee River. All three parts of the Divide Section--lake, Divide Cut, and dredged channel--will contain water at Tennessee River level. No locks or dams will be built within the Divide Section north of those at Bay Springs.

The purpose of this report is to evaluate the effects that constructing the Divide Section will produce on ground water. Expected effects are of three principal kinds:

(1) The Divide Cut will reach depths up to 170 feet. It will cut through much or all the thickness of one of the principal aquifers of the area. Ground water will drain toward the Divide Cut, lowering ground-water levels over a wide area. Concern exists that private and public water supplies may be adversely affected.

(2) The dam at Bay Springs will impound water to a depth of 80 feet. Ground-water heads in the immediate vicinity will be raised by the same amount, and raised heads will spread throughout an area surrounding the dam.

(3) Streams may be affected. Where ground-water levels are lowered, the effect will be decreased dry-weather flow and greater likelihood of periods of no flow. Where water levels are raised, dry-weather streamflow is expected to increase. Marshy areas may shrink where ground-water levels fall and grow larger where levels rise.

This report describes the results of digital modeling of the study area. The shape of the hydrogeological units, their capacity for storing and transmitting water, and the various inputs and outputs of water to and from the system are simulated using a digital computer. Natural conditions are simulated first to test the accuracy of measurements and estimates used in the model. Output consists of calculated water levels for natural conditions. Changes to the input data can then be introduced to model the effect of the Divide Cut; the result consists of estimates of changed, post-construction water levels.

PREVIOUS STUDIES

Various reports provide information on the geology and water resources of the study area.

State-wide geologic maps are available for Mississippi (Bicker, 1969), Alabama (Alabama Geological Survey, 1926) and western Tennessee (Miller, and others, 1966).

Reports useful as broad background include a summary of the geology of the Black Warrior Basin, Alabama and Mississippi (Mellen, 1947) and a regional geologic cross section from central Mississippi to northern Michigan (Dott and Murray, 1954). Another cross section, from northeastern Mississippi south to the Gulf of Mexico, was published by Bicker (1970).

Paleozoic rocks in northeastern Mississippi were described by Bramlette (1925) and by Morse (1930). Welch (1958) described certain of the Upper Mississippian rocks and later described the Mississippian rocks of the northern Black Warrior Basin (Welch, 1959). The Mississippian stratigraphy of Alabama was summarized in a monograph by Thomas (1972). Bicker (1979) summarized what is known about the outcropping Carboniferous rocks of Mississippi.

The Little Bear residuum was described by Mellen (1937).

The Tuscaloosa aquifer system, which includes the Gordo Formation in the area of this report, was the subject of a report by Boswell (1978).

The Eutaw-McShan aquifer was the subject of a similar report (Boswell, 1977).

Cretaceous deposits were the topic of three more general reports, The Upper Cretaceous deposits (Stephenson and Monroe, 1940); Cretaceous aquifers of northeastern Mississippi (Boswell, 1963); and Cretaceous aquifers in the Mississippi Embayment (Boswell, Moore, MacCary, and others, 1965). Outcropping Cretaceous, Paleocene, and lower Eocene formations of western Tennessee were described by Russell and Parks (1975).

Loess deposits in Mississippi were described by Snowden and Priddy (1968).

Several studies used in this report describe the geology of restricted areas. Moore and Harris (1962) produced a geologic map of Colbert County, Alabama. The Pickwick quadrangle, Tennessee, was mapped geologically and its mineral resources summarized by Russell and others (1972). Geology of the Divide Cut area was mapped by the U.S. Army Corps of Engineers (1972).

Reports more specifically on hydrogeology include the following. Newcome (1971) summarized results of aquifer tests in Mississippi. Boswell and Wasson (1974) investigated ground-water resources at the Yellow Creek Port, located near where the Waterway joins the Tennessee River. Wasson and Tharpe (1975) summarized the water resources of Alcorn, Itawamba, Prentiss, and Tishomingo Counties. Potentiometric maps providing "instantaneous" views of water levels were produced for the Eutaw aquifer (Wasson, 1979a), the Gordo aquifer (Wasson, 1979b), and the Paleozoic aquifer (Wasson, 1979c) of northeastern Mississippi. Moran (1980) described occurence of aquifers in the Fort Payne Formation.

Another group of reports contains basic data on stream discharge, ground-water levels, and water chemistry throughout the Tennessee-Tombigbee Waterway area from 1973 to the present (Brahana, 1974; Shell, 1975, 1977, 1978, 1979).

The geology and hydrology of the Waterway is specifically covered by the following. Corps of Engineers design memoranda (U.S. Army Corps of Engineers 1973, 1975) contain general information on hydrogeology of the Divide Cut area. Cross-sections along the axis of and perpendicular to the cut are particularly useful. Boswell (1972) described the hydrogeology of the Divide Cut area and provided an initial estimate of the lowering of ground-water levels that might be caused by construction of the Divide Cut. Aquifer tests subsequently run to better characterize hydraulic properties of the aquifers were described by the U.S. Army Corps of Engineers (1974, ?) and by Daniel and Newcome (1974). Brahana, and others (1974) provided slightly more refined estimates of water-level lowering on the basis of a simplified analytical model. Leake (1977) described detailed digital modeling of ground-water flow in materials immediately adjacent to the Divide Cut.

LOCATION

The area covered by the digital model (fig. 2) extends 50.86 miles east-west and 64.36 miles north-south, for a total area of 3,273 mi^2. Almost all the model area is in Mississippi; small portions of the area lie in Tennessee and Alabama. All of Tishomingo, Alcorn, and Prentiss, most of Itawamba, and parts of Tippah, Union, Pontotoc, and Lee Counties are included.

Stratigraphic Extent

This model principally concerns the Cretaceous units in the study area; specifically, the Gordo, McShan, and Eutaw Formations and the Coffee Sand. One of these formations is at the surface nearly everywhere within the model area. Their aggregate thickness ranges from zero to more than 400 ft.

The Cretaceous formations overlie approximately 7,000 to 8,000 ft of Paleozoic rocks (Bicker, 1970, plate 1), which in turn overlie Precambrian basement rocks.

The model deals principally with Cretaceous rocks because

(1) These rocks are in immediate contact with the Waterway, and thus, water in them is most affected.
(2) They are the chief aquifers in the area, whereas, the Paleozoic rocks are used for water supply only in a few places.
(3) Low-permeability rocks at or near the top of the Paleozoic rocks apparently form an effective lower limit to the surface-ground-water flow system.
(4) Information available on the Paleozoic rocks is insufficient to do more than group them in a general way for modeling purposes.

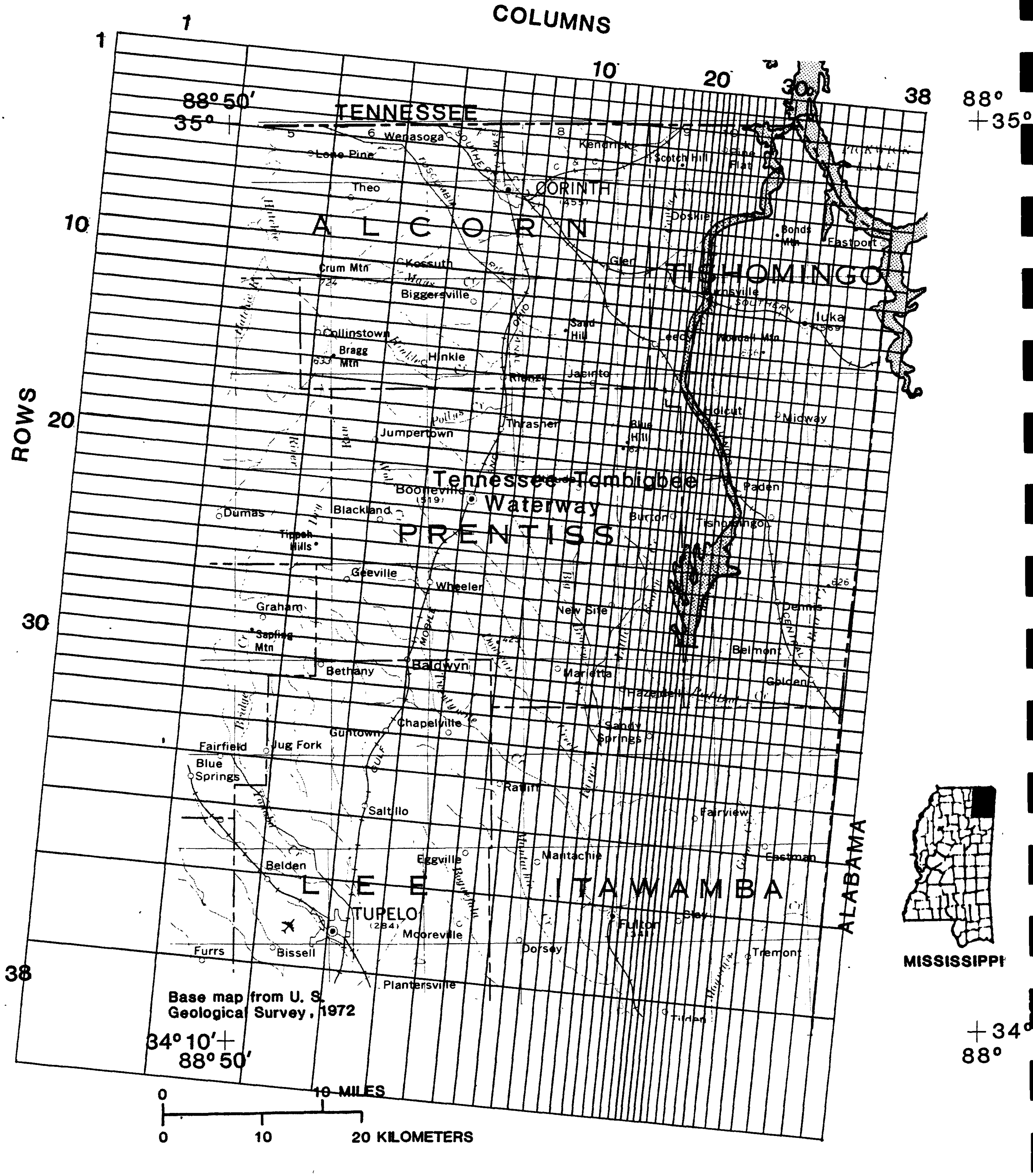

Figure 2.—Area covered by digital model showing model grid.

Degree of Detail Included in Model

The model is intended to represent general features of the hydrogeologic system. It emphasizes coverage of the whole area affected by the Waterway, rather than providing a detailed look at a smaller area. The model extends beyond the area likely to be affected in order to minimize distorting model results by the presence of artificial boundaries.

METHODS

Sources of Data

Surface Geologic Mapping

Statewide geological maps were used in placing the model in its overall geological setting. Maps used were of Alabama (Alabama Geological Survey, 1926), Mississippi (Bicker, 1969), and the western quarter of Tennessee (Miller and others, 1966).

More detailed maps cover most of the model area close to the Waterway (fig. 3). Russell mapped a circular area with a radius of 5.2 mi. centered on the Yellow Creek Nuclear Plant site (Tennessee Valley Authority,1976, figure 2.58(T)). The U.S. Army Corps of Engineers (1972) mapped an irregular area generally following the Waterway. Colbert County, Alabama, which extends slightly into the model area, was mapped by Moore and Harris (1962).

Wells and Test Holes Drilled by Corps of Engineers

The Corps of Engineers has drilled hundreds of test holes within approximately 1,000 feet of the Waterway centerline. Although the shallower holes were not pertinent to this project, deeper holes completed as piezometers provided useful information. Most of the useful center-line observation wells are shown on a cross-section published by the U.S. Army Corps of Engineers (1975, plate 4).

Three lines of piezometers, containing twenty-six sites, were drilled at right angles to the Waterway. Sites generally consisted of from two to six piezometers, each at a different depth. Locations of sites are shown in figure 4. Geophysical and drillers logs were obtained at the sites, and regular water-level measurements made after installation.

Other Wells

Geological Survey files contained information on over 1,600 wells in Alcorn, Prentiss, and Tishomingo Counties. Data that could be used in this study were not available for most of these wells.

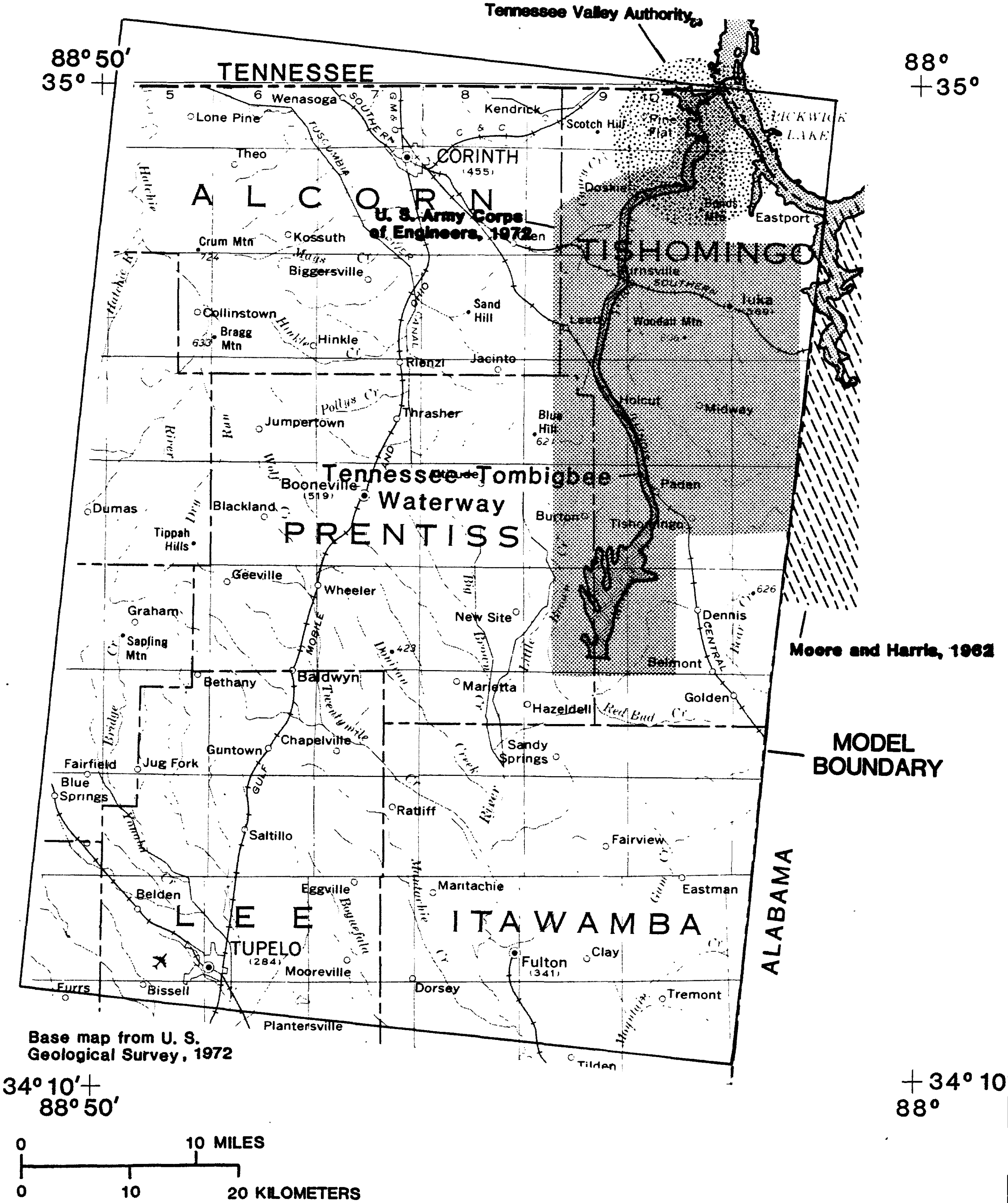

Figure 3.--Areas covered by detailed geological maps used in this report.

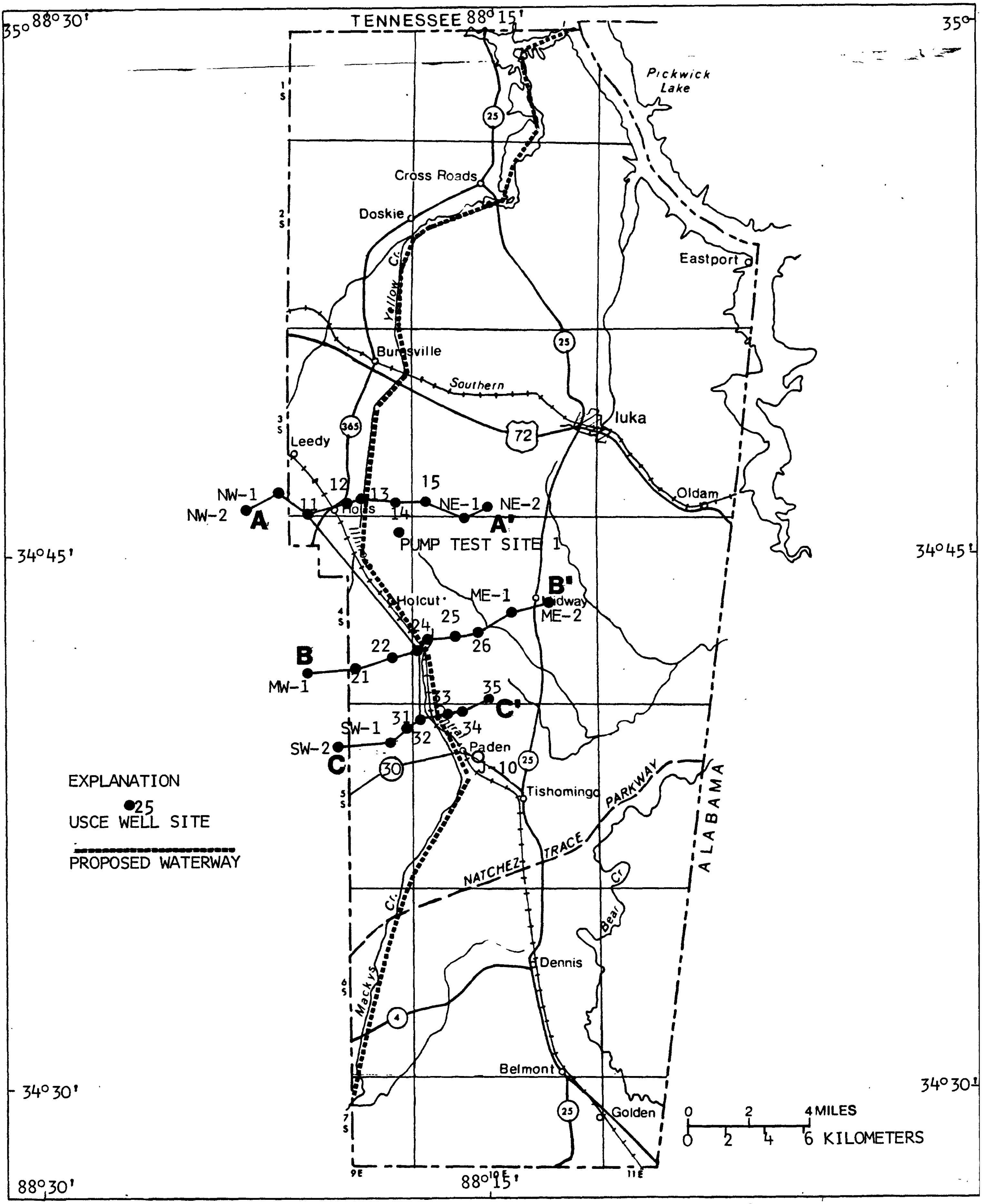

Figure.4.—Location of Corps of Engineers piezometer lines (from U.S. Army Corps of Engineers).

Geophysical well logs (usually only spontaneous potential and resistivity) were available at over 260 locations in these three counties.

Approximately 3,000 wells close to the Waterway in the Divide Section were visited and water levels measured by Corps of Engineers personnel. Copies of schedules of these wells were used principally in connection with study of perched water tables.

Aquifer Tests

Results of aquifer tests made in Mississippi by pumping wells and observing drawdown were summarized by Newcome (1971).

Daniel and Newcome (1974) and the U.S. Army Corps of Engineers (1974) reported on results of six aquifer tests made for the Waterway project. These tests produced values for hydraulic conductivity of the Eutaw and Gordo Formation, and investigated the degree of hydraulic connection between these units.

Handling Subsurface Data

The Geological Survey's Ground Water Site Inventory System (GWSI), a computer data base, was used in initial selection of subsurface data derived from wells. GWSI produced tables showing location, ownership, depth, and other information on wells in the study area.

Location, elevation, depth to formation contacts, and other data on selected wells and outcrops were managed using SAS (Statistical Analysis System)[1], a proprietary software package for statistics, data-base management, and report generation (SAS Institute, Inc., 1979). SAS programs selected and tabulated data, as well as generating input for GPCP, a proprietary contour-plotting program (California Computer Products, 1973). Contoured plots were invaluable in detecting incorrect data since such data would usually cause noticeable peaks or depressions in the contour surface.

Input values of transmissivity, storage coefficient, and other data were coded for each cell in the model. Where appropriate, these values were taken directly from the contour plots. Some values were generated by transforming others; for example, a short Fortran program was used to multiply each thickness value by an estimated specific storage to give storage coefficient, then to write the entire storage coefficient array in a form ready to use as model input.

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[1] The use of brand names in this report is for identification purposes only and does not imply endorsement by the the U.S. Geological Survey.

HYDROGEOLOGY

Stratigraphy

Paleozoic Rocks

Rocks of Paleozoic age are the oldest occurring at the surface in the model area (figure 5, and table 1). Outcrops are confined to Tishomingo County, in particular along the Tennessee River and its tributary streams, but also along Mackey's Creek at and near the Bay Springs lock and dam site.

Knowledge of Mississippi's Paleozoic rocks has been summarized by Bicker (1979). Much useful information is also provided by a summary of the Mississippian Stratigraphy of Alabama (Thomas, 1972). The nomenclature for Paleozoic units used in this report is that of Welch (1958; 1959).

Paleozoic rocks underlie the Cretaceous rocks, which are of principal interest throughout the study area. Although numerous formations of Mississippian age have been recognized within the study area, most have restricted outcrop areas. The "Iuka Terrane" of Morse (1930), now called "Iuka Formation" (Bicker, 1979), is the most extensive exposed pre-Cretaceous unit in the study area.

The Iuka Formation as described by Bicker (1979, p. I42) consists of blocks of residual chert interbedded with residual clay. It is derived from equivalents of the Fort Payne Chert and the Tuscumbia Limestone as defined in Alabama (Thomas, 1972) and in part from the upper part of the Fort Payne Chert as defined in Tennessee (Russell and others, 1972). The Iuka Formation reaches thicknesses of 200 feet in the southern part of its outcrop area.

Evidently the highly-weathered zone does not extend far downdip from the outcrop area. At most places in the study area, Paleozoic rocks lying beneath Cretaceous deposits consist of hard, less weathered chert or sometimes limestone or sandstone. Data are insufficient to allow further mapping or subdivision.

Sparse data suggest that the hydraulic conductivity of the Paleozoic rocks is low. In some places where test wells have been drilled the Paleozoic rocks do not supply adequate water for wells of any great capacity. Very productive public-supply wells completed in Paleozoic rocks at Corinth and Iuka draw water from weathered chert and limestone. The productive Paleozoic aquifers at Corinth and Biggersville are apparently limited in area (Wasson and Tharpe, 1975, p. 57) and sporadic in occurence. Wells at Iuka and Burnsville produce water from weathered chert which apparently is hydraulically connected with overlying Gordo gravel (Wasson and Tharpe, 1975, p. 57). Other wells at Yellow Creek Industrial Park, Short Creek Water Association, and at other localities may have a similar source of water.

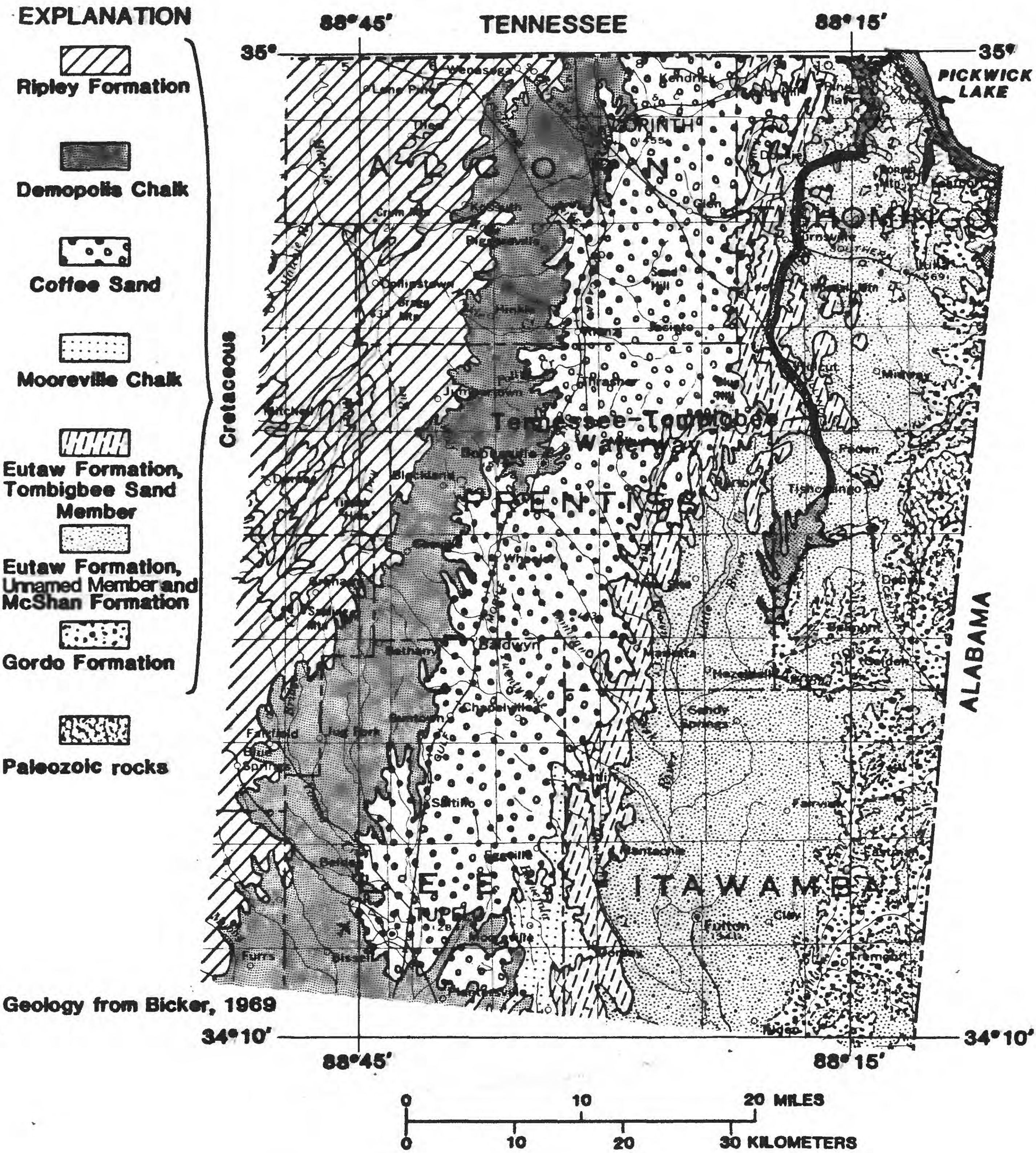


Figure 5.---Geology of study area.

Table 1. Geologic units referred to in this report.

Geologic Unit	Lithology	Thickness, feet
Quaternary		
Terrace deposits	Sand, gravel, silt, clay	
Alluvium	do.	
Loess	Silt	
Upper Cretaceous		
Demopolis Chalk	Chalk	0-500
Coffee Sand	Sand with clay beds	0-200
Eutaw Formation		
Tombigbee Sand Member	Massive fine sand	0-90
Unnamed member	Fine-medium sand with clay beds	0-100
McShan Formation	Thin-bedded sand, silt, clay	0-50
Gordo Formation	Chert gravel, with sand and clay beds	0-200
Little Bear Residuum (of Mellen, 1937)	Massive red-white-brown clay	0-60
Lower Mississippian		
Iuka Formation (as defined by Bicker, 1979)	Residual chert and clay	0-200

At many places Paleozoic rocks are overlain by as much as about 60 feet of residual clay that was described by Mellen (1937), who termed it the "Little Bear residuum." The clay is typically massive; red, white, and brown in color, typically mottled, and may contain angular blocks of chert. A thick, apparently massive clay occurs at the top of the Paleozoic rocks in scattered locations. The only place where such a clay seems to be persistent is in the area of the U.S. Corps of Engineers piezometer lines B-B' and C-C', northwest of Paden (fig. 4). Here the clay appears on many (but not all) geophysical logs and is from 30 to 50 feet thick.

The regional slope of the top of the Paleozoic rocks is westward at an average of about 25 feet per mile (fig. 6). The general pattern is broken in northeastern Prentiss County and adjacent parts of Tishomingo County by a northeastward-trending depression. At the deepest point in the depression, the top of the Paleozoic rocks is about 200 feet below where it would be if the surface were smooth. Origin of the depression is unknown.

Upper Cretaceous Rocks

Gordo Formation.--The Gordo Formation crops out in northern, eastern, and southern Tishomingo County; eastern Itawamba County; and the southeastern corner of Prentiss County (Bicker, 1969). The Gordo Formation does not underlie the entire study area. The eastern edge of the outcrop belt lies roughly along the Mississippi-Alabama border. Gordo Formation underlies most of Tishomingo County, extreme eastern Alcorn County, and much of Prentiss County (fig. 7). The greatest thickness, more than 200 feet, occurs in central Tishomingo County, coinciding approximately with the depression in the Paleozoic surface described previously.

The Gordo Formation in the study area consists of chert gravel with thinner beds of sand and clay. Southward in Mississippi, the Gordo Formation typically consists of a lower chert and coarse sand unit, and an upper unit of purple to red varicolored and mottled clay (Boswell, 1963, p. 47). In the study area the gravel predominates. Furthermore, it is generally difficult with existing subsurface information to distinguish Gordo sand and clay from the overlying Eutaw or McShan Formations. The top of the Gordo was generally picked as the top of the gravel section in electric or driller's logs; consequently, more detailed study might result in assignment of some of the sand and clay considered part of the Eutaw or McShan in this report to the Gordo instead.

The hydraulic conductivity of the Gordo is high when compared with other aquifers in the area. Wells in the Gordo aquifer in Mississippi are generally designed to produce from 500 to 1,000 gal/min. The hydraulic conductivities measured in two aquifer tests in the Divide Cut area were 1.4×10^{-4} and 8.5×10^{-5} ft/s. Calibration of the model described in this report produced an average value of 7.2×10^{-4} ft/s.

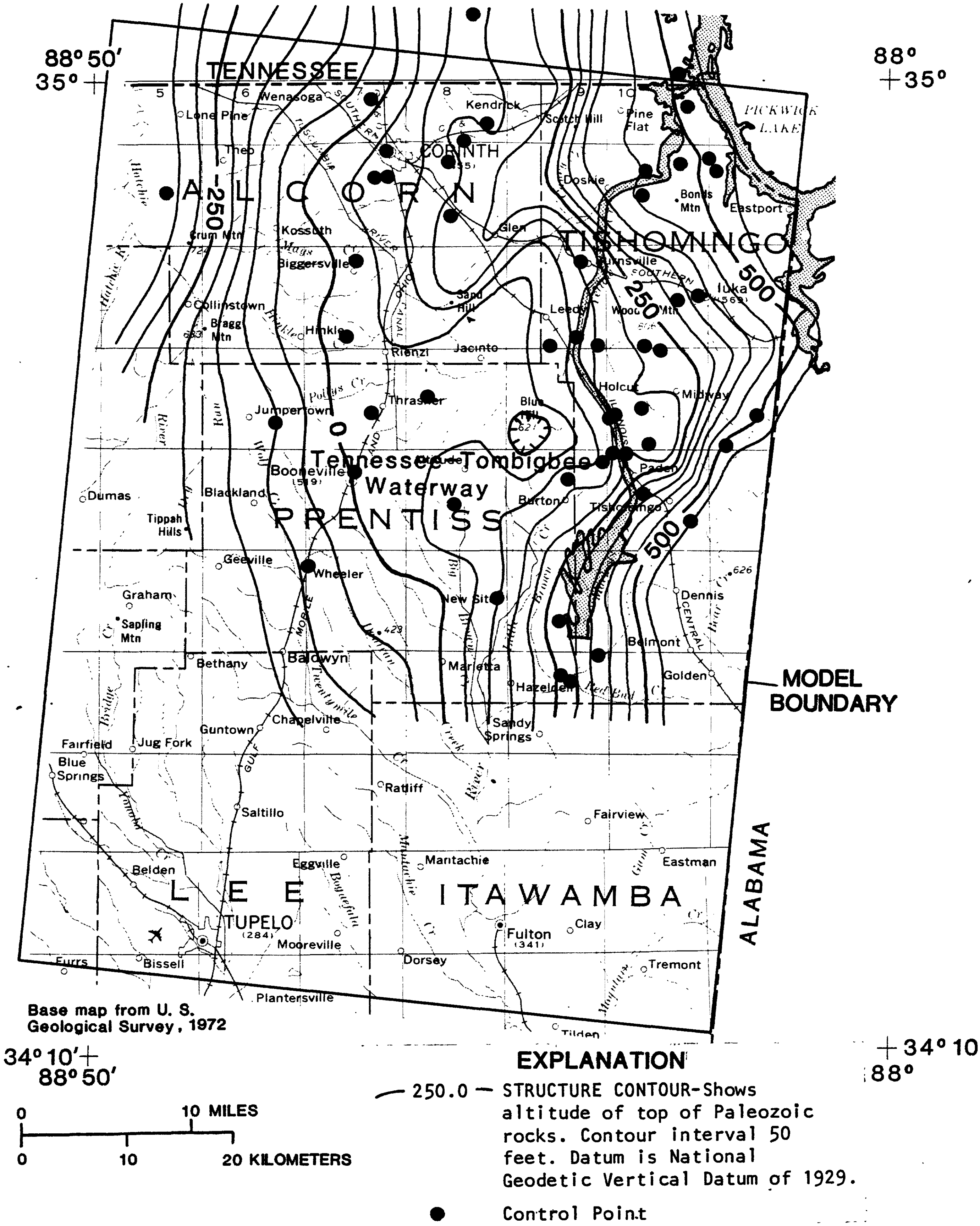


Figure 6.—Altitude of top of Paleozoic rocks.

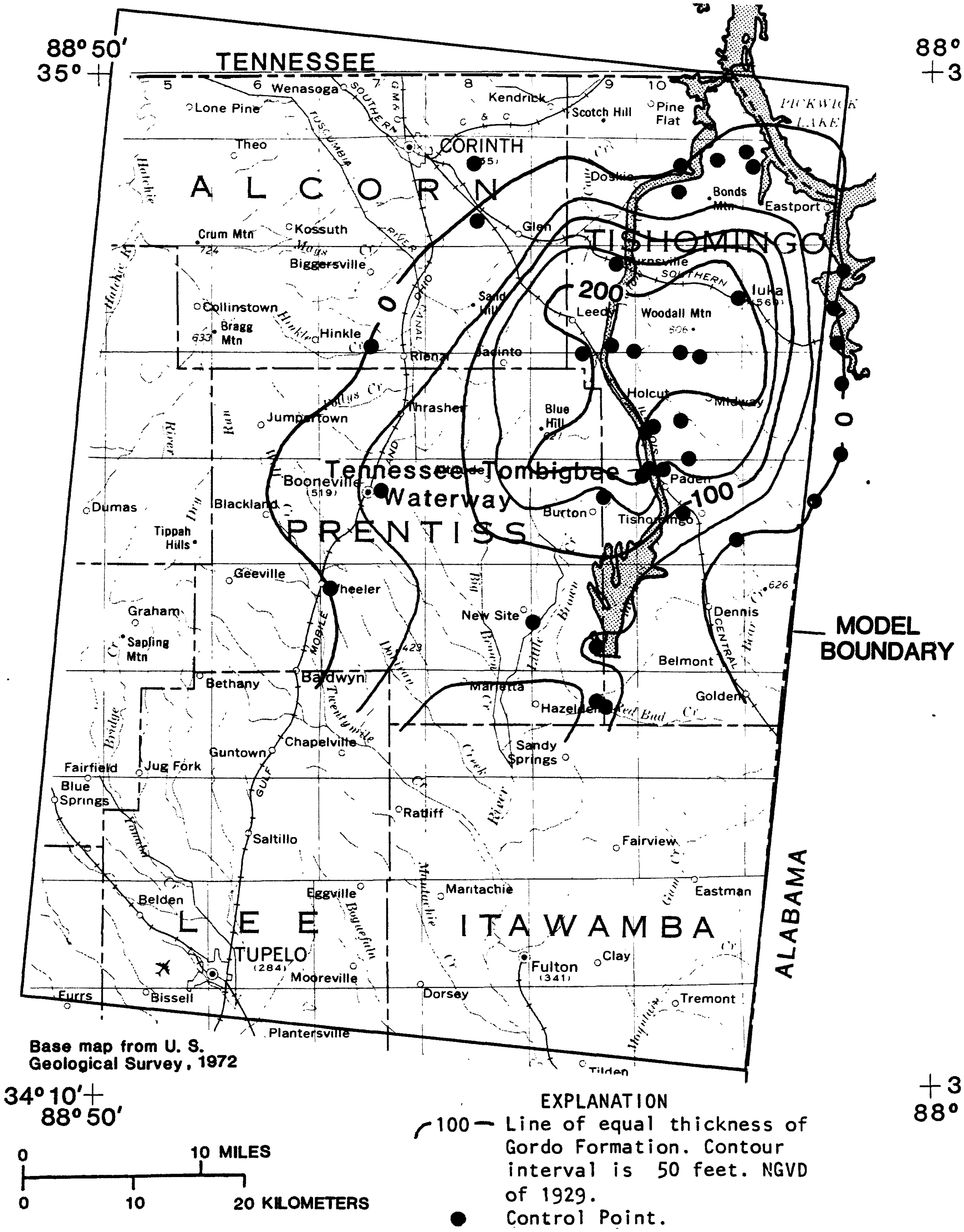


Figure 7.--Thickness of Gordo Formation, in feet.

McShan Formation.--The McShan Formation in the study area consists of thinly inter-laminated sand, silt, and clay. The sand and silt contain abundant muscovite, and the sand generally contains light-colored glauconite. The clay is gray and carbonaceous. Irregular lenticular beds of sand seldom exceed a few feet in thickness. Although the formation may have a thickness of 50 feet in Itawamba County, it is much thinner in most of the study area. The McShan thins northward, and becomes patchy north of Paden (Boswell, 1963; U.S. Army Corps of Engineers, 1973, Plate I-2).

The McShan is generally not a good aquifer in the study area. Southward where the formation is thick and contains thick sand layers it may supply enough water for moderate capacity wells.

The McShan is difficult to recognize in the subsurface. Parks (1960) reported difficulty in recognizing the contact between the McShan and the overlying Eutaw Formation even in specially-drilled test holes. He reported that the contact between the McShan and the Gordo Formation was not easy to distinguish even on the surface. In most subsurface information used in this project, it was not considered feasible to determine the presence or absence of the McShan or to determine its limits.

Eutaw Formation.--The Eutaw Formation includes an unnamed lower part and, at the top, the Tombigbee Sand Member. The lower part is commonly 100 or more feet of thin-bedded gray clay and fine sand. Irregular lenticular beds of fine-to-medium glauconitic sand occur sporadically throughout the unit. The Tombigbee Sand Member, as much as 90 feet thick, is typically composed of massive, very glauconitic, slightly calcareous, fossiliferous sand. The Eutaw Formation will account for most of the material excavated during construction.

Model layer 2, corresponds loosely to the Eutaw Formation, as will be explained later. Average Eutaw Formation hydraulic conductivity within the study area, estimated on the basis of model calibration results, is 3×10^{-4} ft/s.

Coffee Sand.--The Coffee Sand is similar in lithology to the Eutaw Formation, consisting of calcareous and glauconitic sand, gray clay, and silt. Because of this similarity, their total thickness, together with that of the McShan Formation, was mapped for this report (fig. 8). The two units are difficult to distinguish in the subsurface. The Tombigbee Sand Member in Prentiss County ".....appears to grade into less calcareous and finely glauconitic sandy shale-like silts and silty sand of the basal Coffee" (Parks, 1960, p. 42). Although the Coffee Sand attains a thickness of more than 200 feet in Prentiss County, only the lower part is present in the Divide-Cut area where the unit is restricted to hill and ridge tops. In the southern part of the model area the Coffee grades into the Mooreville Chalk, consisting of marly chalk and calcareous clay. Average Coffee Sand hydraulic conductivity, as estimated from calibration of model layer 3, is 6×10^{-4} ft/s.

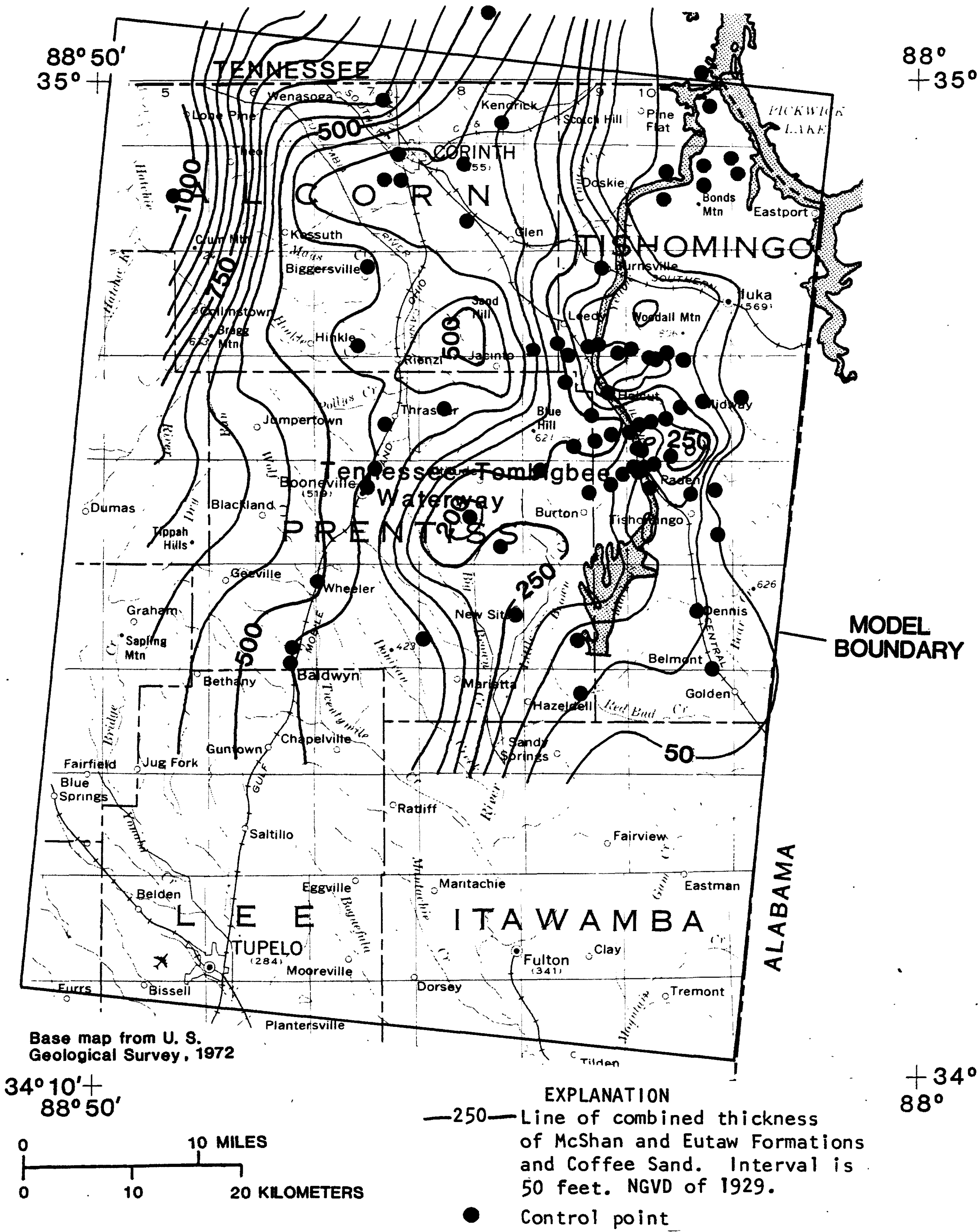


Figure 8.—Combined thickness of McShan and Eutaw Formations and Coffee Sand.

Demopolis Chalk.--The Demopolis Chalk consists of relatively pure, compact chalk. It overlies the Coffee Sand west of Corinth and Boonville. Near the north edge of the model area the Demopolis Chalk is about 250 feet thick. To the south, in Pontotoc County, the thickness increases to 500 feet as the upper part of the Coffee Sand grades into the lower part of the Demopolis Chalk. The unit has a very low hydraulic conductivity and acts as a very effective confining bed above the Coffee Sand. The Ripley Formation and other units above the Demopolis Chalk were consequently not considered in this study.

Quaternary Deposits

Quaternary deposits in the study area include valley alluvium and terrace deposits of sand, gravel, silt, and clay. High terrace deposits, some of which are mined for gravel and sand, occur on uplands and generally are older than the valley deposits. A thick blanket of Quaternary loess may cap some hills in the northern part of the area (Snowden and Priddy, 1968, figure 1).

Ground-Water Movement

Occurrence and movement of ground water are determined largely by three factors: precipitation, topography, and geology.

Precipitation supplies the water which recharges aquifers. This constant replenishment keeps the ground-water system in motion. Recharge into a hydrogeologic unit may be direct, by precipitation on its outcrop area, or indirect, by water moving from adjacent units.

Topography of the study area is dominated by relatively steep-sided stream valleys typically spaced 1 to 2 miles apart and cut 100 to 300 feet below the level of the intervening ridges. The streams generally discharge ground water, acting in effect like a set of interconnected drains. Increases in ground-water level caused by recharge lead to increased stream base flow, which in turn lowers the ground-water level. Consequently, the streams tend to stabilize ground-water levels in their vicinity.

Geology, in the form of the stratigraphy and petrology of the sediments in the study area, determines how readily ground water can move, and how its movement varies with position and direction within the sediments. Ground-water movement in the study area has significant components of motion both in the vertical and horizontal directions. After water infiltrates it moves downward until it reaches the water table. In the Eutaw and Coffee, whose outcrops cover most of the study area, the numerous thin clay beds restrict downward seepage. Water builds up in lenses above the clay beds, forming many perched water tables, each covering only a small area. These perched water tables are the source of water for most domestic wells in upland areas. Perched water tables vary considerably in elevation within short distances. Maps of water-table elevation based on all wells are not meaningful, since on both perched water tables and the main water table (below which there are no unsaturated zones) are represented.

To investigate perched water table levels, fifty wells were randomly selected from among those near the Waterway whose water levels were measured by the Corps of Engineers. Selection was limited to shallow wells (maximum depth was 76 feet) located in the Eutaw outcrop area. Water elevation (in feet above National Geodetic Vertical Datum of 1929) was plotted as a function of ground elevation at the well. The slope of the resulting line was 1:1, for ground elevations from 390 to 638 feet, and the data closely followed the regression line. This indicates that the water elevation is closely controlled by topography, as would be expected in the case of perched water table closely spaced in the vertical direction. Wells penetrating to a single water table from various ground elevations would give a much less clear relationship.

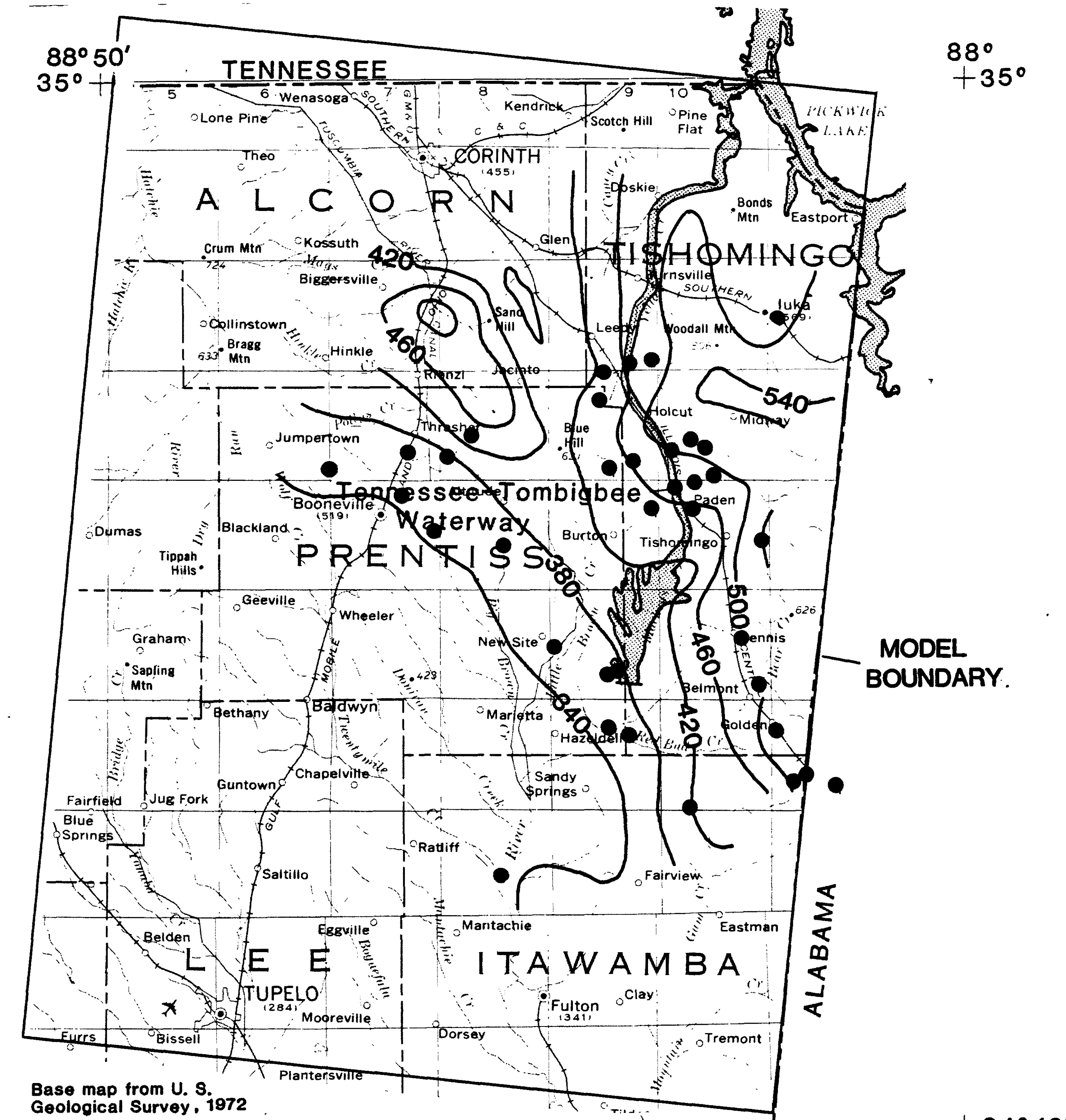
Vertical water movement in the saturated zone beneath the main water table is not so easy to characterize. In most of the study area, sets of wells completed at different depths are not common enough to provide a detailed picture of vertical head gradients. The Corps of Engineers piezometer lines (figure 4) provide better information, however, for the Divide Cut area. Here, hydraulic gradients within the Eutaw are downward, with values typically in the range 0.1 to 0.3. These moderately large gradients reflect anisotropy caused by the numerous clay beds present within the Eutaw sands. The few wells completed in the underlying Paleozoic rocks have anomalously low water levels; for example, well 23I, completed in the Paleozoic rocks, has a head of about 400 feet, whereas well 23J, completed 60 feet above it at the same location, has a head of 480 feet. Large downward head gradients reflect low vertical hydraulic conductivity in the Paleozoic rocks and in overlying residual clays.

Horizontal ground-water movement is, very generally, to the southwest (figs. 9-11). Water in the Gordo flows from an area of high heads near Paden and Midway, in east-central Tishomingo County, southwestward paralleling the overall topographic slope (fig. 9). In the Eutaw and Coffee, overall flow is also southwestward, but the pattern is more affected by the details of topography (figs. 10 and 11). Locally, ground-water flow is toward the upper reaches of Yellow and Mackey's Creeks. Flow diverges from an area of high head along the topographic divide about 5 miles south of Booneville, central Prentiss County.

CONSTRUCTION OF DIGITAL MODEL

Modeling Program

The modeling program used in this study was written by Trescott (1975) and enhanced by Trescott and Larson (1976). It simulates time-dependent ground-water flow in three dimensions. The modeling program considers the region where ground-water flow is modeled to be divided vertically into layers, each of which is subdivided horizontally into rectangular cells. Solutions are calculated using the Strongly Implicit Procedure (SIP).



Base map from U. S. Geological Survey, 1972

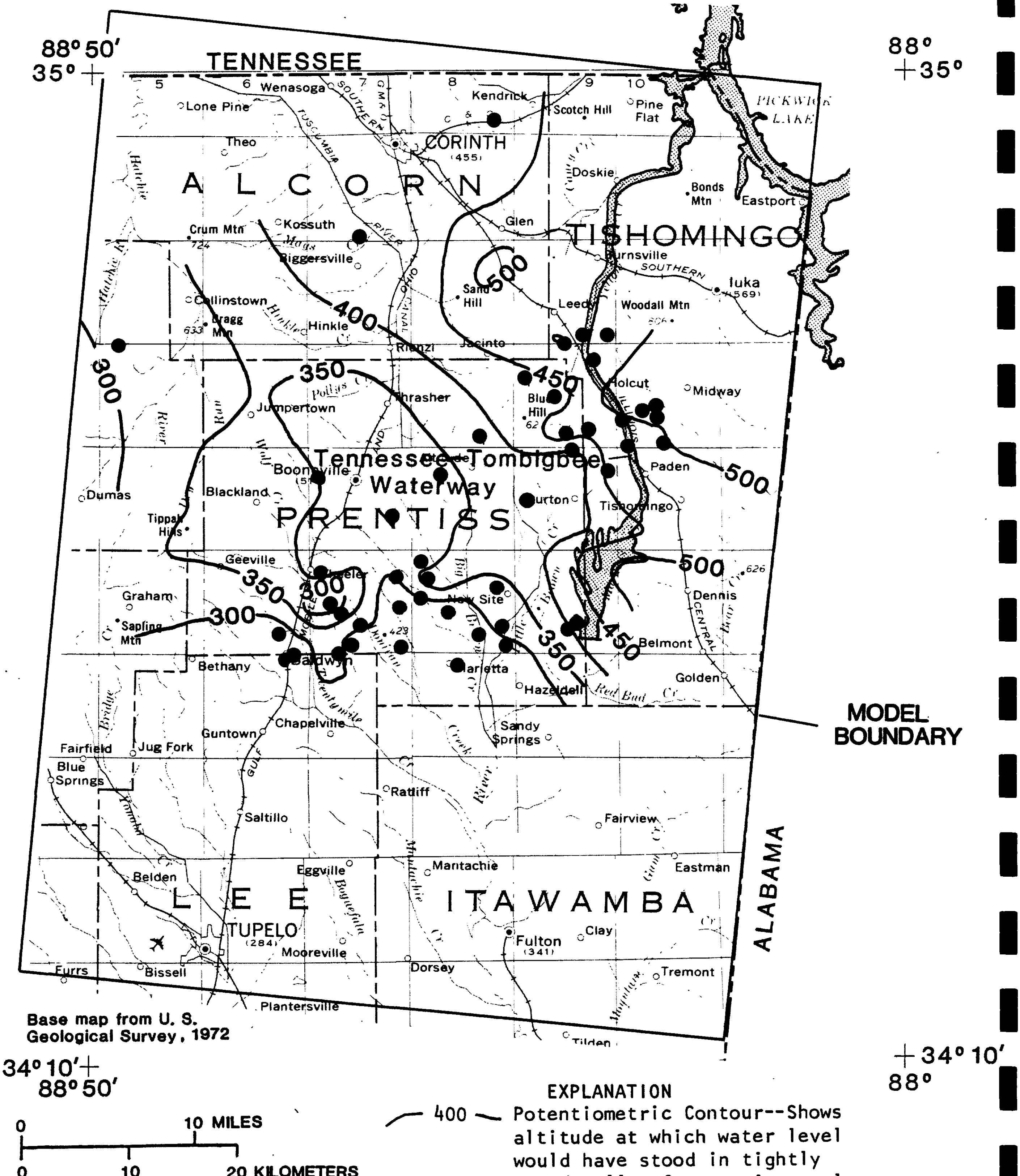
0 10 MILES
0 10 20 KILOMETERS

EXPLANATION

460 — POTENTIOMETRIC CONTOUR--Shows altitude at which water level would have stood in tightly cased wells. Contour interval is 40 feet. Datum is National Geodetic Vertical Datum of 1929.

● Control Points

Figure 9.—Water levels in wells completed in the Gordo Formation.

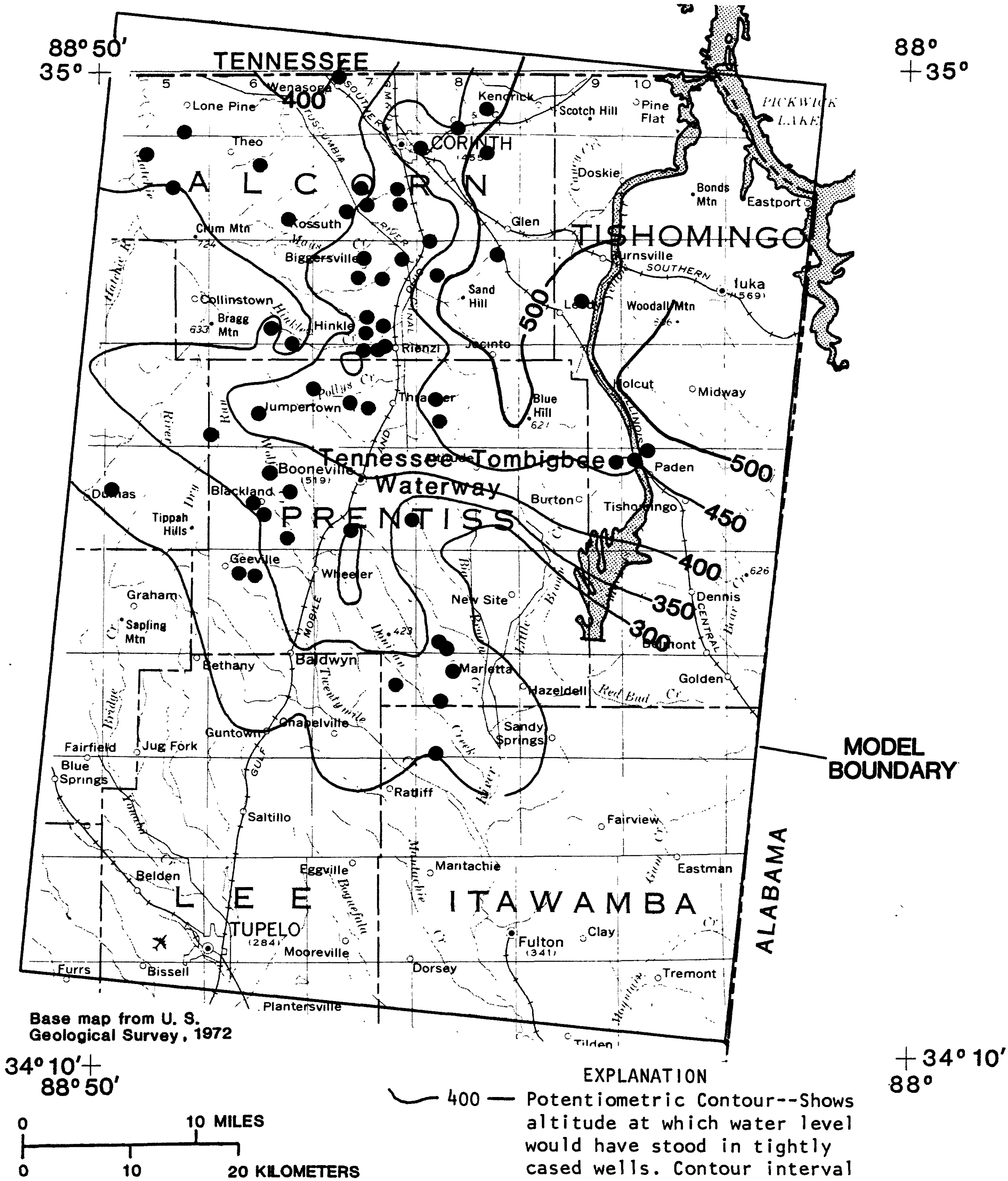


EXPLANATION

— 400 — Potentiometric Contour--Shows altitude at which water level would have stood in tightly cased wells. Contour interval is 50 feet. Datum is National Geodetic Vertical Datum of 1929.

● Control Points

Figure 10.—Water levels in wells completed in the lower part of the Eutaw–Coffee sequence.



EXPLANATION

400 — Potentiometric Contour--Shows altitude at which water level would have stood in tightly cased wells. Contour interval is 50 feet. Datum is National Geodetic Vertical Datum of 1929.

● Control Points

Figure 11.—Water levels in wells completed in the upper part of the Eutaw–Coffee sequence.

Model Grid

The model grid used in this study consists of three layers. The lowest layer (layer 1) represents the Gordo Formation. For the purposes of this study, the Eutaw Formation and the Coffee Sand are considered as a single hydrogeologic unit because of the lack of any clear distinction between the two in the subsurface. The McShan Formation, being thin, patchy, and often absent, is combined with the Eutaw and Coffee. In order to represent the stress imposed by the Divide Cut, the resulting unit was divided into two equal layers for modeling purposes, the lower part forming model layer 2, and the upper part, layer 3. In the earliest stages of modeling the Paleozoic rocks were included as the lowest layer. This layer was discarded when further study of these rocks suggested that their hydraulic conductivity was much lower than that of overlying rocks, and they could thus be omitted from the model.

Each layer is divided into 1,444 rectangular cells, arranged in 38 rows and 38 columns. The outermost rows and columns have transmissivities set to zero because of internal requirements of the modeling program. Consequently no heads are calculated there, and what will be called the "active area" of the model is confined to the 1,296 cells totaling 2,300 mi^2 in the inner 36 rows and columns (fig. 2).

Data within the model are represented and computed only on the basis of whole cells. Water level, for example, is approximated as being everywhere the same within each individual cell. Thus, the model would not give useful information on difference in water level between two wells only a few hundred feet apart, but could accurately reflect differences between wells separated by several miles.

Boundary Conditions

Conditions along model boundaries were set as either constant-head or impermeable depending on hydrogeological considerations. A constant-head model boundary is one along which the modeled heads are not allowed to change. An impermeable boundary is one across which no modeled ground-water flow is allowed.

The Gordo Formation, not being present throughout the model area, had impermeable boundaries set where it pinched out along the edges of its subcrop area. Its southern boundary was made constant head (fig. 12).

The upper two layers were specially treated where they pinched out along the eastern edge of the Eutaw outcrop area. An impermeable boundary was established along the eastern edge of the active model area. In areas such as the Gordo outcrop area where the Eutaw and Coffee were physically absent, layers 2 and 3 were given a nominal thickness of 1 foot. This allowed areal recharge of about 11 in/year (which the model applied only to the topmost layer 3) to reach the Gordo, as would have been impossible had the thickness and therefore the transmissivities of the upper layers simply been set to zero.

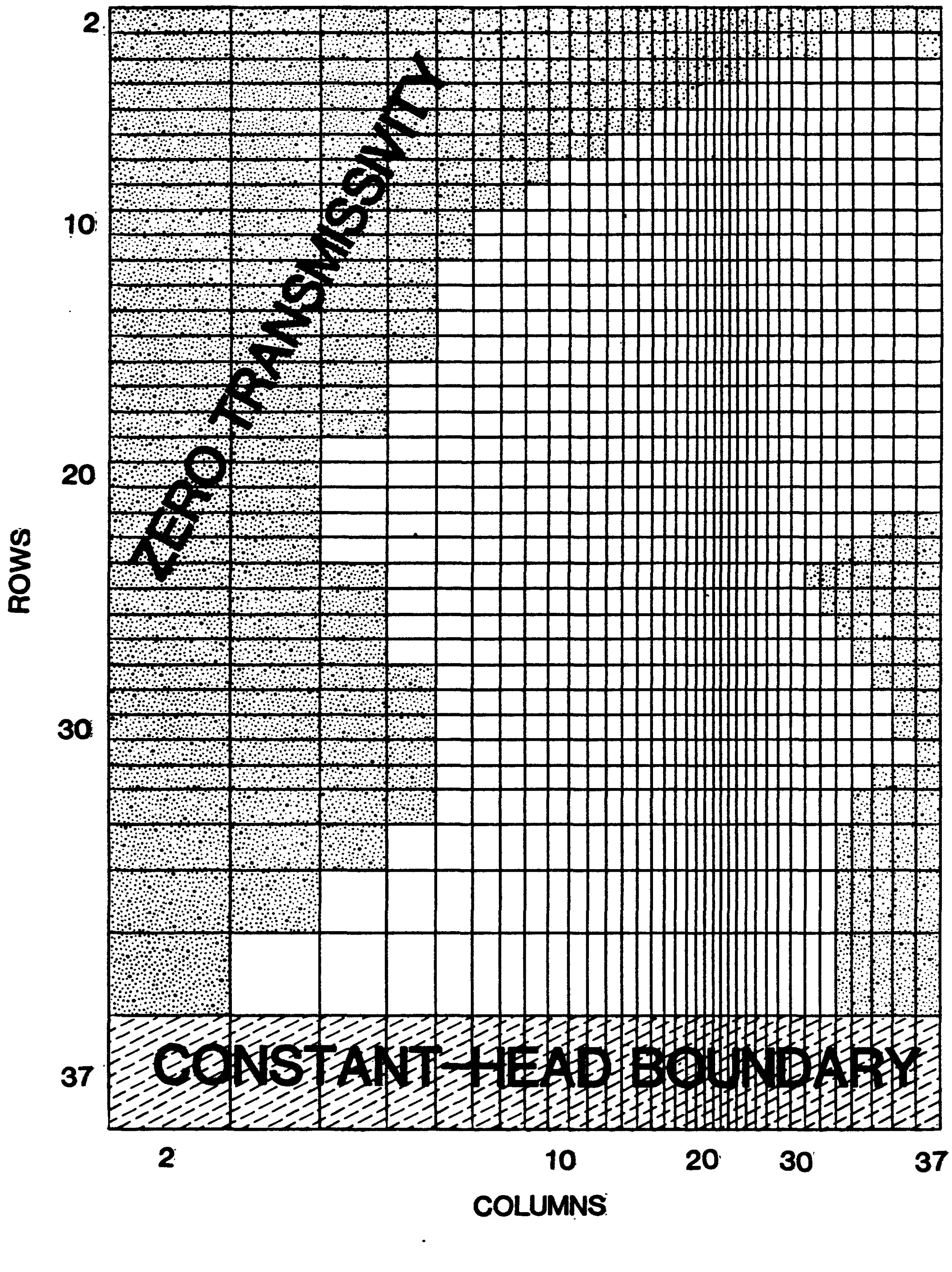


Figure 12.—Model boundary and internal conditions, layer 1 (Gordo Formation).

The west and most of the north and south boundaries of the upper two layers were made constant-head (fig. 13). This was because they were far enough from the Divide Cut, the area of prime interest, that fixing heads at pre-construction values would have little effect on calculated drawdowns. In other words, it was assumed that the Divide Cut would cause little head change at the location of these boundaries. This assumption seems to be satisfactory on the basis of model results. Namely, there appears to be little change in the constant head contribution to the mass balances calculated by the model for runs with and without the Divide Cut present.

Initial Estimates of Model Parameters

Model parameters were estimated on the basis of the hydrogeology of the study area. Adjustments were then made, in particular to transmissivity, in order to make the model simulate more accurately the steady-state natural distribution of heads.

For purposes of parameter estimation the model area was divided into two parts of roughly equal area. This division arose because the model was at first designed with a 32 by 32 cell grid, corresponding to rows 1 through 32, and columns 7 through 38 of the present model. The 32 by 32 model extended only slightly south of the Bay Springs lock and dam. Subsurface data were examined with considerable care in and slightly beyond this original model area. Data thus selected were used to produce detailed hydrogeological maps, the most important of which are presented as figure 6 (altitude of top of Paleozoic rocks), figure 7 (thickness of Gordo Formation), and figure 8 (combined thicknesses of McShan and Eutaw Formations, and Coffee Sand).

Later the model was extended to the south and west in order to guard against distorting results by having model boundaries too close to areas of interest. Because the areas added to the model were distant from the areas of greatest importance, estimates of parameters did not need to be greatly refined. Altitudes and thicknesses were therefore taken from published reports (Wasson and Tharpe, 1975; Boswell, 1977; Boswell, 1978).

Because the two different degrees of refinement in the estimates, discontinuities are evident on maps of parameters, as for example transmissivities shown in figures 14-16. No attempt was made to smooth over what was felt to be a merely cosmetic effect.

Initial estimates of transmissivity were made by coding the thickness of the layer for each cell, then multiplying by an estimated value of hydraulic conductivity which differed between Gordo and McShan-Eutaw-Coffee layers. Published transmissivities obtained from aquifer tests were not used in estimating transmissivities for the model because aquifer tests sample a volume of aquifer which is tiny in comparison to that dealt with by a model.

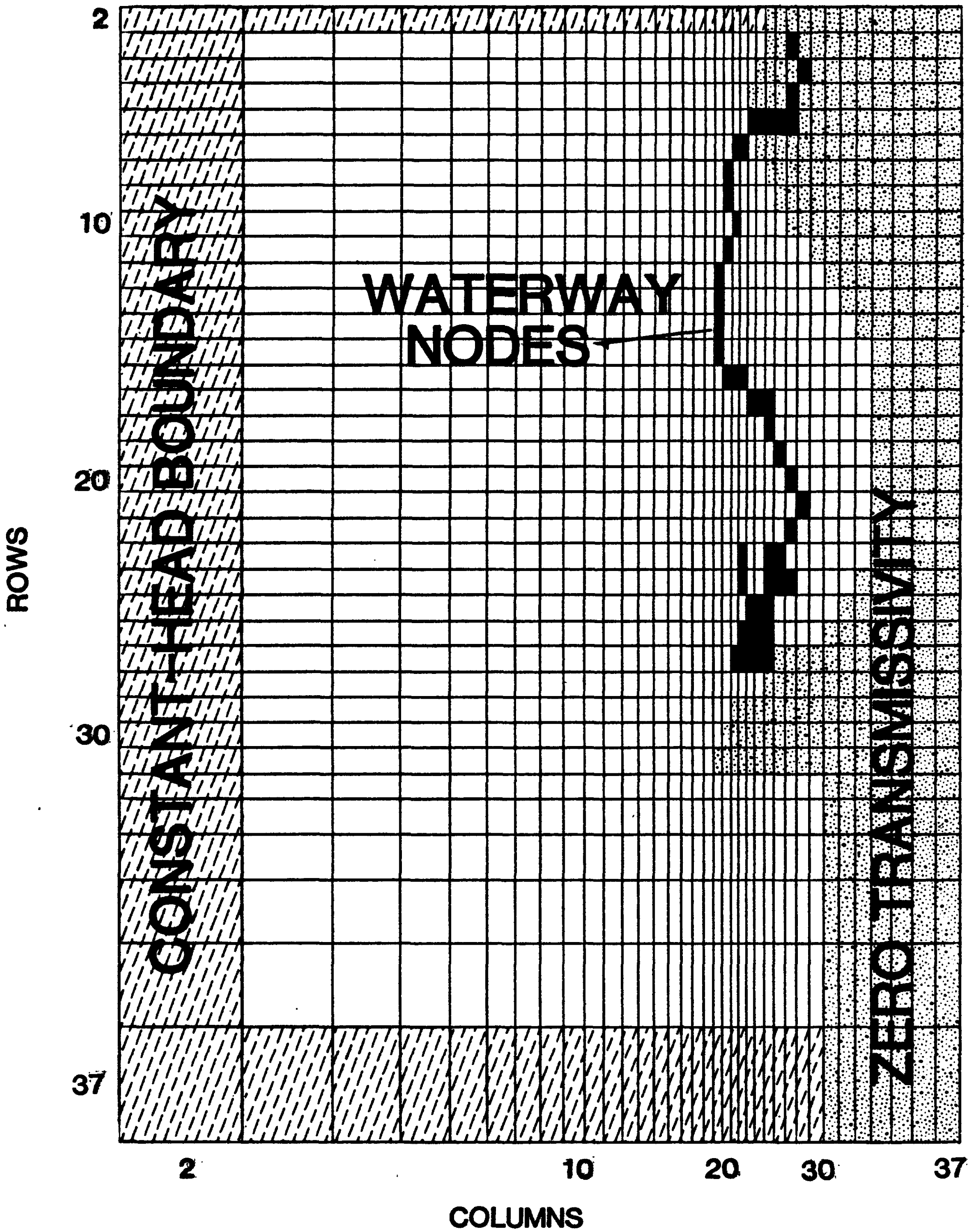


Figure 13.—Model boundary and internal conditions, layers 2 and 3 (McShan–Eutaw–Coffee).

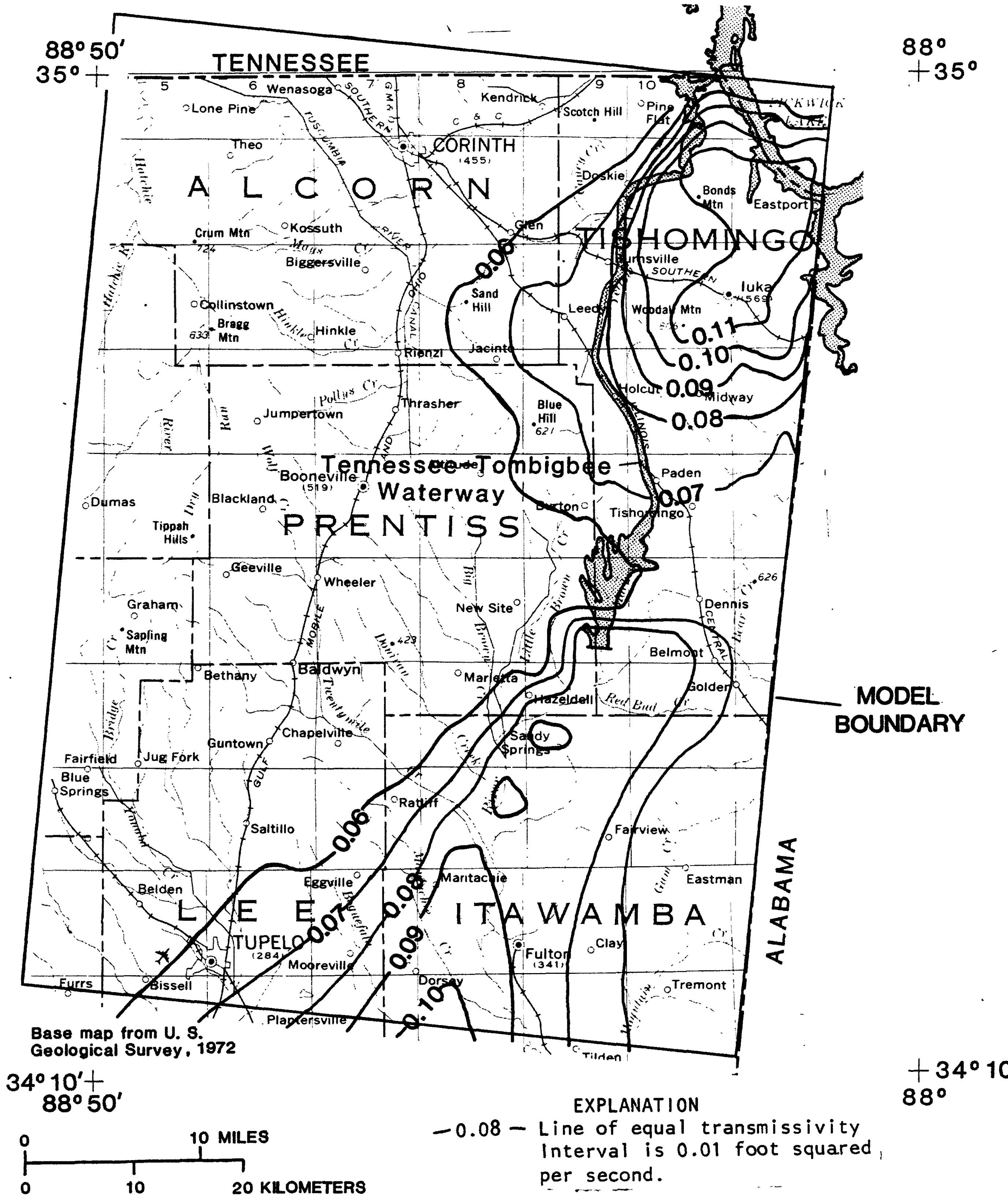


Figure 14.--Distribution of transmissivity in model layer 1 (Gordo formation).

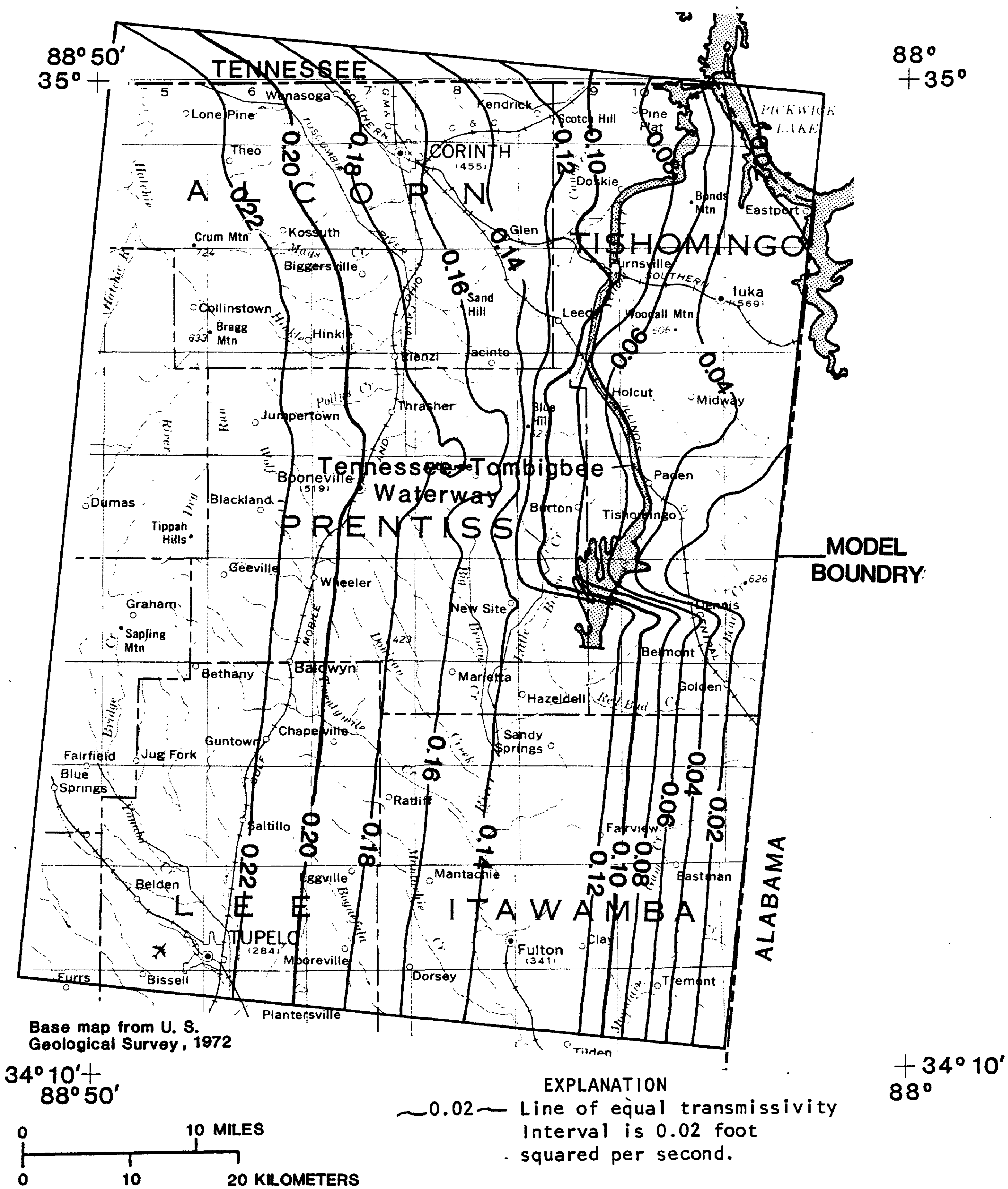


Figure 15.—Distribution of transmissivity in model layer 2 (lower part of the Eutaw-Coffee sequence.

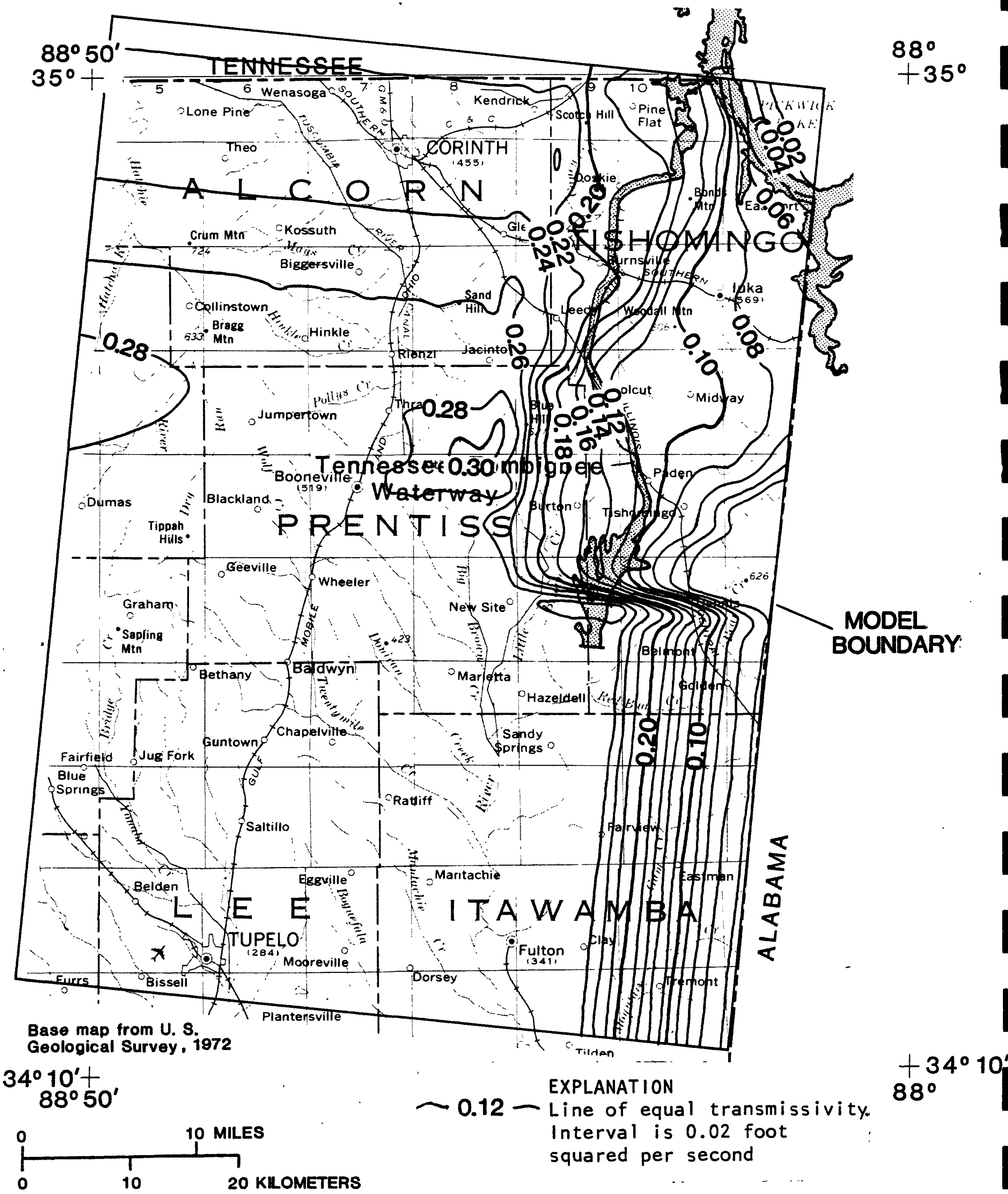


Figure 16.—Distribution of transmissivity in model layer 3 (upper part of the Eutaw-Coffee sequence).

Estimates of storage coefficient for the lower layers (1 and 2) were made by multiplying their thickness at each cell by 10^{-6}, an average value of specific storage (units 1/ft) recommended for artesian aquifers (Stallman, 1971, p. 8). The top layer (3) was given a storage coefficient of 0.15, in the water-table range although strictly speaking this layer was modeled as artesian like the others, in the sense that its transmissivity did not change with changes in head. For steady-state simulations, where storage was immaterial, all storage values were set to zero to speed computations.

Confining layers were not explicitly modeled, that is, no model layers were used specifically to represent confining beds. In the model area, confining beds are not laterally continuous over great enough areas to justify this approach. Even the McShan Formation is too patchy. Instead, coefficients representing resistance to flow between layers were chosen to represent combined effects of vertical hydraulic conductivity of the sand and also the presence of thin, discontinuous clay beds.

Calibration of Model

Calibration of a model consists of adjusting its inputs in a physically reasonable way so as to make its outputs match a set of observed data as closely as desired. In the present case, adjustments in transmissivity, inter-layer conductivity, recharge rate, and drain length served to improve the match between hydraulic head computed by the model and head observed in wells for the steady-state pre-development system.

Head data for calibration were selected according to the following criteria:

1) Well construction at any well used for head measurement must be accurately known; in particular, the position of the screen must be available.
2) The strata penetrated by the well must be known, preferably from an electric log.
3) The water level must not represent a perched water table. Perched water tables were hard to recognize, in practice, when an individual well was concerned. This criterion caused rejection of nearly all small domestic wells.

Although water-level measurements were available from several thousand wells, these criteria eliminated most wells from consideration. Selected water levels, together with information on the wells, were made part of a data base managed using SAS. Programs written in SAS language selected subsets of the data (for example, by model layer), and passed the data to a cartographic coordinate conversion program. Converted data were contoured using GPCP. Contour plots were used to help recognize, then revise or delete, the numerous questionable data which were present. Out of this editing process came a calibration data set consisting of heads in 121 model cells as follows:

Layer 1	Gordo....................................	32 heads
Layer 2	(Lower part of the McShan-Eutaw-Coffee).....	43 heads
Layer 3	(Upper part of the McShan-Eutaw-Coffee).....	46 heads

Adjustments to model inputs were based on the model residuals, or differences between calculated and measured heads. To make interpretation of residuals easier and more objective, a Fortran program was written which, in conjunction with GPCP, calculated residuals, displayed them as a contour plot of residuals within each model layer, and calculated the root-mean-squared (RMS) error for each layer and for the model as a whole. RMS error was the basic criterion of how closely the model simulated measured heads. Contour plots were used to decide which areas within the model should have input parameters adjusted.

Thirty-five computer runs were made during the calibration process. A first series of runs was made in which initial estimates of transmissivity, inter-layer conductance, recharge rate, and drain length were multiplied by various factors -- in other words, values for all cells raised or lowered together -- and RMS errors compared. All layers were multiplied by the same factor at this stage. These runs also revealed the sensitivity of RMS error to changes in the parameters. RMS error was quite insensitive to inter-layer conductivity and to drain length; moderately sensitive to recharge rate; and most sensitive to transmissivity.

Transmissivities were then adjusted for one layer at a time. A Fortran program was written which allowed transmissivities to be manipulated within a layer; for example, to decrease the transmissivity of a selected block of cells.

The result of all runs was to reduce RMS error from 57 feet to 39 feet.

Lack of Verification

It should be carefully noted that this model was not verified. Verification consists of using a calibrated model to simulate a previously-known response to a known change in model inputs. For example, a ground-water model calibrated to pre-pumping conditions could be verified by simulating past pumping and comparing model results to measured drawdown. If the comparison were satisfactory, the verification would increase confidence in predictions of drawdown caused by future pumping.

Satisfactory data were not available for verification of this model. Although water levels were measured in numerous observation wells near the Divide Cut, corresponding information was not available on ground-water extraction. Some water was metered when pumped from wells, but much was discharged from drainage trenches. This water was not measured, and the distribution of discharge along the trenches was not determined. Furthermore, the complex timing of installation of wells and trenches, even if their discharge were known, would make accurate simulation beyond the resources of this project.

Although verification is desirable for any model, its lack is not a fatal defect nor is it uncommon in actual practice. The present model still represents a best estimate of the behavior of the ground-water system based on available data and general knowledge of the behavior of such systems.

MODEL PREDICTIONS

The principal purpose of the model is to predict the changes in water level which construction of the Divide Cut will cause. Two specific questions are addressed here: first, how rapidly will the changes take place; and second, what will water levels be when the hydrogeological system has reached a new equilibrium with the Divide Cut?

Simulation of Divide Cut

The Divide Cut was represented in the model by a line of grid cells with fixed head (fig. 13). The fixed head of 414 feet corresponds to the water level in the Waterway, which will be at the level of Pickwick Lake as far south as the Bay Springs Dam. Constant-head cells were introduced into layers 2 and 3, that is, into lower and upper parts of the McShan-Eutaw-Coffee sequence.

Speed of System Response

How rapidly the system approaches steady state was investigated by simulating five consecutive time periods following the imposition of the constant-head nodes which represent the waterway. The actual progress of construction was not simulated; instead, the Divide Cut was modeled as though it had been instantaneously imposed on the pre-existing natural steady-state ground-water system. Changes in water level were followed onward from that time.

Figures 17 through 21 show contours of drawdown in model layer 2 (lower part of the McShan-Eutaw-Coffee sequence) at the end of each of the five time periods, and figure 22 shows hydrographs of head versus time for selected nodes. Total simulation times at the end of the periods are, respectively, 26 days, 227 days, 4.8 years, 16.2 years, and 36.4 years.

Most of the change in water levels occurs within the first 26-day time period. Changes that occur thereafter are relatively small. After 4.8 years, changes are negligible; and the drawdowns at 16.2 years and 36.4 years are indistinguishable.

Change in drawdown is not shown for layers 1 and 3, as the pattern is very similar to that of layer 2. Most change in drawdown occurs within the first time period, and detectable changes cease after a few years.

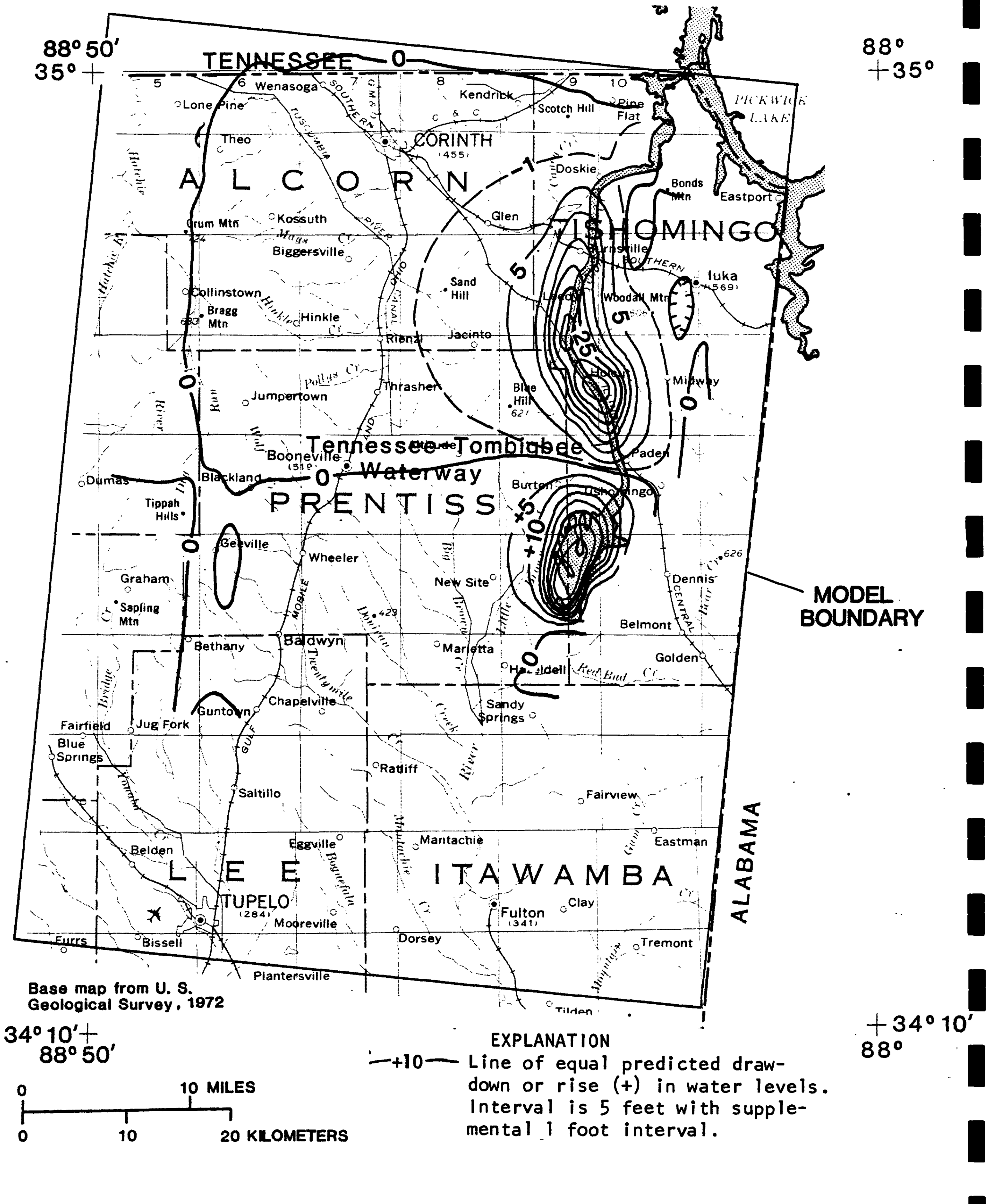
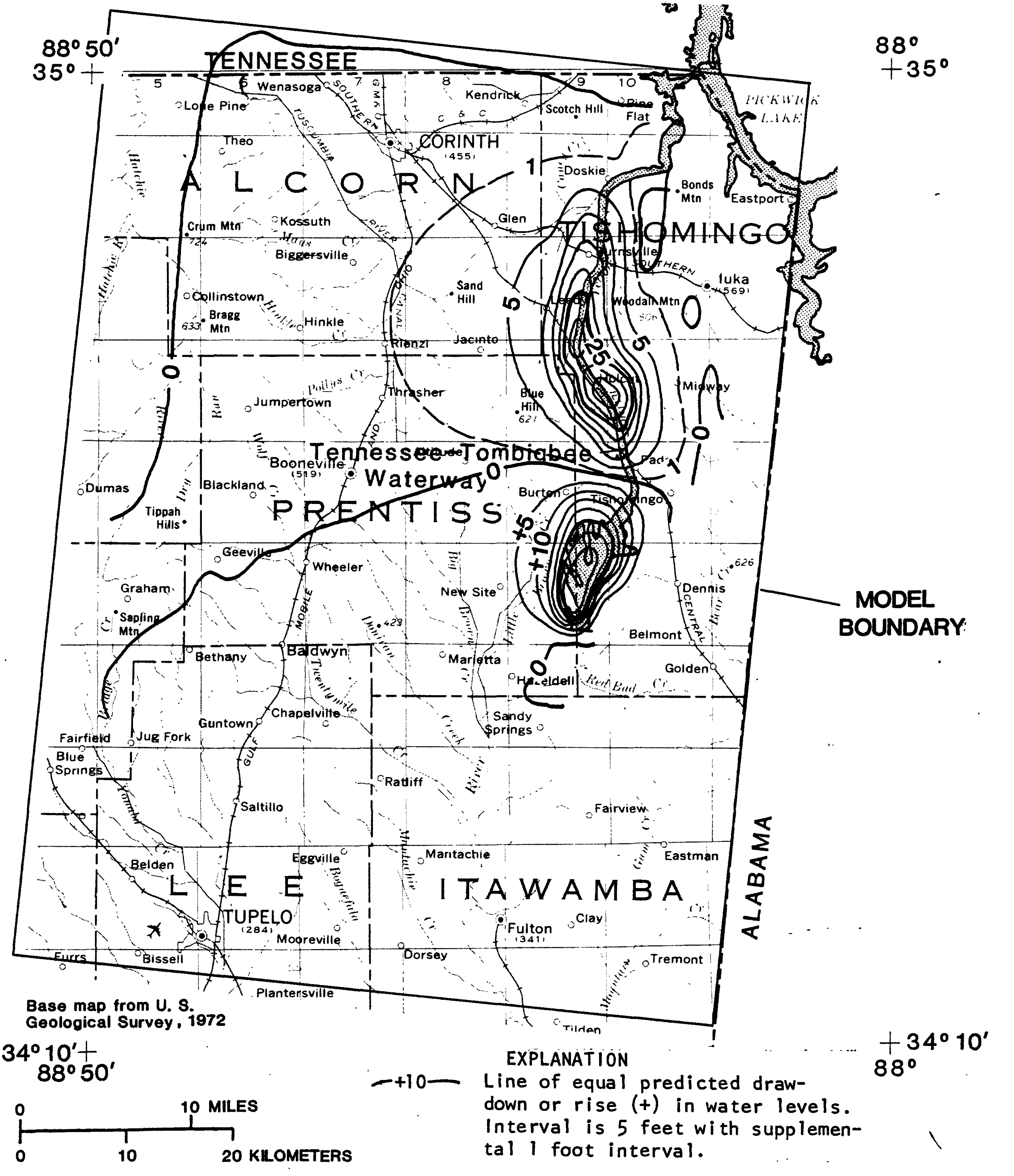


Figure 17.—Predicted drawdown in model layer 2 (lower part of the Eutaw-Coffee sequence) after 26 days.



EXPLANATION

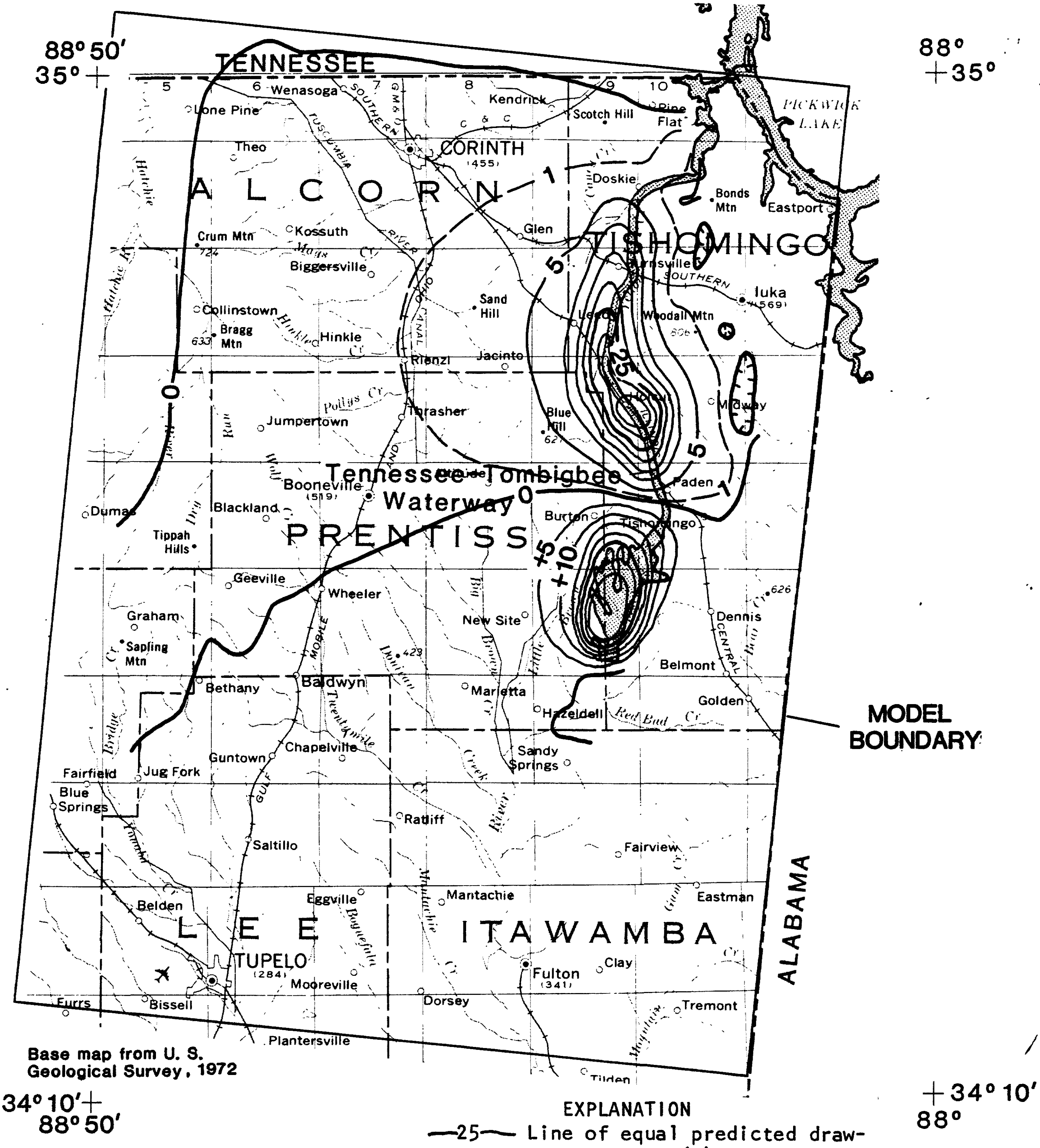
—+10— Line of equal predicted drawdown or rise (+) in water levels. Interval is 5 feet with supplemental 1 foot interval.

Figure 18.—Predicted drawdown in model layer 2 (lower part of the Eutaw-Coffee sequence) after 227 days.

EXPLANATION

— +10 — Line of equal predicted drawdown or rise (+) in water levels. Interval is 5 feet with supplemental 1 foot interval.

Figure 19.—Predicted drawdown in model layer 2 (lower part of the Eutaw–Coffee sequence) after 4.16 years.



EXPLANATION

—25— Line of equal predicted drawdown or rise (+) in intervals. Interval is 5 feet with supplemental 1 foot interval.

Figure 20.—Predicted drawdown in model layer 2 (lower part of the Eutaw–Coffee sequence) after 16.19 years.

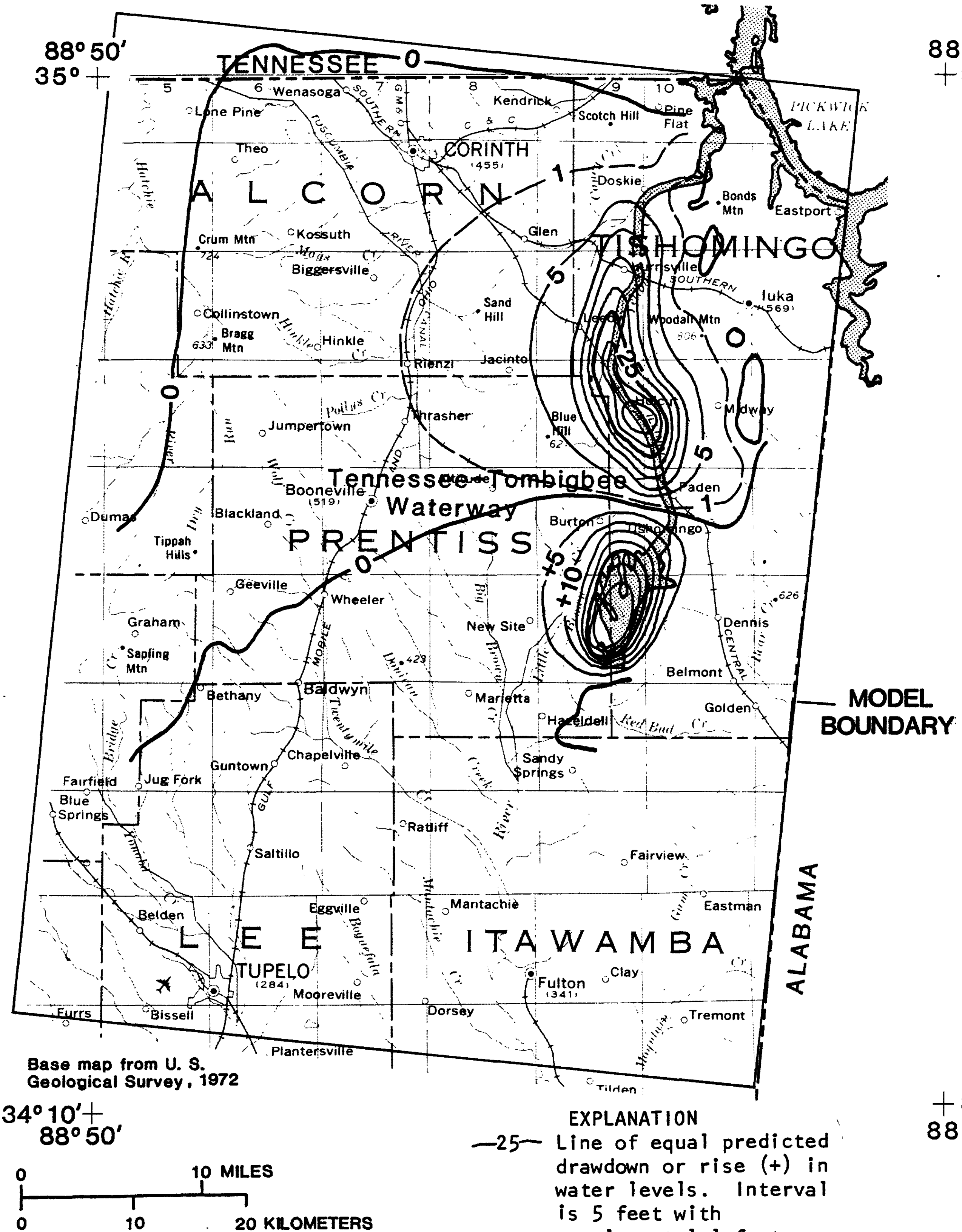


Figure 21.—Predicted drawdown in model layer 2 (lower part of the Eutaw-Coffee sepuence) after 36.43 years.

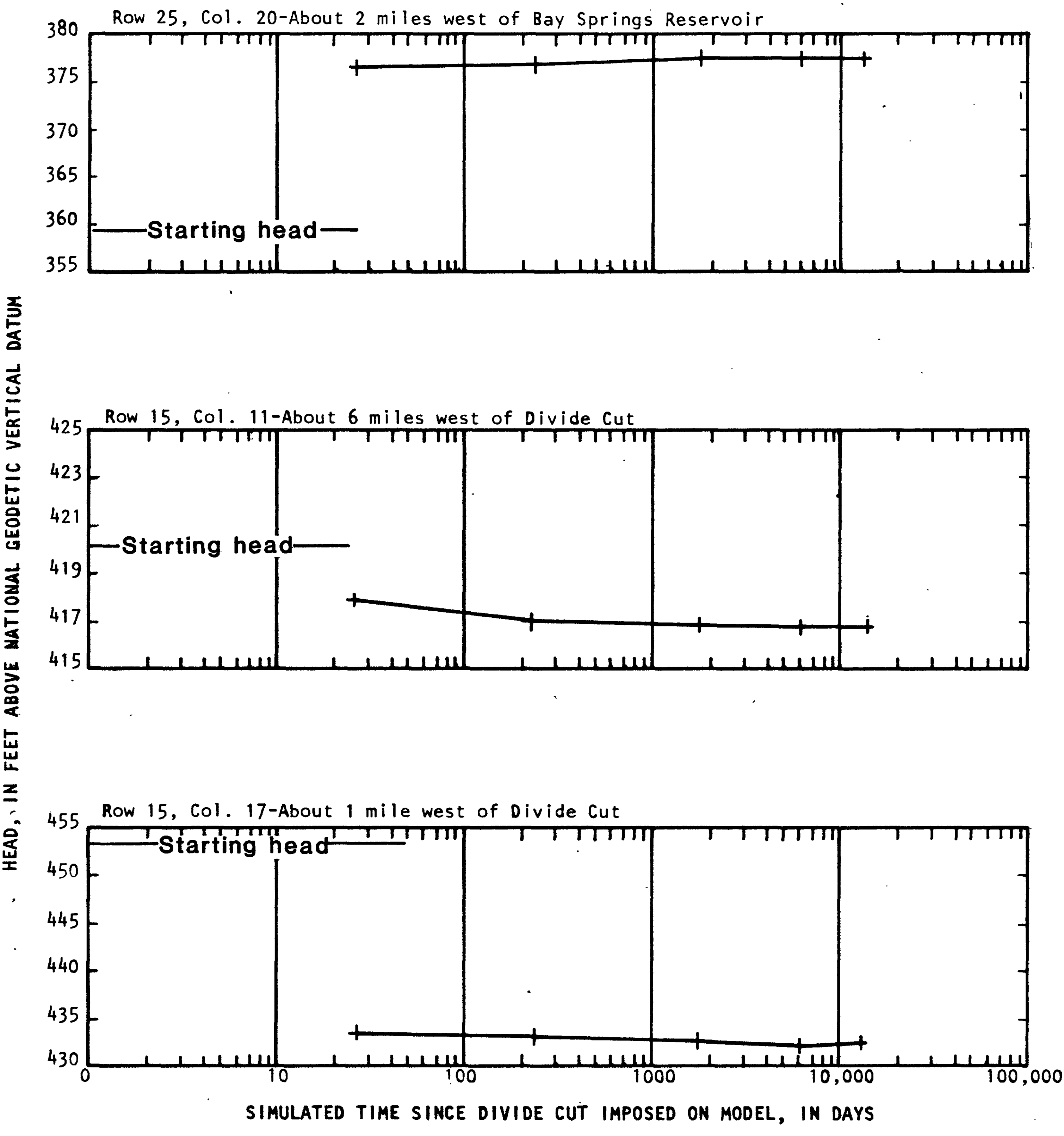


Figure 22.—Hydrographs showing change in predicted heads with time at some representative modes in layer 2.

Steady-State Water-Level Changes

After the Divide Cut is completed, the hydrologic system will reach a new equilibrium which reflects the effects of the Divide Cut on the natural system. The model was allowed to run to steady state to simulate this situation. Figures 23, 24, and 25 show steady-state drawdown in model layers 1, 2, and 3, respectively.

All three layers show the same general features. In the northern part of the Divide Cut, where the water level in the Waterway will lie below the present water table, ground water drains into the Divide Cut, lowering ground-water levels. In the southern part, where water is impounded behind the Bay Springs Dam, water entering the ground causes buildup of ground water levels. Between the two areas is a line of zero drawdown (or buildup) along which there is no net change in water level.

Layer 1, the Gordo Formation (fig. 23) shows the least drawdown. Maximum drawdown, near the center of the Divide Cut, is slightly over 15 feet. The area of major drawdown (out to the 5-foot drawdown interval line) extends, at most, about 8 miles east and west of the Waterway. The water-level depression is relatively broad and shallow, because it represents the effects of leakage upward into the Eutaw. Note that the simulation of the Gordo does not include dewatering wells completed in the Gordo. These would probably increase drawdowns moderately close to the Waterway, but have little effect elsewhere.

Water-level buildup near the Bay Springs Reservoir is at most about 40 feet. Buildup affects a smaller area than drawdowns farther north. The 5-foot buildup interval line is at most about 6 miles from the reservoir, and the area affected is, because of the reservoir being shorter than the Divide Cut, about a quarter the size.

Maximum drawdown in layer 2, the lower part of the McShan-Eutaw-Coffee sequence (fig. 24), is about 40 feet (somewhat greater than in the Gordo). Major drawdown is less extensive than in the Gordo; in most places the 5-foot interval line is about 1 mile inside of that shown for the Gordo.

Buildup near the Bay Springs Reservoir is shown as somewhat over 35 feet. This may be understated by a few feet, since drawdown at the constant-head nodes which represent the Waterway in this layer are not included in the contouring.

Maximum drawdown in layer 3, the upper part of the McShan-Eutaw-Coffee sequence (fig. 25) is the largest, about 55 feet. The affected area is, however, somewhat smaller than in the other two layers. The interval lines are noticeably less regular. This is an effect of the topography, which causes stream valleys to act as drains which tend to stabilize water levels more than in the other two layers. Recharge into this layer, beyond what is carried off as ground-water flow, is discharged by streams; thus, increased ground-water flow toward the Waterway will, in some areas, decrease drainage by streams rather than to lower ground-water levels.

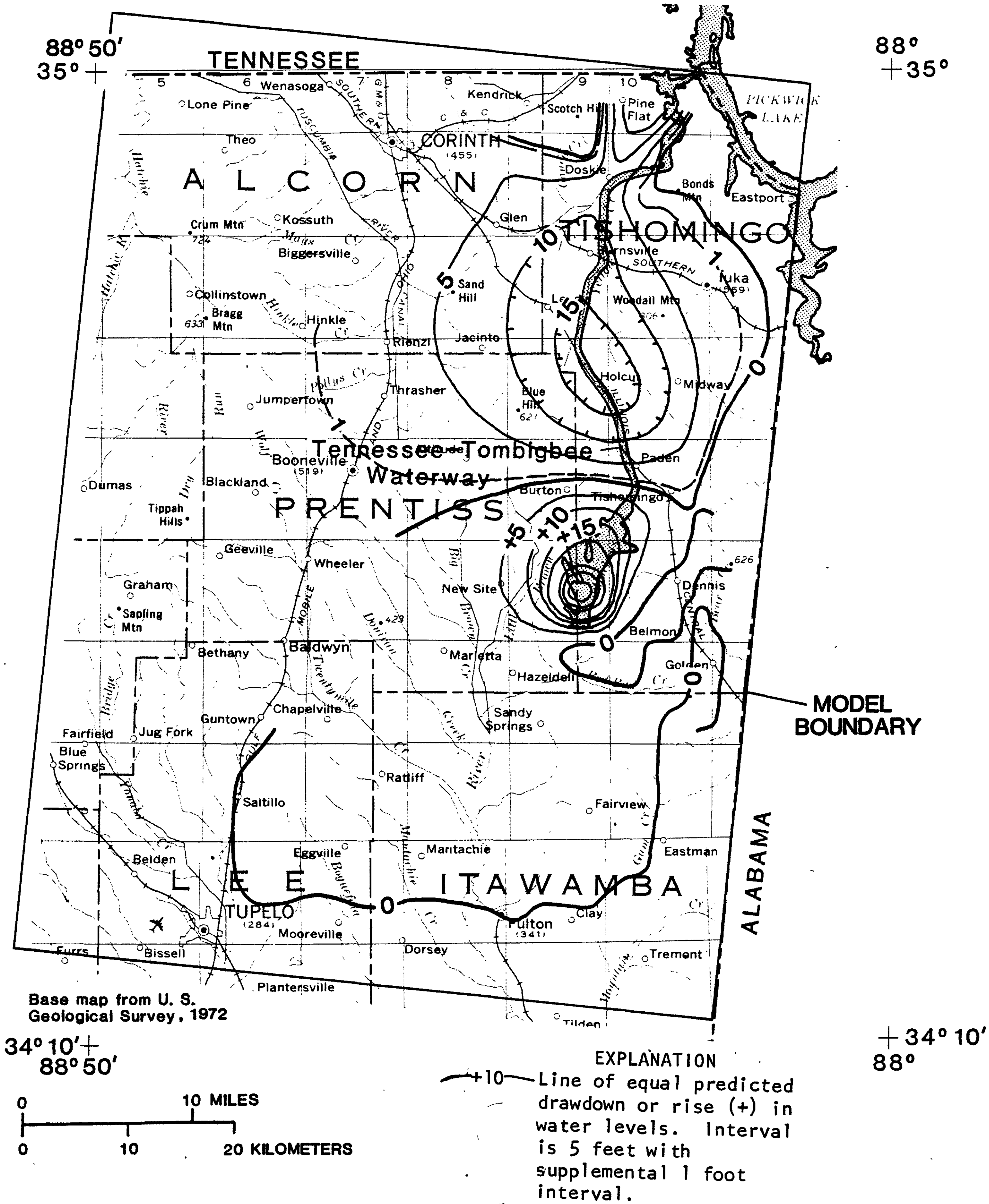
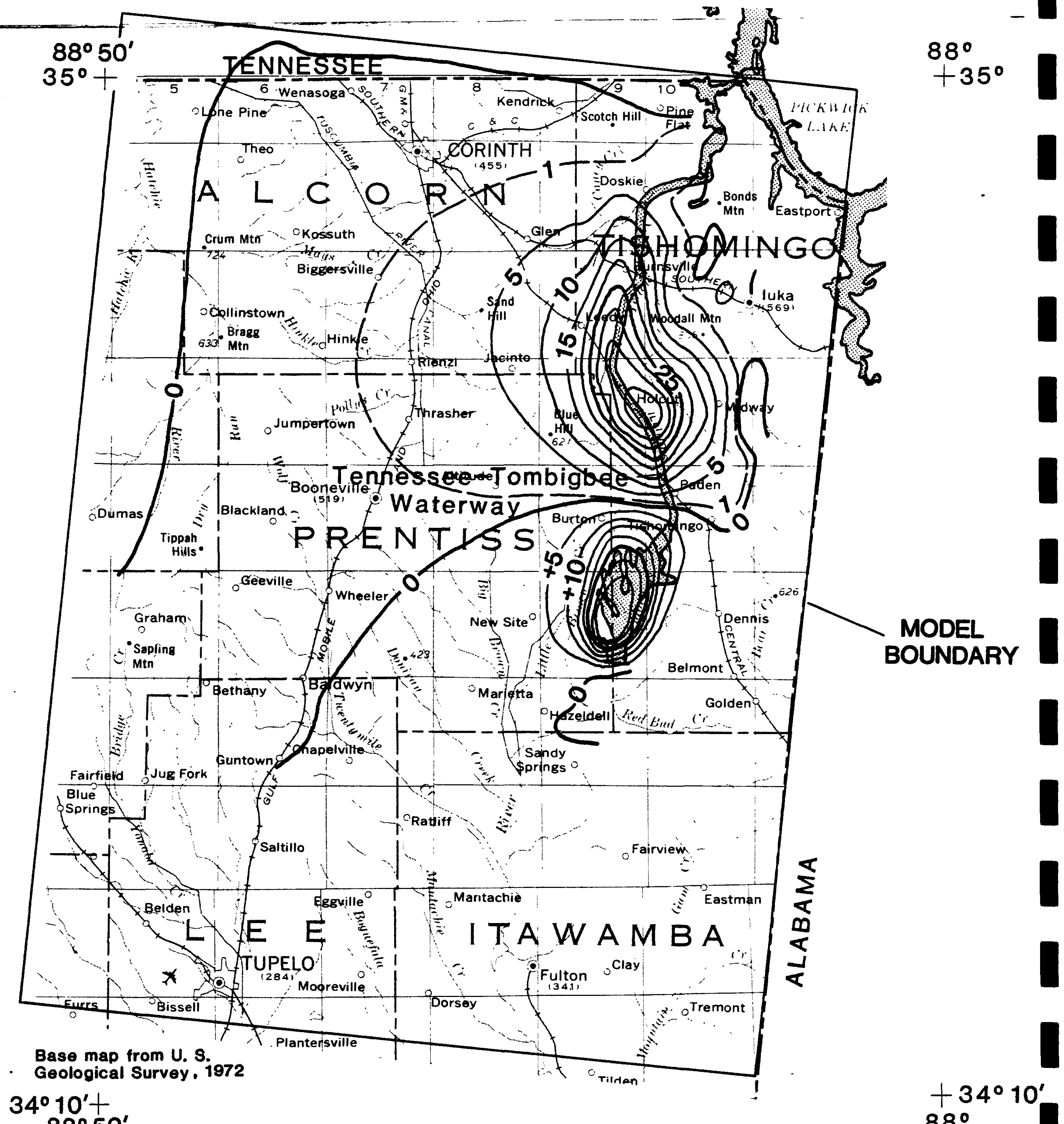


Figure 23.—Predicted steady-state drawdown in model layer 1 (Gordo Formation) for entire model area.



0 10 MILES

0 10 20 KILOMETERS

EXPLANATION

— 5 — Line of equal predicted drawdown or rise (+) in water levels. Interval is 5 feet with supplemental 1 foot interval.

Figure 24.—Predicted steady-state drawdown in model layer 2 (lower part of the McShan-Eutaw Coffee sequence) for entire model area.

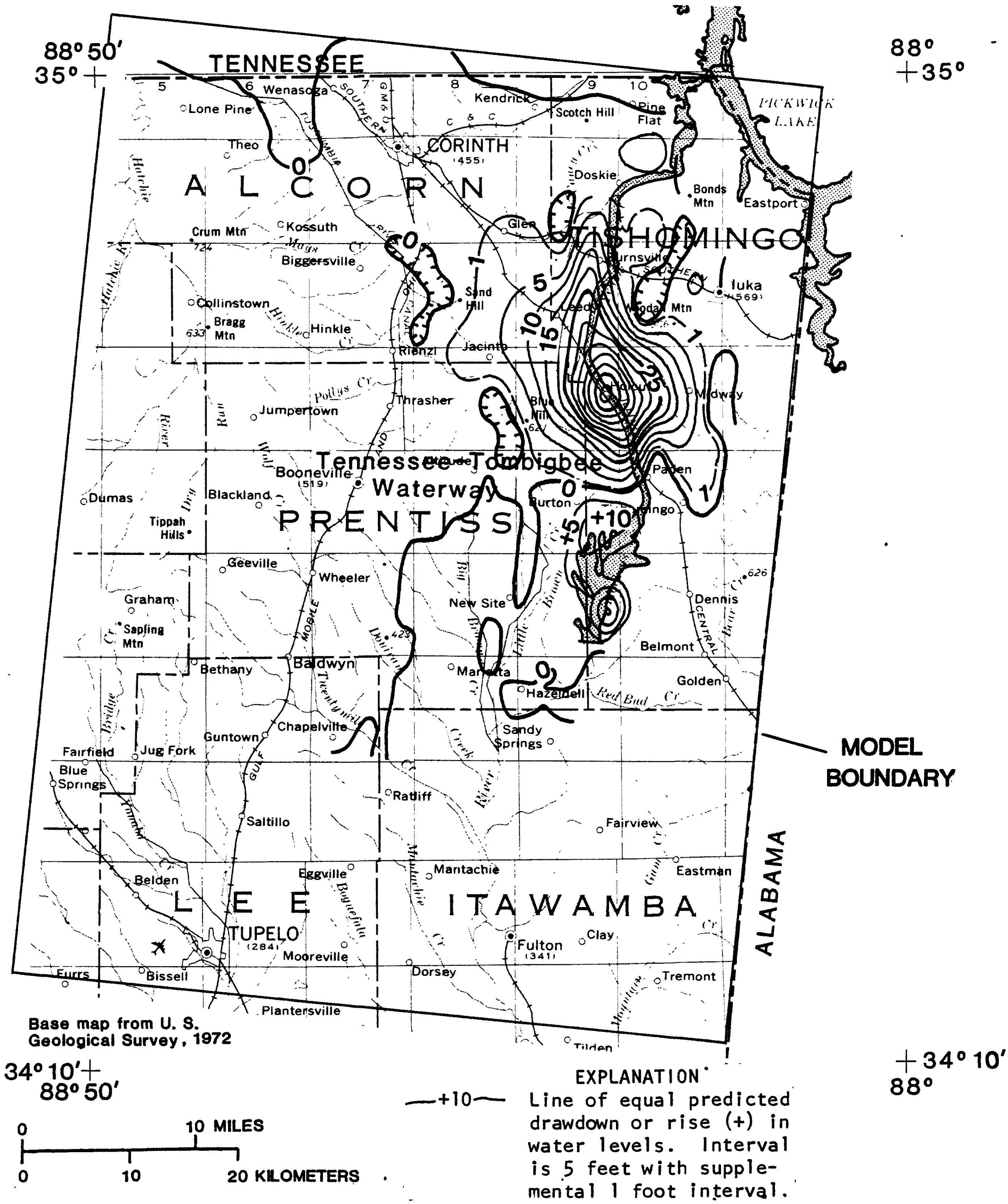


Figure 25.—Predicted steady-state drawdown in model layer 3 (upper part of the McShan-Eutaw-Coffee sequence) for entire model area.

Buildup near the Bay Springs Reservoir is smaller than in the other two layers, the maximum being about 20 feet.

External Effects of Changes in Ground-Water Level

Three possible external effects may result from water-level changes caused by construction of the Divide Section. They may be grouped as (1) effects on public water supplies, (2) effects on private water supplies, and (3) effects on streamflow.

Modeling indicates that four public-water supplies shown by Wasson and Tharpe (1975) may be affected by lowering of water levels. The well of the Holcut-Cairo Water Association, in northeastern Prentiss County, is completed in the Gordo formation. Figure 23 indicates that simulated Waterway-induced drawdown will be approximately 15 feet at that location. At Tishomingo, a well completed in the Gordo would have an indicated drawdown of 1 ft.

Paleozoic rocks were not modeled because of their low hydraulic conductivity. Thus, effects on Paleozoic wells can only be inferred indirectly. Wells at Burnsville and Iuka take water from the weathered and fractured top of the Paleozoic rocks. The Paleozoic aquifer at Burnsville is believed to be well-connected to the Gordo; at Iuka, the degree of interconnection has not been established. These municipal wells would therefore be expected to show the effects of the Waterway to a lesser, but not precisely known, degree than would hypothetical Gordo wells at their locations. At Burnsville, lowering in the Gordo is indicated at about 10 feet, and at Iuka, 1 foot. Whether water supplies at any of these locations will actually be affected depends on well construction, pump setting, and rate of pumping. At Corinth, the Gordo is absent, and water levels in the upper layers are lowered by considerably less than 1 foot. Effects in the Paleozoic are likely to be undetectably small.

Private water supplies are so numerous that they cannot be cited individually. Deeper private wells which draw water from beneath the regional water table may be adversely affected by Waterway-induced drawdown. The exact effect, and whether it is significant to users of the well, will depend on the well's location and individual characteristics. Some domestic wells within the area of major drawdown are likely to be made unuseable. It should be noted, however, that many and in the Eutaw outcrop belt at least, probably the majority of shallow domestic wells draw water from localized perched water tables. These frequently have no direct connection to the regional water table, which lies at some distance below them. Such wells are unlikely to be affected by the Waterway, even when they are located close to it.

Streams are simulated as a drain function, therefore, stream base flow will decrease where ground-water levels are lowered, and increase where they are raised.

CONCLUSIONS

The Divide Cut will act as a drain, reducing ground-water levels in places as much as 55 feet. Steady-state levels could fall by 5 feet at distances as much as 8 miles east and west of the Waterway. Actual drawdown at a given well location will depend on distance from the Divide Cut and on well depth. Drawdown will occur rapidly as the Divide Cut is constructed; delay between dewatering of a part of the cut and drawdown being felt everywhere within the affected area is not likely to exceed a few months.

Public supplies that may be affected include the Holcut-Cairo Water Association, with an indicated drawdown of about 15 feet, and Tishomingo, 1 foot. Wells at Burnsville and Iuka, completed in Paleozoic aquifers, may show drawdowns of at most 10 feet and 1 foot depending on the degree of connection with the Gordo. Some private wells will probably be made unuseable.

Impounding water behind the Bay Springs Dam will raise ground water levels locally as much as 40 feet. The area where levels are raised 5 feet or more extends from 2 to 6 miles from the Bay Springs Reservoir, depending on the layer being considered.

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