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Prepared for:
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CHARACTERIZATION OF GROUNDWATER FLOW AND TRANSPORT IN THE GENERAL SEPARATIONS AREAS SAVANNAH RIVER PLANT:

EFFECT OF GROUNDWATER WITHDRAWALS ON THE TUSCALOOSA-CONGAREE AQUIFER HEAD REVERSAL IN H AREA

January 1988
Final Report

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Technical Memorandum

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January 1988

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EXECUTIVE SUMMARY

In most portions of the General Separations Area at the Savannah River Plant (SRP) an upward hydraulic gradient exists between the Congaree[1] and upper Tuscaloosa aquifers, i.e., hydraulic heads within the Congaree aquifer are lower than those in the upper Tuscaloosa. Because a downward hydraulic gradient generally exists in layers overlying the Congaree, this upward gradient is referred to as a head reversal. Maintenance of this hydraulic head reversal is one element of the SRP groundwater protection program. Numerical simulations of the General Separations Area hydrogeologic system and predictive simulations of current and proposed pumping scenarios were made to assist in the management of area groundwater resources.

The USGS three-dimensional groundwater flow code, MOD-3D, was used for hydrologic simulations. The hydrogeologic system was conceptualized as consisting of a five aquifer, four aquitard framework. Calibration of the flow model was made using available data and estimated hydrologic boundary conditions. Residual maps and a statistical analysis of the residuals show a reasonable match of actual and simulated water levels. Sensitivity analyses were performed on specific groundwater parameters relating to the response of the system to groundwater withdrawals.

Transient simulations based on past and current groundwater pumping rates show a loss of the Congaree/upper Tuscaloosa head reversal in portions of H Area. In the areas of head reversal loss, there is a downward gradient from the Congaree into the Tuscaloosa. By 1987, simulated Congaree hydraulic heads within H Area are at most 11.8 feet higher than the hydraulic heads of the upper Tuscaloosa and approximately 90 percent of the area within the H Area boundary has a downward gradient between these two layers. Currently-proposed groundwater withdrawals were also modeled for pumping locations within S, F, and H areas. Transient simulations show the head difference between the Congaree and upper Tuscaloosa aquifers at a peak value of 14.5 feet by 1990.

Several pumping scenarios were proposed to reduce the loss of

between the Congaree and upper Tuscaloosa aquifers at a peak value of 14.5 feet by 1990.

Several pumping scenarios were proposed to reduce the loss of Congaree/upper Tuscaloosa head reversal. Simulations of these scenarios were made to aid in the selection of projected pumping well locations and screened intervals for optimization of Tuscaloosa aquifer isolation. These scenarios include: (1) currently-proposed pumping, (2) pumping from the Congaree aquifer in H Area, (3) moving production wells currently located within H Area to a location near Upper Three Runs Creek, (4) moving production wells from H Area to F Area, (5) pumping only from the lower Tuscaloosa in H and S Area, and (6) replacement of current H Area production wells with lower discharge production wells around the H Area boundary. By SRP mandate, any new wells installed after 1986 are to be completed in the lower Tuscaloosa aquifer, rather than the upper Tuscaloosa. Therefore, all pumping scenarios that included installation of new production wells assumed that the wells were screened only in the lower Tuscaloosa. Each scenario was modeled assuming steady-state conditions. Results of initial transient simulations showed that steady-state conditions were achieved within the system approximately one to two years after a change in aquifer stress, e.g., a change in pumping rate. Therefore, steady-state simulations were used to illustrate the hydrogeologic response of the conceptualized system to each specific pumping scenario. Results for each model scenario are presented in this report including: (1) head difference maps, (2) calculations showing the areas with loss of Tuscaloosa aquifer isolation, and (3) calculations of peak head differences across the Ellenton confining unit.

A pumping rate of approximately 1000 gpm per facility is the minimum pumping rate for the current F and H Area production centers which would cause a loss of head reversal within H Area. All of the proposed scenario results indicate an improved maintenance of Tuscaloosa isolation in comparison to currently-proposed groundwater withdrawals. Only one scenario, movement of wells from H Area to F Area, ensured complete removal of the head reversal loss from H Area. Based on the results of this study, movement of H Area pumping wells to

F Area is the most effective pumping scheme for ensuring Tuscaloosa isolation. Transient simulation results indicate that steady-state conditions may be achieved within two years after the pumping scenario has been implemented. Although every scenario presented in this report shows improvement over currently-proposed pumping schemes, the most appropriate scenario must be technically and economically feasible as well as ensure Tuscaloosa isolation.

1 INTRODUCTION

1.1 BACKGROUND

The Savannah River Plant (SRP), a major U.S. Department of Energy (DOE) facility, has maintained a number of sites used for land disposal of various waste materials. These materials contain leachable fractions of radionuclide, organic, and inorganic constituents. Environmental programs are presently being conducted at SRP to ensure the protection of water resources, human health, and the environment. The groundwater protection programs consist of detailed site characterization studies, flow system and water quality monitoring, design and implementation of facility closure and, if necessary, corrective action implementation.

The General Separations Area at SRP, located between the Upper Three Runs and Four Mile Creeks, has served as an active area for waste storage for about thirty years. This area contains four major facilities which have received a variety of solid and liquid wastes during plant operations: (1) F Area seepage basins, (2) H Area seepage basins, (3) old radioactive waste burial grounds (643-G), and (4) new radioactive waste burial grounds (643-7G) (Figure 1.1).

The Tuscaloosa aquifer,[1] which lies beneath the General Separations Area, is a water source for SRP and the surrounding area. Maintaining isolation of this aquifer from SRP wastes is of importance to the DOE and SRP. The isolation of the Tuscaloosa aquifer in the General Separations Area has been maintained by an upward hydraulic gradient from the Tuscaloosa aquifer to the overlying Congaree aquifer. This upward gradient is referred to as a hydraulic head reversal in the General Separations Area, i.e., hydraulic heads in the upper Tuscaloosa are higher than hydraulic heads in the Congaree. This head reversal has declined in recent years and no longer exists near H Area due to increased groundwater pumping in the upper and lower Tuscaloosa formations.

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[1] In this report the hydrogeologic nomenclature of Siple (1967) has been utilized (see Appendix A for correlation with other hydrogeologic units).

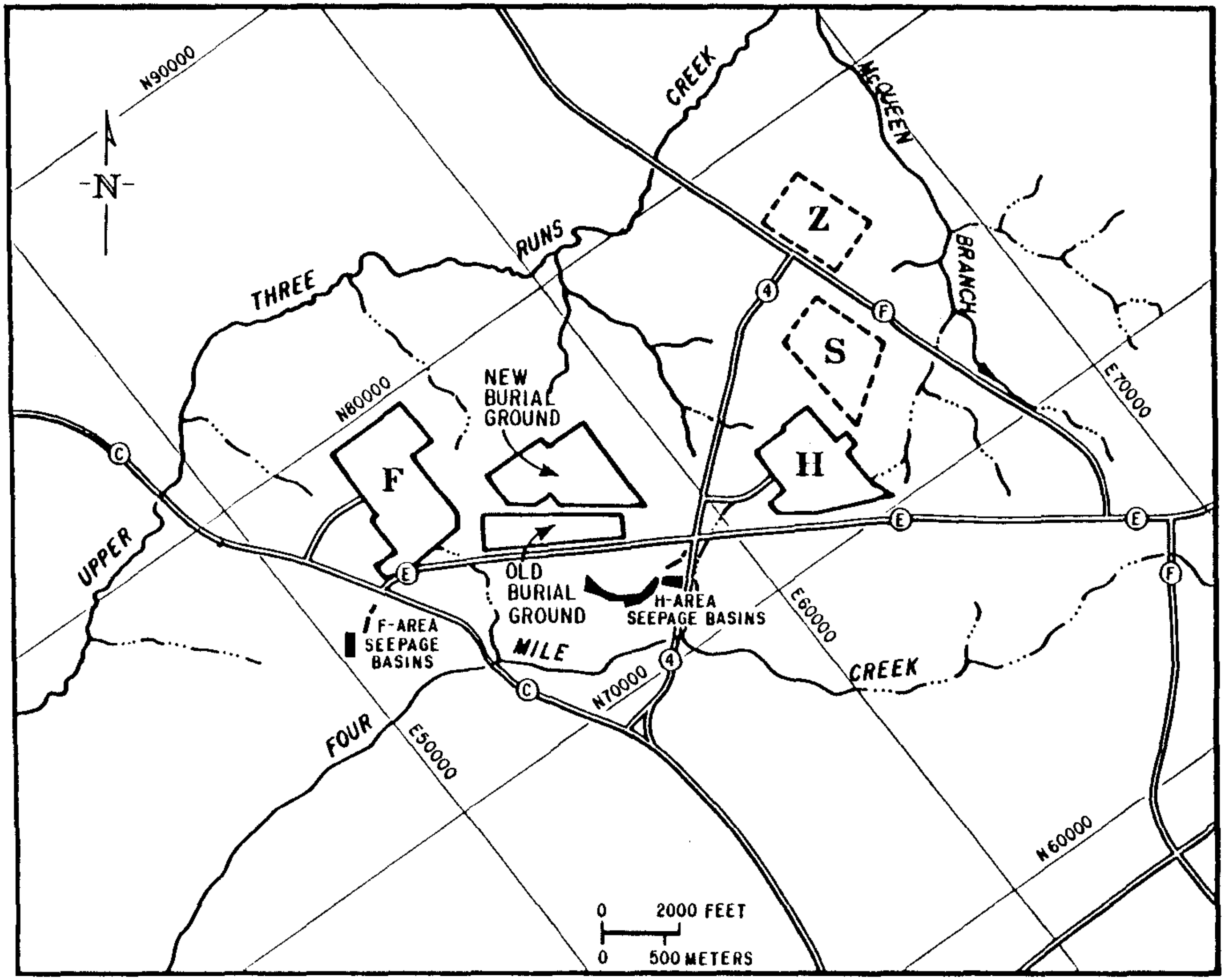

Figure 1.1. Location of General Separations Area.

In May 1987, GeoTrans was requested to address the impact of various groundwater pumping scenarios on the H Area head reversal. A conceptualized hydrogeologic system was simulated using a three-dimensional flow model. Flow modeling was performed with the USGS modular code MOD-3D, (McDonald and Harbaugh, 1984). Model calibration was completed with available water-level measurements, pump test results, and pumping and recharge rates. Predictive simulations on S Area pumping wells, to be operative in 1988, were performed. To better understand the impact of pumping from the Tuscaloosa on the H Area head reversal, the number, rates, and locations of pumping wells were varied.

1.2 OBJECTIVES

The objective of this investigation is to assess the effects of pumping within the General Separations Area on the Congaree/upper Tuscaloosa head reversal. Methods of maintaining future Tuscaloosa aquifer isolation through the optimization of groundwater withdrawal location and rate were studied. Steady-state and transient groundwater flow models were used to characterize past and potential future groundwater conditions. Future groundwater conditions were simulated for a variety of pumping scenarios.

1.3 CONCEPTUAL MODEL OF THE HYDROGEOLOGIC SYSTEM AT THE GENERAL SEPARATIONS AREA

A conceptual model of the hydrogeologic system for the General Separations Area was developed prior to construction of a numerical model. The conceptual model, based on all available data, reports, and field observations, represents a qualitative understanding of the groundwater flow system including aquifer properties, boundary conditions, and physical stresses on the system. The conceptual model forms the basis for development of a mathematical model and subsequent numerical solution, which will be used to simulate groundwater flow.

The conceptual model of the hydrogeologic system at the General Separations Area is illustrated in Figure 1.2. The hydrogeologic system consists of nine important hydrostratigraphic units (Siple,

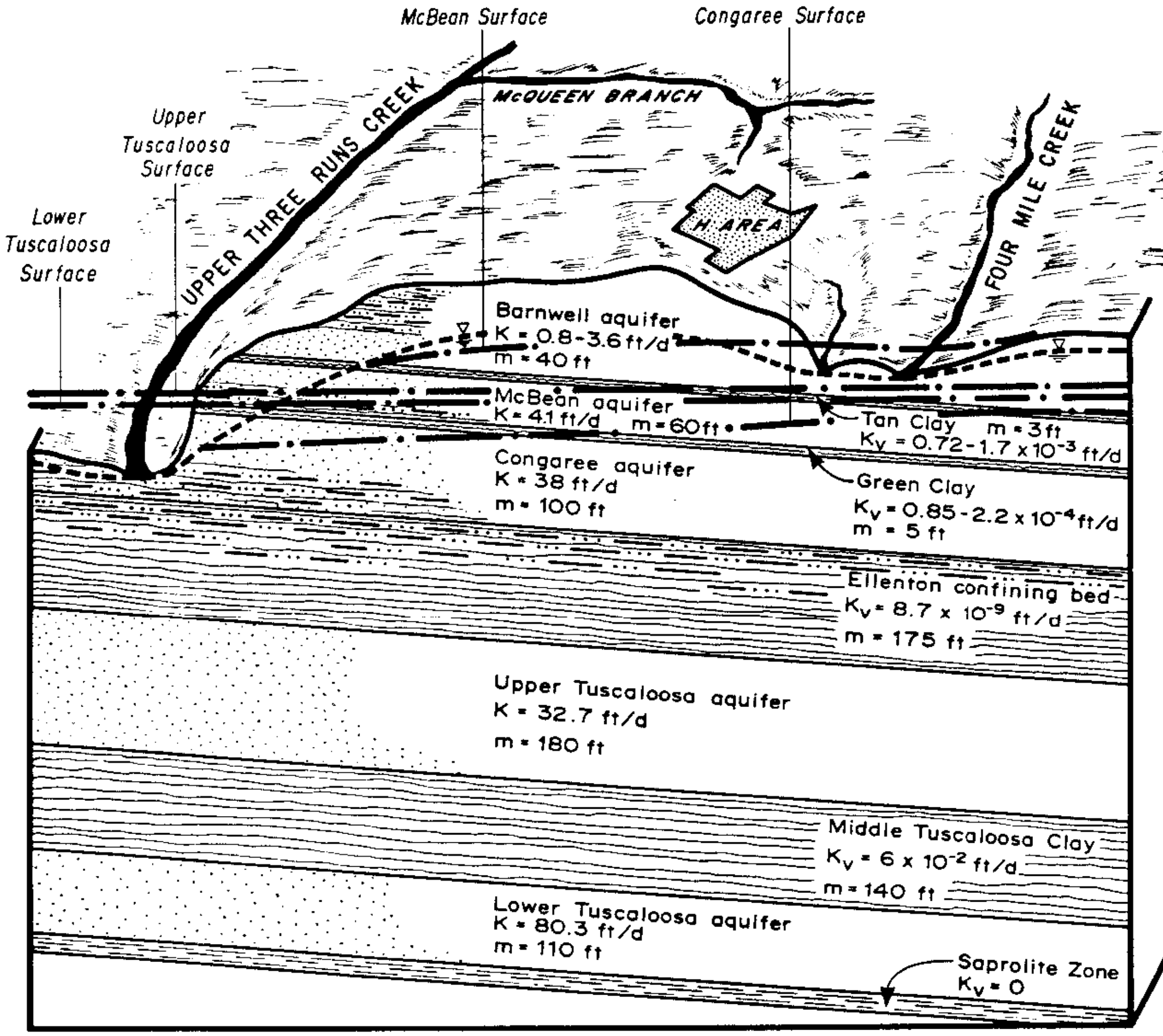

Figure 1.2. Summary of the hydrogeologic system of the model area.

1967). These units include the Barnwell, McBean, Congaree, upper and lower Tuscaloosa aquifers, Tan Clay, Green Clay, Ellenton Clay, and middle Tuscaloosa Clay confining units. Note that since the completion of previous GeoTrans reports, the lithology and thickness of the Tuscaloosa, Ellenton, and Congaree formations were redefined by Everest GeoTech, a geologic consulting firm (unpublished results, Everest GeoTech, 1987). As a result of their findings, this report utilizes revised upper Tuscaloosa and Ellenton saturated thicknesses. The revisions include an increase in Ellenton confining unit thickness and a decrease in upper Tuscaloosa thickness. The vertical sequence and lithologies are summarized in Figure 1.3. The following discussion of the hydrostratigraphic units focuses on the lithologic character, hydraulic characteristics, and flow directions of each unit.

The Barnwell aquifer can be separated into two distinct units by textural characteristics. The upper part of the Barnwell is mostly clayey sand with discontinuous clay and silt lenses; in the lower part, silty and poorly-graded sand predominates. The Tan Clay separates the Barnwell and McBean aquifers. The Tan Clay ranges from 0 to more than 10 ft thick, averaging 3 to 5 ft thick. This clay is thickest and most continuous under H Area. Although the clay is a discontinuous layer, it appears to have confining effects extensively over the study area and is assumed a continuous unit in the model.

The McBean aquifer also exhibits vertical textural trends. The upper part of the unit is mostly clayey sand and poorly-graded sand, while the lower part is predominantly clayey and silty sand; clay and silt lenses are distributed throughout the full thickness of the McBean. Some portions of the McBean also exhibit calcareous zones. The McBean and Congaree aquifers are separated by the Green Clay confining unit. This clay is areally extensive through the model and is treated as a continuous confining unit. The observed thickness ranges from 0 to 20 ft but averages between 3 and 6 ft.

The Congaree is composed of a coarsening upward sequence of clays, silts, and sands. The upper part of the unit consists of poorly-sorted sand. The lower part consists of primarily fine-grained materials such as clayey and silty sand. The Congaree is underlain by the Ellenton

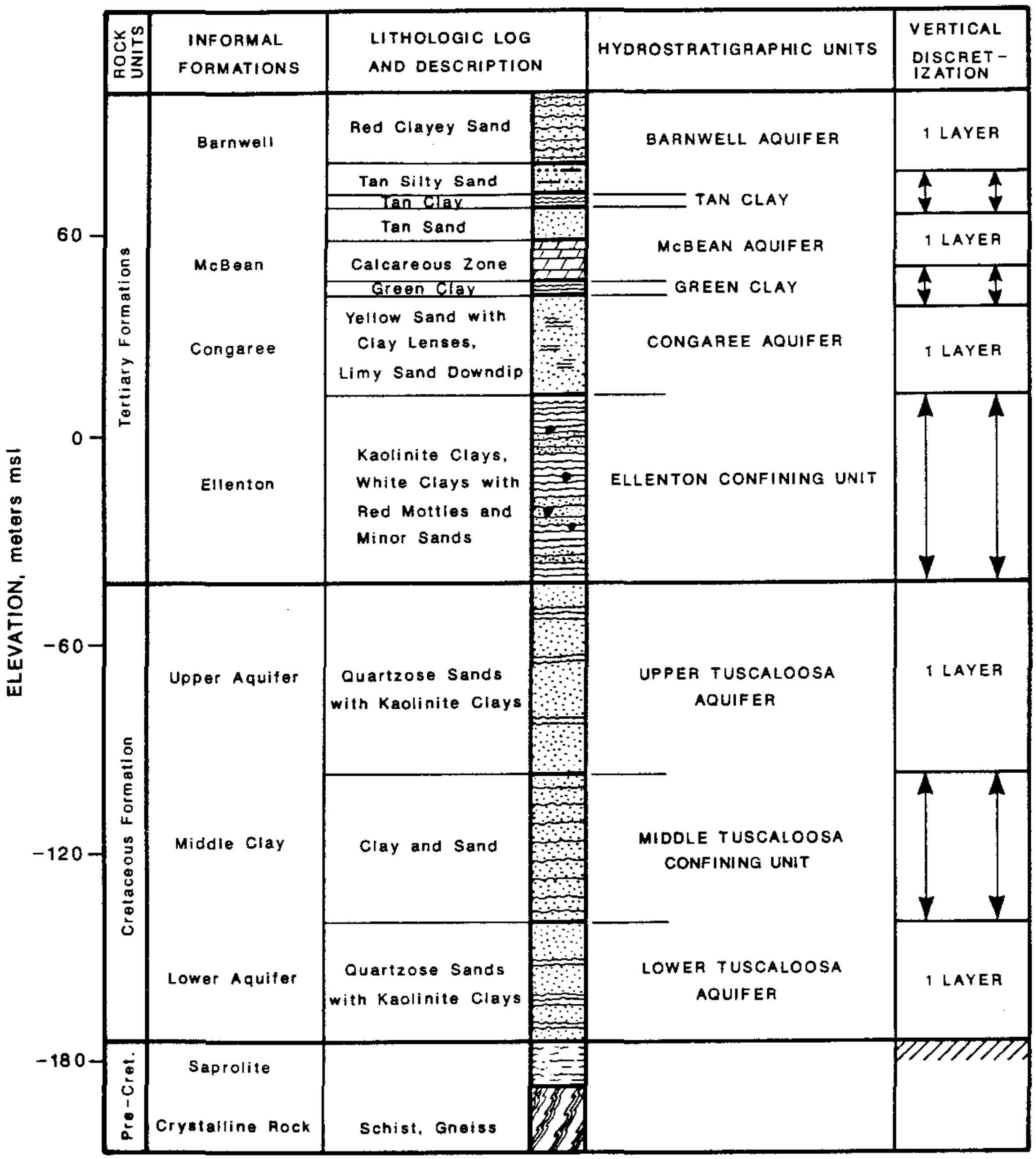

Figure 1.3. Vertical sequence of hydrogeologic units and corresponding model layers at the General Separations Area.

confining unit, a very compact clay and silt sequence approximately 175 ft in thickness. This confining unit restricts flow between the Congaree and upper Tuscaloosa aquifers.

The upper Tuscaloosa consists of cross-bedded quartzose sand and gravel interbedded with lenses of clay and silt. The upper Tuscaloosa is about 180 ft thick in the study area. The upper Tuscaloosa and lower Tuscaloosa aquifers are separated by the middle Tuscaloosa Clay, also known as the Middle Clay. The Middle Clay confining layer consists of an approximately 140-ft thick clay, silt, and sand sequence. The lower Tuscaloosa is about 110 ft thick in the study area and consists of cross-bedded sand and gravel with minor amounts of clay and silt. The lower Tuscaloosa is underlain by a basal variegated clay and saprolite unit. The lower and upper Tuscaloosa formations serve as major sources of water for SRP and the region.

These units are integrated into a multi-aquifer groundwater flow system that exhibits vertical interconnection. The flow paths are characterized by complex horizontal and vertical directions. Large-scale aquifer flow directions are influenced by the following: (1) structural attitude of the aquifers, (2) topographic relief and outcrop pattern, (3) lithologic character (hydraulic conductivity distribution) of the unit, and (4) elevation of bounding streams. Within the model area, the multi-aquifer system has three important factors to consider in relation to hydraulic head distributions: (1) the local reversal of vertical leakage between the Congaree and Tuscaloosa aquifer units in the vicinity of the pumping wells, (2) multidirectional horizontal flow paths in all five aquifers, and (3) strong downward vertical gradients in the Barnwell and McBean aquifers, especially in the area of elevated topography near the center part of the General Separations Area. These features are important in assessing groundwater flow characteristics within the study area.

Two important features within this multi-aquifer system control the flow direction and magnitude of hydraulic head: (1) the elevation of Upper Three Runs Creek and (2) the location of the groundwater divide in the water-table (Barnwell) aquifer. Upper Three Runs Creek acts as a regional discharge area for the Congaree aquifer. This is the result of vertical gradients in the Barnwell and McBean aquifers. Due to vertical gradients, a regional sink for groundwater flow is created in these upper three aquifers. Thus, vertical leakage and contaminants from the Barnwell and McBean aquifers that reach the Congaree will flow toward Upper Three Runs Creek. Horizontal flow in the Barnwell and McBean formations is controlled by a groundwater divide in each formation. This groundwater divide separates flow toward Upper Three Runs Creek from flow toward Four Mile Creek.

The following discussion of the hydraulic properties of the nine hydrostratigraphic units is based on information compiled by various researchers at SRP. Detailed information can be found in Christensen and Gordon (1983) and Parizek and Root (1986).

The water table occurs primarily in the lower Barnwell. The water table slopes laterally away from an east-west trending groundwater divide toward Upper Three Runs Creek and Four Mile Creek. As a result, the saturated thickness of the Barnwell varies from 0 to 80 ft, averaging 40 ft. Based on aquifer tests, the hydraulic conductivity of the formation ranges from 0.1 to 1.0 ft/d. Accordingly, the average transmissivity is about 40 ft^2/d. Assuming a horizontal-to-vertical conductivity ratio of 100:1, the vertical conductivity is 0.01 ft/d.

Near Upper Three Runs Creek, the McBean becomes unsaturated as the water table exists in the underlying Congaree. Therefore, the saturated thickness of the McBean in part of the study area approaches zero. Where the formation is fully saturated, its thickness is approximately 60 ft. The hydraulic conductivity of the formation is on the order of 0.1 to 1.0 ft/d (based on aquifer tests). Thus, the transmissivity ranges from 0 to 60 ft^2/d. Assuming a horizontal-to-vertical conductivity ratio of 100:1, the vertical conductivity is 0.01 ft/d.

Transmissivity measurements of the Congaree aquifer range from 500 to 7000 ft^2/d. Its saturated thickness is about 100 ft. The estimated horizontal-to-vertical conductivity ratio is 100:1; therefore, vertical conductivity is estimated to be in the range of 0.05 to 1.0 ft/d.

Reported transmissivity values for the combined upper and lower Tuscaloosa aquifers range from 10,000-26,000 ft^2/d. Estimates for the specific upper and lower Tuscaloosa aquifer transmissivities range from 4,000 to 10,000 ft^2/d and 6,000 to 16,000 ft^2/d, respectively. The saturated thickness of the upper Tuscaloosa aquifer is 180 ft; the saturated thickness of lower Tuscaloosa aquifer is 110 ft. Assuming a horizontal-to-vertical conductivity ratio of 10:1, the vertical conductivity of the upper Tuscaloosa may be on the order of 2 to 5 ft/d.

Only very limited hydraulic testing has been performed on the confining units within the study area. The Tan Clay vertical conductivity of 2×10^{-3} ft/d is estimated from one measurement north of H Area. Vertical conductivity measurements are not available for the Green Clay, the upper Ellenton Formation, or the middle Tuscaloosa Clay; the estimated average vertical conductivities for Green Clay, the upper Ellenton and the middle Tuscaloosa Clay are 1.5×10^{-4} ft/d, 8.7×10^{-9} ft/d, and 6×10^{-2} ft/d, respectively.

Two source terms are important for the steady-state flow model construction. A recharge estimate of 15 in/yr is assigned uniformly over the model domain. Additional sources exist at the F and H Area seepage basins. The mean flux rate from the basins to the water table are 0.14 ft^3/s and 0.34 ft^3/s, respectively (Christensen and Gordon, 1983).

Several groundwater sinks have been identified within the General Separations Area. In 1987, an estimated average of 2200 gpm per facility was pumped from the Tuscaloosa formations to provide water for F and H Areas. Predicted groundwater withdrawals averaging 500 gpm are proposed for future S Area production wells with alternating pumpage from two separate wells. These wells have been installed and are screened over portions of the lower Tuscaloosa, middle Clay, and upper Tuscaloosa formations. In addition, increased pumping of the lower Tuscaloosa in F and H Areas is proposed for activation in 1989.

1.4 SUMMARY OF PREVIOUS GROUNDWATER FLOW MODELING

At SRP, considerable technical effort and cost has been expended to employ three-dimensional flow and transport models in quantifying subsurface phenomena related to environmental management and conditions near waste facilities. GeoTrans has contributed significantly to this effort by constructing and calibrating a series of numerical flow and contaminant transport models within the General Separations Area. The purpose of this section is to summarize briefly the nature of the flow modeling applications and reference pertinent reports which provide supporting detail and technical analysis.

Five specific modeling studies concerning groundwater flow and solute transport have been completed by GeoTrans.

1. Buss, D.R., G.M. Duffield, R.W. Root, Jr., S.S. Hughes, and J.W. Mercer, 1986a. Characterization of groundwater flow and transport in the General Separations Areas, Savannah River Plant: Flow model calibration report, prepared for E.I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

2. Duffield, G.M., D.R. Buss, and R.W. Root, Jr., 1986. Characterization of groundwater flow and transport in the General Separations Areas, Savannah River Plant: Flow model refinement and particle-tracking analysis report, prepared for E.I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

3. Rumbaugh, J.O., III, D.R. Buss, G.M. Duffield, J.W. Mercer, 1986. Characterization of groundwater flow and transport in the General Separations Areas, Savannah River Plant: Unsaturated flow and transport analysis for H Area, prepared for E.I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

4. Buss, D.R., G.M. Duffield, T.S. Wadsworth, J.W. Mercer, 1986b. Characterization of groundwater flow and transport in the General Separations Areas, Savannah River Plant: Evaluation of a corrective groundwater action for the F and H Area Seepage Basins, prepared for E.I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

5. Duffield, G.M., D.R. Buss, and C.P. Spalding, III, 1987. Characterization of groundwater flow and transport in the General Separations Area, Savannah River Plant: Evaluation of closure cap effectiveness Mixed Waste Management Facility (643-28G), GeoTrans, Inc., Phase I Report, Prepared for E.I. du Pont de Nemours Company, Savannah River Plant, Aiken, South Carolina.

The numerical model reports consider flow and transport at two scales within the General Separations Area at SRP. Calibration of the regional flow model of the General Separations Area provided a set of hydraulic parameters (transmissivities and leakage coefficients) for a four aquifer and three aquitard groundwater flow system. The conceptual model of Parizek and Root (1985) and its supporting data were reviewed and modified to provide the basis for a three-dimensional flow model of the General Separations Area. The conceptual model and the preliminary flow model results are presented in Buss, et al. (1986). Further studies were performed to refine and validate the groundwater model. Topics covered in Duffield et al. (1986) included: (1) a summary of the hydrogeologic conditions of the area, (2) observed flow velocities at the study site, (3) a summary of results from the preliminary flow modeling effort, (4) flow model refinement and results, and (5) particle tracking analyses based on the refined flow model.

Based on the results of the regional model, local models were constructed to simulate groundwater flow and solute transport at two waste sites within the General Separations Area. A two-dimensional flow and solute transport model was applied by Rumbaugh et al. (1986) to a vertical cross-section through the H Area Seepage Basin No. 4. The modeling results illustrated the dominance of vertical flow beneath the seepage basin.

Using a telescopic mesh refinement (TMR) technique, Buss et al. (1986b) constructed groundwater models using boundary conditions and hydraulic parameter estimates abstracted from the larger regional flow model by Duffield et al. (1986) to study the F and H Area seepage basins. Flow and solute transport were simulated from the refined grid by applying a quasi-three-dimensional representation of the Barnwell and McBean aquifers and the Tan and Green Clay confining units. The smaller models for the F and H Area seepage basins encompassed 1.8 and 0.54 mi^2 areas, respectively, within the regional model domain. The local models, incorporating hypothetical initial contaminant distributions, were designed to: (1) predict concentrations at point-of-compliance wells located 30 ft downgradient from the seepage basin facilities, and (2) design and evaluate a postulated groundwater extraction/injection well system for each facility.

The regional flow model previously calibrated for the General

Separations Area (Duffield et al., 1986) was used for quantitative assessment of closure capping alternatives at Mixed Waste Management Facility (643-28G). The USGS modular three-dimensional (MOD-3D) flow code (McDonald and Harbaugh, 1984) was used to evaluate 84, 90, and 96 percent reductions in the 15 in/yr estimated average recharge rate induced by cap emplacement. Water balance calculations, potentiometric surfaces, vertical head differences, and travel estimates were studied.

The regional flow model of the General Separations Area presented in this report covered a 17 mi^2 area. The limits of the model domain were carefully selected to coincide with appropriate hydrologic boundaries controlling regional groundwater flow. A five layer model of the hydrogeologic system at the General Separations Area was chosen. This groundwater flow model discretized the lower Tuscaloosa formation in addition to the discretization of the Barnwell, McBean, Congaree, and upper Tuscaloosa formations presented in previous GeoTrans reports. This discretization allowed groundwater withdrawals from the H, F, and S Areas to be accounted for. Calibration of the regional model was first attempted by a nonlinear least-squares technique, resulting in hydraulic parameter estimates for the five aquifers and four aquitards represented. The parameter estimation algorithm used 54 observed water-levels distributed areally and vertically in the model domain as targets for the calibration of the model. The nonlinear least-squares technique failed to converge, however, due to the scarcity of water-level data for the Tuscaloosa aquifers. Transmissivities in the Tuscaloosa were then selected based on site-wide pump test results and simple model calibrations.

2 QUANTITATIVE ASSESSMENT AND RESULTS

2.1 METHOD OF INVESTIGATION

The regional flow model for the General Separations Area (Duffield et al., 1986) was used for the quantitative assessment of groundwater withdrawal alternatives in the Tuscaloosa and Congaree formations. Modeling was performed with the USGS modular three-dimensional (MOD-3D) flow code (McDonald and Harbaugh, 1984). An estimated average precipitation recharge of 15 in/yr was considered to reach the water-table surface. Steady-state and transient simulations were performed to develop an understanding of interactions of estimated aquifer transmissivities, hydraulic head changes, flow directions, and time-dependent response of the flow system to different pumping scenarios. The sensitivity of the system to differing transmissivities and storage coefficients within the Tuscaloosa formation also was assessed.

2.2 MODEL CONFIGURATION, BOUNDARY CONDITIONS, SOURCES, SINKS, AND ASSUMPTIONS

A block-centered, finite-difference grid consisting of 39 rows and 40 columns was constructed for the General Separations Area model (Figure 2.1). Block dimensions along the rows and columns range from 400 to 1500 ft. Variable grid spacing was used to achieve greater detail in the vicinity of the pumping wells, burial grounds, and the F and H Area seepage basins.

Five aquifer units from the study area are included in the vertical discretization of the model. As shown in Figure 2.2, these aquifer units are the Barnwell, McBean, Congaree, and upper and lower Tuscaloosa. Transmissivity/hydraulic conductivity was considered to be isotropic within each discretized layer and each of the aquifers is represented in the model by a single layer of nodes.

The Tan Clay, Green Clay, Ellenton Clay and middle Tuscaloosa Clay confining beds were not discretized in the model. These units were represented by leakance coefficients accounting for both vertical conductivity and saturated thickness of each aquitard. This quasi-

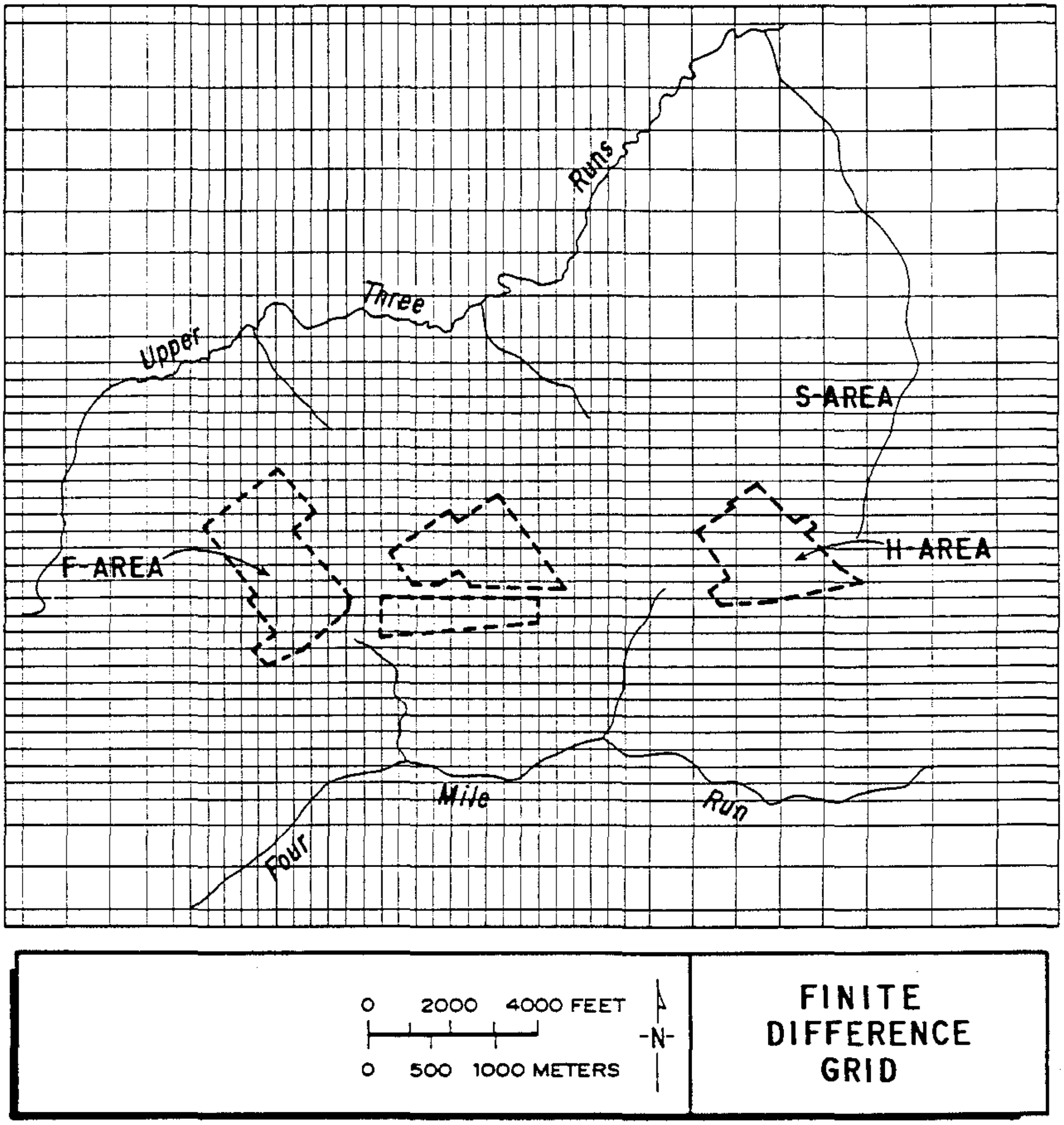

Figure 2.1. Finite-difference grid for General Separations Area flow model.

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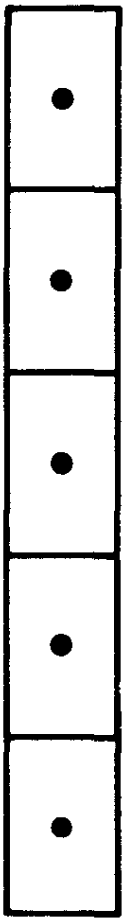

MODEL LAYER	AQUIFER UNIT	UNDERLYING CONFINING UNIT/TYPE
1	Barnwell	Tan Clay/aquitard
2	McBean	Green Clay/aquitard
3	Congaree	Ellenton Clay/aquitard
4	Upper Tuscaloosa	Middle Clay/aquitard
5	Lower Tuscaloosa	Saprolite/aquiclude

Figure 2.2. Vertical discretization in flow model.

three-dimensional approach assumes approximately horizontal flow in the aquifers and both vertical flow and no storage in the confining beds.

To represent the variety of physical boundaries and conditions existing in the General Separations Area, mixed boundary conditions including specified hydraulic head and specified flux conditions are prescribed in the numerical model. For example, in the steady-state model, rivers and streams are represented by a specified head boundary condition and precipitation recharge is simulated by a specified flux boundary condition. Depending upon the model layer, these boundary conditions differ according to the specific physical boundaries. In general, surface streams are the limiting lateral boundaries of the model. These streams are Upper Three Runs Creek, McQueen Branch, and Four Mile Creek (Figure 1.1). The following discussion of the model boundary conditions identifies the boundaries specified in each model layer.

No-flow and specified head boundary conditions assigned to the Barnwell aquifer are shown in Figure 2.3. Specified heads are assigned to the upper part of McQueen Branch, the greater portion of Four Mile Creek located within the model space, and two unnamed tributaries to Four Mile Creek to the south of the old burial ground. The no-flow boundary prescribed along the model boundary to the east of H Area corresponds to a flow-line running from the topographic high toward McQueen Branch and Four Mile Creek. No-flow conditions assigned at other Barnwell aquifer boundaries represent (1) limits of the aquifer defined by stream incision, or (2) limits of saturated aquifer conditions. The Barnwell is an unconfined aquifer with a variably saturated thickness. The base of the aquifer was defined by structure contours on the top of Tan Clay (Parizek and Root, 1986). A leakance coefficient assigned to the lower aquifer boundary controls the vertical flow across the Tan Clay confining bed to the McBean aquifer. Inflow to the Barnwell aquifer includes precipitation recharge at a rate of 15 in/yr and seepage from F and H area seepage basins. Estimated seepage rates are assigned as 7,776 and 11,060 ft^3/d for F and H area, respectively, and are simulated up to 1987. These seepage rates are based on those results reported by Christensen and Gordon

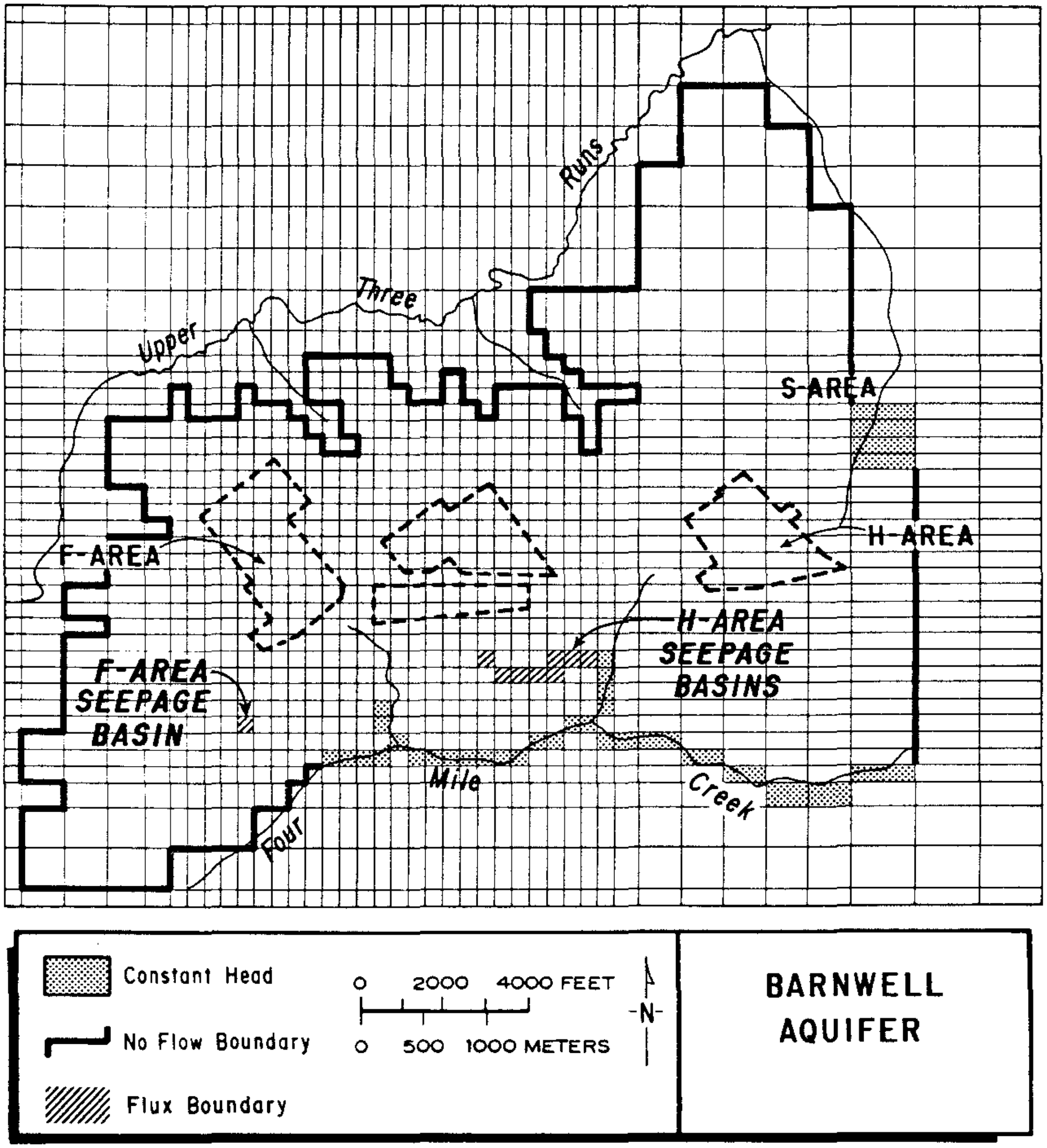

Figure 2.3. Boundary conditions in Barnwell aquifer.

(1983) and conversations with SRP personnel.

Figure 2.4 shows specified head and no-flow boundary conditions for the McBean aquifer. Specified head values were assigned along McQueen Branch, the lower segment of Four Mile Creek (within the model space), and upper segments of the two unnamed tributaries to Upper Three Runs Creek north of the old burial ground. Specified heads assigned at the southwest corner of the model domain were based upon a water-table surface presented in Parizek and Root (1986). Stream incision by Upper Three Runs Creek has removed the McBean aquifer along Upper Three Runs Creek (Parizek and Root, 1986); therefore, fluxes at these boundaries are set to zero. The no-flow boundary at the eastern limit of the model domain corresponds to a flow-line from the H Area topographic high north toward McQueen Branch and south toward Four Mile Creek. The no-flow boundary fixed along Four Mile Creek is based on the assumption that groundwater flow in the McBean from the study site is upward to Four Mile Creek. Similarly, flow from the unmodeled area south of the General Separations Area is assumed to discharge to Four Mile Creek. The base of the aquifer was defined by structure contours of the top of the Green Clay (Parizek and Root, 1986). The underlying Green Clay is represented by a leakance coefficient which controls the vertical flow between the McBean and the underlying Congaree aquifer. Precipitation recharge at a rate of 15 in/yr is specified in areas where the McBean is unconfined. No pumping occurs in the McBean.

The boundary conditions prescribed for the Congaree aquifer are shown in Figure 2.5. All lateral model boundaries in this aquifer are modeled as specified head nodes. Stream elevations define the specified heads at Upper Three Runs Creek, the lower reach of McQueen Branch, and the lower reaches of two unnamed tributaries to Upper Three Runs Creek located north of the radioactive burial grounds (643-7G). All other specified head values shown in Figure 2.5 were determined from a map of the Congaree potentiometric surface given in Parizek and Root (1986). Vertical flow across the Ellenton confining bed was treated by a leakance coefficient and allows leakage to occur between the Congaree and the upper Tuscaloosa aquifer. Except for a single hypothetical case, no pumpage from the Congaree is included in the

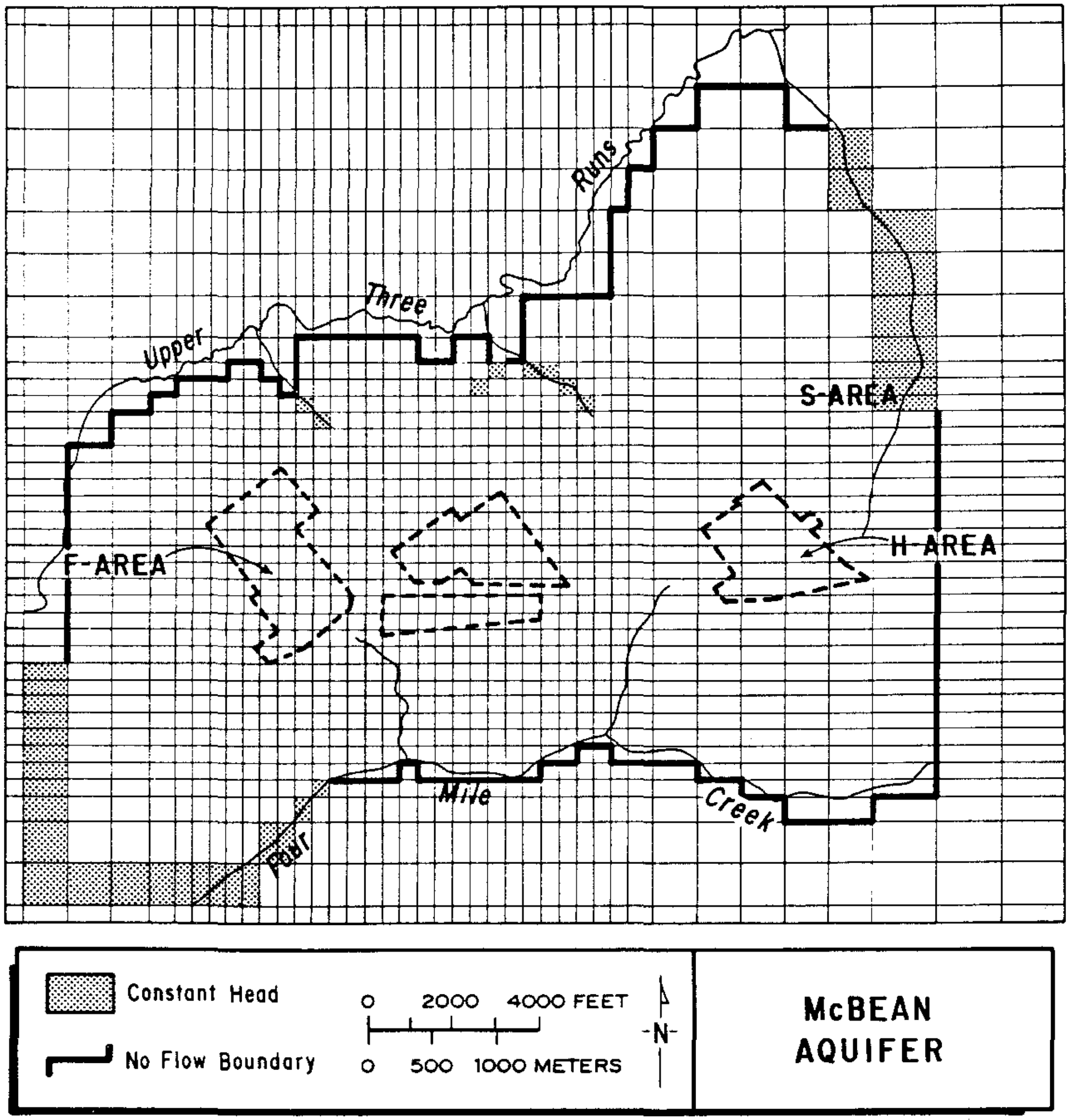

Figure 2.4. Boundary conditions in McBean aquifer.

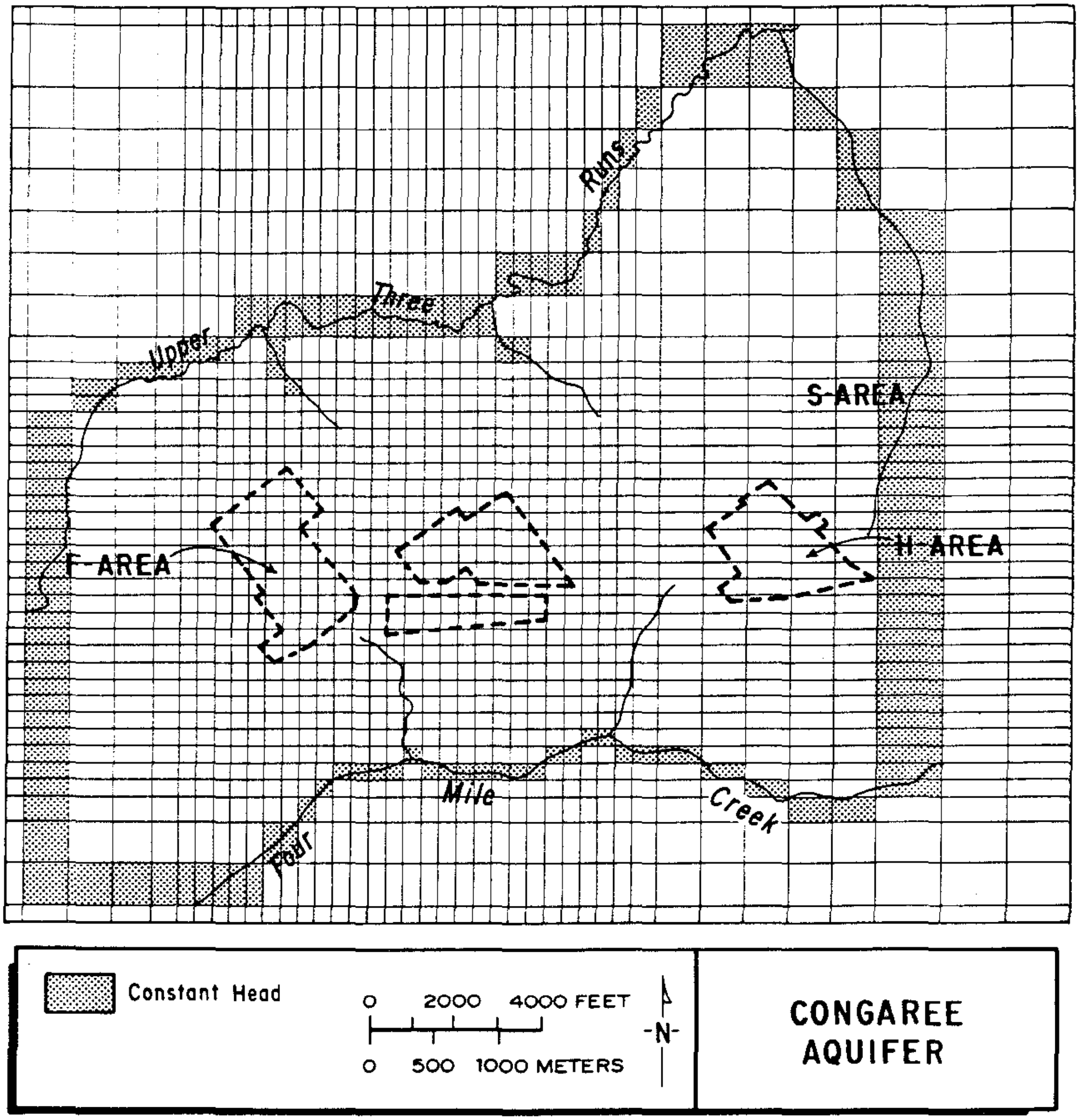

Figure 2.5. Boundary conditions in Congaree aquifer.

model, and because the Congaree is treated as a confined unit, no precipitation recharge is specified.

Boundary conditions for the upper Tuscaloosa aquifer are shown in Figure 2.6. Specified head conditions are prescribed along all lateral boundaries for this aquifer. The specified head values are based upon the potentiometric surface contours of Siple (1967), and more recent hydraulic head measurements available from Christensen and Gordon (1983) and Bechtel (1982). A leakance coefficient is specified for the middle Tuscaloosa Clay and allows vertical flow between the upper and lower Tuscaloosa aquifers. Specified head boundaries are also prescribed along all lateral boundaries for the lower Tuscaloosa as shown in Figure 2.7. Specified head values are based on groundwater head values reported by SRP (personal communication, Stephenson, 1987). A no-flow boundary is specified at the base of the lower Tuscaloosa aquifer coinciding with the lithologic contact between the lower Tuscaloosa and underlying pre-Cretaceous formations. Pumping occurs at two locations in the upper and lower Tuscaloosa aquifers in F and H Areas. Total pumpage at each location was approximately 1700 gpm in 1979 and 2200 gpm in 1987. These well locations were selected to represent the combined pumping of the individual wells at F and H Areas. The total pumping rate for the F and H Area was apportioned to sixty percent of groundwater withdrawals from the lower Tuscaloosa and forty percent of groundwater withdrawals for the upper Tuscaloosa. These estimates were based in part on the reported lithologic character of each unit. The upper and lower Tuscaloosa aquifers receive no precipitation recharge.

2.3 MODEL CALIBRATION AND SENSITIVITY ANALYSIS

Calibration of the General Separations Area model was performed using estimates of transmissivities based on site-wide results of SRP pump tests and transmissivities estimated from previous model calibrations made by GeoTrans. Previously calibrated values of transmissivity were selected for the Barnwell, McBean, and Congaree aquifers. Aquifer transmissivities for the upper and lower Tuscaloosa formations were obtained using an iterative process of comparing actual

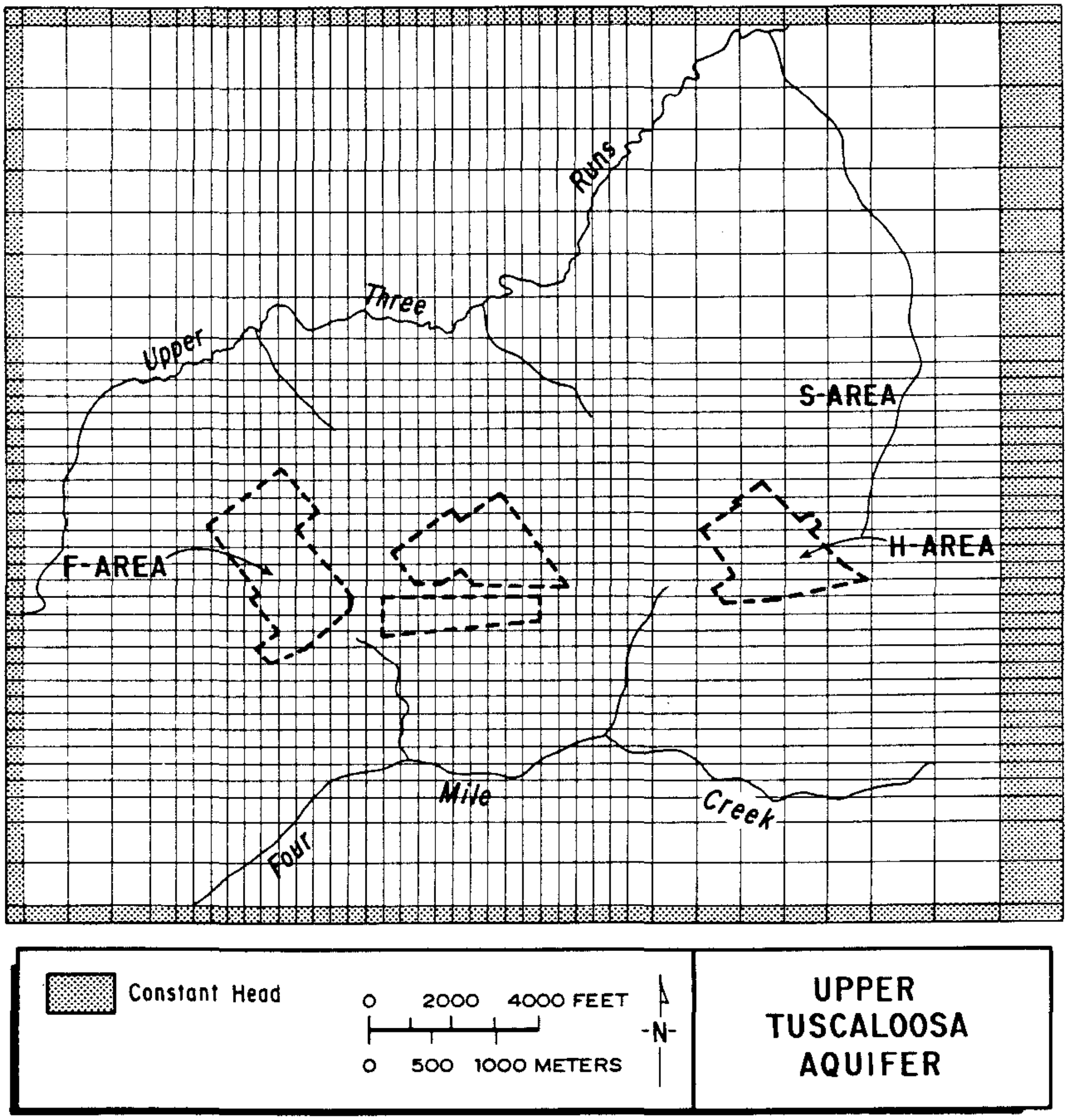

Figure 2.6. Boundary conditions in upper Tuscaloosa aquifer.

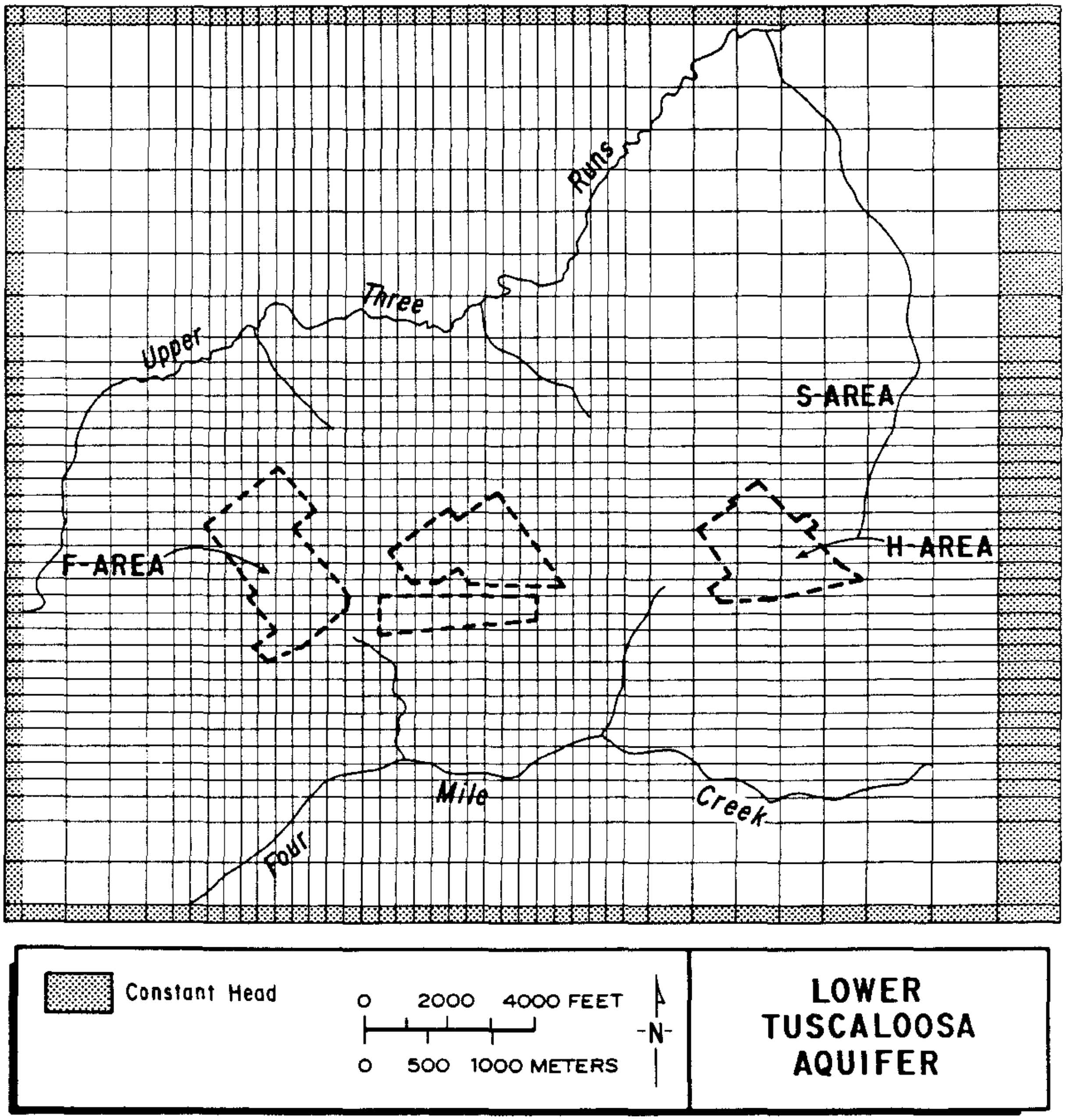

Figure 2.7. Boundary conditions in lower Tuscaloosa aquifer.

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groundwater head values with simulated head values generated from estimated aquifer transmissivities. Initial estimates were chosen to apportion a combined upper and lower Tuscaloosa transmissivity of sixty percent to the lower Tuscaloosa and forty percent to the upper Tuscaloosa. This division of aquifer transmissivities is based on knowledge of specific aquifer lithologies. Predictive simulations could be made after trial transmissivity values produced a satisfactory match of actual and simulated hydraulic heads. Hydraulic properties estimated by previous calibration procedures are presented in Table 2.1. Two zones were defined for (1) Barnwell hydraulic conductivity, (2) Tan Clay leakance coefficient, and (3) Green Clay leakance coefficient. The zonation for these properties are shown in Figures 2.8 and 2.9. In general, the calibrated hydraulic parameters agreed well with field and laboratory estimates.

An attempt was made to automatically calibrate the General Separations Area model using a nonlinear least-squares technique known as the Gauss-Newton method. This algorithm was incorporated by GeoTrans into the MOD-3D code to ease calibration of groundwater flow models. This calibration technique essentially automates and optimizes the iterative process of matching aquifer transmissivities and hydraulic heads. A total of 54 observed water-levels were selected for steady-state (1979) calibrations. Due to a scarcity of measured hydraulic head values in the lower and upper Tuscaloosa aquifers, however, the model failed to give satisfactory results and a trial-and-error technique was utilized.

An analysis of model residuals (differences between observed and calculated hydraulic heads) was performed to check the fit of the model to the real flow system. Various diagnostic checks were applied to the model residuals to examine their statistical and spatial distributions. Summary statistics for the residuals for steady-state conditions are shown in Table 2.2. Analysis of residual distribution was performed on both steady-state (1979) and transient simulations (1979-1987). Residual plots for the 1979 steady-state and 1987 transient simulations are shown in Figures 2.10 and 2.11. These figures show a reasonable match between both steady-state (1979) and transient (1987) simulated

Table 2.1. Hydraulic parameters in the flow model and their calibrated estimates.

Hydrostratigraphic unit	Hydraulic parameter	Calibrated estimate
Lower Tuscaloosa aquifer	transmissivity	8824 ft^2/d
Upper Tuscaloosa aquifer	transmissivity	5882 ft^2/d
Congaree aquifer	transmissivity	3800 ft^2/d
McBean aquifer	hydraulic conductivity	4.1 ft/d
Barnwell aquifer		
zone I	hydraulic conductivity	0.8 ft/d
zone II	hydraulic conductivity	3.6 ft/d
Middle Tuscaloosa Clay confining bed		
	leakance coefficient	4.0×10^{-4} d^{-1}
	vertical hydraulic conductivity[1]	6.0×10^{-2} ft/d
Ellenton confining bed	leakance coefficient	5.0×10^{-11} d^{-1}
	vertical hydraulic conductivity[2]	8.7×10^{-9} ft/d
Green Clay confining bed		
zone I	leakance coefficient	4.4×10^{-5} d^{-1}
	vertical hydraulic conductivity[3]	2.2×10^{-4} ft/d

[1]Saturated thickness = 140 ft.
[2]Saturated thickness = 175 ft.
[3]Saturated thickness = 5 ft.
[4]Saturated thickness = 3 ft.

Table 2.1. (continued).

Hydrostratigraphic unit	Hydraulic parameter	Calibrated estimate
zone II	leakance coefficient	$1.7 \times 10^{-5}\ d^{-1}$
	vertical hydraulic conductivity[3]	8.5×10^{-5} ft/d
Tan Clay confining bed		
zone I	leakance coefficient	$5.5 \times 10^{-4}\ d^{-1}$
	vertical hydraulic conductivity[4]	1.7×10^{-3} ft/d
zone II	leakance coefficient	$2.4 \times 10^{-4}\ d^{-1}$
	vertical hydraulic conductivity[4]	7.2×10^{-4} ft/d

[1] Saturated thickness = 140 ft.
[2] Saturated thickness = 175 ft.
[3] Saturated thickness = 5 ft.
[4] Saturated thickness = 3 ft.

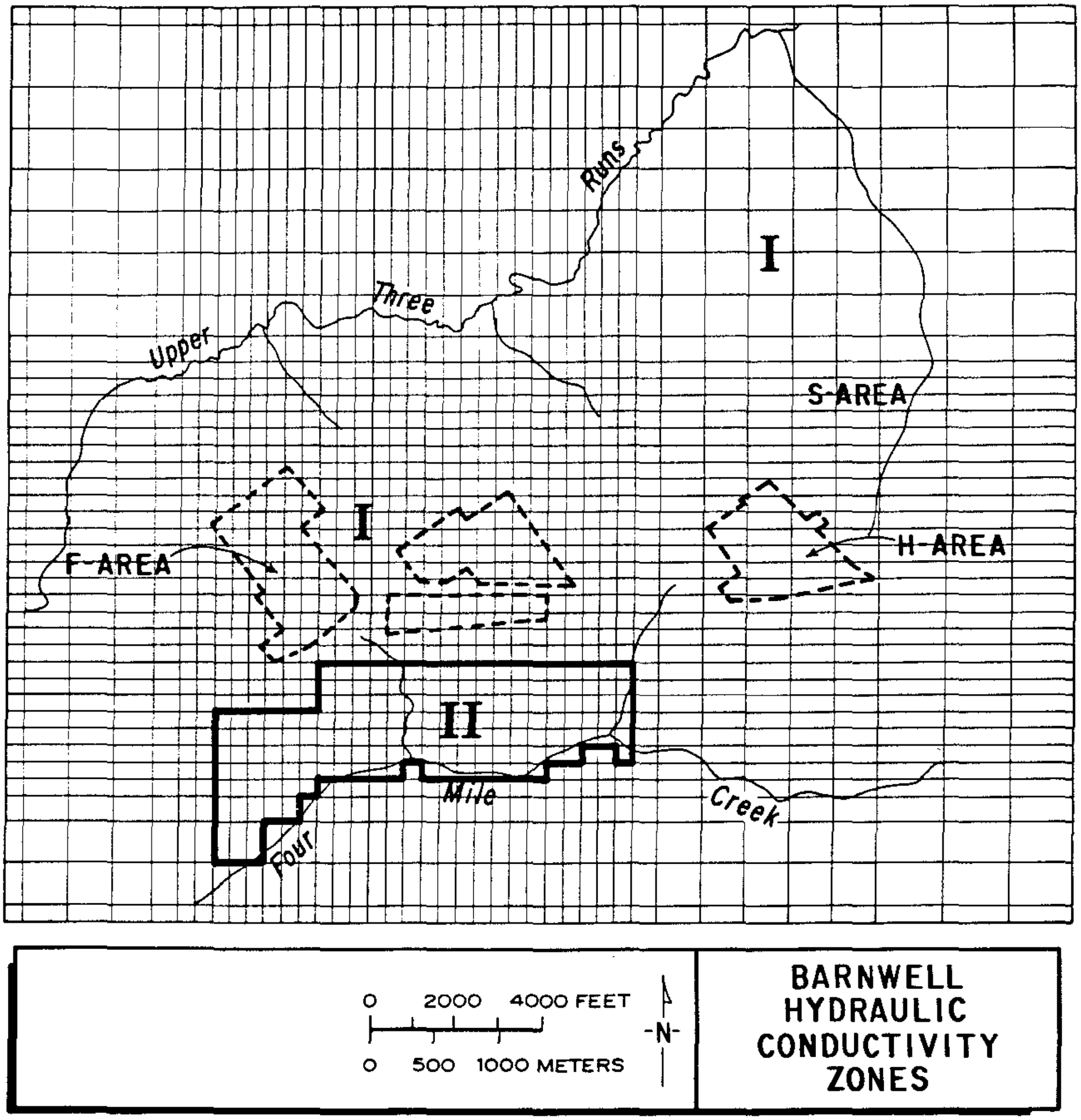


Figure 2.8. Barnwell hydraulic conductivity zones.

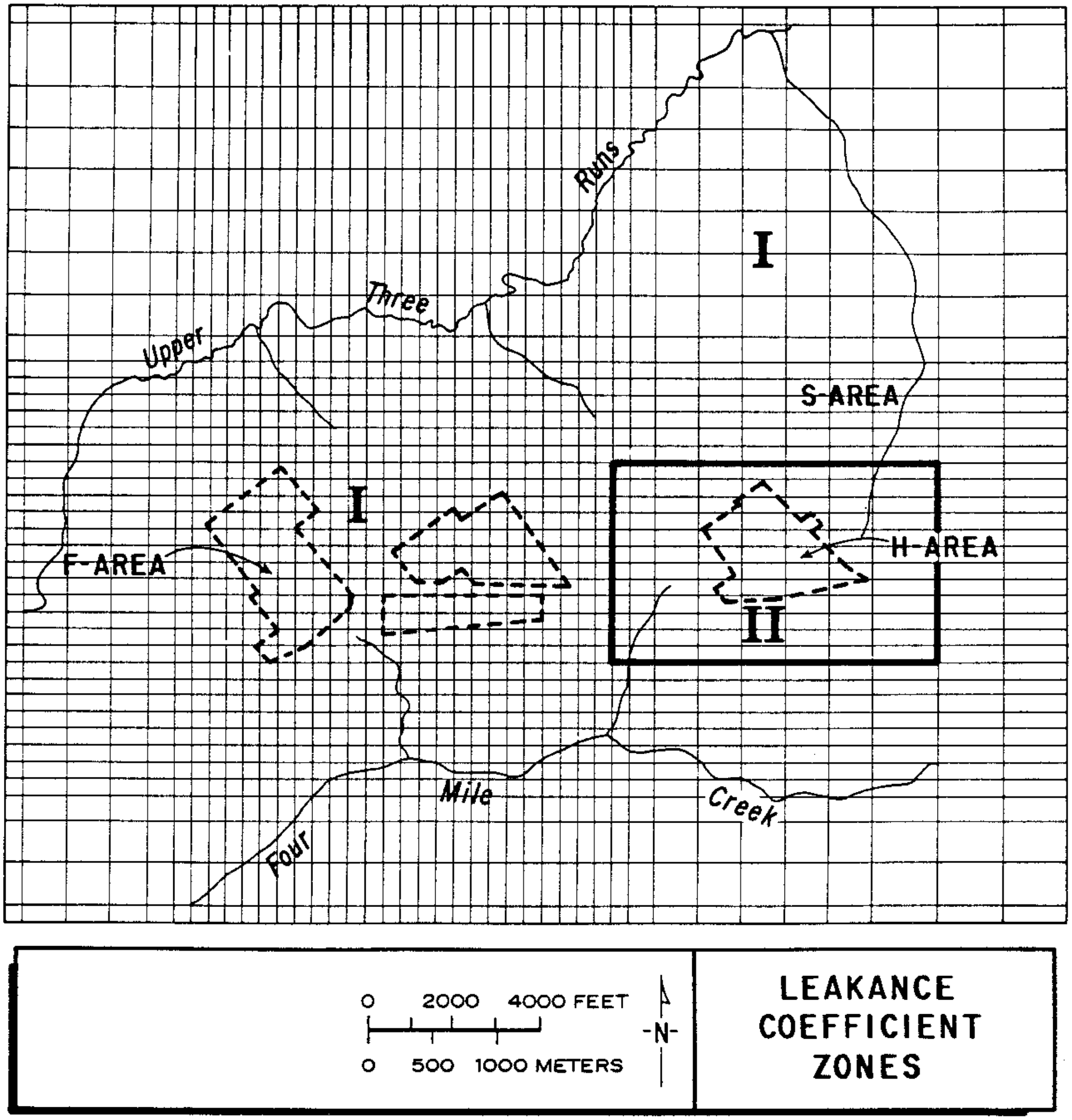


Figure 2.9. Tan Clay and Green Clay leakance coefficent zones.

Table 2.2. Summary statistics for the residuals in the calibrated flow model.

residual, e = observed head - calculated head

number of residuals, n = 54

mean residual, $\bar{e} = \frac{1}{n} \sum_{i=1}^{n} e_i = -0.088$

residual sum of squares = $\sum_{i=1}^{n} e_i^2 = 408.90$

residual variance, $s_e^2 = \frac{\sum_{i=1}^{n} e_i^2}{n-p}$, p = number of model parameters = 12

$= 9.735$

residual standard deviation, $s_e = \sqrt{s_e^2} = 3.120$

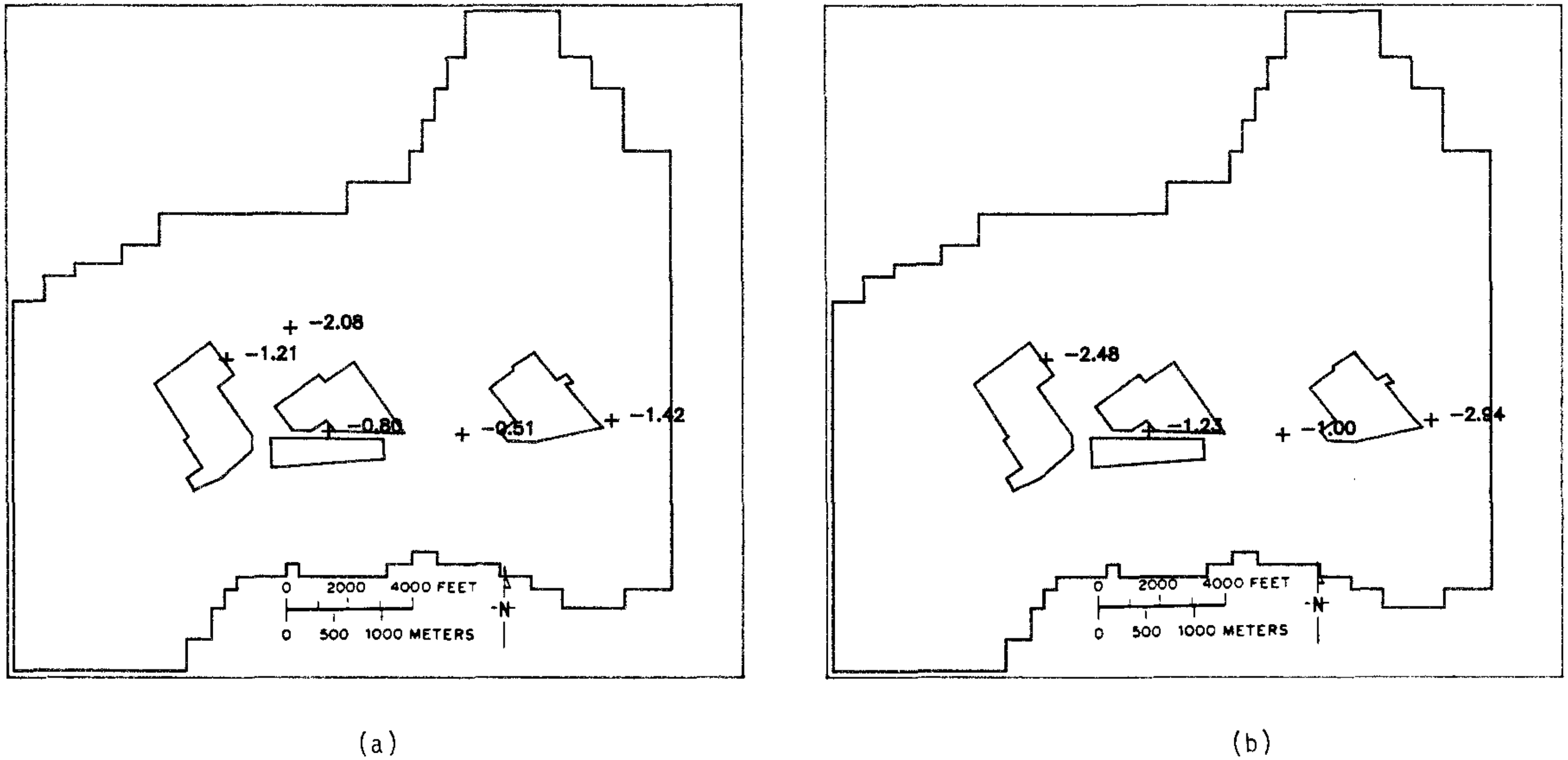
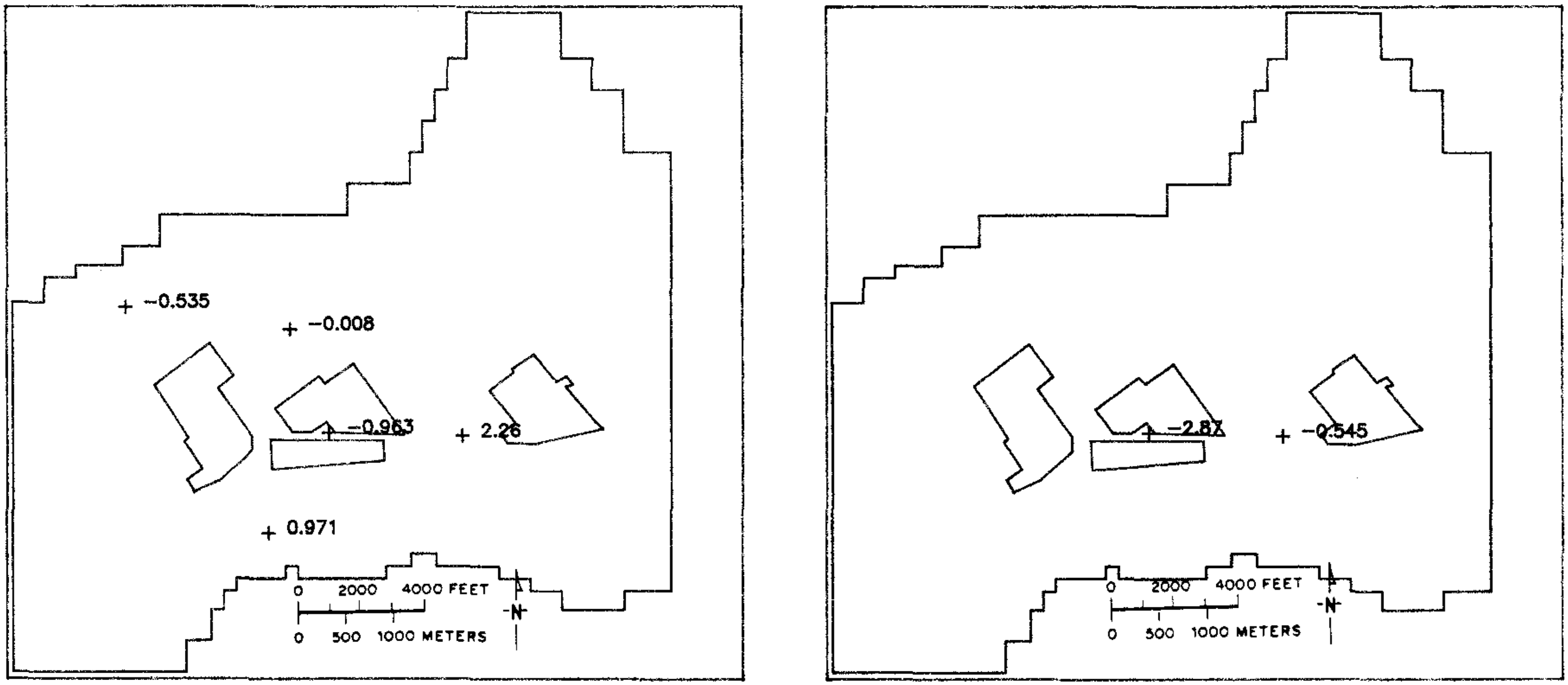


Figure 2.10. Spatial distribution of residuals (in ft) in (a) upper Tuscaloosa and (b) lower Tuscaloosa in 1979.



(a) (b)

Figure 2.11. Spatial distribution of residuals (in ft) in (a) upper Tuscaloosa and (b) lower Tuscaloosa aquifers in 1987.

and actual groundwater levels. Residual maps were not provided for 1987 groundwater levels in the Barnwell, McBean, and Congaree aquifers as these layers were insensitive to calibrations performed on the lower and upper Tuscaloosa aquifers and the middle Clay confining bed. The residual plots do not indicate spatial correlation of the residuals. The approximate normal distribution and lack of spatial correlation strongly indicate that the model errors resulting from the calibration are random, e.g., further zonation of aquifer transmissivities is not necessary.

The sensitivity of the model to parameter perturbations was examined by the determination of sensitivity coefficients. Sensitivity coefficients measure the change in hydraulic head per unit change in a specific hydraulic parameter. Within the General Separations Area, the Ellenton confining unit limits effects of groundwater stress in the upper and lower Tuscaloosa aquifers on the Barnwell, McBean, and Congaree aquifers. For this reason, sensitivity analyses were confined to the upper and lower Tuscaloosa aquifers and the middle Tuscaloosa Clay confining unit.

Each of the layers were analyzed for the effects of ten and fifty percent decreases in aquifer transmissivity (upper and lower Tuscaloosa aquifers) and/or aquitard vertical conductance (middle Tuscaloosa Clay). The relative degree of modeled aquifer/aquitard sensitivity is presented in Table 2.3. Locations for the piezometers studied are presented in Figure 2.12. Table 2.3 shows that, as measured at the selected locations, a given layer's head distribution is affected most readily by changes in aquifer transmissivity within that specific layer. These responses, however, are most pronounced within the lower Tuscaloosa. The response of heads in the lower Tuscaloosa to 10 and 50 percent changes in aquifer transmissivity are shown in Figure 2.13. The figure illustrates that the response is nonlinear, a condition that is also true for upper Tuscaloosa aquifer transmissivity and middle Tuscaloosa Clay confining bed conductance. The upper Tuscaloosa head elevations are the most sensitive to changes in the middle Tuscaloosa Clay vertical conductance.

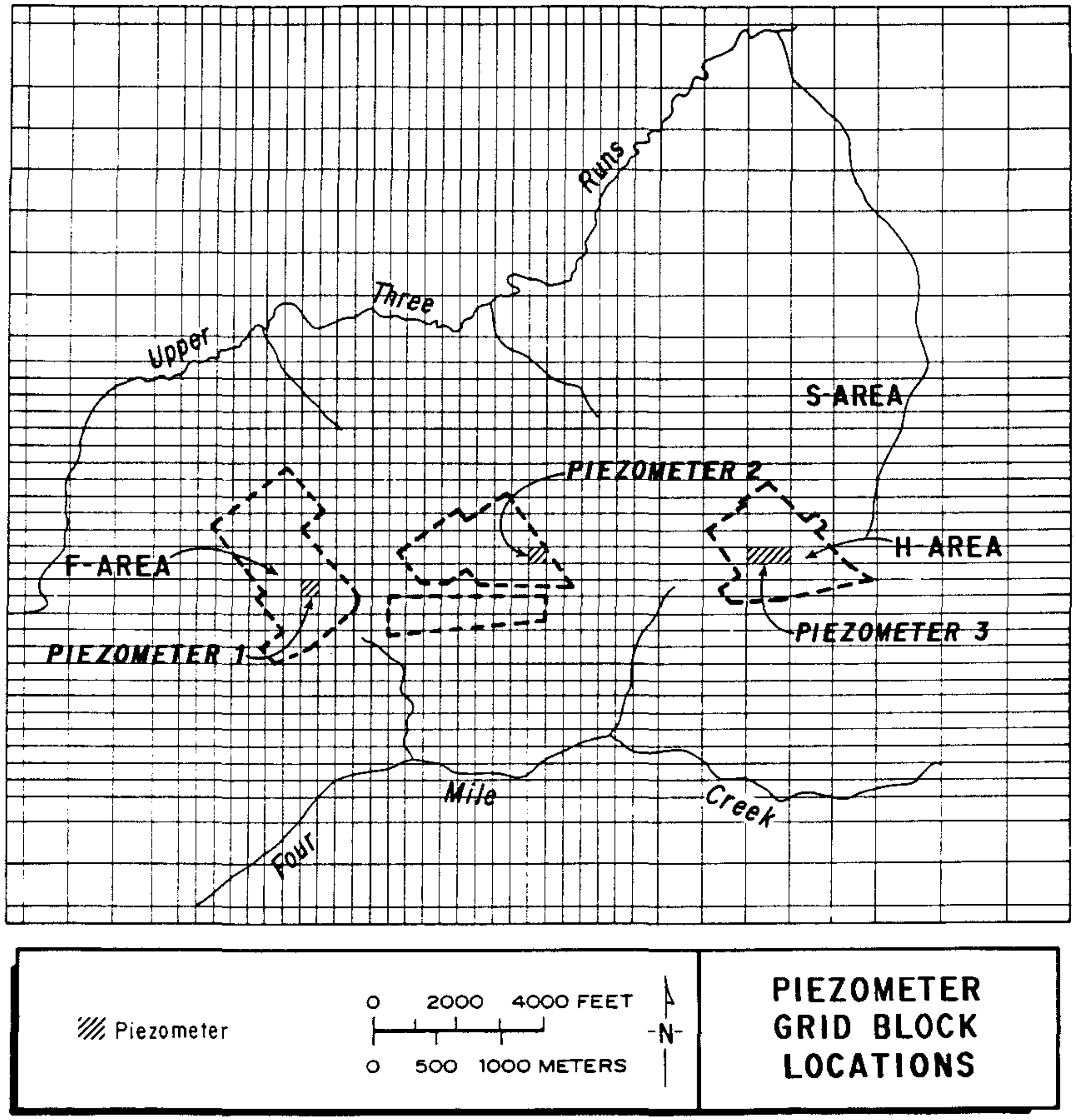
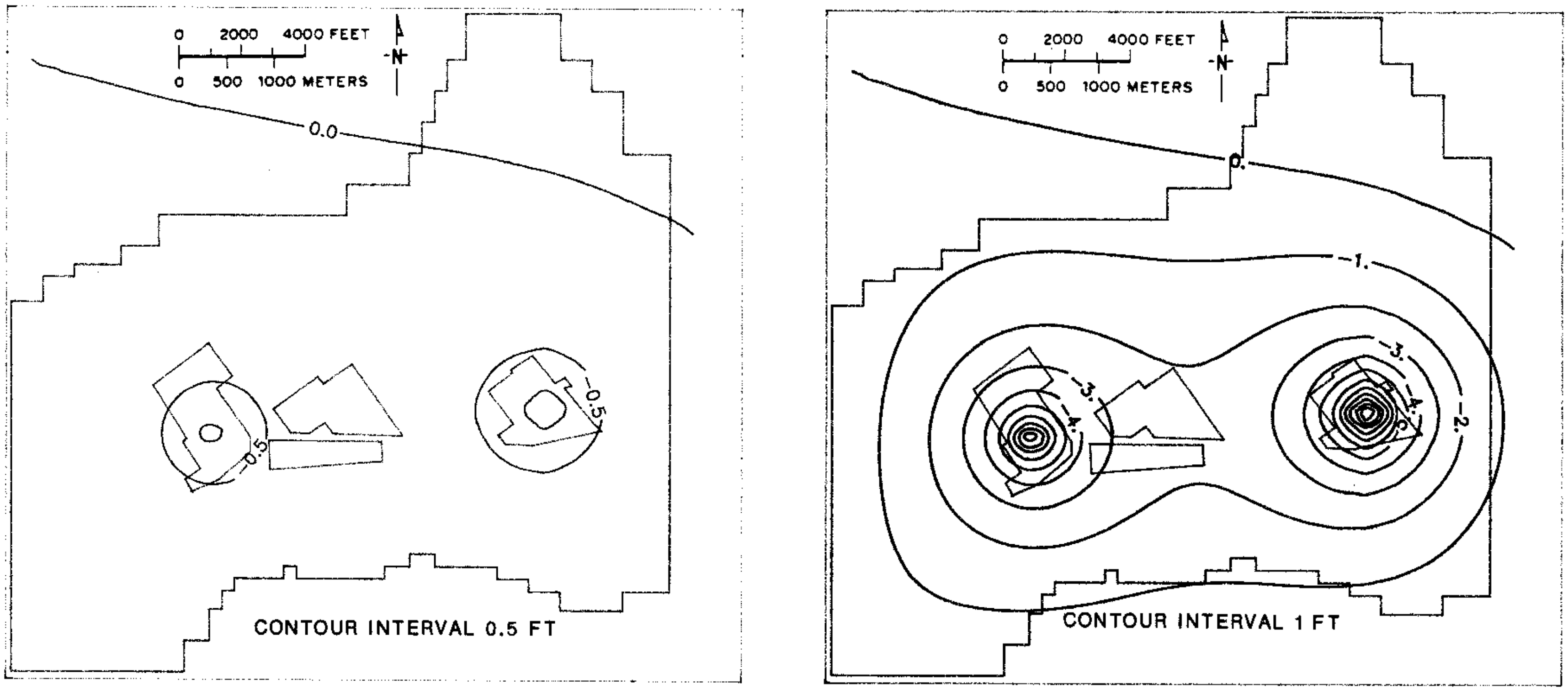


Figure 2.12. Location of sensitivity analysis piezometers.

Table 2.3. Response of hydraulic head (ft) at selected points to changes in aquifer transmissivity or aquitard conductance.

	Piezometer 1		Piezometer 2		Piezometer 3	
	Upper Tuscaloosa	Lower Tuscaloosa	Upper Tuscaloosa	Lower Tuscaloosa	Upper Tuscaloosa	Lower Tuscaloosa
10% Decrease in Lower Tuscaloosa Transmissivity	-0.25	-1.20	-0.23	-0.23	-0.27	-1.57
10% Decrease in Upper Tuscaloosa Transmissivity	-0.98	-0.08	-0.32	-0.21	-1.45	-0.24
10% Decrease in Middle Clay Conductance	-0.01	-0.00	0.03	-0.02	-0.05	-0.03
10% Decrease in Both Upper and Lower Tuscaloosa Transmissivity	-1.25	-1.30	-0.58	-0.56	-1.75	-1.83
50% Decrease in Lower Tuscaloosa Transmissivity	-1.84	-9.90	-1.67	-2.23	-2.05	-13.17
50% Decrease in Upper Tuscaloosa Transmissivity	-7.97	-1.03	-1.96	-1.35	-11.69	-1.64
50% Decrease in Middle Clay Conductance	-0.20	0.10	0.14	0.10	-0.81	0.54
50% Decrease in Both Upper and Lower Tuscaloosa Transmissivity	-11.40	-12.30	-5.15	-5.04	-15.67	-16.53

(-) Decrease in head
(+) Increase in head



(a) (b)

Figure 2.13. Response of heads in the lower Tuscaloosa to (a) 10 and (b) 50 percent changes in lower Tuscaloosa transmissivity.

A sensitivity analysis was also performed on aquifer storage coefficients. The results showed that changes in storage coefficients of up to two orders of magnitude had little effect on the predicted hydraulic heads for transient simulations of 1987 levels. These results indicate that the model (without confining bed storage) is approaching steady-state conditions for the specified pumping rates. A description of transient pumping rates and the approach of equilibrium conditions is given in the following section.

2.4 TRANSIENT FLOW SIMULATIONS (1987-1994)

Transient simulations were performed using the MOD-3D code in order to characterize the temporal response of groundwater withdrawals on the H Area head reversal and to estimate the length of time required to reach steady-state conditions. Groundwater flow conditions were simulated for the period from 1979 to 1994. Pumping rates for the period 1979-1987 were collected from unpublished SRP documents and are presented for the F Area and H Area pumping centers in Figure 2.14. Projected pumping rates from proposed S, F, and H Area pumping wells from 1987-1990 were also obtained. F and H Area seepage basins were assigned estimated seepage rates of 7,770 and 11,060 ft^3/d, respectively. Seepage from the F and H Area seepage basins was simulated until 1987 after which these facilities were assumed inactive. Estimates of storage coefficients utilized in the transient simulations are presented in Table 2.4. These storage coefficient estimates are based on values reported in Christensen and Gordon (1983) and Siple (1967).

As a result of groundwater withdrawals, groundwater levels generally decline steadily in all layers from 1979 to 1990. The rate of this decline is greatest, however, in the lower and upper Tuscaloosa aquifers where groundwater pumping occurs. The piezometric surface of each of the layers for 1987 are presented in Figures 2.15-2.19. From 1987 to 1990, simulated groundwater withdrawals increased slightly causing a corresponding decrease in modeled groundwater levels. Groundwater withdrawals from 1990 to 1994 were simulated at a constant rate to allow calculation of the rate at which the hydrogeologic system

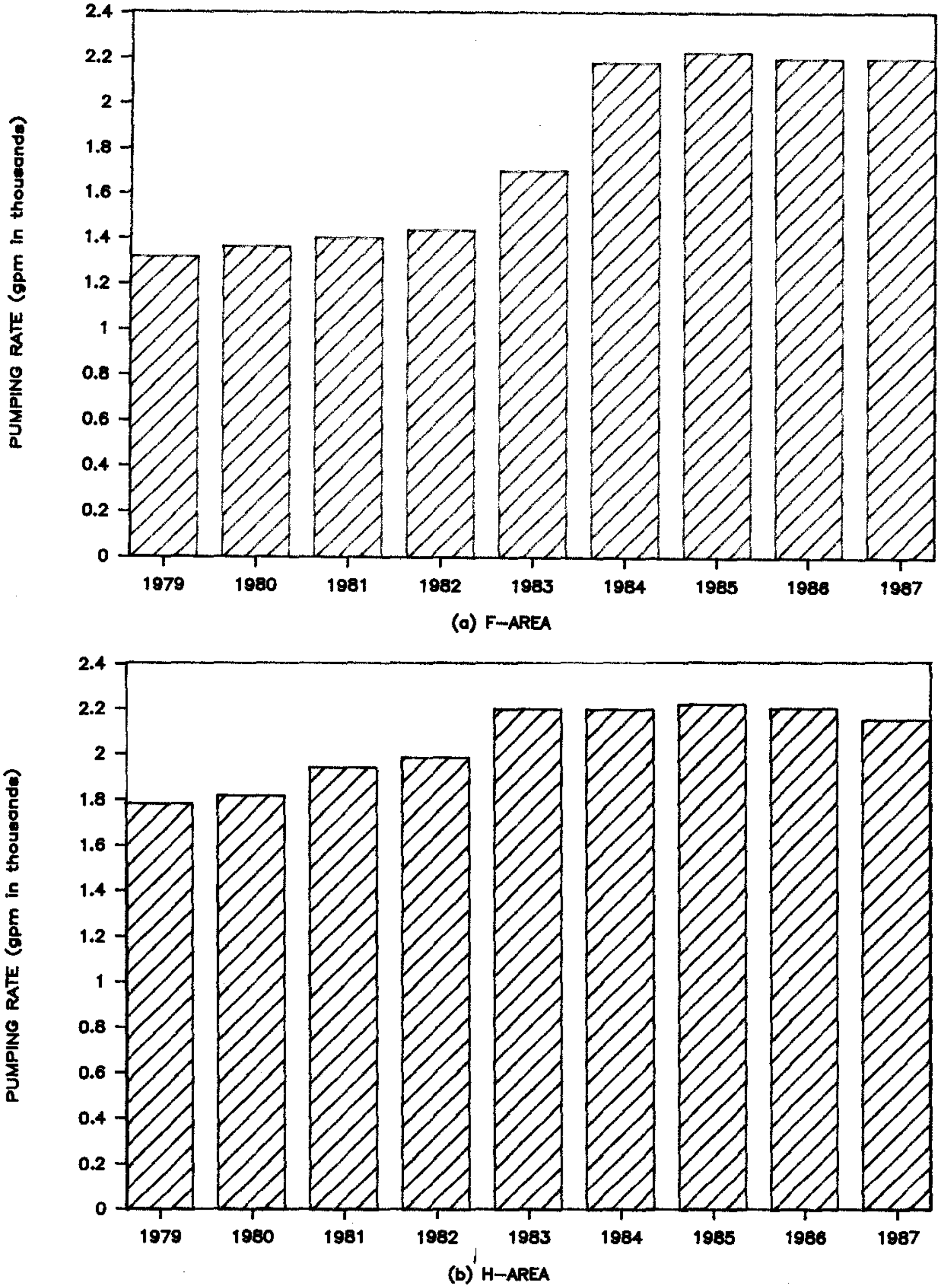


Figure 2.14. Mean annual pumping rates for F and H Areas (1979-1987) used in transient simulations.

Table 2.4. Storage coefficient estimates used in transient modeling.

Aquifer	Estimated Storage Coefficient
Barnwell	0.11
McBean	
Unconfined	0.11
Confined	4.0×10^{-4}
Congaree	2.0×10^{-4}
Upper Tuscaloosa	4.2×10^{-4}
Lower Tuscaloosa	4.5×10^{-4}

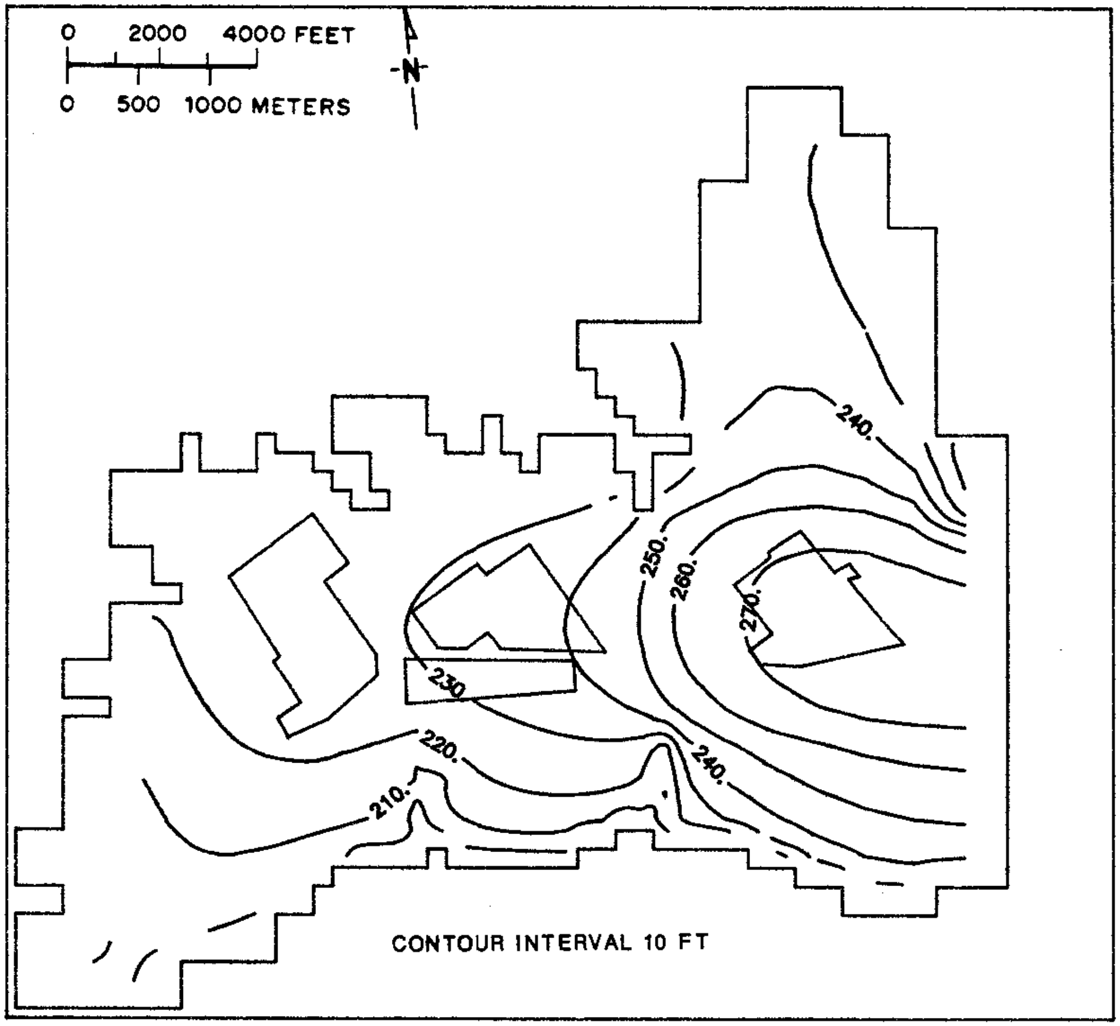


Figure 2.15. Simulated 1987 transient Barnwell potentiometric surface.

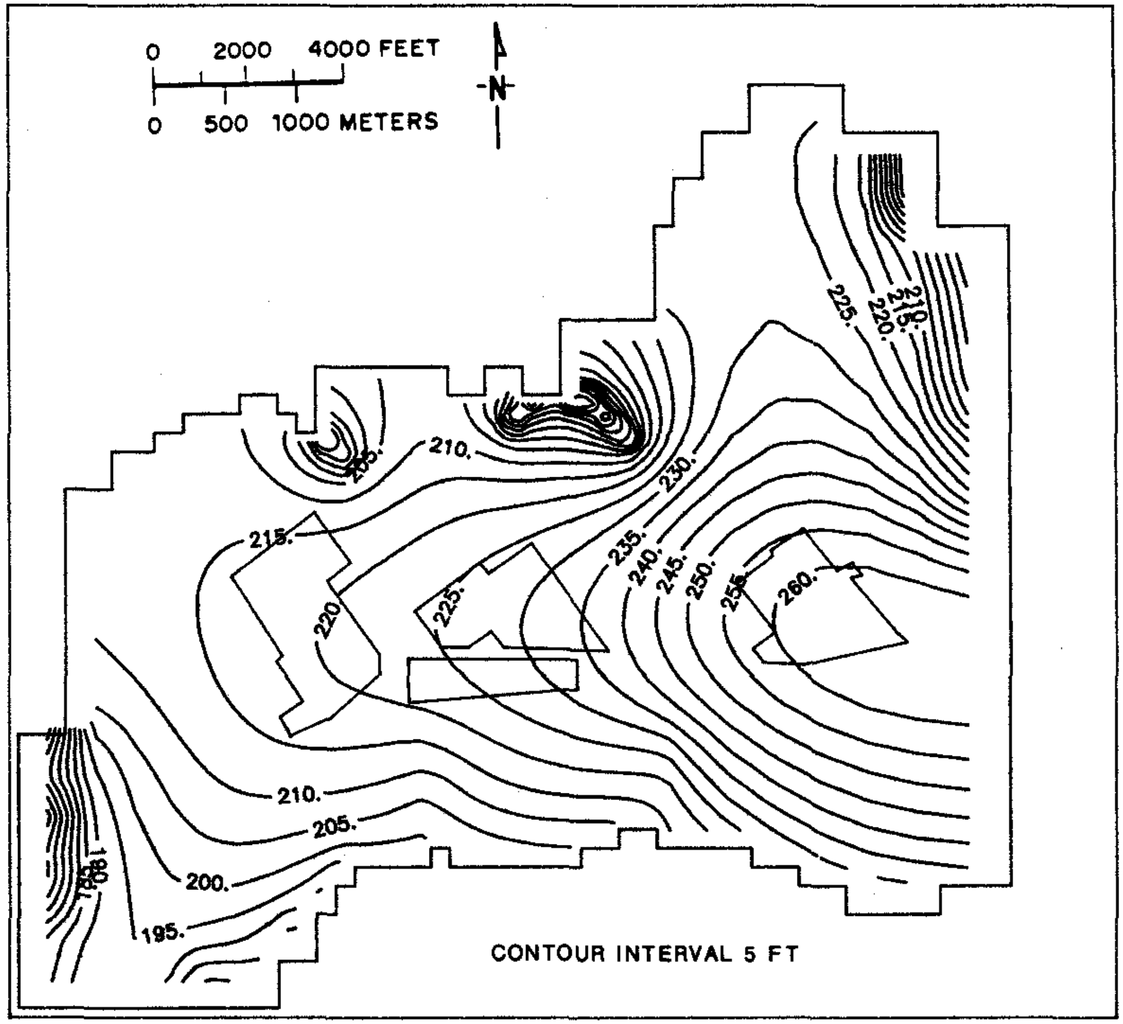


Figure 2.16. Simulated 1987 transient McBean potentiometric surface.

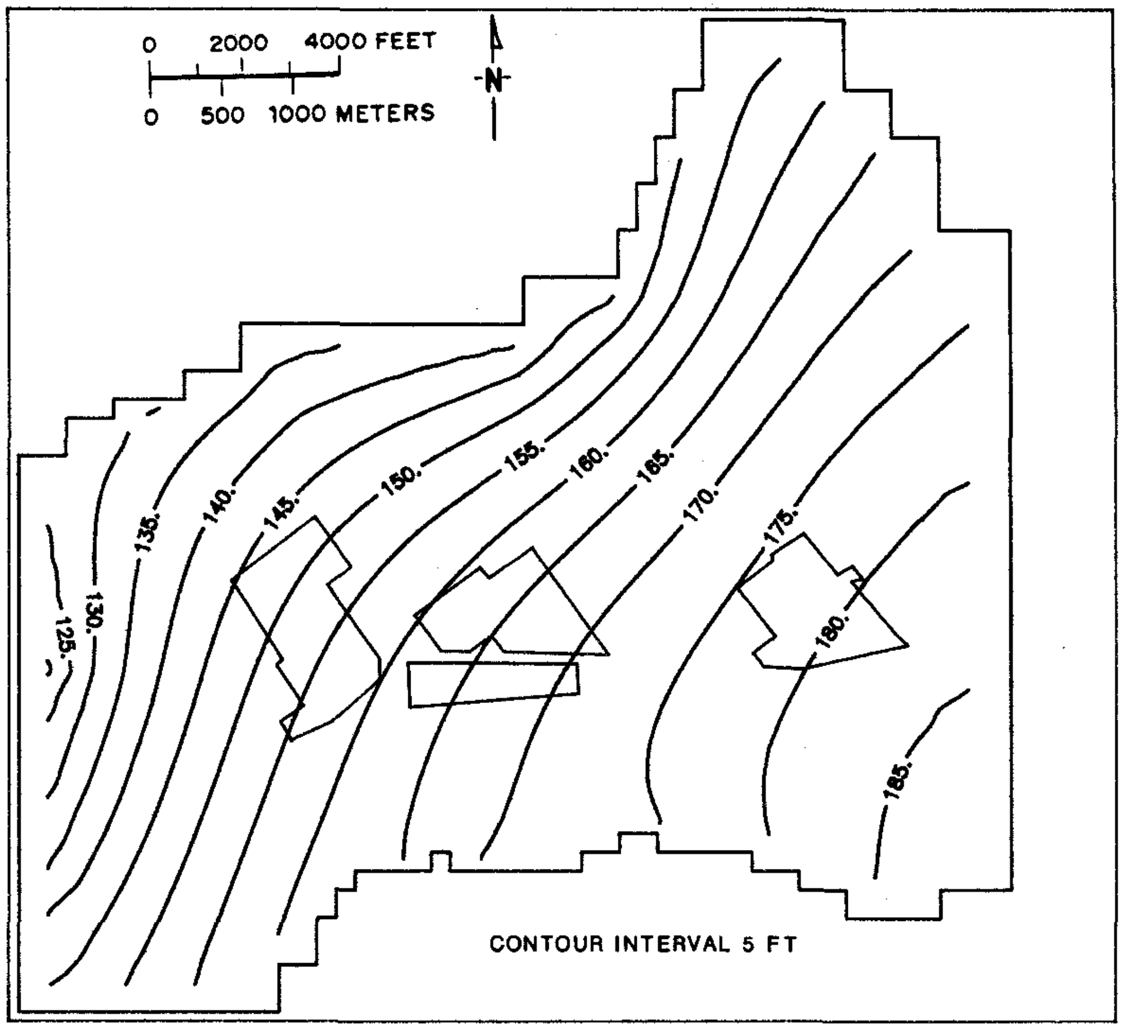


Figure 2.17. Simulated 1987 transient Congaree potentiometric surface.

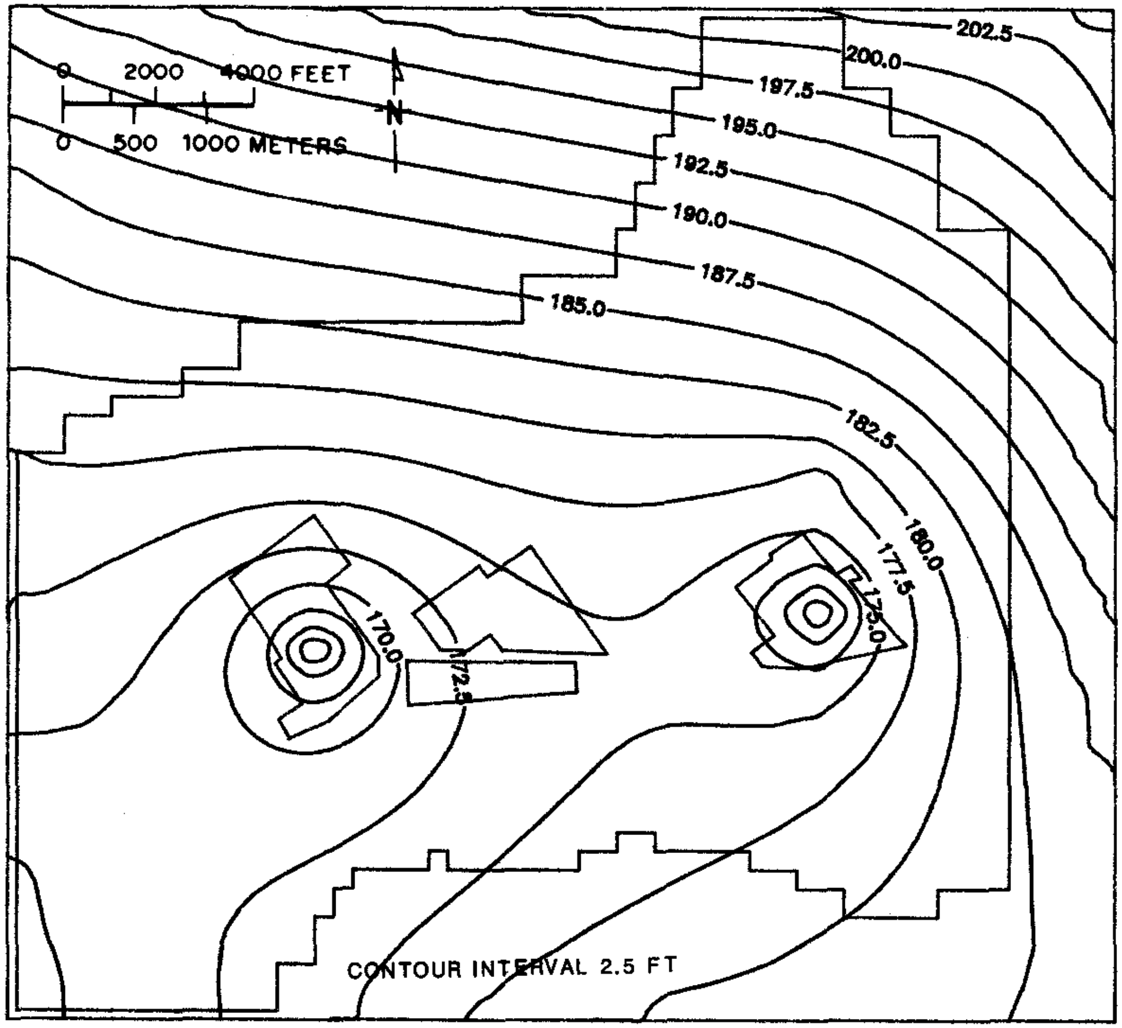


Figure 2.18. Simulated 1987 transient upper Tuscaloosa potentiometric surface.

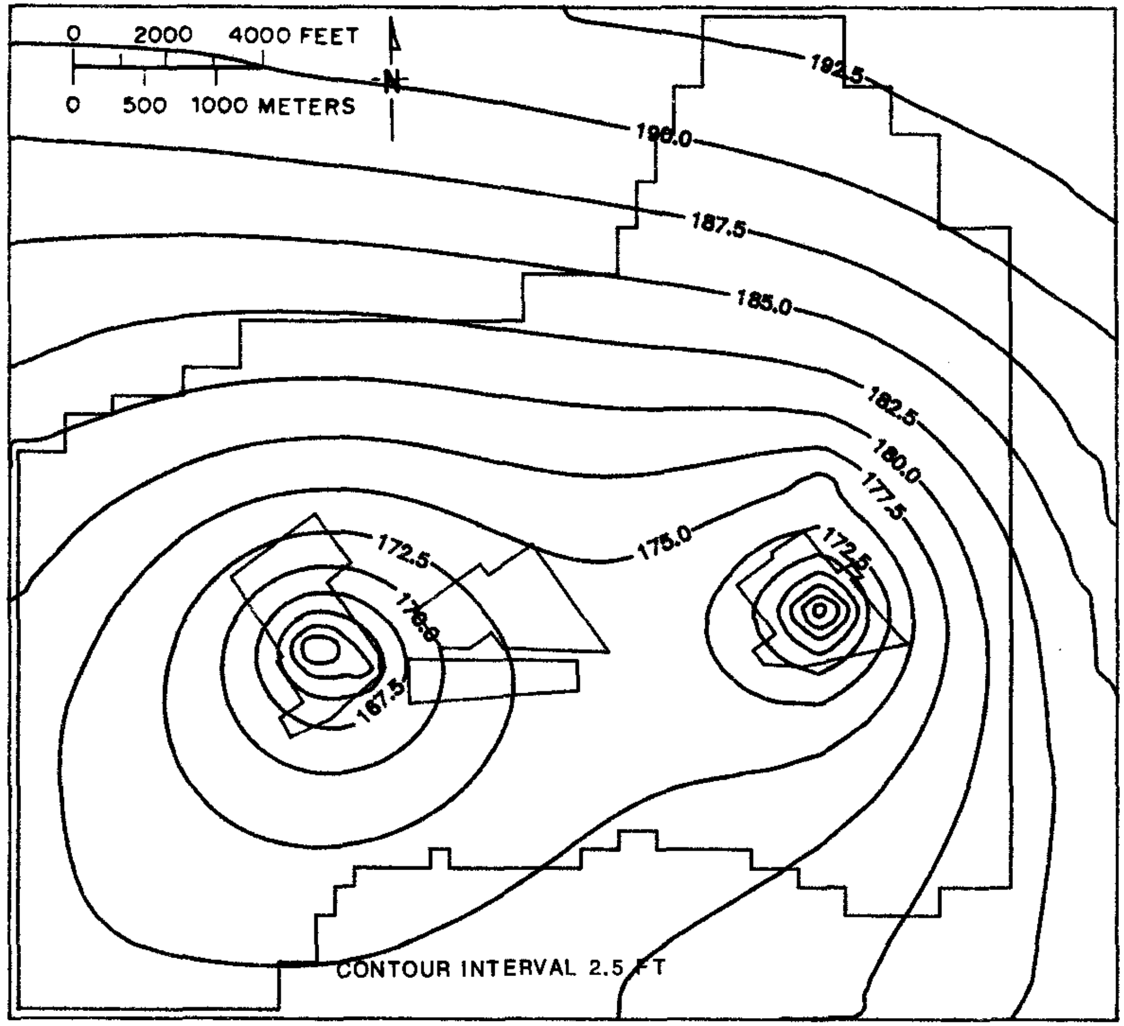


Figure 2.19. Simulated 1987 transient lower Tuscaloosa potentiometric surface.

reached steady-state conditions. Simulated pumping rates from 1987 to 1994 are presented in Figure 2.20. The hydrogeologic system approaches steady-state conditions very rapidly; within two years in the upper and lower Tuscaloosa aquifers. Three model grid blocks identified in Figure 2.21 were studied for the response of groundwater levels to pumping from 1987 to 1994. Figures 2.22 and 2.24 represent piezometers located in pumping well blocks while Figure 2.23 represents a piezometer located elsewhere in the system. The figures show that groundwater levels have generally reached steady-state conditions by 1990. Due to the presence of the Ellenton confining layer between the upper Tuscaloosa aquifer and the overlying formations, the approach to steady-state conditions occurs more rapidly in the Tuscaloosa aquifers than in the other layers. The Ellenton confining layer delays the response of the overlying aquifers to groundwater withdrawals in the Tuscaloosa formations. Although nearly imperceptible in the figures, groundwater levels in the Barnwell and McBean continue to decline in 1994 while water-levels stabilize in the Congaree, upper Tuscaloosa, and lower Tuscaloosa aquifers.

Figure 2.24 depicts a piezometer located in a pumping well grid block within H Area. Water-levels here are higher in the Congaree aquifer than in the upper Tuscaloosa aquifer, indicating that the head reversal within this piezometer has been lost. A plan view of the 1987 head difference across the Ellenton confining unit (Figure 2.25) shows the aerial extent of the head reversal. A plot of the change in this surface compared to 1979 conditions is presented in Figure 2.26. Similar maps are presented for 1990 conditions in Figure 2.27 and 1990 versus 1979 conditions in Figure 2.28. Apparent steady-state conditions are achieved in 1990. With the currently proposed pumping rates for F, S, and H Area, the area of head reversal loss between the upper Tuscaloosa and Congaree aquifers will increase. By 1990, the simulated head difference across the Ellenton reaches a peak value of 14.5 ft within H Area; a downward gradient occurs throughout H Area. However, note that storage in the Ellenton confining bed is ignored in the model. Therefore, considering the effects of storage in the Ellenton, steady state and the maximum head difference will take longer to occur.

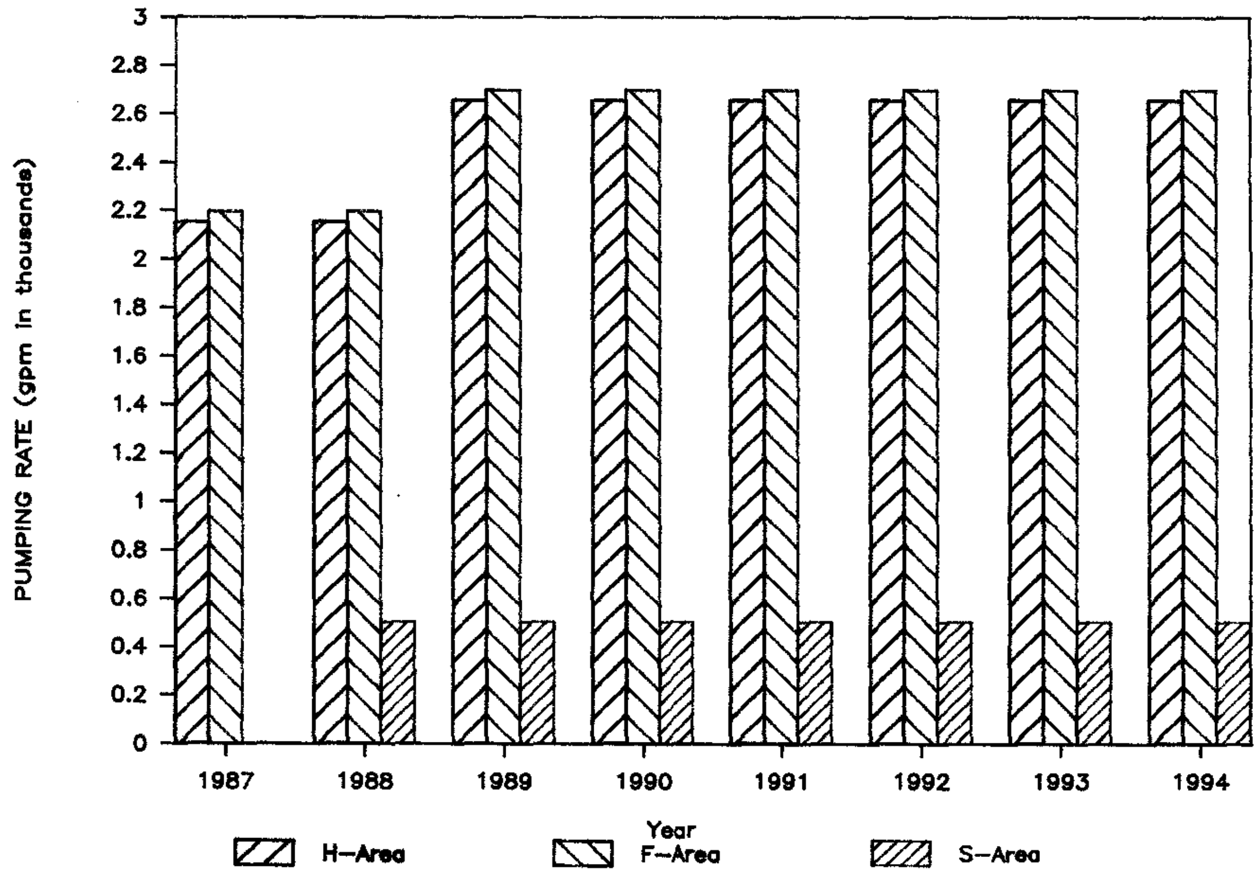


Figure 2.20. Simulated pumping rates from 1987 to 1994 as currently proposed.

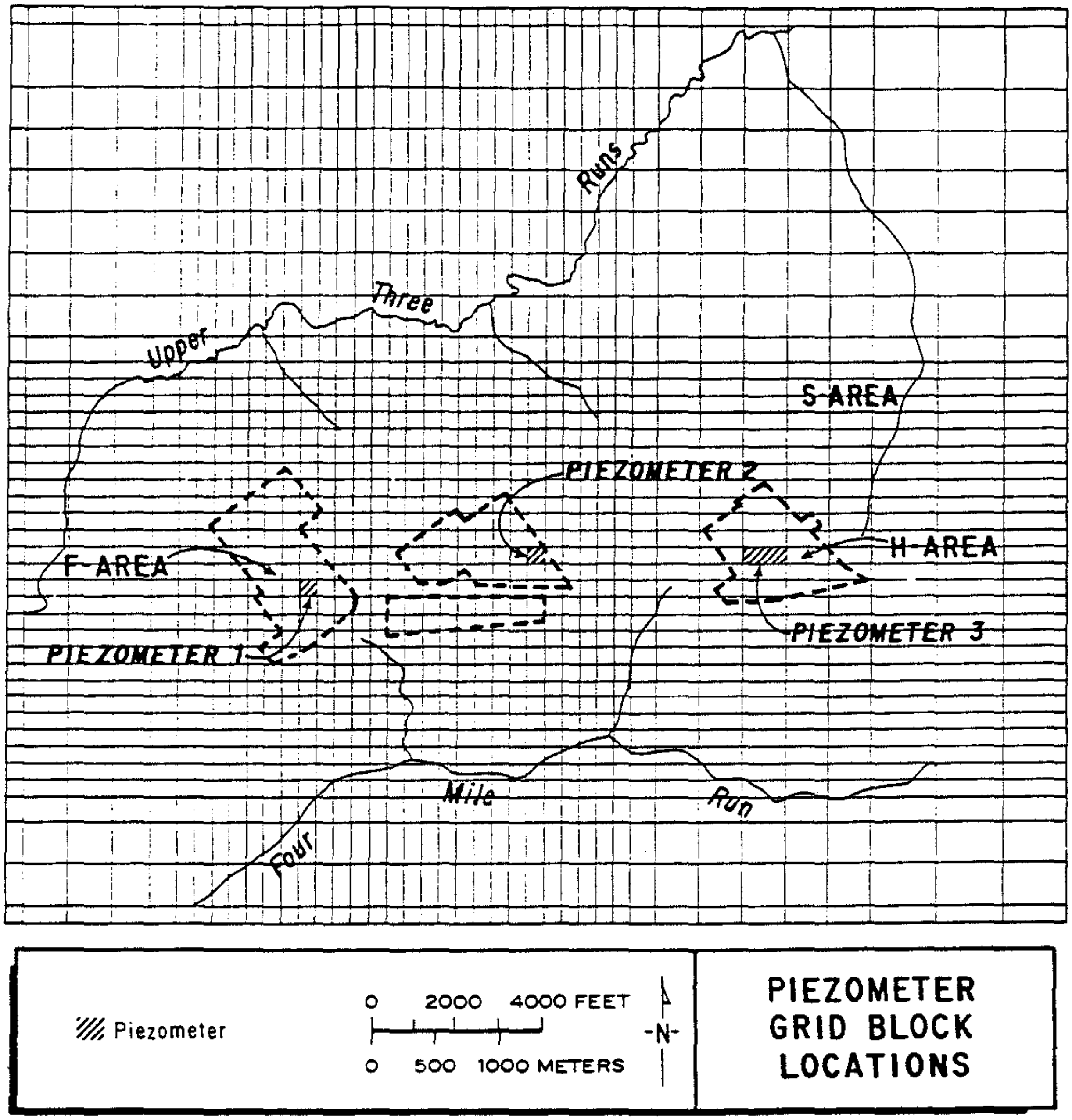


Figure 2.21. Location of three piezometers studied for the response of groundwater levels to pumping from 1987 to 1994.

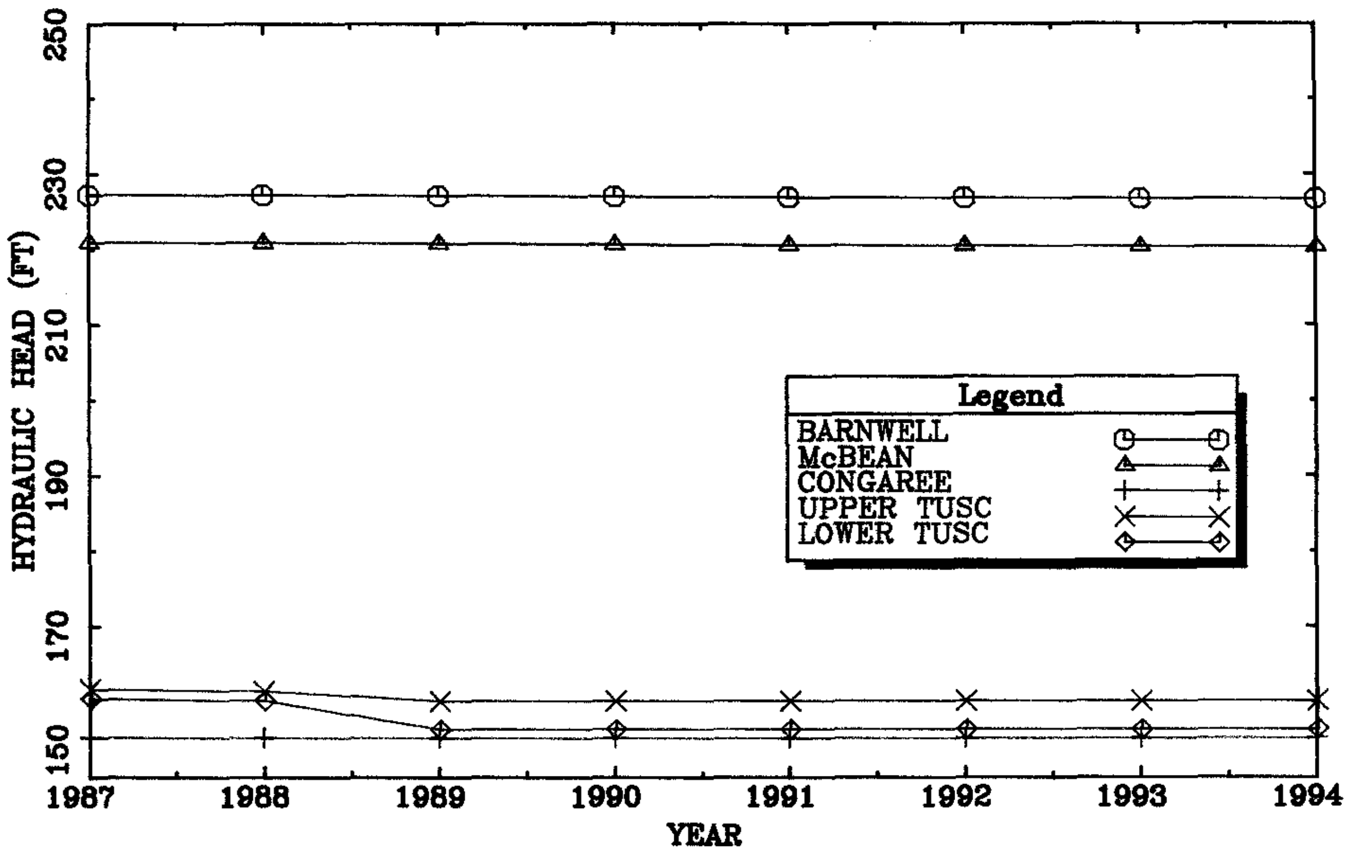


Figure 2.22. Hydraulic head declines in piezometer 1 from 1987-1994.

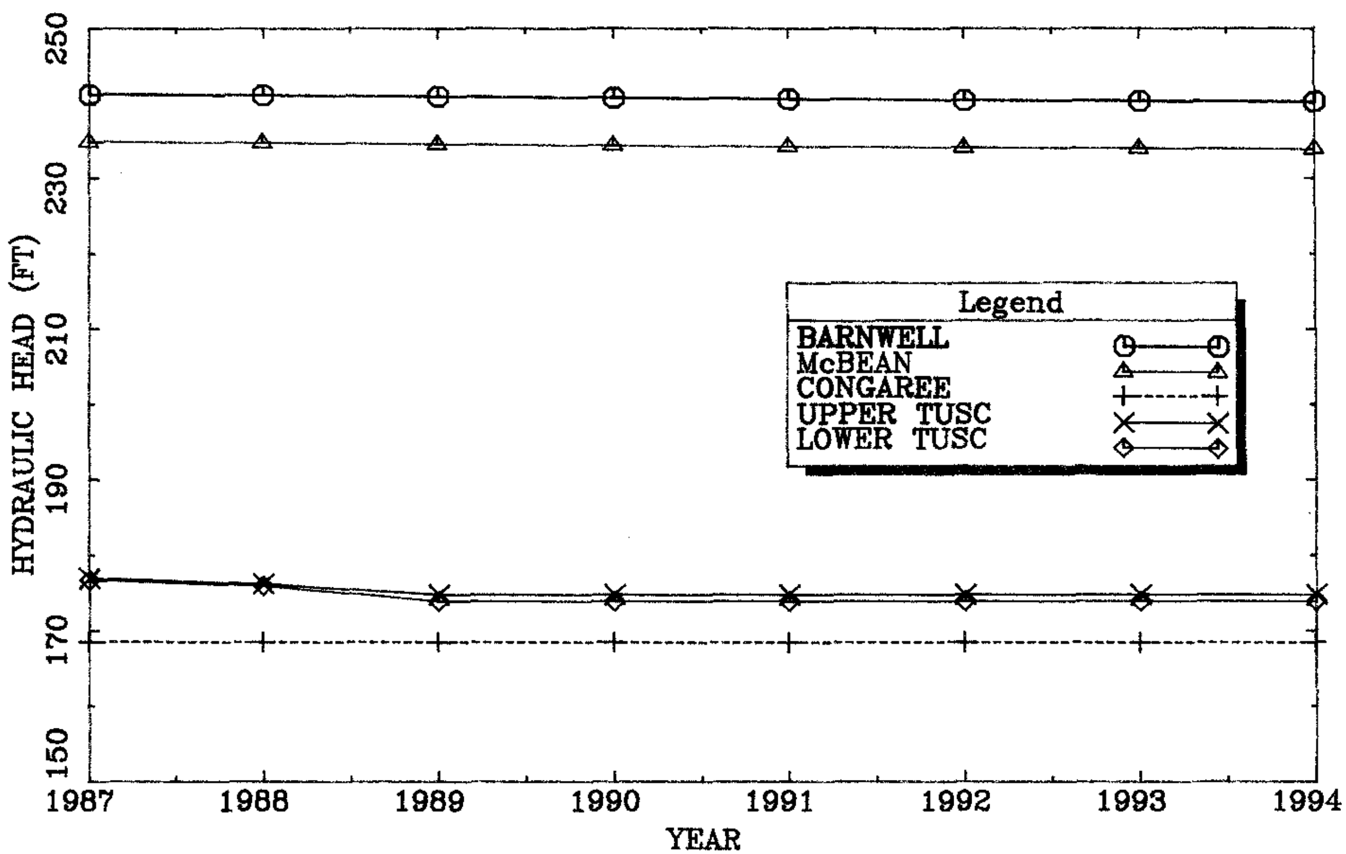


Figure 2.23. Hydraulic head declines in piezometer 2 from 1987-1994.

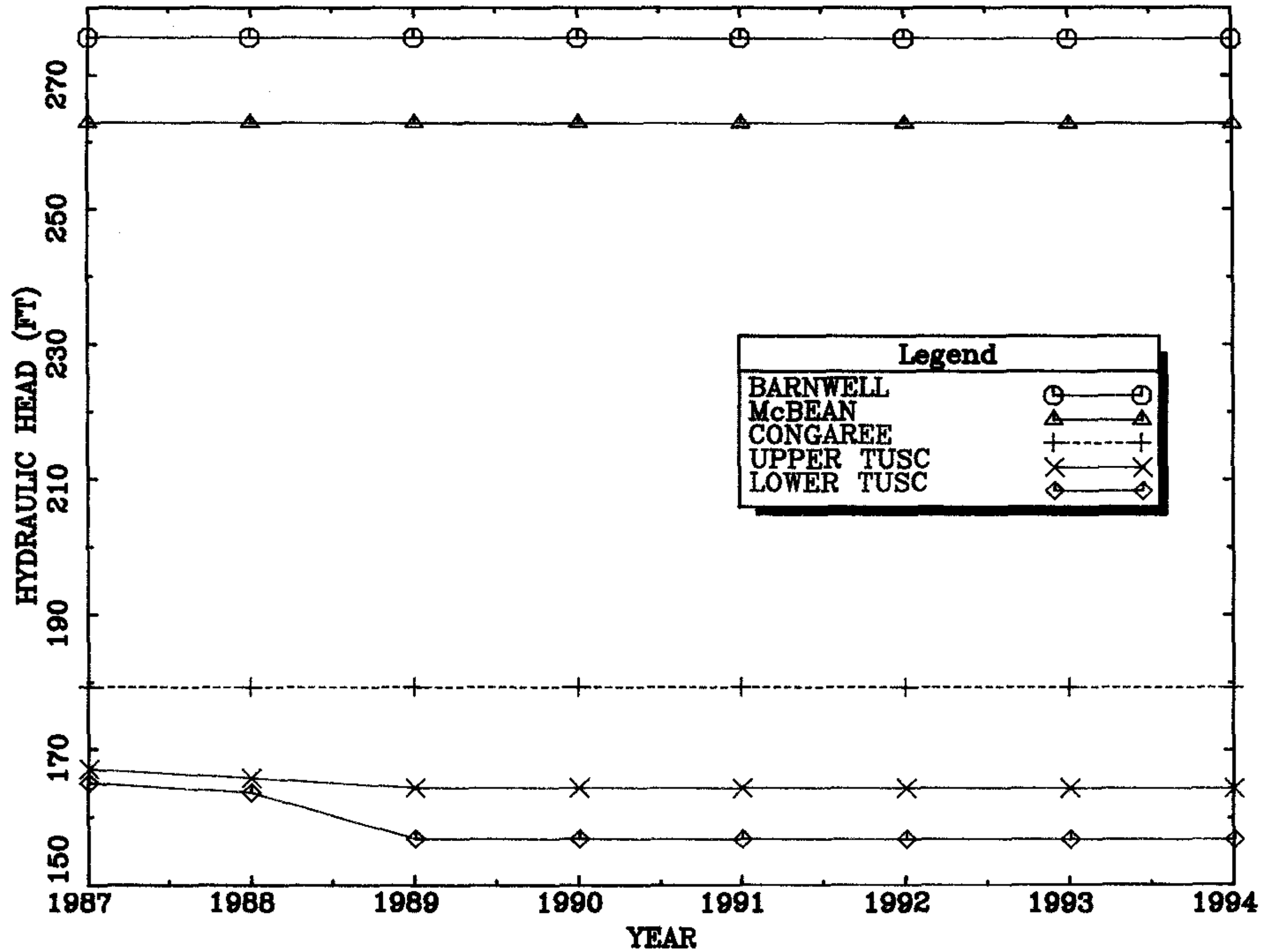


Figure 2.24. Hydraulic head declines in piezometer 3 from 1987-1994.

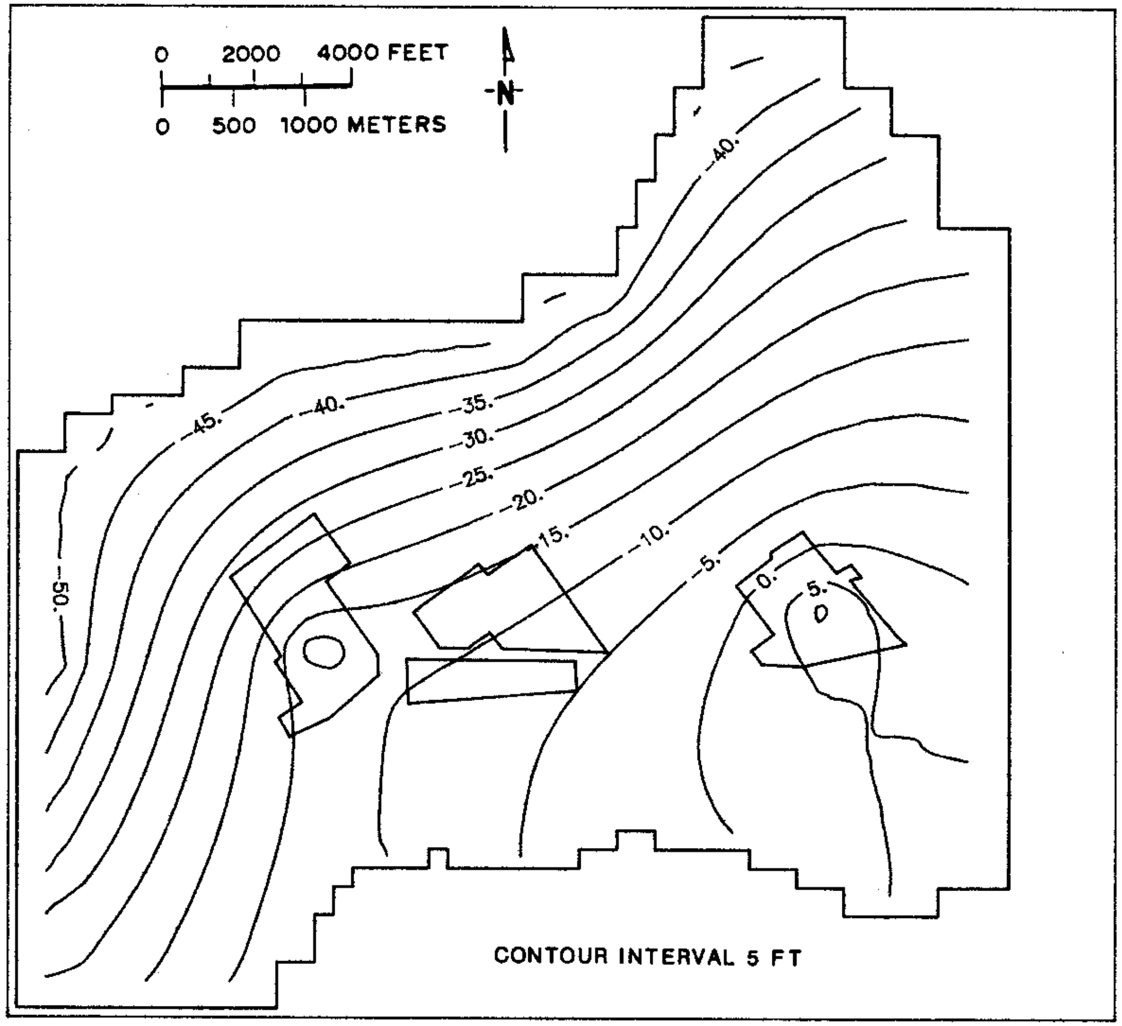


Figure 2.25. Head difference across the Ellenton confining unit in 1987.

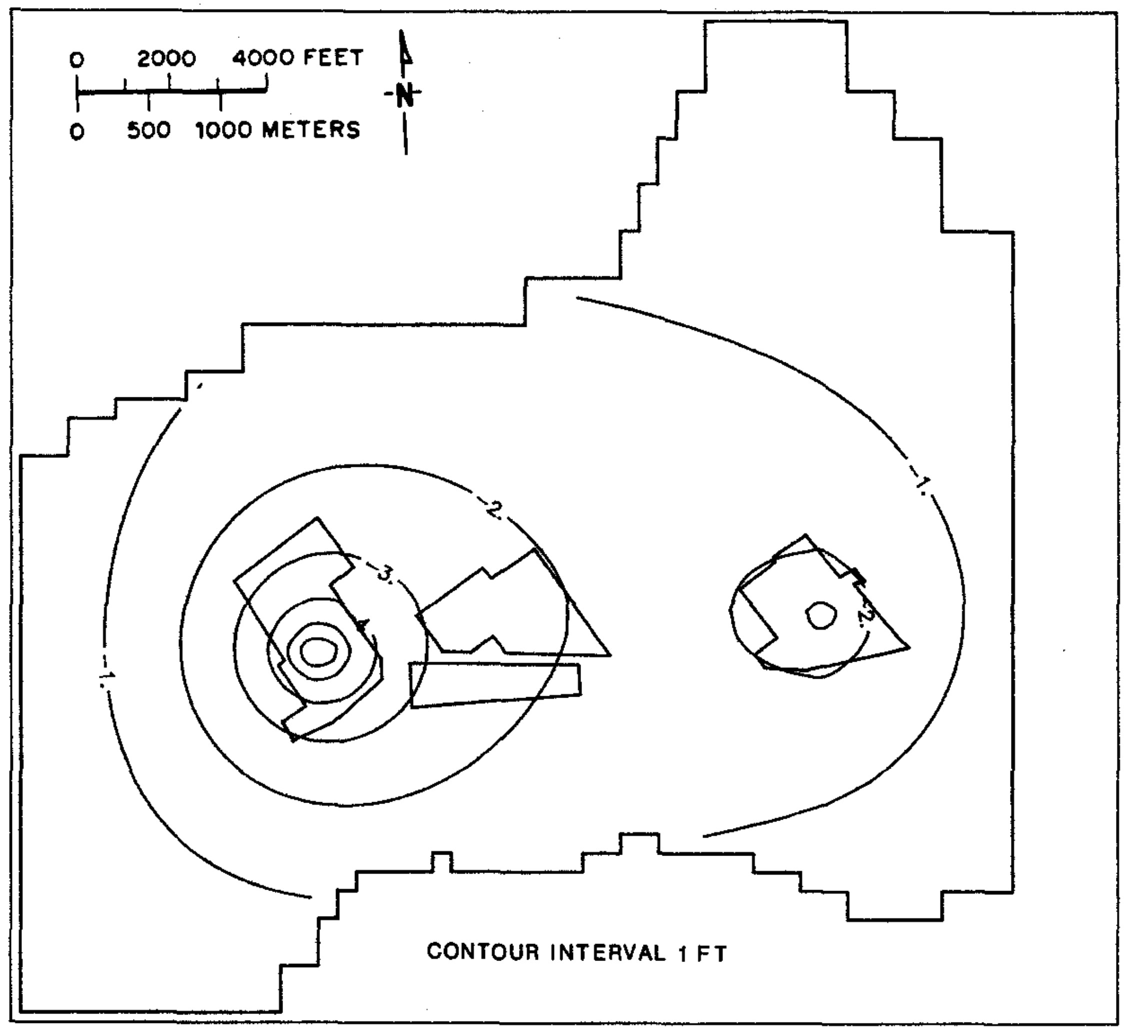


Figure 2.26. Change in head difference across the Ellenton confining unit from 1979 to 1987.

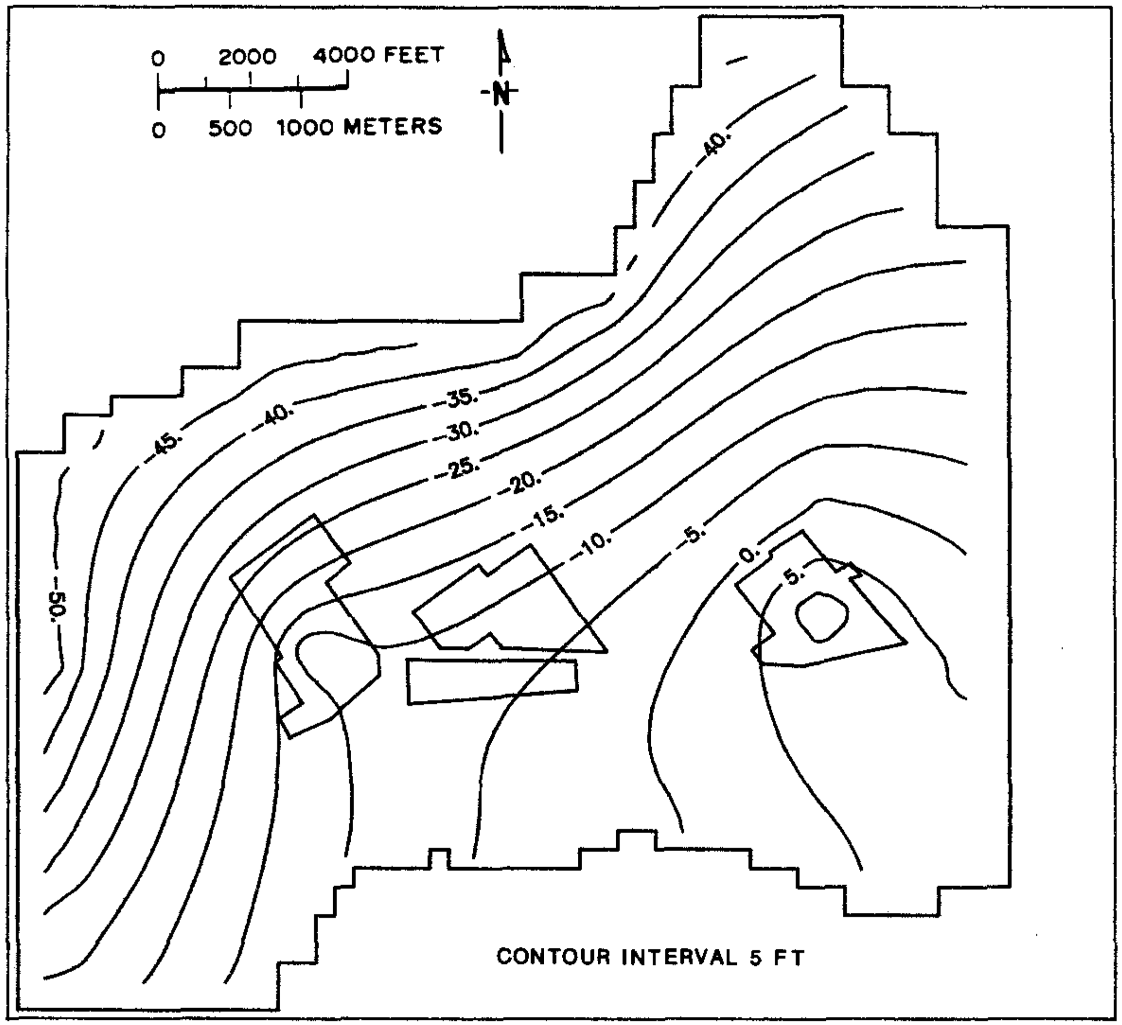


Figure 2.27. Head difference across the Ellenton confining unit in 1990.

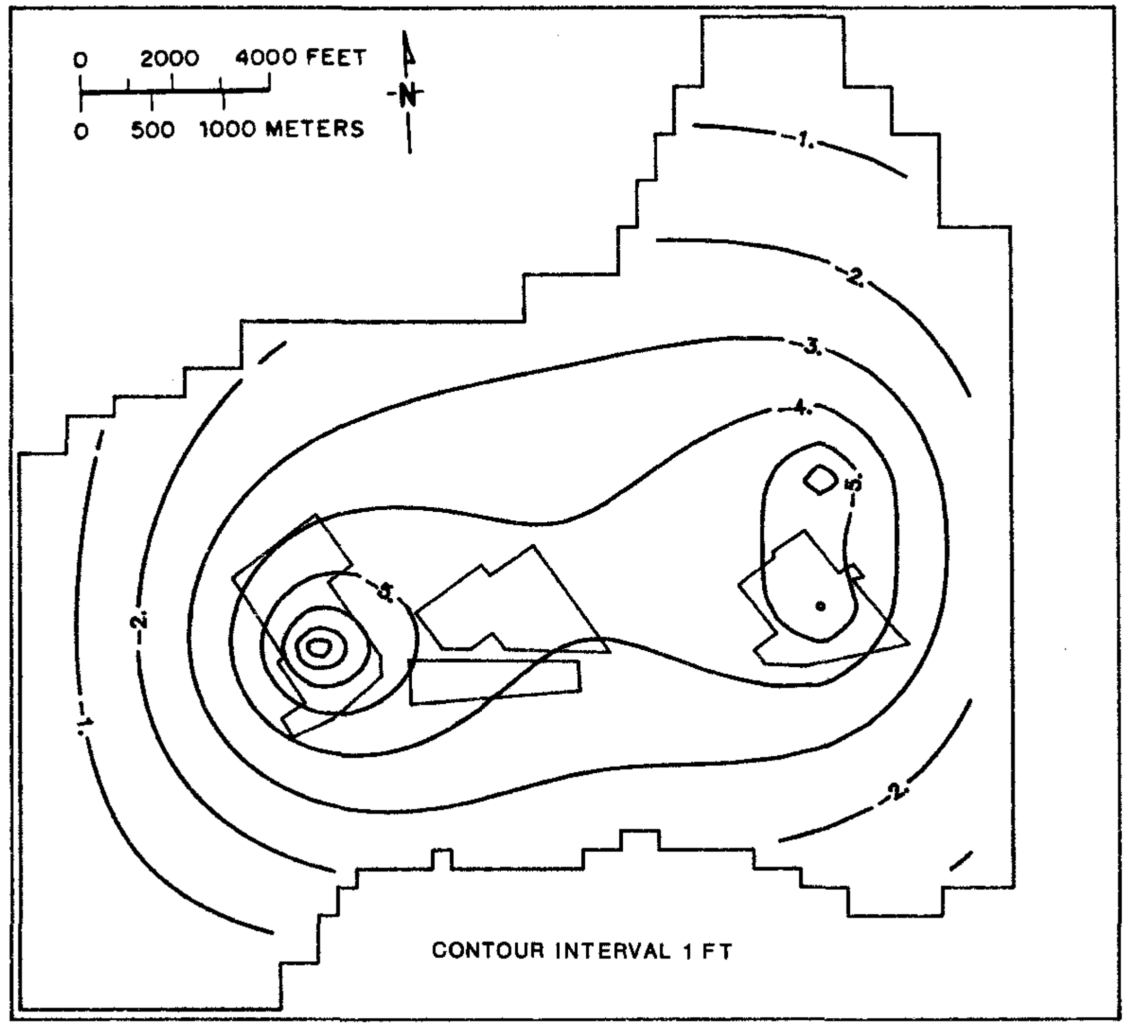


Figure 2.28. Change in head difference across the Ellenton confining unit from 1979 to 1990.

As part of this study, several alternative pumping rates and locations were analyzed to minimize the effects of groundwater withdrawals on the upper Tuscaloosa/Congaree head reversal condition within the General Separations Area. Alternatives to the presently proposed pumping rates are examined in the following section.

2.5 EVALUATION OF PUMPING ALTERNATIVES

2.5.1 Pumping Scenarios and Method of Analysis

Alternative scenarios to the currently-proposed groundwater withdrawal scheme were analyzed with the goal of minimizing the effect on the Congaree/upper Tuscaloosa head reversal. Several groundwater pumping scenarios were selected by SRP personnel in collaboration with GeoTrans staff. Pumping rates and other attributes of the various scenarios are presented in Table 2.5. The criteria for selecting the specific pumping scenarios are: (1) technical feasibility, (2) consistency with SRP regulations and mandates, (3) economic feasibility, and (4) consistency with the goal of Tuscaloosa aquifer isolation through maintenance of the head reversal in H Area.

All new production wells at the site installed after 1986 are to be screened only in the lower Tuscaloosa. Thus, all pumping scenarios that considered the installation of new production wells were simulated with well completions in the lower Tuscaloosa.

Groundwater flow was simulated under steady-state conditions with MOD-3D. Steady-state rather than transient simulations were used for the following two reasons: (1) steady-state simulations required less computer time and thus were less costly than transient simulations; (2) results from previous modeling studies established that steady-state conditions were reached within one to two years in the hydrogeologic domain, where confining bed storage was ignored.

The results of each scenario are presented by head difference maps, a table of maximum head difference values, and the calculated aerial extent of the head reversal loss beneath the H Area boundary. The degree of head reversal loss is partially dependent on the boundary conditions assigned within the model domain. For comparison purposes

Table 2.5. Summary of predictive steady-state (1990) simulations for the various pumping scenarios.

		Pumping Rates[1] and Well Location		
Case	H-Area (layer)	F-Area (layer)	S-Area (layer)	Upper Three Runs (layer)
1	2700 (total) 814 (upper Tuscaloosa) 1886 (lower Tuscaloosa)	2700 (total) 814 (upper Tuscaloosa) 1886 (lower Tuscaloosa)	500 (total) 185 (upper Tuscaloosa) 315 (lower Tuscaloosa)	----
2	3200 (total) 500 (Congaree) 814 (upper Tuscaloosa) 1886 (lower Tuscaloosa)	2700 (total) 814 (upper Tuscaloosa) 1886 (lower Tuscaloosa)	500 (total) 185 (upper Tuscaloosa) 315 (lower Tuscaloosa)	----
3[2]	----	5400 (total) 814 (upper Tuscaloosa) 4586 (lower Tuscaloosa)	500 (total) 185 (upper Tuscaloosa) 315 (lower Tuscaloosa)	----
4	----	2700 (total) 814 (upper Tuscaloosa) 1886 (lower Tuscaloosa)	500 (total) 185 (upper Tuscaloosa) 315 (lower Tuscaloosa)	2700 (total) 2700 (lower Tuscaloosa)
5	2700 (total) 2700 (lower Tuscaloosa)	2700 (total) 814 (upper Tuscaloosa) 1886 (lower Tuscaloosa)	500 (total) 500 (lower Tuscaloosa)	----
6[3]	2700 (total) 2700 (lower Tuscaloosa)	2700 (total) 814 (upper Tuscaloosa) 1886 (lower Tuscaloosa)	500 (total) 185 (upper Tuscaloosa) 315 (lower Tuscaloosa)	----

[1] gpm
[2] H-Area wells are replaced with F-Area wells north of present F-Area pumping center
[3] 6 wells around H-Area replacing currently placed pumping wells

and to determine the portion of head reversal related directly to the prescribed boundary conditions, a no-pumping scenario was simulated. The results of this simulation show the minimal possible modeled area of Congaree/upper Tuscaloosa head reversal loss for the assigned boundary conditions. As shown in Figure 2.29, if no pumping occurs, the head difference between the Congaree and upper Tuscaloosa can be maintained within the entire H Area boundary. However, this condition is not feasible due to the requirements of SRP plant operations. Following this baseline simulation, a series of simulations tested head reversal response to variations of pumping location and rate. These simulations, presented below, are identified by case number.

2.5.2 Case 1: Present and Currently Proposed Groundwater Withdrawals

The first case involves steady-state simulation of the present and currently proposed withdrawals modeled in the transient simulation described in Section 2.3. The location of pumping wells for this scenario are shown in Figure 2.30. Comparisons show that by 1990, the maximum head difference between the transient and steady-state simulations is less than two one-hundredths of a foot within the Tuscaloosa formations. Based on this result and the head versus time graphs presented in Section 2.3, steady-state conditions can reasonably be assumed to exist by 1990. Figure 2.31 illustrates the steady-state head difference across the Ellenton confining unit for this case. The Congaree/upper Tuscaloosa head reversal is lost in all portions of H Area; the maximum head difference is 14.5 ft. In the transient simulations, the maximum simulated head difference across the Ellenton was 11.8 ft in 1987. This shows head reversal loss increasing over time with currently proposed rates.

2.5.3 Case 2: Withdrawal of Groundwater from the Congaree Aquifer.

Case 2 investigates the effect of pumping from the Congaree aquifer in H Area. It was postulated that pumping within the Congaree would lower the heads in the Congaree and thus reduce the head difference across the Ellenton confining layer within H Area. Congaree withdrawal was simulated at a rate of 500 gpm at the same grid block as

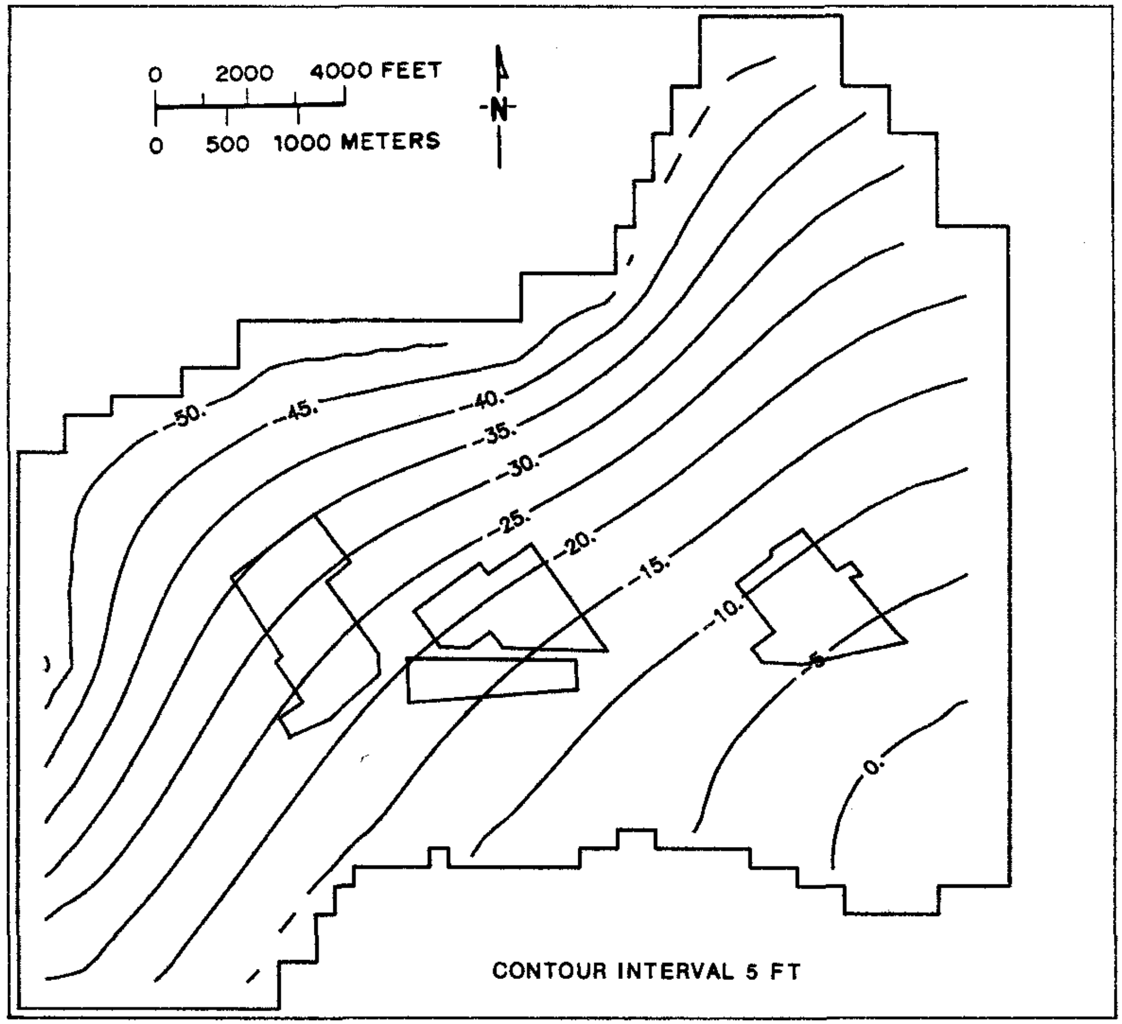


Figure 2.29. Steady-state head difference across the Ellenton without groundwater withdrawals.

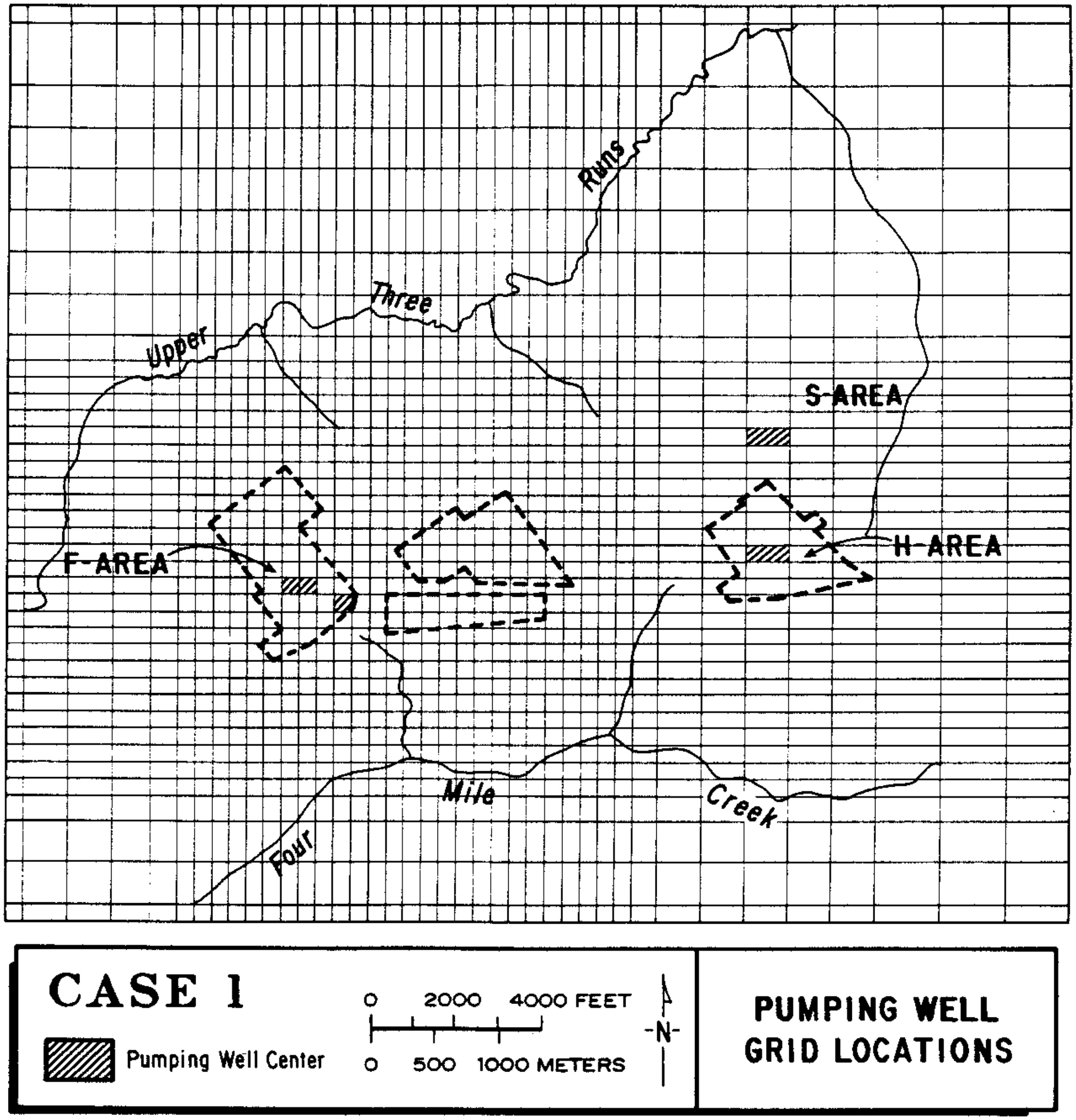


Figure 2.30. Pumping well locations for Case 1.

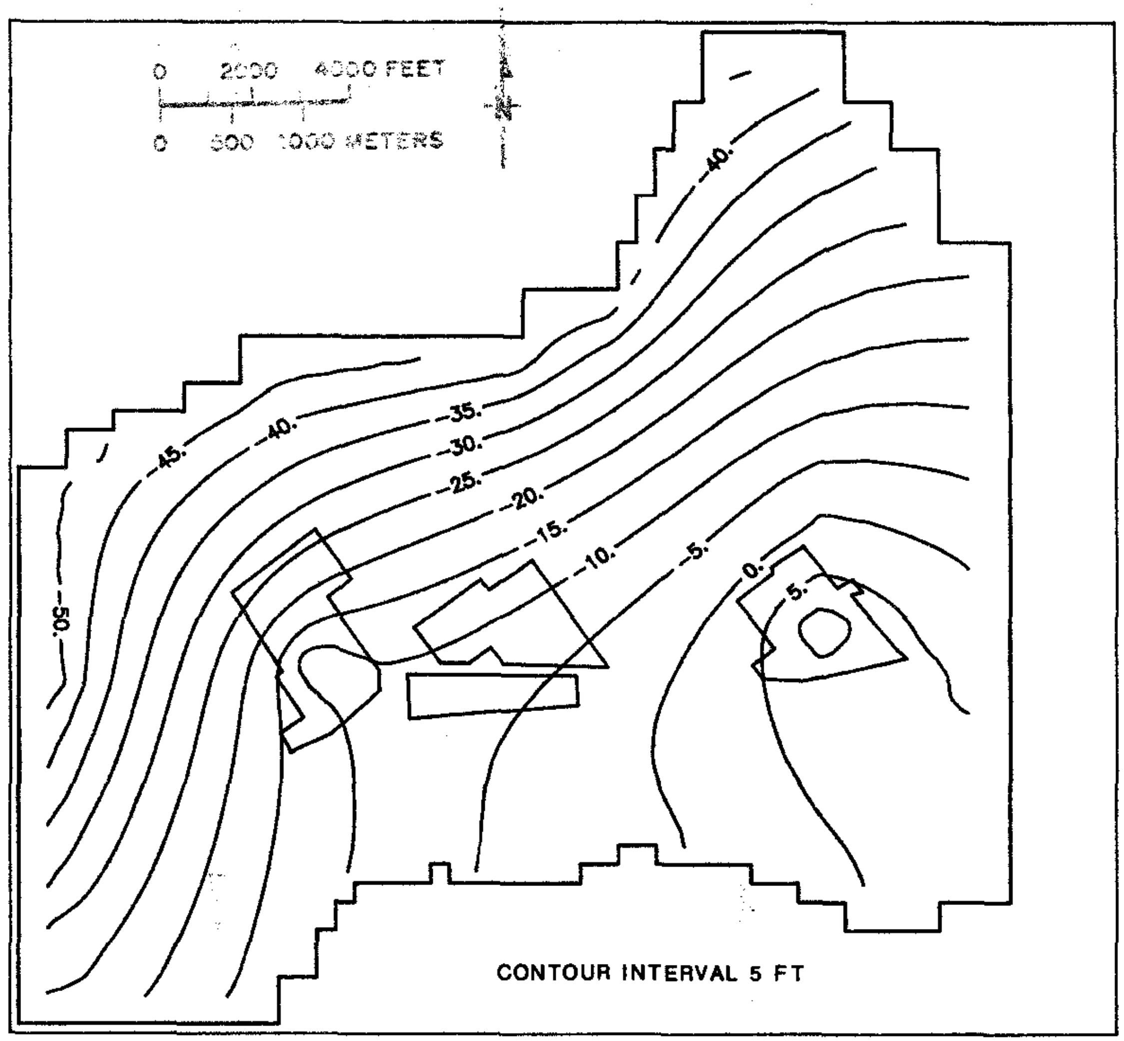


Figure 2.31. Steady-state head difference across the Ellenton confining unit for Case 1.

pumping in the upper and lower Tuscaloosa aquifers (Figure 2.32). Simulated Congaree piezometric levels are shown in Figure 2.33. This scenario shows an improvement over Case 1 of the location of the zero contour line in the Ellenton head difference map (Figure 2.34). The zero contour line in the Ellenton head difference map represents the divide between zones with head reversal and zones with head reversal loss. In this scenario, the head reversal moves southward across the H Area boundary when compared with Case 1. Negative aspects of this proposed pumping scheme include increasing downward gradients between the Congaree and overlying aquifers. This effect must be weighed against the contribution of this scenario to maintaining Tuscaloosa aquifer isolation.

2.5.4 Case 3: Replace H Area Groundwater Withdrawals with F Area Groundwater Withdrawals in the Lower Tuscaloosa.

Case 3 involves moving the H Area wells to F Area and restricting pumping from these newly installed wells to the lower Tuscaloosa. The location of pumping wells for this case is given in Figure 2.35. This proposed pumping scheme eliminates withdrawals in H Area, the area with the highest potential for head reversal loss, and moves wells to F Area, the area with a lower potential for this problem. It should be noted that the relocation of wells to F Area increases the drawdowns in that region. As the drawdowns propagate toward the constant head boundaries specified on the left edge of the model, some error in the simulation of actual conditions may occur. The constant head boundaries would tend to limit drawdown at the model edge. However, this effect has been assumed to be insignificant. The movement of H Area wells to F Area proved to be the best scenario in terms of moving head reversal loss boundary outside the H Area border. As shown in Figure 2.36, head reversal has been maintained within H Area for this case. Technical difficulties may arise in the transportation of water from the F Area facility to other sites within the General Separations Area.

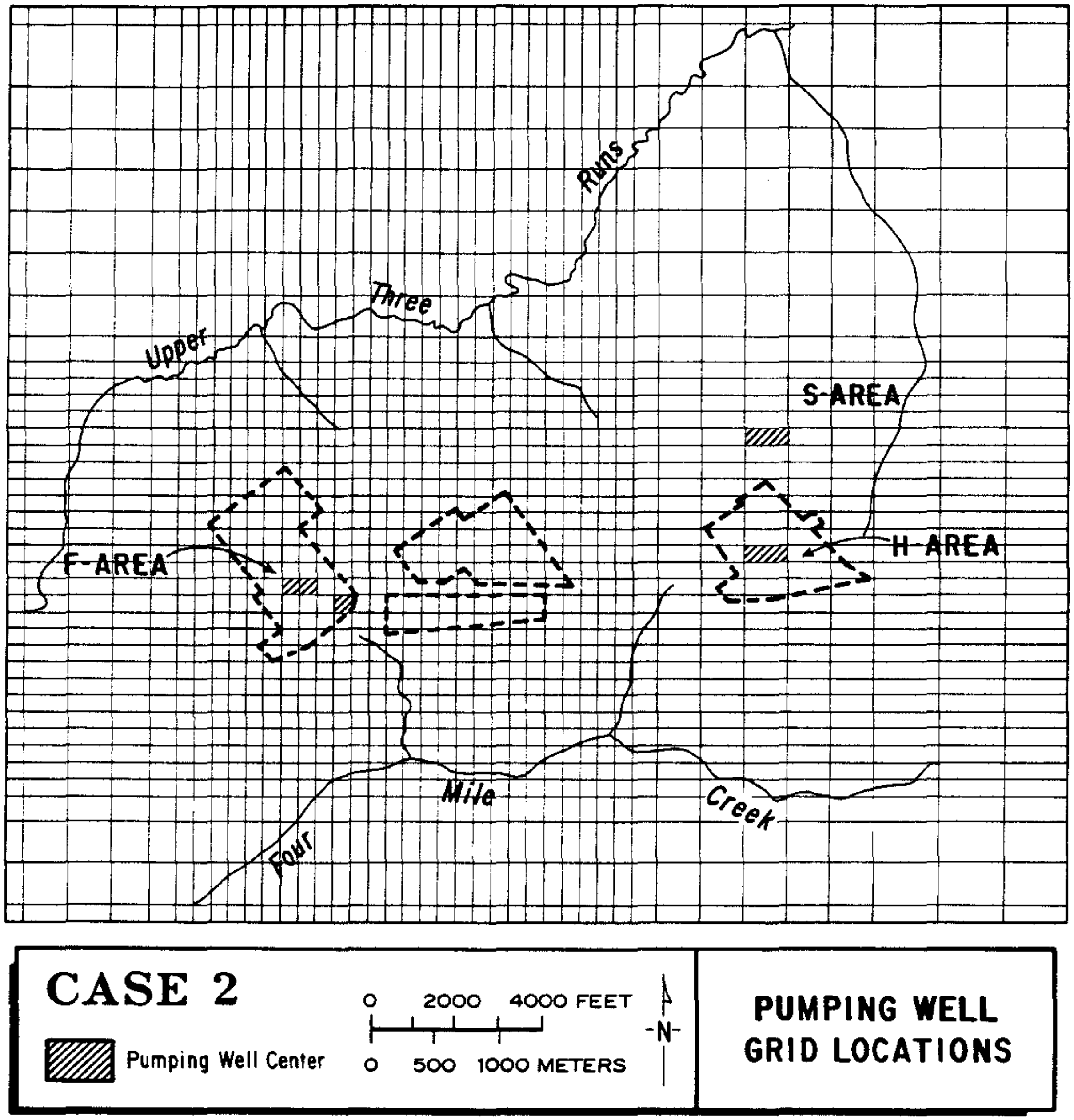


Figure 2.32. Pumping well locations for Case 2.

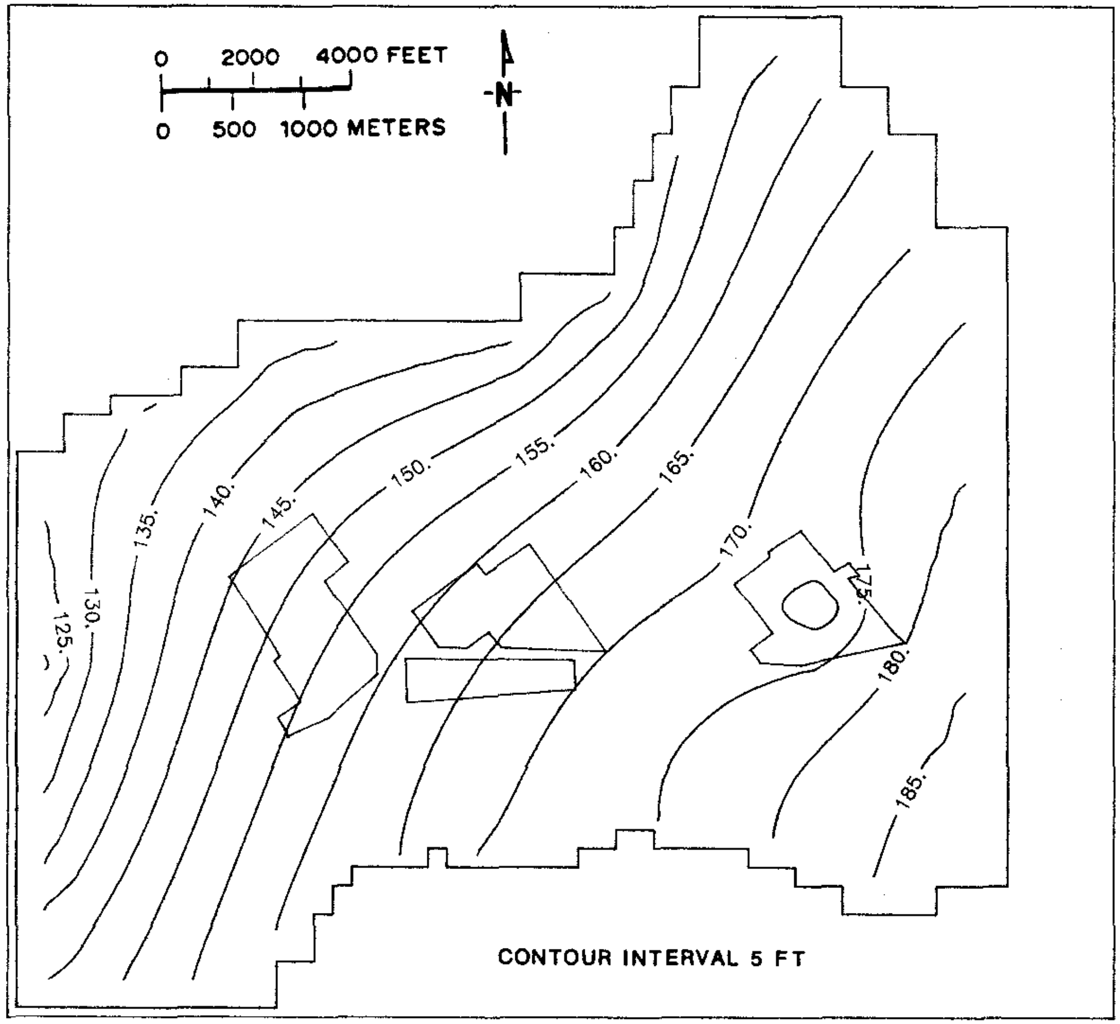


Figure 2.33. Steady-state Congaree potentiometric surface for Case 2.

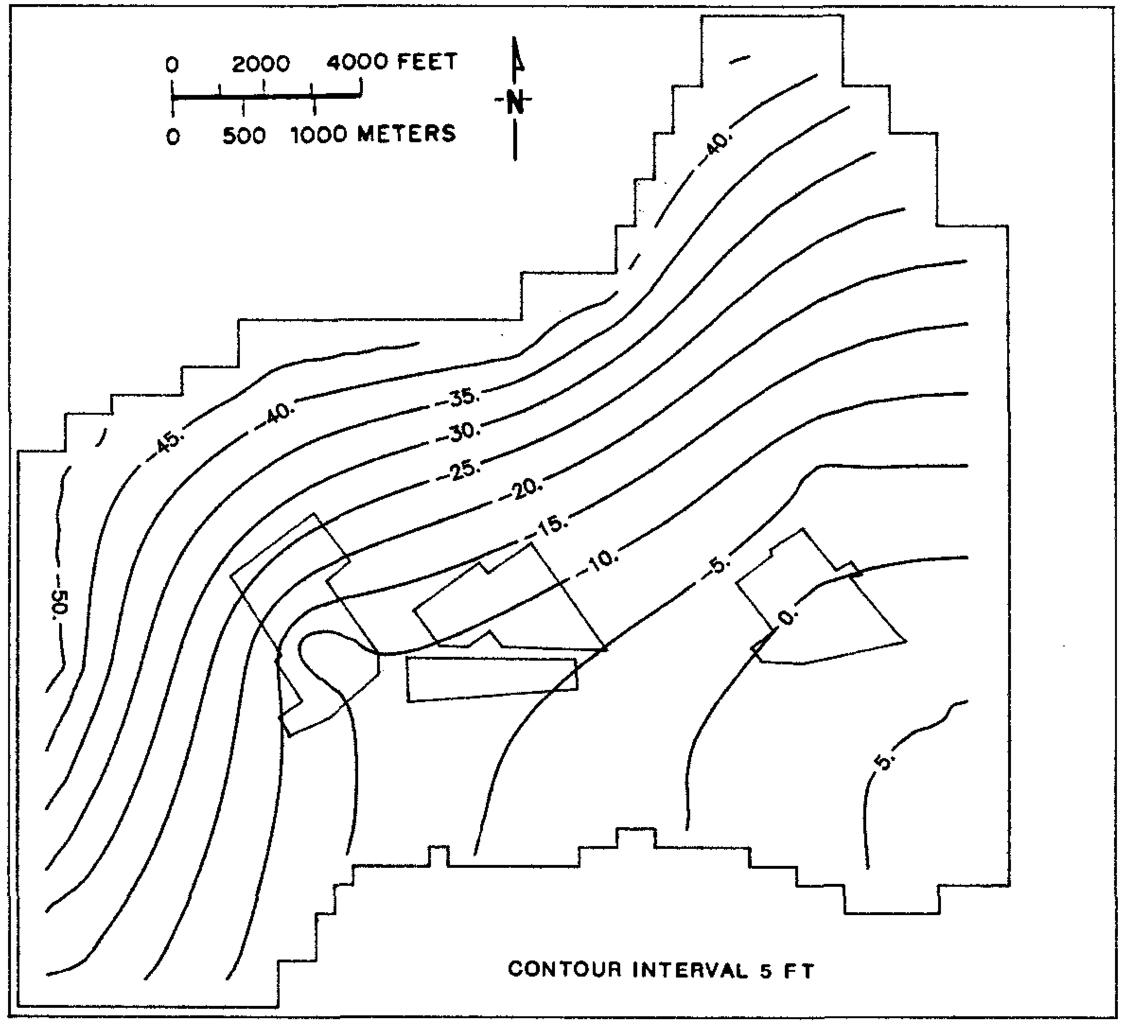


Figure 2.34. Steady-state head difference across the Ellenton confining unit for Case 2.

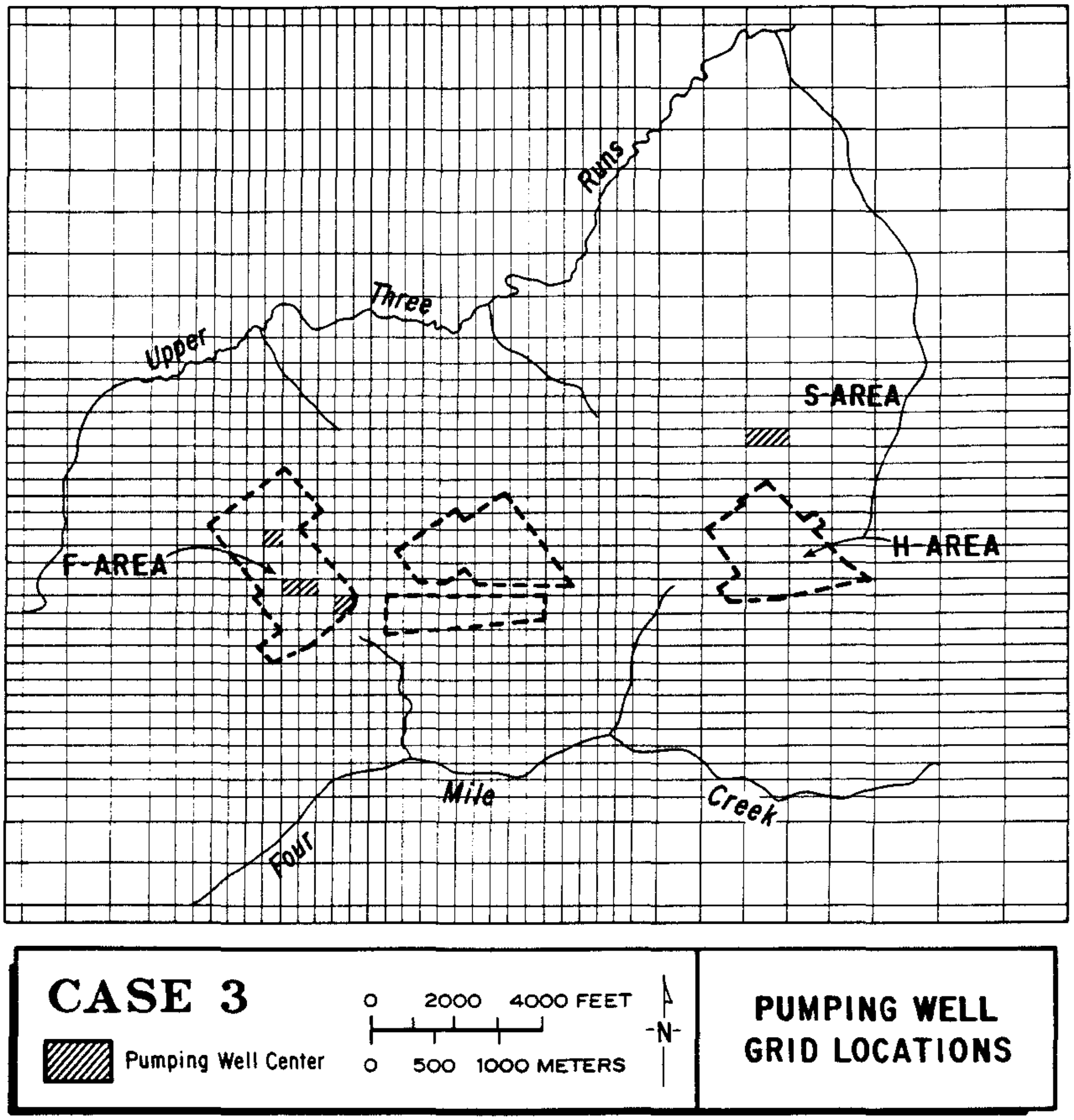


Figure 2.35. Pumping well locations for Case 3.

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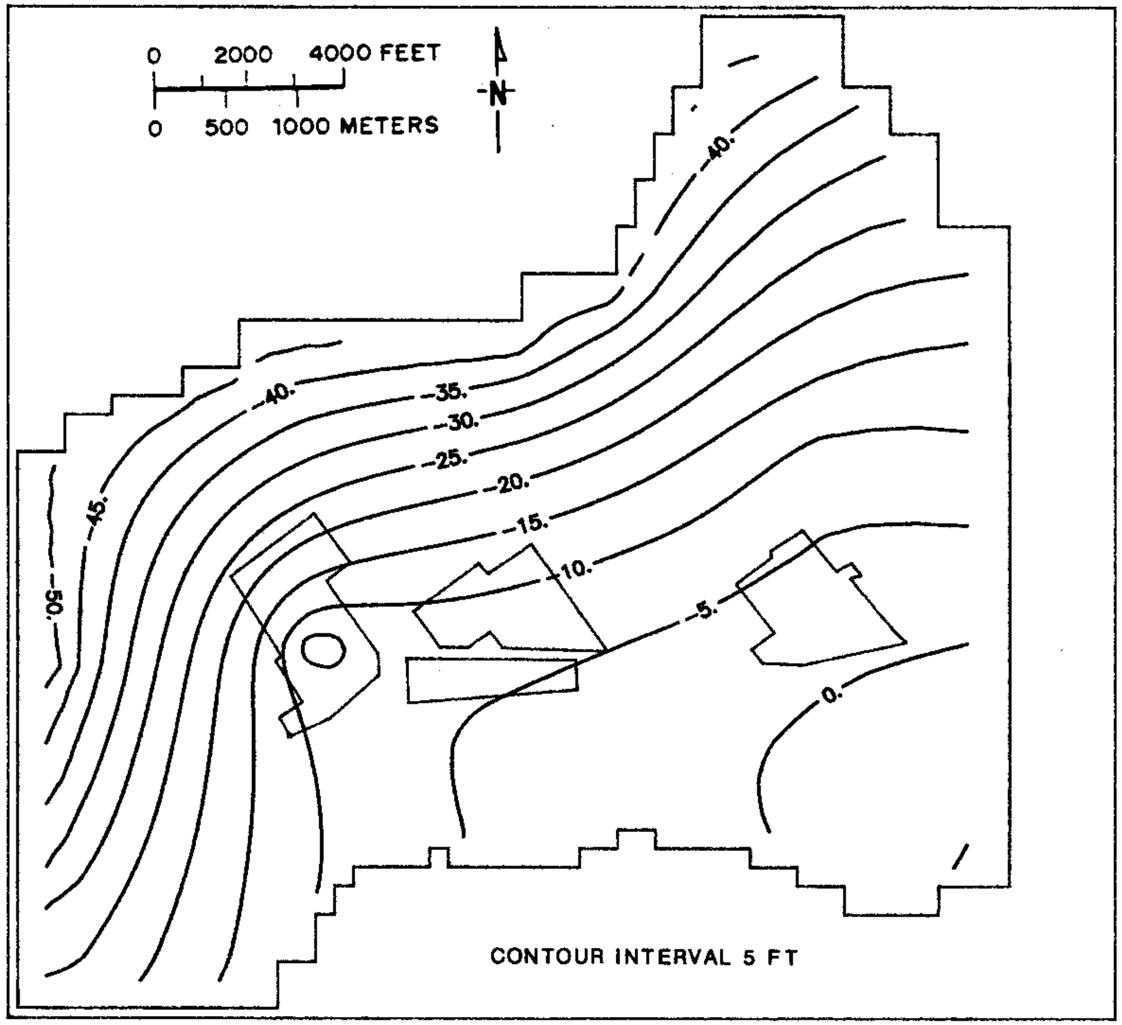

Figure 2.36. Steady-state head difference across the Ellenton confining unit for Case 3.

2.5.5 Case 4: Replace H Area Groundwater Withdrawals with Lower Tuscaloosa Pumping Wells Near Upper Three Runs.

Case 4 involves moving the H Area wells to the Upper Three Runs area and completing them in the lower Tuscaloosa. Pumping well locations are presented in Figure 2.37. The intent of this scenario is to reduce the Congaree/upper Tuscaloosa head reversal loss by moving the pumping wells away from H Area where head reversal loss conditions are the worst. The new pumping well locations were chosen because the transient simulation showed a large (25 ft) head difference between the Congaree and the upper Tuscaloosa aquifers in the Upper Three Runs area. It was postulated that movement to this area would reduce the head difference without causing a loss of head reversal. This pumping location was also chosen because of the level ground surface available in this area for drilling. This scenario offered an alternative to Case 3, where site conditions might prove that scenario technically and economically infeasible. In terms of the movement of the zero contour divide and degree of head difference across the Ellenton formation, this scenario was second only to Case 3 in reduction of head reversal loss. These conditions are shown in Figure 2.38.

2.5.6 Case 5: Pumping of H and S Area Wells only in the Lower Tuscaloosa.

Case 5 involves restricting current and future pumping of wells in H and S Areas to the lower Tuscaloosa. The F Area wells will stay in their current locations with currently proposed pumping rates. Locations of pumping wells for this scenario are presented in Figure 2.39. New wells would have to be drilled or a packer installed to confine groundwater withdrawals to the lower Tuscaloosa according to the SRP mandate. The middle Tuscaloosa confining unit between the upper and lower Tuscaloosa aquifer limits the interaction of the Tuscaloosa aquifers. Restricting pumping to the lower Tuscaloosa aquifer will cause a dampening effect on head drops in the upper Tuscaloosa aquifer and thus the head difference across the Ellenton Clay. Results of this case indicate less improvement in Tuscaloosa isolation than in Cases 2 through 4; however, some improvement is shown

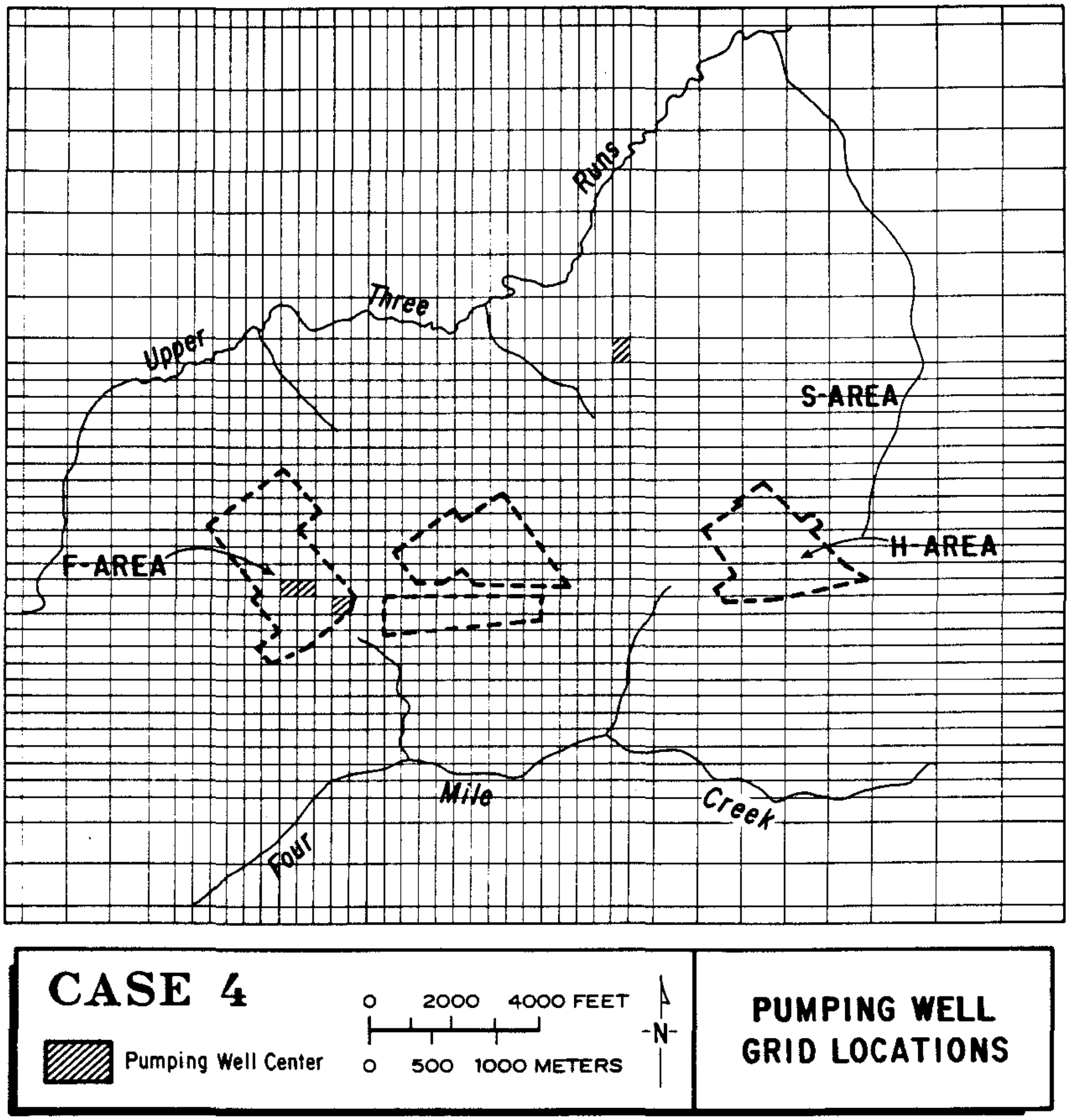

Figure 2.37. Pumping well locations for Case 4.

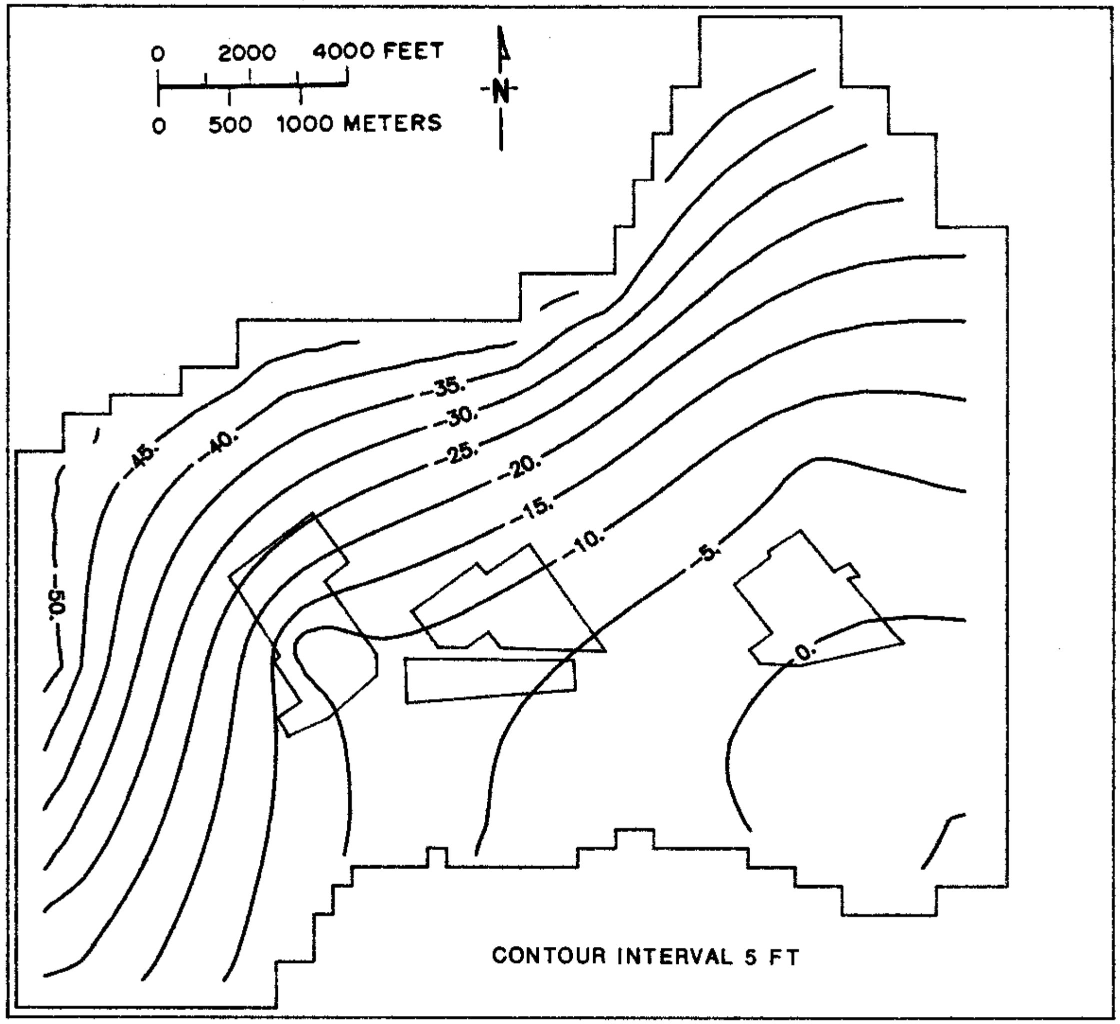

Figure 2.38. Steady-state head difference across the Ellenton confining unit for Case 4.

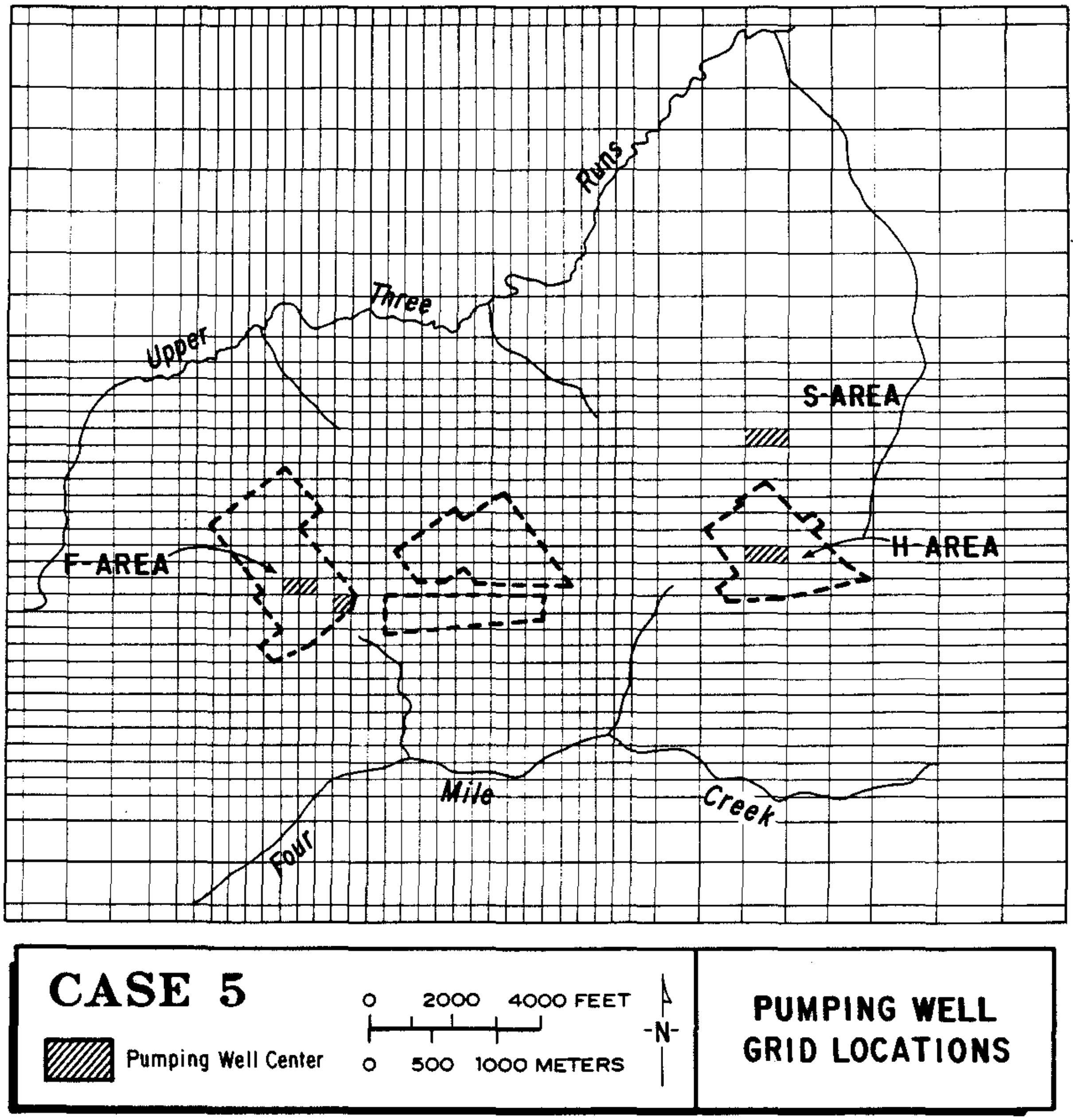

Figure 2.39. Pumping well locations for Case 5.

over conditions simulated in Case 1, which represents currently proposed conditions. Figure 2.40 presents head reversal conditions for this scenario.

2.5.7 Case 6: Replace Current H Area Well Locations with Six Wells Around H Area Completed in the Lower Tuscaloosa.

Case 6 involves replacing current and proposed wells in H Area with six wells spaced around H Area as shown in Figure 2.41. These wells would be installed in the lower Tuscaloosa per the SRP mandate. As conceived, the replacement of the single H Area pumping center with a number of smaller discharge wells would spread out the stress on the system and therefore improve head reversal conditions. Reductions in groundwater levels in the Tuscaloosa Formations would not be amplified by a single high discharge center and thus, the Congaree/upper Tuscaloosa head reversal loss would not be increased. The head difference across the Ellenton is shown in Figure 2.42. Although this figure shows improvement over conditions in Case 1, it is the least desirable of the remaining cases.

2.5.8 Sensitivity of Downward Gradient across the Ellenton to F and H Area Pumping Rates.

The production rates of the F and H Area wells partially determine which portion of the model domain has a downward gradient across the Ellenton confining unit. A series of simulations were made to assess the sensitivity of downward gradient limits to F and H Area production rates. Seperate simulations were made where production rates per facility of 1200, 750, 500, and 250 gpm were assigned to the F and H Area pumping centers. As in previous simulations, pumping rates were apportioned between the upper and lower Tuscaloosa aquifers. Pumping well grid block locations for this series of simulations are presented in Figure 2.43.

The results of steady-state simulations of the various well production rates are depicted in Figures 2.44 - 2.47. As expected, with increased pumping, the portion of the model domain with a downward gradient across the Ellenton increases. These figures also show that a downward gradient across the Ellenton first occurs between pumping rates of 750 and 1200 gpm per facility.

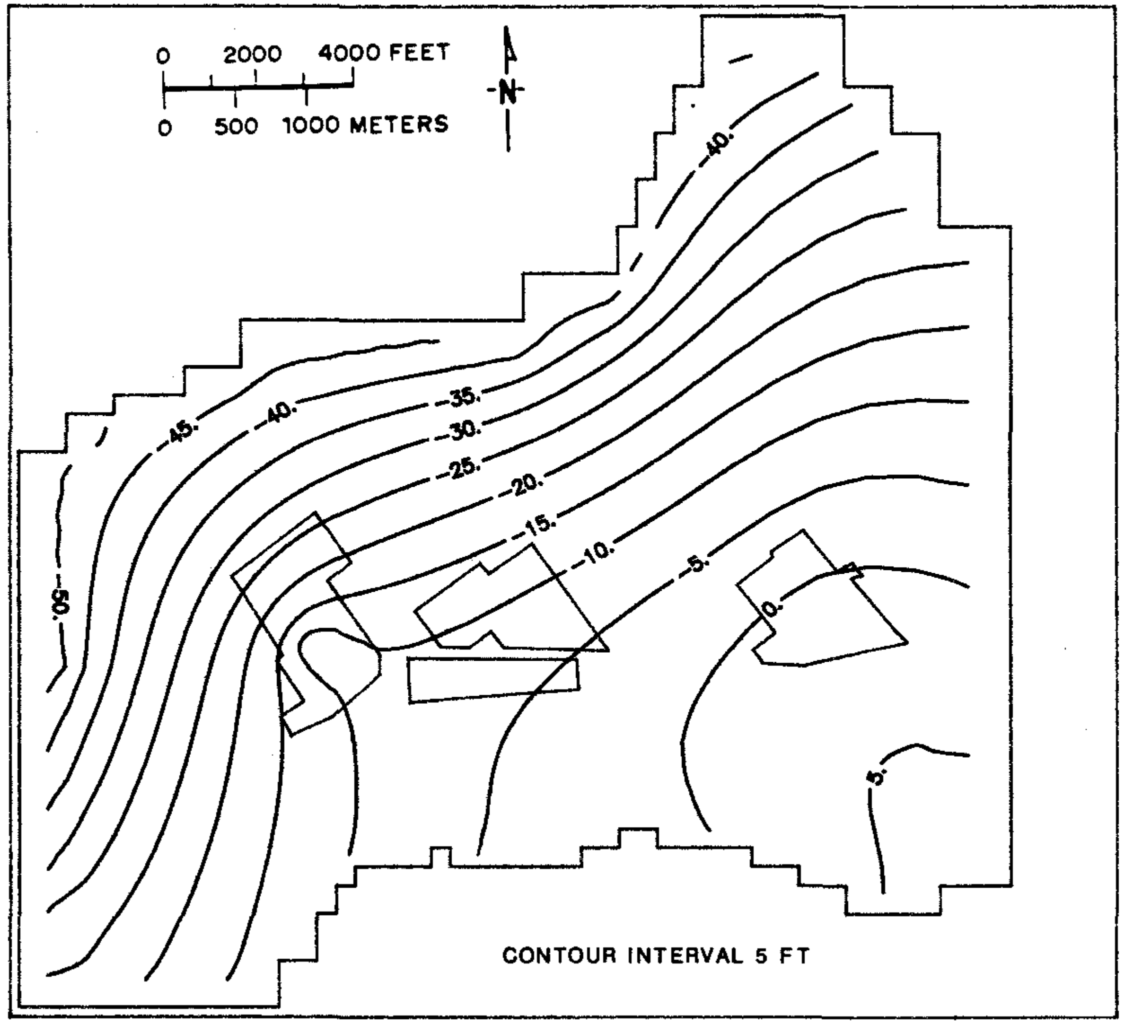

Figure 2.40. Steady-state head difference across the Ellenton confining unit for Case 5.

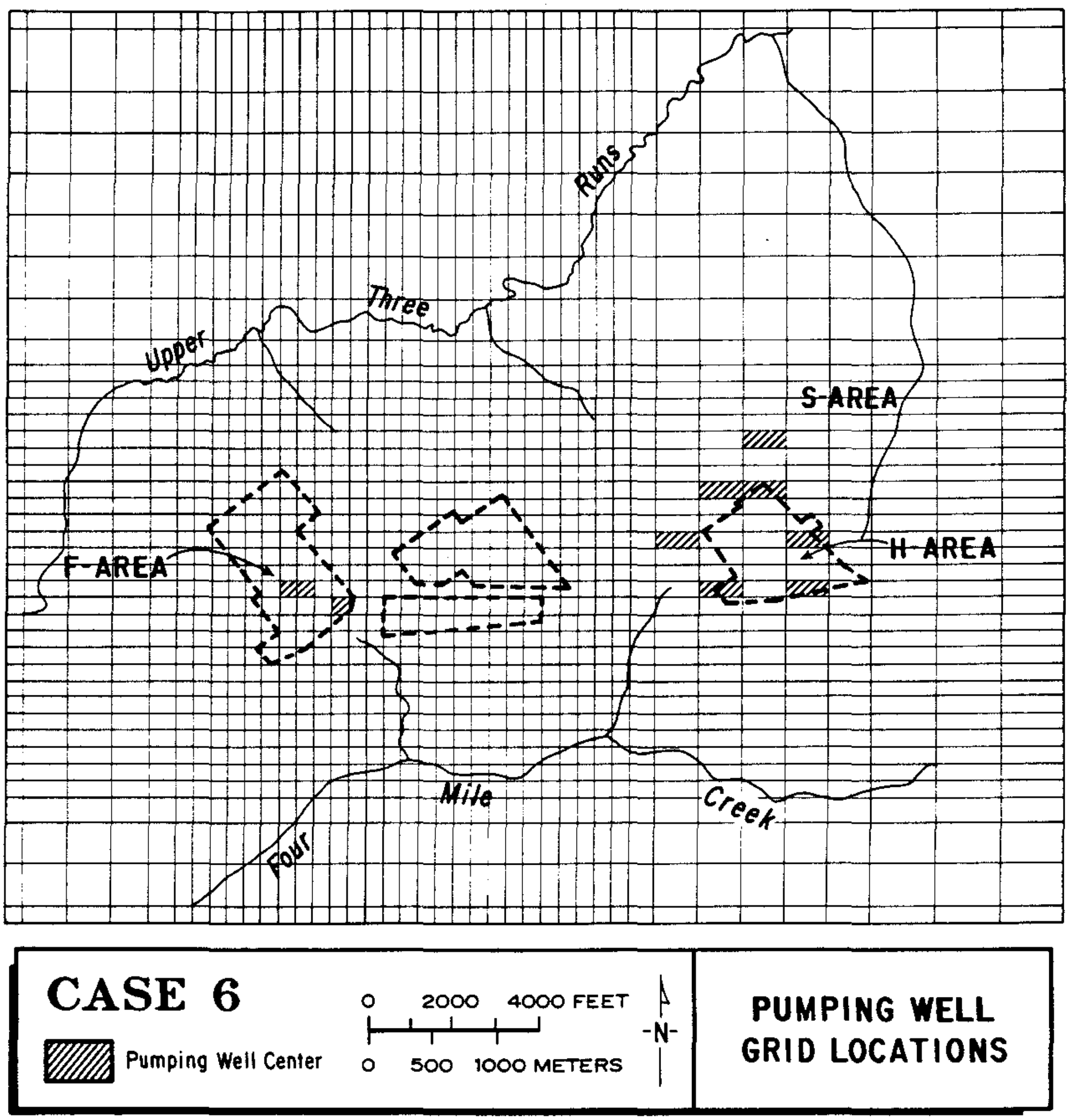

Figure 2.41. Pumping well locations for Case 6.

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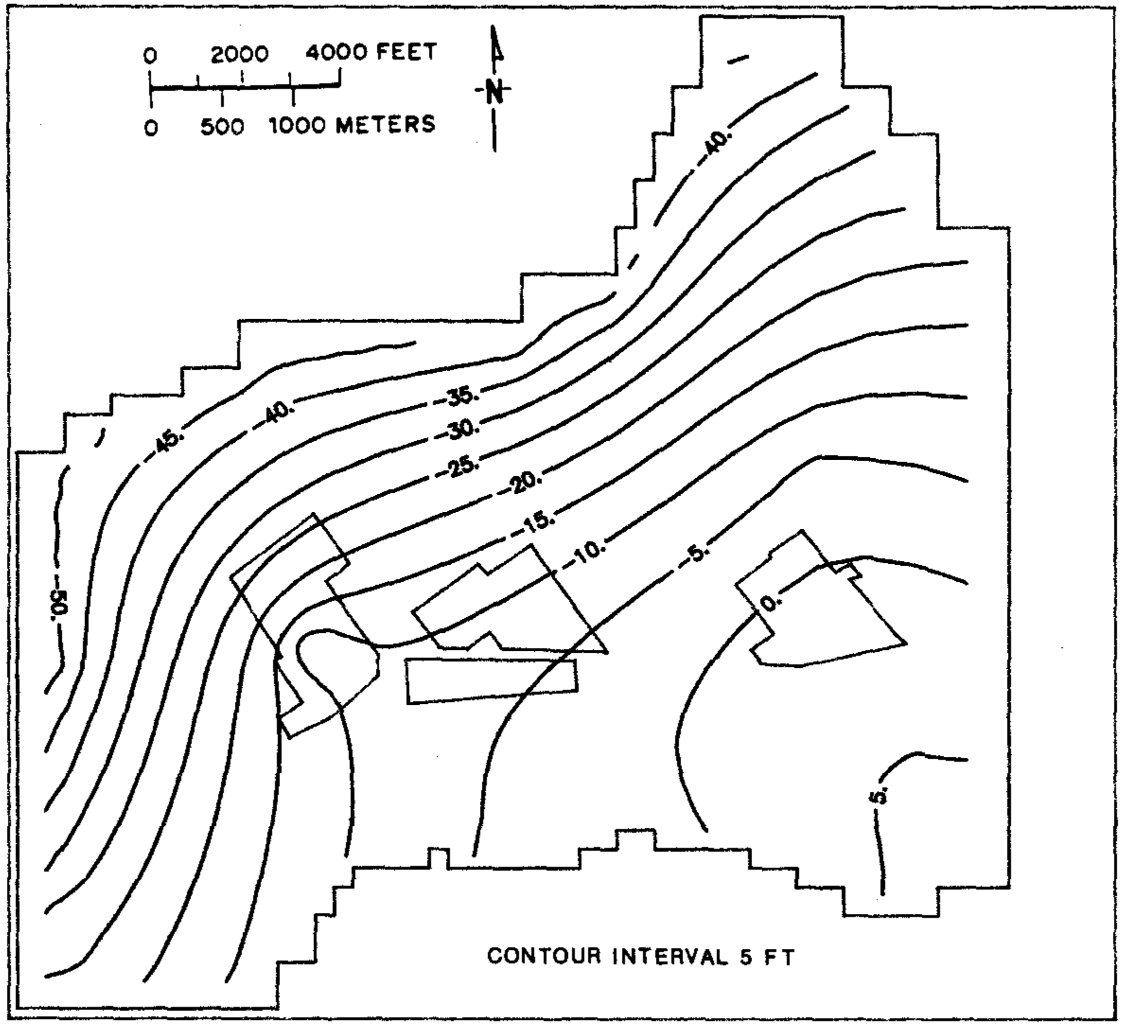

Figure 2.42. Steady-state head difference across the Ellenton confining unit for Case 6.

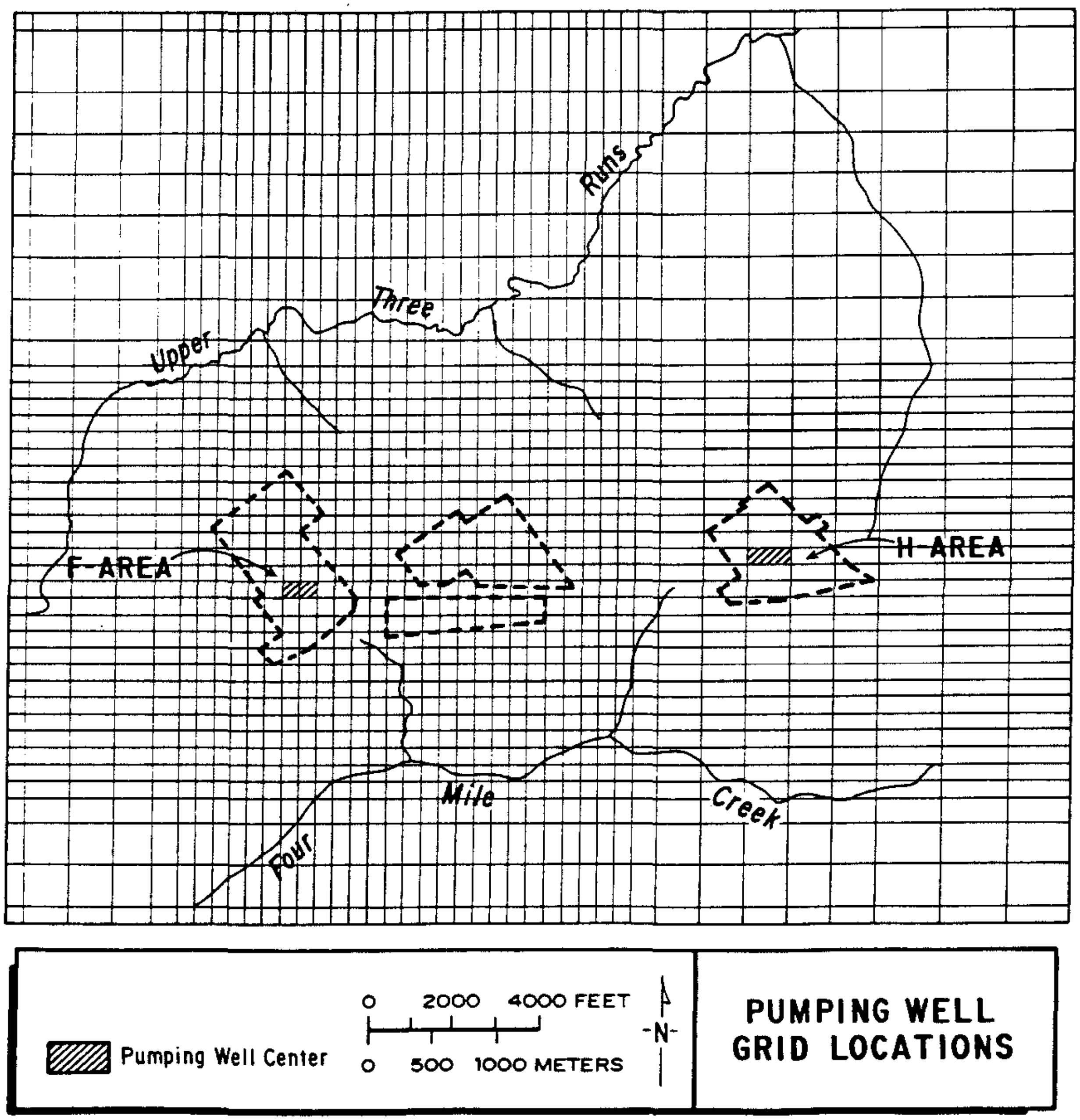

Figure 2.43. Pumping well locations for well production variations.

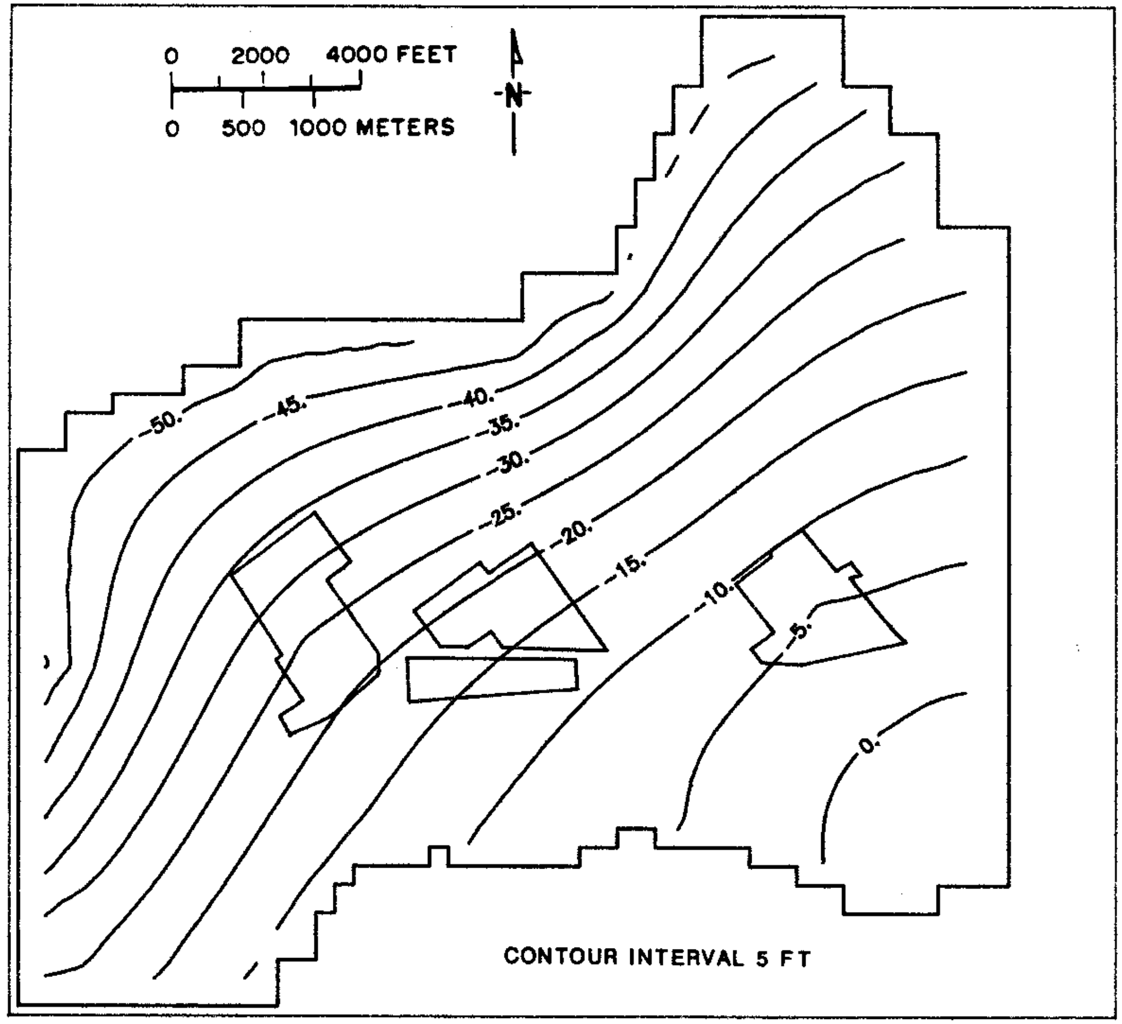

Figure 2.44. Steady-state head difference across the Ellenton confining unit for 250 gpm per F and H Area facility.

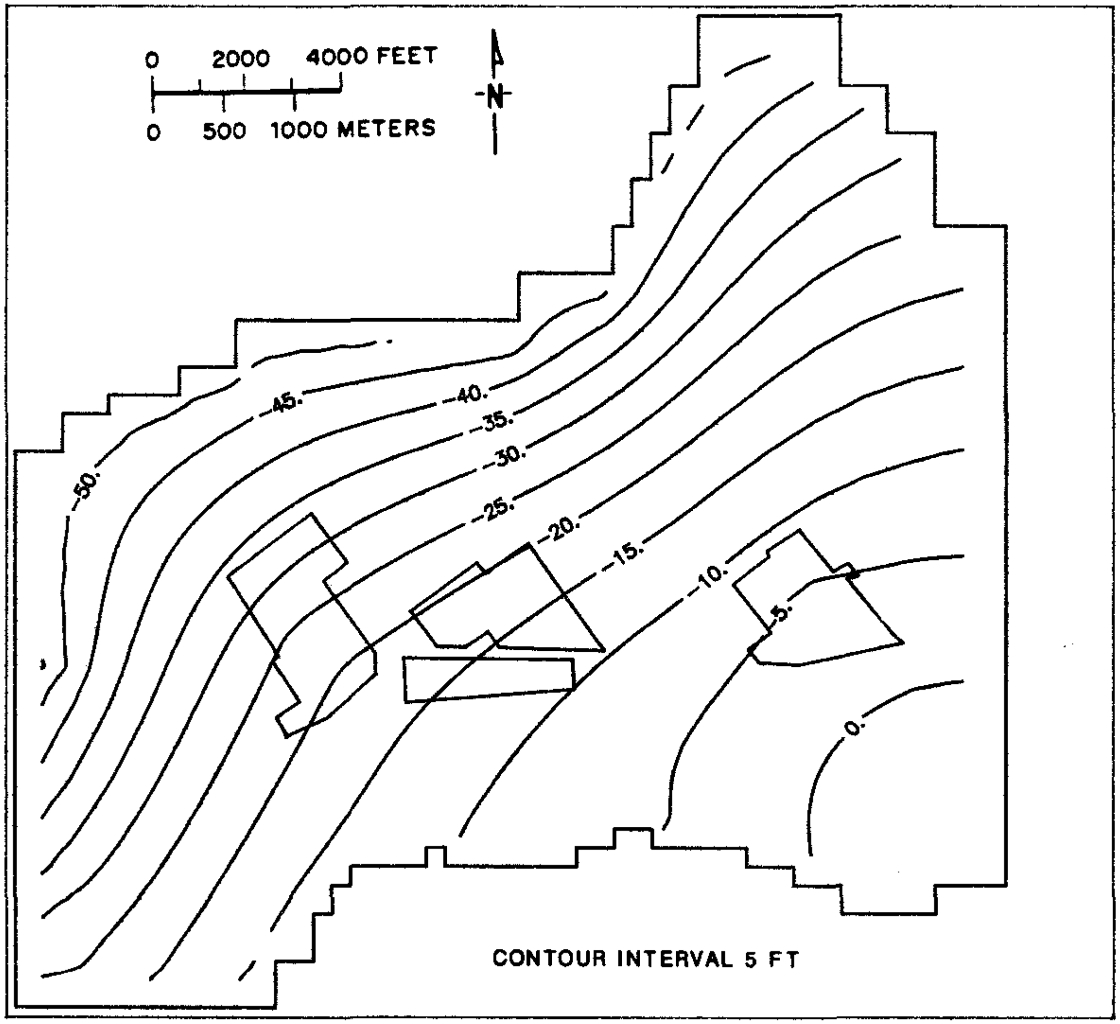

Figure 2.45. Steady-state head difference across the Ellenton confining unit for 500 gpm per F and H Area facility.

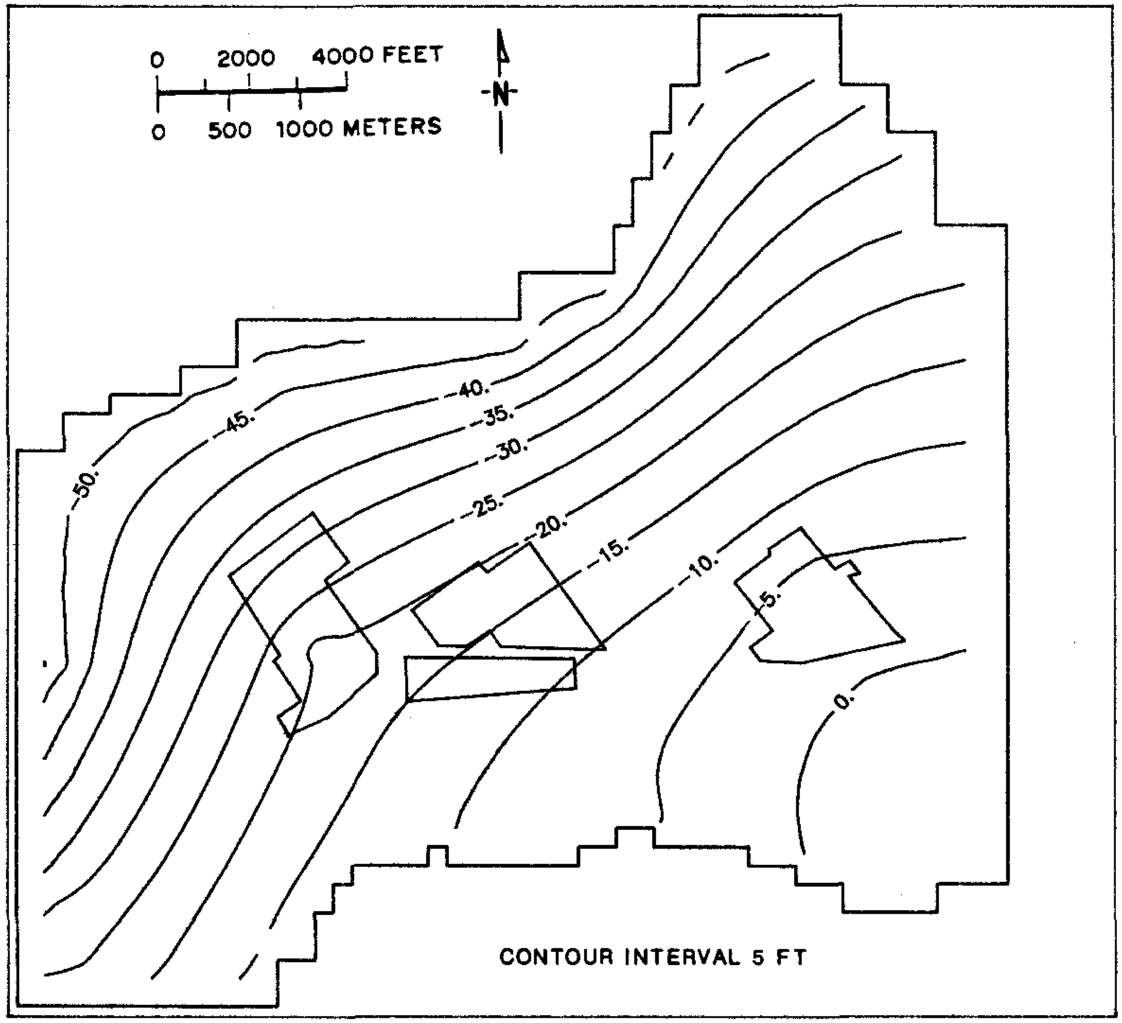

Figure 2.46. Steady-state head difference across the Ellenton confining unit for 750 gpm per F and H Area facility.

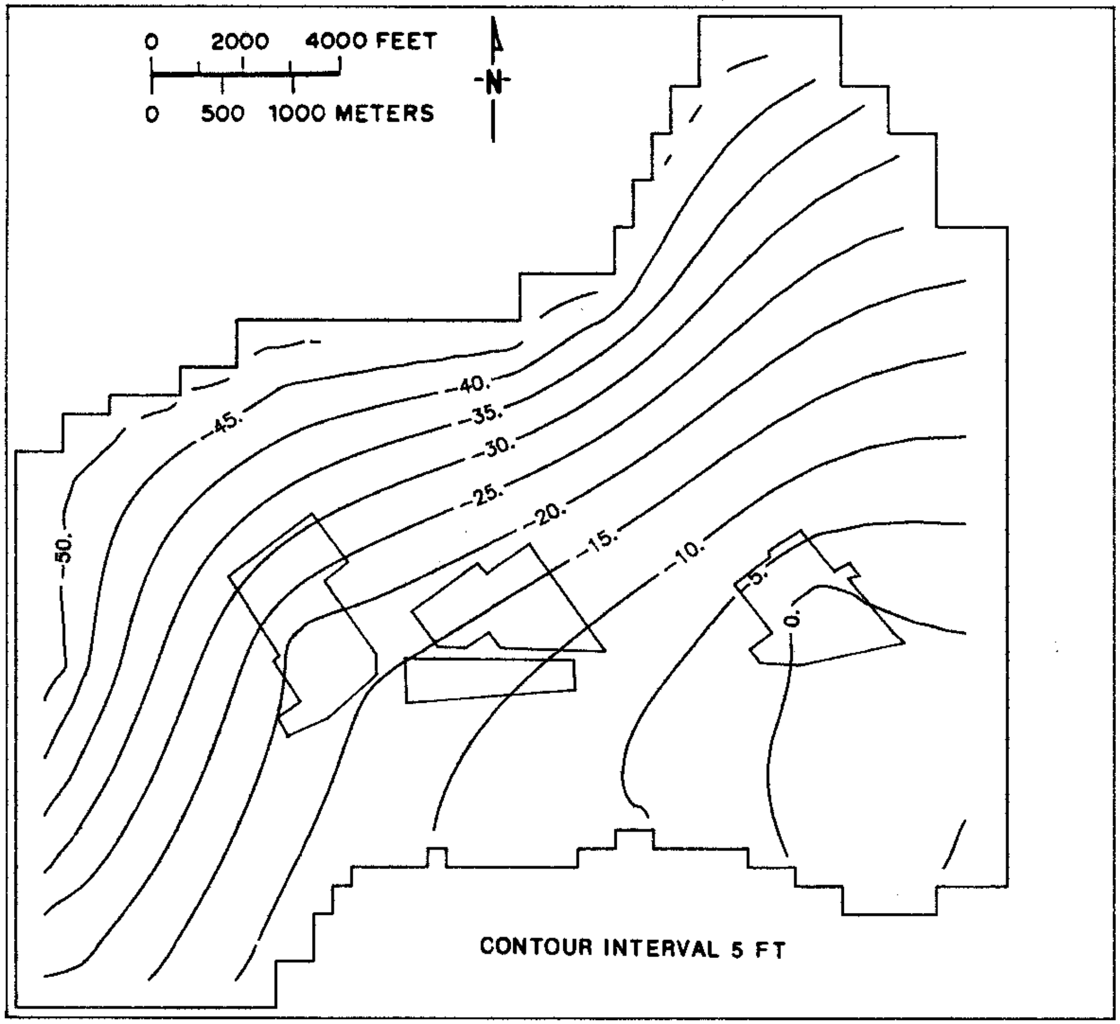

Figure 2.47. Steady-state head difference across the Ellenton confining unit for 1200 gpm per F and H Area facility.

2.5.9 <u>Summary of Results</u>

As Tuscaloosa pumping rates increase within the General Separations Area, the portion of the model domain which has a downward gradient across the Ellenton also increases. Once production rates reach approximately 1000 gpm per facility, simulated downward gradients across the Ellenton occur beneath H Area.

Currently-proposed pumping rates within the Tuscaloosa formation exceed 1000 gpm at both F and H Area facilities. Scenarios which varied production rates, screen locations, and well placements were simulated in Cases 1 through 6 to assess different approaches to limiting downward gradients across the Ellenton within the General Separations Area. Only one scenario completely ensured no loss of head reversal in H Area, whereas all scenarios simulated showed improvement over currently-proposed pumping rates. Table 2.6 quantifies the maximum value of head difference within H Area for each case. The grid blocks beneath H Area shown in Figure 2.48 were analyzed to determine maximum head differences for each scenario. Based on a relative comparison, Table 2.6 shows the best improvement of conditions will be achieved by moving H Area wells to F Area. The percentage of the total area within the H Area boundary with a head reversal loss is presented for each case in Table 2.7. This table also shows that the movement of H Area wells to F Area best maintains Tuscaloosa isolation.

Strict adherence to the conditions presented in Figures 2.29 through 2.48 and Tables 2.6 through 2.7 of this report may not be the best approach to ensuring maintenance of Tuscaloosa isolation within the General Separations Area. The best solution may be a modification of one of these scenarios or a combination of these scenarios. The final decision should be made by SRP personnel based on the economic and technical feasibility of each scenario.

Table 2.6. Peak value of head difference across the Ellenton within H Area for Cases 1-6.

Peak value of Ellenton head difference in feet	
Case 1	14.5
Case 2	3.3
Case 3	-0.1
Case 4	1.1
Case 5	3.3
Case 6	3.2

(+) Higher heads in Congaree aquifer.
(-) Higher heads in upper Tuscaloosa.

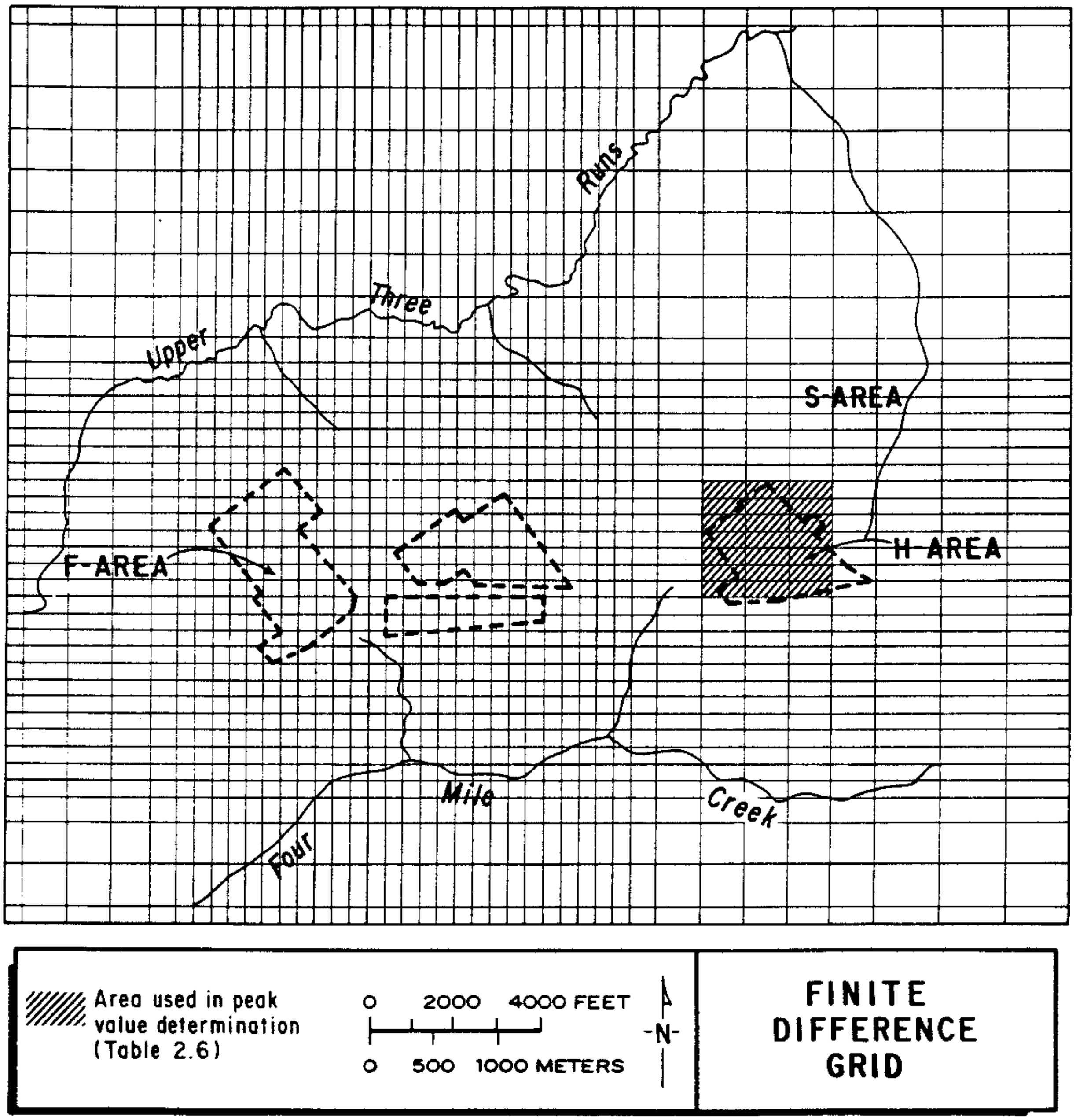

Figure 2.48. Grid blocks used for peak Ellenton head difference results presented in Table 2.6.

Table 2.7. Percent of H Area with a loss in the Congaree/upper Tuscaloosa head reversal for Cases 1-6.

Percent of H Area with loss in head reversal.[1]	
Case 1	100
Case 2	61
Case 3	0
Case 4	47
Case 5	77
Case 6	87

[1] Due to digitizing accuracy, values are within ±7.5 percent

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APPENDIX A. CORRELATION OF HYDROSTRATIGRAPHIC UNITS.

The hydrostratigraphic nomenclature that will be assigned to the regional groundwater system at Savannah River Plant (SRP) is currently being reviewed by the State of South Carolina Hydrostratigraphic Nomenclature Subcommittee. This committee comprises representatives of industry, government, and regulatory agencies in South Carolina. Figure 1 is a comparison of existing hydrostratigraphic nomenclature currently being used at SRP with respect to the hydrostratigraphic unit names selected for this report.

Everest Geotech is a geologic consulting firm contracted by the Savannah River Laboratories (SRL) to develop a comprehensive model of the stratigraphy underlying the SRP. Everest Geotech has subdivided the stratigraphy at SRP into numbered units (Units I - VII) based on stratigraphic, paleontological and geophysical interpretations of onsite well logs and geologic cores. This stratigraphic model is being used by GeoTrans to develop a conceptual hydrogeologic model for an ongoing sitewide groundwater investigation and modeling project. Therefore, in order to remain consistent with the ongoing sitewide work, the hydrostratigraphic model for this report is also based on the units defined by Everest Geotech. For the purposes of this report, the hydrostratigraphic nomenclature developed by Siple (1967) was reinterpreted to correspond to the units defined by Everest Geotech (see Table A.1). Technically, with respect to depositional environment, the Everest Geotech units and the Siple (1967) units cannot be correlated. However, on a local scale (i.e., within the General Separations Area), the hydrologic properties of the units remain the same. For example, Everest Geotech's Unit II (referred to as the lower Tuscaloosa in this report) and Siple's lower Tuscaloosa are both comprised primarily of sand with minor amounts clay.

The currently accepted hydrostratigraphic nomenclature utilized by SRL personnel divides the "Tuscaloosa" of Siple (1967) into four distinct units; the Cape Fear, the Middendorf, the Black Creek, and the Peedee Formations. The Cape Fear Formation corresponds to the Basal Tuscaloosa of Siple and to Unit I of Everest Geotech. The Middendorf Formation corresponds to the lower Tuscaloosa of Siple and to Unit II

Table A.1. Correlation between Everest GeoTech and Siple (1967) hydrostratigraphic nomenclature.

Siple (1967)	Everest GeoTech
Barnwell McBean Congaree	Unit VII + Unit VI
Ellenton Upper Tuscaloosa Clay	Unit V
Upper Tuscaloosa	Unit IV
Middle Tuscaloosa Clay	Unit III
Lower Tuscaloosa Clay	Unit II
Basal Clay	Unit I

of Everest Geotech. The Black Creek Formation roughly corresponds to the Middle Tuscaloosa Clay unit, and the lower portion of the upper Tuscaloosa Formation of Siple. This unit also corresponds to Unit III and the lower portion of Unit IV of Everest Geotech. The Peedee Formation corresponds to the upper portion of the upper Tuscaloosa of Siple (1967) and the upper portion of Unit IV of Everest Geotech.

The Ellenton and Congaree hydrostratigraphic nomenclature has remained consistent since Siple (1967) although the upper portion of the Ellenton is now defined as the Williamsburg Formation. The Tobacco Road and Dry Branch Formation terminology has been utilized by some authors as equivalents to the Barnwell and upper McBean Formations, respectively. At the time of this report, Everest Geotech units equivalent to the Tertiary formations were not available.

The hydrostratigraphic units and corresponding nomenclature selected for this report were the units defined by Everest Geotech and the correlating nomenclature defined by Siple (1967). The justifications for this decision are as follows: (1) use of the units defined by Everest Geotech is consistent with the ongoing GeoTrans sitewide work; (2) use of the Siple (1967) nomenclature is consistent with previous General Separations Area groundwater flow and transport studies reports by GeoTrans; (3) on a local scale, within the General Separations Area, the hydrogeology of the aquifer units remains consistent even though the interpretations of depositional environments change i.e., Unit II (Everest Geotech), the lower Tuscaloosa (Siple, 1967) and Middendorf (SRL nomenclature) are all defined as an aquifer unit comprised primarily of sand with minor amounts of silt and/or clay.