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DP-MS-80-112

CONF-801145--3

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

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This paper is to be presented at the
Annual Meeting of the
Geological Society of America
Atlanta, Georgia, November 17-20, 1980.

This paper was prepared in connection with work under Contract No. DE-AC09-76SR00001 with the U.S. Department of Energy.

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Abstract

A predictive model for the space-time distributions of hydraulic head and ground-water flow velocity has been developed for the vicinity of the low-level radioactive waste burial grounds at the Savannah River Plant. The hydraulic head distribution is being modeled using a computer code that solves the ground-water flow equation using a three-dimensional finite-difference scheme. Steady-state calibration of this model is complete, and transient calibration is under way.

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. Low-level radioactive waste generated during operation is buried in back-filled trenches excavated above the water table in specific areas designated for this purpose. To assess storage risks, it is desirable to be able to predict quantitatively the movement and concentration of potential contaminants in the ground. To this end, a mathematical model of ground-water flow beneath the burial ground has been developed.

For this model the distribution of hydraulic head in time and space is required. Input to this hydraulic head model includes: water levels for the hydrogeologic units, obtained from well measurements; initial values for transmissivity and coefficient of storage, obtained from pumping tests; and a conceptual geologic framework, based on subsurface coring. After comparing calculated heads to measured heads, values for transmissivity and storage can be adjusted in order to obtain an acceptable fit.

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 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. Models have been developed for the overall waste-storage area; this study focuses specifically on the low-level waste burial ground. The ground-water system of interest is bounded on one side by Four Mile Creek, on two sides by no-flow boundaries, on the fourth side by a ground-water divide, on top by the water table, and on the bottom by an impermeable boundary. The topography is generally flat to slightly rolling. A few small streams drain the area. Precipitation 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 bounding stream to the south. The eastern hydrologic boundary for the water-table aquifer in the study area is a small stream and swamp, while the western hydrologic boundary is the no-flow condition imposed by flow approximately normal to Four Mile Creek. The northern boundary is the ground-water divide separating flow between the northern and southern discharge areas. The gradient of the water table varies from fairly flat along the crest of the ground-water ridge to relatively steep as the water table approaches Four Mile Creek.

The clay layers in the subsurface retard the downward movement of water, thereby causing a vertical head gradient across these clays. With increasing depth, therefore, the potentiometric surfaces tend to stand lower for deeper formations.

Computer Simulation of Ground-Water Flow

The ground-water flow system is being simulated by a three-dimensional, finite-difference solution of the ground-water flow equation. The computer program was developed by the U.S. Geological Survey and calculates the distribution of hydraulic head in time and space.

Developing the three-dimensional hydraulic head model involved superposing a rectilinear grid over the study area and adding the vertical hydraulic conductivity, coefficient of storage, 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, constant head, or subject to constant flux.

The hydraulic head model is being calibrated to actual conditions by adjusting various input parameters until measured water-level distributions are reproduced. The progress of calibration is evaluated by summing the squares of the deviation of the calculated heads from measured heads in the region of the study area where data are most available. When this sum is minimized, calibration is achieved. In addition, the mass balance of the system has to be within acceptable limits. The model was first calibrated to the steady-state head distribution existing in the study area by specifying the coefficient of storage as zero and by adjusting the transmissivities of each block. Despite seasonal fluctuations, the head distribution observed in the field is approximately constant over time. After the steady-state calibration was completed, the resulting distribution of transmissivities was considered as representative of the subsurface material in the study area, although some additional adjustments may be necessary. Transient calibration will then be accomplished by varying the values of the coefficient of storage of each block until the model satisfactorily reproduces the actual changes in hydraulic head levels measured in wells over a period of time. The model will then be considered ready for predictive use.

Results

The model area was first approached as a two-dimensional problem by assuming that the tan clay was an impermeable boundary and that all flow was laterally in the Barnwell Formation toward discharge areas. The calibration resulted in a hydraulic conductivity for the Barnwell of 21 meters per day (8×10^{-4} feet per second). Given the hydraulic gradients in the area and assuming an effective porosity of 20 percent, flow velocities on the order of 1 meter per day (4×10^{-5} feet per second) were calculated. This velocity was believed to be much too large for the types of subsurface material present. Additionally, no aquifer tests conducted produced hydraulic conductivities so large, so it was concluded that the tan clay is not an impermeable boundary and that groundwater flow occurs vertically down into the McBean Formation.

Considering the problem as a three-dimensional one, then, calibration was achieved with a horizontal hydraulic conductivity for the Barnwell and McBean Formations of 1.8 meters per day (8×10^{-5} feet per second) and a vertical hydraulic conductivity of the tan clay of 1.6×10^{-3} meters per day (6×10^{-8} feet per second). Although some discrepancies occur in the fit between calculated and measured head distributions (Figure 5), the comparison is considered acceptable.

Simulation of the water-table mound north of the large seepage basin posed some problems when the simplified model was used. Some topographic relief occurs in this area which may contribute to the formation of the mound; however, the water-table relief is large compared to the topographic relief. Drilling is planned soon in this area to explore the possibility of low-conductivity perching layers influencing the water table distribution. For the present, however, a reduced vertical hydraulic conductivity of the tan clay was assumed beneath this area and was used to reproduce the observed mound.

Limited data are available to develop a detailed potentiometric map of the McBean Formation. Therefore, the hydraulic head model was used for this purpose, with the available data used as control. The head distribution generated by the code is reasonable considering the expected flow pattern in the McBean Formation and the water-table distribution in the overlying Barnwell formation (Figure 6).

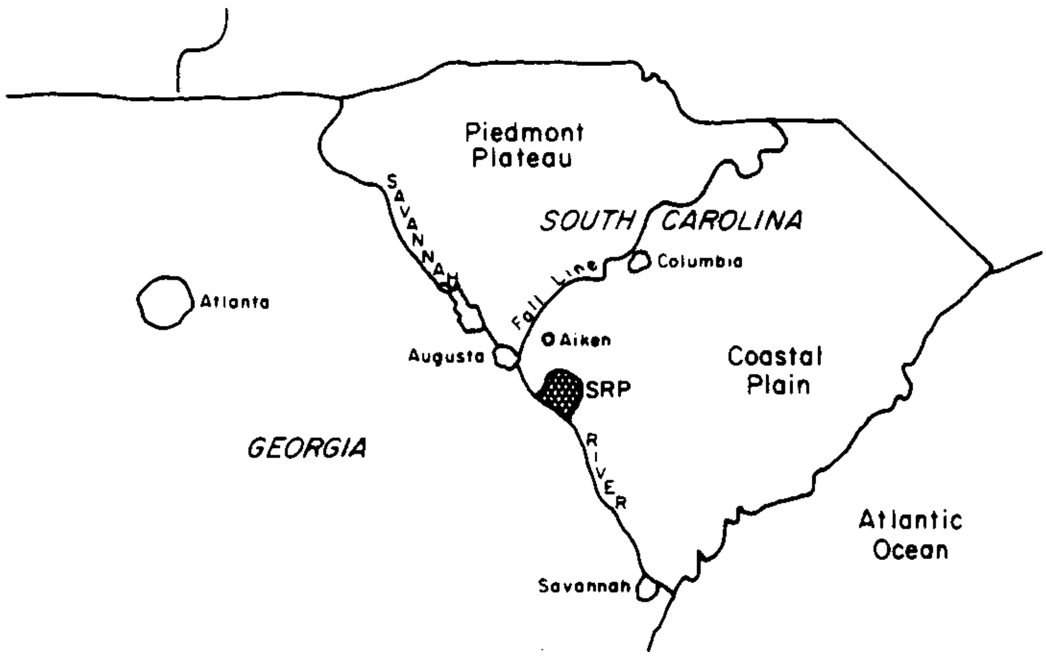

FIGURE 1. Location of Savannah River Plant and Nearby Geologic Provinces

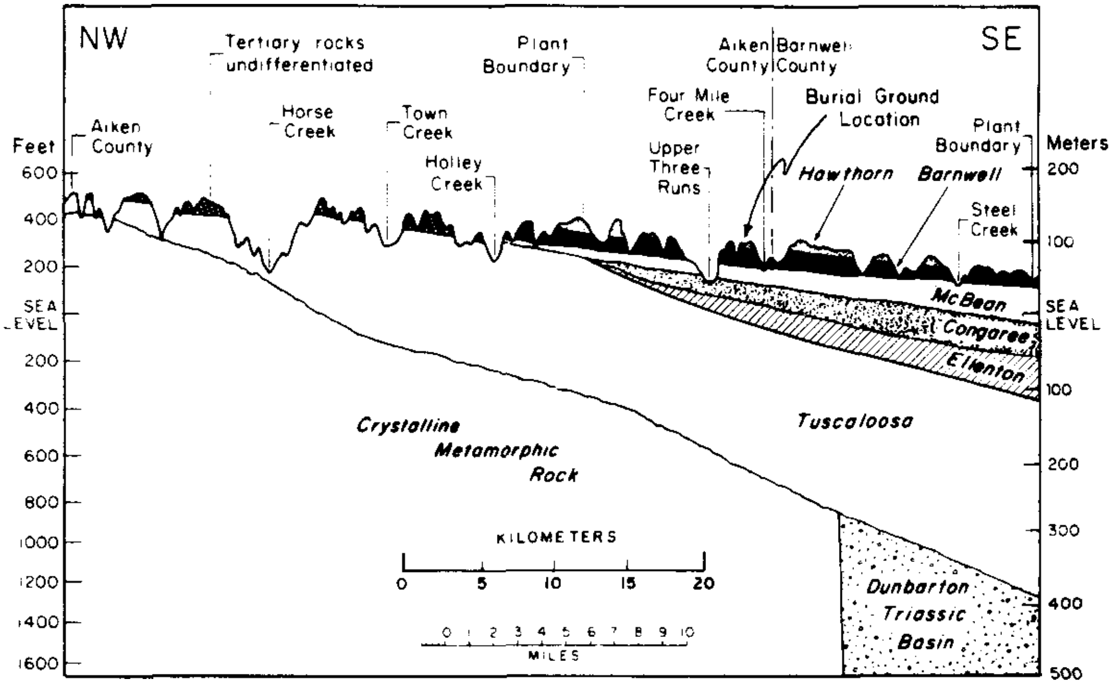

FIGURE 2. Generalized NW to SE Geologic Profile Across the Savannah River Plant (Marine and Routt, 1975)

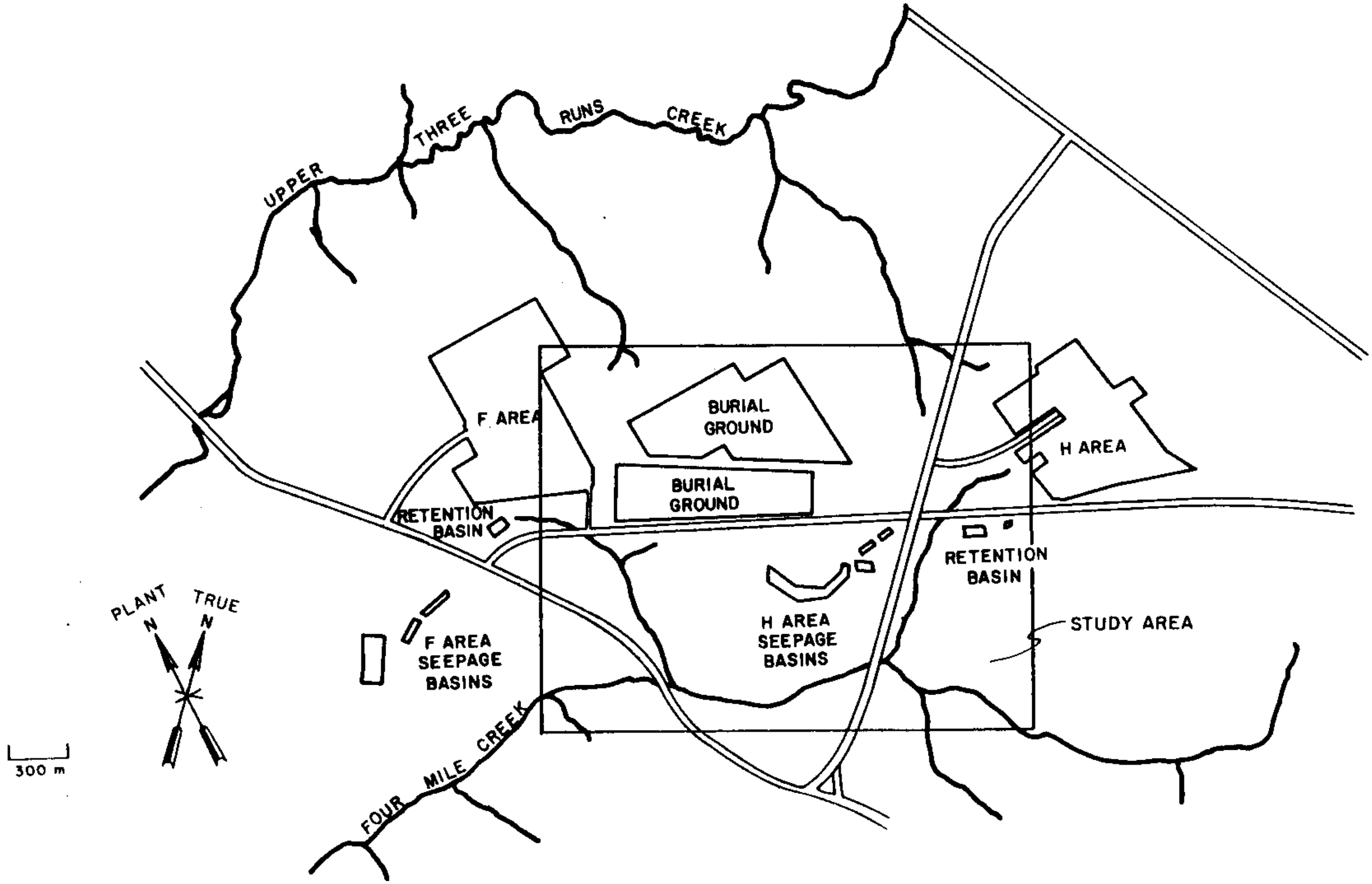

FIGURE 3. Map of the Study Area

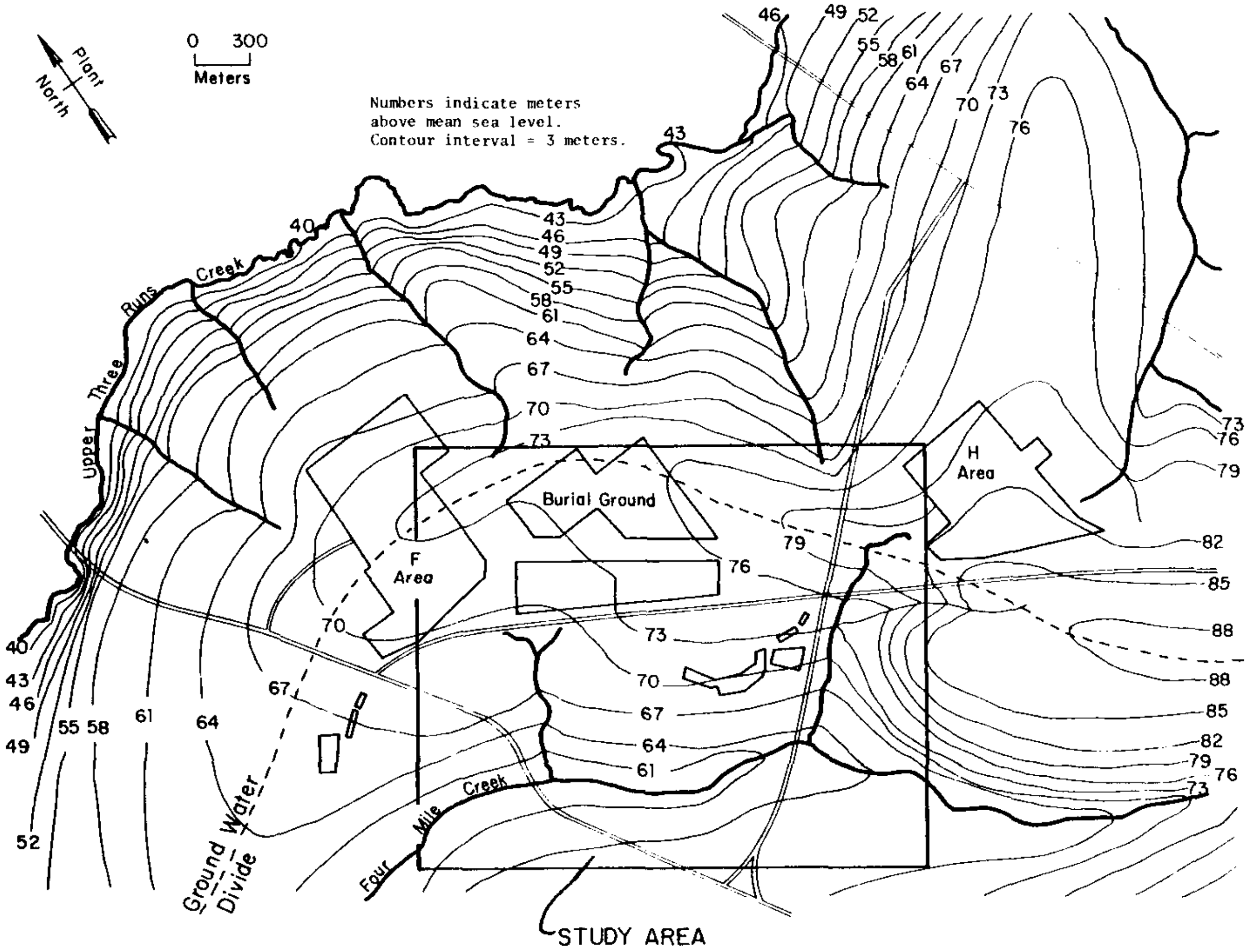

FIGURE 4. Average Elevation of the Water Table at SRP During 1968

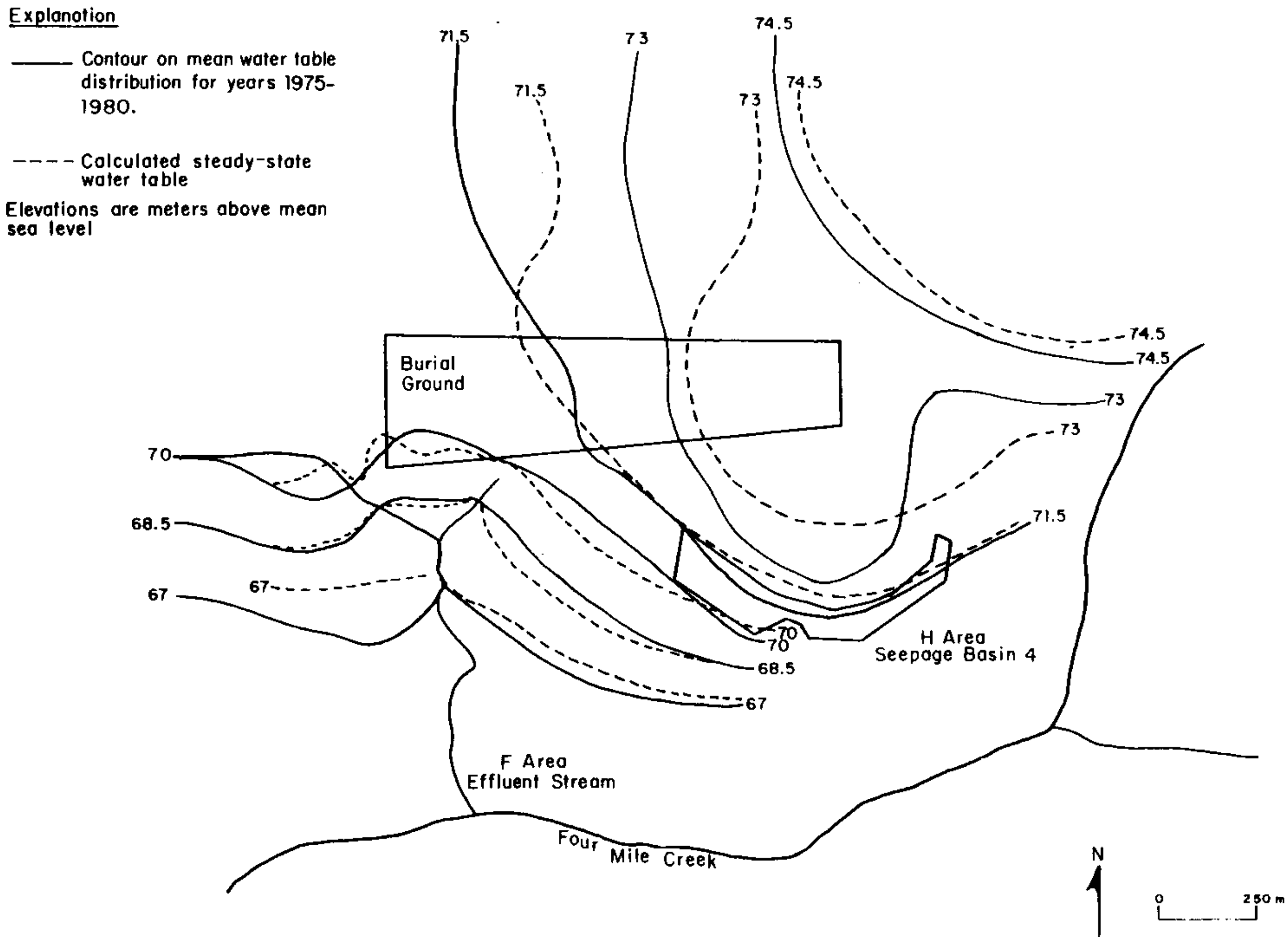

FIGURE 5. Comparison of Observed and Calculated Steady-State Water Table

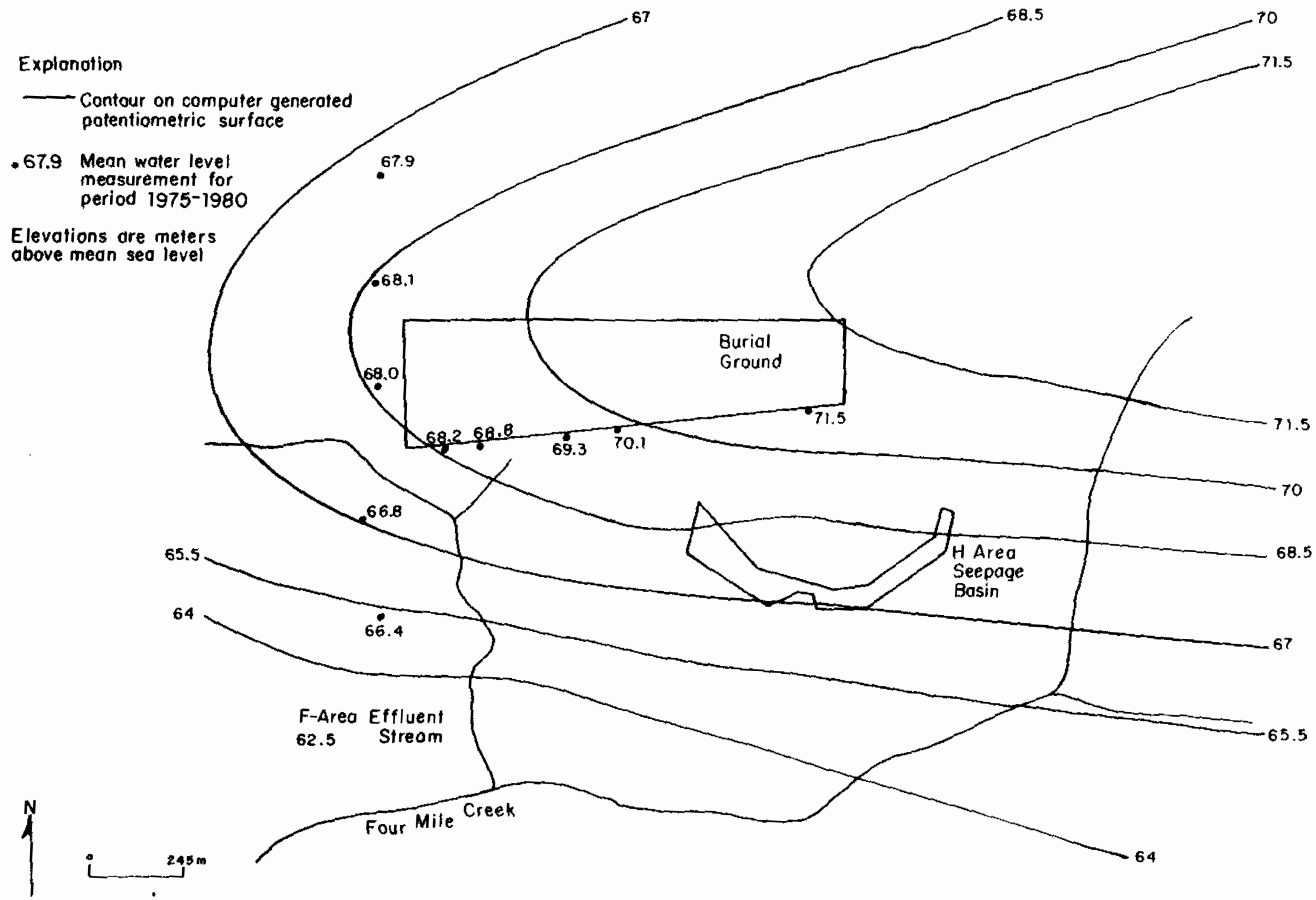

FIGURE 6. Computer-Generated Potentiometric Surface in the Upper Part of the McBean Formation and Control Point Measurements