PROJECTED EFFECTS OF THE PROPOSED TENNESSEE COLONY RESERVOIR ON GROUND-WATER CONDITIONS IN THE ALLUVIUM OF THE TRINITY RIVER AND CEDAR CREEK, TEXAS

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PRELIMINARY RESULTS FOR THE TRINIDAD AREA

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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By Sergio Garza, 1929-

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PRELIMINARY RESULTS FOR THE TRINIDAD AREA

By
Sergio Garza

SUMMARY

The U.S. Army Corps of Engineers proposed the construction of Tennessee Colony Dam and Reservoir as part of a multipurpose plan for the Trinity River and tributaries between the Dallas-Fort Worth area and the Texas Gulf Coast. The Corps requested the assistance of the U.S. Geological Survey (1) to define the existing ground-water conditions in the alluvium of the Trinity River and Cedar Creek in the Trinidad area, and (2) to project the long-term effects of stresses imposed on the ground-water system by Tennessee Colony Reservoir.

Ground water in the alluvium is discharged mainly by evapotranspiration and by seepage into the Trinity River and Cedar Creek; discharge by wells is minor. The main source of recharge to the alluvium is precipitation on the alluvial surface, but the relatively impermeable bedrock probably contribute small amounts of water by upward leakage at the base of the alluvium.

A two-dimensional digital-computer model was developed and calibrated by steady-state simulation. Areally distributed rates of accretion were used as the applied stresses. The calibrated model was used to project the steady-state effects of stresses imposed by the upstream part of the proposed Tennessee Colony Reservoir on water levels in the alluvium of the Trinidad area. The projections included changes in accretion rates in places where the projected head was above the land surface and where the head changes resulted in changes in the rates of evapotranspiration.

The projected potentiometric head will be less than 5 feet below land surface in most of the low-lying areas adjacent to the shoreline of the proposed reservoir. The projected rises in head range from about 15 feet near the Trinity River and Cedar Creek in the southern part of the Trinidad area to less than 1 foot in the northernmost part of the area.

INTRODUCTION

The construction of Tennessee Colony Dam and Reservoir was proposed by the U.S. Army Corps of Engineers as part of a multipurpose plan for the Trinity River and tributaries between the Dallas-Fort Worth area and the Texas Gulf Coast. In connection with the proposed Tennessee Colony project, the Corps requested the assistance of the U.S. Geological Survey (1) to define the existing ground-water conditions in the alluvium of the Trinity River and Cedar Creek in the Trinidad area, and (2) to project the long-term effects of stresses imposed on the ground-water system by Tennessee Colony Reservoir.

Figure 1 shows the location of the project area, which in this report will be referred to as the Trinidad area. Part of the Trinidad area was considered in previous studies related to the effects of proposed navigation structures between Dallas and Lake Livingston. These studies contained gross estimates of the effects of the upstream part of the proposed Tennessee Colony Reservoir in areas that included most of the Trinidad area. In May 1978, the Corps requested additional studies in the Trinidad area, including the construction of a digital-computer model to project the effects of the proposed reservoir on water levels in the alluvium of the Trinity River and Cedar Creek.

Data on approximately 40 private wells and 14 test holes in the Trinidad area consisted mainly of the collection of well-construction data, water-level data, and drillers' logs. Streamflow-stage data were obtained from records of streamflow stations on the Trinity River near Rosser (fig. 1), Trinity River at Trinidad (fig. 2), and Cedar Creek near Trinidad (fig. 2).

The records from the stations on the Trinity River were used to estimate the average rate of accretion to the alluvial aquifer, and the results of five pumping tests were used with drillers' logs to estimate transmissivity. Water levels in 10 wells were measured periodically during 1971-73 in connection with other hydrologic studies. The average water levels in the Trinidad area were estimated from these records and from the water-level data available for 1978. It was assumed, in making approximate projections with the model, that these estimates represented the long-term average water levels.

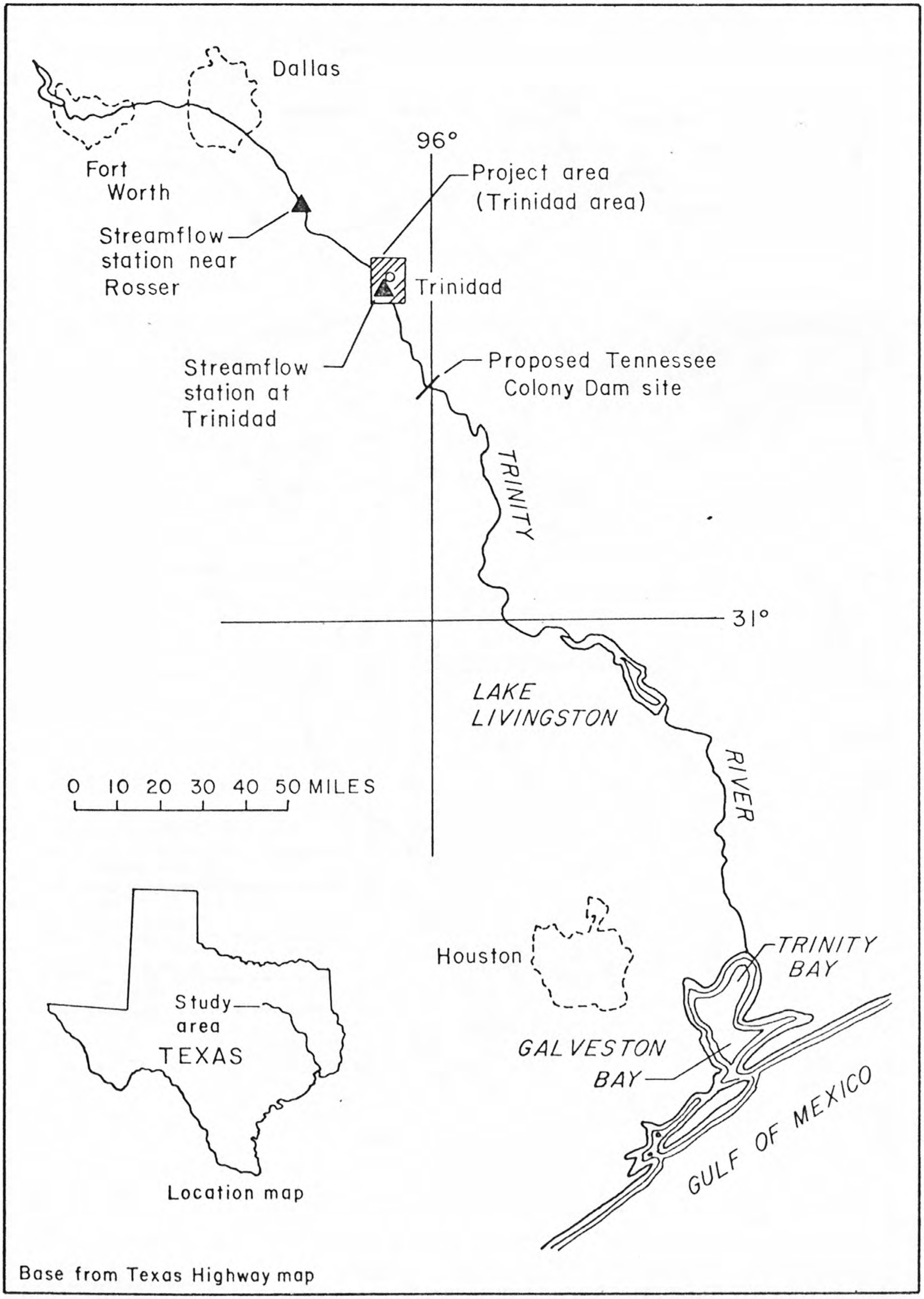

FIGURE 1.-Location of the project area

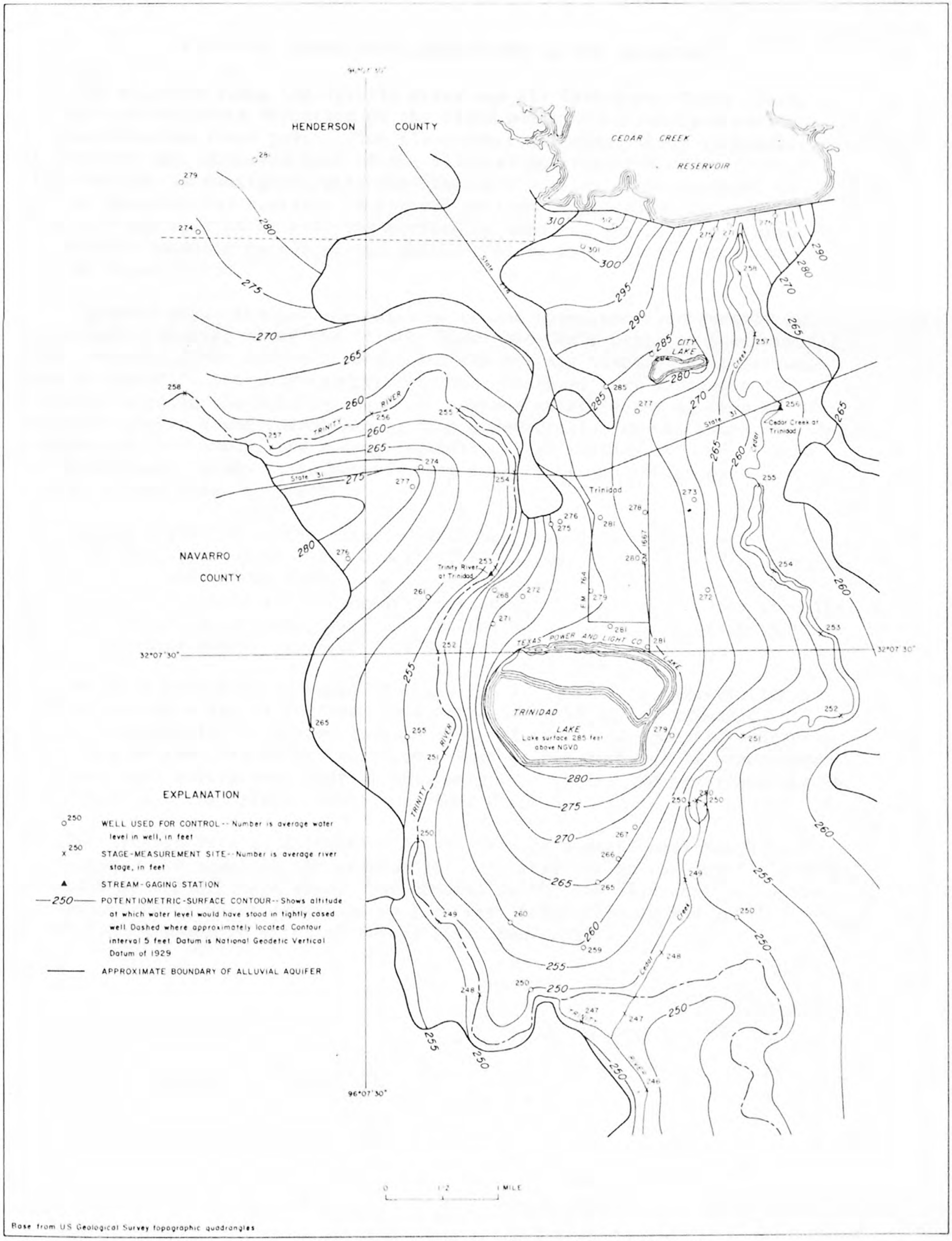

FIGURE 2.-Average altitude of the potentiometric surface in the alluvium of the Trinity River and Cedar Creek in the Trinidad area

EXISTING GROUND-WATER CONDITIONS IN THE ALLUVIUM

The alluvium along the Trinity River and its tributary, Cedar Creek, consists of sediments deposited on the flood plain and at various terrace levels above the flood plain. The flood-plain material, which is generally of Holocene age, composes most of the alluvial aquifer; the older terrace alluvium that is contiguous with the flood-plain alluvium is included as part of the alluvial aquifer. A typical section of the alluvium grades from clay and silt at or near the surface to sand and gravel at the base. The aquifer consists mainly of the coarse-grained material in the lower part of the alluvium.

Figure 2 shows the average altitude of the potentiometric surface in the alluvial aquifer along the Trinity River and Cedar Creek in the Trinidad area. Average water levels in wells and the average streamflow stages were used to construct the potentiometric-surface contours that represent hydraulic head in the alluvial aquifer. Ground water in the aquifer is inferred to move downgradient along paths perpendicular to the contours. For purposes of this study, the average potentiometric surface is used to show the approximate steady-state ground-water conditions and the general direction of ground-water movement.

Figure 2 also shows the effects of Cedar Creek Reservoir on water levels in the alluvium of Cedar Creek. The configuration of the potentiometric surface immediately downstream from the dam reflects the effects of wells constructed to relieve the hydrostatic pressure in this area. Water from the wells is channeled to Cedar Creek and is considered to be part of the surface water that is released regularly from the reservoir.

The main source of recharge to the alluvial aquifer is infiltration of rainfall on the alluvial surface; however, a small amount of recharge is probably contributed by upward leakage from relatively impermeable bedrock formations at the base of the alluvium. Part of the recharge is evaporated or transpired, a very small part is discharged by wells, and the remainder is discharged into the Trinity River and Cedar Creek.

The average rate of discharge to the river in a particular reach is considered to be equal to the average rate of accretion to the aquifer within that part of the drainage area. The general definition of accretion is the net rate at which water is gained or lost vertically through the aquifer surface in response to external forces (Stallman, 1956).

Records from the streamflow stations on the Trinity River near Rosser and Trinidad were used to identify 35 periods of low flow during 1965-77 (U.S. Geological Survey, 1969, 1971-74, 1975a, b, 1976-78). The differences in the average monthly discharges, or the average monthly losses or gains between streamflow stations, varied from -17 (loss) and +73 (gain) ft^3/s (cubic feet per second). This range in values apparently reflects some of the variations in climatic conditions that affect the amount of ground-water seepage between the stations. The average of the values is a gain of about 27 ft^3/s, which may have an error of ±30 percent due to errors in the streamflow data. Assuming no other significant errors, the estimated value may be between 18 and 36 ft^3/s.

For purposes of this study, it was assumed that 27 ft^3/s represents the approximate long-term average amount of ground-water seepage, which is equivalent to the long-term average rate of accretion to the alluvial aquifer between the stations at Rosser and Trinidad. The drainage area between the stations includes about 135 square miles of the outcrop of the aquifer; therefore, the average rate of accretion is computed to be about 0.23 foot per year.

PROJECTED EFFECTS OF THE PROPOSED TENNESSEE COLONY RESERVOIR

Description of the Digital Model

A digital-computer model was constructed and used to project the effects of the proposed Tennessee Colony Reservoir on water levels in the Trinidad area. The basis for the model is a finite-difference model developed by the U.S. Geological Survey for aquifer simulation in two dimensions (Trescott and others, 1976). The report by Trescott and others (1976) presents derivation of the finite-difference approximation to the partial differential equation describing ground-water flow. The report also includes a documentation of the computer programs designed to use three numerical techniques to solve the approximation to the equation. The technique used in the model of the Trinidad area is the strongly implicit procedure, which requires less computer time and has fewer numerical difficulties than the other methods.

The grid network for the model of the Trinidad area consists of a matrix of 35 rows and 24 columns with a nodal spacing of 0.25 mile. The assumptions made in the construction of the model are:

(1) The average water levels in wells and the average streamflow stages represents steady-state conditions.

(2) The movement of water occurs in the horizontal plane of the confined alluvial aquifer, which is totally incised by the Trinity River and Cedar Creek. A two-dimensional model is adequate to simulate this single aquifer system.

(3) The hydrologic properties of the aquifer are constant within the area of each node.

(4) The potentiometric heads in the model are simulated at the center of each node. The stresses applied to the area of each node during the calibration simulations are the rates of accretion. The principal stresses applied during projection simulations are the changes in head in the Trinity River, Cedar Creek, and surrounding areas that will be created by the proposed Tennessee Colony Reservoir. Additional stresses in the projection simulations are the changes in accretion rates resulting from (a) changes in evapotranspiration rates with changes in depth to water in the aquifer and (b) projection of aquifer head that was above the land surface in some areas.

The types of boundaries used in the model are constant head (constant potentiometric surface) and no flow (zero constant flux or impermeable). Constant-head boundaries were imposed on the Trinity River, Cedar Creek, and Cedar Creek Reservoir. Constant-head boundaries were also imposed on Trinidad Lake (Texas Power and Light Co. Lake) and City Lake (city of Trinidad), which are assumed to have constant levels and to be in hydraulic continuity with the alluvial aquifer. A no-flow boundary was imposed approximately where the alluvium pinches out and at the base of the alluvium. Upward vertical leakage at the base of the aquifer is assumed to be negligible, but probably is a small part of the average rate of accretion as determined from streamflow gains and losses. The borders of the model, which are located in areas removed from the principal area of interest, have no-flow boundaries for reasons inherent in the computational scheme of the model (Trescott and others, 1976, p. 30).

Figure 3 shows the approximate distribution of transmissivity of the alluvial aquifer in the Trinidad area. Partial drillers' logs of more than 40 wells and test holes, plus the analyses of 5 pumping tests were used to construct the map. Data derived from the pumping tests were analyzed by the Theis recovery method (Ferris and others, 1962). The resultant transmissivity values range from 1,000 to about 2,500 ft^2/d (feet squared per day), and the average values of hydraulic conductivity range from 70 to 140 ft/d (feet per day). The latter were used with drillers' logs to estimate the ranges in the areal distribution of transmissivity that were used in the model (fig. 3).

Calibration of the Model

The Trinity River alluvium is a relatively minor aquifer that has been developed mainly for small quantities of water for domestic supply and livestock. The major changes in aquifer head are related to the cyclic changes in rainfall and evapotranspiration, which are the principal processes affecting the changes in the rate of accretion to the aquifer.

The calibration procedure involved matching a model-computed potentiometric surface with the observed steady-state potentiometric surface (fig. 2). The estimated average rate of accretion (0.23 foot per year) was used in the first attempts at stressing the model. The results of the matching procedure were very poor, and calibration was not achieved through reasonable changes in transmissivity or with changes in the average rate of accretion (0.2 to 0.3 foot per year). The next step was to consider the areal variations in the rates of accretion, which were apparently significant in the calibration procedure. The infiltration capacity of the various soils in the area is probably the most important factor affecting the accretion rates. For the purpose of this study, the areal variations in accretion rates were based on the areal distribution of soil groups, each of which has a different infiltration capacity.

The U.S. Department of Agriculture (1974, p. 46) has classified the soils within the project area into four major groups that are characterized by high, moderate, slow, and very slow infiltration rates. Most of the soils on flood plains of the Trinity River and Cedar Creek are sandy clays and dark, heavy clays that have slow and very slow infiltration rates, respectively. Some of the alluvial-terrace soils in the Trinidad area consist of sandy clays, but most of these soils are fine sandy loams that have moderate infiltration rates. In a few of the terrace areas, the soils are loamy sands that have high infiltration rates. The Department of Agriculture (1974, table 3) reports vertical permeabilities of less than 0.06 inch per hour (0.12 ft/d) for the clays, 0.63 to 2 inches per hour (1.2 to 4 ft/d) for the fine sandy loams, and 2 to 6.3 inches per hour (4 to 12.6 ft/d) for the loamy sands.

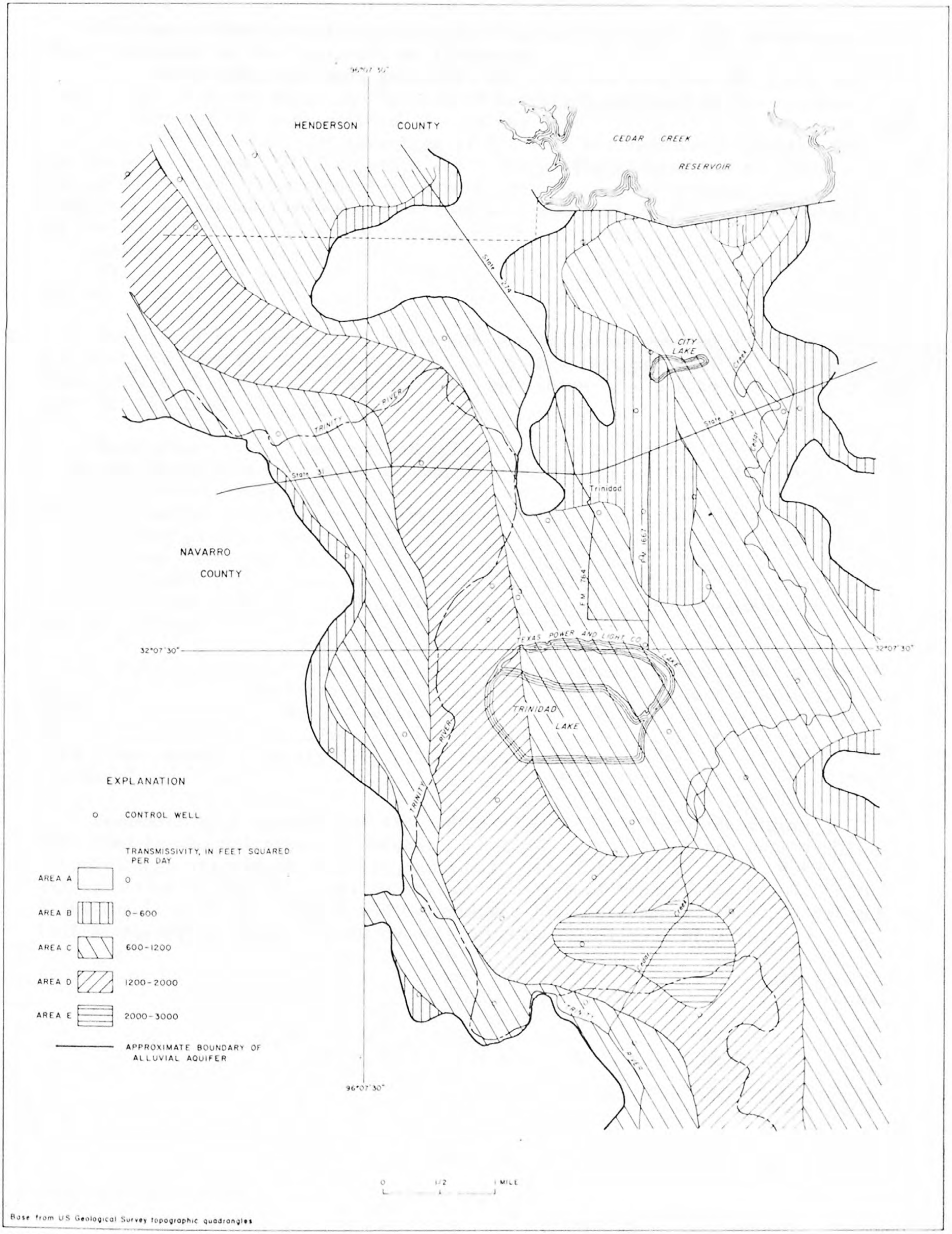

FIGURE 3.-Distribution of transmissivity of the alluvial aquifer in the Trinidad area

A range in the rate of accretion for each of the major soil groups was first estimated on the basis of the following:

(1) The predominant soil groups in the Trinidad area are the clays and sandy clays, and the range in the rate of accretion assigned to these areas should encompass the average of 0.23 foot per year.

(2) A maximum rate of accretion of 1.3 feet per year was estimated for the loamy-sand area. This estimate was based on the application of Darcy's law in an area of known transmissivity, where the computed average horizontal rate of flow at a defined section of the aquifer is assumed to be equivalent to the average vertical rate of accretion at a defined area upstream from the section.

(3) A similar analysis from an area of clay and sandy clay gave an average rate of accretion of 0.16 foot per year.

The ranges in the rates of accretion initially assigned were: 0 to 0.2 foot per year for the heavy clays; 0.2 to 0.4 foot per year for the sandy clays; 0.4 to 0.8 foot per year for the sandy loams; and 0.8 to 1.3 feet per year for the loamy sands.

Soil maps (U.S. Department of Agriculture, 1929, 1974) were used to delineate the four areas (A, B, C, and D) shown on figure 4. The initial range in the estimated accretion rates for each area was used to stress the model for calibration. Each calibration simulation had a "cumulative mass balance check," which was used to assure that the average accretion rate for the total area was between 0.2 and 0.3 foot per year. Changes in the accretion rates within the range for each area, plus a modification of the ranges for areas A and B, were used through trial-and-error procedures to achieve calibration.

Figure 4 shows the ranges in accretion rates used for each area in the calibrated model. The accretion rate used for each node in each area varied within the range, and the average for each range is probably near the median for each range. During calibration, the range in the accretion rate for area A was reduced from the original estimate, and the range for area B was increased accordingly.

Transmissivity values near the median of each range shown on figure 3 were used in the calibration procedure. During calibaration, the only significant change was made in the transmissivity used for area B, where an average value of 500 ft^2/d was substituted for the original value of 300 ft^2/d. A few checks made for areas B and C indicated that a change of about 20 percent in transmissivity produced head changes of generally 1 foot or less.

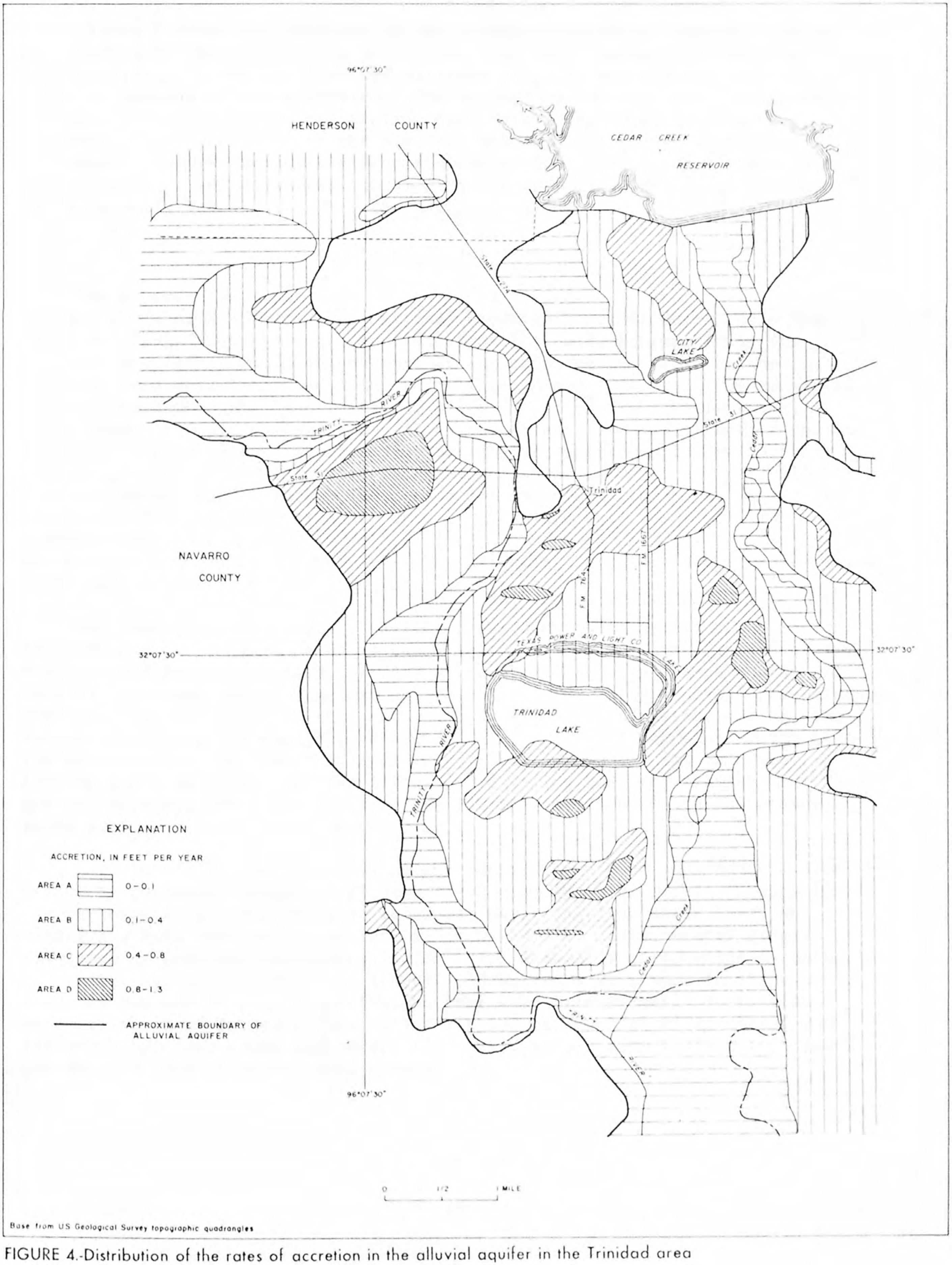

FIGURE 4.-Distribution of the rates of accretion in the alluvial aquifer in the Trinidad area

Figure 5 shows the altitude of the steady-state potentiometric surface as computed by the calibration procedure. The maps showing the computed altitude (fig. 5) and the observed altitude (fig. 2) are similar, and the model is assumed to be calibrated. The aquifer system that was defined with the available data by the calibration procedure is believed to be a reasonable representation of the physical system. The degree of model refinement that can be derived from additional field data is not known. Verification of the calibrated model with man-made stresses is not feasible, at least until Tennessee Colony Dam and Reservoir are constructed.

Model Projections

The proposed Tennessee Colony Reservoir will have a conservation-storage stage of 265 feet above National Geodetic Vertical Datum (mean sea level of 1929). The hydraulic-head stresses that will be imposed on the alluvial aquifer by the upstream part of the proposed reservoir in the Trinidad area were simulated with the calibrated model. The stress consisted of imposing a constant head (altitude of 265 feet) on the Trinity River, Cedar Creek, and all surface areas along the streams at an altitude of 265 feet or less. The configuration of the potentiometric surface obtained by this initial projection was inspected to determine areas in which the potentiometric head was above land surface. The projection was recomputed by adjusting the accretion rates in these areas to zero or to values that would effect a computed head that was approximately at land surface. An additional adjustment to the accretion rates was imposed in areas where changes in evapotranspiration rates due to changes in depth to water were significant.

The average steady-state accretion rates used in calibrating the model incorporated the average rates of evapotranspiration. A change in the steady-state potentiometric surface, brought about by stresses such as the construction of Tennessee Colony Dam, may change the average rates of evapotranspiration and therefore the rates of accretion. In a defined steady-state system, the factors affecting the change in accretion and, therefore the equilibrium of the system are: (1) The change in water level applied on the boundary; (2) the depth to water; (3) the lithology, layering, and thickness of the fine-grained material above the aquifer; and (4) the amount by which the steady-state accretion rates could potentially change.

Adjustments to the projected potentiometric head were made in accretion caused by increased evapotranspiration with rise in water level. Change in evapotranspiration with depth to water was estimated from water level and lithologic data from wells and test holes using a digital-computer program developed by Bedinger and others (1973). The method of computation is based on studies by Stallman and Reed (1966). Adjustments were made in three areas where the changes in evapotranspiration rate were significant. These areas were (1) south of Trinidad Lake, (2) northeast of the city of Trinidad, and (3) south of Cedar Creek Reservoir. The rates ranged from 10^{-4} to 10^{-5} foot per day per foot of water-level change.

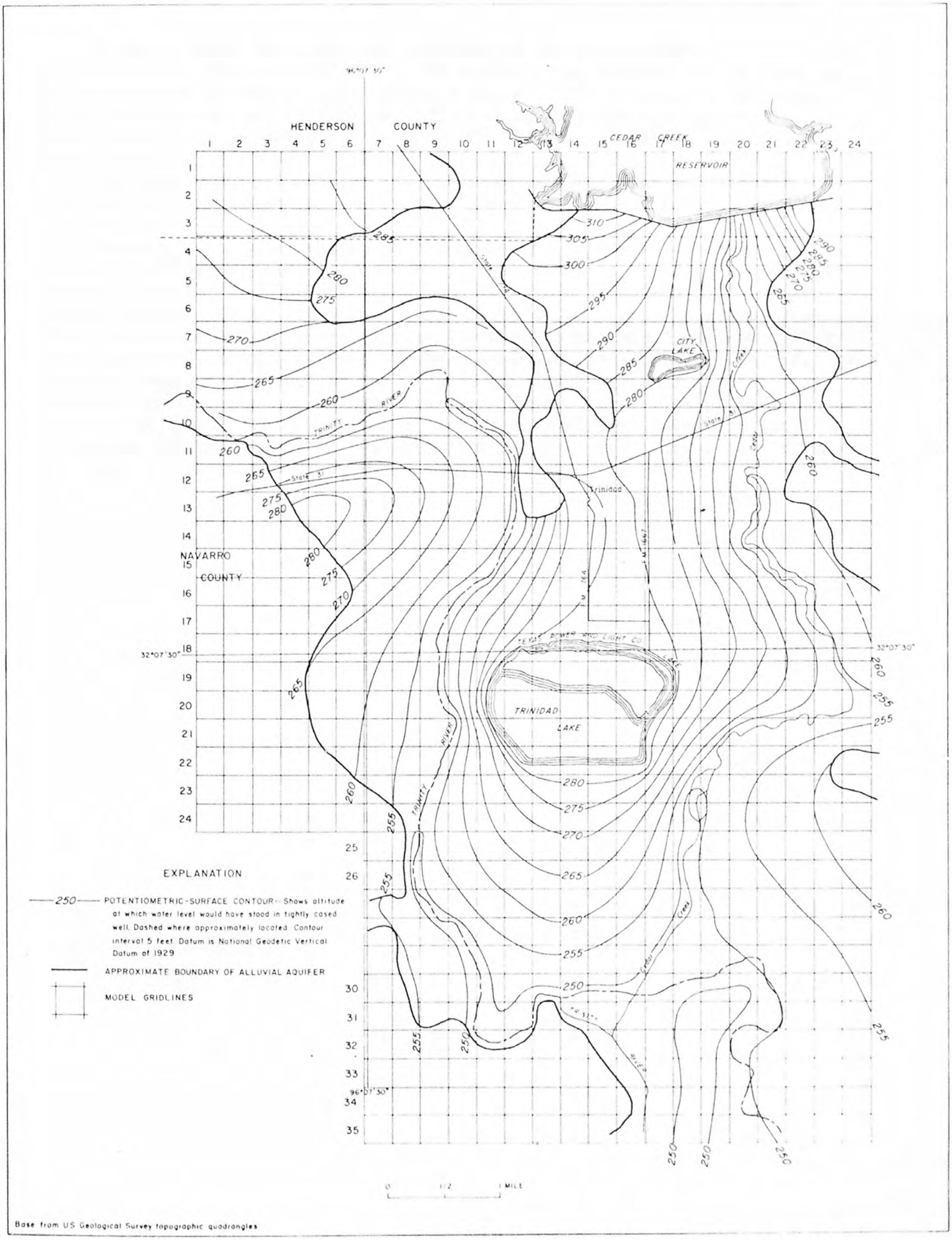

FIGURE 5.-Average altitude of the potentiometric surface in the Trinidad area as derived from model calibration

Figure 6 shows the projected altitude of the potentiometric surface in the alluvium in the Trinidad area. It reflects the adjustments in head due to decreases in accretion rates brought about by (1) a computed potentiometric head above land surface and (2) changes in evapotranspiration rates due to changes in potentiometric head. The average accretion rates for the steady-state (fig. 5) and projected (fig. 6) simulations were 0.26 and 0.21 foot per year, respectively; approximately 80 percent of this decrease resulted from the computed head being above land surface.

Figure 6 also shows the areal extent of the proposed Tennessee Colony Reservoir and the approximate land areas where the projected potentiometric head will be less than 5 feet below land surface. These areas include most of the low-lying areas adjacent to the shoreline of the proposed reservoir. The areas in which the potentiometric surface was already less than 5 feet below land surface include part of the island area at Trinidad Lake, part of the area immediately south of the Cedar Creek Reservoir dam, and the very low-lying areas along the Trinity River and Cedar Creek. The projected net rises in head vary from 15 feet near the Trinity River and Cedar Creek in the southern part of the modeled area to less than 1 foot downstream from and in proximity to the Cedar Creek Reservoir dam.

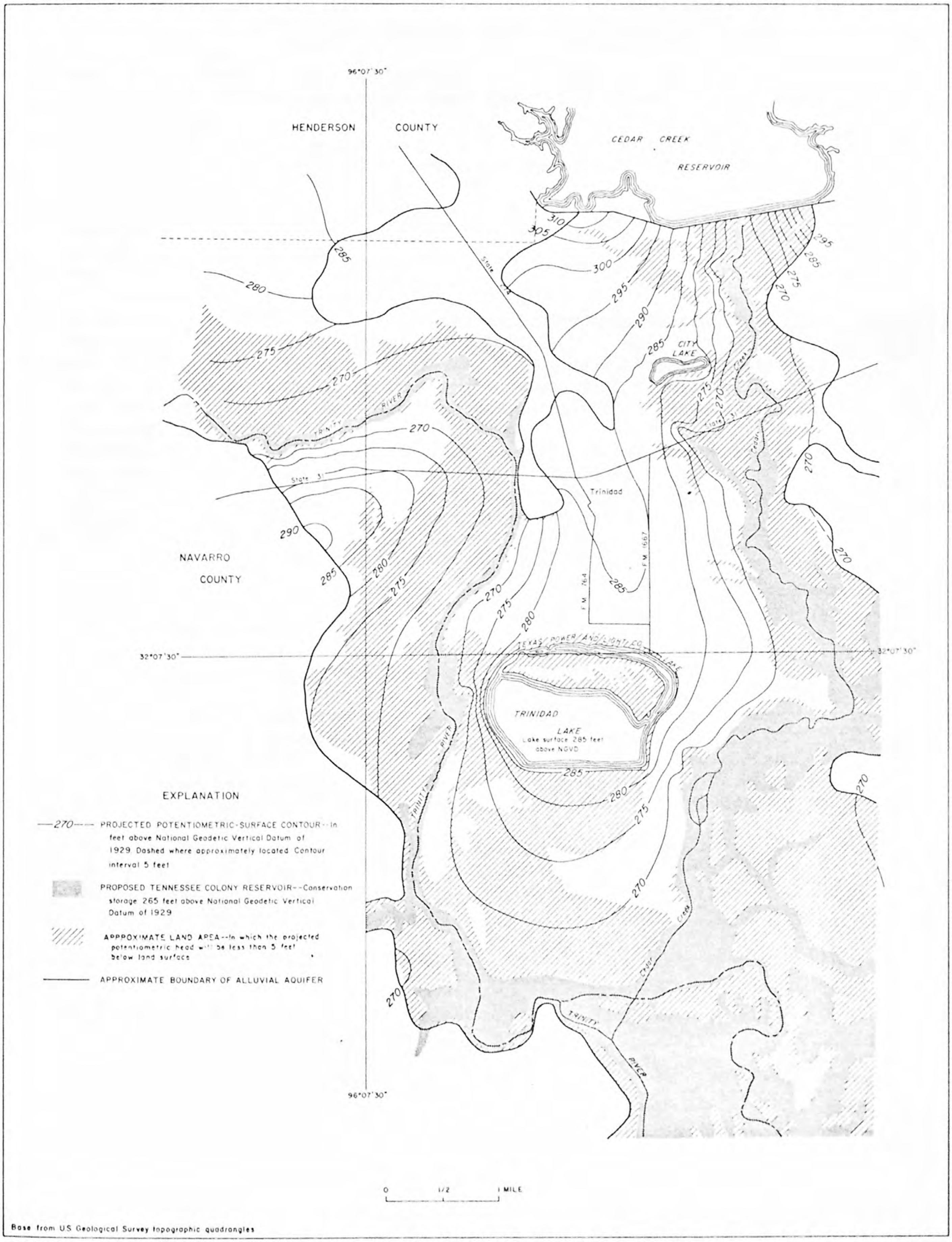

FIGURE 6.- Projected altitude of the potentiometric surface in the alluvium of the Trinity River and Cedar Creek in the Trinidad area

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