PROJECTED EFFECTS OF PROPOSED CHLORIDE-CONTROL PROJECTS ON SHALLOW GROUND WATER--PRELIMINARY RESULTS FOR THE WICHITA RIVER BASIN, TEXAS

By Sergio Garza

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METRIC CONVERSIONS

Most units of measurement used in this report are inch-pound units. For those readers interested in using the metric system, the inch-pound units may be converted to metric units by the following factors:

From	Multiply by	To obtain
acre-foot	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
foot	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
foot per mile (ft/mi)	0.189	meter per kilometer
inch	25.4	millimeter
mile	1.609	kilometer
ton	0.9072	megagram

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "mean sea level."

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SUMMARY

The U.S. Army Corps of Engineers' plan to control the natural chloride pollution in the Wichita River basin includes the construction of Truscott Brine Lake on a tributary of the North Wichita River. In connection with the proposed brine lake, the U.S. Geological Survey was requested to: (1) Define the existing ground-water conditions in the shallow fresh-water system of the project area; and (2) project the post-construction effects of the proposed lake on the fresh-water aquifer, especially in relation to hydraulic-head changes but also with respect to possible changes in the chemical quality of the ground water.

The fresh-water aquifer in the project area is a shallow water-table system with relatively fresh water (generally a calcium sulfate type) that contains approximately 500 to 5,000 milligrams per liter of dissolved solids. The aquifer consists of Permian rocks with very small values of hydraulic conductivity and overlies a brine system (sodium chloride type) that is even less permeable. A thin transition zone separates the fresh-water aquifer and the brine system. Small quantities of infiltration from precipitation throughout the area's watershed constitute the recharge to the aquifer. Discharge from the aquifer consists of the small base flow along creeks; well discharge is negligible.

Two-dimensional mathematical computer models were developed for aquifer simulation of: (1) Steady-state conditions in a fresh-water system and (2) transient conditions in a brine- fresh-water system where the density effects of the brine are considered. The main results of projecting the effects of the proposed Truscott Brine Lake on the fresh-water aquifer are: (1) Hydraulic-head rises of 5 to 40 feet would be confined to areas near the proposed dam and along the lake shoreline, and (2) migration of salt water downstream from the dam generally would be limited to less than 1 mile and apparently would not reach equilibrium during the 100-year duration of the project. The modeling efforts did not include possible effects related to hydrodynamic dispersion in the brine- fresh-water system. Possible changes in the hydraulic conductivity of the aquifer, due to physical and chemical interactions in the brine and fresh-water environments, also were not considered.

INTRODUCTION

In 1959 the U.S. Congress authorized the U.S. Army Corps of Engineers, Tulsa District, to develop plans to control the natural salt pollution in the Red River basin in Texas and Oklahoma. Chloride had been identified as the principal pollutant in streams tributary to the upper Red River during previous studies; a high sulfate concentration also was found. Subsequently, a regional chloride-control plan was developed for the Red River basin. The plan includes three brine storage lakes; several low-flow, brine-collection areas in four subbasins; and pipeline and pumping-station facilities for transporting the collected brines to the storage lakes (U.S. Army Corps of Engineers, 1980). The plan to retain the brines in a specific depository by storage and evaporation was found to be the most feasible of several alternatives that were considered.

In 1966 the Congress authorized construction of the various structural measures related to chloride-pollution control in the Wichita River basin, a subbasin of the Red River basin (U.S. Army Corps of Engineers, 1980). These measures are part of the regional chloride-control plan and include the construction of Truscott Brine Lake on a tributary (Bluff Creek) of the North Wichita River (fig. 1). In connection with the construction of Truscott Brine Lake, the Corps of Engineers asked the U.S. Geological Survey to define the shallow fresh-water aquifer in the vicinity of the proposed lake and to study the effects of such a structure on the shallow ground-water system.

Purpose and Scope

The purpose of this report is to present preliminary results of the study by the Geological Survey on the following: (1) The existing ground-water conditions in the shallow fresh-water system in the vicinity of the proposed Truscott Brine Lake (fig. 1) and (2) the projection of the post-construction effects of the proposed Truscott Brine Lake on the fresh-water aquifer, especially in relation to changes in hydraulic head but also with respect to possible changes in the chemical quality of the ground water. The project area, referred to in this report as the Truscott area, includes the drainage areas of Bluff Creek, Buffalo Creek, and China Creek (fig. 2).

The existing ground-water conditions in the Truscott area were defined principally through test-hole data provided by the Corps of Engineers in connection with the test-drilling program related to the chloride-control project in the basin. The data included borehole-geophysical and drillers' logs from 80 test holes. Fifty (50) private wells and springs were inventoried; most of these were included in the water-level and water-quality observation-well program. Fifteen (15) ponds in the Truscott area also were included in the water-quality program. The location of the wells, test holes, and ponds is shown in figure 2.

The projections of the effects of the proposed Truscott Brine Lake on the fresh-water aquifer were obtained through two digital-modeling procedures. One was used to simulate flow in the fresh-water aquifer for the principal purpose of calibrating the digital model used in the projections. The other was used to simulate the areal flow in a system containing both brine and fresh water

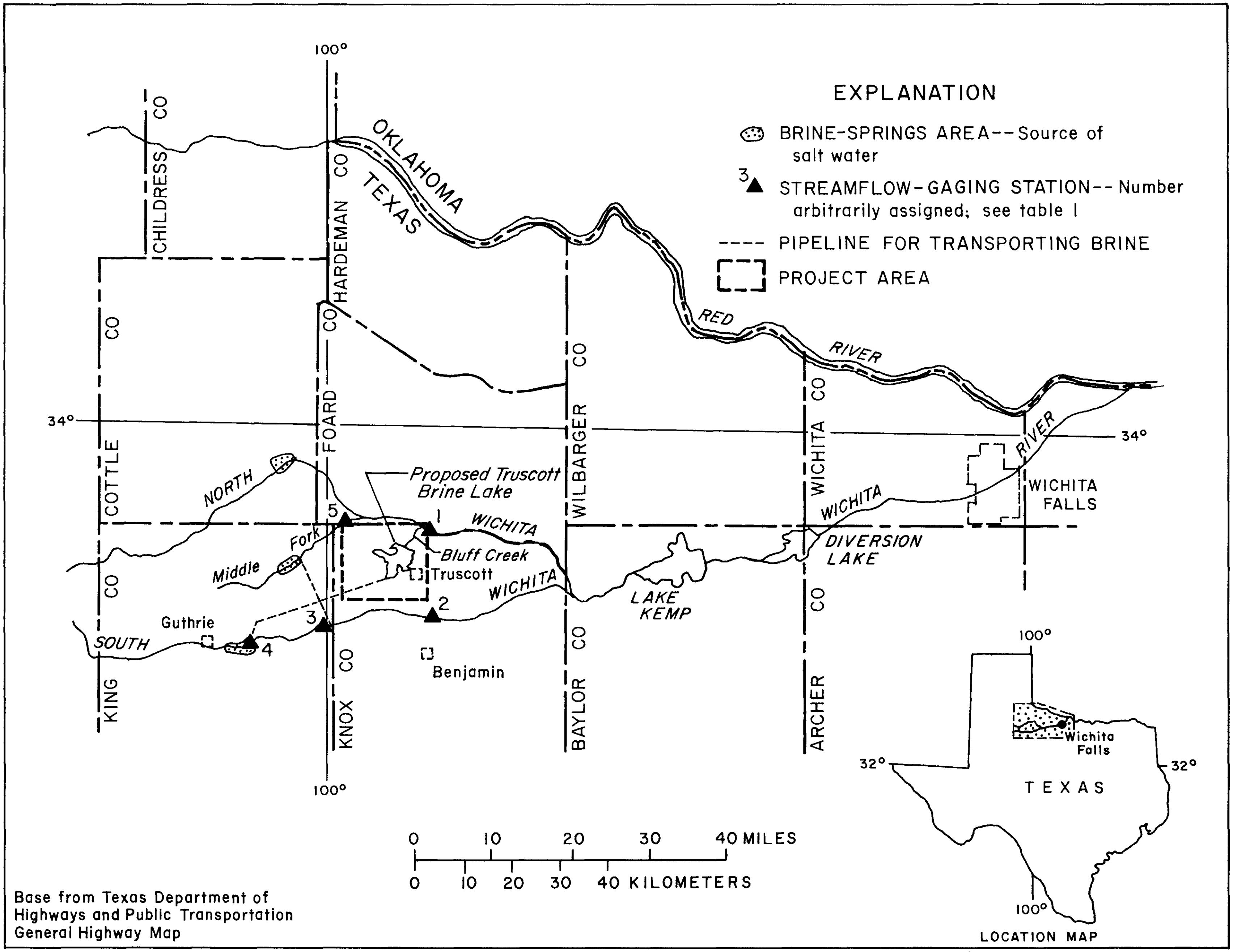

Figure 1.-Location of project area

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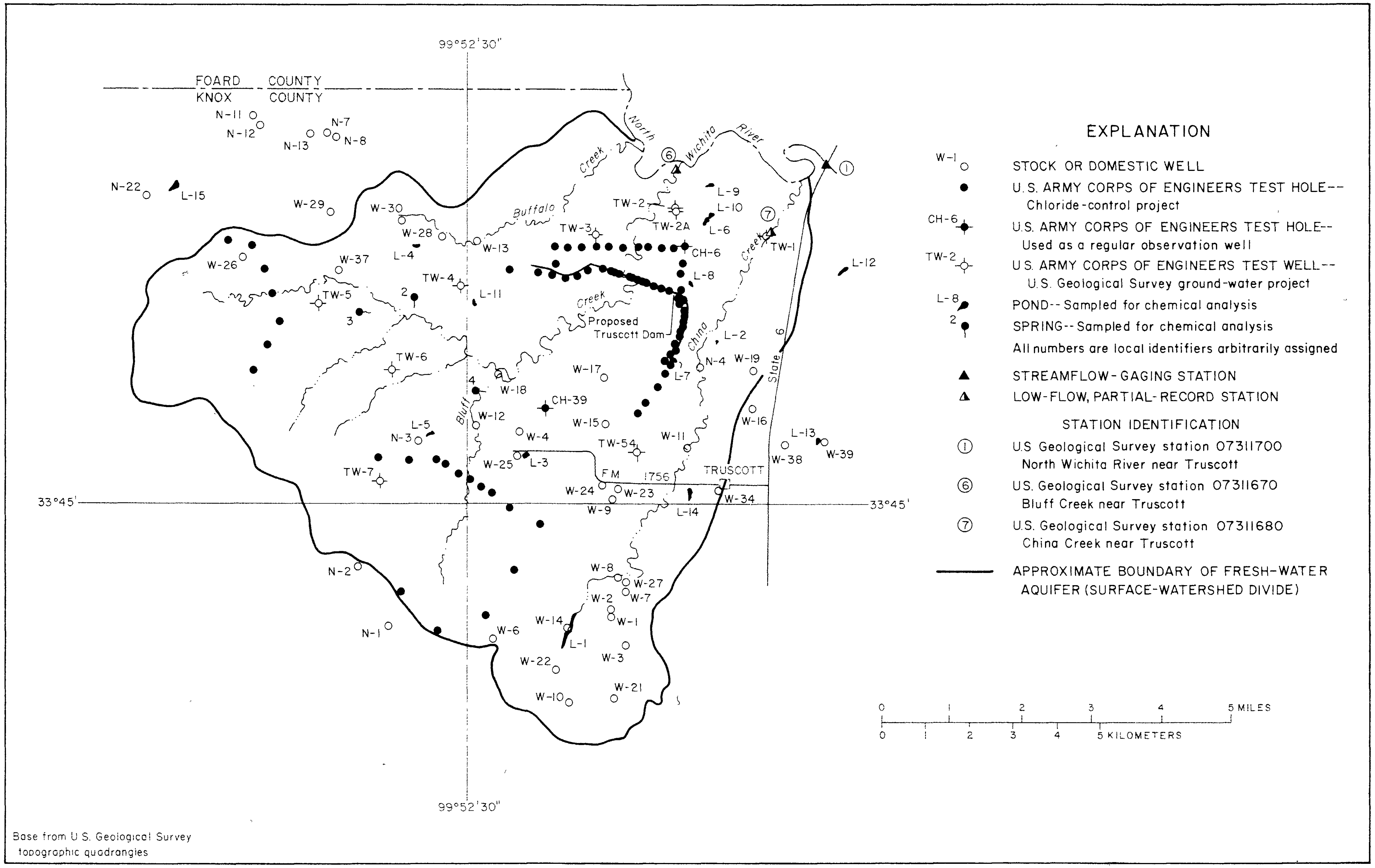

Figure 2.-Location of wells, test holes, and ponds in the Truscott area

for the purpose of projecting the effects of the brine lake on the fresh-water aquifer. The period used in the projections was 100 years, the expected duration of the brine lake. Results of the simulations appear adequate, particularly the projected rises in aquifer hydraulic head. Tracing the migration of salt water in the fresh-water aquifer is limited to approximations because of the inherent assumptions of the modeling procedures.

Physical and chemical interactions within the proposed brine impoundment and in the affected areas of the fresh-water aquifer may change the hydraulic conductivity in the fresh-water system. Projecting the results of these possible effects is beyond the scope of this study.

Proposed Chloride-Control Plan

Truscott Brine Lake is the only brine-disposal lake proposed in the chloride-control plan for the Wichita River basin. The plan includes the collection of brines at low-flow dams located near the brine-spring area (fig. 1) on the South and Middle Fork Wichita Rivers. Pumping-station facilities will be used to transport the brines by pipeline to Truscott Brine Lake. Brines collected in the North Wichita River are scheduled for impoundment in another brine lake that is part of the regional plan of the Red River system.

The sources of the brines that will be collected for impoundment in the upper Wichita River basin are the brine springs and seeps issuing from Permian rocks. The chemical quality of the runoff that is measured and sampled at various streamflow stations in the basin may indicate the general chemical character of these brines. Average discharge and the average concentration of certain chemical constituents in the surface water at five streamflow stations in the North, Middle Fork, and South Wichita Rivers are summarized in table 1. Streamflow stations 4 and 5 (numbers arbitrarily assigned and keyed to fig. 1) are located near the source areas of the brines scheduled for storage at Truscott Brine Lake. The water sample collected during low-flow conditions at streamflow station 4 on July 17, 1971, probably reflects the chemical concentration of the brine issuing from springs in the South Wichita River. The U.S. Army Corps of Engineers (1972, p. 6-10) reports that the brine in the Wichita River system generally is a sodium chloride type with a high sulfate concentration; chloride concentration ranges between 5,000 and 30,000 mg/L (milligrams per liter).

Truscott Brine Lake, as conceived in the plan, is designed to store, without outflow, the following: (1) Brine collected during 100 years of impoundment, (2) local runoff and sediment from Bluff Creek, and (3) the 100-year flood discharge from the drainage area of Bluff Creek. Nearly 110,000 acre-feet of liquids and sediment could be stored at the conservation-pool altitude of 1,499 feet.

The Corps of Engineers selected Lake Kemp, an existing multipurpose-use lake (fig. 1), as the downstream control point to check chloride-control goals in the basin. The average chloride load of inflow to Lake Kemp is about 450 tons per day (U.S. Army Corps of Engineers, 1980), equivalent to a mean chloride concentration of more than 600 mg/L. A large part of this load is pro-

Table 1.--Average streamflow and average concentration of chemical constituents in streamwater of the upper Wichita River basin

[Micromhos = micromhos per centimeter at 25° Celsius; mg/L = milligrams per liter]

U.S. Geological Survey streamflow station (no. keyed to fig. 1)	Period of record (water years1/)	Drainage area (square miles)	Average discharge (cubic feet per second)	Discharge-weighted averages: Specific conductance (micromhos)	Dissolved solids (mg/L)	Dissolved chloride (mg/L)	Dissolved sulfate (mg/L)
North Wichita River near Truscott (no. 1)	1969-79	937	50.9	7,800	5,070	2,160	1,070
Middle Fork Wichita River near Truscott (no. 5)	1971-76	161	9.3	10,000	6,720	2,620	1,720
South Wichita River near Guthrie (no. 4)	1971-76	239	5.3	31,800	21,200	10,800	2,510
	(7-27-71)2/		2/(2.6)	2/46,500)	2/(30,800)	2/(16,000)	2/(3,200)
South Wichita River at Ross Ranch near Benjamin (no. 3)	1971-79	499	12.3	17,600	11,800	5,430	2,040
South Wichita River near Benjamin (no. 2)	1968-79	584	30.7	8,040	5,370	2,160	1,280

1/ From records of U.S. Geological Survey, 1965-75, 1969, 1972-75, 1975, 1976-80.
2/ Instantaneous discharge and chemical-analysis results for a sample collected during low-flow conditions that reflect character of ground-water effluent.

jected for removal through the brine impoundment at Truscott Brine Lake, so that the chloride concentration in the Lake Kemp water is expected to be decreased to the desired goal of 250 mg/L most of the time.

EXISTING FRESH-WATER AQUIFER

The fresh-water aquifer in the Truscott area is a shallow water-table system that is separated from a deeper and confined Permian aquifer containing widespread sodium chloride brines. The fresh water has a dissolved-solids concentration ranging from about 500 to about 5,000 mg/L. Most of the water in the system is termed "fresh" only in relation to the confined brines. The chloride concentration of the brine springs in the Wichita River drainage system may vary between 5,000 and 30,000 mg/L, but the chloride concentration of the confined brines in deep aquifer systems is in excess of 100,000 mg/L.

Some of the less mineralized fresh water in the aquifer is a calcium bicarbonate type, but most of the fresh water is a calcium sulfate type with varying quantities of sodium and chloride. Most of the chemical analyses of water from wells in table 2 (supplemental information) represent this general type; however, some of the analyses probably reflect mixtures of water from both the fresh-water and brine horizons penetrated in some wells. For example, the analysis for the water sampled from test hole CH-39, which is more than 200 feet deep, indicates a mixture of fresh water and sodium chloride brine. The range of well depth for test wells TW-4, TW-5, TW-6, and TW-7 is from 100 to 121 feet; all other wells in table 2 are less than 100 feet deep. Also included in table 2 are chemical analyses (L-1 through L-15) for ponded water, the source of which initially was thought to be ground water; this water generally contains less than 250 mg/L of dissolved solids and apparently represents surface runoff.

General Geology Associated with the Aquifer

The fresh-water aquifer consists of rocks of Permian age, which include in order of increasing age, the Blaine Formation, the San Angelo Formation, and the Clear Fork Group of the Leonardian Series. The Blaine Formation in the Truscott area mostly consists of interbedded shale and gypsum with some sandstone and dolomite. The San Angelo Formation mostly is a fine-grained quartz sandstone with some shale and conglomerate, and the Clear Fork Group generally is a red shale with some thin lenses of dolomite, sandstone, and gypsum. The younger sediments in the Truscott area consist of thin and unsaturated Quaternary deposits, which include Holocene floodplain material plus the fluviatile terrace deposits and the Seymour Formation of the Pleistocene Epoch. These unconsolidated deposits generally are not very significant in the ground-water study of the area.

The area's surficial geology, which is shown in figure 3, was derived mainly from information that is in preparation by the University of Texas, Bureau of Economic Geology for a geologic atlas of the Wichita Falls area. The Corps of Engineers, Tulsa District, provided additional information used in preparation of the geologic map. The Permian formations generally dip

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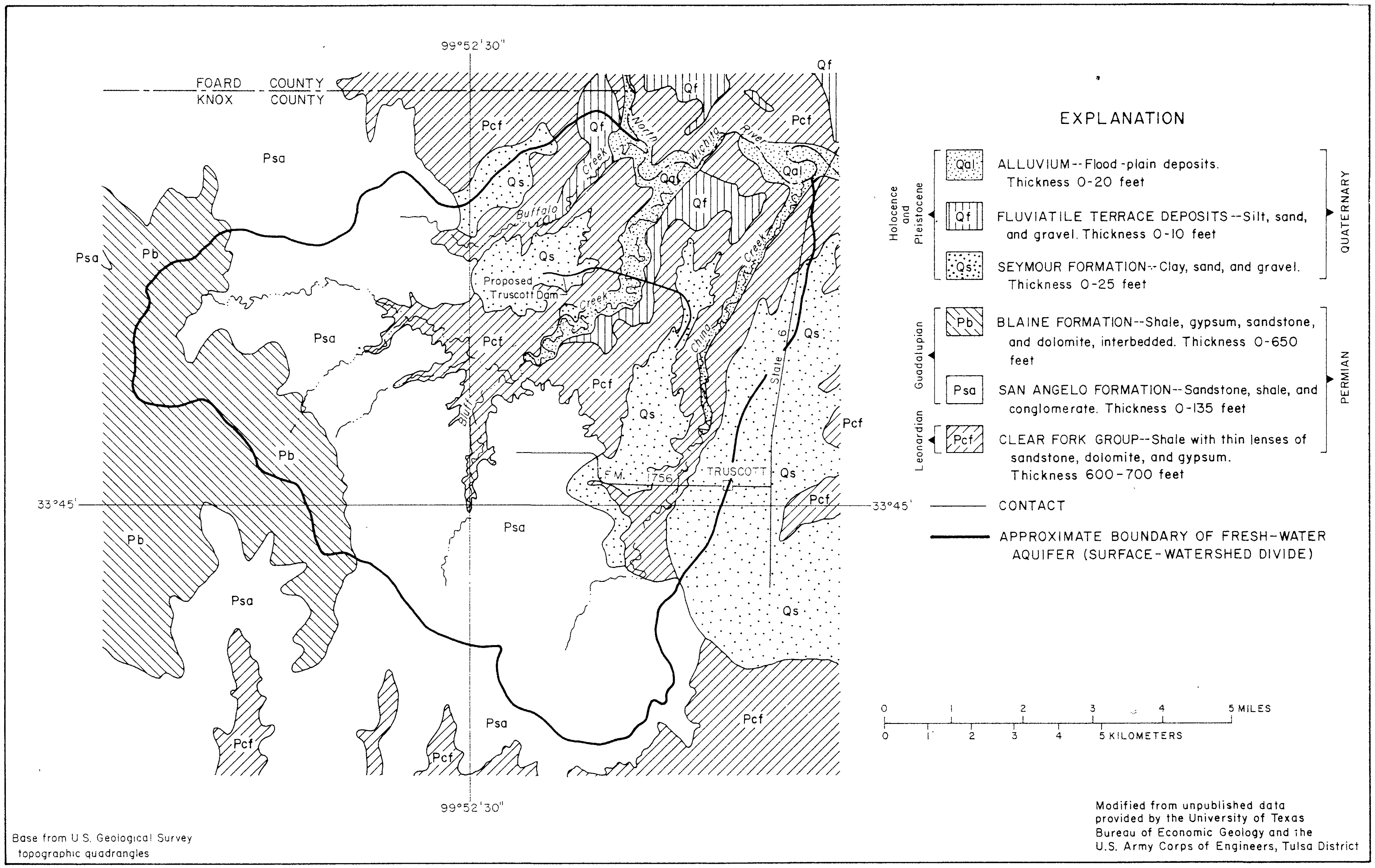


Figure 3.-Geology of the Truscott area

westward at about 25 feet per mile (U.S. Army Corps of Engineers, 1972). The flow of the major streams generally is eastward; the topography of the area's Permian strata consists of rolling hills, canyons, and gullies.

Recharge, Movement, and Discharge of Ground Water

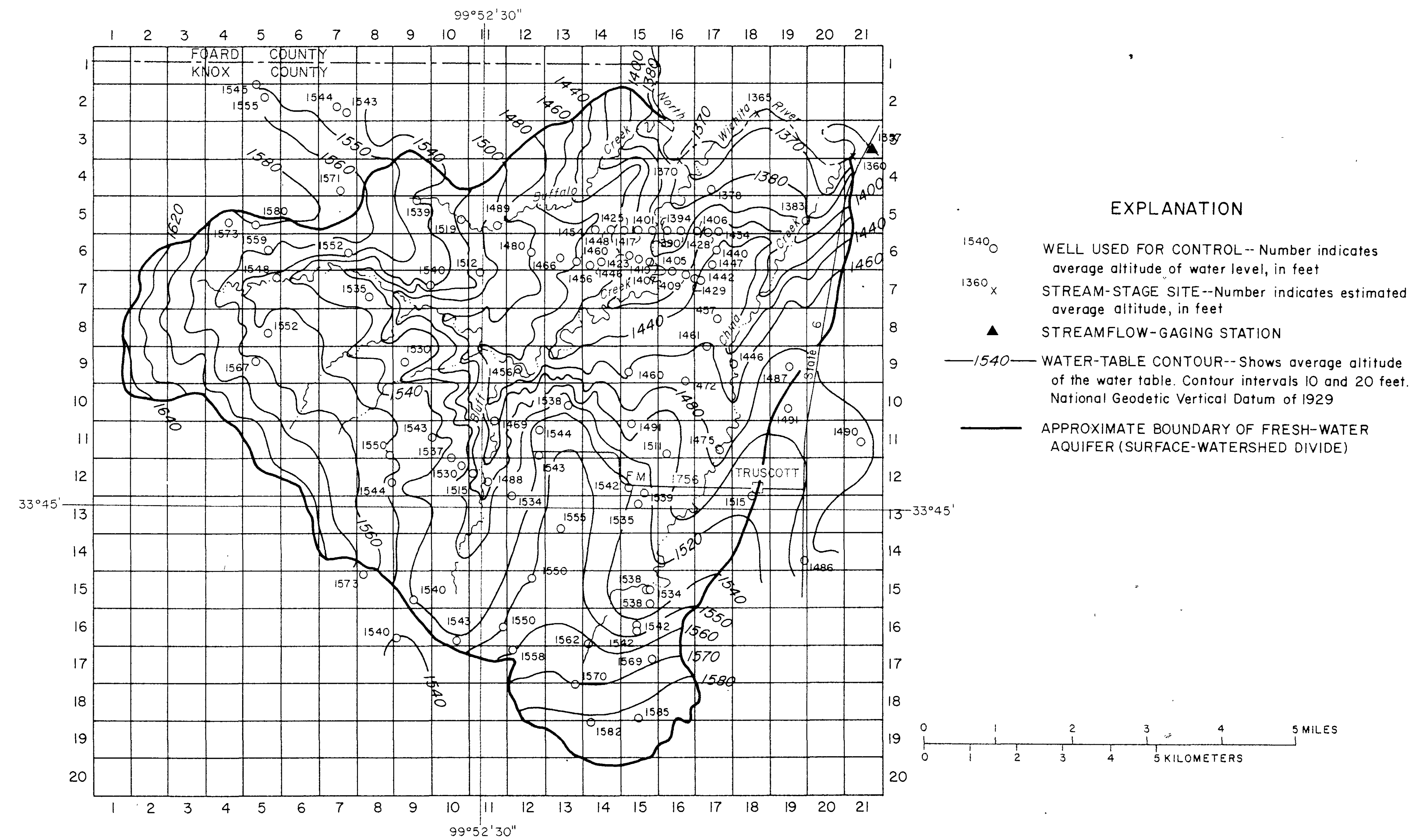
Recharge to the fresh-water aquifer in the Truscott area is from precipitation throughout the watershed. That small percentage of the precipitation infiltrating into the unsaturated zone generally moves in a vertical direction toward the water table, the upper surface of the saturated zone. The movement of water in the water table is approximately in a horizontal direction, more or less parallel to the land surface, from areas of recharge to areas of discharge.

The contours of the average altitude of the water table in the Truscott area is shown in figure 4. The contours are based on (1) average water levels in wells and test holes used for control, (2) estimates of Bluff Creek stage, (3) altitude of small springs and seeps along Buffalo Creek, China Creek, and those creeks tributary to Bluff Creek, and (4) Geological Survey topographic maps (7-1/2 minute). The slope of the water table generally is from the western and southern parts of the area toward the east and northeast; in detail it is from the high ridges and hills to the low areas along the creeks. The range of the altitude contours is from about 1,640 feet in the extreme western part to about 1,370 feet near the point where Bluff Creek joins the North Wichita River. The water table appears to be a generalized image of the land surface; and the shallow ground water is inferred to move from topographically high areas to the lower creek valleys.

Accretion is the net rate at which water is gained or lost vertically through an aquifer's surface, such as the water table, in response to external forces (Stallman, 1956). In the Truscott area, the two major forces affecting the water table are recharge (gains) from precipitation and discharge (losses) by evapotranspiration. Well discharge is small and may be neglected. The long-term differences between these two major forces is the average rate of base flow (ground-water effluent) discharging to the creeks. In this study, the average base flow is assumed to be the average accretion to the fresh-water aquifer. Base-flow analyses of the streamflow records for the stations listed in table 1 indicate average accretion values from slightly less to slightly more than 0.1 inch per year for areas in the vicinity of the Truscott area. Short-term streamflow records for low-flow, partial-record stations 6 and 7 (fig. 2) indicate negligible base-flow discharge. The average value of accretion in the Truscott area probably is less than 0.1 inch per year. This very small value for average accretion in the area appears to be closely related to the very small overall permeability of the Permian strata, and also partly to the lack of rainfall. The average precipitation at Truscott for 1964-80 is about 24 inches (U.S. Department of Commerce, 1964-80).

Base of Fresh Water

The base of the fresh-water aquifer in the Truscott area is assumed to be a thin zone of transition, which can be approximated by a surface, between the fresh water and the deeper brine. The confined brine system generally is much



Base from U.S. Geological Survey topographic quadrangles

Figure 4.-Average altitude of the water table in the Truscott area

less permeable than the fresh-water aquifer, primarily because of the existence of halite in the brine system. The zone of transition between the two systems has been identified in studies of the upper Brazos River basin, which has similar geohydrologic conditions to those found in the same Permian strata in the upper Wichita River basin. Stevens and Hardt (1965, p. 7-8) called this zone the "brine-freshwater interface" and assumed it to be a surface that was identified during test drilling and through interpretation of borehole geophysical logs (Keys and MacCary, 1973). The shallow fresh water generally is a calcium sulfate type, which is attributed to solution of gypsiferous material (Stevens and Hardt, 1965). The deeper brine-saturated rocks are associated with the existence of halite. According to Stevens and Hardt (1965), halite is present in the brine rocks under an environment conducive to very small values of permeability and small halite-solution rates. Water from some of the brine springs in the upper Brazos River basin contains more than 200,000 mg/L of dissolved solids, mostly sodium chloride (Baker, Hughes, and Yost, 1964, p. 58). In the brine springs area of the South Wichita River, a confined aquifer system with brine containing 169,000 mg/L of chloride was penetrated during test drilling (U.S. Army Corps of Engineers, 1972, p. 6-22).

The altitude of the base of the fresh-water aquifer in the Truscott area is shown in figure 5. The delineation mainly was approximated through the interpretation of borehole-geophysical data provided by the Corps of Engineers. Comparison between figures 4 and 5 indicates a variation of aquifer thickness of slightly less than 20 to slightly more than 70 feet; the average is about 45 feet. The aquifer appears to thin towards the creek areas in some places, but no definitive pattern in this regard or in any other aquifer-thickness variation is indicated.

Characteristics of Fresh-Water Aquifer

The principal aquifer characteristics used in this report to describe the fresh-water aquifer are hydraulic conductivity and specific yield. Hydraulic conductivity is a term used to incorporate the permeability of a rock or soil with the properties of the fluid, namely density and viscosity. In ground water, the fluid properties are identified at temperatures normally found in aquifer systems. Permeability of a rock or soil is a measure of its ability to transmit fluid under a hydropotential gradient (Lohman, 1972, p. 4). The specific yield of an aquifer system is a measure of its capacity to store and yield water by gravity drainage.

Determinations of hydraulic conductivity of the Permian strata in the project area, as well as in the same formations of nearby areas, have indicated extremely small values, ranging from very small fractions of a foot per day to several feet per day. The U.S. Army Corps of Engineers, Tulsa District (1972), conducted pressure tests in more than 20 of the test holes drilled in the vicinity of the proposed Truscott Dam. Results of most of the tests indicate a range of hydraulic conductivity of 0.03 to 8.5 ft/d as representative of the Clear Fork Group in the area. The fresh-water aquifer in the Clear Fork Group mostly consists of a red shale with thin lenses of sandstone, dolomite, and nodular gypsum. The Corps of Engineers identified a weathered zone (blue-gray sandy shale) that is associated with the larger values of the hydraulic-conductivity range. The Corps of Engineers also identified the

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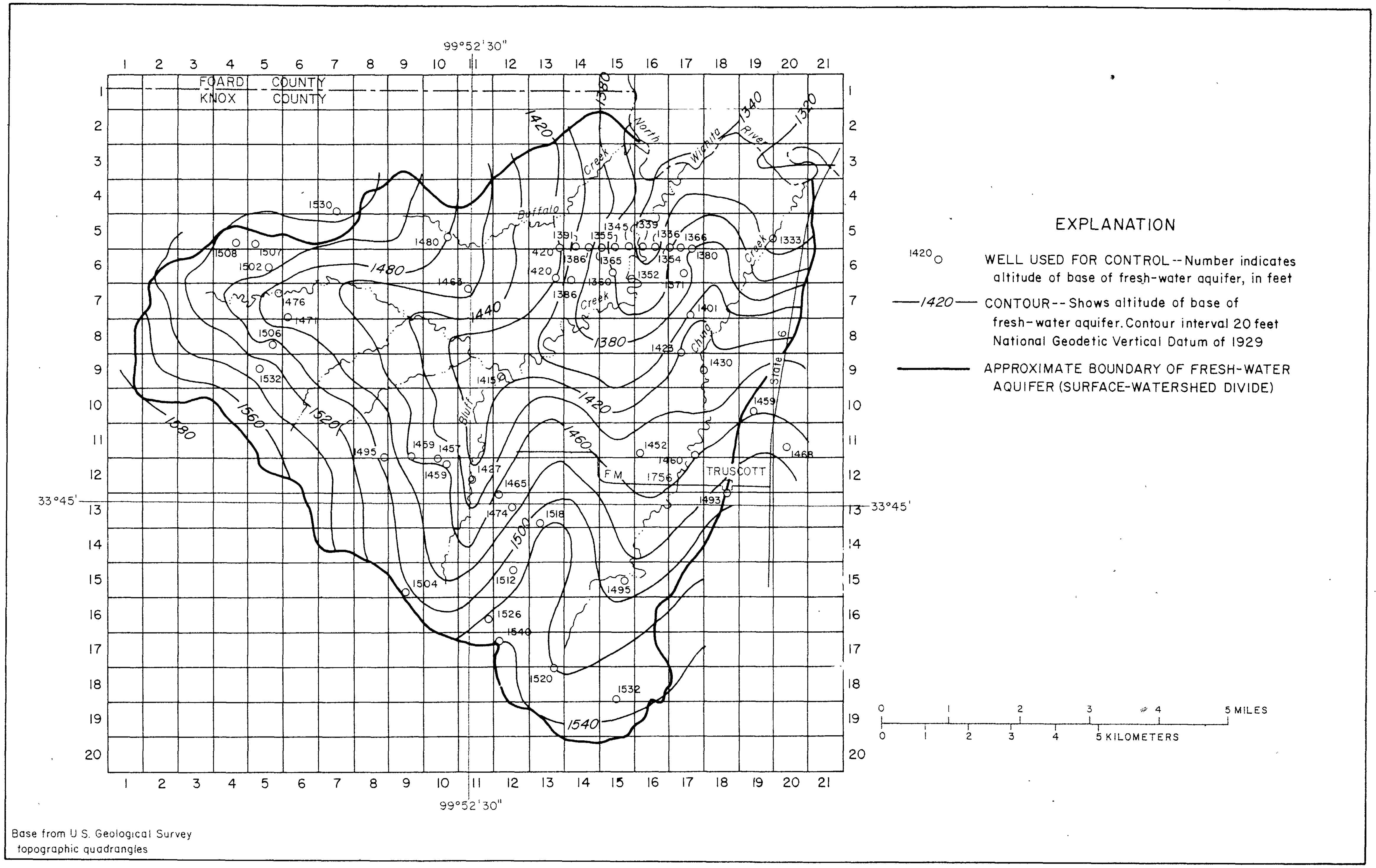

Figure 5.-Altitude of the base of the fresh-water aquifer in the Truscott area

San Angelo Formation as mostly a massive, fine-grained sandstone with a generally small value of hydraulic conductivity. Only the basal part of the Blaine Formation is found in the Truscott area; it mostly consists of a red-brown shale with interbedded gypsum. The hydraulic conductivity of the fresh-water system in the Blaine Formation generally is very small.

Laboratory values of hydraulic conductivity determined for sandstone cores of the San Angelo Formation in the upper Brazos River basin range from 0.002 to 0.009 ft/d (Garza, 1982). Hogan and Sipes (1966, table 1) report the following laboratory values of horizontal hydraulic conductivity (converted from reported permeability) for Permian Basin formations: 0.0005 to 1.2 ft/d for cores from the upper part of the San Andres Limestone (mostly equivalent to Blaine Formation); 0.0005 to 0.306 ft/d for cores from the Glorietta Sandstone (equivalent San Angelo Formation); and 0.0002 to 0.06 ft/d for cores from the Clear Fork Group.

The specific yield of a saturated unit of an unconfined aquifer is the ratio (fraction) of the volume of water drained by gravity to the total volume of the unit. The specific yield of most unconfined aquifers ranges from about 0.1 to about 0.3 and averages about 0.2 (Lohman, 1972, p. 8). The values used in this study range from 0.15 to 0.2.

MODELING PROCEDURES

Two modeling procedures were used in the development of mathematical (digital-computer) models to project the effects of the proposed Truscott Brine Lake on the existing fresh ground water. Ground-water flow in a fresh-water aquifer is simulated in one of the models; the other includes the simulation of the areal flow in a system containing both brine and fresh water.

The modeling procedure used to simulate the flow of fresh ground water is the two-dimensional finite-difference approach developed by the Geological Survey (Trescott, Pinder, and Larson, 1976). This procedure is the basis for the development and calibration of the model that is representative of the fresh-water aquifer in the vicinity of the proposed Truscott Brine Lake. The primary purpose of this model was to determine the distribution of hydraulic conductivity of the aquifer. The main steps include: (1) Construction of a model that is representative of the fresh-water aquifer, through development of parameters derived from the geohydrologic data; and (2) calibration of the model through a steady-state analysis by mainly adjusting the hydraulic conductivity until the model-computed water table approximately is matched with the observed water table obtained from historical water-level records. The principal product of this modeling phase is the calibrated distribution of hydraulic conductivity essential in the modeling effort to project the effects of the proposed brine lake.

The effects of the proposed brine reservoir on fresh ground water were approximated through the use of a finite-difference modeling procedure for simulating two-dimensional areal flow of salt water and fresh water separated by a sharp interface (Mercer, Larson, and Faust, 1980a). This modeling procedure was selected mainly because it incorporates the density effect of salt water, which is considerable in the project area. A digital model was developed to simulate the movement of this interface and was used to project the effects of the proposed Truscott Brine Lake on the fresh-water aquifer. Items related to the construction and use of the interface model include: (1) Transferring information from the calibrated fresh-water model; (2) quantifying additional aquifer parameters essential in the transient analysis, including fluid properties and the initial interface conditions; and (3) imposing the hydraulic-head stress of the brine reservoir on the fresh-water aquifer. The finite-difference grid and the areal dimensions of the interface model are the same as the calibrated fresh-water model.

The principal stress in the interface model is simulated by using a constant salt-water head that is representative of the hydraulic head throughout the proposed brine-reservoir area. The initial model conditions consist of the steady-state conditions (average aquifer hydraulic head) of the fresh-water system plus the distribution and altitude of the initial interface. The only period used in model simulation is 100 years, the projected duration of the proposed brine lake and the simulation period specifically requested by the Corps of Engineers. The final products of the simulation include the projected rises of hydraulic head in the fresh-water system and the areal extent of the brine- fresh-water interface throughout the aquifer.

SIMULATION OF FLOW IN FRESH-WATER AQUIFER

Description of Modeling Procedure

The modeling procedure used in this study to simulate the flow of fresh ground water can be used to simulate flow in an artesian aquifer, a water-table aquifer, or a combined artesian and water-table aquifer. It is possible to treat aquifers that are heterogeneous and anisotropic and with irregular boundaries. Well discharge, constant recharge, leakage, and other features may be incorporated in the basic flow equation. The derivation of the finite-difference approximation to the partial-differential equation describing ground-water flow is presented in the report by Trescott, Pinder, and Larson (1976). Also presented is the documentation of the computer programs with three numerical techniques to solve the approximation to the equation, as well as results of numerical experiments and instructions for data entry.

Use of the modeling procedure in the development of the fresh-water model for the Truscott area requires certain assumptions and boundary conditions necessary for steady-state simulation. These are:

(1) The movement of water occurs in a single layer comprising the water-table fresh-water aquifer.

(2) The modeled areas were divided into discrete units or cells by a rectangular grid (cell blocks), and the hydrologic properties are constant throughout the area of each cell.

(3) The aquifer hydraulic head is simulated at the center (node) of each cell.

(4) The average water levels in wells and the average stream stages represent steady-state conditions in the aquifer-stream system. (The average water level in a well is the average of measurements made throughout a historical period that encompasses seasonal variations.)

(5) The model is assumed to be calibrated when the water-table surface, computed through steady-state analysis from an assumed position, matches the water-table surface constructed from the averages of observed (measured) water levels in wells. The principal parameter that is varied to match the two water tables is hydraulic conductivity.

(6) The types of boundaries used in the simulation are constant head and no-flow (zero constant flux or impermeable). For calibration purposes, a constant-head boundary was imposed on Bluff Creek and parts of its principal tributaries. A no-flow boundary was imposed along the drainage divide within the Truscott area watershed. A no-flow boundary also was imposed at the base of the fresh-water aquifer; any vertical leakage, upward or downward, is assumed to be negligible. The borders of the rectangular model have no-flow boundaries for reasons inherent in the computational scheme of the models (Trescott, Pinder, and Larson, 1976, p. 30).

Construction and Calibration of Fresh-Water Model

The construction of the model for the Truscott area includes the design of the rectangular-grid system plus the development and input of the aquifer parameters from the geohydrologic data. The grid network for the model consists of a matrix of 20 rows and 21 columns, and the grid spacing is 0.5 mile. The aquifer parameters used in the preparation of the model for the calibration procedure are as follows:

(1) The average altitude of the water table of the fresh-water aquifer in the Truscott area (fig. 4);

(2) constant net recharge (accretion) rate, or a flux throughout the entire watershed; the average accretion of 0.1 inch per year, obtained from streamflow records was used;

(3) distribution of hydraulic conductivity; the geologic formation is the principal basis for the areal distribution of hydraulic conductivity in the Truscott area (see fig. 6 for the range of values assigned); and

(4) the altitude of the base of the fresh-water aquifer in the Truscott area (fig. 5).

The hydraulic conductivity, within the range assigned to each geologic formation in the fresh-water zone, was the major parameter that was varied during the calibration. Values of hydraulic conductivity that are representative of the fine-grained Permian formations in the area are difficult to obtain. The average values of laboratory determinations from core samples were used to obtain an approximate range of values for each geologic formation. Results of the Corps of Engineers' pressure tests also were used to determine an approximate range of values. These determinations were the guidelines in the development of the ranges of values shown in figure 6. In essence, the calibration involved the modeling of the water-table surface as a function of hydraulic conductivity. The other parameters derived from the geohydrologic data are assumed to be representative and were not changed significantly during calibration.

The calibration procedure involved matching a model-computed water table with the observed steady-state water table. It was achieved with the following adjusted range of values for hydraulic conductivity (in feet per day): Blaine Formation, 0.005 to 0.25; San Angelo Formation, 0.01 to 4.0; Clear Fork Group

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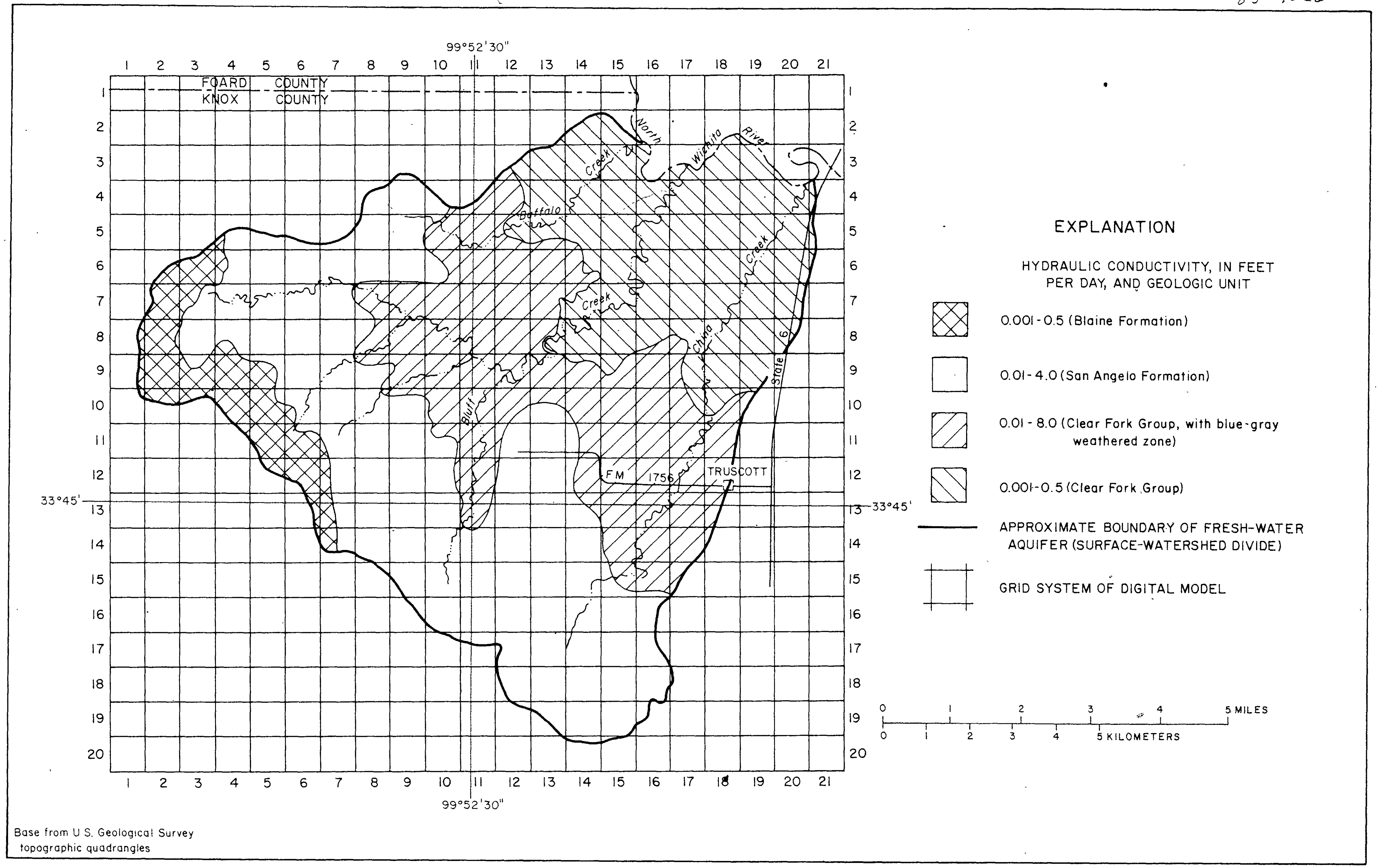

Figure 6.-Distribution of hydraulic conductivity in fresh-water aquifer in the Truscott area

(blue-gray weathered zone), 0.01 to 3.0; and the Clear Fork Group, 0.001 to 0.5. The average altitude of the steady-state water-table surface in the Truscott area, as computed during calibration is shown in figure 7. The map showing the observed average altitude of the water-table surface (fig. 4) is similar. Actually, the difference between the computed and observed hydraulic-head values for each of the model nodes was 3 feet or less for 96 percent of the nodes. The difference for each of the remaining nodes was between 3 and 3.5 feet. For the purposes of this study, the model was assumed to be calibrated and a reasonable representation of the physical system.

The cumulative mass balance between the volumetric sources and discharges of the model during the calibration procedure was a small fraction of 0.1 percent. The calibrated model was subjected to sensitivity analysis with regional changes in hydraulic conductivity and accretion. A change in hydraulic conductivity of 50 percent resulted in hydraulic-head changes of 0 to 3 feet. A 50-percent change in accretion resulted in hydraulic-head changes of less than 1 foot.

SIMULATION OF FLOW IN BRINE- FRESH-WATER SYSTEM

Description of Modeling Procedure

The modeling procedure used in this study to project the effects of a salt-water impoundment on a fresh-water aquifer was developed by Mercer, Larson, and Faust (1980a) to simulate the flow systems of coastal aquifers, where the salt-water front is assumed to be approximated by a sharp interface separating the salt and fresh water. The relationship between the salt and fresh water in the coastal systems is similar, in principle, to the relationship between the salt-water impoundment proposed in the Truscott area and the existing fresh-water aquifer. The interface modeling procedure was used in this study principally because it incorporates the density effect of salt water. The sharp-interface assumption, which is used in order to neglect the effects of hydrodynamic dispersion, may not be particularly applicable to the fine-grained fresh-water aquifer of the area. Use of the modeling procedure to project the distribution of hydraulic head in the fresh-water system appears adequate. However, the projected location of the sharp salt-water front (interface) in this study is considered only an approximation. This interface is wholly within the fresh-water system and is not related to the "interface" defined by Stevens and Hardt (1965, p. 7-8) as the boundary that separates the fresh-water aquifer and the deeper brine system.

The interface-modeling approach is based on the one-dimensional analysis of Shamir and Dagan (1971) and the two-dimensional extension of Bonnet and Sauty (1975). The two-dimensional partial-differential equation of ground-water flow is integrated over the thickness of fresh water and also over the thickness of salt water. The resulting two equations (one for the fresh water and the other for the salt water) are interrelated with terms defining the movement of the water table and the interface, along with the included densities and viscosities for the two water systems. The results are two vertically-integrated, two-dimensional equations that are formulated in terms of fresh-water and salt-water heads (equations 33 and 34, p. 17, Mercer, Larson, and Faust, 1980a). Finite-difference approximations of these equations are then

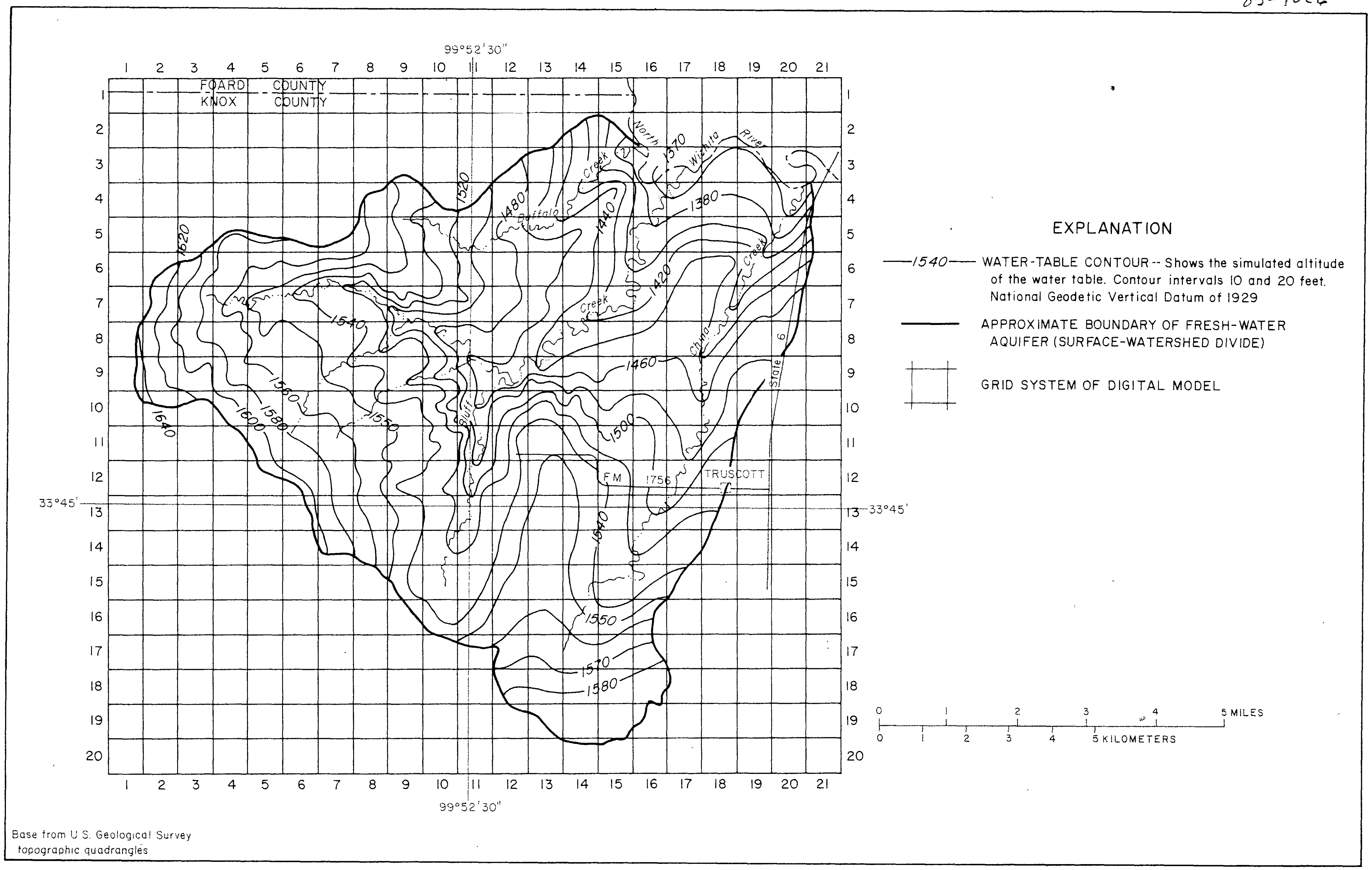

Figure 7.–Altitude of the water table in the Truscott area, as derived from model calibration

solved through a block form of an iterative numerical technque called line-successive over-relaxation, which was found to be the most efficient and accurate of several matrix-solution techniques that were attempted (Mercer, Larson, and Faust, 1980b). The interface-modeling procedure is designed to simulate time-dependent problems and can be used to simulate water-table conditions or confined conditions that may include the steady-state leakage of fresh water. The computer program, documentation for construction of models, and data-input procedures are included in Mercer, Larson, and Faust (1980a).

Most of the assumptions that were made for the model of the fresh-water aquifer in the calibration procedure also are applicable to the interface-modeling procedure. In addition to the sharp-interface assumption, Mercer, Larson, and Faust (1980b) include two others: (1) The Dupuit approximation (hydraulic heads in both the salt-water and fresh-water systems do not vary vertically); and (2) hydraulic conductivity and specific storage do not vary with depth. The ratio of the storage coefficient (specific yield) to aquifer thickness is the specific storage, a parameter which is essential in the transient analyses used in the projections.

Development of the Interface Model

The interface model represents the same area as the fresh-water model developed for the calibration procedure, but the interface model is used to project the brine and fresh-water conditions in the fresh-water aquifer as a result of the stresses imposed by the proposed brine reservoir.

The construction of the interface model involved the assimilation of the information described under the data-input procedures in Mercer, Larson, and Faust (1980a, p. 34-40). Other than items related to model size and model-control parameters, the information may be separated into three general categories: (1) Aquifer parameters from the calibrated fresh-water model; (2) information essential for the transient analyses, including additional aquifer parameters, fluid properties, and the initial interface; and (3) stresses imposed on the fresh-water system by the brine impoundment.

The aquifer parameters used or obtained from the calibrated fresh-water model include: (1) The average altitude of the water table (fig. 4); (2) the altitude of the base of the fresh-water aquifer (fig. 5); (3) the average accretion (0.1 inch per year), and (4) the distribution of hydraulic conductivity, which was the principal purpose of the calibration procedure.

The additional aquifer parameters used in the transient analyses with the interface model include effective porosity and specific storage of the fresh-water aquifer. An average value of 20 percent (0.2) was used to represent effective porosity. Values of 0.15 to 0.20 were used to represent the specific yield, which was used to compute specific storage.

The fluid properties needed for the interface model are the densities and viscosities of the aquifer's fresh water and the brine proposed for impoundment. The density of fresh water is slightly more than 1.0 g/mL (gram per milliliter) and is assumed to be 1; the absolute viscosity of fresh water at 20°C (Celsius) is about 1 centipoise. The average (100-year) density of the brine to be impounded in the proposed Truscott Brine Lake was determined from: (1) The average 100-year chloride concentration of the impounded brine as derived from the chloride-concentration curve estimated for the proposed Truscott Brine Lake (fig. 8); and (2) the relationship between density and the chloride concentration of brines from Permian formations in the upper Brazos River basin (fig. 9). The 100-year average chloride concentration is estimated to be about 34,000 mg/L and the average density about 1.04 g/mL. The absolute viscosity of a pure sodium chloride solution with a density of 1.04 g/mL is about 1.10 centipoises (Weast and Astle, 1978, p. D300), which is assumed to be the same for the impounded brine. The Corps of Engineers provided the information for the preparation of figure 8, which includes the estimated pool altitude for the first 100 years of impoundment at the proposed Truscott Brine Lake. Figure 9 was obtained from Garza (1982, fig. 12).

Part of the input data required for the interface model is the distribution of the initial interface between the brine and the fresh water. The initial interface consists of the altitude of the top of the brine pool throughout the areal extent of the brine lake and the altitude of the base of the fresh-water aquifer throughout the remainder of the modeled area. The interface between model cells representing the brine-pool surface at the proposed lake boundary and the cells representing the base of the fresh-water aquifer is vertical and not the classical sloping interface presented by Mercer, Larson, and Faust (1980a). In order to test the model computations associated with the vertical interface, computations with several sloping (pseudo) interfaces were attempted. The tests indicated that the computations with the vertical interface are reasonable.

The only stress imposed on the fresh-water aquifer in this study is the distribution of hydraulic head (constant salt-water head) in the area of the brine impoundment. The 100-year average pool altitude estimated for the proposed Truscott Brine Lake (1,488 feet above NGVD of 1929, as derived from fig. 8) was simulated in the interface model for the Truscott area. The average density estimated for the brine is 1.04 g/mL and the average viscosity is 1.10 centipoises. Actually, the density of the brine is estimated to be nearly 1.07 g/mL (chloride concentration of about 58,000 mg/L) at the end of 100 years (figs. 8 and 9); however, the modeling procedure does not allow for the variation of densities. Therefore, the average values were used.

Projections with Interface Model

The simulation period used in the projections with the interface model is 100 years, the expected duration of the proposed reservoir. The Corps of Engineers required no additional simulation periods for this preliminary study. The principal results of the simulation are the fresh-water heads in the aquifer (or projected hydraulic-head rises) and the altitude and location of the resultant interface or salt-water front.

The projected hydraulic-head rises in the fresh-water aquifer after 100 years of salt-water impoundment in the proposed Truscott Brine Lake are shown in figure 10. Significant hydraulic-head rises (5 to 40 feet) are projected only for the areas adjacent to the lake shoreline and the proposed Truscott Dam. Hydraulic-head rises at the embankment in the central part of the dam

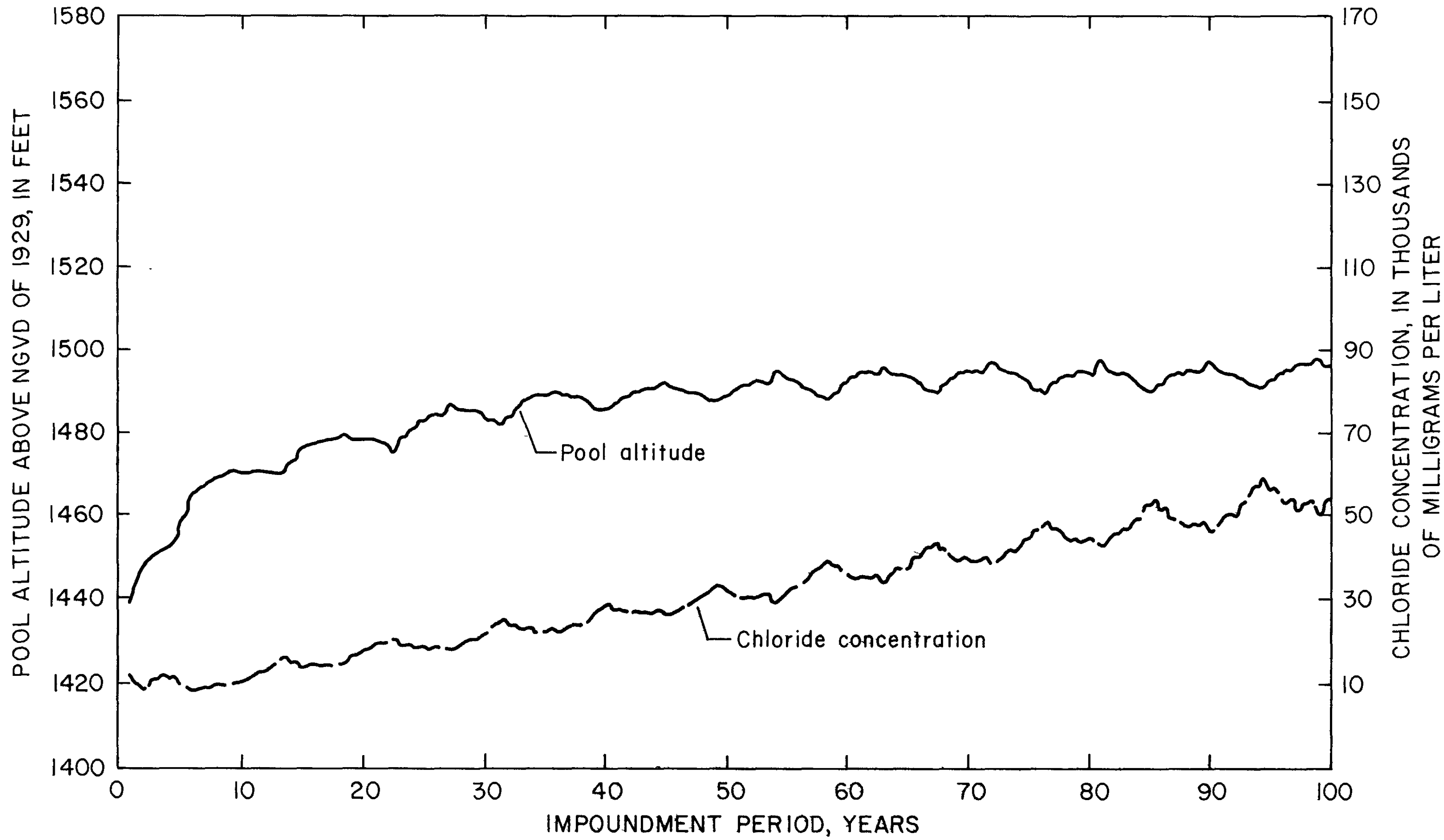

Figure 8.-Estimated pool altitude and chloride concentration during the first 100 years of impoundment at Truscott Brine Lake

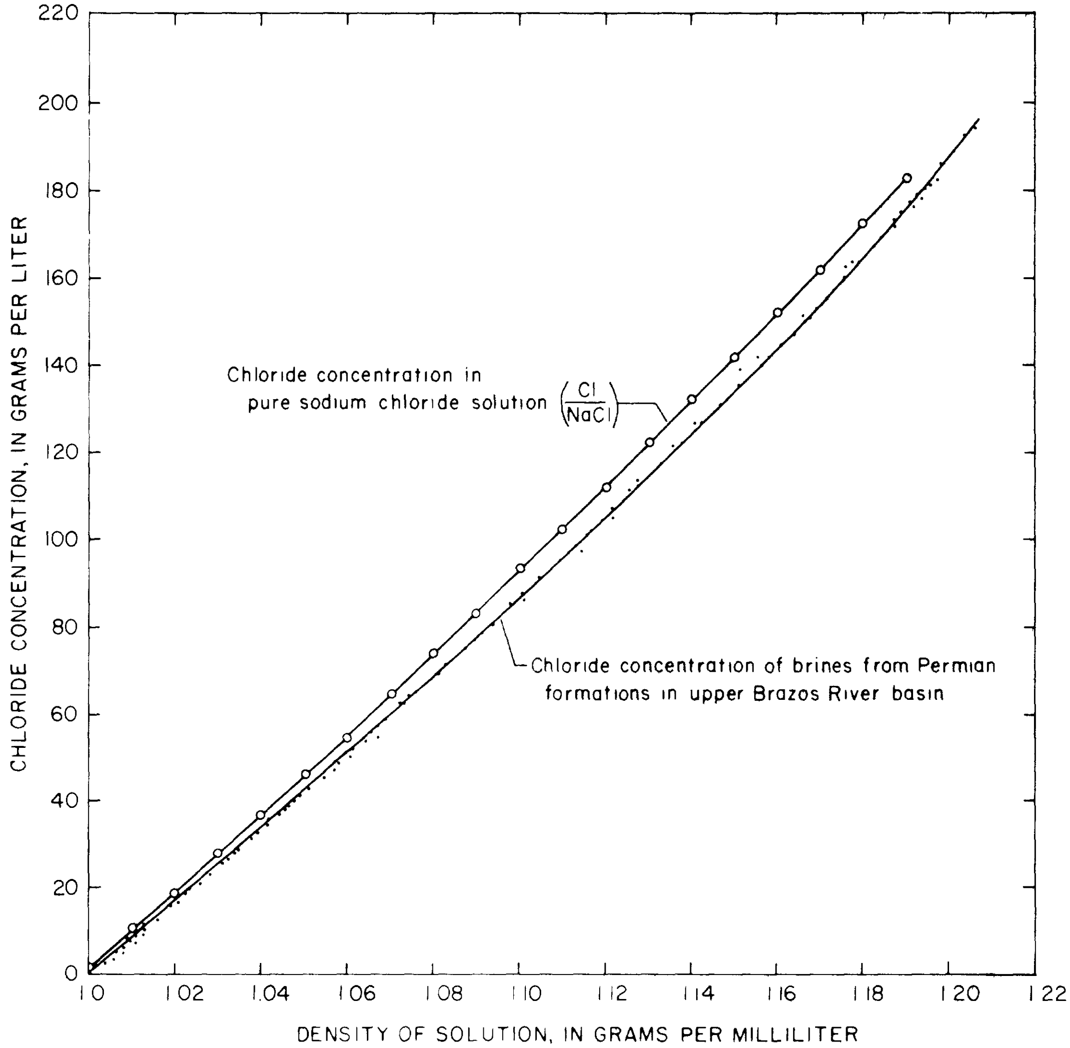

Figure 9.-Density versus chloride concentration of sodium-chloride solution and brine from Permian formations in the upper Brazos River basin (from Garza, 1982, fig. 12)

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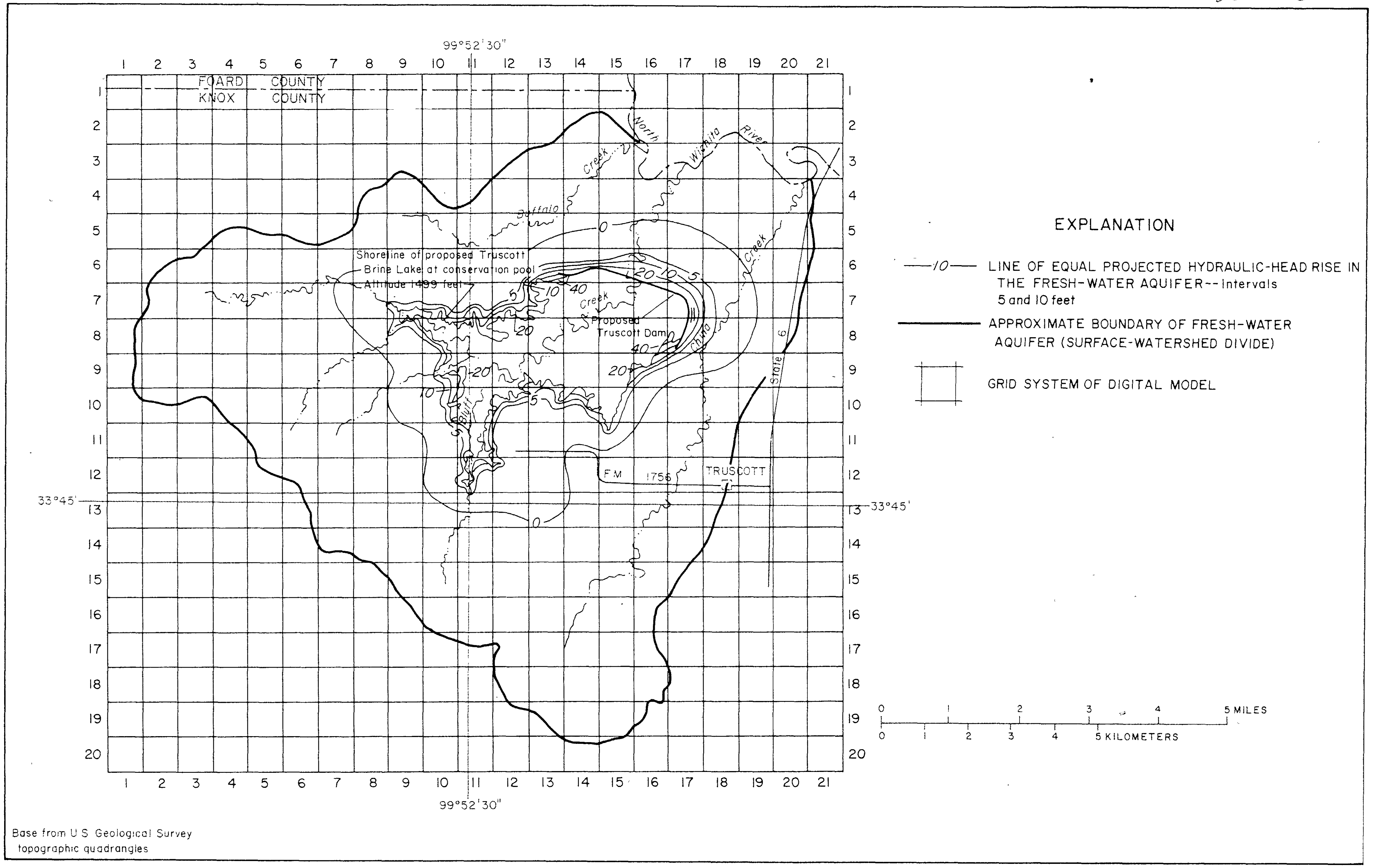

Figure 10.-Projected hydraulic-head rises in the fresh-water aquifer after 100 years of brine impoundment in the proposed Truscott Brine Lake

probably will be about 80 feet and are not included in figure 10. Analysis of the hydraulic-head gradients along the embankment may involve detailed seepage studies not discussed in this report; the Corps of Engineers will incorporate plans related to the embankment design for decreasing the hydraulic pressure at the dam. The areal hydraulic-head effects of the proposed lake on the fresh-water aquifer are not extensive. This is attributed mainly to the very poor transmissive character of the fine-grained aquifer system.

No provisions were made in the interface model to simulate changes in evapotranspiration (ET) with changes in depth to water as a result of the projections. The average ET rate is incorporated in the average steady-state accretion and is not modeled in the calibration of the fresh-water aquifer. Changes in hydraulic head caused by the proposed brine structure may change ET and with it the accretion. Under these conditions, the degree of the accretion changes will depend on the factors affecting the ET changes (applied stresses, depth to water, lithology of unsaturated zone), plus the quantity by which the accretion itself can potentially change. The steady-state accretion in the project area is very small (0.1 inch per year or about 2×10^{-5} ft/d). Changes in the ET rate per foot of water-level change in the area are estimated to be 10^{-4} to 10^{-5} ft/d. Therefore, the small accretion can be nullified by 1 to 2 feet of water-level rises; however, rises in water level due to the proposed impoundment are limited to only a few areas in the vicinity of the dam and the lake shoreline. In order to test the effects of decreased accretion in these areas, the model used in the calibration procedure was stressed by eliminating the accretion in the areas of expected rise in water level. The effects were small, generally less than 1 foot of projected hydraulic-head change in most areas and 1 to 2 feet in a few areas. The effects of negative accretion (aquifer-storage losses to ET) on hydraulic head in the vicinity of the lake are considered to be minor, mainly because of the presence of the lake itself. In summary, the effects of the changes in ET on the hydraulic-head projections are assumed to be negligible, primarily because the major hydraulic-head rises occur only in a few areas along the lake shoreline and near the dam.

The projected altitude of the brine- fresh-water interface (salt-water front) in the fresh-water aquifer after 100 years of brine impoundment in the proposed Truscott Brine Lake is shown in figure 11. The approximate location of the salt-water toe, which is the extension of the salt-water front at the base of the aquifer, also is shown; its longest extension is less than 1 mile downstream from the dam. It appears that conditions illustrated in both figures 10 and 11 did not reach equilibrium during the 100-year simulation.

The U.S. Army Corps of Engineers (1972, p. 6-17) has made provisions to eliminate or decrease underflow seepage across the proposed Truscott Dam. These include: (1) A positive cut-off trench, 15 feet wide and 10 feet deep into bedrock, along the entire embankment and through the abutments of the dam; and (2) a thick (as much as 100 feet) grout curtain across the full length of the trench. Movement of the brine in the vicinity of the dam is expected to be in the form of interstitial bedrock flow, which will take place mainly in the thin sandy zones of the Clear Fork Group as underflow across parts of the dam as well as around the abutments. Estimates of interstitial velocities in areas downstream from the dam were made by assuming piston-type flow with the use of hydraulic-head gradients from the simulation after 100 years of impoundment. Gradients of 20 to 80 feet per mile and an effective porosity of

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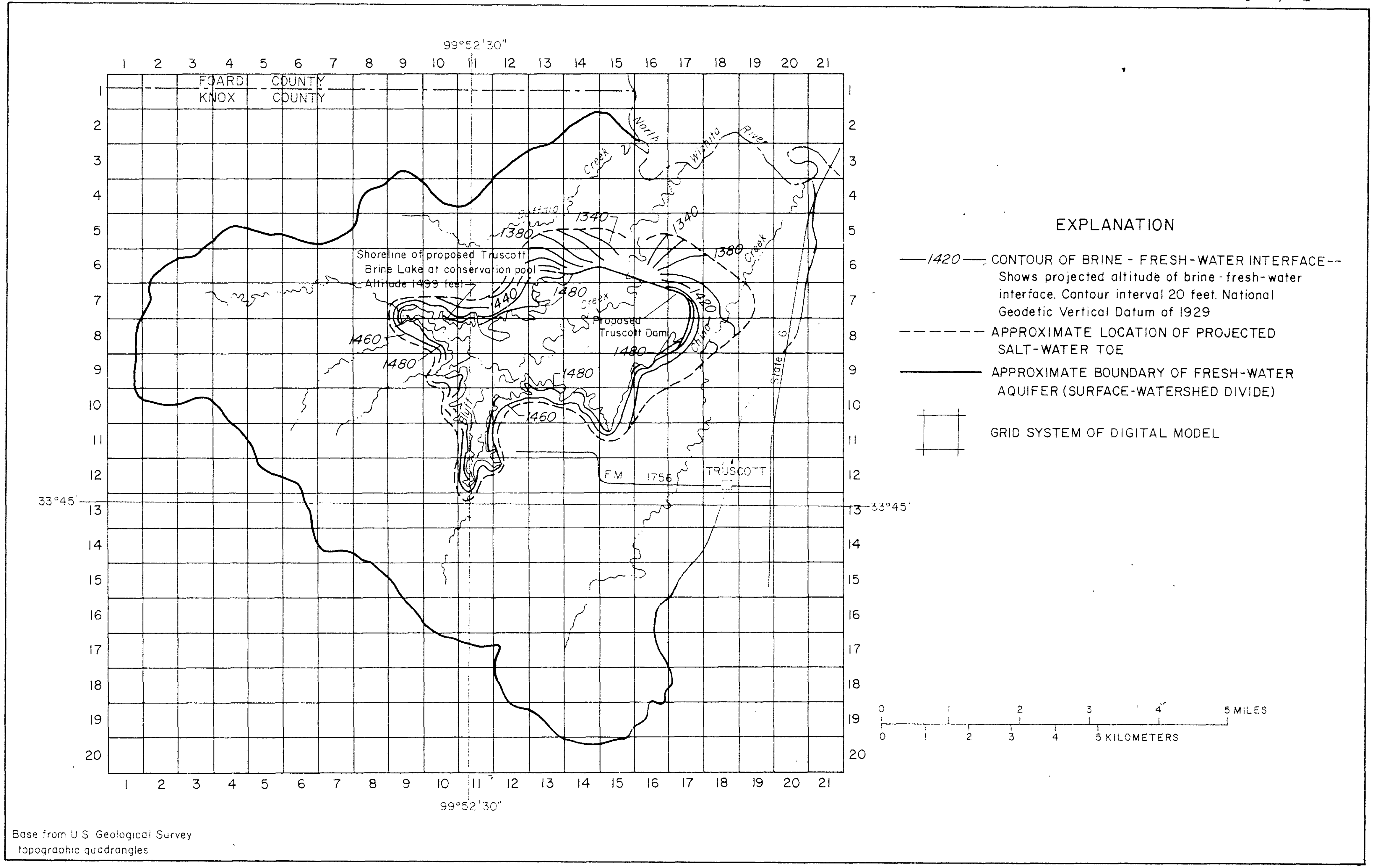

Base from U.S. Geological Survey topographic quadrangles

Figure 11.-Projected altitude of brine - fresh-water interface in the fresh-water aquifer after 100 years of brine impoundment in the proposed Truscott Brine Lake

20 percent were used to compute velocities of very small fractions of a foot per year to nearly 15 feet per year. Velocities in the upper part of this range reflect movement in the sandy zones of the Clear Fork Group.

The position of the salt-water front downstream from the proposed Truscott Dam is controlled in part by discharge from the aquifer to Bluff Creek. The fresh-water component of the discharge to Bluff Creek is a large percentage of the steady-state fresh-water discharge, which is about 0.2 ft^3/s in the Truscott area. The salt-water component, due to the proposed impoundment, is estimated to be less than 0.1 ft^3/s by the end of the 100-year simulation. If this salt-water discharge contains a chloride concentration of 34,000 mg/L (average in the proposed reservoir), the chloride load in Bluff Creek will be about 8 tons per day at the end of the 100-year impoundment.

The interface model was subjected to sensitivity analyses by changing accretion and hydraulic conductivity for the 100-year simulation. A regional change of 50 percent in accretion resulted in hydraulic-head changes of 0 to 2 feet. A regional change of 50 percent in hydraulic conductivity resulted in hydraulic-head changes of 0.1 to more than 7 feet. The hydraulic conductivity of the Clear Fork Group in the vicinity of and downstream from the proposed Truscott Dam was increased by a factor of 100 in order to estimate changes caused by these extreme increases in hydraulic conductivity in this critical area. The results of the 100-year simulation included hydraulic-head rises of 1 to 8 feet in some places and hydraulic-head decreases of less than 1 to about 5 feet in others. The salt-water toe generally was extended additional distances downstream from the dam; most of the extensions were less than 0.5 mile, but in one area the extension was about 1 mile.

Significance of Results of Projections

The results of the projections made in this study may be evaluated in part through a review of the modeling procedures used plus consideration of possible effects of certain physical and chemical aspects not included in the modeling effort. The interface model of Mercer, Larson, and Faust (1980a) has distinct advantages and disadvantages that are reflected in the results of the projections. The primary consideration in the use of this modeling approach has been the incorporation of the density effects of salt water in the projections. It is believed that hydraulic-head changes, as a result of stresses imposed by the proposed impoundment of brine, have been adequately projected. The projected location of the sharp salt-water front or interface is believed to be an approximation mainly because the sharp-interface assumption may not be particularly applicable to the generally fine-grained aquifers in the area.

Use of the interface model in this study has produced some errors in the salt-water mass balance. Mercer, Larson, and Faust (1980b) attribute this to problems related to locating the salt-water toe. It seems that the equations describing the flow system at node blocks along the salt-water toe may contain non-zero terms for both the fresh water and salt water but may indicate an interface position below the aquifer bottom. The changes in the interface position necessary to balance mass-flow residuals for the block may produce an artificial increase or decrease of mass within the block. One solution is the regeneration of a grid system for each time step so that the toe coincides with the edge of a grid block; for two-dimensional finite-difference computations, this is prohibitive. Mercer, Larson, and Faust (1980b, p. 378) conclude that mass-balance errors in many instances will have to be tolerated. In this study, the fresh-water mass-balance error at the end of the 100-year simulation was less than 1 percent; during the simulation, fluctuation of the error generally varied between less than 1 to about 5 percent for each time step. The salt-water mass-balance error was about 8 percent at the end of the 100-year simulation; however, the fluctuation during the simulation varied between 6 and 64 percent.

Changes in the hydraulic conductivity of the fresh-water aquifer that may result from the physical and chemical changes in the salt-water and fresh-water areas were not considered in the simulations in this study. These physical and chemical changes may occur within the impounded salt water, between the salt water and the native fresh water in the aquifer, and between the salt water and the aquifer material. The impoundment of salt water will be accompanied by an accumulation of sediment that may clog parts of the aquifer system. The reactions involving aqueous solutions include mineral precipitation by thermodynamic supersaturation with respect to a particular mineral; this reaction also may cause clogging of parts of the aquifer. The redox potential for the salt water may be determined in order to assess redox reactions, which are not likely to cause clogging but could cause a lowered pH (acid solutions) and dissolution reactions. The reactions between the chemically varying salt water and the type of material in the fresh-water aquifer can be complex and may increase or decrease the hydraulic conductivity of the aquifer. Generally, studies to determine the effects of these interactions on hydraulic conductivity will require: (1) Projections on the physical and chemical nature of the impounded salt water throughout the duration of the project; (2) analyses on the mineral composition of the aquifer material, particularly those areas of the aquifer that may contain clay; and (3) additional analyses on the chemical concentration of the fresh water.

CONCLUSIONS

The fresh-water aquifer in the Truscott area is a shallow water-table system with relatively fresh water (calcium sulfate type) containing about 500 to 5,000 mg/L of dissolved solids. The aquifer consists of Permian rocks with very small values of hydraulic conductivity; it is separated from an even less permeable and deeper brine system (sodium chloride type) by a relatively thin transition zone. The variation of aquifer thickness is between slightly less than 20 to slightly more than 70 feet; the average is about 45 feet. The average annual accretion, assumed equivalent to the average stream base flow, is about 0.1 inch per year.

The principal projected effects of the 100-year brine impoundment at Truscott Brine Lake on the fresh-water aquifer in the project area are as follows:

(1) The areal hydraulic-head effects of the proposed brine structure would not be extensive, and hydraulic-head rises of 5 to 40 feet would be limited to the areas near the proposed dam and along the lake shoreline.

(2) The salt-water migration downstream from Truscott Dam generally would be confined to less than 1 mile and apparently would not reach equilibrium during the 100-year impoundment.

Results of the projections do not reflect possible effects associated with hydrodynamic dispersion and physical and chemical changes interacting in the salt-water and fresh-water environments, the results of which may effect changes in the hydraulic conductivity of the aquifer.

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SUPPLEMENTAL INFORMATION

Table 2.--Chemical analyses of water from selected wells, springs, and ponds in the Truscott area

(COUNTY = 275 - Knox; MG/L = milligrams per liter; AC-FT = acre-feet; MICROMHOS = micromhos per centimeter at 25° Celsius; DEG C = degrees Celsius)

TEST-HOLE NUMBER (FIG. 2)	STATION NUMBER	COUNTY	DATE OF SAMPLE	SILICA, DIS-SOLVED (MG/L AS SIO2)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	BICAR-BONATE (MG/L AS HCO3)
W-1	334337099502201	275	79-02-28	18	140	61	70	4.2	350
			79-07-25	--	--	--	--	--	--
			80-02-20	--	--	--	--	--	--
			80-07-15	--	--	--	--	--	--
W-2	334342099502301	275	79-02-28	20	90	53	40	2.1	450
			80-07-15	--	--	--	--	--	--
W-3	334316099500901	275	79-03-02	16	420	88	130	6.2	220
			80-02-20	--	--	--	--	--	--
			80-07-14	--	--	--	--	--	--
W-4	334555099514301	275	79-02-28	21	230	75	53	6.8	480
			80-02-21	--	--	--	--	--	--
W-6	334321099520601	275	80-07-15	--	--	--	--	--	--
W-10	334233099510001	275	79-02-28	17	420	120	380	16	350
			79-07-25	--	--	--	--	--	--
			80-02-20	--	--	--	--	--	--
			80-07-15	--	--	--	--	--	--
W-11	334542099491401	275	79-03-01	11	730	250	670	13	350
			79-07-26	--	--	--	--	--	--
			80-02-21	--	--	--	--	--	--
			80-07-16	--	--	--	--	--	--
W-14	334327099510201	275	79-07-25	24	120	28	6.0	4.0	480
			80-02-20	--	--	--	--	--	--
			80-07-15	--	--	--	--	--	--
W-16	334612099481701	275	79-02-28	13	240	110	350	5.3	290
			79-07-26	--	--	--	--	--	--
			80-02-21	--	--	--	--	--	--
			80-07-14	--	--	--	--	--	--
W-17	334635099502701	275	79-03-01	11	510	120	230	12	170
			79-07-25	--	--	--	--	--	--
			80-02-21	--	--	--	--	--	--
			80-07-16	--	--	--	--	--	--
W-18	334637099520201	275	79-03-01	8.3	420	380	800	21	360
			79-07-26	--	--	--	--	--	--
			80-02-21	--	--	--	--	--	--
			80-07-16	--	--	--	--	--	--
W-22	334258099511201	275	79-02-28	11	390	340	800	31	380
			80-02-20	--	--	--	--	--	--

Table 2.--Chemical analyses of water from selected wells, springs, and ponds in the Truscott area--Continued

TEST-HOLE NUMBER (FIG. 2)	CAR-BONATE (MG/L AS CO3)	CARBON DIOXIDE DIS-SOLVED (MG/L AS CO2)	ALKA-LINITY (MG/L AS CACO3)	SULFATE DIS-SOLVED (MG/L AS SO4)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SOLIDS, DIS-SOLVED (TONS PER AC-FT)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)
W-1	0	44	287	280	91	0.6	838	1.21	600	310
	--	--	--	86	51	--	--	--	--	--
	--	--	--	97	63	--	--	--	--	--
	--	--	--	110	60	--	--	--	--	--
W-2	0	114	369	83	54	.7	565	.70	440	71
	--	--	--	850	150	--	--	--	--	--
W-3	0	22	180	1300	140	.5	2210	3.01	1400	1200
	--	--	--	1300	140	--	--	--	--	--
	--	--	--	320	75	--	--	--	--	--
W-4	0	77	394	490	47	.5	1160	1.58	880	490
	--	--	--	460	36	--	--	--	--	--
W-6	--	--	--	1800	1800	--	--	--	--	--
W-10	0	22	287	1300	510	.4	2940	4.00	1500	1300
	--	--	--	1400	550	--	--	--	--	--
	--	--	--	1400	530	--	--	--	--	--
	--	--	--	1200	590	--	--	--	--	--
W-11	0	28	287	2100	1300	.3	5260	7.15	2900	2600
	--	--	--	2300	1200	--	--	--	--	--
	--	--	--	2100	1100	--	--	--	--	--
	--	--	--	2100	690	--	--	--	--	--
W-14	0	31	390	21	5.9	1.3	447	.61	420	21
	--	--	--	38	20	--	--	--	--	--
	--	--	--	15	7.9	--	--	--	--	--
W-16	0	23	238	1200	290	1.4	2350	3.20	1100	810
	--	--	--	1100	200	--	--	--	--	--
	--	--	--	1200	340	--	--	--	--	--
	--	--	--	1200	200	--	--	--	--	--
W-17	0	14	139	1900	310	.3	3180	4.32	1800	1600
	--	--	--	1300	78	--	--	--	--	--
	--	--	--	1600	340	--	--	--	--	--
	--	--	--	1600	160	--	--	--	--	--
W-18	0	29	295	2300	760	.1	4870	6.62	2600	2300
	--	--	--	3000	1400	--	--	--	--	--
	--	--	--	2800	910	--	--	--	--	--
	--	--	--	2500	1100	--	--	--	--	--
W-22	0	96	312	2400	580	1.4	4740	6.45	2400	2100
	--	--	--	3100	750	--	--	--	--	--

Table 2.--Chemical analyses of water from selected wells, springs, and ponds in the Truscott area--Continued

TEST-HOLE NUMBER (FIG. 2)	SODIUM PERCENT	SODIUM AD-SORP-TION RATIO	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH FIELD (UNITS)	TEMPER-ATURE, WATER (DEG C)	IODIDE, DIS-SOLVED (MG/L AS I)	BROMIDE DIS-SOLVED (MG/L AS BR)
W-1	20	1.2	1300	7.1	15.5	0.02	0.5
	--	--	980	7.0	18.0	--	--
	--	--	1000	--	17.0	--	--
	--	--	1015	--	20.0	--	--
W-2	16	.8	959	6.8	16.0	.02	.3
	--	--	2240	--	19.0	--	--
W-3	17	1.5	2800	7.2	19.0	.04	.8
	--	--	2700	--	18.0	--	--
	--	--	1330	--	23.0	--	--
W-4	11	.8	1620	7.0	19.0	.01	.3
	--	--	1600	--	19.0	--	--
W-6	--	--	8010	--	27.0	--	--
W-10	35	4.2	4050	7.4	17.0	.04	3.0
	--	--	3640	7.2	17.5	--	--
	--	--	4150	--	17.0	--	--
	--	--	4520	--	18.0	--	--
W-11	34	5.5	7000	7.3	15.0	.03	8.5
	--	--	6850	7.1	18.0	--	--
	--	--	6600	--	15.0	--	--
	--	--	5340	--	17.0	--	--
W-14	4	.1	740	7.4	18.5	.10	.2
	--	--	650	--	17.0	--	--
	--	--	558	--	21.0	--	--
W-16	42	4.7	3180	7.3	15.5	.39	.0
	--	--	2600	7.6	17.5	--	--
	--	--	--	--	16.0	--	--
	--	--	3110	--	18.0	--	--
W-17	22	2.4	3690	7.3	14.0	.02	1.9
	--	--	3750	7.1	17.5	--	--
	--	--	3900	--	13.0	--	--
	--	--	3140	--	18.5	--	--
W-18	40	6.8	7520	7.3	13.5	.04	4.7
	--	--	8100	7.2	17.5	--	--
	--	--	6810	--	13.0	--	--
	--	--	7310	--	17.0	--	--
W-22	42	7.1	7200	6.8	16.0	.05	3.0
	--	--	7000	--	16.0	--	--

Table 2.--Chemical analyses of water from selected wells, springs, and ponds in the Truscott area--Continued

TEST-HOLE NUMBER (FIG. 2)	STATION NUMBER	COUNTY	DATE OF SAMPLE	SILICA, DIS-SOLVED (MG/L AS SIO2)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	BICAR-BONATE (MG/L AS HCO3)
W-22	334258099511201	275	80-07-14	--	--	--	--	--	--
W-26	334808099554901	275	80-02-22	--	--	--	--	--	--
W-29	334840099542901	275	79-03-01	20	550	40	6.6	3.9	500
			79-07-26	--	--	--	--	--	--
			80-02-22	--	--	--	--	--	--
			80-07-17	--	--	--	--	--	--
W-30	334833099532501	275	79-03-01	18	67	31	13	3.8	370
			79-07-26	--	--	--	--	--	--
			80-02-21	--	--	--	--	--	--
			80-07-15	--	--	--	--	--	--
W-34	334510099484401	275	79-07-25	4.3	450	170	550	12	66
			80-02-20	--	--	--	--	--	--
			80-07-16	--	--	--	--	--	--
W-37	334756099542301	275	80-07-15	--	--	--	--	--	--
W-38	334546099474801	275	80-07-16	--	--	--	--	--	--
W-39	334548099471701	275	80-07-16	--	--	--	--	--	--
CH-39	334612099512101	275	79-03-01	12	750	300	1200	27	80
			80-02-21	--	--	--	--	--	--
			80-07-16	--	--	--	--	--	--
N-1	334330099533801	275	80-02-21	--	--	--	--	--	--
			80-07-16	--	--	--	--	--	--
N-2	334419099540701	275	80-02-21	--	--	--	--	--	--
N-3	334548099531601	275	79-03-02	7.9	400	140	310	15	450
N-4	334642099490301	275	79-07-26	6.9	300	150	460	13	--
			80-07-17	--	--	--	--	--	--
N-8	334937099542801	275	80-07-17	--	--	--	--	--	--
SPRING #2	334737099531401	275	80-07-17	--	--	--	--	--	--
TW-1	334822099480401	275	81-01-30	--	--	--	--	--	--
TW-2A	334842099492202	275	81-01-30	--	--	--	--	--	--
TW-4	334744099523301	275	81-01-29	--	--	--	--	--	--
TW-5	334731099543901	275	81-01-30	--	--	--	--	--	--

Table 2.--Chemical analyses of water from selected wells, springs, and ponds in the Truscott area--Continued

TEST-HOLE NUMBER (FIG. 2)	CARBONATE (MG/L AS CO3)	CARBON DIOXIDE DIS-SOLVED (MG/L AS CO2)	ALKALINITY (MG/L AS CACO3)	SULFATE DIS-SOLVED (MG/L AS SO4)	CHLORIDE, DIS-SOLVED (MG/L AS CL)	FLUORIDE, DIS-SOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTITUENTS, DIS-SOLVED (MG/L)	SOLIDS, DIS-SOLVED (TONS PER AC-FT)	HARDNESS (MG/L AS CACO3)	HARDNESS, NONCARBONATE (MG/L CACO3)
W-22	--	--	--	3000	700	--	--	--	--	--
W-26	--	--	--	220	16	--	--	--	--	--
W-29	0	80	410	1100	9.4	0.8	1980	2.69	1500	1100
	--	--	--	560	8.0	--	--	--	--	--
	--	--	--	1100	16	--	--	--	--	--
	--	--	--	690	9.2	--	--	--	--	--
W-30	0	30	303	10	4.5	.5	330	.45	300	0
	--	--	--	19	4.7	--	--	--	--	--
	--	--	--	20	6.4	--	--	--	--	--
	--	--	--	11	4.9	--	--	--	--	--
W-34	4	.4	61	1600	930	.2	3760	5.11	1800	1800
	--	--	--	1600	1000	--	--	--	--	--
	--	--	--	1800	1100	--	--	--	--	--
W-37	--	--	--	120	68	--	--	--	--	--
W-38	--	--	--	1400	1600	--	--	--	--	--
W-39	--	--	--	62	9.4	--	--	--	--	--
CH-39	0	5.1	66	2300	2500	.2	7160	9.74	3100	3000
	--	--	--	2000	1100	--	--	--	--	--
	--	--	--	1800	900	--	--	--	--	--
N-1	--	--	--	330	8.6	--	--	--	--	--
	--	--	--	310	11	--	--	--	--	--
N-2	--	--	--	1700	960	--	--	--	--	--
N-3	0	72	369	950	240	1.1	2290	3.11	1600	1200
N-4	0	--	--	1500	400	.2	--	--	1400	--
	--	--	--	2300	1300	--	--	--	--	--
N-8	--	--	--	220	38	--	--	--	--	--
SPRING #2	--	--	--	3000	1400	--	--	--	--	--
TW-1	--	--	--	2100	990	--	--	--	--	--
TW-2A	--	--	--	2500	2200	--	--	--	--	--
TW-4	--	--	--	1900	3000	--	--	--	--	--
TW-5	--	--	--	990	1600	--	--	--	--	--

Table 2.--Chemical analyses of water from selected wells, springs, and ponds in the Truscott area--Continued

TEST-HOLE NUMBER (FIG. 2)	SODIUM PERCENT	SODIUM AD-SORP-TION RATIO	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH FIELD (UNITS)	TEMPER-ATURE, WATER (DEG C)	IODIDE, DIS-SOLVED (MG/L AS I)	BROMIDE DIS-SOLVED (MG/L AS BR)
W-22	--	--	7100	--	17.0	--	--
W-26	--	--	720	--	13.0	--	--
W-29	1	0.1	2280	7.0	17.0	0.11	0.4
	--	--	1450	7.2	17.0	--	--
	--	--	2420	--	15.5	--	--
	--	--	1650	--	--	--	--
W-30	9	.3	620	7.3	15.0	.03	.1
	--	--	630	7.2	16.5	--	--
	--	--	620	--	14.0	--	--
	--	--	519	--	17.0	--	--
W-34	39	5.6	4650	8.5	21.0	.06	7.6
	--	--	5800	--	19.0	--	--
	--	--	5930	--	19.0	--	--
W-37	--	--	1190	--	19.0	--	--
W-38	--	--	7550	--	19.5	--	--
W-39	--	--	637	--	19.0	--	--
CH-39	45	9.4	10000	7.4	20.0	.15	28
	--	--	5850	--	20.0	--	--
	--	--	5540	--	20.5	--	--
N-1	--	--	1200	--	16.0	--	--
	--	--	1210	--	18.0	--	--
N-2	--	--	5750	--	19.0	--	--
N-3	30	3.4	3800	7.0	18.0	.03	1.4
N-4	42	5.4	3490	7.1	18.0	.02	2.4
	--	--	7650	--	18.0	--	--
N-8	--	--	1280	--	19.0	--	--
SPRING #2	--	--	8180	--	27.0	--	--
TW-1	--	--	5900	--	19.0	--	--
TW-2A	--	--	10000	--	19.0	--	--
TW-4	--	--	10000	--	20.0	--	--
TW-5	--	--	6350	--	17.0	--	--

Table 2.--Chemical analyses of water from selected wells, springs, and ponds in the Truscott area--Continued

TEST-HOLE NUMBER (FIG. 2)	STATION NUMBER	COUNTY	DATE OF SAMPLE	SILICA, DIS-SOLVED (MG/L AS SIO2)	CALCIUM DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K)	BICAR-BONATE (MG/L AS HCO3)
TW-6	334642099533601	275	81-01-30	--	--	--	--	--	--
TW-7	334518099534401	275	81-01-29	--	--	--	--	--	--
L-1	334327099510202	275	79-07-25	9.1	27	3.7	1.6	13	1
			80-02-20	--	--	--	--	--	--
			80-07-15	--	--	--	--	--	--
L-2	334703099484801	275	79-07-26	10	44	5.7	3.5	5.2	120
			80-07-17	--	--	--	--	--	--
L-3	334537099513701	275	79-07-26	8.8	17	2.7	2.9	7.9	130
			80-07-16	--	--	--	--	--	--
L-4	334815099531001	275	79-07-26	19	22	4.2	7.8	1.6	110
			80-02-22	--	--	--	--	--	--
			80-07-15	--	--	--	--	--	--
L-5	334553099525801	275	79-07-26	6.8	22	2.1	1.0	15	33
L-6	334835099485601	275	79-07-27	14	48	5.6	1.3	1.4	150
L-7	334648099492701	275	79-07-26	6.5	34	4.6	1.4	9.3	140
L-8	334745099490801	275	79-07-27	16	59	8.4	2.4	19	230
L-9	334900099485001	275	80-07-17	--	--	--	--	--	--
L-10	334836099485601	275	80-02-22	--	--	--	--	--	--
L-11	334732099522301	275	80-02-22	--	--	--	--	--	--
			80-07-15	--	--	--	--	--	--
L-12	334757099465301	275	80-02-22	--	--	--	--	--	--
			80-07-15	--	--	--	--	--	--
L-13	334548099471801	275	80-07-16	--	--	--	--	--	--
L-14	334509099491101	275	80-07-16	--	--	--	--	--	--
L-15	334858099564901	275	80-07-17	--	--	--	--	--	--

Table 2.--Chemical analyses of water from selected wells, springs, and ponds in the Truscott area--Continued

TEST-HOLE NUMBER (FIG. 2)	CAR-BONATE (MG/L AS CO3)	CARBON DIOXIDE DIS-SOLVED (MG/L AS CO2)	ALKA-LINITY (MG/L AS CACO3)	SULFATE DIS-SOLVED (MG/L AS SO4)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	SOLIDS, SUM OF CONSTI-TUENTS, DIS-SOLVED (MG/L)	SOLIDS, DIS-SOLVED (TONS PER AC-FT)	HARD-NESS (MG/L AS CACO3)	HARD-NESS, NONCAR-BONATE (MG/L CACO3)
TW-6	--	--	--	1500	1400	--	--	--	--	--
TW-7	--	--	--	1200	320	--	--	--	--	--
L-1	6	0.8	100	11	1.9	0.1	128	0.17	83	0
	--	--	--	6.4	2.9	--	--	--	--	--
	--	--	--	15	11	--	--	--	--	--
L-2	0	1.2	98	46	3.8	.4	178	.24	130	35
	--	--	--	11	2.8	--	--	--	--	--
L-3	0	2.6	110	12	8.0	.2	124	.17	54	0
	--	--	--	4.5	6.6	--	--	--	--	--
L-4	0	5.6	90	13	4.8	.2	127	.17	72	0
	--	--	--	13	1.4	--	--	--	--	--
	--	--	--	7.4	6.0	--	--	--	--	--
L-5	28	.0	74	11	1.6	.2	104	.14	64	0
L-6	0	1.2	120	38	2.1	.3	185	.25	140	20
L-7	9	.5	130	13	5.4	.2	141	.19	100	0
L-8	0	2.9	190	14	9.4	.3	242	.33	180	0
L-9	--	--	--	19	4.4	--	--	--	--	--
L-10	--	--	--	45	3.9	--	--	--	--	--
L-11	--	--	--	12	6.6	--	--	--	--	--
	--	--	--	5.8	4.1	--	--	--	--	--
L-12	--	--	--	10	3.4	--	--	--	--	--
	--	--	--	13	6.4	--	--	--	--	--
L-13	--	--	--	13	4.9	--	--	--	--	--
L-14	--	--	--	17	2.8	--	--	--	--	--
L-15	--	--	--	360	9.0	--	--	--	--	--

Table 2.--Chemical analyses of water from selected wells, springs, and ponds in the Truscott area--Continued

TEST-HOLE NUMBER (FIG. 2)	SODIUM PERCENT	SODIUM AD-SORP-TION RATIO	SPE-CIFIC CON-DUCT-ANCE (MICRO-MHOS)	PH FIELD (UNITS)	TEMPER-ATURE, WATER (DEG C)	IODIDE, DIS-SOLVED (MG/L AS I)	BROMIDE DIS-SOLVED (MG/L AS BR)
TW-6	--	--	6450	--	19.0	--	--
TW-7	--	--	3300	--	20.0	--	--
L-1	3	0.1	210	8.4	26.0	0.01	0.1
	--	--	290	--	14.0	--	--
	--	--	240	--	27.0	--	--
L-2	5	.1	200	8.2	27.0	.01	.1
	--	--	241	--	28.0	--	--
L-3	9	.2	270	7.9	27.0	.01	.1
	--	--	264	--	26.0	--	--
L-4	19	.4	220	7.5	26.0	.01	.1
	--	--	295	--	10.0	--	--
	--	--	295	--	30.0	--	--
L-5	3	.1	170	9.8	31.0	.00	.0
L-6	2	.0	370	8.3	32.0	.00	.1
L-7	3	.1	280	8.6	31.0	.02	.2
L-8	3	.1	440	8.1	32.0	.02	.2
L-9	--	--	378	--	29.0	--	--
L-10	--	--	395	--	12.5	--	--
L-11	--	--	310	--	13.0	--	--
	--	--	309	--	33.0	--	--
L-12	--	--	320	--	12.0	--	--
	--	--	317	--	29.0	--	--
L-13	--	--	170	--	27.0	--	--
L-14	--	--	226	--	28.0	--	--
L-15	--	--	836	--	25.0	--	--