# APPLICATION OF A LAYERED GROUNDWATER MODEL TO CRITICAL AREAS IN NORTHEAST MISSISSIPPI

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## INTRODUCTION

During the past two decades the field of groundwater hydrology has turned toward numerical simulation models to help evaluate the safe yield expected from groundwater resources. Solutions to the equations of flow by finite difference and finite element methods have permitted the modeling of complex, real world systems. Numerical simulations have enabled hydrologists to develop a better understanding of the functioning of regional aquifers and to test various hypotheses concerning the behavior of aquifers under various stress situations due to pumpage. The simulation method has provided a framework for conceptualizing and evaluating aquifer systems. Models have thus become the tools to evaluate the impacts of sustained groundwater withdrawals.

The present study is an attempt to upgrade the mathematical and conceptual quality of a previous model of the Eutaw-McShan aquifer developed as part of earlier work by Zitta, Frnka and Pang (1984) and Pang (1985). The previous model used a single layer, one- dimensional representation developed by Trescott, Pinder and Larson (1976). This present effort uses a modular three-dimensional model by McDonald and Harbaugh (Released 1985). The previous conceptionalization of the aquifer was with a 10 mile by 10 mile square grid. This effort uses a 2.5 by 2.5 mile square grid. The previous calibration period was from 1929 to 1978 whereas this effort is a calibration from 1978 to 1982.

Geological logs and recent pumping records were obtained to refine the physical constants and to establish the reliability of the pumping data. Calibration is a continuing process as new data are accumulated and assessed. The final proof of the validity of the aquifer constants will be the accuracy of predictions based on model results as compared to actual data gathered by future generations of hydro-geologists.

The objective of this study was the upgrading of a model of the Eutaw-McShan aquifer to simulate accurately the piezometric heads for the calibration period from 1978 to 1982. Emphasis was on the major pumping areas around West Point, Tupelo and Aberdeen-Amory.

Recently McDonald and Harbaugh (Released 1985) have released a modular three-dimensional groundwater model that has as its objectives to produce "a program that can be readily modified, is simple to use and maintain, can be executed on a variety of computers with minimal changes, and is relatively efficient with respect to computer memory and execution time". The program uses a modular programming structure so that each option is independent of the other. Major options presently available include well pumping, recharge from land surface or rivers, drains from the aquifer, evapotranspiration and boundary effects. Solution algorithms include the strongly implicit procedure (SIP) and the slice successive overrelaxation method (SSOR).

To place the application of mathematical models to real aquifer systems in perspective, Kernodle (1981) described a digital groundwater flow model as a composite of three elements. One element is a computer program for solving the complex equations of flow by some numerical technique. The program tends to be general, not particularly applicable to any given hydrologic situation. The second element of a model is the hydrologist's concept of the groundwater flow system within the region of application. This concept is stated as a series of assumptions on the area of recharge and discharge, path of the groundwater movement, the hydrologic connection between the rivers and the aquifer and the hydrologic connection between the adjoining geologic formations. The third element is the data required to describe the aquifer geometry, the hydraulic properties of the aquifers and confining beds, historical water levels, and groundwater pumping rates. These data are either field collected at site- specific points where test, observation and pumping wells are located or obtained from files of local governments, local industry or from state and federal data collection agencies.

## THE MATHEMATICAL MODEL

### Equation of Flow

There are two types of aquifers, water table (unconfined) and artesian (confined). Most aquifer systems including the Eutaw-McShan contain a combination of both. The groundwater model applied in this study is described by McDonald and Harbaugh (Released 1985) and is applicapable to both confined and unconfined aquifers. The material that follows is abstracted from their report and the reader is referred to their manuscript for a more complete description.

The three-dimensional movement of groundwater of constant density in porous media is described by the partial differential equation

$$\frac{\delta}{\delta x}(Kxx\frac{\delta h}{\delta x}) + \frac{\delta}{\delta y}(Kyy\frac{\delta h}{\delta y}) + \frac{\delta}{\delta z}(Kzz\frac{\delta h}{\delta z}) = Ss\,(\frac{\delta h}{\delta t}) + W \qquad (1.1)$$

where Kxx, Kyy, and Kzz are the principal components of the hydraulic conductivity tensor ($Lt^{-1}$) aligned along the x,y,z cartesian coordinate axes, h is the potentiometric head (L), t is time ($t^{-1}$), Ss is the specific storage of the aquifer ($Lt^{-1}$), and W is the volumetric flux rate per unit volume ($t^{-1}$) and represents sources and/or sinks. In general, Ss, Kxx, Kyy, and Kzz, are functions of space (x,y,z) and h and W are functions of space and time (x,y,z,t). The head, h, is defined from NGVD datum. The source and sink terms W may consist of seepage through streambeds, drains, areal recharge evapotranspiration and well pumpage.

Equation 1 when written in finite difference form for n cells in the entire flow domain will yield n equations in n unknowns. Since there is one unknown per cell, the system of simultaneous equations must be solved for head in each cell at time m. This requires that the head at time $t^{-1}$ be known for all cells or is commonly designated as an initial condition. For the cells on the boundary, heads must be specified for all time as the finite-difference operator does not occupy these boundary cells.

In most cases, the number of equations will be less than the number of cells in the model. The number of equations is equal to the number of active or "variable head cells" which vary with time. Cells that are not variable head cells will be either constant head or no-flow. Constant head cells do not vary with time. A choice of two numerical solution techniques is provided in the model. They are: 1) the strongly implicit procedure (SIP) and 2) the slice-successive overrelaxation procedure (SSOR). Each method is most efficient under particular types of simulation. The SIP was used exclusively in this study without observed convergence difficulties.

## MODEL CALIBRATION

### General

The mathematical model written by McDonald and Harbaugh (Released 1985) was calibrated to the Eutaw-McShan aquifer for the period 1978 to 1982 using a 2.5 mile square grid. Geological logs and pumping data were obtained and analyzed to refine the data input to the degree possible. The result is a working model of the aquifer that can be used with judgment and confidence in a predictive mode.

### Aquifer Description

The Eutaw-McShan aquifer is the geologic strata of the Upper Cretaceous series which occurs between the Selma Group and the Tuscaloosa Group. The base of the aquifer slopes generally to the southwest at a rate of approximately 30 ft/mi. The aquifer outcrops in the eastern portion of the state generally in the area between the Tombigbee River and the Alabama line. The thickness of the aquifer increases from northeast to southwest. The aquifer is some 100 feet thick in the north to over 400 feet thick in the southwest part of the study area (Boswell; 1977, 1978).

Lithologically the entire aquifer is composed of fine to medium glauconitic sand interbedded with shale and clay (Wasson, 1980b). The upper part of the aquifer is the Tombigbee sand member of the Eutaw formation and commonly a massive glauconitic sand. Sand in the lower part of the formation is less glauconitic and more permeable than sand in the upper part. The basal portion of the Eutaw-McShan, sometimes referred to as the McShan, consists of many layers of sand and clay. The thickness of the water-bearing formations varies widely within the aquifer system.

The Mooreville chalk overlays the aquifer, serving as an impermeable confining layer in the region west of the Tombigbee River. Generally east of the Tombigbee, the Eutaw-McShan is unconfined with the river serving as the approximate dividing line between the confined and unconfined regions.

Geologically the aquifer does not change drastically. Thick water bearing beds are rare, and the screened portions of large wells include numerous clay lenses. General thinning of the aquifer occurs in the north and northeast portions of the study area.

Sections through the aquifer for which electric logs were obtained are shown in Figure 1. In this study, six geological cross sections were developed to more accurately define the aquifer. Four of the six cross sections run from east to west, while the other two run from north to south. Table 1 shows the well log numbers of the east-west cross-sections in the same order as they are appeared in Figure 1. Shown also are the well log numbers of the north-south cross sections in the same order as they appeared in Figure 1.

**Table 1. Data for Geological Sections Through Eutaw-McShan Aquifer**

| Cross Section (E to W.) | County | Well Log No. (E. to W.) | Aquifer Elevation Bottom (feet) | Aquifer Elevation Top (feet) |
|---|---|---|---|---|
| A - A' | Itawamba | 55 | 220 | GL |
| | | 9 | 80 | GL |
| | Lee | 54 | -200 | 30 |
| | Pontotoc | 24 | -690 | -500 |
| | | 19 | -1180 | -900 |
| B - B' | Monroe | 52 | 135 | GL |
| | | 120 | 170 | GL |
| | | 123 | -80 | 400 |
| | | 23 | -230 | 40 |
| | Chickasaw | 38 | -760 | -460 |
| C - C' | Lowndes | 6 | -200 | 400 |
| | Clay | 27 | -320 | 50 |
| | | 52 | -550 | -150 |
| | | 9 | -980 | -600 |
| | Webster | 17 | -1300 | -700 |
| | | 9 | -1560 | -1200 |
| D - D' | Lowndes | 54 | -110 | 400 |
| | Oktibbeha | 25 | -740 | -350 |
| | | 68 | -1120 | -700 |
| **Cross Section (N to S.)** | **County** | **Well Log No. (N to S.)** | **Aquifer Elevation Bottom (feet)** | **Aquifer Elevation Top (feet)** |
| E - E' | Lee | 45 | -200 | 0 |
| | | 129 | -180 | 50 |
| | | 118 | -200 | 40 |
| | | 19 | -200 | 30 |
| | Monroe | 38 | -100 | 190 |
| | Chickasaw | 56 | -300 | -25 |
| | Monroe | 64 | -225 | 80 |
| | | 58 | -275 | 30 |
| | Clay | 27 | -320 | 50 |
| | Lowndes | 1 | -400 | 0 |
| | Oktibbeha | 18 | -700 | -350 |
| F - F' | Itawamba | 42 | 240 | GL |
| | | 56 | 90 | GL |
| | Monroe | 34 | 25 | GL |
| | | 7 | 0 | GL |
| | Lowndes | 6 | -200 | GL |
| | | 68 | -130 | GL |
| | | 14 | -230 | 180 |

Elevations from the electric logs were compared with elevations reported by Boswell (1963, 1977). Good comparison was generally obtained, except a few minor variations and subsequent adjustments were made in the model data base.

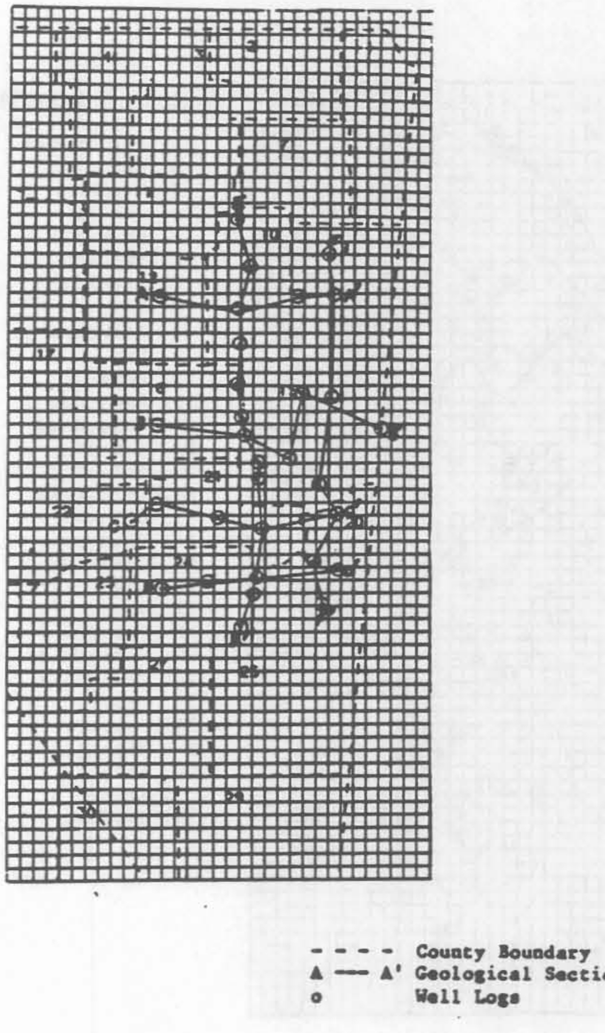


**Figure 1. Locations of Geological Sections Through the Eutaw-McShan Aquifer**

Recharge to the area occurs as precipitation in the outcrop area. The original movement of water to the south and southwest has been modified by recent flows towards the large centers of pumping near Tupelo and West Point. In the early studies of the aquifer (Stephenson, et al, 1928; Crider and Johnson, 1906), numerous wells were found to flow freely in the river valleys, especially in the valley of the Tombigbee River. At the present time it is assumed that the Tombigbee River valley remains hydraulically connected to the Eutaw-McShan aquifer and this was accounted for in the modeling effort. The clay layer of the upper Gordo is assumed to effectively retard leakage between the lower Tuscaloosa aquifers and the Eutaw-McShan (Boswell, 1978).

**Finite-Difference**

Grid The finite-difference grid used in the Eutaw- McShan study was orientated in a N-S, E-W direction with cells 2.5 miles square (Figure 2). This allowed wells to be located with sufficient resolution in each cell so that the drawdown due to pumpage for each well, was sufficiently accurate for purposes of this study. It was not deemed necessary to orientate the axes in the downdip of the aquifer since the direction of the principal transmissivity tensor is unknown or greatly modified by pumpage.

The finite-difference grid is composed of 67 rows and 33 columns. Basically the grid covers the area from the Tennessee border on the North to parts of the western edge of Alabama on the East. The limit of the aquifer to the West and South is the line of 1,000 mg/l dissolved solids. Cells to the West of this line were omitted from the computations. Imposed upon the grid in Figure 3 is the outcrop area of the Eutaw-McShan which includes the area basically from the Tombigbee River eastward into Alabama. General lines of equal aquifer thickness are superimposed upon the grid to show the increasing thickness of the aquifer from northeast to southwest.

**Aquifer Parameters**

Of the major aquifers in the study region, the Eutaw-McShan is the lowest in capacity to transmit and yield water. The median value for hydraulic conductivity is 13.4 cuft/da/sqft (Boswell, 1977, 1978; Newcome, 1971) obtained from 41 well tests in the aquifer. Transmissivity values, the product of hydraulic conductivity and aquifer thickness, tend to be low, especially in the northern portion of the study area. Aquifer parameters used in the model are summarized in Table 2. Both average published values from aquifer tests and values used in the model are given. The vertical hydraulic conductivity, K', was assumed to be 6.0*E-8 cuft/sec/sqft. For specific parameters in each cell of the model, the reader is referred to the original report (Zitta and Pang, 1986).

**Table 2. Eutaw-McShan Aquifer Parameters; Published and Model Values**

| | Published | Model |
|---|---|---|
| Hydraulic Conductivity (ft/sec) | 1.55E-4 | 1.65E-5 |
| Storage Coefficient (dimensionless) | 0.0002 | 0.0002 |
| Specific Yield (dimensionless) | 0.2-0.0002 | 0.25-0.0006 |
| Areal Recharge (ft/sec) | – | 9.25E-11 |

The storage coefficient is the specific storage, Ss, times the vertical thickness of the cell, and applies to an confined aquifer. The specific yield is the same definition as storage coefficient but is applied to unconfined aquifers. Obviously, the specific yield for unconfined aquifers is usually much larger than the storage coefficient for confined aquifers. Table 2 gives the range of aquifer values for the calibrated model. The reader is referred to Appendix A of the original report (Zitta and Pang, 1986) for a complete listing of aquifer parameters in each cell of the model.

**Well Records and Pumping Data**

Data from more than 3800 wells drilled into the Eutaw-McShan were input into computer files to automate the well location, date of construction and pumping capacity. Lists of wells were obtained from the files of the USGS. These data were input into a computer file with well number, year completed, pumping capacity, longitude and latitude as primary data. From the longitude and latitude, software was written to compute state plane coordinates of all wells. Each well location was checked to determine if located in the assigned county. In this process the county location was assumed correct and the longitude and/or latitude were corrected for obvious mistakes in the master file.

Part of the research effect was to obtain actual pumping records from all major pumping centers within the study area, in particular, the city of Tupelo, West Point and Aberdeen with their associated

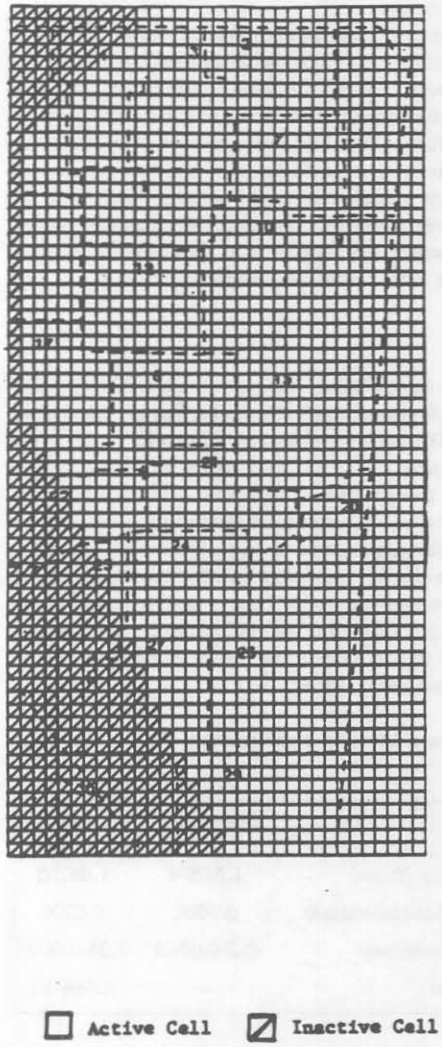


Figure 2. Finite-Difference Grid of the Eutaw-McShan Showing Active and Inactive Cells

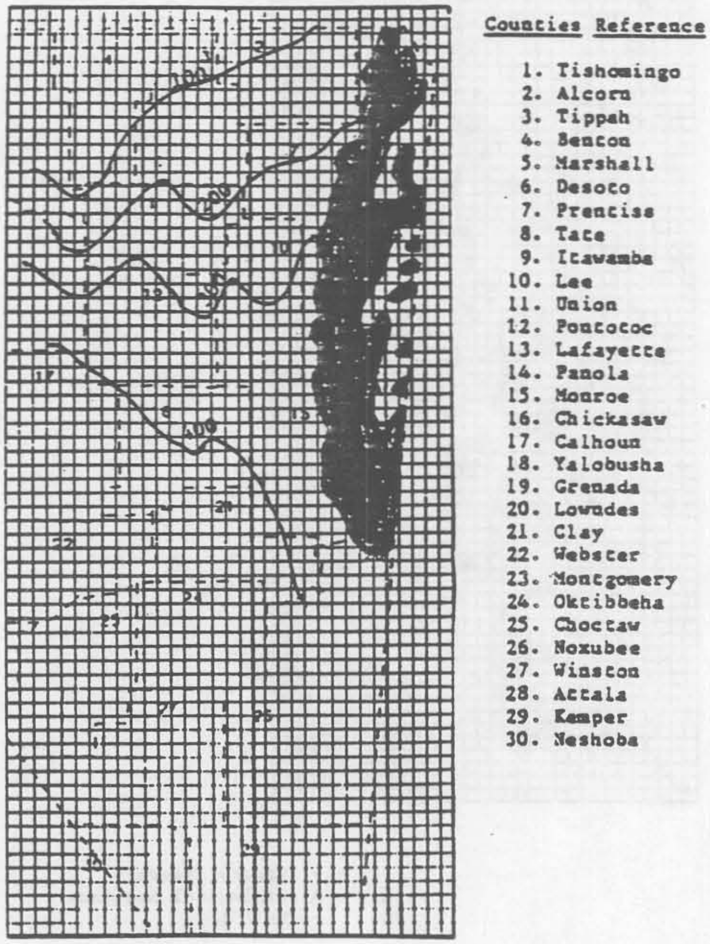


Figure 3. Finite-Difference Grid of the Eutaw-McShan Showing the Outcrop Area and the Thickness of the Aquifer

industrial pumpage. A majority of the pumping records available and obtained were from 1981 to present. Although some pumping records, from cities are fairly complete, others had limited installation of meters and pumping volumes are at best estimates. For all users, the best estimate of the historical pumping volumes were used in the calibration process.

### Potentiometric Maps

Two potentiometric maps of water levels in the aquifer were available for calibration of the groundwater model. One is a potentiometric map for the year 1978 (Wasson, 1980a) and one is for the year 1982 (Darden, 1985). The 1978 map in Figure 4 shows the cones of depression in the confined region under Tupelo in Lee County and in the region under West Point in Clay County. No major cones of depression are evident below Booneville or in Monroe County where large withdrawals presently occur or have occurred in the past. The 1982 (Darden, 1985) map in Figure 5, shows that in addition to the cones of depression under Tupelo in Lee County and West Point in Clay County, a cone of depression has developed in the region near Aberdeen in Monroe County. Small, localized cones have developed in New Albany in Union County, Baldwyn in Prentiss County and Rienzi in Alcorn County.

### Model Calibration

Best estimates of the potentiometric head in each grid cell were made from the 1978 map and the 1982 map. These data were used as the initial starting head and calibration heads respectively for the model. The model was calibrated from 1978 to 1982. The contour map for the computed piezometric heads for the year 1982 was plotted (Figure 6) and compared with the actual potentiometric surface reported by USGS (Figure 5). Good agreement was obtained.

It should be noted that with the limited piezometric maps available, the calibration process cannot be considered rigorous but serves as a base for future refinement of the aquifer parameters. Good agreement is generally evident between the computed and the observed 1982 piezometric heads. As a general rule, the area to the east of the Tombigbee River in the unconfined region was much more difficult to calibrate than the confined region to the west of the river. Sensitivity of the model to aquifer parameters, pumping and recharge was most noticeable in the unconfined region. Values for the calibrated aquifer parameters for each cell in the model are given in the original report (Zitta and Pang,1986)

## CONCLUSIONS

A modular, three-dimensional, finite-difference groundwater flow model developed by McDonald and Harbaugh (Released 1985) was applied to the Eutaw- McShan aquifer in Northeast Mississippi. Based upon the analysis of electric logs, the geometry of the aquifer was refined for input into a 2.5 mile square grid. Pumping data were obtained from municipalities and industries as a check and confirmation of estimated values presented in a variety of publications. Based upon the work performed in this study the following conclusions are drawn:

1. A 2.5 mile square grid model of the Eutaw-McShan aquifer is adequate to define the regions of critical drawdown in Northeast Mississippi.
2. Geological logs and available pumping records were available to refine the geometry of the aquifer and withdrawal rates.
3. With the aquifer coefficients given in Table 2 and in the original report (Zitta and Pang, 1986), the actual and computed potentiometric maps for 1982 exhibit good agreement.

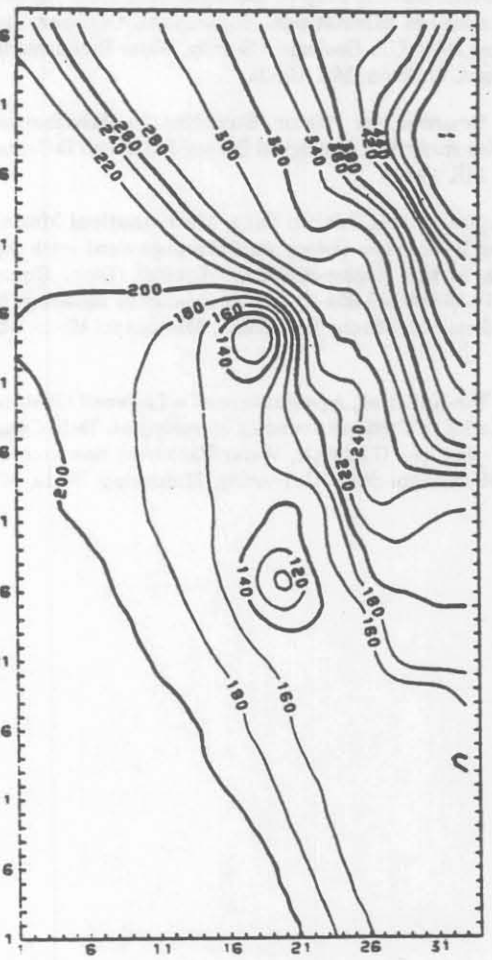


**Figure 4. Potentiometric Map of the Eutaw-McShan, 1978 (After Wasson, 1980a)**

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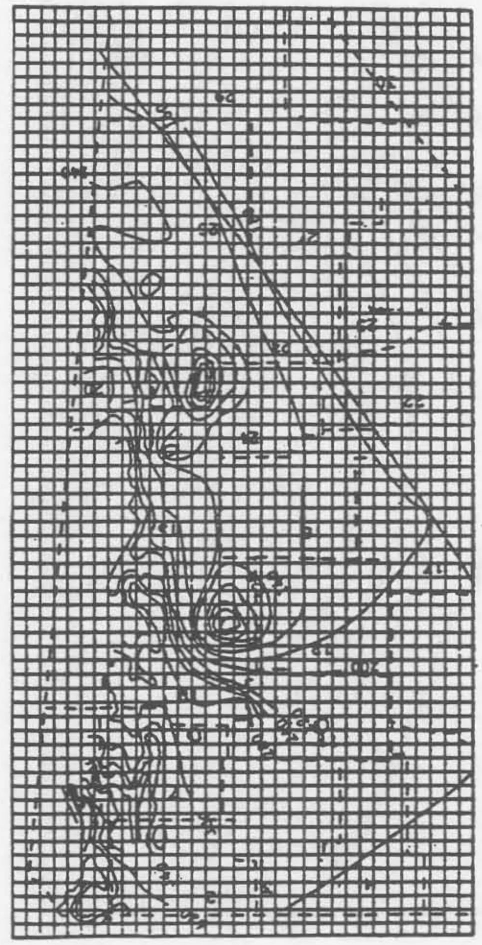

**Figure 5. Potentiometric Map of the Eutaw-McShan, 1982 (After Darden, 1985)**

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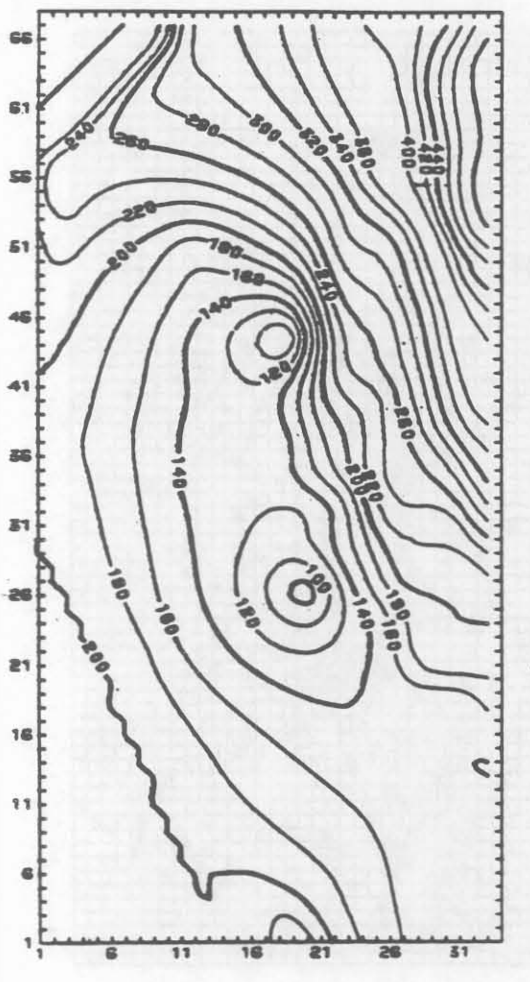


**Figure 6. Computed Potentiometric Map of the Eutaw-McShan Aquifer, 1982**

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