POTENTIOMETRIC SURFACE OF THE MISSISSIPPI RIVER VALLEY ALLUVIAL AQUIFER, 1981 - 1989

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Introduction

The Mississippi River Valley alluvial aquifer is the principal source of water used for irrigation and fish culture throughout the region of Mississippi known as the "Delta." Potentiometric maps generated biannually from water levels measured in the Delta since 1981 have been used to monitor seasonal fluctuations and annual changes in the aquifer. These maps show that significant water level declines have occurred in some areas of the Delta as a result of increased levels of pumping. Because of the dependence of the Delta on an available water supply from the alluvial aquifer, a finite-difference digital model (Sumner and Wasson 1984) was developed which can be used to simulate flow in the aquifer. The model will be utilized as a tool to assist in the management of the water resources in the Delta.

Study Area

The Delta region of Mississippi is synonymous with the Mississippi River Alluvial Plain, an area of approximately 7,000 square miles located in northwestern Mississippi (Fig. 1). The Delta is distinctly separated from the rest of the state by the Bluff Hills, a topographic feature that forms the eastern and southern boundaries of the study area. On the west, the Mississippi River is the boundary of the Delta region. The virtually flat topography throughout the alluvial plain and the available water resources have resulted in large tracts of land being set aside for agricultural purposes.

Hydrologic Data

Stratigraphy and Lithology

The Mississippi River alluvium consists of Quaternary-aged sediments deposited by meandering streams on an unconformity. This erosional surface separates the alluvial sediments from older underlying Eocene strata. Outcrop areas for the Eocene formations occur along and east of the Bluff Hills that partially encompass the Delta. These older strata consist primarily of representatives of the Claiborne Group and dip to the west, passing under the Delta and the Mississippi River before partially outcropping again in Louisiana and Arkansas.

Discontinuous beds of sand, gravel, and clay compose the Mississippi River alluvium. Although the distribution and arrangement of these sediments are not exactly homogeneous, the clastics commonly are arranged in a characteristic fining-upward depositional sequence normally associated with alluvial deposits. The alluvium reaches a maximum thickness of 240 feet, but generally only 80 to 180 feet is actually sand and gravel.

The alluvium at or immediately above the unconformity typically is predominately bimodal gravel consisting of mainly cobble-sized clastics with sand comprising the secondary mode. Above the base, the rudite material gradually grades into "pea-sized" detritus. Even though it occurs in irregular lenses, the alluvial gravel appears to be thickest in the center of the Delta, where the alluvial sediments are thickest, and it gradually thins toward the periphery (Sumner and Wasson 1984).

The middle layers of the Mississippi River alluvium consist primarily of sand-sized particles. Coarse-grained sand forms the lower beds and gradually fines-upward through medium-grained and fine-grained sand. A clay layer that generally caps the alluvium averages approximately 20 feet in thickness across the Delta. The thickness of the lutite layer varies greatly with some clay "plugs" reaching thicknesses of as much as 70 feet according to Sumner and Wasson (1984).

The water-bearing beds in the alluvium form the Mississippi River Valley alluvial aquifer. It is the most extensive aquifer in the Lower Mississippi region.

Aquifer Characteristics

Irrigation and fish culture wells in the Delta are normally drilled to depths of 100 to 120 feet. These wells, commonly completed with 16 inch casing and 40 feet of screen, are capable of delivering up to 3000 gallons per minute. The numerous large-capacity wells in operation throughout the Delta are good indicators of the prolific nature of the Mississippi River alluvial aquifer.

Newcombe (1971) reported an average transmissivity value of 35,000 ft^2/d and an average hydraulic conductivity value of 320 ft/d for the alluvial aquifer. According to Sumner and Wasson (1984), the coefficient of storage for the alluvial aquifer should approximate its specific yield which commonly exceeds 0.30 (Johnson and others 1966). The highest, most desirable values associated with these aquifer characteristics generally occur in the center portion of the Delta where the aquifer is thickest.

Even though most of the Delta surface is underlain by a clay layer, the alluvial aquifer exhibits either confined or unconfined aquifer characteristics depending on the position of the potentiometric surface in the system. Partially unconfined (semi-confined) conditions occur in areas of the Delta, notably in the central part, where the potentiometric surface of the alluvial aquifer has fallen below the bottom of the clay confining layer because of heavy pumping. Sumner and Wasson (1984) report that these unconfined conditions may be in part related to the proximity of point-bar and backswamp deposits. The only true confined conditions that may occur in the alluvial aquifer are in some areas in the eastern Delta, where water levels in the alluvial aquifer are high because of the ready accessibility to recharge.

Recharge

The primary source of recharge to the alluvial aquifer is the Mississippi River. Hydrographs for wells in the aquifer show a close parallel to river stages and confirm the obvious hydraulic connection between the two units. High river stages, typically in the winter and spring months, result in increased surface water heads. The head differential between the river at high stage and the aquifer with its lower heads results in recharge to the aquifer system. Although the potentiometric surface in the alluvial aquifer declines as it furnishes baseflow to the river during periods of low-flow, normal head relations result in an overall recharging of the aquifer. Sumner and Wasson (1984) estimated that the recharge from the Mississippi River averaged 47.8% of the total annual recharge received by the alluvial aquifer between April 1981 and April 1983.

Some vertical recharge of the alluvial aquifer occurs during the 52 inches of average annual precipitation that the Delta region receives. Because the alluvial aquifer is generally overlain by surficial clay averaging about 20 feet in thickness, Sumner and Wasson (1984) calculated that there is only about 0.5 inches per year of areal recharge due to precipitation. This seemingly small amount of recharge spread over the 7,000 square mile Delta region, however, accounts for 21.7% of the total recharge to the alluvial aquifer (Sumner and Wasson 1984).

A notable amount of the alluvial recharge occurs along the eastern edge of the Delta where the Mississippi River alluvial deposits abut the Eocene strata that underlie the Bluff Hills, creating a very complex hydro-geologic arrangement. In this region, the surficial clay typical of most areas of the Delta is discontinuous. An abundance of sandy deposits and alluvial fans on and near the surface suggest that precipitation and leakage from streams crossing this area contribute significantly to recharge of the alluvial aquifer. The relation of the aquifer with the underlying and interfingering Eocene aquifers (the Cockfield and Sparta systems) provides hydraulic connection and alluvial recharge. Sumner and Wasson (1984) estimated the recharge in this complex region at 20.6% of the total recharge between April 1981 and April 1983.

The remaining 9.9% of the recharge to the alluvial aquifer is associated with stream leakage throughout the Delta (Sumner and Wasson 1984). This factor involves several streams, including the Yazoo-Tallahatchie-Coldwater River system, the Sunflower River, and the Bogue Phalia, as well as various large oxbow lakes that are assumed to be hydraulically connected to the aquifer. The actual amount of recharge the aquifer receives from the Sunflower River and Bogue Phalia appears to be steadily declining due to diminishing flow regimes in these streams.

Water Use

The number of acres being irrigated and devoted to catfish ponds in the Delta increased every year during the 1980's. Unfortunately, the delta streams that once provided a plentiful source of water for primarily rice irrigation are not dependable because of dwindling stream flows. Most of the irrigation water and all of the water used for fish culture is pumped from wells screened in the alluvial aquifer. In 1975, the estimated volume of water withdrawn from the alluvial aquifer was only 745 million gallons per year, but by 1985 this pumpage had increased to an estimated 1,600 million gallons per year.

According to a 1988 water use survey conducted by Dean Pennington with the Delta Branch Experiment Station, rice farming is the largest consumer of water in the Delta. Approximately 45% of all the agricultural water used in the region during 1988 was pumped to flood rice fields. Catfish farming and soybean irrigation each accounted for over 20% of the total volume pumped in 1988. About 9% of the total was applied to Delta cotton crops.

Potentiometric Maps

Static Water Levels

The U. S. Geological Survey began monitoring water levels in the alluvial aquifer in the early 1950's using some of the first irrigation wells drilled in the Delta. These records are sporadic until 1981 when the Bureau of Land and Water Resources began taking biannual measurements in the aquifer. Typically, static water levels measured in the late spring of each year have reflected non-stressed conditions in the alluvial aquifer, after the aquifer has been recharged throughout the winter and spring months of heavy rain and corresponding high stream levels. Fall water levels have been lower than in the spring reflecting the stressed conditions in the aquifer after pumping for irrigation during the growing season.

Fall 1981

A potentiometric map of the alluvial aquifer using the static water level measurements collected during the fall of 1981 (Fig. 2) indicates the basically non-stressed condition in the aquifer before the escalation of pumping throughout the 1980's. The overall potentiometric surface exhibited on the map generally parallels the regional ground-surface altitude which is higher in the northern part of the Delta and gradually decreases to the south.

Although 1981 was an extremely dry year, only a few small cones of depression roughly aligned in a north-south line along the center axis of the Delta are recognizable on the 1981 potentiometric map. These cones reflect relatively poor recharge in the center of the alluvial aquifer as a result of the large distances between this portion of the Delta and the main areas of recharge. Toward the eastern edge of the Delta, the east-west equipotential lines normally exhibited on the potentiometric map of 1981 change to generally parallel the Bluff Hills line. This relationship clearly demonstrates the recharge effect on the aquifer system that occurs along the bluffs.

Fall 1988

Drought conditions were prevalent across much of the Southeastern United States throughout 1988. The lack of soil moisture in the Delta during the spring planting season necessitated fields being "flushed" several times in some instances to insure seed germination. As the growing season progressed, many new irrigation wells were required in certain areas due to the lack of available surface water in some Delta streams that had been used for irrigation sources in the past. These drought conditions and the extra irrigation that was required placed a tremendous stress on the alluvial aquifer as the volume of groundwater pumped from the system reached a record approximately 2,000 million gallons per day. The situation was further aggravated because of the extremely low flows on the Mississippi River, the major source of recharge for the aquifer system.

Measurements made during the fall of 1988 generally indicated significant water level declines in the alluvial aquifer across the Delta, especially in the middle of the region. A potentiometric surface map of 1988 (Fig. 3) displays several moderately-sized cones of depression along the center portion of the Delta. The 1988 map appears very similar to the potentiometric map of 1981 when the periphery of the Delta is compared. However, upon closer examination, the equipotential lines displayed on the 1988 map expanded dramatically outward from the center to signify serious water level declines in this region.

Fall 1981 to Fall 1988

To compare the changes in water levels that occurred in the alluvial aquifer between the fall of 1981 and the fall of 1988, the differences between the two potentiometric surfaces was mapped. The resulting water level difference map (Fig. 4) illustrates the regional trends in water levels across the Delta.

Between 1981 and 1988, water levels were generally up in the alluvial aquifer along the eastern edge of the Delta. In some cases, rises of over 10 feet occurred in this area, but water level increases were typically between 0 and 4 feet. This trend was a reflection of substantial recharge to the aquifer along the Bluff Hill line. Apparently, the aquifer was able to draw water very effectively from the Eocene aquifer systems and from the overlying streams crossing this area of the Delta as it compensated for stressed conditions during the drought of 1988.

Water level differences between 1981 and 1988 were quite variable along the Mississippi River. Major increases in water levels of over 10 feet generally were indicated in the northern and southern areas of the Delta located next to the river; however, in the west-central portion of the Delta, particularly large parts of Bolivar, Coahoma, and Washington Counties, appreciable declines in water levels occurred between 1981 and 1988. These declines were probably related to large rice allotments in this area of the Delta and to decreased flows on some Delta streams and the Mississippi River.

The most conspicuous features on the water level difference map are the areas of decline encompassing large portions of the Delta along its center axis. A notable portion of central Humphreys County with its abundance of catfish ponds is depicted on the map as being underlain by a major area of decline. However, the largest water level declines throughout the Delta region between 1981 and 1988 were noted in Sunflower County. The central Sunflower County area appears to be surrounded by a vast area of decline that almost connects with another significant depression in northern Sunflower County. Water level declines in excess of 18 feet or approximately 2 feet per year are indicated in the very center of the large area of decline.

Fall 1981 to Fall 1989

Exceptionally wet conditions in 1989 delayed the spring planting in the Delta and prevailed throughout most of the summer. The above average rates of precipitation in the region resulted in minimal withdrawals of groundwater for irrigation purposes. This allowed water levels to recover dramatically from the stressful year that resulted from the severe drought conditions in 1988. Fall measurements of water levels in 1989 were mostly higher than those from the preceding spring. Significant recharge to the aquifer system from the peripheral areas of the Delta occurred throughout all of 1989, including the irrigation season.

When water level difference maps for 1981 to 1988 (Fig. 4) and 1981 to 1989 (Fig. 5) are compared, some dramatic differences are readily apparent. According to the 1981 to 1988 map, a majority of the Delta region showed overall water level declines during that seven year interval. However, because of the substantial water level increases measured in the fall of 1989 in most areas of the Delta, the water level difference map for 1981 to 1989 depicts an overall increase in water levels throughout most regions during the eight year period.

Even with decreased rates of pumping from the alluvial aquifer in 1989, the center of the Delta still displayed dramatic water level declines between 1981 and 1989. Most of Bolivar County experienced static water declines of between 2 and 4 feet during this interval. The areas of decline which cover large sections of central Humphreys and Sunflower Counties decreased in size aerially during 1989 as water levels generally rose between 2 and 4 feet in the affected areas.

Year 2003

In 1984, the U. S. Geological Survey in cooperation with the Mississippi Department of Environmental Quality's Bureau of Land and Water Resources developed a finite-difference model of the alluvial aquifer system (Sumner and Wasson 1984). The purpose of this investigation was to simulate flow in the aquifer, so that the effects of additional pumping on the system could be predicted. Several pumping scenarios were developed for the model to reflect the effect of various amounts of irrigation in the Delta.

The simulated potentiometric map of the alluvial aquifer for 2003 (Fig. 6) is based on a withdrawal rate of 1,900 million gallons of water per day from the alluvial aquifer between the years of 1983 and 2003. This "worst case" scenario of the possible choices devised by Sumner and Wasson (1984) was compared to the 1981 potentiometric map (Fig. 2), since the volume of groundwater pumped from the alluvial aquifer was estimated at about 1,600 million gallons per day in 1985 and probably was near 2,000 million gallons per day in 1988. Under these stressful pumping conditions, most of the region would undergo tremendous water level declines and, according to the model, an enormous cone of depression would engulf the central Delta. Only the northern Delta counties and those areas that are proximate to recharge along the periphery would escape substantial declines; however, even in these less affected areas, equipotential lines are projected to shift outward signifying appreciable water level declines in those areas.

Under this pumping scenario, the aquifer would be the most severely affected in the center of the Delta. Three large cones of depression indicated on the potentiometric map of 2003 would collectively form a U-shaped trough comprising a significant part of the Delta. One of these cones would underlie most of Humphreys County and include substantial parts of southeast Washington County and northeast Sharkey County. According to the model, water levels portrayed in this region would suffer declines between 30 and 80 feet when compared to 1981.

Another large cone of depression is predicted in central Sunflower County and western Leflore County.

A considerable part of this region would show decreases of at least 40 feet in the alluvial aquifer, and declines of up to 100 feet may occur in the very center of this cone according to the potentiometric map of 2003. The third significant area of decline is projected in west-central Bolivar County. Even though this area is located in very close proximity to the Mississippi River, the potentiometric surface would show decreases of up to 90 feet between 1983 and 2003.

Summary And Conclusions

Water levels in the Mississippi River Valley alluvial aquifer have fluctuated dramatically during the last eight years in response to the variation in precipitation that has occurred in north Mississippi, the stages of the Mississippi River, and the volume of water being pumped from the aquifer for irrigation and fish culture purposes. The aquifer was severely taxed during the drought of 1988 when a predicted record volume of groundwater, 2,000 million gallons per day, was withdrawn. Although water levels showed significant increases during 1989, including throughout the usually stressful irrigation season, the trend for water levels across most of the Delta is one of steady decline.

The center of the Delta has shown the largest rates of decline in the aquifer; especially susceptible to declines are parts of Humphreys County and central Sunflower County. Pronounced cones of depression underlying these counties are on the verge of merging which will create a substantial north-south trough of depression encompassing most of the two counties. The recent construction of numerous catfish ponds in southern Sunflower County will accelerate the development of this trough feature.

A computer model map projecting the potentiometric surface of the alluvial aquifer in 2003 using a pumping rate of 1,900 million gallons per day indicates tremendous water level declines across the Delta (Sumner and Wasson 1984). The water levels measured in the region have not approached these predicted declines at present; however, it is alarming that over 1,900 million gallons of water per day, a volume thought almost unattainable by agricultural experts in 1984, was pumped from the aquifer during 1988. In order for the Bureau of Land and Water Resources to use the computer model as a tool to assure the proper management of the aquifer, it is imperative that the model be constantly updated and revised so that reliable water levels can be projected.

As critical as the alluvial aquifer is to the Delta economy, relatively little is actually known about the hydrology of the aquifer system. Only a few pumping tests have been conducted on the aquifer, so more data concerning such aquifer characteristics as transmissivity and hydraulic conductivity are needed. The areal extent and thickness of the surficial clay layer overlying the alluvial aquifer must be better described in order to better define vertical recharge and stream leakage in the Delta. Grain-size analysis of the alluvial sediments must be conducted to determine its basic lithology and to comprehend the discontinuous nature of its strata. Such investigations will identify more precisely the physical properties and hydrology of the alluvial aquifer and allow for a better understanding of this complex and important system.

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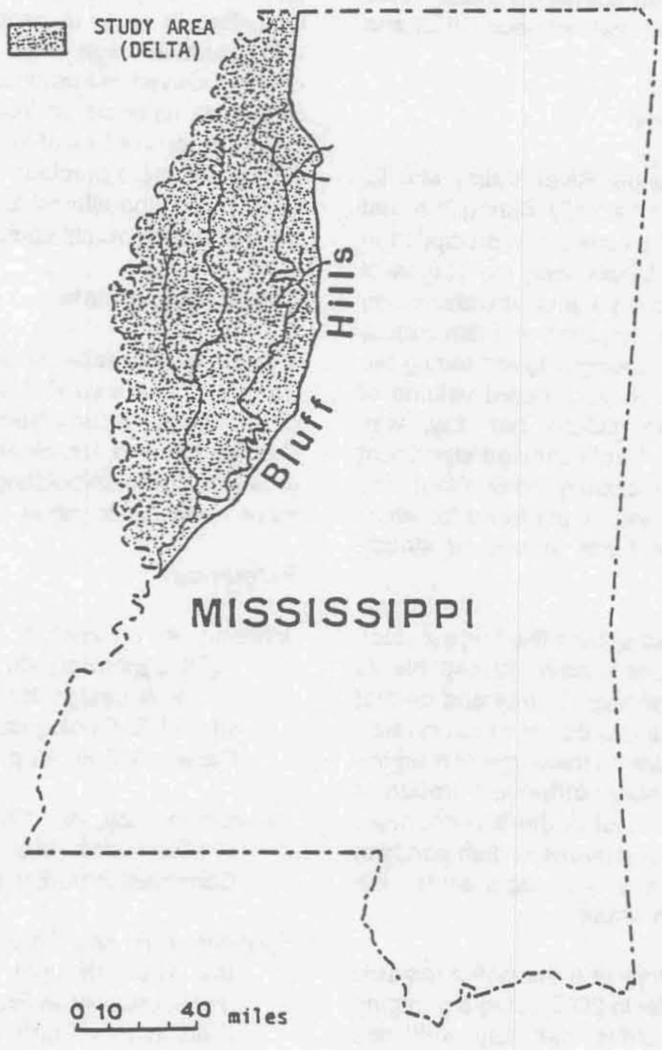

Figure 1. Location of study area
(Delta) in northwestern Mississippi
(after Spencer and Ehret, 1987).

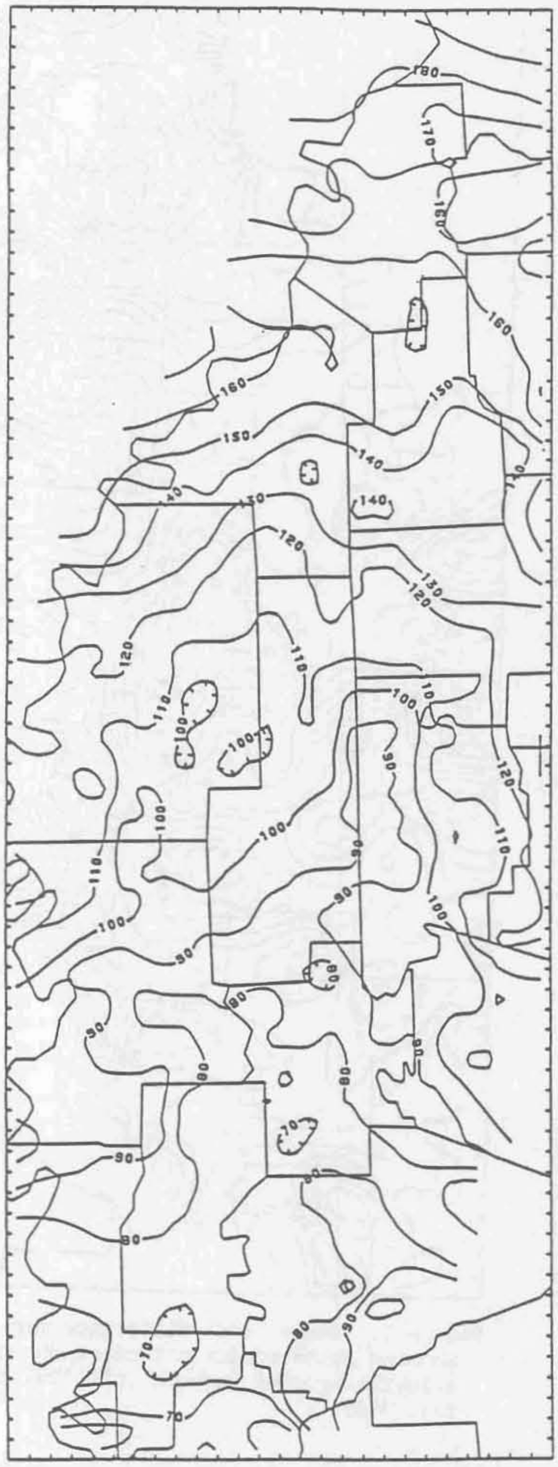

Figure 2. Computer-generated potentiometric map of alluvial aquifer, fall 1981.

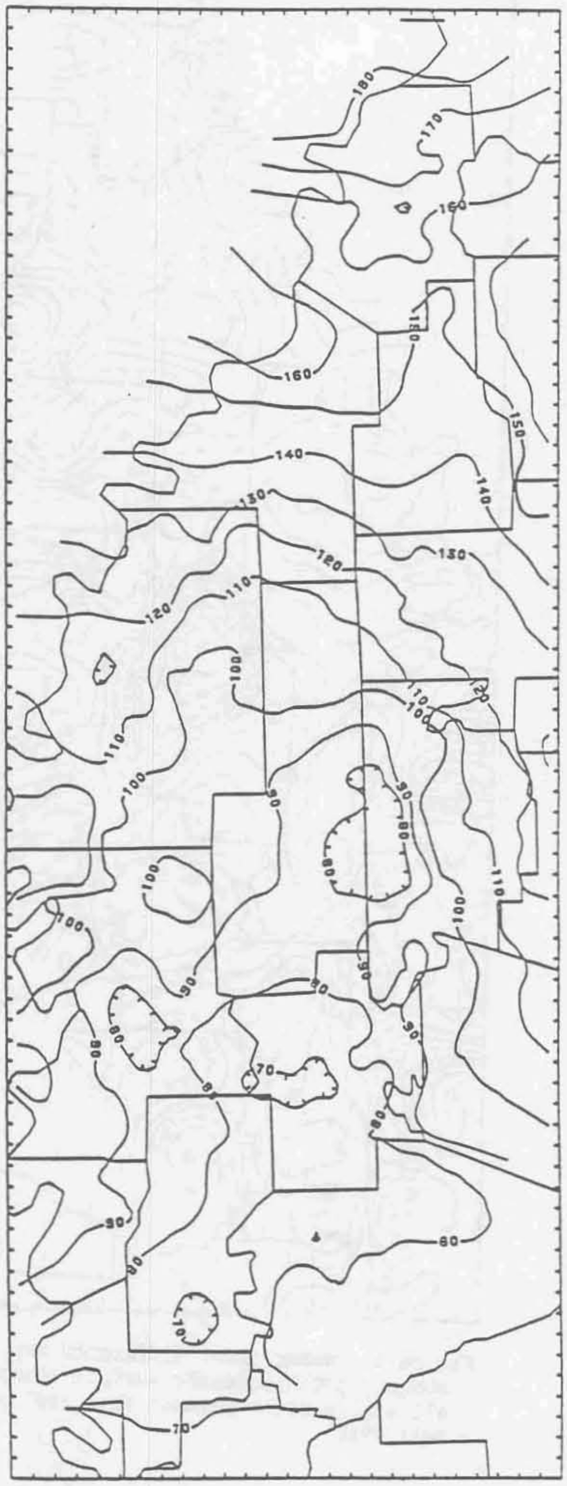

Figure 3. Computer-generated potentiometric map of alluvial aquifer, fall 1988.

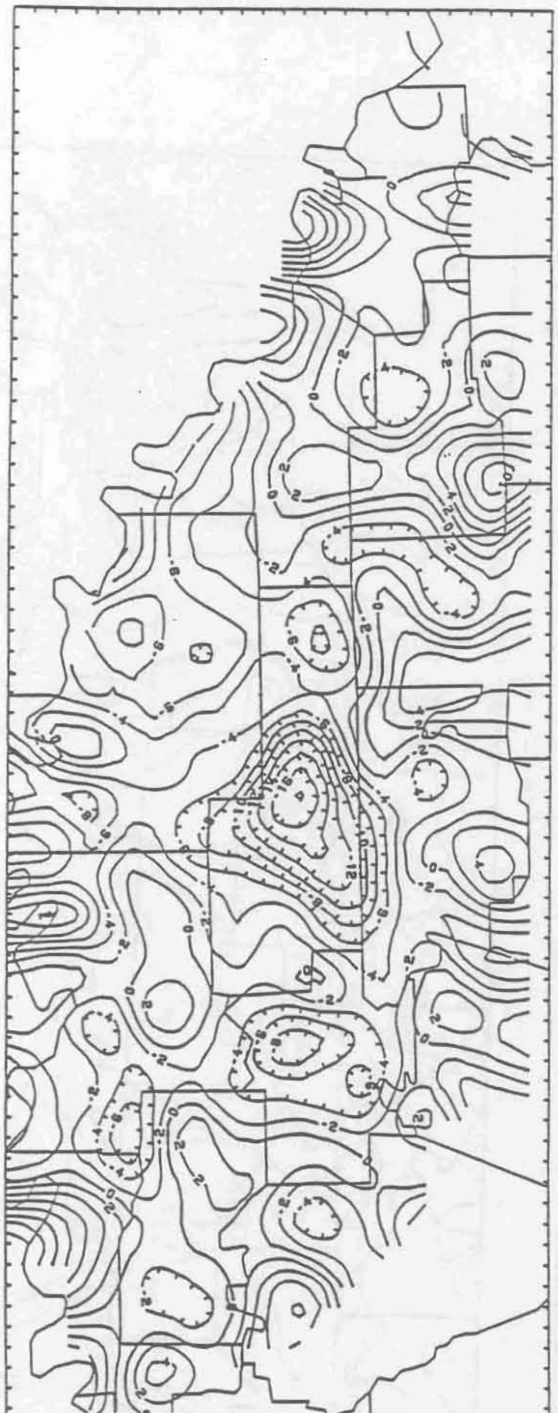

Figure 4. Water level difference map showing potentiometric surface changes in alluvial aquifer between fall 1981 and fall 1988.

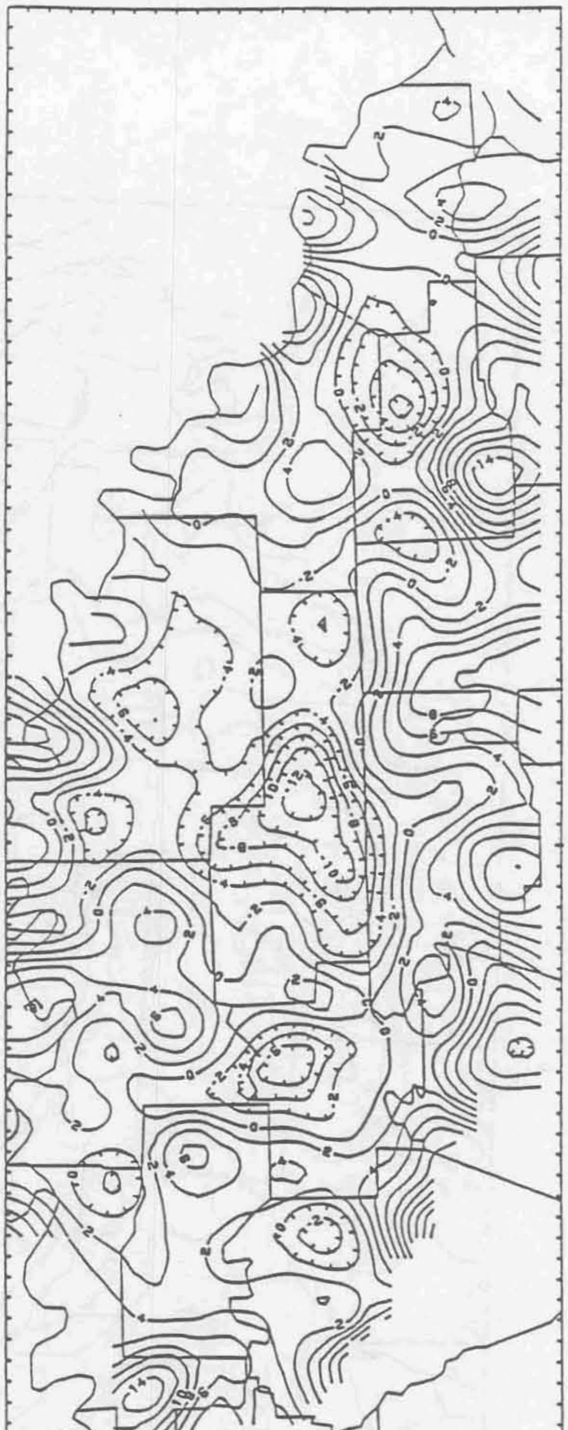

Figure 5. Water level difference map showing potentiometric surface changes in alluvial aquifer between fall 1981 and fall 1989.

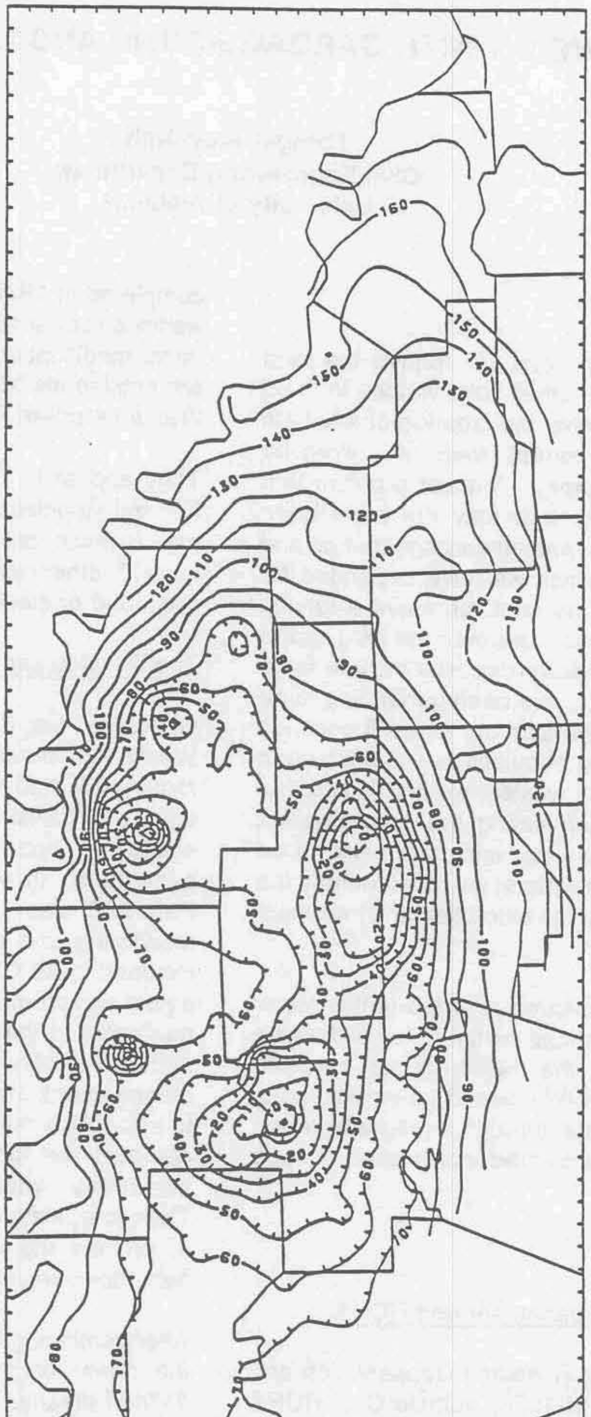

Figure 6. Simulated potentiometric map of alluvial aquifer for 2003 assuming pumpage at 1,900 mgd (Sumner and Wasson, 1984).