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COMPUTER MODELING OF GROUND-WATER FLOW AT THE SAVANNAH RIVER PLANT

by

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ABSTRACT

Mathematical equations describing ground-water flow are used in a computer model being developed to predict the space-time distribution of hydraulic head beneath a part of the Savannah River Plant site. These equations are solved by a three-dimensional finite-difference scheme. Preliminary calibration of the hydraulic head model has been completed and calculated results compare well with water-level changes observed in the field.

INTRODUCTION

The Savannah River Plant (Figure 1) is a Department of Energy facility operated by E. I. du Pont de Nemours and Co. primarily to produce nuclear materials for national defense. High-level radioactive waste generated during operation are stored in double-walled steel tanks in concrete encasements. To assess storage risks, it is desirable to be able to predict quantitatively the movement and concentration of potential contaminants in the ground. Contaminant transport in the ground is primarily due to ground-water flow; therefore, a mathematical model of ground-water flow in the waste storage area is being developed to predict the rate and direction of contaminant transport in the subsurface under the influence of ground-water movement, hydrodynamic dispersion, and ion exchange.

Calculation of contaminant transport due to ground-water flow requires knowledge of the distribution of hydraulic head in time and space. Development of a program to calculate the head distribution is briefly described in this paper. Input to this hydraulic head model includes: water levels for the hydrogeologic units, obtained from well measurements; values for hydraulic conductivity and specific storage, obtained from pumping tests; and a conceptual geologic framework, based on subsurface coring.

DESCRIPTION OF STUDY AREA

The 800-square-km plant site is located on the Coastal Plain of South Carolina about 20 miles southeast of the Fall Line. The site is bounded on the southwest by the Savannah River. The plant is underlain by unconsolidated and semiconsolidated Coastal Plain deposits -- sands, clays, sandy clays, and clayey sands (Figure 2). From the surface, the hydrologic units are (1) the Barnwell Formation, which consists of clays, sandy clays, and clayey sands, to a depth of about 30 meters; (2) a tan clay about 3 meters thick; (3) the McBean Formation, which consists of an upper layer of clayey sand and a lower layer of calcareous clay and clayey sand containing small cavities, to a depth of about 55 meters; (4) a green clay about 2 meters thick; (5) the Congaree Formation, which consists of layers of sand interbedded with layers of clay, to a depth of about 90 meters; (6) the Ellenton Formation, which consists of lignitic micaceous clay and coarse sand, to a depth of about 110 meters; and (7) the Tuscaloosa Formation, which consists of interbedded sand, gravel, and clay down to crystalline rock at about 290 meters. The Tuscaloosa Formation is the major water-supply aquifer for much of the Coastal Plain of South Carolina and Georgia.

The study area is shown in Figure 3. The ground-water system of interest is bounded on two sides by Upper Three Runs Creek and Four Mile Creek, on the third side by a piezometric high, on top by the water table, and on the bottom by a permeable flow boundary. The topography is generally flat to slightly rolling. Upper Three Runs Creek has a steep bluff on its southeast side with about 35 meters of relief. A few small intermittent streams also drain the area. The presence of low-conductivity clay layers causes vertical gradients of hydraulic head. Recharge is distributed approximately uniformly over the area and amounts to about 1.2 meters per year.

GEOHYDROLOGY

The water table (Figure 4) conforms to a subdued expression of the topography, forming a ground-water ridge that discharges laterally toward the two bounding streams. The eastern hydrologic boundary for the water-table aquifer is the east-west potentiometric high south of H Area. In the western part of the study area, the two streams are close enough so that most ground water flows laterally to the streams. The gradient of the water table varies from fairly flat along the crest of the ground-water ridge to fairly steep as the water table approaches Upper Three Runs Creek and parts of Four Mile Creek.

The clay layers in the subsurface retard the downward movement of water, thereby causing a vertical head gradient (Figure 5) across these clays. With increasing depth, therefore, the potentiometric surfaces tend to stand lower for deeper formations. Thus, the potentiometric surface in the upper part of the McBean Formation (Figure 6) is lower than the water table. Although the potentiometric surface still retains some expression of the topography and inter-stream drainage, gradients are not as steep.

The potentiometric surface in the Congaree Formation (Figure 7) stands still lower and lacks any significant topographic expression, except where water in the Congaree Formation discharges into Upper Three Runs Creek. The water levels in this formation are primarily influenced by the elevation of Upper Three

Runs Creek and the recharge area off-plant. Water-bearing formations below the Congaree Formation exhibit a reversal in the downward head gradient of the shallow formations, and water levels of the deeper formations are higher than those of the Congaree. The discharge area for the Congaree Formation is Upper Three Runs Creek.

Measured hydraulic conductivities are listed in Table 1.

COMPUTER SIMULATION OF GROUND-WATER FLOW

The ground-water flow system will be simulated by a three-dimensional, finite-difference solution of the ground-water flow equation. A computer program, developed at the Savannah River Laboratory, calculates the distribution of hydraulic head in time and space that will be required for this flow simulation. The hydraulic head program was verified by calculations for conditions for which exact analytic solutions are available, such as drawdown in an aquifer undergoing constant discharge from a well. Satisfactory simulations were demonstrated for a variety of confined and unconfined situations.

Developing the three-dimensional hydraulic head model involved superposing a rectilinear grid over the study area, adding the vertical cross-section, and then assigning values for horizontal and vertical hydraulic conductivity, specific storage, effective porosity, and hydraulic head to each grid block. Recharge is specified for blocks in which the water table occurs. The model allows boundaries to be either impermeable or open to flow. Time increments must be so chosen as to minimize numerical errors.

The hydraulic head model is being calibrated to actual conditions by adjusting various input parameters until measured water-level distributions are reproduced. To eliminate the specific storage variable from initial consideration, the model is first being calibrated to the steady-state head distribution existing in the study area by adjusting the hydraulic conductivities of each block; despite seasonal fluctuations, the observed head distribution is approximately constant. After the steady-state calibration has been completed, the resulting distribution of hydraulic conductivities will be considered as representative of the subsurface material in the study area. Transient calibration will then be accomplished by varying the values of the specific storage of each block until the model satisfactorily reproduces the actual changes in hydraulic levels measured in wells over a period of time. The model will then be considered ready for use.

STATUS

Steady-state calibration based on hydraulic conductivities from pumping tests and estimates of recharge and porosity is still in progress. Some deviation persists between the calculated and observed steady-state head distribution. Figure 8 shows that the absolute weighted mean deviation of the water table is 3.2 meters, i.e., the water table over 50% of the area is deviating from the initial head distribution by 3.2 meters or more. Since this deviation is unacceptably large, more calibration calculations will be made. Figure 9 shows that the absolute weighted deviation of the upper McBean Formation potentiometric surface is 1.3 meters. This deviation, which is nearly acceptable, should be maintained or reduced by further calibration. Figure 10 shows that the mean deviation for the Congaree Formation is 0.076 meter, which is quite acceptable.

FUTURE UTILIZATION

Ground-water flow velocities anywhere in the study area will be calculated from the hydraulic conductivities of the model blocks, the effective porosities of the blocks, and the hydraulic head distribution predicted by the calibrated model. Another computer program will use these ground-water velocities, together with information about ion exchange properties of the soil, hydrodynamic dispersion, and radioactive decay of contaminants in the soil, to solve contaminant transport equations.

TABLE 1

Mean Hydraulic Conductivity of Formations Beneath the Separations Area at the Savannah River Plant

Formation	Hydraulic Conductivity from Pumping Tests, meters/day
Upper Barnwell sand lens	1.75
Lower Barnwell Formation	0.49
Upper McBean Formation	0.50
Lower McBean Formation	0.49
Congaree Formation	1.33

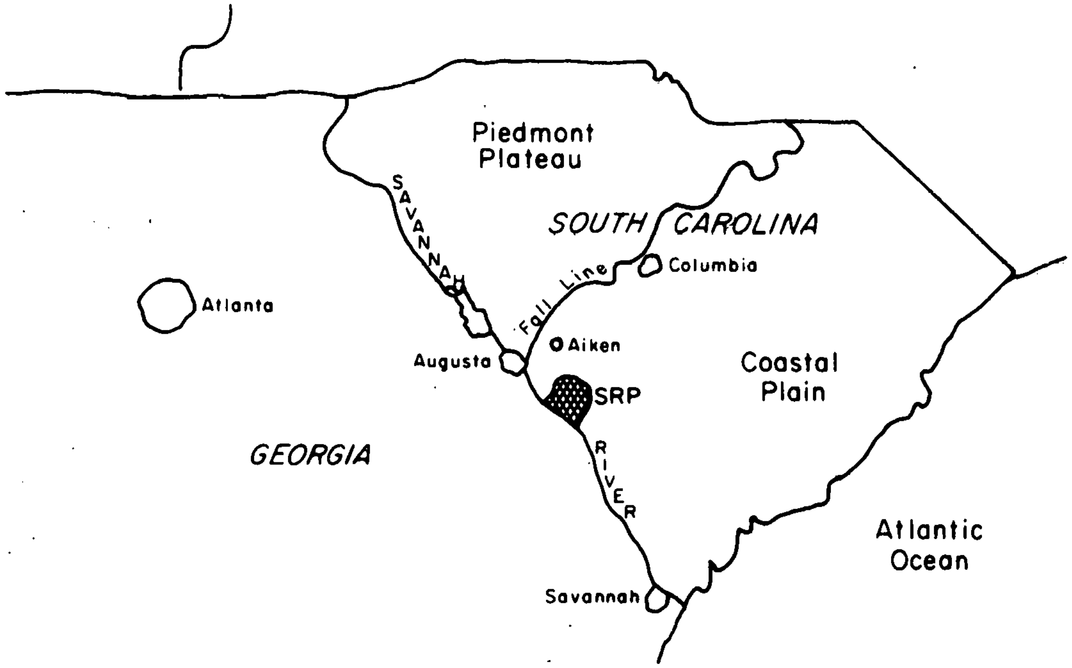


FIGURE 1. Location of Savannah River Plant and Nearby Geologic Provinces

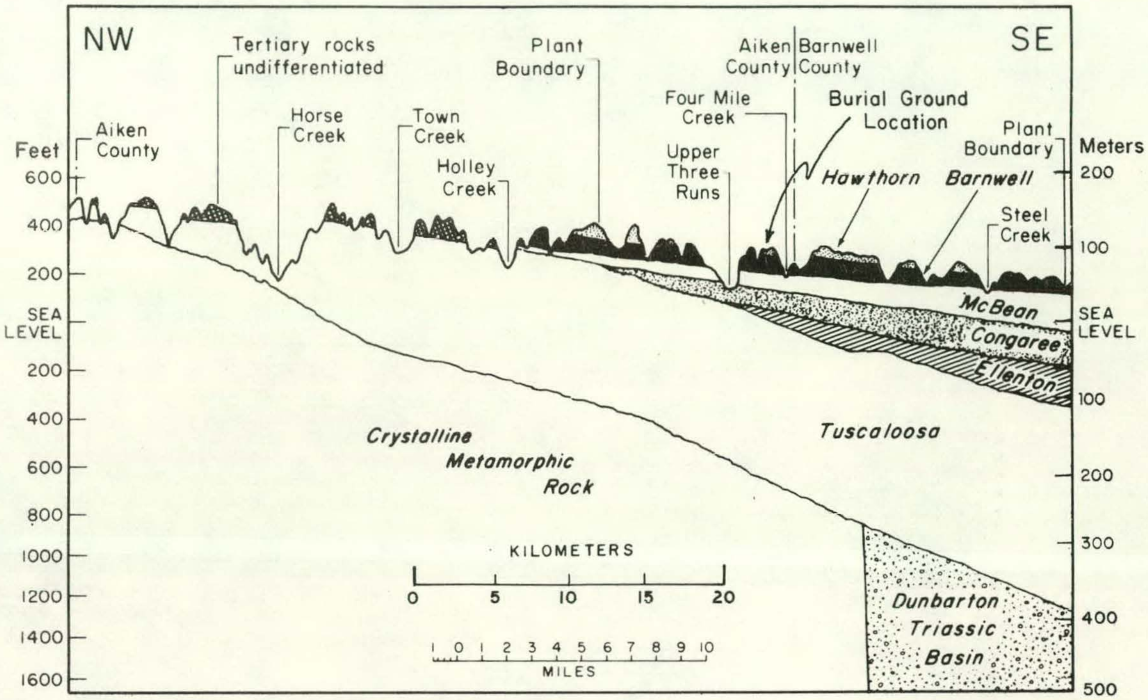


FIGURE 2. Generalized NW to SE Geologic Profile Across the Savannah River Plant (Marine and Routt, 1975)

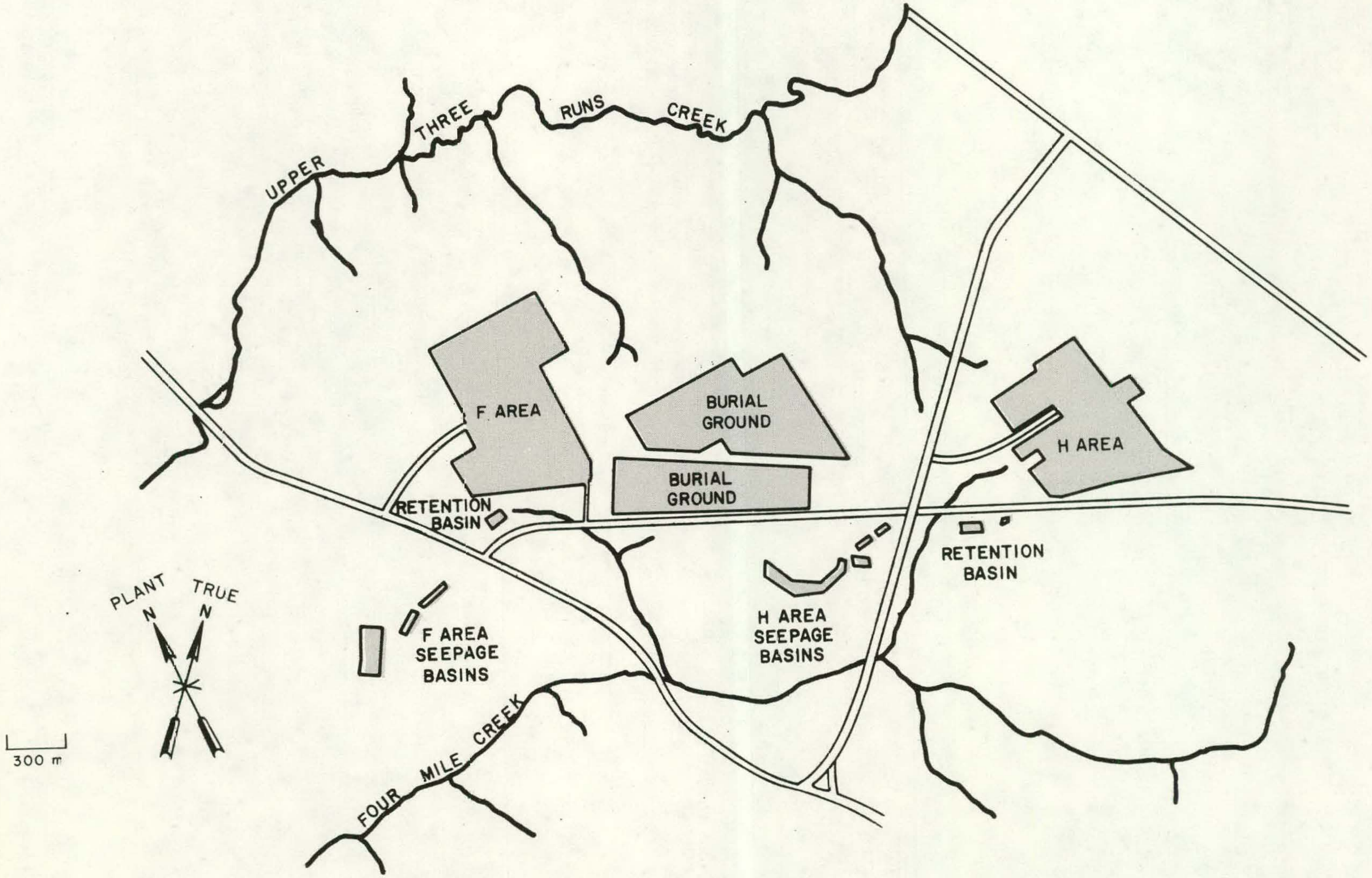
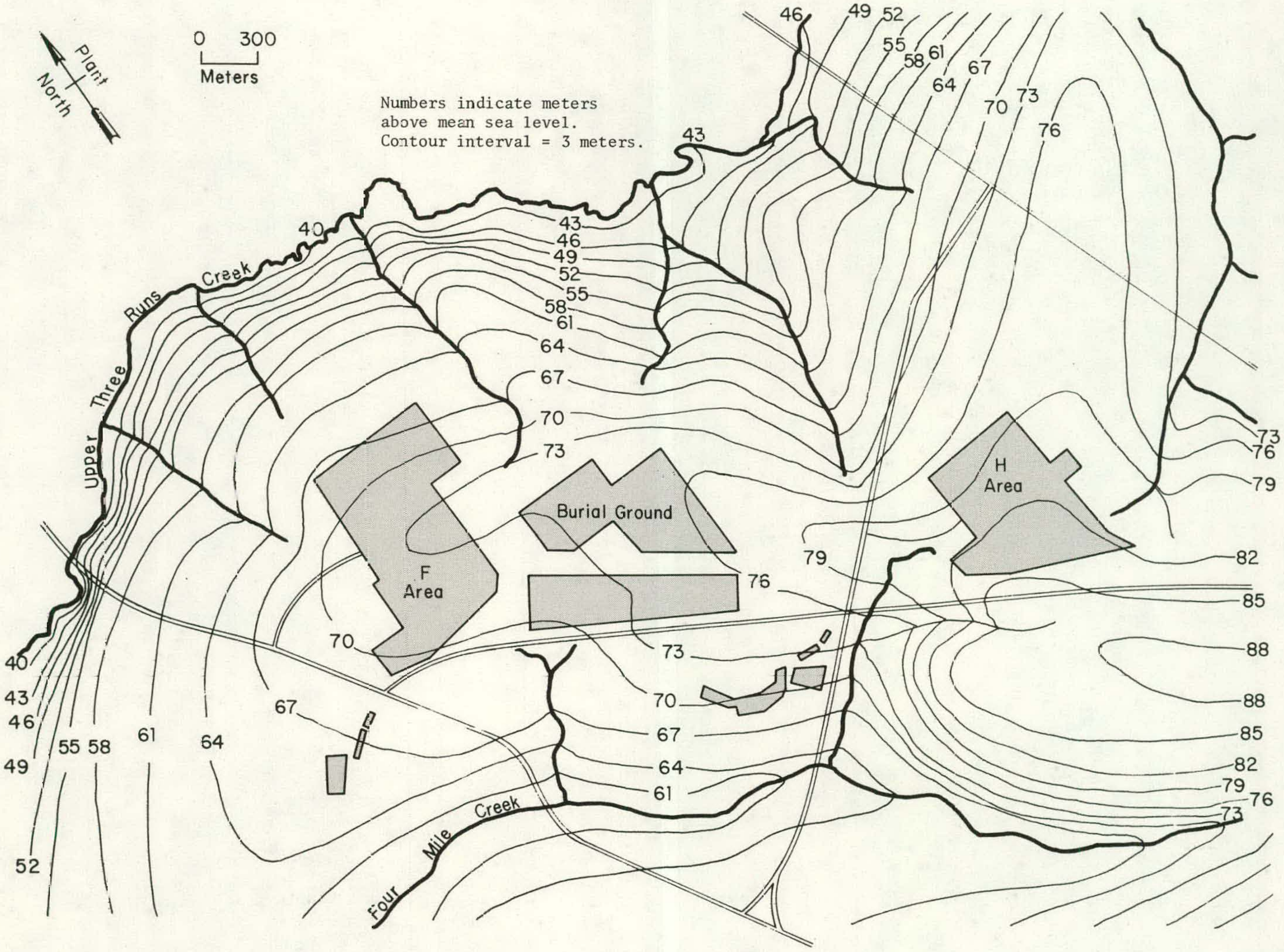


FIGURE 3. Map of the Study Area



Numbers indicate meters
above mean sea level.
Contour interval = 3 meters.

FIGURE 4. Average Elevation of the Water Table at SRP During 1968

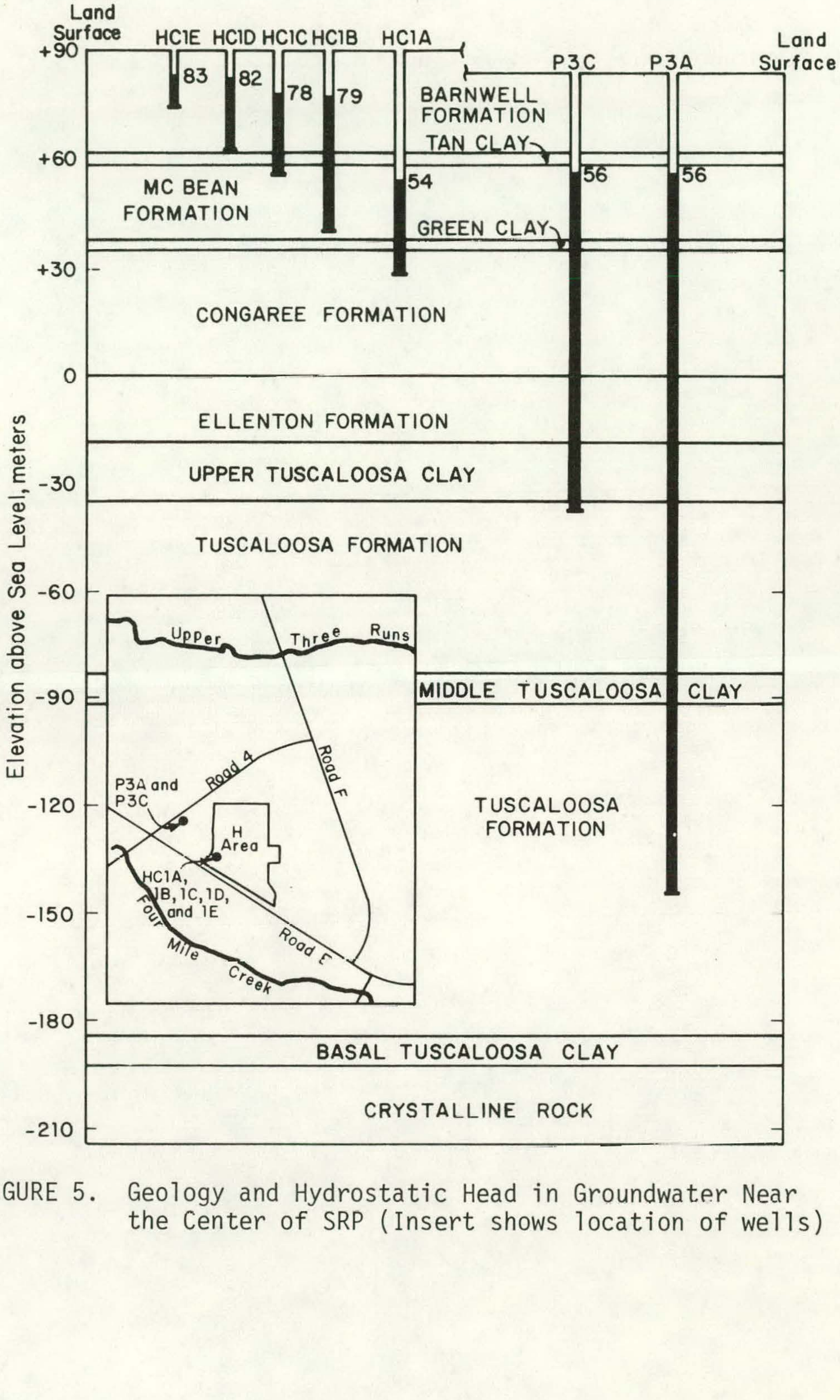


FIGURE 5. Geology and Hydrostatic Head in Groundwater Near the Center of SRP (Insert shows location of wells)

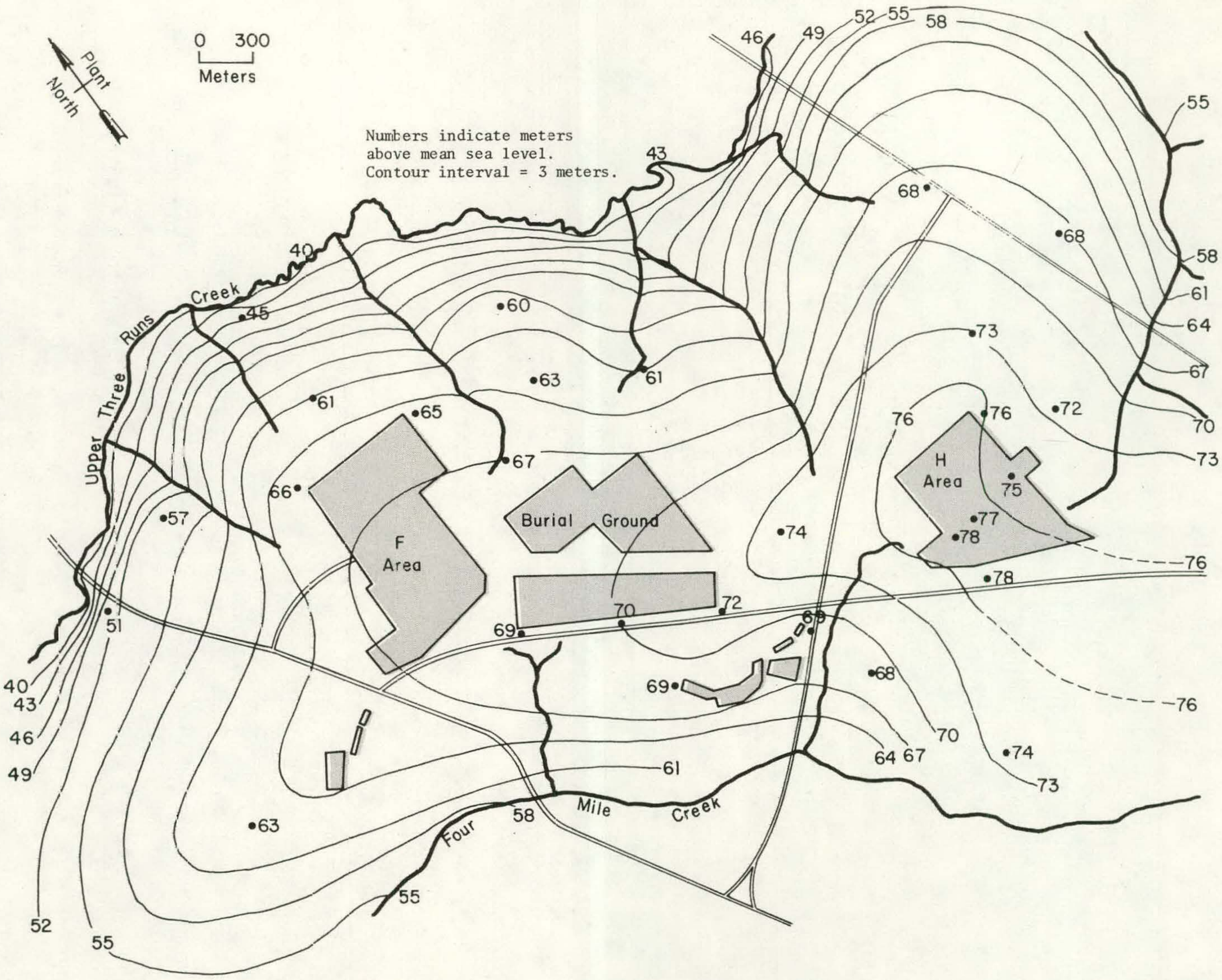


FIGURE 6. Elevation of the Hydraulic Head in the Upper Part of the McBean Formation (measured 8/29/77)

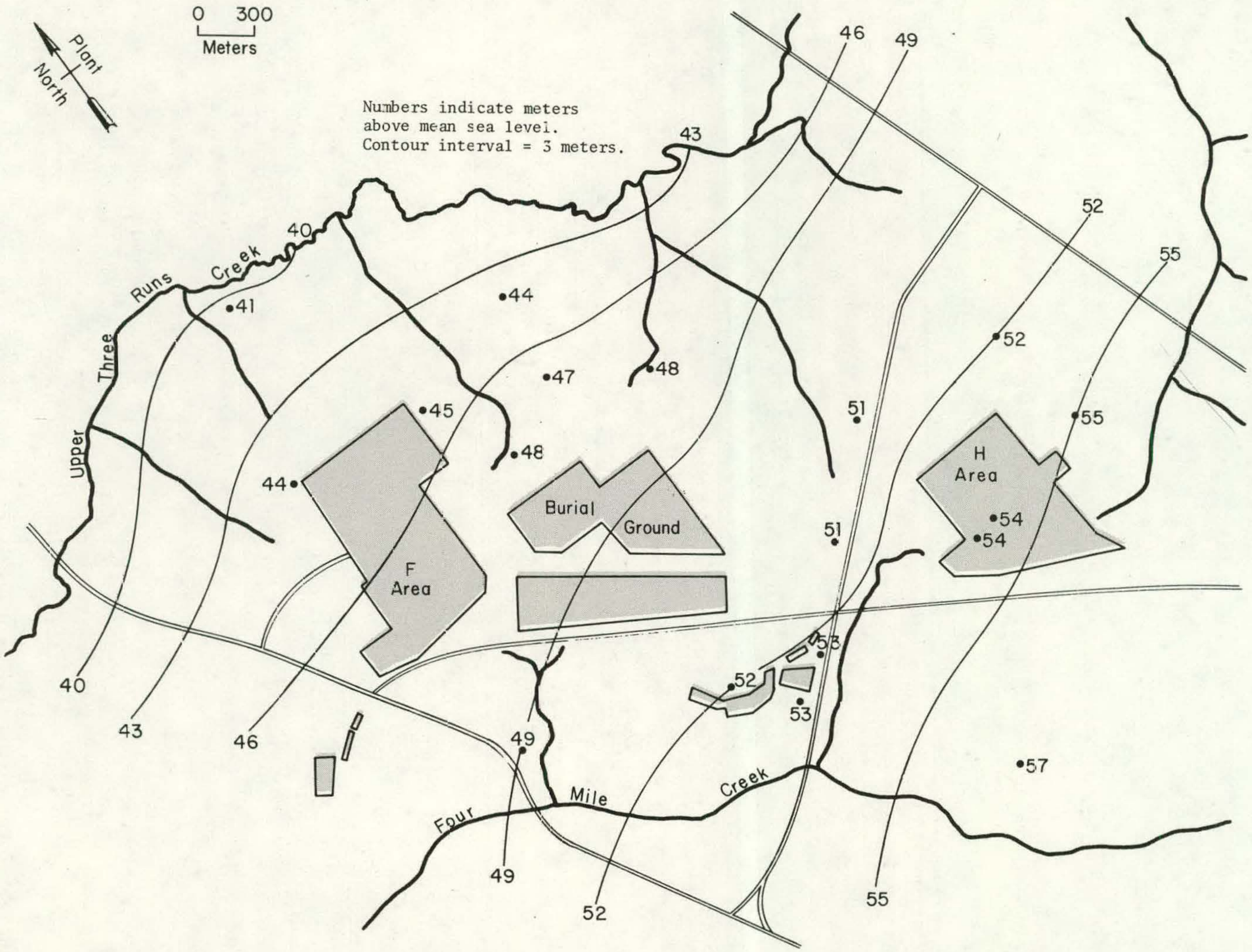


FIGURE 7. Elevation of the Hydraulic Head in the Upper Part of the Congaree Formation (measured 8/29/77)

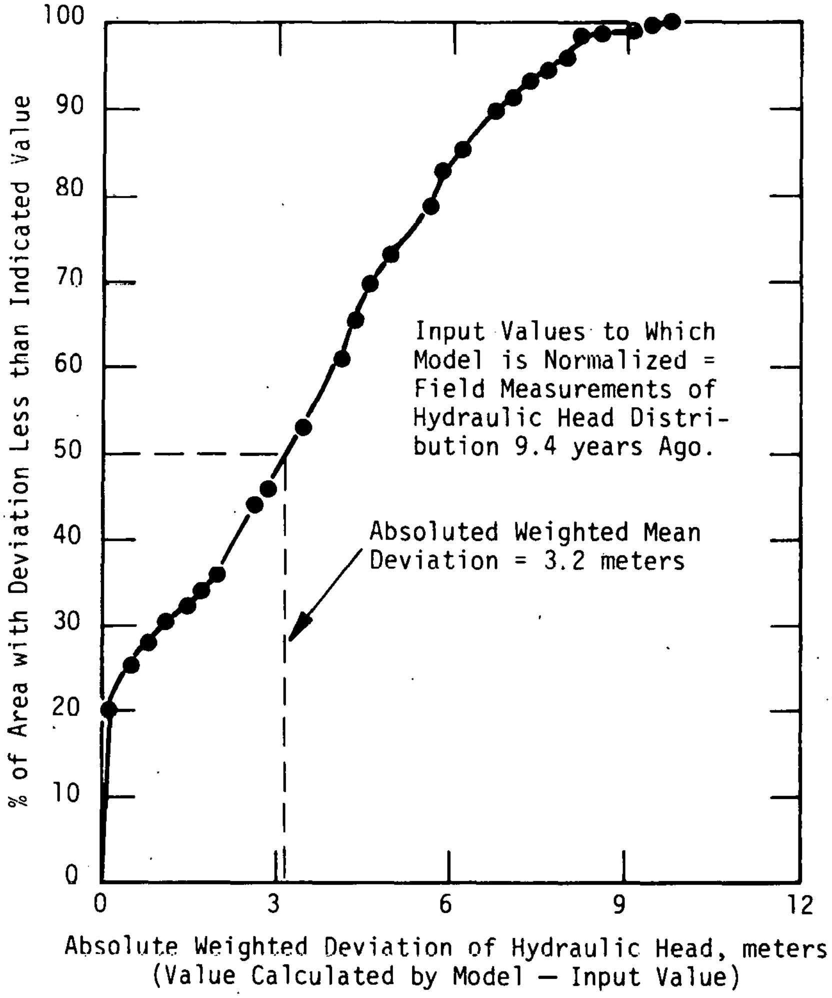


FIGURE 8. Steady-State Calibration of Hydraulic Head Model for the Water Table

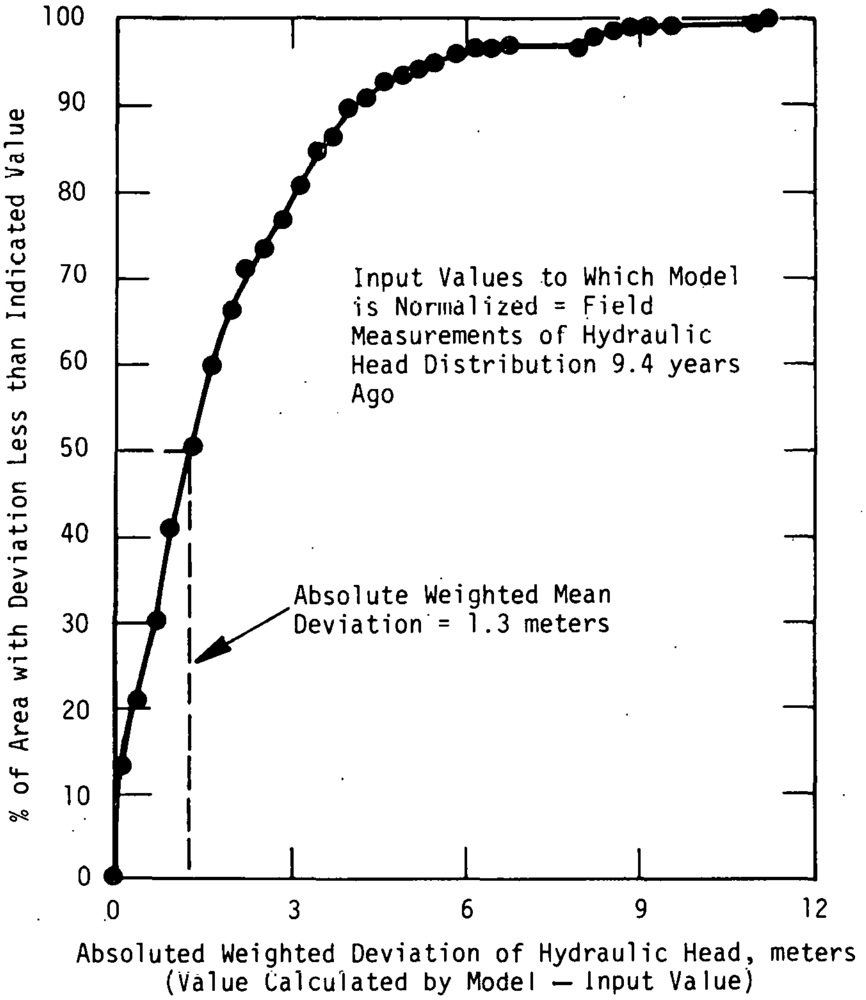


FIGURE 9. Steady-State Calibration of Hydraulic Head Model for the McBean Formation

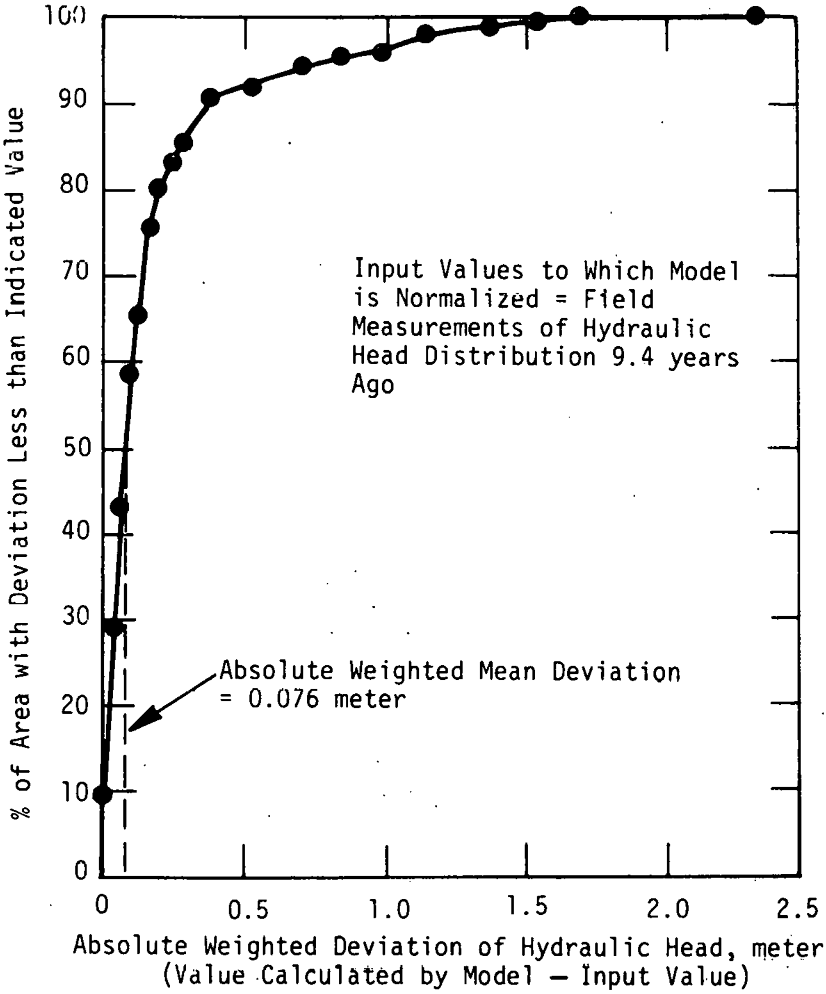


FIGURE 10. Steady-State Calibration of Hydraulic Head Model for the Upper Congaree Formation