PREDICTION OF WATER LEVELS FOR THE HOUSTON REGION

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ABSTRACT: The purpose of this study is to predict the water heads in the Houston area by using the Modular Three Dimensional Finite Difference Groundwater Flow Model developed by the U.S. Geological Survey (USGS). The simulation of the hydrological conditions of the Chicot and Evangeline Aquifers that underlie Houston is made using the available information about the geological profile in the Houston region, and the current information about the existing production wells. The regional model is calibrated using actual data from extensometers and piezometers operated by the U.S. Geological Survey in many places throughout Houston. No parameter identification (inverse estimation) procedures beyond determining the boundary conditions were used. The model uses flux boundary conditions that were estimated using a radial flow analog and Darcy's law. Some head data were generated using the regional variable theory called kriging to supply head estimates in areas where data were unavailable. A one year simulation is presented and a rough estimate of prediction error indicates that the model performs well for locations where data were available.

INTRODUCTION

The major water bearing units in the Houston-Galveston area are the Chicot and Evangeline aquifers. The Chicot aquifer overlies the Evangeline aquifer that overlies the Burkeville confining layer. The relationship of the Chicot aquifer, the Evangeline aquifer, and the Burkeville layer is shown in Figure 1. The Chicot and Evangeline aquifers consist of unconsolidated and discontinuous layers of sand and clay that dip toward the Gulf of Mexico.

Ground water in the Houston area is used for public supply, industry and irrigation. Generally speaking, water levels in the Houston area (regional basis) declined from the beginning of development (1943) until 1977.

Since late 1976, changes in the pumping distribution resulting from efforts to control subsidence and the introduction of surface water from Lake Livingston have altered the pattern of water level changes.The average daily withdrawals of ground water in Harris County and parts of Fort Bend and Waller Counties between 1975-1984 was 20 m^3/s (464 Mgal/day). The percentage of ground water to total average daily use during 1975-1984 was between 48 to 58% (Williams and Ranzau, 1987). During 1985-1989, the City of Houston's water supply averaged about 55% ground water. During the decade 1980-1989 the average daily withdrawal of ground water in Harris County and parts of Fort Bend and Waller Counties was 19.26 m^3/s (439.77 Mgal/day).

The purpose of the present work is to present a flow model to determine the head distributions in the underlying aquifers.

CONCEPTUAL HYDROLOGICAL MODEL

This work describes a methodology to incorporate flux boundary conditions and uses regional variable theory to estimate initial conditions for locations where there are no data.

The subsurface lithology of the Houston area is composed of sand and clay layers of varying thickness. Bravo (1990) studied sonic, spontaneous-potential, and conductivity logs for five of the eleven borings shown in Figure 2 (Baytown, Clear Lake, Johnson

Space Center, Southwest and Addicks). The logs were manually interpreted to generate geologic profiles of the subsurface at the five sites.

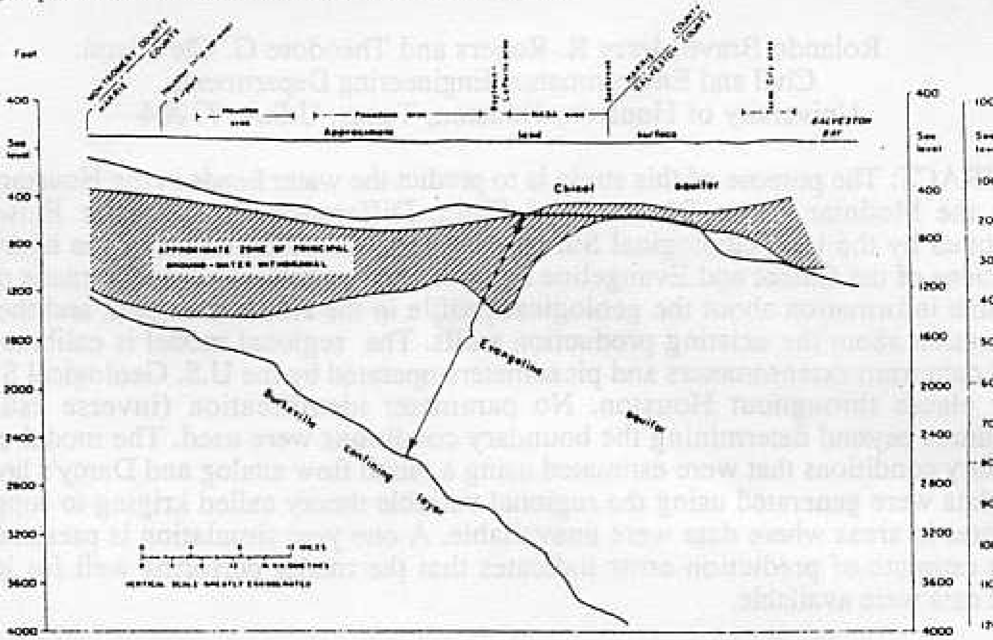


Figure 1 Hydrological profile from the Houston area (from Gabrysch and Bonnet 1975)

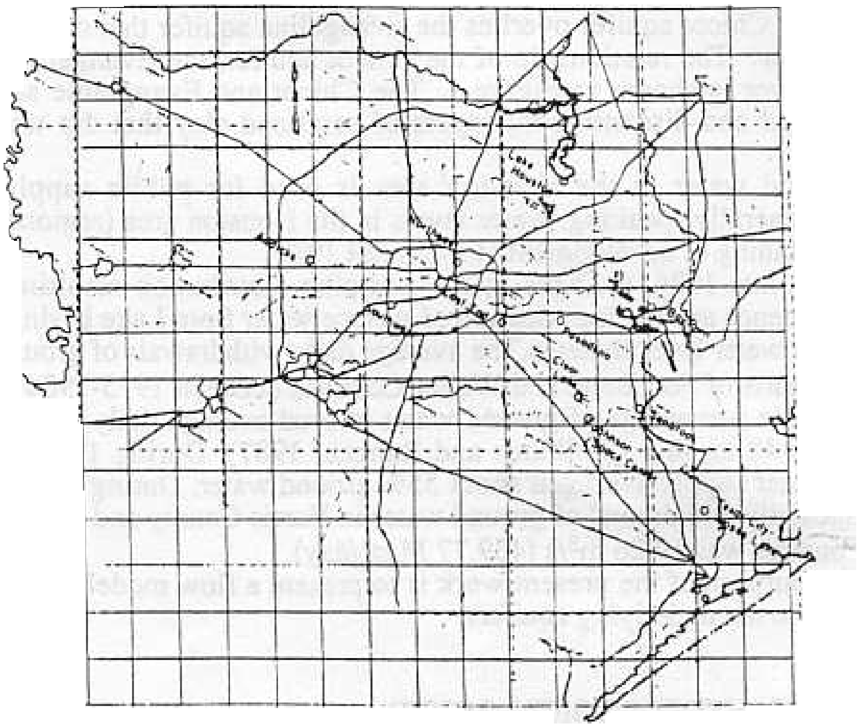


Figure 2 Location of borehole extensometers of the USGS (Open File Report 89-057) Boundary and grid of the model.

The representation of the subsurface geology was further simplified by concentrating the sand and clay layers in a manner consistent with the stratigraphy in the East-West direction and developing the eight layer conceptual model shown in Figure 3. The North-South subsurface geology was modeled using the conceptual model and adjusting the thickness of each layer so that the overall aquifer thickness follows the transect shown in Figure 1. The East-West subsurface model was extrapolated horizontally beyond the limits shown in Figure. 3 because there was no further stratigraphic information.

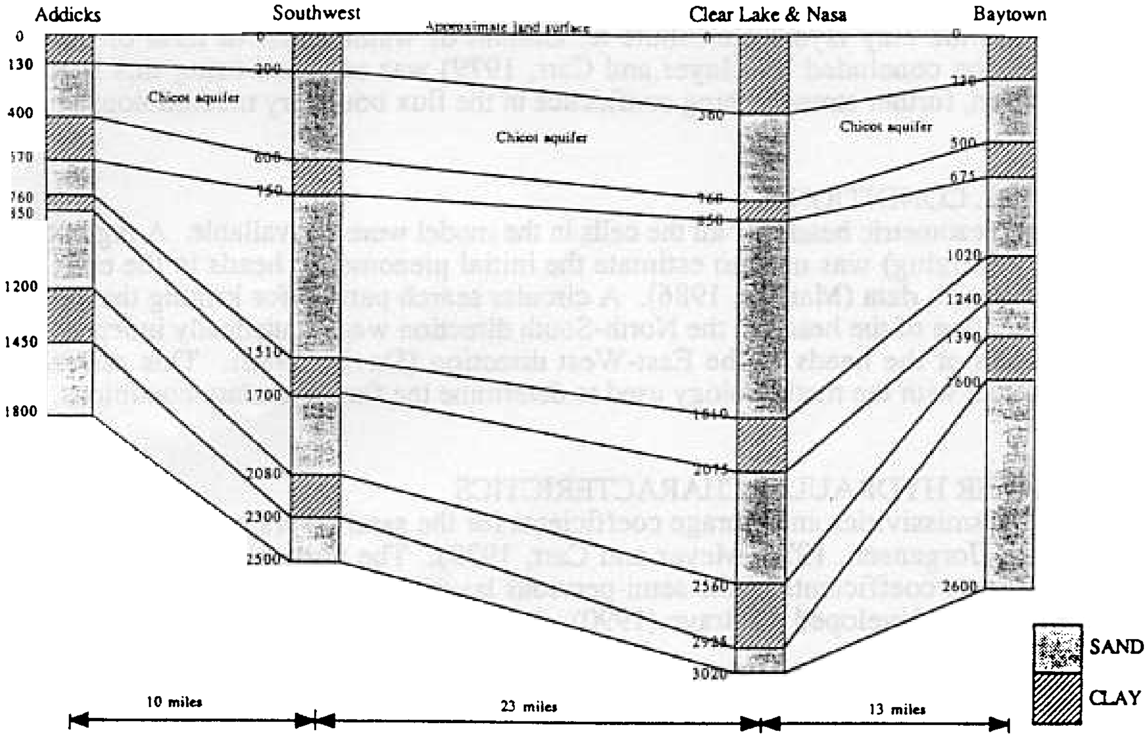


Figure 3 Conceptual model of the ground water hydrology of the Houston area. The numbers indicate meters below land surface.

CONCEPTUAL AQUIFER FLOW MODEL

The Chicot Aquifer was modeled as an isotropic aquifer with the potential for either confined or unconfined horizontal flow. The Evangeline Aquifer sand layers were modeled as confined leaky isotropic aquifers. The intervening clay layers were modeled as semi-pervious formations. The effects of delayed storage in the clay layers were modeled as a source term in the flow model.

A prescribed piezometric head boundary condition (Dirichlet) was applied along the edge of the model that intersects Galveston Bay, while a prescribed flux boundary condition (Neuman) was applied along the rest of the boundary. The previous regional models of groundwater flow in the Houston area used prescribed head everywhere along the boundary. The present work used a flux boundary condition because there were not sufficient data to determine a prescribed head boundary condition for the area studied.

Piezometric contour maps from 1980 to 1989 were observed to have the same appearance as contour maps that would be expected for radial steady flow to a well. This fact suggested that one test the relationship between radial distances from a hypothetical origin and the piezometric head. In most directions the relationship between the piezometric head and the logarithm of the radial distance was found to be linear and the slopes of the regression lines were almost the same for the ten years studied (Bravo, 1990). These slopes can be used to estimate the hydraulic gradient at the boundary. Figure 4 shows the regression lines for the altitude of water levels at the Chicot and Evangeline aquifer in the North-West and South East direction from 1980 to 1989.

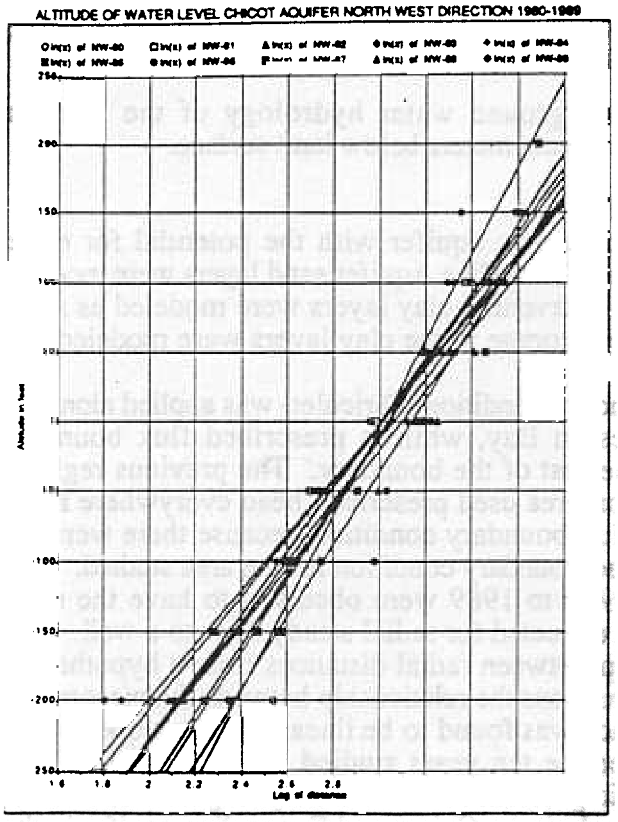
The extent of the region studied was chosen to cover the withdrawal areas (pumping areas) for the same decade. The boundary is shown in Figure 2. The radial flow analog and Darcy's law were used to estimate the flux into the domain of interest. The pumping rates for the ten years studied varied from 143000 million gallons per year (470 million m^3 $year^{-1}$) to 180000 million gallons per year (590 million m^3 $year^{-1}$); yet the values for the fluxes were relatively constant. Because of this behavior, it was assumed that the fluxes remain constant for prediction horizons of several years. A groundwater budget that assumes the clay layers contribute an amount of water equal to 25% of pumping (the proportion concluded by Meyer and Carr, 1979) was satisfied using this flux boundary condition, further strengthening confidence in the flux boundary methodology.

INITIAL CONDITIONS

Initial piezometric heads for all the cells in the model were unavailable. A regional variable theory (kriging) was used to estimate the initial piezometric heads in the cells for which there was no data (Marsily, 1986). A circular search pattern for kriging the data assumed the variation of the heads in the North-South direction were statistically independent for the variation of the heads in the East-West direction (Davis, 1986). This assumption was consistent with the methodology used to determine the flux boundary conditions.

AQUIFER HYDRAULIC CHARACTERICTICS

The transmissivities and storage coefficients for the sand layers were taken from previous studies (Jorgensen, 1975, Meyer and Carr, 1979). The vertical hydraulic conductivities and storage coefficients of the semi-pervious layers were determined independently using the methods developed by Bravo (1990).



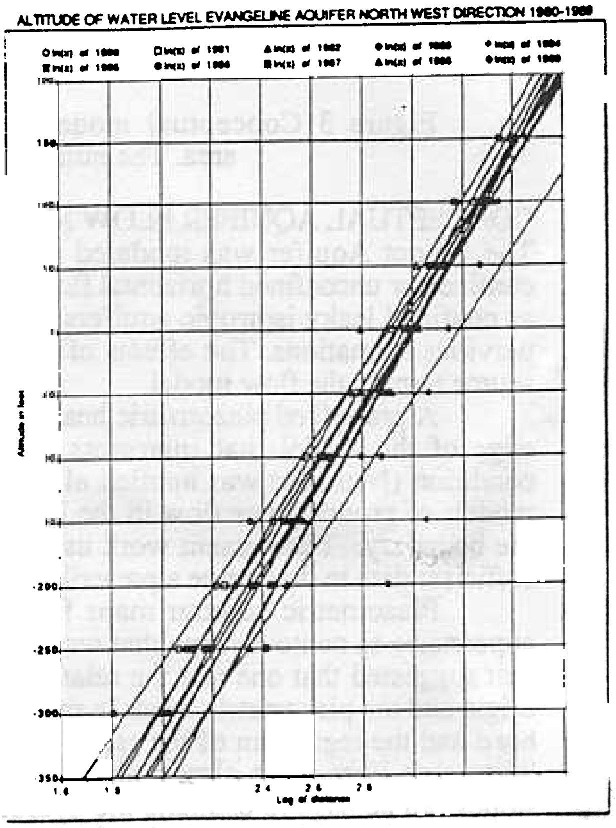


Figure 4 Regression lines for the altitude of water levels at the Chicot and Evangeline aquifer North-West from 1980 to 1989.

FLOW MODEL SOLUTION

The flow model was solved using the Modular Three-Dimensional Finite Difference Ground Water Flow Model (MODFLOW) developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988). Transient flow for the geometry defined by the boundary shown in Fig. 2 was modeled using injection wells to simulate the fluxes along the boundary.

RESULTS

The flow model was operated for a simulation period of one year, using initial data from 1983. Figure 5 shows the observed (missing data are estimated by kriging) and the simulated 1984 head distribution in the Chicot Aquifer. Contours are head in feet. The vertical and horizontal scales are in miles. Figure 6 shows the observed and simulated head distributions in 1984 for the Evangeline Aquifer system. To measure the performance of the model the relative prediction error for the Chicot and Evangeline Aquifers were calculated. The formula used was

$$RPE(x,y) = \frac{\phi^{predict}_{(x,y)} - \phi^{actual}_{(x,y)}}{\phi^{actual}_{(x,y)}} \qquad (1)$$

where RPE(x,y) is the relative prediction error of the flow model.

Figure 5 shows a map of RPE for the Chicot Aquifer. The model performed well in predicting piezometric heads in the Chicot Aquifer at locations where actual data were available. Figure 6 shows a map of RPE for the Evangeline Aquifer. Again the model performs well for those locations where there were data. What is remarkable is that no parameter identification (inverse estimation) procedures beyond determining the boundary conditions were used; yet the model performed adequately.

CONCLUSIONS

The University of Houston Civil and Environmental Engineering group has developed a new groundwater flow model of the Houston area. Based on the 1983 to 1984 simulation the flow model appeared to perform well in areas where data were available.

The model used regional variable theory for estimating initial conditions at locations where there were no data, and a radial flow analog to estimate flux boundary conditions in the Houston area. The techniques used may be applicable to similar regions; the flux boundary condition eliminates the need to model areas that are greater than the given area of interest.

Further research includes a study to determine the sensitivity of the model to changes in aquifer parameters, a study of the influence of storage in the clay layers when the vertical flow assumption is relaxed, and a study of the influence of the search pattern in the kriging algorithm when the assumption of statistical independence of the variation of head with direction is relaxed.

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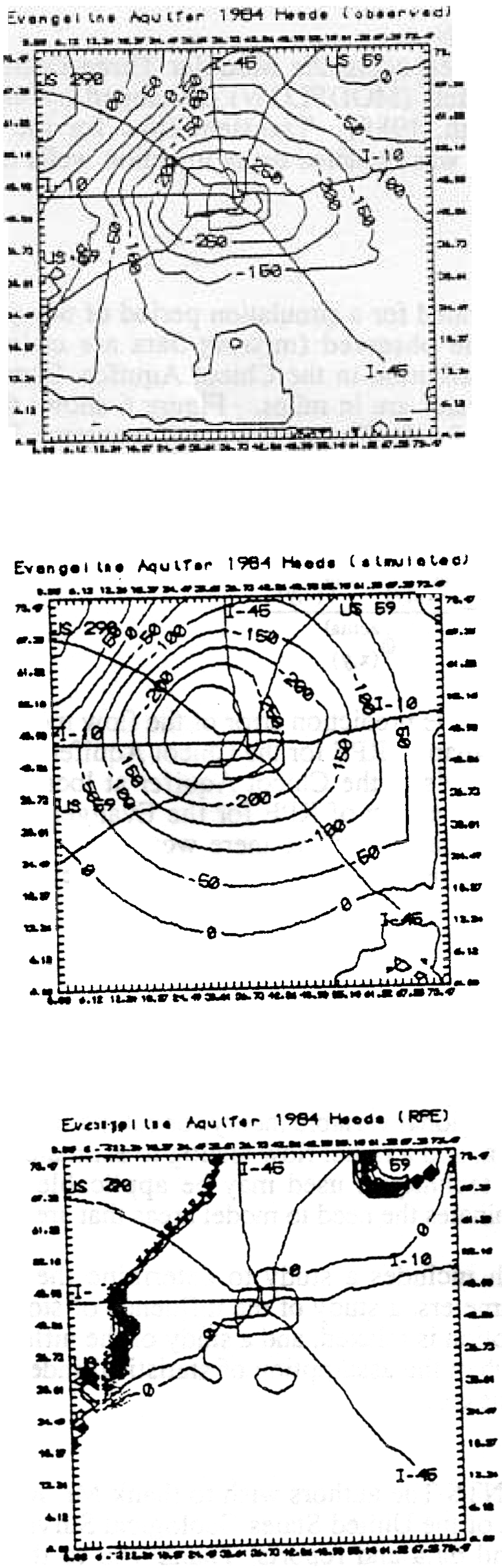

Figure 6 Evangeline aquifer 1984 heads (observed, simulated and relative prediction error).

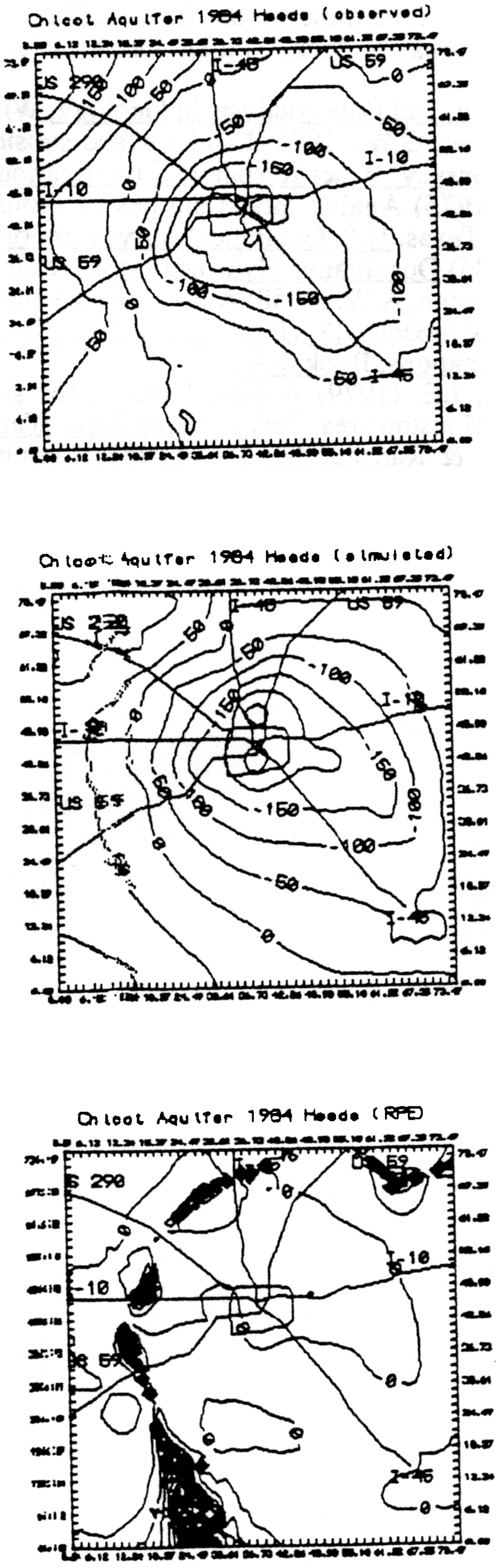

Figure 5 Chicot aquifer 1984 heads (observed, simulated and relative prediction error).

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