Gulf Coast Regional Aquifer-System Analysis--
A Kentucky Perspective

By Hayes F. Grubb, and J. Kerry Arthur

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Factors for converting inch-pound units to International System of Units (SI).

Multiply	*By*	*To obtain*
square mile	2.509	square kilometer
foot	0.3048	meter
mile	1.609	kilometer
million gallons per day	0.04381	cubic meter per second
inches per year	25.4	millimeters per year

National Geodetic Vertical Datum of 1929 (NGVD of 1929).--A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

GULF COAST REGIONAL AQUIFER-SYSTEM ANALYSIS--A KENTUCKY PERSPECTIVE

By

Hayes F. Grubb and J. Kerry Arthur

ABSTRACT

The Gulf Coast Regional Aquifer-System Analysis is a study of regional aquifers in sediments of mostly Cenozoic age in an area of about 230,000 square miles in the Coastal Plain of Kentucky, Alabama, Arkansas, Florida, Illinois, Louisiana, Mississippi, Missouri, Tennessee, and Texas and an additional 60,000 square miles offshore. Three aquifer systems have been identified: two in sediments of mostly Eocene age (the Mississippi embayment aquifer system and the Texas coastal uplands aquifer system) and one in sediments of mostly Miocene and younger age (the coastal lowlands aquifer system). Major objectives of the study are to delineate the geohydrologic framework, describe the ground-water chemistry, and to determine regional flow patterns. To study regional flow patterns the aquifer systems have been divided into regional aquifers and confining units based on regional-scale permeability. Maps depicting characteristics of the geohydrologic framework and dissolved-solids concentrations in water in the aquifers have been completed. Evaluation of ground-water flow using both regional- and subregional-scale digital models is nearing completion.

The Mississippi embayment aquifer system is the only one of the three aquifer systems found in Kentucky. About 1 percent of the total area underlain by the aquifer system is located in all or parts of eight counties in western Kentucky. Results of ground-water flow simulation indicate that much of the area underlain by the aquifer system in Kentucky is part of a regional recharge area. Regional predevelopment recharge (prior to pumping ground-water) exceeded 2 inches per year throughout a large part of Graves County and recharge occurred in all eight counties underlain by the aquifer system.

Ground-water pumpage from aquifers of the Mississippi embayment aquifer system in Kentucky has increased by a factor of about 3 from about 4 to 12 million gallons per day, during the period 1960-85. An increase in recharge to aquifers in Kentucky and an increase in aquifer outflow to adjacent States has resulted from pumpage. The increase in net recharge supplied the 12 million gallons per day pumpage from aquifers in Kentucky and a small increase in outflow to adjacent States. The increase in outflow to adjacent States from predevelopment conditions is due mostly to pumpage in Tennessee that induces recharge in aquifer outcrop areas located in Kentucky. The potentiometric surface of the middle Claiborne aquifer was lowered about 10 feet from predevelopment.

The aquifers of the Mississippi embayment aquifer system have the potential to produce much more water than was pumped during 1985. The effects of pumping large additional quantities of water from the Mississippi embayment aquifer system would be: substantial lowering of the potentiometric surface, decreasing the rate of discharge, shrinking the size of the discharge areas compared to predevelopment, and reducing aquifer outflow to adjacent States in the pumped aquifer as well as lowering of the potentiometric surface of the aquifers

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overlying the pumped aquifer, and increasing the rate of recharge and expanding the size of the recharge areas compared to predevelopment. The potential for sustaining additional ground-water withdrawals from the aquifers of the Mississippi embayment aquifer system in Kentucky are from greatest to least: the middle Claiborne aquifer, the lower Wilcox aquifer, the upper Claiborne aquifer, and the middle Wilcox aquifer.

Simulation of ground-water flow with a digital computer model was used to evaluate the magnitude of the effects of additional pumpage within Kentucky. Pumping an additional 30 million gallons per day from the middle Claiborne aquifer would increase the area having 2 inches per year or more recharge about twofold; an area of substantial size that was a predevelopment discharge area would become part of the recharge area. An elongate area of about 75 square miles with recharge of 4 inches per year or more would be expected to develop across the central part of Graves County. The potentiometric surface of the middle Claiborne aquifer would be lowered by more than 20 feet at the center of each of three additional pumping centers in Kentucky. The potentiometric surface would remain well above the top of the aquifer at the locations near Clinton in Hickman County and near Bardwell in Carlisle County. At the location south of Mayfield in Graves County the potentiometric surface might be as much as 80 feet below land surface.

Pumping an additional 10 million gallons per day from the lower Wilcox aquifer near Clinton in Hickman County, in addition to the 30 million gallons per day of simulated pumpage from the middle Claiborne aquifer, would have substantial impact on the potentiometric surfaces of aquifers and the vertical flow between aquifers, but minimal impact on size of recharge and discharge areas. The potentiometric surface of the lower Wilcox aquifer would be lowered about 330 feet at the pumping center, but it would be about 500 feet above the top of the aquifer. About 7 million gallons per day of the additional pumpage from the lower Wilcox aquifer would move downward through the overlying middle Wilcox aquifer from either the middle Claiborne aquifer or the upper Claiborne aquifer. The direction of flow would be reversed in the lower Wilcox aquifer and the 2 million gallons per day of outflow to adjacent States that existed under predevelopment conditions would be captured by the additional pumpage. In addition, about 1 million gallons per day would flow from adjacent States to the pumping center in the lower Wilcox aquifer located near Clinton in Hickman County.

INTRODUCTION

The Gulf Coast Regional Aquifer-System Analysis is a study of regional aquifers in sediments of mostly Cenozoic age. The study area underlies about 230,000 square miles of the Coastal Plain in Kentucky, Alabama, Arkansas, Florida, Illinois, Louisiana, Mississippi, Missouri, Tennessee, and Texas, and about 60,000 square miles of the Gulf of Mexico, between the coast and the edge of the Continental Shelf (fig. 1). The study is part of the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) program, which began in 1978 and is designed to provide a regional understanding and assessment of the Nation's ground-water resources (Bennett, 1979). A summary of progress on the RASA program through 1984 is given by Sun (1986). Major objectives of the study are to delineate the geohydrologic framework, describe the ground-water chemistry, and to determine regional flow patterns.The project objectives and the study approach have been discussed in detail by Grubb (1984, and 1985).

A discussion of regional ground-water flow in the aquifers in Tertiary-age sediments underlying western Kentucky is presented in this report. A general summary of the gulf coast aquifer systems is given first followed by a more detailed description of the geohydrologic units that underlie Kentucky. The primary focus of the report is an analysis of ground-water flow in Kentucky under predevelopment conditions (prior to pumping) compared to conditions during 1985, and an evaluation of the potential for the aquifers to yield additional water within Kentucky. The analysis and evaluation are based upon results from ground-water flow simulations using the model described by Arthur and Taylor (1990).

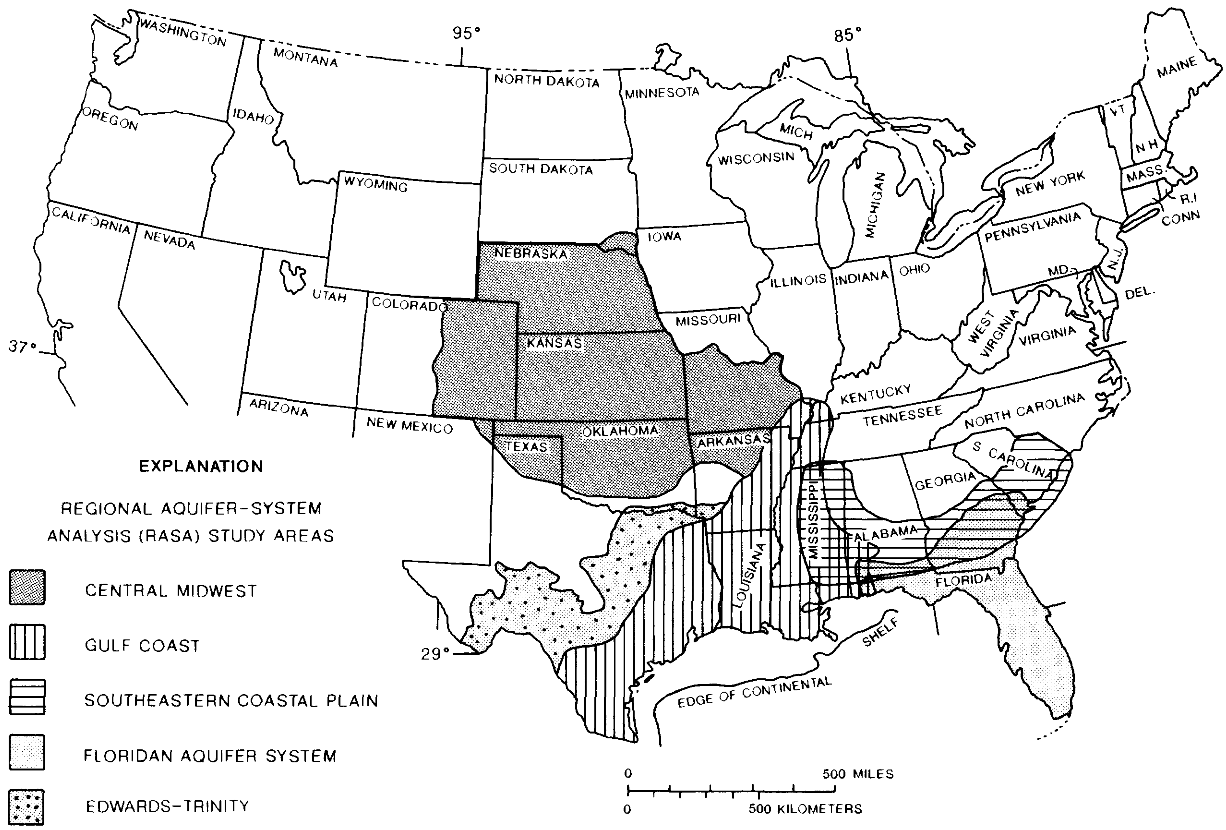


Figure 1.--Location of Gulf Coast Regional Aquifer-System Analysis study area and adjacent Regional Aquifer-System Analysis study areas.

GULF COAST AQUIFER SYSTEMS

The sediments that make up the gulf coast aquifer systems of the south-central United States can be described in a general way as a gulfward-thickening wedge of unconsolidated to semiconsolidated, complexly interbedded sand, silt, and clay with minor beds of lignite, gravel, and limestone. The sediments crop out in bands roughly parallel to the present day Gulf coastline except for the large inland extent of middle Eocene and older sediments in the Mississippi embayment, the East Texas embayment and the Rio Grande embayment (fig. 2, and Hosman, 1988). The oldest exposed sediments in the study area are of Cretaceous age and crop out in a band up to 20 miles wide along the northeastern rim of the Mississippi embayment. The oldest exposed sediments along the northwestern boundary of the study area in Arkansas and Texas are of Paleocene age and crop out in a 10 to 15 mile-wide band adjacent to older, mostly-consolidated sediments of Cretaceous age. Bands of progressively younger sediments crop out seaward or toward the axis of the Mississippi embayment in an offlap relation. A major exception is a 30 to 120 mile-wide band of alluvium of Pleistocene and Holocene age that covers the older units from southern Illinois to the modern delta of the Mississippi River in extreme southern Louisiana (fig. 2).

The geologic units typically thicken from a feather edge near the updip limit in the outcrop area to thousands of feet near the present day coastline. A zone of abnormally high fluid pressure (also called geopressure, Dickinson, 1953, and Jones, 1969) occurs at depth in geologic units ranging in age from Paleocene to Pliocene in coastal Louisiana and Texas. The flow of fluids from the abnormally high pressure zone to the normally pressured zone is believed to be small because of the minimal permeability of the sediments. Therefore, for purposes of this

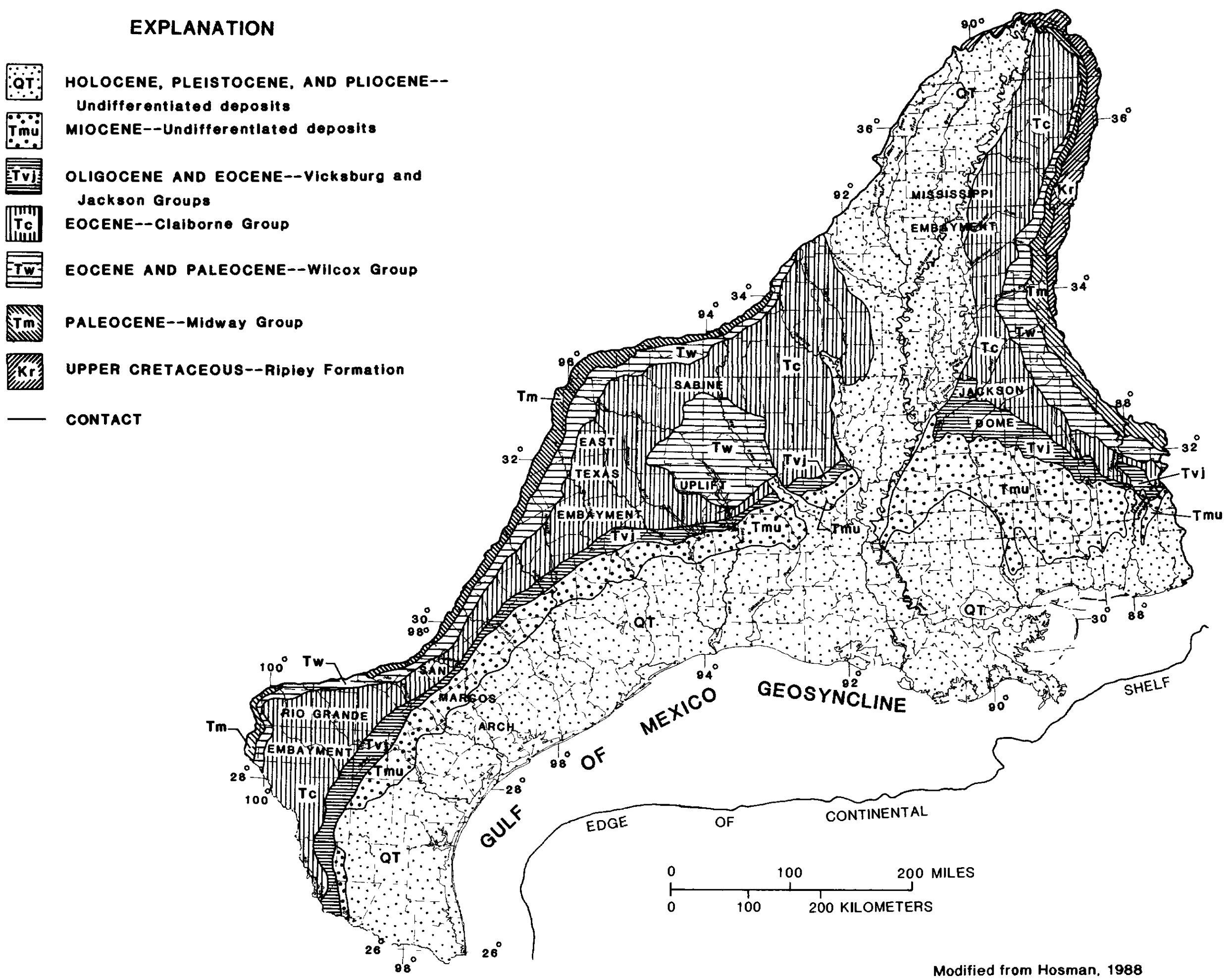


Figure 2.--Generalized geology, Gulf Coast Regional Aquifer-System Analysis study area.

study the top of the geopressured zone (or the transition from normal pressure to abnormally high pressure) is considered the base of the ground-water flow system where it occurs above the massive clay of Paleocene age. No attempt was made to characterize the sediments downdip beyond either that line where the top of the geopressured zone intersects the top of the individual aquifers or confining units, or beyond the edge of the continental shelf. The occurrence of geopressure in successively younger sediments gulfward results in the aquifer systems as well as most individual geohydrologic units within each aquifer system, attaining maximum thickness several tens of miles updip of their downdip limit.

Three aquifer systems have been identified within the Gulf Coast RASA study area (Grubb, 1984, and fig. 3): the Mississippi embayment and Texas coastal uplands aquifer systems, which occur principally in Eocene-age sediments, and the coastal lowlands aquifer system, which occurs principally in Miocene age and younger sediments. These aquifer systems were delineated on the basis of differences in regional ground-water flow patterns, the distribution of fine-grained sediments, and the presence of two regional units of minimal permeability (the Midway confining unit in Paleocene-age sediments, and the Vicksburg-Jackson confining unit in Eocene- and Oligocene-age sediments) recognizable on geophysical well logs. The two confining units are predominantly massive marine clays that restrict the vertical movement of water between aquifer systems. The Mississippi embayment aquifer system is the only one of the three systems found in Kentucky. The aquifer system underlies all or parts of eight counties in western Kentucky or about 1 percent of the total area underlain by the system.

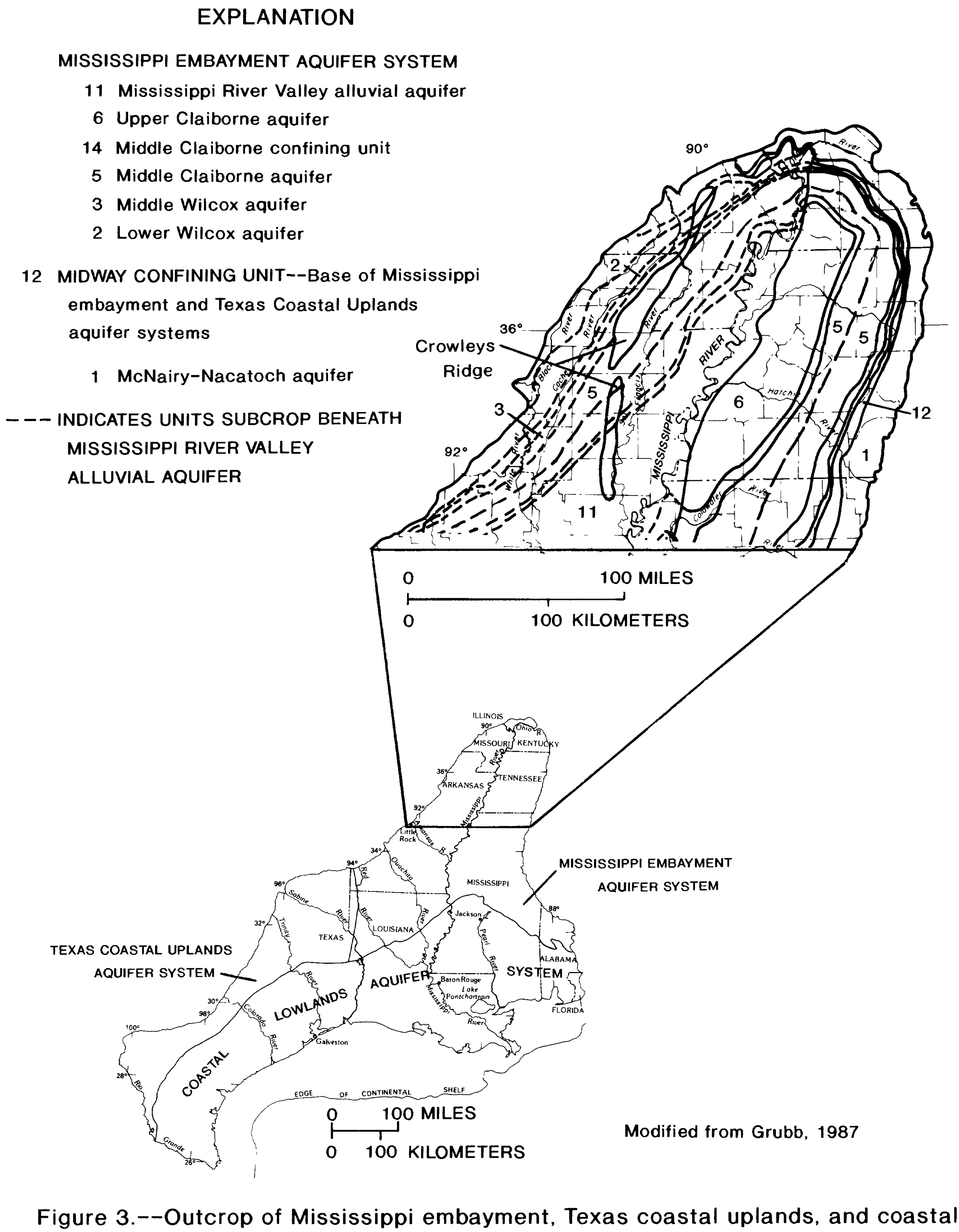


Figure 3.--Outcrop of Mississippi embayment, Texas coastal uplands, and coastal lowlands aquifer systems, and generalized outcrop of regional geohydrologic units in the northern area of the Mississippi embayment aquifer system.

A regional-scale aquifer (the McNairy-Nacatoch) underlies the Midway confining unit throughout the northern part of the study area. The McNairy-Nacatoch aquifer is composed of sediments of Cretaceous age and crops out to the east of the Mississippi embayment aquifer system's outcrop area in Kentucky, Tennessee, and northern Mississippi. The aquifer is covered by alluvium of the Mississippi River to the west in Arkansas, and Missouri. Preliminary results from simulation of ground-water flow in this aquifer indicate that there is only a small volume of flow from the McNairy-Nacatoch aquifer across the Midway confining unit and that the aquifer functions independently of the aquifers above the Midway confining unit throughout most of its areal extent (Brahana, 1987, and Brahana and Mesko, 1988). Although the McNairy-Nacatoch aquifer probably has the potential to yield additional water within Kentucky, especially in and near the outcrop area, it is not included in the discussion that follows. The study of the McNairy-Nacatoch aquifer was not as near completion as the study of the Mississippi embayment aquifer system at the time of this writing (1989) and could not be included in the analysis. The net effect of not including the McNairy-Nacatoch aquifer in this analysis is to underestimate the potential of producing ground water in Kentucky from the aquifers that are the subject of the Gulf Coast Regional Aquifer-System Analysis.

Although major contrasts in regional scale permeability are differentiated by mapping the two regional confining units and the three aquifer systems, variations in permeability exist within each aquifer system that affects the vertical flow of water. The variability in permeability is due to the interbedded nature of the sediments. Vertical movement of water within each aquifer system may be restricted by regionally extensive clay beds that occur between aquifers or by thin regionally discontinuous clay beds within the individual aquifers. The aquifers in the Mississippi embayment and Texas coastal upland aquifer systems typically are massive sand beds separated by regionally extensive clay beds. The aquifers in the coastal lowlands aquifer system typically contain discontinuous clay beds and generally are not separated by regionally extensive clay beds.

These aquifer systems have been divided into regional aquifers and confining units based on regional-scale permeability. The divisions are: Mississippi embayment aquifer system with six aquifers and two confining units; Texas coastal uplands aquifer system with five aquifers and two confining units; and the coastal lowlands aquifer system with five aquifers and two confining units.

Hosman and Weiss (1988) present detailed maps of aquifer thickness, percentage and aggregate sand thickness, and altitude of top for each regional geohydrologic unit in the Mississippi embayment and Texas coastal uplands aquifer systems. Detailed maps of the geohydrologic units of the coastal lowlands aquifer system are presented by Weiss (1990). Maps of dissolved-solids concentrations and water temperature for all the aquifers in the three aquifer systems are presented in Pettijohn and others (1988).

Throughout the Gulf Coast RASA study area large volumes of water are being withdrawn from the aquifer systems for use by cities, industry, and agriculture. An estimated 8,900 million gallons per day of ground water was withdrawn from aquifers in the study area for all uses during 1985 (Mesko and others, 1990). Pumpage during 1985 represents a decrease of about 7 percent from the 9,500 million gallons per day withdrawn in the area during 1980. The 1985 decrease in pumpage is the only decrease during the period 1960-85 based on data tabulated at 5-year intervals. During 1960 ground-water pumpage for irrigation was about 1.5 times more than the combined pumpage for all other uses. The ratio increased by a factor of 3 in 1980 and 1985.

Ground-water pumpage from the Mississippi embayment aquifer system was about 5,600 million gallons per day during 1985, about 60 percent of the total pumpage in the study area. Most of the pumpage from the Mississippi embayment aquifer system, about 4,800 million gallons per day during 1985, was from the Mississippi River Valley alluvial aquifer. Only about

14 percent (780 million gallons per day) of the Mississippi embayment aquifer system pumpage was from the aquifers in older sediments of Tertiary age. About 12 million gallons per day or less than 2 percent was withdrawn from aquifers in sediments of Tertiary age underlying western Kentucky during 1985.

The impact of ground-water pumpage has become regional in nature. Water-level declines have migrated across local and state political boundaries beyond the immediate vicinity of cities, industries, and irrigated lands where the water is pumped. Other changes that have occurred because of ground-water pumpage include the movement of the saline-freshwater interface into parts of aquifers that previously contained freshwater, land-surface subsidence due to the compaction of interbedded clays within the aquifers, and an increase in pumping lifts resulting from the lowering of potentiometric surfaces.

Both regional- and subregional-scale digital computer models were used for the simulation of ground-water flow within the Gulf Coast RASA study area. The regional-scale model encompasses the entire study area except for the McNairy-Nacatoch aquifer in the northern part of the Mississippi embayment. The subregional-scale models are limited to smaller areas and to that part of the aquifer systems containing fresh to moderately saline water, except for the model of the combined Texas coastal uplands aquifer system and the coastal lowlands aquifer system of Texas that includes both fresh and saline parts of the aquifer systems.

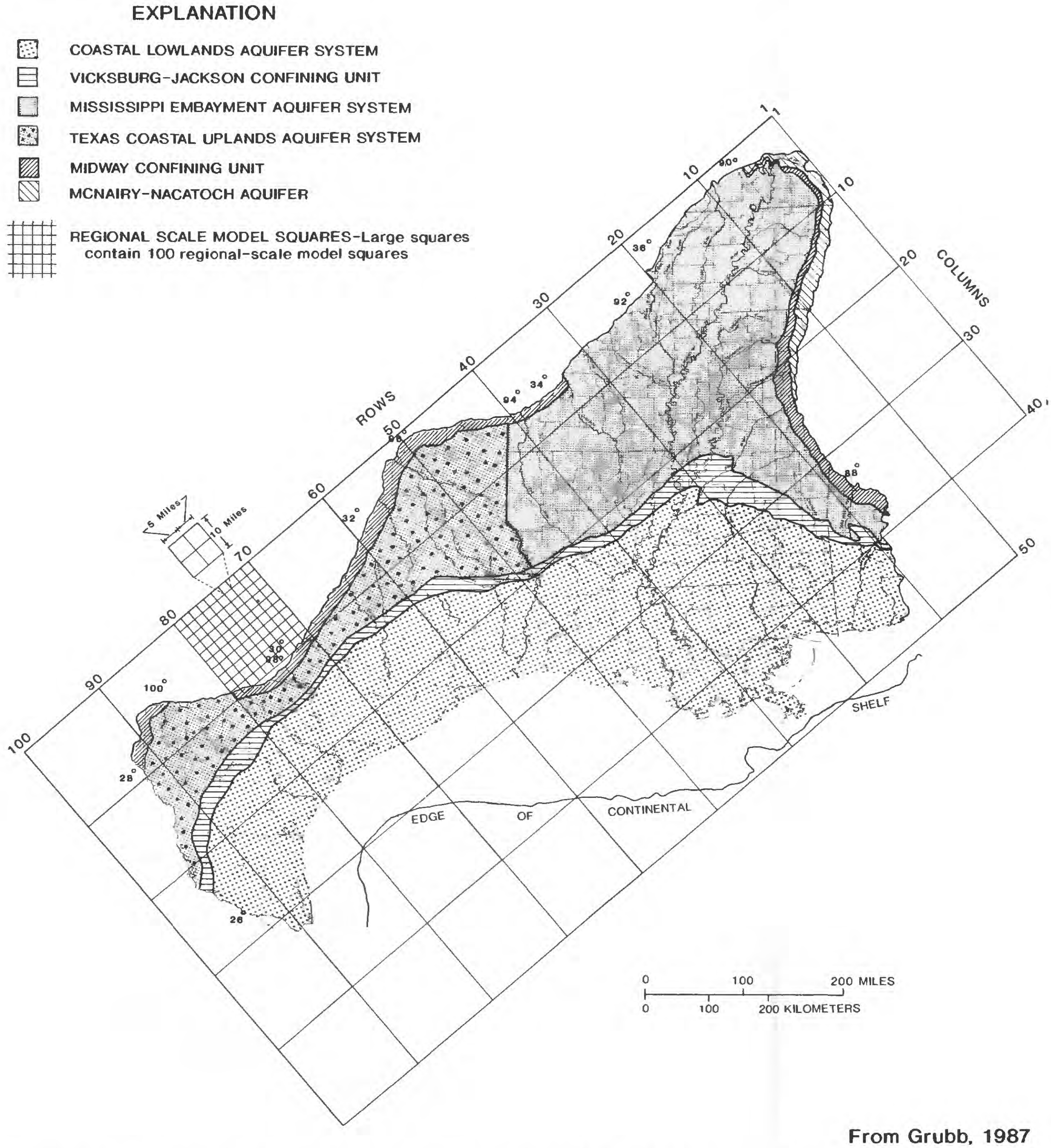
The regional-scale model was constructed using a rectangular grid divided into squares 10 miles on each side (fig. 4). Ground-water flow in the 10 regional aquifers was simulated with a variable-density flow model developed by Kuiper (1983, p. 234-240, and 1985). The subregional models were constructed using rectangular grids with squares 5 miles on each side. Four of the 5-mile squares cover the same area as one square in the regional model (fig. 4). The modular ground-water flow model of McDonald and Harbaugh (1988) was used for most of the subregional models. The model of Kuiper (1983) was used for the subregional model of the combined aquifer systems of the Texas gulf coast. The number of aquifer layers in the subregional models range from one for the Mississippi River Valley alluvial aquifer model to nine for the model of the combined aquifer systems of the Texas gulf coast.

A more detailed discussion of the regional- and subregional-scale models is contained in reports by Arthur and Taylor (1986), Brahana (1987), Williamson (1987), Brahana and Mesko (1988), Ryder (1988), Williamson and others (1989), Ackerman (1989), Martin and Whiteman (1989), and Arthur and Taylor (1990). These reports present preliminary analysis of predevelopment and 1980 flow conditions, the details of model construction, and underlying assumptions. The subregional-scale model of the Mississippi embayment aquifer system (Arthur and Taylor, 1990) was used to analyze ground-water flow in Kentucky and to simulate the effects of the various ground-water pumping schemes described in latter parts of this report.

MISSISSIPPI EMBAYMENT AQUIFER SYSTEM IN KENTUCKY

Kentucky is underlain by the northeastern terminus of the Mississippi embayment aquifer system (fig. 3). The maximum thickness of the aquifer system throughout most of Fulton County, is more than 1,000 feet which is about one-fifth that of the thickest part of the aquifer system in south-central Mississippi and central Louisiana (Hosman and Weiss, 1988). However, the aggregate sand percentage is typically greater than 60 percent in Kentucky where the aquifer system thickness is less than 1,000 feet (Hosman and Weiss, 1988, figs. 15 and 16).

Five aquifers of the Mississippi embayment aquifer system are identified in western Kentucky; in descending order these are: (1) the Mississippi River Valley alluvial aquifer, (2) the upper Claiborne aquifer, (3) the middle Claiborne aquifer, (4) the middle Wilcox aquifer, and (5) the lower Wilcox aquifer (Hosman and Weiss, 1988). The Mississippi River Valley alluvial aquifer underlies only a small area in the westernmost counties of Kentucky. It consists of a



From Grubb, 1987

Figure 4.--Regional aquifer systems and model grid for simulation of ground-water flow.

narrow band a few miles wide along the Mississippi River (fig. 3). The upper Claiborne aquifer is generally less than 200 feet thick and has an area of about 600 square miles in Kentucky. The upper Claiborne aquifer underlies all of Fulton County, most of Hickman County and a small part of both Graves and Carlisle Counties. The middle Claiborne aquifer is generally more than 300 feet thick and has an area of about 1,500 square miles in Kentucky. The middle Claiborne aquifer underlies all of Fulton, Hickman, and Carlisle Counties, most of Graves County, about one-half of Ballard County, and small parts of Calloway and McCracken Counties. The middle Wilcox aquifer is less than 200 feet thick and has an area of about 1,600 square miles in Kentucky. The middle Wilcox aquifer underlies all of Fulton, Hickman, and Carlisle Counties, and a few square miles more of Graves, Ballard, Calloway, and McCracken Counties than the middle Claiborne aquifer. The lower Wilcox aquifer generally is less than 100 feet thick and has an area of about 1,700 square miles in Kentucky. The lower Wilcox aquifer underlies all of Fulton, Hickman, and Carlisle Counties, and a few square miles more of Graves, Ballard, Calloway, and McCracken Counties than the middle Wilcox aquifer. Both the middle Wilcox and the lower Wilcox aquifers underlie a small area in the extreme southwestern corner of Marshall County. The vertical relation of the geohydrologic units in the northern part of the Mississippi embayment aquifer system is shown in figure 5. The above description of the aquifers, subsequent detail of aquifer thickness, sand percentage, and altitude of top is from detailed maps by Hosman and Weiss (1988) that were constructed from the geophysical well-log database described by Wilson and Hosman (1988).

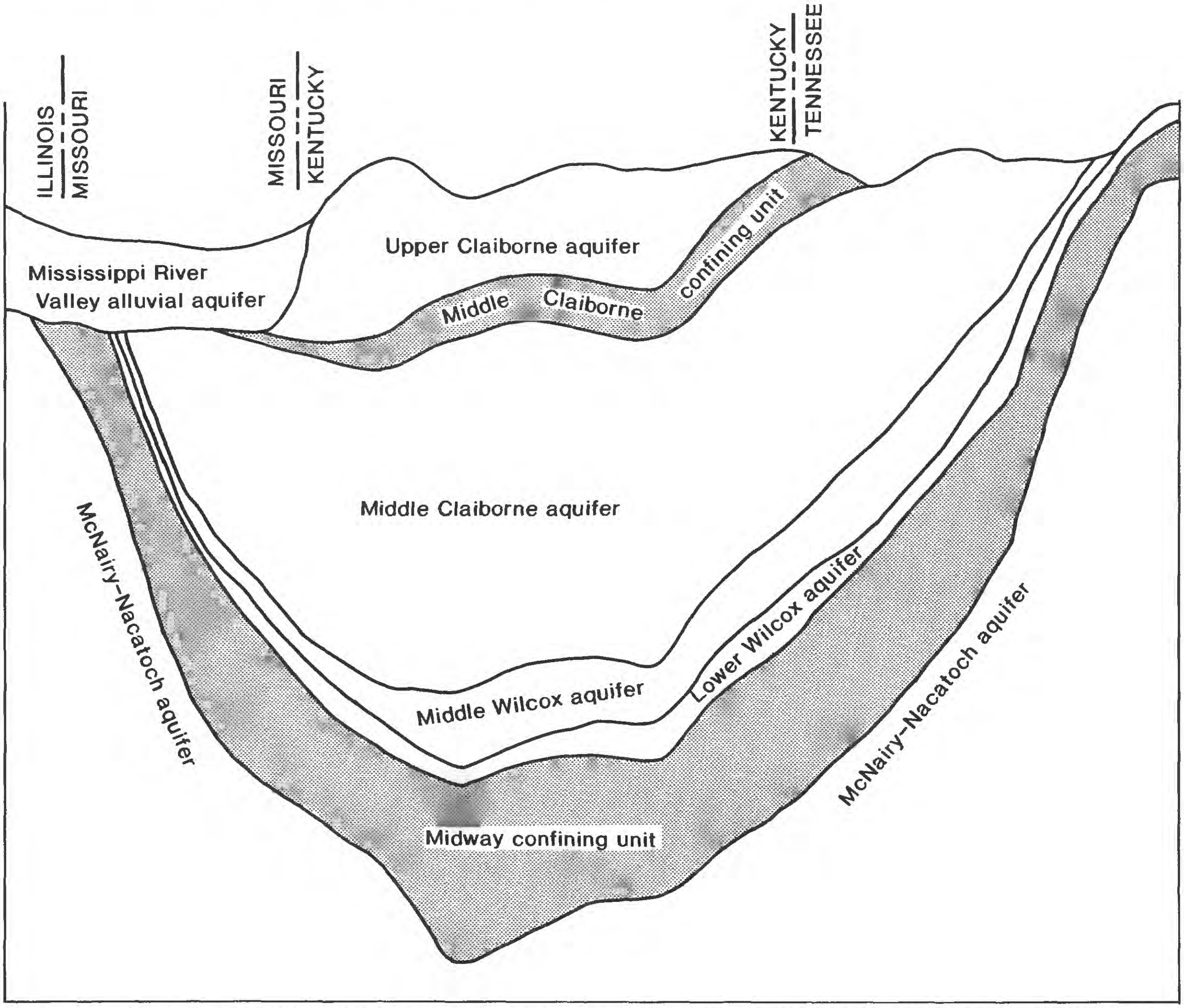


Figure 5.--Idealized diagram showing vertical relation of geohydrologic units from Alexander County, Illinois to near Huntingdon, Tennessee.

The middle Claiborne, middle Wilcox, and lower Wilcox aquifers have almost the same areal extent within Kentucky. The middle and lower Wilcox aquifers have narrow outcrop bands, typically less than 3 miles in width (fig. 3). The upper Claiborne aquifer is the uppermost aquifer in sediments of Tertiary age and also is the uppermost aquifer throughout most of its areal extent in Kentucky. The middle Claiborne aquifer is the thickest, as much as 500 feet thick in parts of Carlisle, Graves, and Hickman Counties. The thinnest aquifer is the lower Wilcox which is less than 100 feet thick throughout Kentucky except for an area in the southwest two-thirds of Fulton County.

Geometric mean hydraulic conductivity of the aquifers range from about 80 feet per day for the middle Claiborne aquifer to about 30 feet per day for the middle Wilcox aquifer. Geometric mean hydraulic conductivity is almost 50 feet per day for the upper Claiborne aquifer and about 60 feet per day for the lower Wilcox aquifer. The hydraulic conductivity data reported above is for the western parts of Kentucky and Tennessee, and much of Mississippi (Prudic, 1991).

Much of the Mississippi embayment aquifer system in Kentucky is part of a regional recharge area that extends southward into Tennessee and Mississippi (Grubb, 1986). Regional predevelopment recharge (prior to pumping ground-water) exceeded 2 inches per year throughout a large part of Graves County (fig. 6) and occurred in all eight counties underlain by the aquifer system. However, most of Fulton County was part of a regional discharge area that extended westward into Missouri, southward through the western most counties of Tennessee, and southwestward into Arkansas. Most of the predevelopment recharge to the aquifers in Tertiary-age sediments in Kentucky flowed to discharge areas in the adjacent States of Missouri and Tennessee. The recharge and discharge areas were delineated based on results from a ground-water flow model described in detail by Arthur and Taylor (1986 and 1990).

Ground-water pumpage from the Mississippi embayment aquifer system in Kentucky has increased by a factor of about 3, from about 4 to 12 million gallons per day, during the period 1960-85 (fig. 7). Most of the pumpage (more than 95 percent) is from the middle Claiborne aquifer. The effects of pumpage were evaluated by simulation of ground-water flow using the model described by Arthur and Taylor (1986 and 1990). Pumpage in adjacent States was incorporated into the simulation and had some effect on the aquifers within Kentucky. The hydrologic conditions in the aquifer system, referred to subsequently as 1985 conditions, are simulated conditions in which pumpage at the 1985 rate was simulated for the 5-year period 1983-87.

Recharge to the aquifer system in Kentucky increased 16 million gallons per day and outflow to adjacent States increased 2 million gallons per day from predevelopment to 1985 conditions (table 1). The increase in net flow through the aquifer system in Kentucky is about 30 percent more than the 12 million gallons per day pumpage during 1985. Pumpage from the aquifer system in Tennessee near the Kentucky-Tennessee boundary caused some of the increased recharge to the aquifer system in Kentucky and most of the increased outflow from Kentucky. The size of the regional recharge area in Kentucky increased slightly from predevelopment to 1985 conditions and there has been about a 45 percent increase (16 million gallons per day) in recharge with maximum areal rates increasing from 2.5 to 4.0 inches per year. The area of substantially increased recharge is centered near Mayfield, Kentucky, and is less than 10 square miles in extent. However, a small increase in recharge has occurred throughout much of the southern one-half of Graves County, Kentucky (figs. 8 and 6).

The 1985 potentiometric surface of the middle Claiborne aquifer in Kentucky was drawn down only slightly from predevelopment levels even though it was the most heavily pumped aquifer. Comparison of simulated potentiometric surfaces shows that water levels in the middle Claiborne aquifer were about 10 feet lower throughout most of Fulton County with smaller changes elsewhere (figs. 9 and 10).

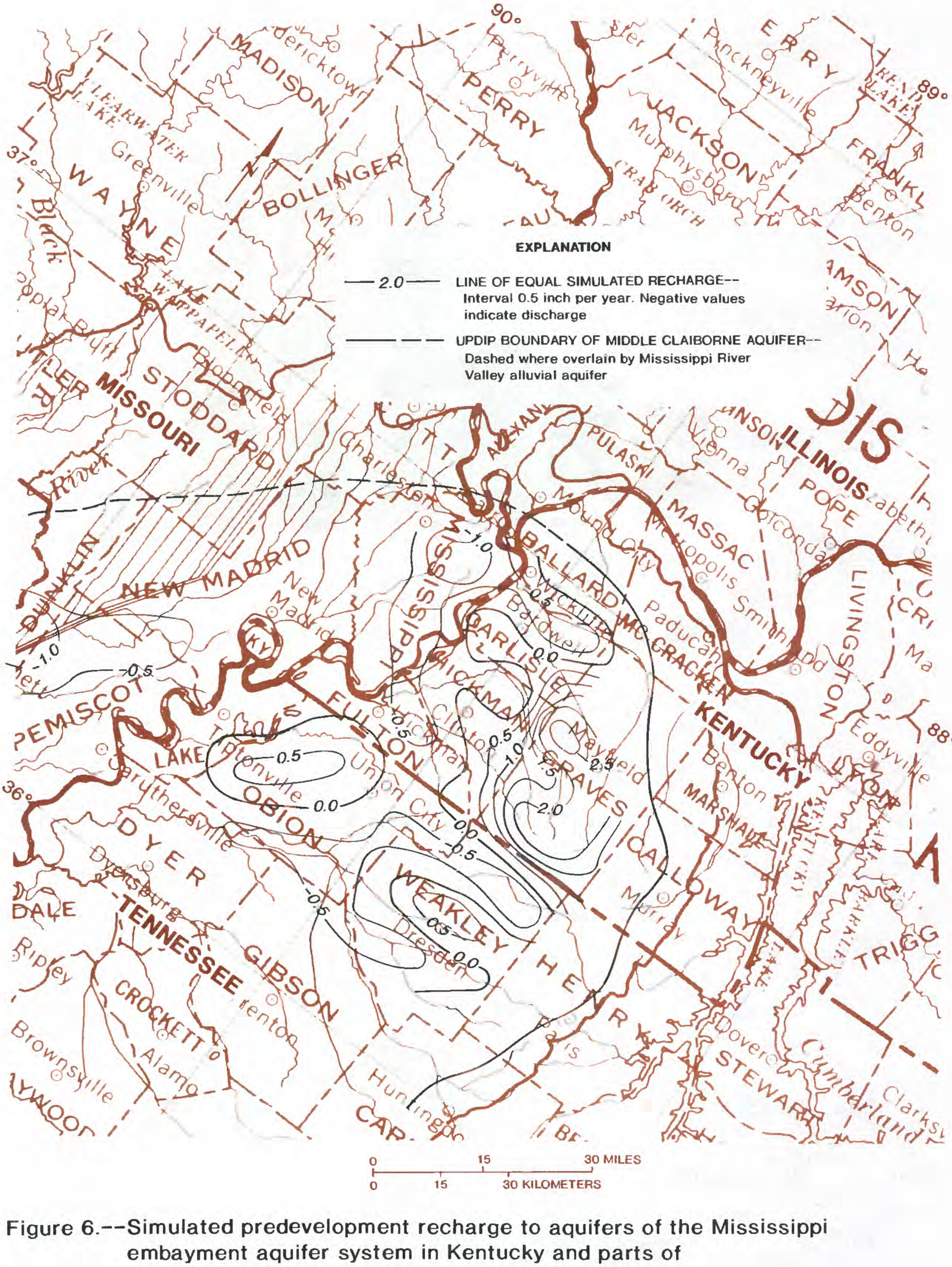


Figure 6.--Simulated predevelopment recharge to aquifers of the Mississippi embayment aquifer system in Kentucky and parts of adjacent States.

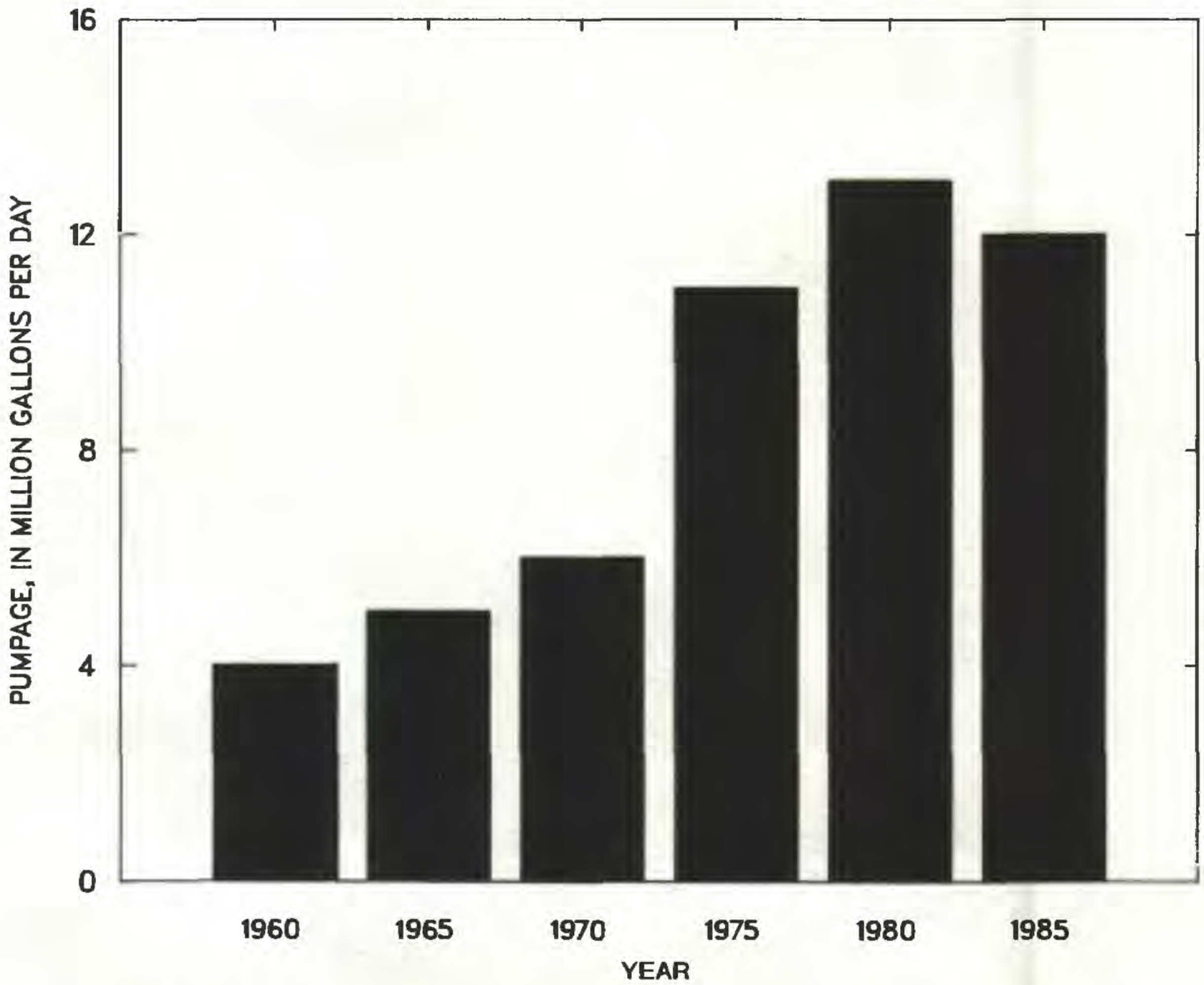


Figure 7.--Ground-water pumpage from the Mississippi embayment aquifer system underlying Kentucky, 1960-85.

Table 1.--*Ground-water flow budget for the Mississippi embayment aquifer system underlying Kentucky for predevelopment, 1960, 1985, and several simulated conditions*

[All quantities are in million gallons per day.]

Condition	Recharge	Net out-flow from Kentucky	Change in storage	Pumpage
Predevelopment	36	36	0	0
1960	41	36	<1	4
1985	52	38	<1	12
1985 pumpage increased by 20 percent	54	39	<1	14
1985 pumpage plus 10 Mgal/d at each of 3 locations	72	30	<1	42
1985 pumpage plus 10 Mgal/d at each of 2 locations plus 10 Mgal/d from each of 2 aquifers at 1 location	77	26	<1	52

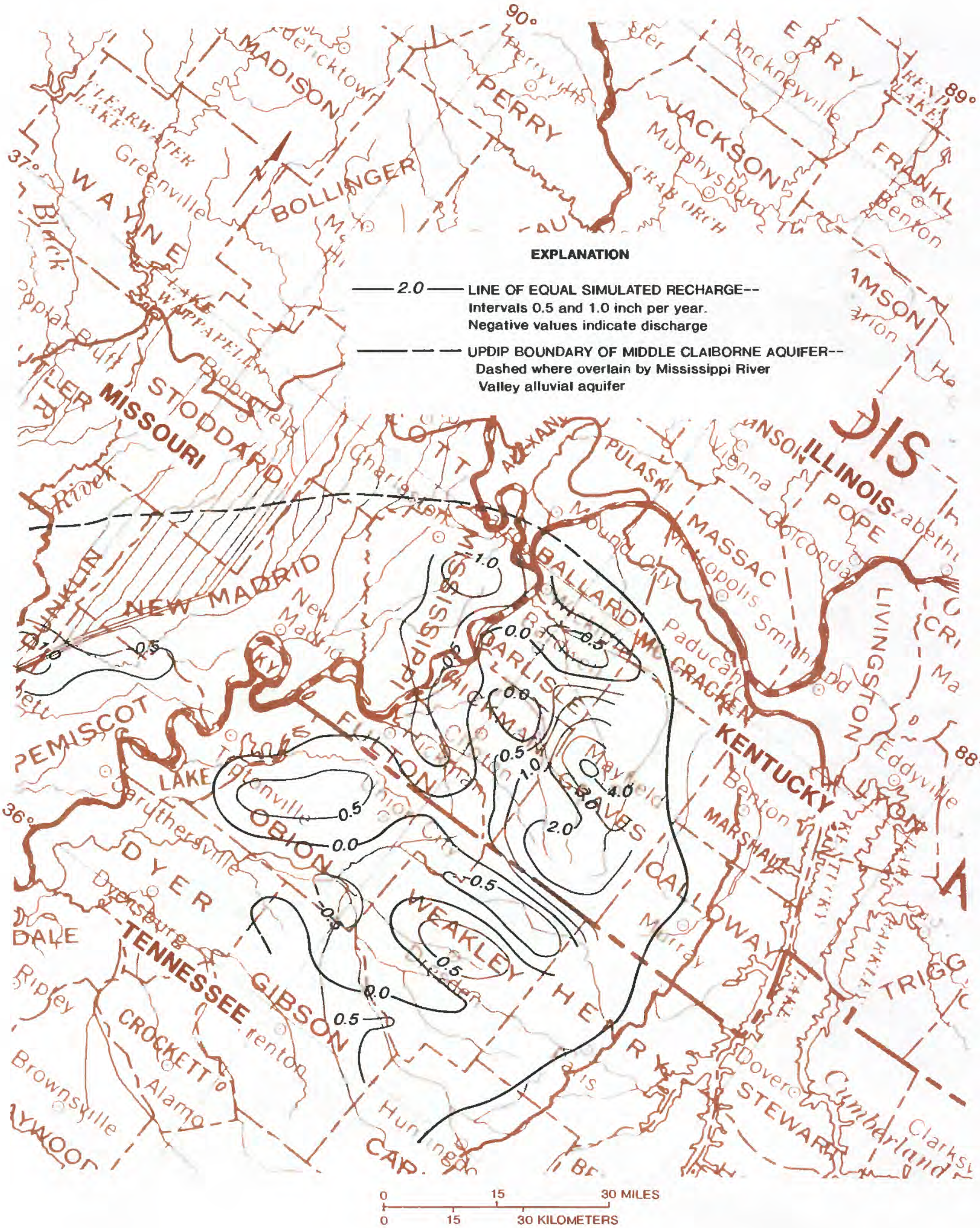


Figure 8.--Simulated 1985 recharge to aquifers of the Mississippi embayment aquifer system in Kentucky and parts of adjacent States.

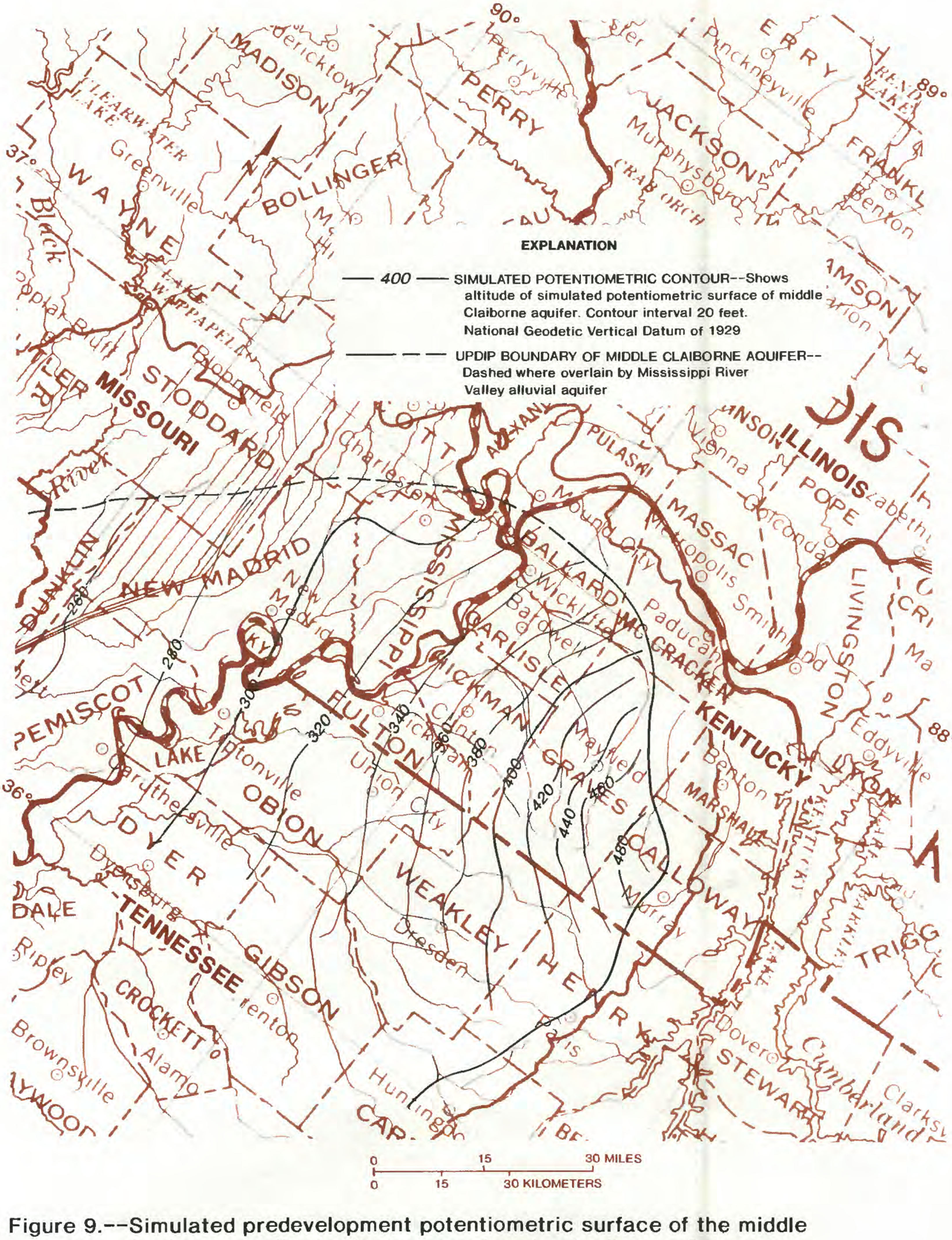


Figure 9.--Simulated predevelopment potentiometric surface of the middle Claiborne aquifer in Kentucky and parts of adjacent States.

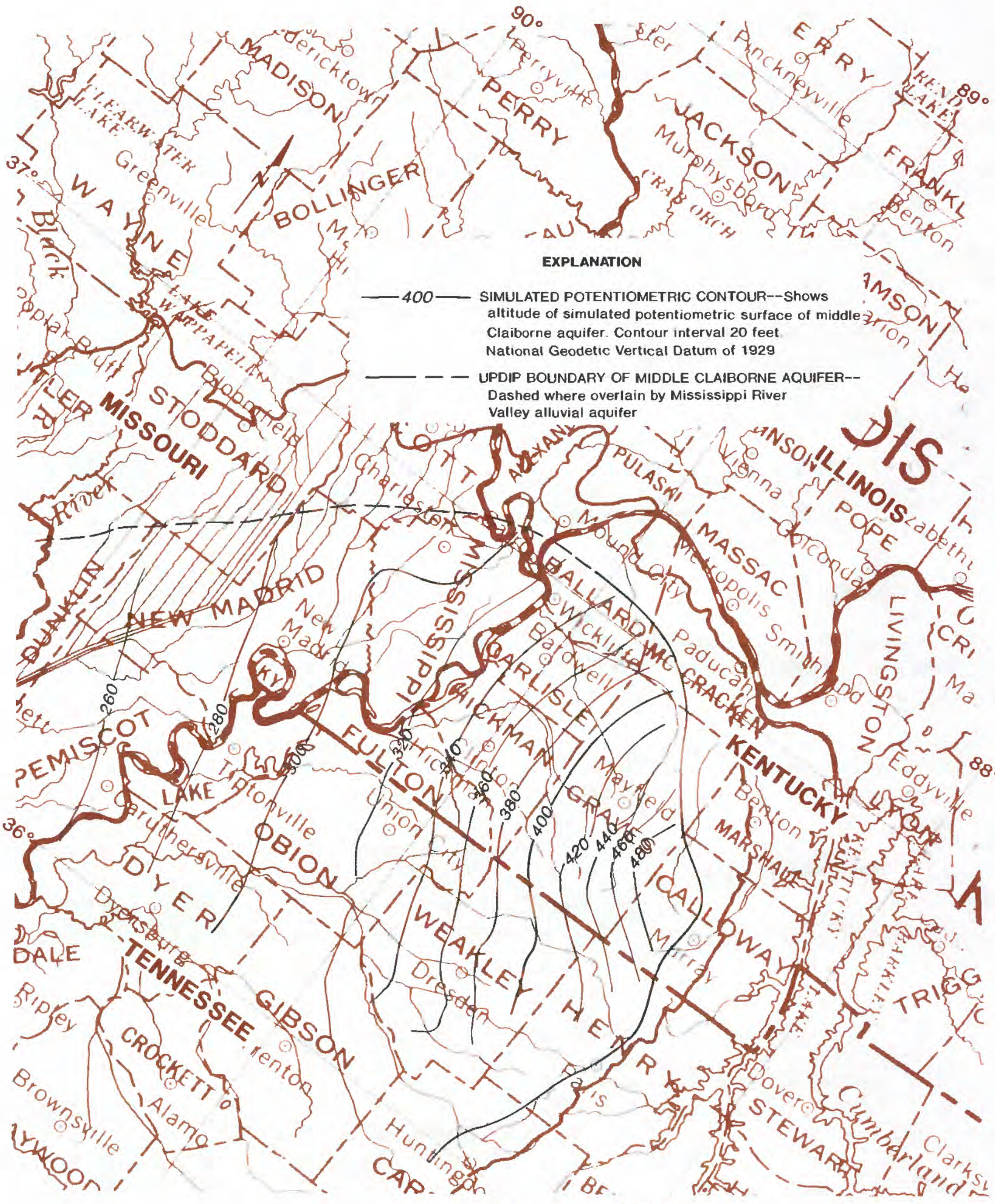


Figure 10.--Simulated 1985 potentiometric surface of the middle Claiborne aquifer in Kentucky and parts of adjacent States.

POTENTIAL FOR AND EFFECTS OF ADDITIONAL PUMPAGE

The aquifers of the Mississippi embayment aquifer system have the potential to yield much more water than was pumped during 1985. However, the individual aquifers do not have equal potential for development of additional pumpage. Neither the upper Claiborne aquifer nor the middle Wilcox aquifer has as much potential for increased pumpage in Kentucky as does the middle Claiborne aquifer or the lower Wilcox aquifer. The hydraulic conductivity of the middle Claiborne aquifer is about 30 feet per day larger than the hydraulic conductivity of the upper Claiborne aquifer. The middle Claiborne aquifer has an areal extent in Kentucky more than two times larger than the areal extent of the upper Claiborne aquifer, and the outcrop of the middle Claiborne aquifer is slightly larger than the outcrop area of the upper Claiborne aquifer. The middle Wilcox aquifer has a much larger areal extent in Kentucky than the upper Claiborne aquifer and underlies almost as much of Kentucky as the lower Wilcox aquifer. However, the potential for pumping large quantities of water from the middle Wilcox aquifer at any given site is less than for either the middle Claiborne or the lower Wilcox aquifers. The reason for the lesser potential of the middle Wilcox aquifer is the hydraulic conductivity, which is only about one-half that of the middle Claiborne and lower Wilcox aquifers. Sand beds within the middle Wilcox aquifer typically are thinner and they are interspersed with more clay beds than the other aquifers of the aquifer system. Although the area underlain by the Mississippi River Valley alluvial aquifer in Kentucky is small the potential for inducing infiltration from the Mississippi River probably is large.

The potential for additional pumpage in Kentucky is demonstrated by the results of three simulations, each for a 13 year period superimposed upon 1985 conditions. The aquifer system adjusts quickly to the volume of withdrawals simulated and thus the quantity of water that would be released from storage is minimal after 13 years of pumping at the constant rates described below.

Mississippi Embayment Aquifer System

Simulation of a 20 percent increase in 1985 pumpage rates throughout the Mississippi embayment aquifer system indicates only minor changes in flow characteristics within Kentucky. Aquifer recharge and outflow from Kentucky would be expected to increase slightly (table 1). The combined increase in recharge and outflow (3 million gallons per day) is more than the 20 percent pumpage increase (2 million gallons per day) within Kentucky. The increased pumpage would slightly enlarge the area over which 4.0 inches per year is recharged and slightly lower the potentiometric surface of the middle Claiborne aquifer.

Middle Claiborne Aquifer

The potential for additional ground-water withdrawal from the middle Claiborne aquifer was investigated by simulating 1985 pumpage plus 10 million gallons per day withdrawals at each of three selected locations. The three additional pumping centers were located near Bardwell in Carlisle County, near Clinton in Hickman County, and about 5 miles south of Mayfield in Graves County (fig. 11). The additional pumpage would be expected to cause substantial changes in recharge, outflow to adjacent States, and in the level of the potentiometric surface of the middle Claiborne aquifer.

Two-thirds of the 30 million gallons per day of additional pumpage would came from increased recharge and most of the remainder would came from reduced outflow from Kentucky to adjacent States (table 1). The recharge area would expand and parts of Ballard, Carlisle, Fulton, and Hickman Counties that were predevelopment discharge areas would become recharge areas (fig. 12). The area of substantial increase in recharge would extend throughout much of Graves County and the area with 2 inches per year or more of recharge would increase

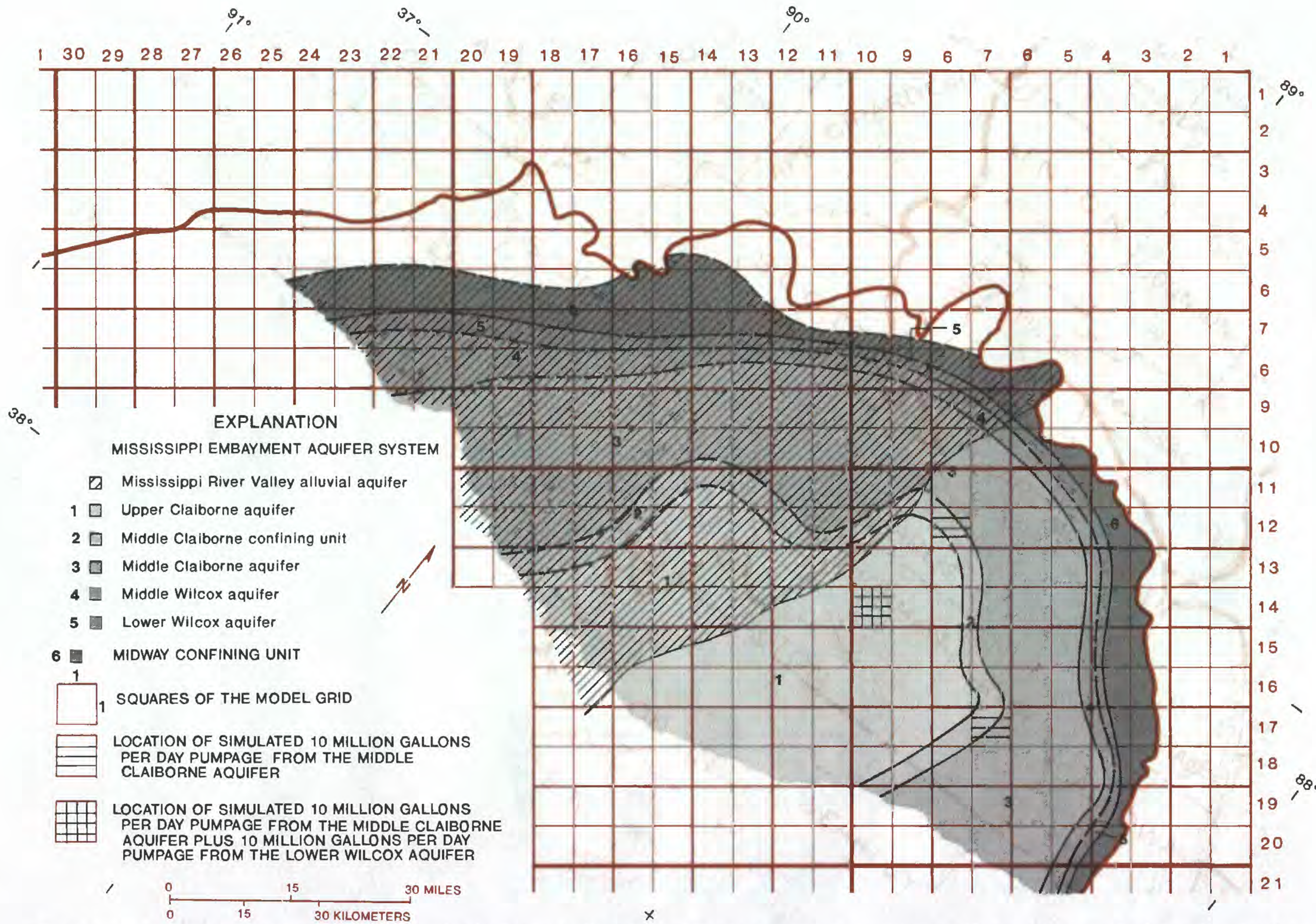


Figure 11.--Generalized outcrop of geohydrologic units of the Mississippi embayment aquifer system underlying Kentucky and parts of adjacent States, model grid with squares 5 miles on a side, and location of three additional pumping centers in Kentucky.

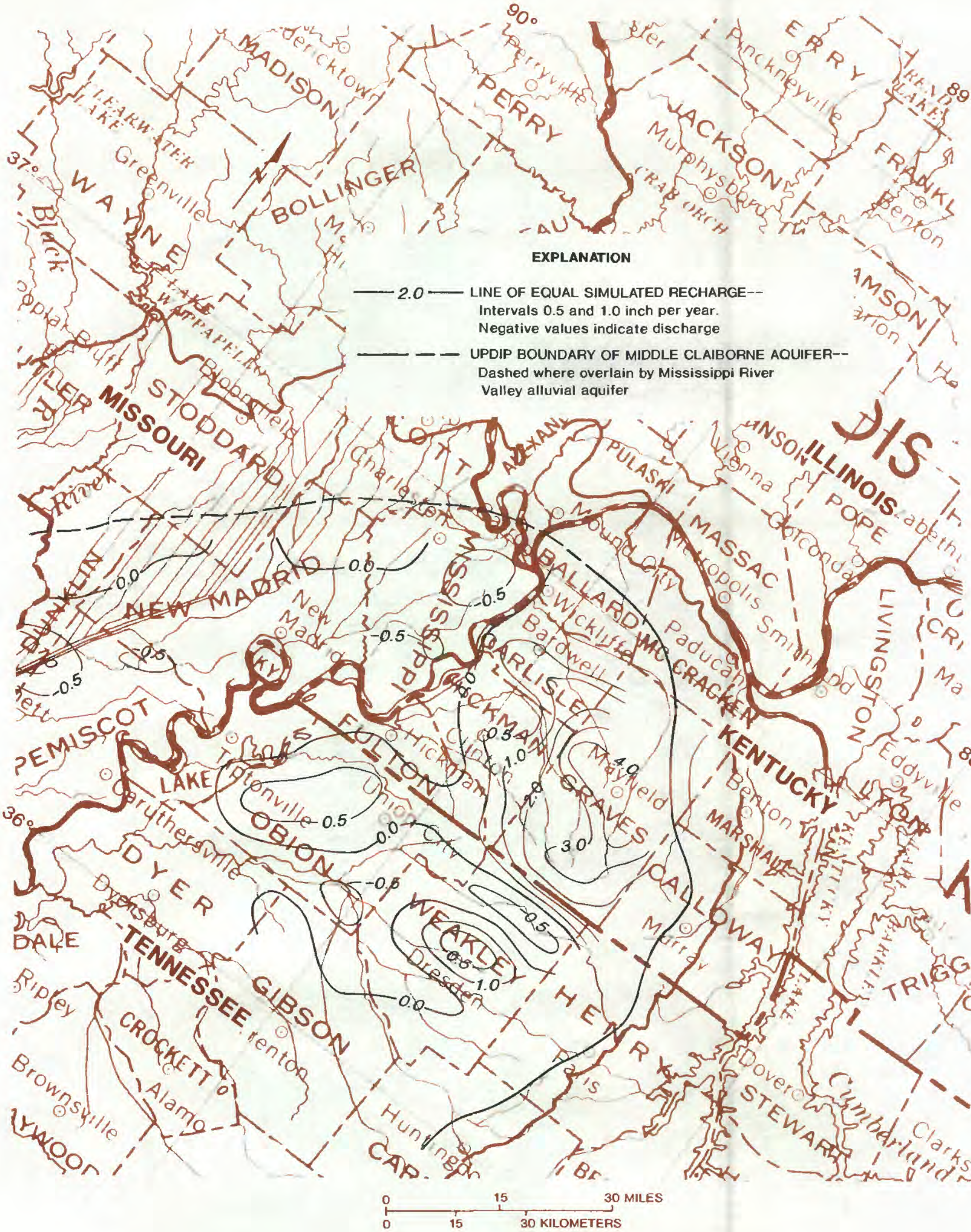


Figure 12.--Simulated recharge to aquifers of the Mississippi embayment aquifer system underlying Kentucky and parts of adjacent States, for 1985 pumpage plus an additional pumpage of 10 million gallons per day at each of three locations in Kentucky.

about twofold. The area with 4 inches per year or more of recharge would be expected to expand in an elongate band about 5 miles wide and 15 miles long across the central part of Graves County (fig. 12).

The increased pumpage would result in a reduction of outflow from Kentucky to adjacent States of about 6 million gallons per day compared to predevelopment conditions and a reduction of 8 million gallons per day compared to 1985 conditions (table 1). The reduction of outflow occurred because the pumpage in adjacent States was retained at the 1985 rate and the pumpage from the middle Claiborne aquifer in Kentucky was increased.

The potentiometric surface of the middle Claiborne aquifer would be lowered more than 25 feet around the additional pumping center near Clinton in Hickman County and Bardwell in Carlisle County, and more than 20 feet around the additional pumping center south of Mayfield in Graves County. The potentiometric surface of the middle Claiborne aquifer would be lowered more than 5 feet throughout most of the area underlain by the aquifer in Kentucky and into adjacent areas in Missouri and Tennessee (fig. 13). However, hydraulic heads would remain above the top of the middle Claiborne aquifer except in and near aquifer outcrop areas. The top of the middle Claiborne aquifer at Clinton in Hickman County is about 125 feet above sea level; the potentiometric surface would be about 320 feet above sea level. The additional pumping center south of Mayfield in Graves County is near the aquifer outcrop area where the land-surface altitude is generally about 500 feet above sea level; the potentiometric surface would be about 420 feet above sea level.

The areas of substantial drawdown are different sizes due to the location of the pumping centers relative to the principal aquifer recharge area. The pumping center near Clinton has the largest area of substantial drawdown and is the greatest distance from the aquifer recharge area (figs. 13 and 11). The pumping center south of Mayfield in Graves County has the smallest area of substantial drawdown and is closest to the aquifer recharge area. The area of drawdown greater than 25 feet is about 25 square miles near Clinton in Hickman County and about 5 square miles near Bardwell in Carlisle County. The area of drawdown greater than 20 feet south of Mayfield in Graves County is less than 5 square miles. A large part of the pumpage from the pumping center south of Mayfield in Graves County would be from increased recharge and a small part would be from the capture of water that moved to regional discharge areas under predevelopment conditions. Conversely, a relatively small part of the pumpage from the pumping center near Clinton in Hickman County would be expected to come from increased recharge and a large part from capture of water that moved to regional discharge areas under predevelopment conditions.

Lower Wilcox Aquifer

The potential to develop additional ground-water withdrawals from the lower Wilcox aquifer was investigated by simulation of 1985 pumping rates, plus an additional 10 million gallons per day at one location from the lower Wilcox aquifer, and the 30 million gallons per day additional pumpage from the middle Claiborne aquifer as noted above. The additional pumpage from the lower Wilcox aquifer was located near Clinton in Hickman County (fig. 11). Substantial changes would occur in recharge, outflow to adjacent States, and in the potentiometric surface of the lower Wilcox aquifer because of the additional pumpage.

The simulated source of water for the additional pumpage from the lower Wilcox aquifer would be about equally divided between increased recharge and reduced outflow from Kentucky to adjacent States (table 1). The recharge area would expanded only slightly and small parts of Ballard, Carlisle, Fulton, and Hickman Counties that were predevelopment discharge areas would become recharge areas. The increase in recharge area and decrease in discharge area was relatively small because the decrease in hydraulic head in the lower Wilcox aquifer extended over a large area.

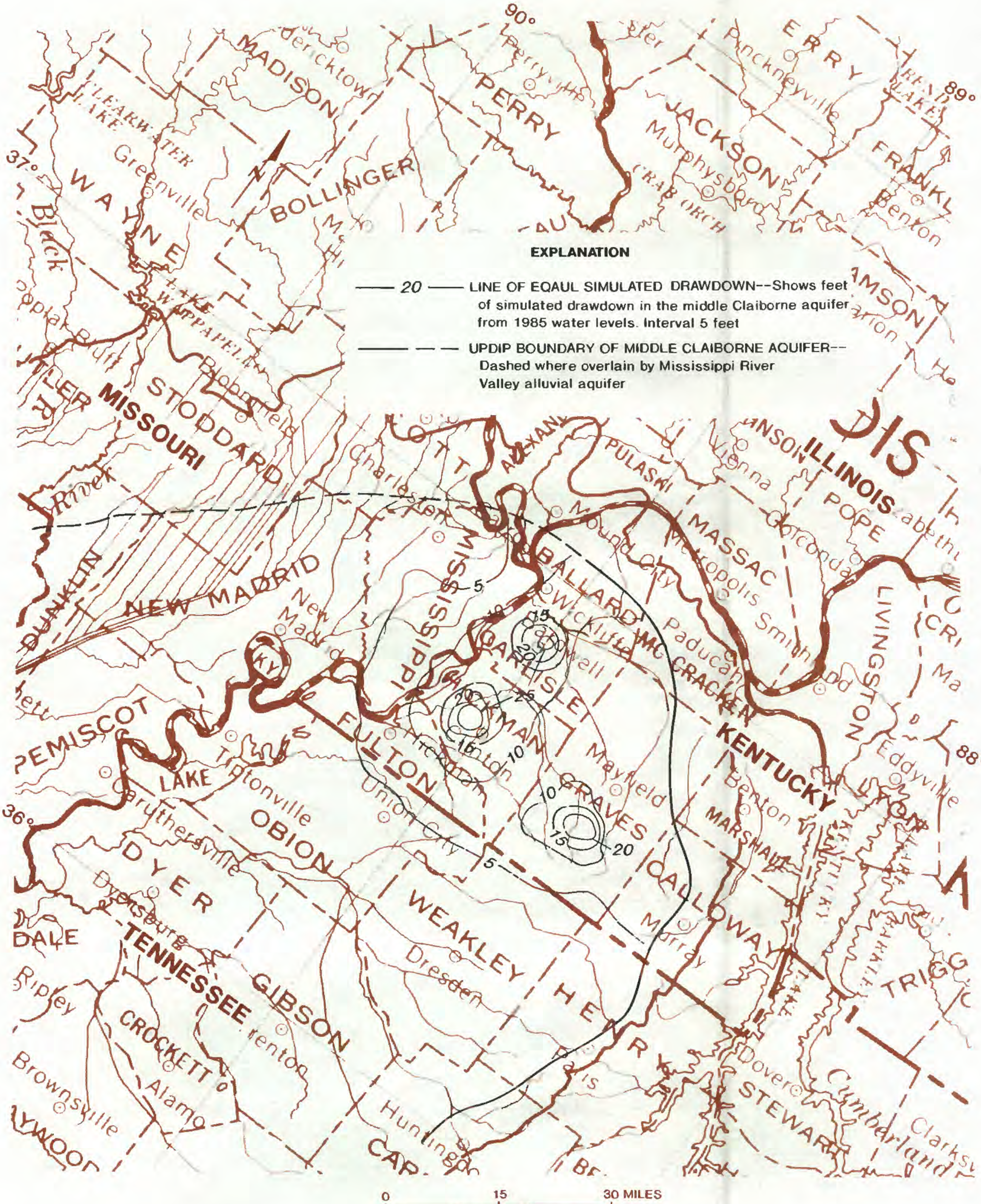
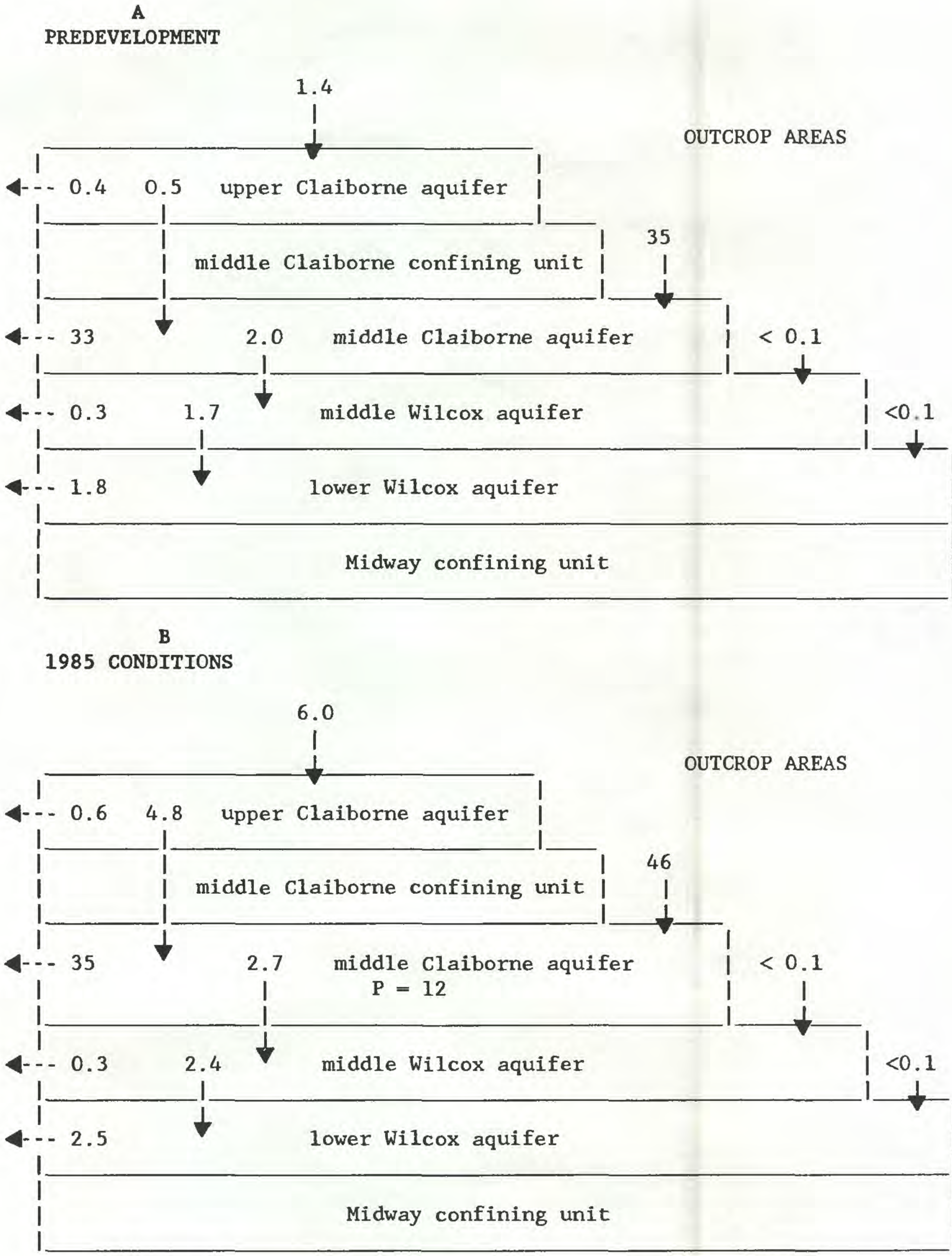


Figure 13.--Simulated drawdown from 1985 levels in the middle Claiborne aquifer in Kentucky and parts of adjacent States due to pumping 10 million gallons per day from the middle Claiborne aquifer at each of three locations in Kentucky.

The simulated reduction in ground-water outflow is a combination of a reduced outflow of about 2 million gallons per day through the lower Wilcox aquifer and about 1 million gallons per day inflow from other States through the lower Wilcox aquifer, plus about 1 million gallons per day reduction in outflow through the middle Claiborne aquifer (fig. 14). The outflow captured from the middle Claiborne aquifer would move vertically downward through the middle Wilcox aquifer to the pumping center in the lower Wilcox aquifer. Recharge would increase about 2 million gallons per day to the upper Claiborne aquifer and about 3 million gallons per day to the middle Claiborne aquifer (fig. 13). Thus, all but about 3 million gallons per day of the 10 million gallons per day pumpage from the lower Wilcox aquifer near Clinton in Hickman County would move vertically downward from the middle Claiborne aquifer through the middle Wilcox aquifer to the lower Wilcox aquifer. Recharge directly to the lower Wilcox aquifer would be essentially unchanged from predevelopment due to the large distance from the aquifer outcrop area to the pumping center.

The simulated potentiometric surface of the lower Wilcox aquifer was lowered from about 330 feet above sea level under 1985 conditions to about sea level at the center of the additional simulated pumpage near Clinton in Hickman County (fig. 15). The hydraulic head in the lower Wilcox aquifer remained well above the top of the aquifer which is about 500 feet below sea level near Clinton.

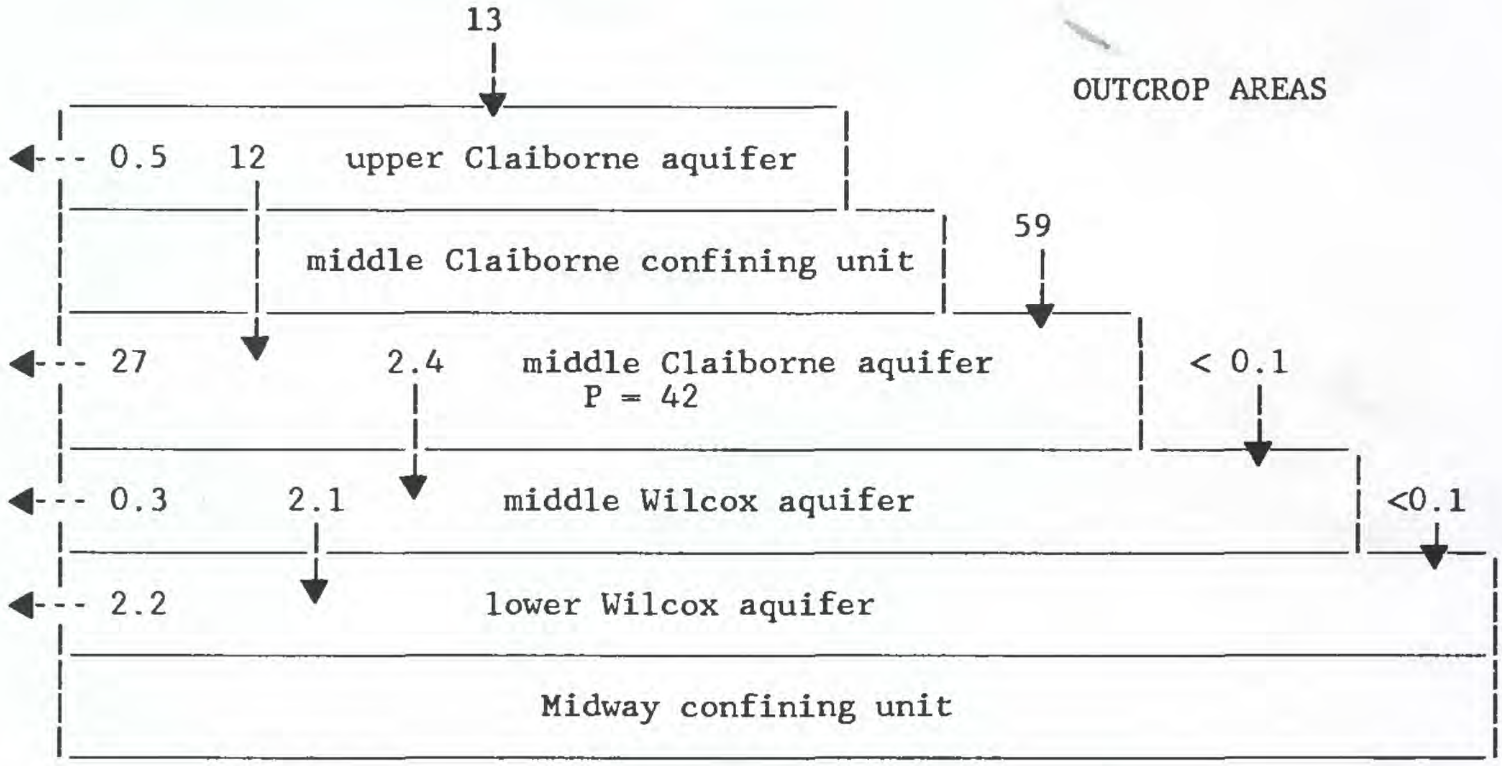
An additional simulation of 10 million gallons per day pumpage from the lower Wilcox aquifer 7 miles east of Mayfield in Graves County indicates that the aquifer cannot support pumpage of this magnitude adjacent to the aquifer outcrop. The potentiometric surface of the lower Wilcox aquifer would need to be lowered about 400 feet below the top of the aquifer before enough recharge could be induced from the middle Claiborne aquifer to equal the pumpage rate. However, the lower Wilcox aquifer is less than 100 feet thick at the location east of Mayfield in Graves County thus there is not the capacity to develop the additional 300 feet of necessary hydraulic gradient. Moreover, the outcrop band of the lower Wilcox aquifer is less than 3 miles wide, affording little opportunity to develop large regional increases in recharge directly to the aquifer. The budget for this simulation was not shown in table 1 because of the physical limitations of the aquifer noted above.



All flows in Mgal/d (million gallons per day). Storage is assumed to be negligible. Flows to and from an aquifer may not be equal because of independent rounding. About 0.5 Mgal/d flows from the upper Claiborne aquifer to the Mississippi River Valley alluvial aquifer. Pumpage (P) is negligible except from the middle Claiborne and lower Wilcox aquifers.

Figure 14.--Net recharge to aquifer outcrop areas in Kentucky, net outflow to adjacent States, and net flow between aquifers for: A, predevelopment conditions, and B, 1985 conditions.

C
10 Mgal/d AT 3 KENTUCKY
LOCATIONS FROM THE MIDDLE
CLAIBORNE AQUIFER



D
PUMPAGE AT 1985 RATES PLUS
10 Mgal/d AT 3 KENTUCKY
LOCATIONS FROM THE MIDDLE
CLAIBORNE AQUIFER PLUS 10 Mgal/d
AT 1 KENTUCKY LOCATION FROM THE
LOWER WILCOX AQUIFER

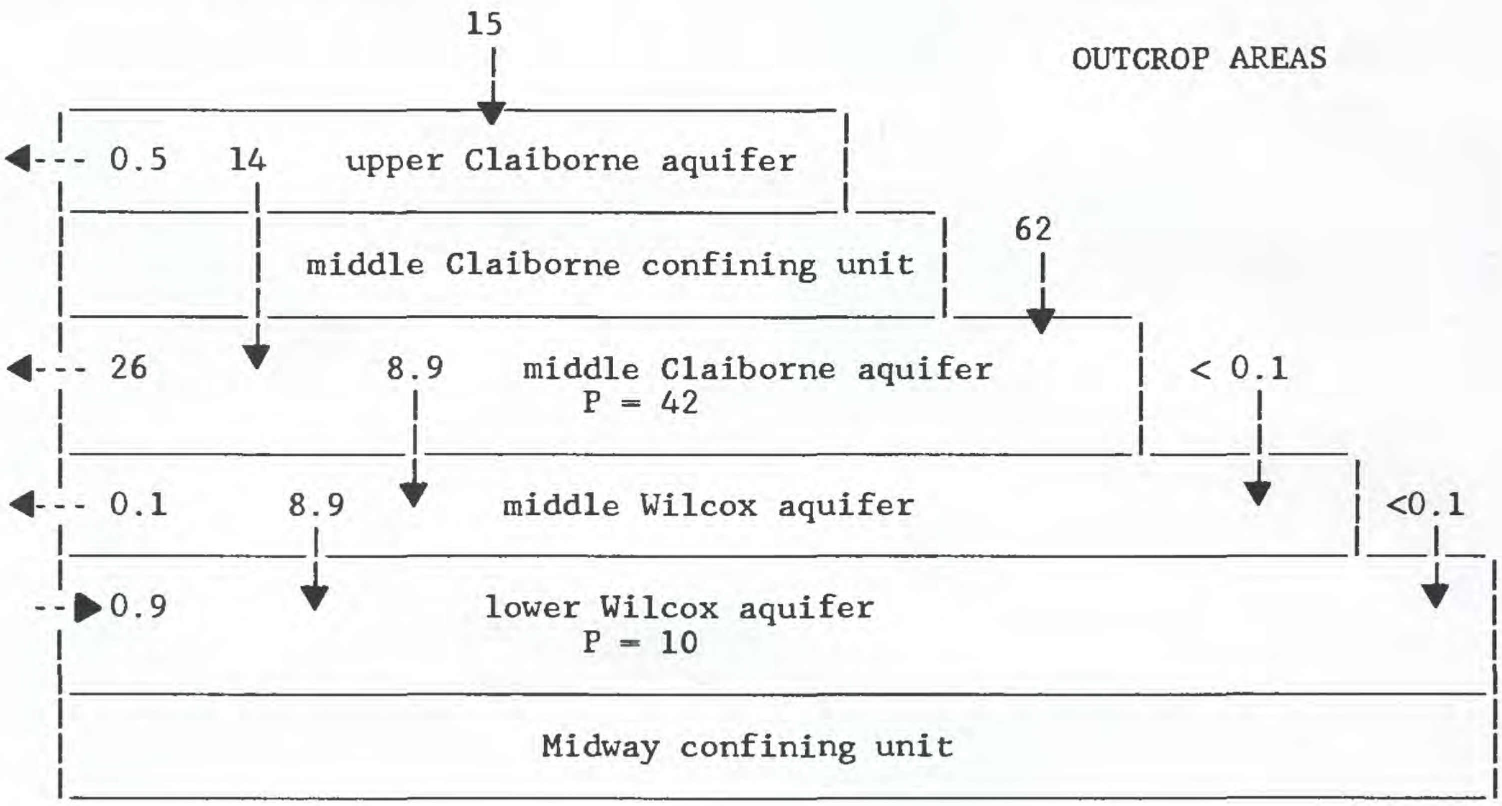


Figure 14.--Continued. Net recharge to aquifer outcrop areas in Kentucky, net outflow to adjacent States, and net flow between aquifers for: C, pumpage at 1985 rates plus 10 Mgal/d (million gallons per day) additional pumpage from the middle Claiborne aquifer at three locations in Kentucky, and D, pumpage at 1985 rates plus 30 Mgal/d additional pumpage from the middle Claiborne aquifer and 10 Mgal/d additional pumpage from the lower Wilcox aquifer at one location in Kentucky.

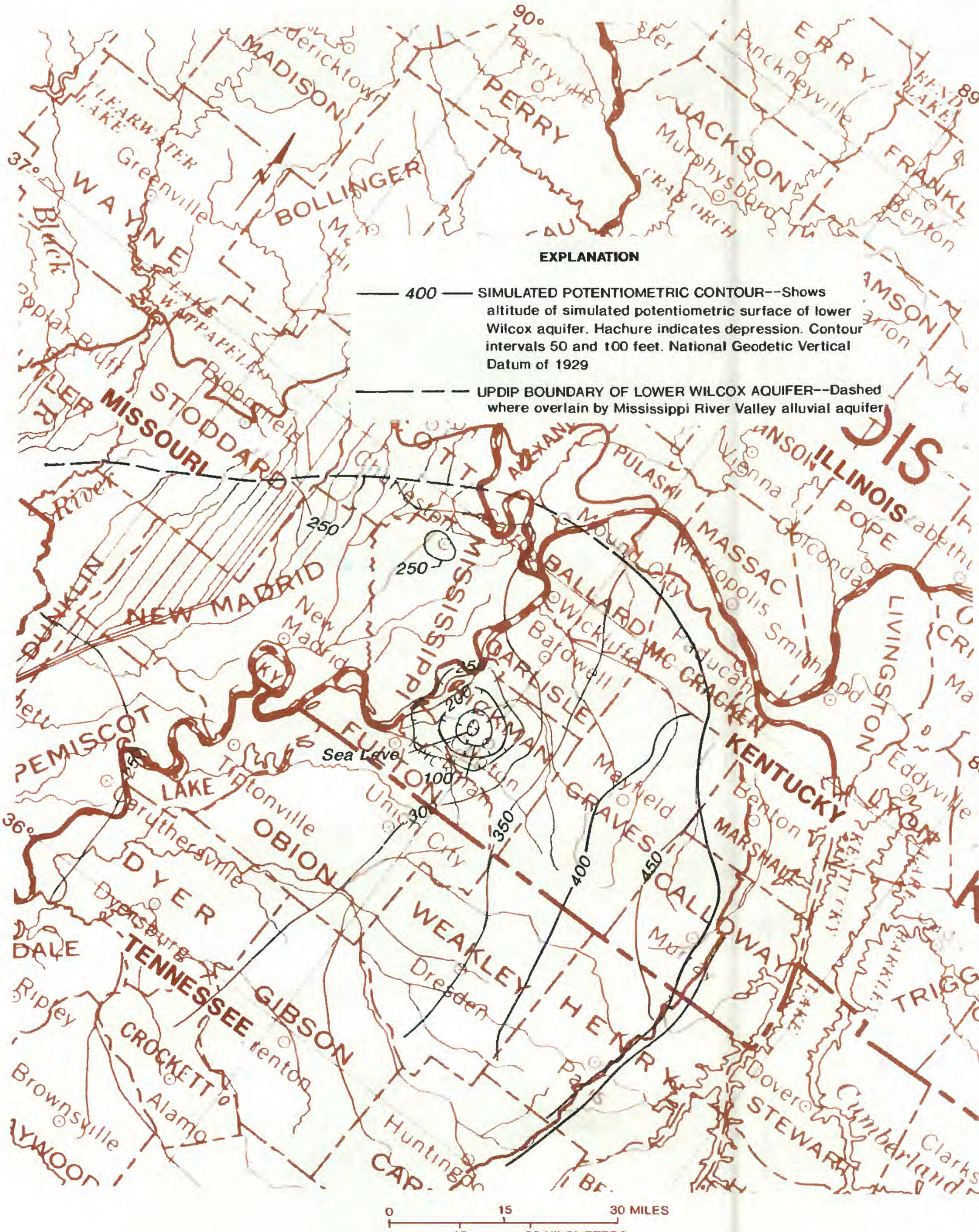


Figure 15.--Simulated potentiometric surface of the lower Wilcox aquifer in Kentucky and parts of adjacent States with 1985 pumpage plus an additional 10 million gallons per day pumpage from the lower Wilcox aquifer in Hickman County, Kentucky, and 10 million gallons per day pumpage from the middle Claiborne aquifer at each of three locations in Kentucky.

SUMMARY

About 1 percent of the area underlain by the Mississippi embayment aquifer system underlies all or parts of eight counties in western Kentucky. Much of the area underlain by the aquifer system in Kentucky is part of a regional recharge area that extends southward into Tennessee and Mississippi. Regional predevelopment recharge (prior to pumping ground-water) exceeded 2 inches per year throughout a large part of Graves County and recharge occurred in all eight counties underlain by the aquifer system.

Ground-water pumpage from aquifers of the Mississippi embayment aquifer system in Kentucky has increased by a factor of about 3, from about 4 to 12 million gallons per day, during the period 1960-85. Most of the pumpage is from the middle Claiborne aquifer. The effects of pumping in Kentucky was evaluated by simulation of ground-water flow using a model that has squares 5 miles on a side.

An increase in recharge to aquifers in Kentucky and an increase in aquifer outflow to adjacent States from predevelopment conditions has resulted from pumpage. The increase in net recharge supplied the 12 million gallons per day pumpage from aquifers in Kentucky and a small increase in outflow to adjacent States. The increase in outflow to adjacent States is due mostly to pumpage in Tennessee that induces recharge in aquifer outcrop areas located in Kentucky. The potentiometric surface of the middle Claiborne aquifer was lowered about 10 feet from predevelopment.

The aquifers of the Mississippi embayment aquifer system in Kentucky have the potential to produce much more water than was pumped during 1985. However, the individual aquifers do not have equal potential for developing additional pumpage. The potential of the aquifers for sustaining additional ground-water withdrawals are from greatest to least: the middle Claiborne aquifer, the lower Wilcox aquifer, the upper Claiborne aquifer, and the middle Wilcox aquifer.

The upper Claiborne aquifer has less potential for large additional ground-water pumpage within Kentucky than the middle Claiborne aquifer because it has about a 30 feet per day smaller hydraulic conductivity, lesser thickness, and a smaller areal extent. The middle Wilcox aquifer has the least potential for large additional ground-water pumpage in Kentucky because it has a small hydraulic conductivity (about 30 feet per day) and thin sand beds that typically are interspersed with thin clay beds.

The effects of pumping large additional quantities of water from the middle Claiborne and lower Wilcox aquifers in Kentucky would be: substantial lowering of the potentiometric surface of the aquifer pumped, lowering of the potentiometric surface of aquifers overlying the pumped aquifer, increasing the rate of recharge and expanding the size of the recharge areas compared to predevelopment, decreasing the rate of discharge and shrinking the discharge areas compared to predevelopment, and reducing aquifer outflow to adjacent States.

The effects of additional pumpage are shown by the results of ground-water flow simulation. Pumping an additional 30 million gallons per day from the middle Claiborne aquifer at three locations would increase the area having 2 inches per year or more recharge about twofold. A predevelopment discharge area of substantial size would become part of the larger recharge area. An elongate area of about 75 square miles with recharge of 4 inches per year or more would be expected to develop across the central part of Graves County. The potentiometric surface of the middle Claiborne aquifer would be lowered by more than 20 feet at the center of each of three additional pumping centers in Kentucky. The potentiometric surface would remain well above the top of the aquifer at the locations near Clinton in Hickman County and near Bardwell in Carlisle County. At the location south of Mayfield in Graves County the potentiometric surface might be as much as 80 feet below land surface.

Pumping an additional 10 million gallons per day from the lower Wilcox aquifer near Clinton in Hickman County, in addition to the 30 million gallons per day pumpage from the middle Claiborne aquifer, would have substantial effect on the potentiometric surfaces of aquifers and the vertical flow between aquifers. Such pumpage would have minimal effect on the size of recharge and discharge areas. The potentiometric surface of the lower Wilcox aquifer would be lowered about 330 feet at the pumping center, but would remain about 500 feet above the top of the aquifer. About 7 million gallons per day of the additional pumpage from the lower Wilcox aquifer would be derived from ground water moving downward through the overlying middle Wilcox aquifer from either the middle Claiborne aquifer or the upper Claiborne aquifer. About 2 of the 7 million gallons per day would move downward from increased recharge to the upper Claiborne aquifer through both the middle Claiborne aquifer and the middle Wilcox aquifer to the lower Wilcox aquifer. Another 3 of the 7 million gallons per day would move downward from increased recharge to the middle Claiborne aquifer through the middle Wilcox aquifer to the lower Wilcox aquifer. The direction of flow would be reversed in the lower Wilcox aquifer and the 2 million gallons per day of outflow to adjacent States under predevelopment conditions would be captured by the additional pumpage. In addition, about 1 million gallons per day would flow from adjacent States to the pumping center in the lower Wilcox aquifer located near Clinton in Hickman County.

REFERENCES

Ackerman, D.J., 1989, Hydrology of the Mississippi River Valley alluvial aquifer, south-central United States--a preliminary assessment of the regional flow system: U.S. Geological Survey Water-Resources Investigations Report 88-4028, 74 p.

Arthur, J.K., and Taylor, R.E., 1986, Mississippi embayment aquifer system in Mississippi--geohydrologic data compilation for flow model simulation: American Water Resources Association, Water Resources Bulletin v. 22, no. 6, p. 1021-1029.

-----1990, Definition of geohydrologic framework and preliminary simulation of ground-water flow in the Mississippi embayment aquifer system, south-central United States: U.S. Geological Survey Water-Resources Investigations Report 86-4364, 110 p.

Bennett, G.D., 1979, Regional ground-water systems analysis: U.S. Corps of Engineers, Water Support Center, Fort Belvoir, Virginia, Water Spectrum, v. 11, no. 4, p. 36-42.

Brahana, J.V., 1987, The role of a multilayer model in refining understanding of deep regional ground-water flow in a tectonically active area: National Water Well Association, Conference on Solving ground-water problems with models, Denver, Colorado, February 10-12, 1987, v. 2, p. 1051-1070.

Brahana, J.V., and Mesko, T.O., 1988, Hydrogeology and preliminary assessment of regional flow in the upper Cretaceous and adjacent aquifers, northern Mississippi embayment: U.S. Geological Survey Water-Resources Investigations Report 87-4000, 65 p.

Dickinson, George, 1953, Reservoir pressures in Gulf Coast Louisiana: American Association of Petroleum Geologists Bulletin, v. 37, p. 410-432.

Grubb, H.F., 1984, Planning report for the Gulf Coast Regional Aquifer-System Analysis in the Gulf of Mexico Coastal Plain, United States: U.S. Geological Survey Water-Resources Investigations 84-4219, 30 p.

-----1985, Gulf Coast Regional Aquifer-System Analysis--An overview, *in* Smerdon, E.T., and Jordan, W.R., eds., Issues in Groundwater Management: University of Texas at Austin, Center for Research in Water Resources, Symposium Number Twelve, p. 71-91.

-----1986, Gulf Coast Regional Aquifer-System Analysis--A Mississippi perspective: U.S. Geological Survey Water Resources Investigations 86-4162, 22 p.

-----1987, Overview of the Gulf Coast Regional Aquifer-System Analysis, *in* Vecchioli, John, and Johnson, A.I., eds. Regional Aquifer Systems of the United States, Aquifers of the Atlantic and Gulf Coastal Plain: American Water Resources Association, Monograph No. 9, p. 101-118.

Hosman, R.L., 1988, Geohydrologic framework of the Gulf Coastal Plain: U.S. Geological Survey Hydrologic Investigations Atlas 695, scale 1:2,500,000, 2 sheets.

Hosman, R.L., and Weiss, J.S., 1988, Geohydrologic units of the Mississippi embayment and Texas coastal uplands aquifer systems, south-central United States: U.S. Geological Survey Open-File Report 87-316, 29 p., 44 oversized figures.

Jones, P.H., 1969, Hydrodynamics of geopressure in the northern Gulf of Mexico basin: Journal of Petroleum Technology, v. 21, p. 803-810.

Kuiper, L.K., 1983, A numerical procedure for the solution of the steady-state variable-density groundwater flow equation: Water Resources Research, v. 19, no. 1, p. 234-240.

Kuiper, L.K., 1985, Documentation of a numerical code for the simulation of variable density ground-water flow in three dimensions: U.S. Geological Survey Water-Resources Investigations Report 84-4302, 90 p.

Martin, Angel, Jr., and Whiteman, C.D., Jr., 1989, Regional ground-water flow in the coastal lowlands aquifer system in parts of Louisiana, Mississippi, Alabama, and Florida--a preliminary analysis: U.S. Geological Survey Water-Resources Investigations Report 88-4100, 88 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations Book 6, Chapter A1, 586 p.

Mesko, T.O., Williams, T.A., Ackerman, D.J., and Williamson, A.K., 1990, Ground-water pumpage from the gulf coast aquifer systems, south-central United States: U.S. Geological Survey Water-Resources Investigations Report 89-4180, 177 p.

Pettijohn, R.A., Weiss, J.S., and Williamson, A.K., 1988, Dissolved-solids concentrations and temperature in ground water of the gulf coast aquifer systems, south-central United States: U.S. Geological Survey Water-Resources Investigations Report 88-4082, map, scale 1:3,500,000, 5 sheets.

Prudic, D.E., 1991, Estimates of hydraulic conductivity from aquifer-test analyses and specific-capacity data, gulf coast regional aquifer systems, south-central United States: U.S. Geological Survey Water-Resources Investigations Report 90-4121, 38 p.

Ryder, P.D., 1988, Hydrogeology and predevelopment flow in the Texas Gulf Coast aquifer systems: U.S. Geological Survey Water-Resources Investigations Report 87-4248, 109 p.

Sun, R.J., ed., 1986, Regional aquifer-system analysis program of the U.S. Geological Survey--Summary of projects, 1978-84: U.S. Geological Survey Circular 1002, 264 p.

Weiss, J.S., 1990, Geohydrologic units of the coastal lowlands aquifer system, south-central United States: U.S. Geological Survey Open-File Report 90-173, 34 p., 33 oversized figures.

Williamson, A.K., 1987, Preliminary simulation of ground-water flow in the gulf coast aquifer systems, south-central United States, *in*, Vecchioli, John, and Johnson, A.I., eds., Aquifers of the Atlantic and Gulf Coastal Plain: American Water Resources Association, Monograph No. 9, p. 119-137.

Williamson, A.K., Grubb, H.F., and Weiss, J.S., 1989, Ground-water flow in the gulf coast aquifer systems, south-central United States--a preliminary analysis: U.S. Geological Survey Water-Resources Investigations Report 89-4071, 125 p.

Wilson, T.A., and Hosman, R.L., 1988, Geophysical well-log database for the gulf coast aquifer systems, south-central United States: U.S. Geological Survey Open-File Report 87-677, 213 p.

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