VUF-1023
FINAL REPORT

VELA UNIFORM PROGRAM

PROJECT DRIBBLE

SALMON EVENT

TATUM SALT DOME, MISSISSIPPI

22 OCTOBER 1964

part of an experiment in seismic decoupling at the nuclear level

SPONSORED BY THE ADVANCED RESEARCH PROJECTS AGENCY OF THE DEPARTMENT OF DEFENSE AND THE U. S. ATOMIC ENERGY COMMISSION

Geohydrology of Tatum Salt Dome Area, and Marion County, Miss.

U. S. Geological Survey

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NUCLEAR EXPLOSIONS—PEACEFUL APPLICATIONS (TID-4500)

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PROJECT DRIBBLE

GEOHYDROLOGY OF TATUM SALT DOME AREA, LAMAR AND MARION COUNTIES, MISS.

Project Engineer:

R. E. Taylor, Hydrologist

Approved:

S. W. West, Coordinator
AEC Hydrology Projects

Approved:

Director
U.S. Geological Survey
Washington, D. C.

August 1971

ABSTRACT

Geohydrology in the Tatum salt dome area of Lamar and Marion Counties, Mississippi, has been studied since 1961 in support of the U.S. Atomic Energy Commission's safety program for the two nuclear tests, the Salmon and Sterling Events.

Tatum salt dome pierced sedimentary rocks ranging from Late Jurassic to middle Tertiary in age. Overlying the salt stock is a caprock which consists, in ascending order, of anhydrite, gypsum, and calcite. The top of the salt stock is 1,220 to 1,260 feet below sea level, and the top of the calcite caprock is 650 to more than 1,500 feet below sea level. The calcite caprock contains saline water.

Ten major aquifers have been identified in the sedimentary rocks of the area; nine of them contain water under artesian pressure. The Cook Mountain Limestone aquifer contains saline water throughout the area, the Vicksburg Group yields brackish water in this area, and the other aquifers (sands of Miocene age and surficial sands) contain fresh water except where they are contiguous to the dome.

The water level of the Cook Mountain Limestone aquifer has risen because of brine injection into this aquifer. Water levels of the other artesian aquifers have declined at a maximum rate of about 1 foot per year. The surficial aquifer contains unconfined water, and the water level in this aquifer fluctuates annually. Water is probably moving upward in the immediate vicinity of the dome because of structural deformation of the rocks and hydraulic pressure differentials. The regional trend of ground-water movement to the southwest has been modified in the dome area for water in the Cook Mountain Limestone and the principal aquifers of Miocene age. Water levels of the sedimentary aquifers were not permanently altered by the nuclear tests.

An inventory conducted prior to the first nuclear test (Salmon Event) listed 360 wells in the study area. Forty-six new records were listed on an inventory prior to the second test (Sterling Event). A total of 139 water-well complaints were filed after the Salmon Event, and 8 complaints were filed after the Sterling Event.

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CHAPTER 1

INTRODUCTION

The U.S. Geological Survey made hydrologic, geologic, and geophysical studies in the Tatum salt dome area of Lamar and Marion Counties, Mississippi, on behalf of the U.S. Atomic Energy Commission. The Survey acted as agency advisor and provided technical support largely with respect to public safety aspects in regards to two nuclear tests, the Salmon and Sterling Events. The objectives of the Survey's programs were to provide basic information necessary to conduct the experiments.

This report summarizes the data relating to the pretest and posttest hydrologic conditions at the Tatum salt dome area for each test, summarizes the geologic setting as it relates to the hydrologic investigations, and describes the effects of the nuclear detonations on water wells and water levels in the vicinity in respect to water-well damage resulting from the nuclear tests in the salt stock.

Tatum salt dome is in the southwestern part of Lamar County where it underlies parts of sec. 11-14, T. 2 N., R. 16 W. The Tatum salt dome study area (fig. 1.1) extends in a 5-mile radius from the dome and consists of moderately dissected terrain characterized by narrow ridges and flat-topped hills rising about 100 feet above the valleys. The land surface ranges from 170 feet

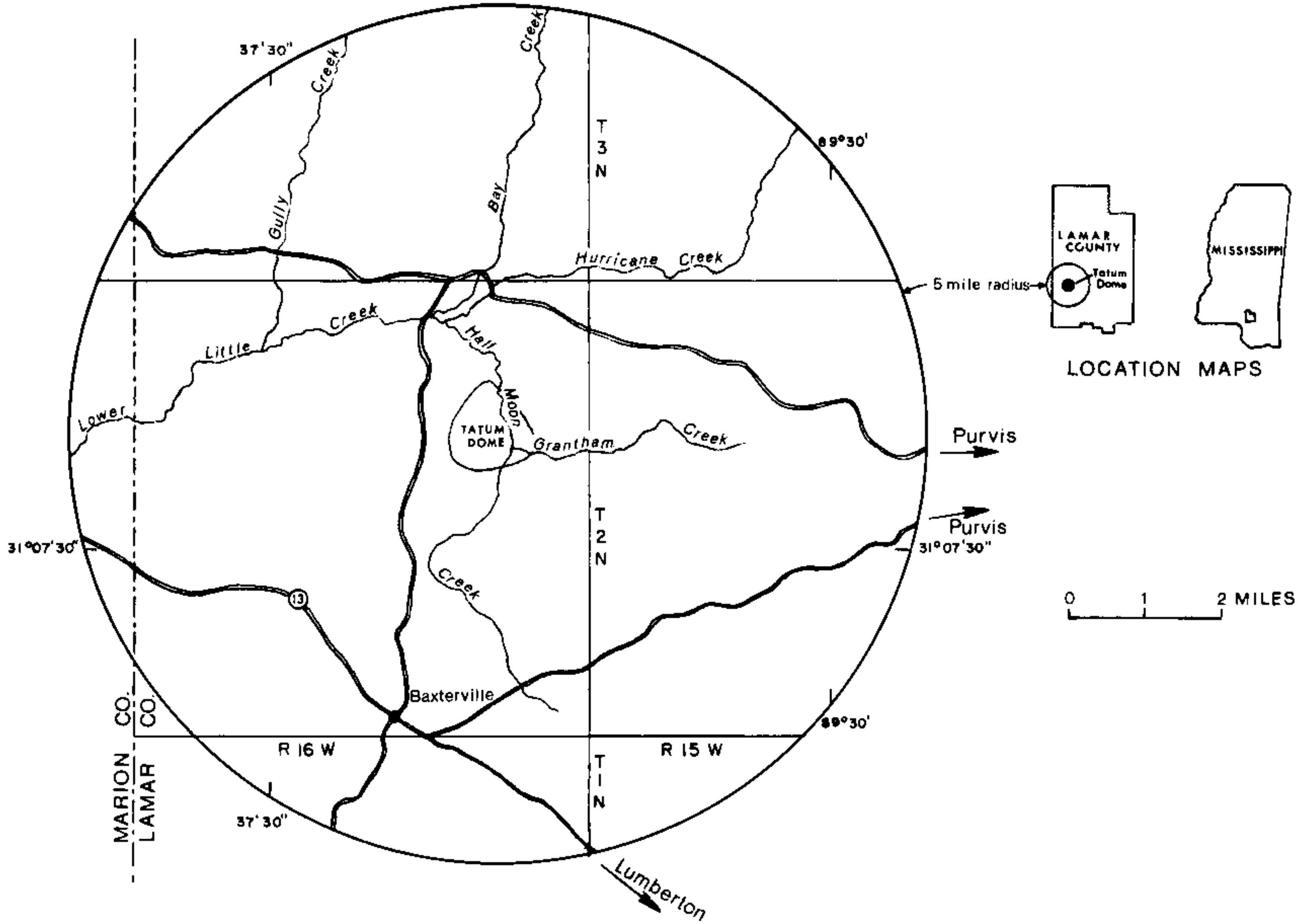


Figure 1.1 Tatum salt dome study area.

above mean sea level along Lower Little Creek to more than 400 feet in the hills.

Lower Little Creek drains most of the area. Main tributaries of the creek are Gully and Bay Creeks from the north, Hurricane Creek from the east, and Half Moon Creek from the south. The high base flow of streams in the area is sustained by springs and seeps which are common along the exposed contact between the surficial deposits and the underlying clay of Miocene age.

Climate of the Tatum salt dome area is subtropical. The nearest point having long-term climatological records is about 20 miles northeast of the dome at Hattiesburg. Hattiesburg has a mean annual precipitation of 60 inches and a mean annual temperature of $19.4^{o}C$. Mean monthly temperatures range from $27.6^{o}C$ in July to $11.0^{o}C$ in December. The highest mean monthly precipitation is recorded in July and March (6.85 and 6.83 inches, respectively), and the lowest is in October (2.29 inches).

ACKNOWLEDGMENTS

Freeport Sulphur Company, Humble Oil and Refining Company, Shell Oil Company, and Willmut Gas and Oil Company contributed significant geologic data to this report. Their permission to publish the information is greatly appreciated.

The author also wishes to acknowledge some of the many persons who were involved in and contributed to this project or report: C. A. Armstrong, W. A. Beetem, R. A. Black, D. H. Eargle, W. E. Hale, E. J. Harvey, J. W. Lang, W. S. Twenhofel, and S. W. West.

CHAPTER 2

GEOLOGY

Tatum salt dome is a salt stock overlain by a caprock. The salt stock, believed to be from the Louann Salt of Jurassic(?) age (Andrews, 1960), pierced sedimentary rocks of Jurassic to Oligocene age. The top of the salt stock partially pierced the adjacent sedimentary rocks of Miocene and Oligocene(?) age and/or deformed them upward so that this series in places overlies the dome. Rocks of late Miocene to Holocene age overlie the dome.

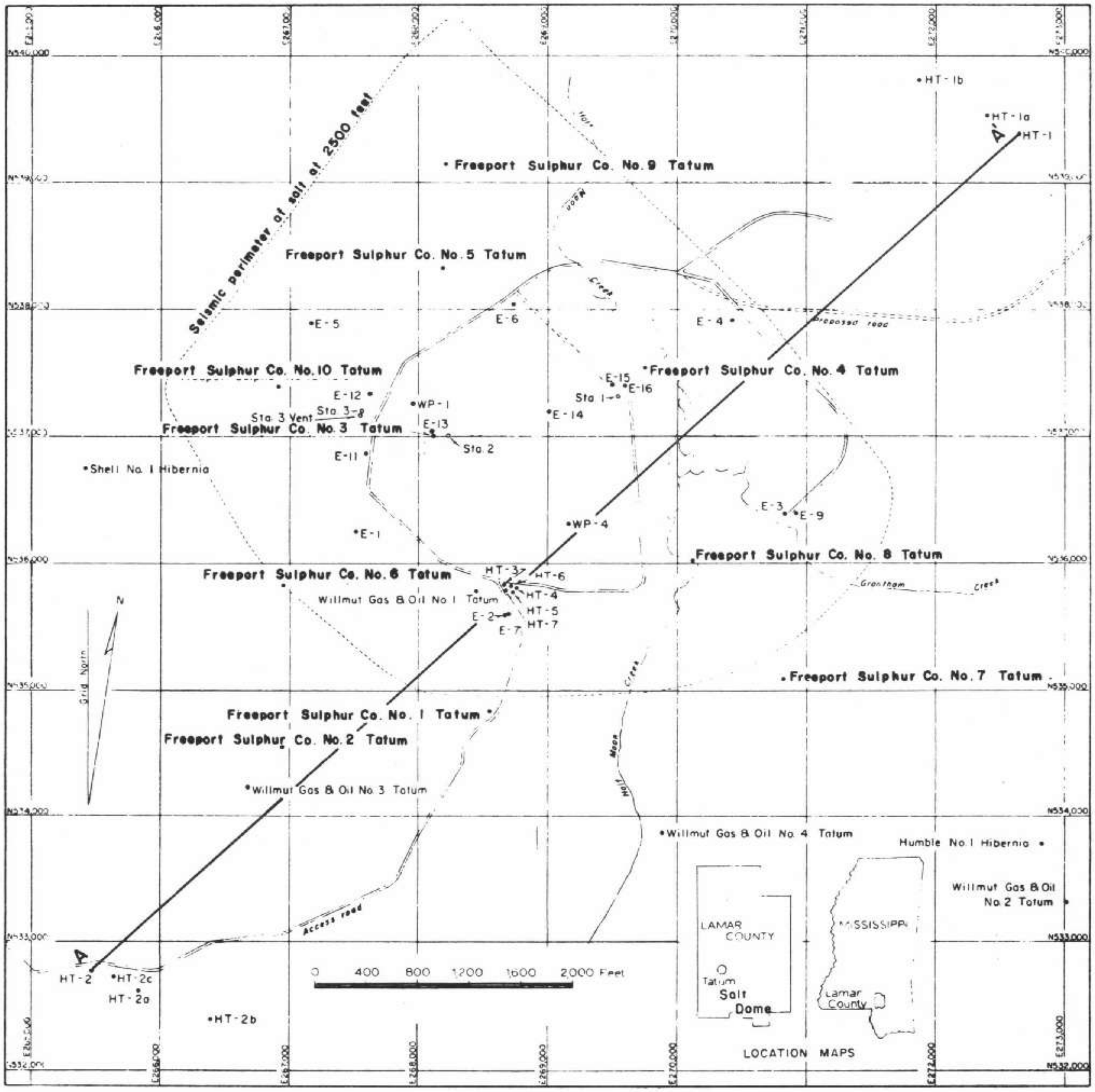
Geologic units in Hydrologic Test Well No. 2 (HT-2), southwest of the Tatum salt dome, are 25 to 230 feet deeper (Armstrong and others, written commun., 1961) than the same units in Hydrologic Test Well No. 1 (HT-1), northeast and on the up-dip side of the dome (figs. 2.1 and 2.2). The sedimentary rocks of Miocene age that were penetrated are lenticular, and the lithologic character changes within short distances. The units are thinner over the dome than on its flanks.

2.1 STRATIGRAPHY

The stratigraphic section, after Eargle (1964), for the region is presented in table 2.1. The deepest unit studied was the Cook Mountain Limestone of Eocene age. Underlying units were not essential to the safety aspects of the project.

Table 2.1. Stratigraphic section in the Tatum salt dome area, Miss.

System	Series	Group	Formation	Member	Thickness (ft)	Lithologic character
Quaternary	Holocene		Alluvium		0- 15	Silt, sand, and gravel.
	Pleistocene		Terrace deposits		0- 30	
Tertiary	Pliocene		Citronelle Formation		0- 150	Clay, silt, sand, and gravel.
	Miocene		Pascagoula and Hattiesburg Formations, undifferentiated		650-1,200	Clay, sand, and gravelly sand.
			Catahoula Sandstone	Upper part	50- 250	Sand, silt, and clay.
	Miocene(?) and Oligocene(?)			Tatum Limestone Member	0- 170	Sandy limestone and marl.
	Oligocene		Chickasawhay Limestone		60- 470	Sandy limestone and fossiliferous sandstone.
		Vicksburg	Byram Formation	Bucatunna Clay Member	120- 140	Calcareous clay.
			Limestone, undifferentiated		140- 190	Soft limestone and marl.
			Red Bluff Clay		40- 60	Gray, fine sand and interbedded calcareous clay.
	Eocene	Jackson	Yazoo Clay		130- 180	Calcareous clay.
			Moodys Branch Limestone		20- 70	Sandy limestone, fossiliferous glauconite and calcerenite.
		Claiborne	Cockfield Formation		90- 120	Lignitic clay.
			Cook Mountain Limestone		160- 190	Clayey limestone.
			Sparta Sand and Zilpha Clay, undifferentiated		90- 625	Clay and sand interbedded.



Compiled by R.A.Black and W.S.Twenhofel, 1961. Modified by R.E.Taylor, 1969.

Perimeter of salt interpreted from seismic reflection data provided by Humble Oil and Refining Co., November 1961.

Figure 2.2 Map of Tatum salt dome.

2.1.1 Claiborne Group (Sparta Sand and Zilpha Clay, Cook Mountain Limestone, and Cockfield Formation). The Sparta Sand and Zilpha Clay form the basal unit of the Claiborne Group; they contain no significant aquifers in the Tatum dome area. The Cook Mountain is 160 feet thick at HT-1 and 190 feet thick at HT-2. Referenced to mean sea level, the formation is 180 feet lower at HT-2 than at HT-1. The Cook Mountain is composed mainly of fine- to coarse-grained, white to gray, marly limestone interbedded with greenish-gray to black, calcareous, glauconitic clay and shale. The Cockfield Formation is 120 feet thick at HT-2 and is composed of greenish-gray to black calcareous clay.

2.1.2 Jackson Group (Moodys Branch Limestone and Yazoo Clay). Overlying the Cockfield Formation is a non-water-bearing sequence of sedimentary rocks comprising the Jackson Group. These units are not continuous across the dome; they are interrupted by the caprock and the salt stock. The Jackson Group is composed, in ascending order, of the Moodys Branch Limestone and the Yazoo Clay. The Moodys Branch attains a maximum thickness of 48 feet at HT-2. It is composed of white to gray, soft, glauconitic limestone. The Yazoo is 170 feet thick at HT-1 and is composed of greenish-gray to gray, soft, calcareous clay.

2.1.3 Red Bluff Clay. The Red Bluff Clay overlies the Jackson Group and is a brown and gray, soft calcareous clay, 45 feet thick at HT-2.

2.1.4 Vicksburg Group and Chickasawhay Limestone. The Vicksburg Group is composed of white, finely crystalline, soft limestone (limestones of the Vicksburg Group, undifferentiated) overlain by gray, fine- to medium-grained sand and green to gray, calcareous, pyritic clay (Bucatunna Clay Member of the Byram Formation). These units are not continuous across the dome, but lie against the caprock. The Vicksburg is 260 feet thick at HT-1 and 320 feet thick at HT-2. Referenced to mean sea level, the group is 100 feet lower at HT-2 than at HT-1.

The Chickasawhay Limestone is composed of gray clays, calcareous sand, and soft limestone. It does not constitute a major aquifer in the area.

2.1.5 Catahoula Sandstone. The next younger sequence of sedimentary rocks is the Catahoula Sandstone which has been separated into two parts. The lower part is the Tatum Limestone Member, a white to gray, finely crystalline, fossiliferous, sandy limestone of Miocene(?) and Oligocene(?) age. The upper part is white to gray, fine- to coarse-grained sand and greenish-gray to gray, soft, calcareous clay of Miocene age. The Catahoula is about 400 feet thick at both HT-1 and HT-2; however, the formation thins over the dome to a minimum thickness of 50 feet at well E-2 (Armstrong and others, written commun., 1961).

2.1.6 Pascagoula and Hattiesburg Formations. The Hattiesburg and Pascagoula Formations of other areas have not been differentiated in the project area because a definite contact between the two formations could not be established. In aggregate, they are composed of lenticular beds of fine- to very coarse-grained sand and gray to greenish-gray, calcareous clay, all of Miocene age. These units together are more than 1,100 feet thick at HT-1, more than 1,200 feet thick at HT-2, and 670 to 850 feet thick across the top of the dome.

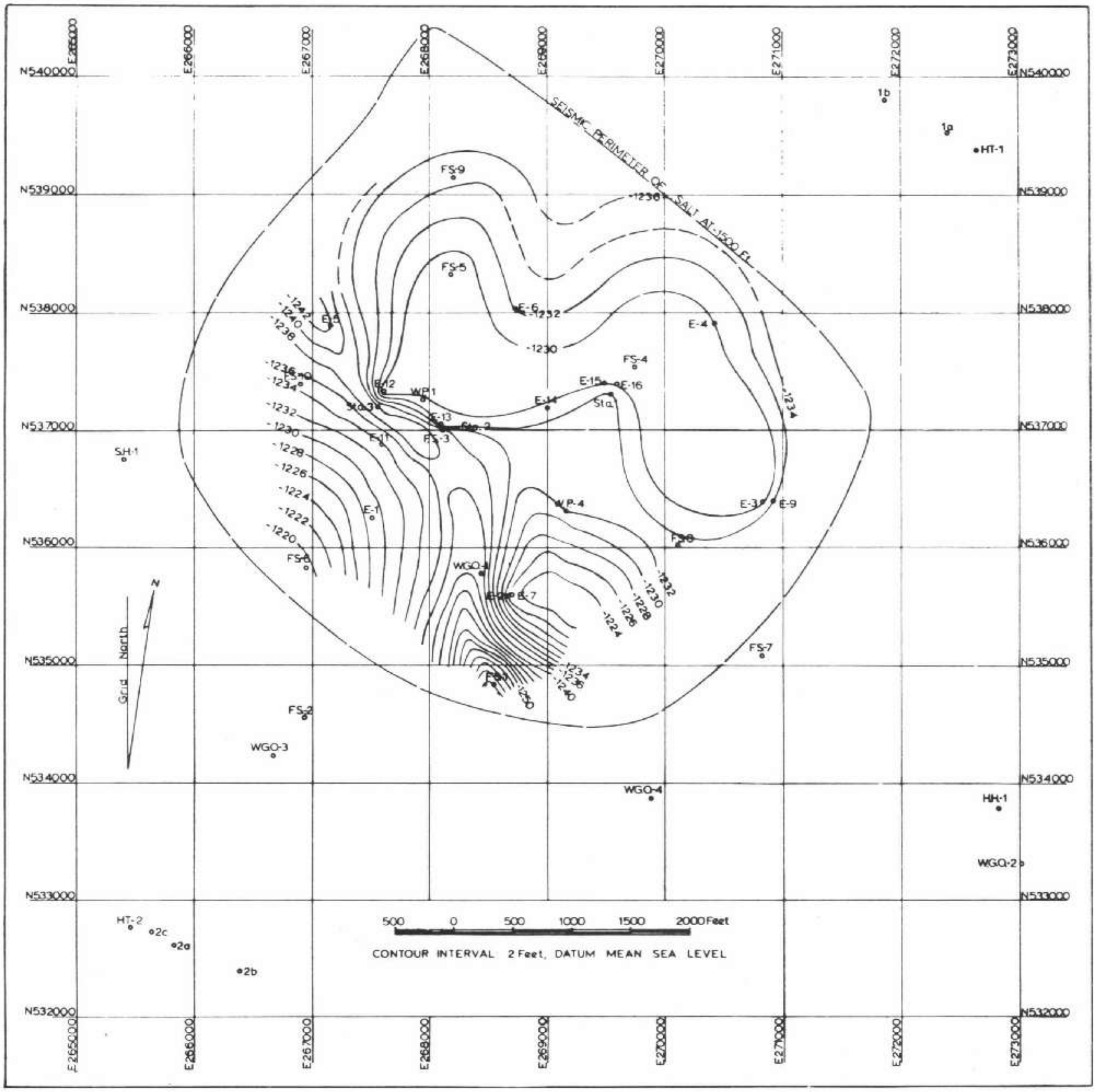
2.1.7 Citronelle Formation, Terrace Deposits, and Alluvium. The Citronelle Formation, terrace deposits, and Holocene alluvium form a surficial cover of sand, gravel, and clay throughout most of the area. These units form hills and ridges and have a thickness as great as 150 feet. In the valleys, these surficial sedimentary deposits are nearly completely eroded and clays of Miocene age are exposed at many places.

2.1.8 Salt Dome Units. The Tatum salt dome is composed of a salt stock and a caprock. The salt stock is composed primarily of halite. The stock attains a maximum diameter near the top of about 4,500 feet and may extend to a depth of 20,000 feet.

The caprock consists, in ascending order, of anhydrite, gypsum, and calcite. The dense, gray anhydrite member attains a thickness of nearly 500 feet, the white gypsum less than 15 feet, and the gray calcite member nearly 150 feet.

2.2 STRUCTURE

2.2.1 Salt Dome. The position relationship between the caprock, the salt stock, and the sedimentary rocks is known for the top of the dome; however, the relationship at the edge of the interface of the caprock and salt stock with the sedimentary rocks at the sides of the dome is known from only one well. This test well, the Freeport Sulphur Co. No. 2 Tatum, was drilled on the southwest edge of the caprock. This well was drilled through caprock into sedimentary rocks, thus indicating a caprock overhang structure at this point in the periphery of the dome.



Compiled by R.A. Black and W.S. Twenhofel, 1961. Modified by R.E. Taylor 1969.

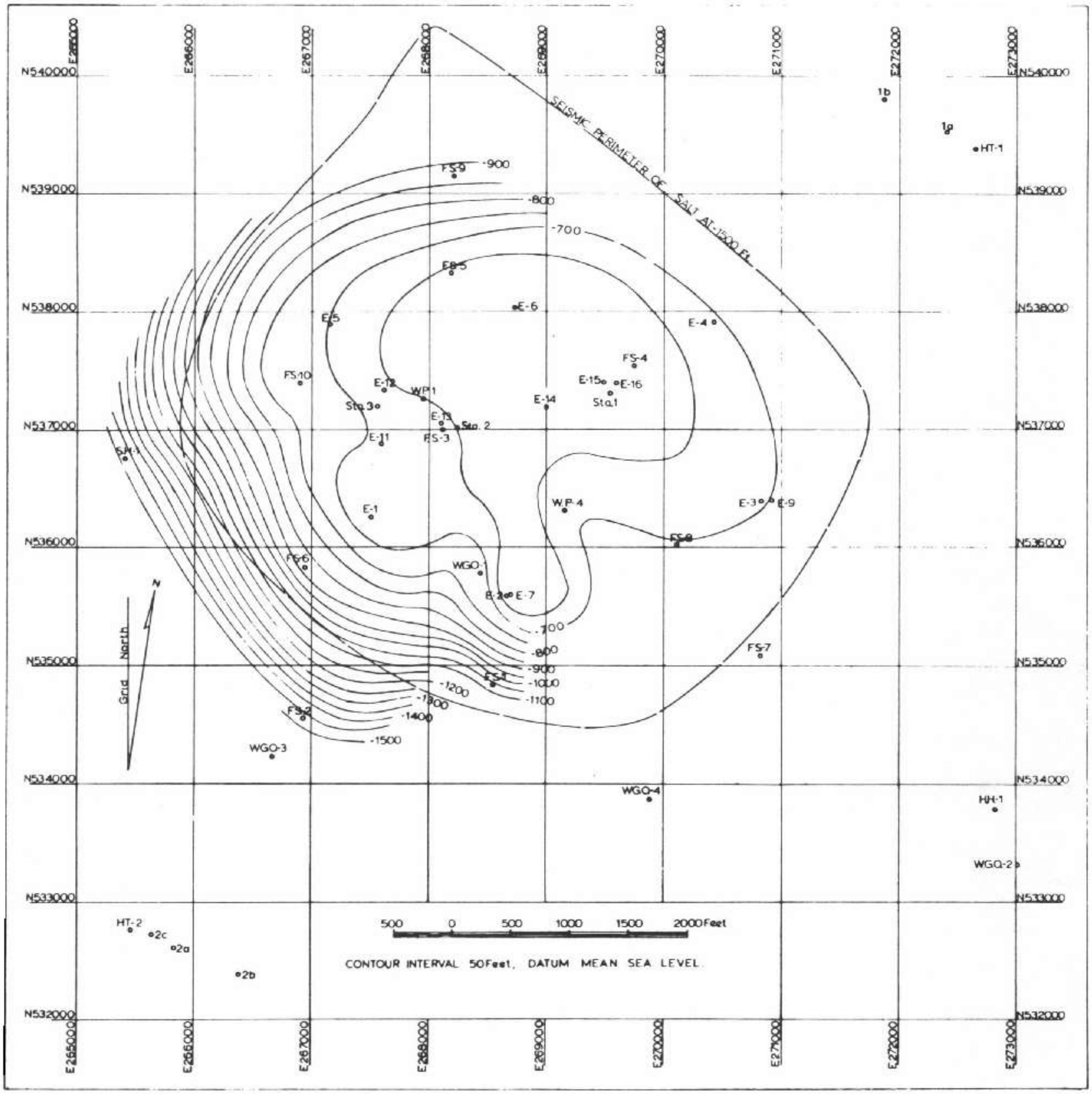
Structure contours interpreted from seismic reflection data provided by Humble Oil and Refining Co., November 1961.

EXPLANATION

E-3
Test hole or well and number

-1236 — — —
Structure contour
Shows elevation of top of salt. Dashed where approximately located. Contour interval 2 feet. Datum is mean sea level.

Figure 2.3 Configuration of top of the salt.



Compiled by R.A. Black and W.S. Twenhofel, 1961. Modified by R.E. Taylor 1969.

Structure contours interpreted from seismic refection data provided by Humble Oil and Refining Co., November 1961.

EXPLANATION

E-3
o
Test hole or well and number

Structure contour
Shows elevation of top of calcite caprock
Contour interval 50 feet. Datum is mean sea level.

Figure 2.4 Configuration of top of calcite caprock.

The top of the salt stock is relatively flat. Elevations of the top (fig. 2.3) range from 1,220 feet below sea level at the Freeport Sulphur Co. No. 6 Tatum well (FS-6) to more than 1,250 feet below sea level at the Freeport Sulphur Co. No. 1 Tatum well (FS-1). The relief is about 20 feet for most of the salt stock area. Elevations of the top of the calcite caprock (fig. 2.4) range from 650 feet to more than 1,500 feet below sea level. The contour pattern is generally circular with the caprock declining outward from a relatively large plateau in the center of the salt dome.

2.2.2 Sedimentary Rocks. Sedimentary rocks of Tertiary age have a regional strike that varies from west-northwest for the younger (Pliocene) to northwest for the older (Eocene). Regionally, the sedimentary rocks dip to the southwest at a rate of 30 to 40 feet per mile, and the rate of dip increases with depth. The salt dome locally modifies the regional geologic structure. Configuration of the top of the Moodys Branch Limestone (fig. 2.5) gives a general idea of the structure of the sedimentary rocks. In this area, the Moodys Branch Limestone strikes about N. 80° W. and dips to the south-southwest at about 30 feet per mile. The highest known point of this unit is 1,300 feet below sea level above the salt dome.

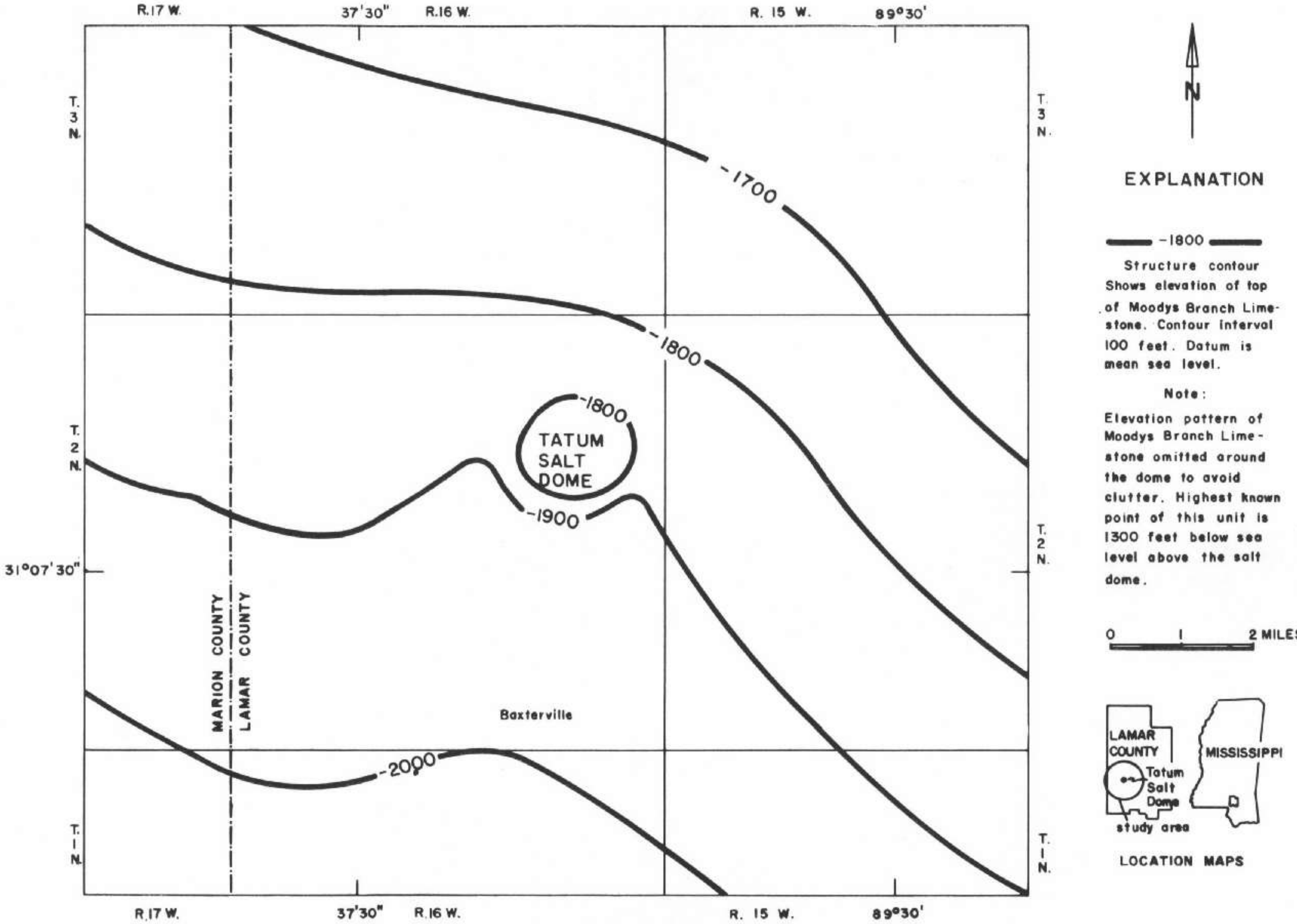


Figure 2.5 Configuration of top of Moodys Branch Limestone, Tatum salt dome area.

CHAPTER 3

HYDROLOGY

Aquifers containing fresh water extend from near the surface to about 1,400 feet below sea level in the Tatum salt dome area; however, the salt dome has locally modified the water quality so that fresh water over the dome extends only to about 700 feet below sea level. Thus, some aquifers that contain saline water on the dome contain fresh water away from the influence of the dome. There are at least seven fresh-water aquifers (surficial, local, 1, 2a, 2b, 3a, and 3b), one brackish aquifer (4), and at least one underlying saline-water aquifer (5) in the strata surrounding Tatum salt dome. Fresh, brackish, and saline are defined as containing less than 1,000 mg/l (milligrams per liter), 1,000 to 5,000 mg/l, and more than 5,000 mg/l, respectively. Two of the fresh-water aquifers--surficial and local--are discontinuous. The important aquifers (1, 2a, 2b, 3a, and 3b) are areally extensive, although they may be locally offset or interrupted by faults near the dome. Table 3.1 lists the aquifers in the area.

3.1 COOK MOUNTAIN LIMESTONE (AQUIFER 5)

Water from the Cook Mountain Limestone (Aquifer 5) is not used in the immediate area of the dome. Brine has been injected into the Cook Mountain Limestone for more than

Table 3.1. Aquifers and subsurface units in the Tatum salt dome area

Formation or series	Thickness (feet)	Local name
Post-Miocene	0-100	Surficial aquifer
Miocene	20- 80	Local aquifer
Do.	0-220	Aquifer 1
Do.	70-120	Aquifer 2a
Do.	70-120	Aquifer 2b
Do.	20-150	Aquifer 3a
Do.	0-160	Aquifer 3b
Limestones of Vicksburg Group	120-140	Aquifer 4
Cook Mountain Limestone	160-190	Aquifer 5

15 years in the vicinity of the Baxterville oil field, which is about 6 miles southwest of the dome. The quantity of brine injected into this aquifer has been sufficient to change the natural head in the aquifer an appreciable amount in the Tatum salt dome area. Wells in the aquifer have the highest head of any that tap artesian aquifers in the area. When static water levels are corrected for density, the water levels are 45 feet higher than the uncorrected static water levels. Water in Aquifer 5 is confined by thick beds of clay above and below. Brine probably is moving upward in the locally deformed zone around the salt dome. Recharge takes place at the outcrop, which is about 75 miles northeast of the dome.

3.2 VICKSBURG GROUP (AQUIFER 4)

The water from the limestone of the Vicksburg Group is brackish and is not used in or near the Tatum salt dome area as a potential water supply. The water level of this artesian aquifer is lower than in the underlying aquifer (5), but higher than levels in the overlying aquifers of Miocene age. Aquifer 4 is separated from the next higher aquifer (3b) by more than 100 feet of sand, limestone, and clay. The Vicksburg probably is hydraulically connected with the calcite caprock. The recharge area is the outcrop, about 55 miles northeast of the dome.

3.3 MIOCENE AGE SEDIMENTS (AQUIFERS 3, 2, 1, AND LOCAL)

Aquifers 3, 2, 1, and local are sands in the Catahoula Sandstone and in the Pascagoula and Hattiesburg Formations. Aquifers 3 and 2 as subdivided are labeled, in ascending order, as Aquifers 3b, 3a, 2b, and 2a. Fresh water is available in all except that part of Aquifer 3a which overlies the caprock. In the Tatum dome area, a few domestic wells tap the shallower Miocene aquifer (Hattiesburg Formation). Outside the area, the deeper aquifers are used for large withdrawals. These aquifers are separated from one another and from the underlying aquifer (4) and the overlying surficial aquifers by beds of clay. Artesian conditions exist at the Tatum dome in all aquifers of Miocene age, and the water levels are the deepest of any of the aquifers in the area. Although the aquifers of Miocene age have been separately identified in the Tatum dome area, regionally they are lenticular beds that cannot be easily delineated over a large area.

Recharge to these aquifers occurs from a few miles northeast of the dome area for the shallower aquifers to about 55 miles for the deeper aquifers.

3.4 SURFICIAL AQUIFERS

The surficial aquifers comprise the sand and gravel of the local terrace deposits, valley alluvium, and the Citronelle Formation. The Citronelle, which is discontinuous, is as much as 100 feet thick and constitutes the major surficial aquifer. Most domestic and stock wells in southern Mississippi are completed in these shallow sedimentary deposits. Precipitation is readily absorbed by the surficial deposits. Later, the ground water is slowly discharged by springs and seeps and provides the large base flow common to the streams in the area. Water in the surficial aquifers occurs mainly under water-table conditions.

3.5 CALCITE CAPROCK AQUIFER

Ground water occurs only in the calcite part of the caprock. The water is saline and is in numerous fractures and solution cavities. An indication of the hydraulic character of this aquifer is demonstrated by lost circulation during the drilling of the test holes in the calcite caprock. Simultaneously, a pressure rise was recorded in nearby observation wells. For example, at previously dry Station 3 Vent hole, the caprock fluid dissolved the salt, entered the hole, and the stage recorder at HT-3 indicated a large decline in water level. The caprock aquifer has a hydraulic connection with Aquifers 3b and 4 on the flank of the dome and with Aquifer 3a over the dome. Water level of the caprock aquifer has a pressure less than that of Aquifer 4, but more than that of Aquifers 3a and 3b.

CHAPTER 4

WATER QUALITY

For each of the major aquifers in the Tatum dome area, two or more chemical analyses of water are available. For this report, the modifiers describing water quality are based on the concentrations in milligrams per liter of dissolved solids measured for samples from each aquifer. Fresh, brackish, and saline are defined as containing less than 1,000 mg/l, 1,000 to 5,000 mg/l, and more than 5,000 mg/l, respectively. With the exception of water contiguous to the dome, water in Aquifer 3b and above is fresh, water in Aquifer 4 is brackish, and water in Aquifer 5 and in the calcite caprock is saline. Due to the stratigraphic position of the aquifers, structural deformation caused by the dome, and pressure differential, water is moving upward in the immediate vicinity of the dome. This results in water that is more mineralized than that normally found in the same aquifers away from the dome.

Water in the Cook Mountain Limestone (Aquifer 5) is saline and of the sodium chloride type. In the vicinity of the dome the dissolved-solids content of the water is 18,800 mg/l. Water temperature of Aquifer 5 is about $36^{\circ}C$.

Water in the limestone of the Vicksburg Group (Aquifer 4) is brackish and of the sodium bicarbonate type having a high chloride content. The dissolved-solids content is approximately 1,300 mg/l. The water temperature of Aquifer 4 is about 33°C.

Water in Aquifer 3a of the Catahoula Sandstone is a calcium sodium bicarbonate type. The mineral content changed considerably from the samples taken immediately after the test holes were drilled as the wells were developed. The dissolved-solids content is less than 100 mg/l. Water temperature is about 22°C.

Water in the local aquifer and Aquifers 1 and 2 of the Pascagoula and Hattiesburg Formations is a soft, sodium bicarbonate type. Samples of water from these formations have concentrations of dissolved solids less than 200 mg/l and in developed wells generally less than 100 mg/l. Water temperatures range from 23 to 26°C.

Water in the Citronelle Formation, terrace deposits, and alluvium is a soft, sodium bicarbonate type. Dissolved solids usually range from 13 to 40 mg/l, although the water in an open or exposed type of well may have a dissolved-solids content of more than 100 mg/l. Some iron problems occur locally because of the low pH of the water and the consequent corrosive effect on well screens and casings as well as the metal of the water distribution system. Although some of the iron is from the aquifer, most is from the plumbing systems. By use of all-plastic systems, the iron problems can be reduced. Water temperature is about 19°C.

Water in the calcite caprock is saline and is a calcium sulfate type. Water from HT-3 has a dissolved-solids content of 2,530 mg/l, a calcium content of 465 mg/l, and a sulfate content of 1,260 mg/l. Sodium and chloride have the next highest concentrations. Water from the Station 3 Vent hole, finished in the salt stock, increased in mineralization and changed to a sodium chloride type as the water moved from the caprock, dissolved the salt around the casing and grout, and entered the hole. The dissolved-solids content is about 320,000 mg/l, the sodium content is 118,000 mg/l, and the chloride content is 189,000 mg/l. Water from the calcite caprock has a temperature of about 36°C.

CHAPTER 5

WATER-LEVEL FLUCTUATIONS

The 30 observation wells that have been used for long-term water-level measurements in the Tatum dome area are listed by aquifer in table 5.1

Wells HT-1 and HT-2, drilled in 1961, are screened in three different aquifers by the use of three separate strings of pipe. Wells HT-1a, 1b, 2a, and 2b were drilled in conjunction with wells HT-1 and HT-2. HT-2c was constructed as a water well by the drilling company for its use during drilling of other wells and was later obtained by the Atomic Energy Commission. In 1963, wells E-1, E-7, and E-9 were converted to U.S. Geological Survey observation wells. In the same year, five new wells (HT-3 through HT-7) were drilled so that each of the major artesian aquifers overlying the salt stock were tapped by a well. Station 3 Vent was obtained as an observation well because caprock fluid flooded the hole and thus defeated the original purpose of the well. Hydrographs of various wells terminate before 1967 because the wells were either sealed or used for other types of studies. The water-level observation program was reduced in 1967 to the measurement of wells in a sand aquifer of Miocene age and the caprock aquifer.

Table 5.1. Designation of aquifers and observation wells in the Tatum salt dome area.

Water-bearing unit	Observation wells
Surficial aquifers	F35-1, J10-2, J15-7, J16-12, J22-4, J27-5, J34-1, J34-11, K17-2, K30-3
Miocene age sediments (Local)	HT-2c
Miocene age sediments (Aquifer 1)	HT-4
Miocene age sediments (Aquifer 2)	HT-1a
Miocene age sediments (Aquifer 2a)	HT-1b, HT-2a, HT-2b, HT-5
Miocene age sediments (Aquifer 2b)	HT-6
Miocene age sediments (Aquifer 3)	HT-1(3)
Miocene age sediments (Aquifer 3a)	HT-2(3), E-1, HT-7
Vicksburg Group (Aquifer 4)	HT-1(4), HT-2(4)
Cook Mountain Limestone (Aquifer 5)	HT-1(5), HT-2(5)
Caprock aquifer	HT-3, E-7, E-9, Station 3 Vent

5.1 COOK MOUNTAIN LIMESTONE (AQUIFER 5)

Since the beginning of measurements in 1961 the water levels of Aquifer 5 have risen in both HT-1(5) and HT-2(5) (fig. 5.1). This rise is a reflection of brine injection into the aquifer in the vicinity of the Baxterville oil field about 6 miles southwest of the Tatum salt dome.

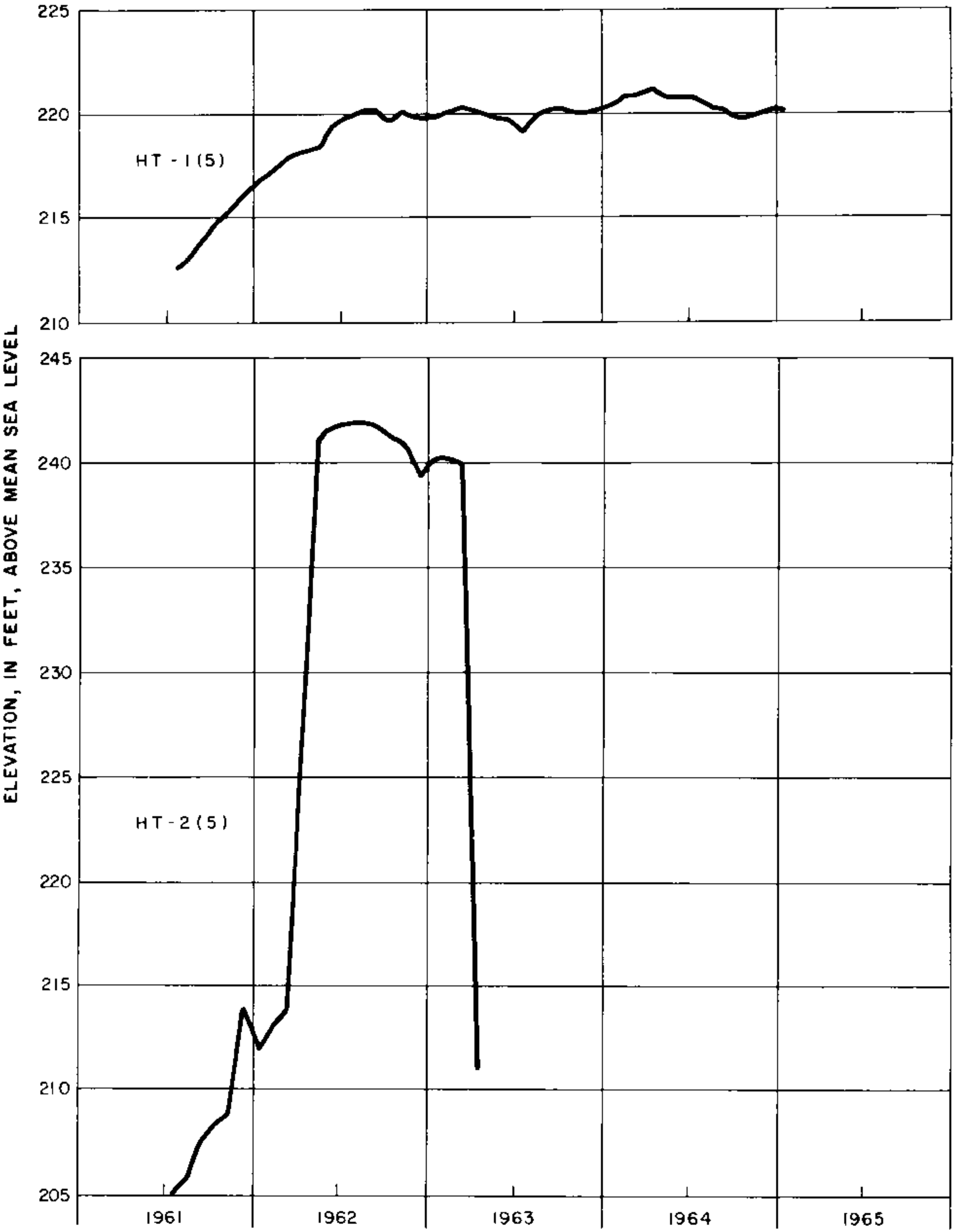


Figure 5.1 Hydrographs for wells HT-1(5) and HT-2(5) in the Cook Mountain Limestone (Aquifer 5).

The two noticeable water-level rises on the HT-2(5) hydrograph are the result of injecting a less dense fluid into the well. Early in 1963, the well was pumped, changing the character of the fluid in the well bore. HT-2(5) was then converted into a disposal well for various test site wastes. The water level in HT-1(5) was measured until the well was changed from an observation well into a water-sampling well after the first nuclear test (Salmon Event) in late 1964.

5.2 VICKSBURG GROUP (AQUIFER 4)

The water levels of Aquifer 4 in HT-1(4) and HT-2(4) did not represent a true aquifer head before February 1963 for HT-1(4) and April 1962 for HT-2(4) (fig. 5.2). Water-level variations before those dates resulted from differences in fluid densities caused by variations in chemical and physical constituents and temperatures in the well bore that differed from those of the formation water. This is especially evident in the water-level record at HT-1(4), which was pumped sufficiently in early 1963 to rid the well of much non-formation water. Water is not injected into or withdrawn from this aquifer in or near the Tatum dome area, except at the test site. The temporary water-level decline observed at HT-1(4) in 1965 was due to the pumping and sampling program at the test site following the Salmon Event. Neither the Salmon Event nor the Sterling Event had any permanent effect on the water levels of Aquifer 4 in wells HT-1(4) and HT-2(4). The water-level decline recorded in Aquifer 4 may be explained by the withdrawal of water from Aquifer 3b (and the Miocene aquifer system throughout the region) and the caprock aquifer, both of which are hydraulically connected with Aquifer 4. The average water-level decline of Aquifer 4 at the Tatum salt dome is 0.5 foot per year.

5.3 MIOCENE AGE SEDIMENTS (AQUIFERS 3, 2, 1, AND LOCAL)

Aquifer 3 (fig. 5.3) has been subdivided in the Tatum dome area into the previously described Aquifer 3a and the underlying Aquifer 3b. Only well HT-1(3) is open to Aquifer 3b, and the pumping test indicated that this aquifer contributed little water to well HT-1(3) and thus is of minor importance. Consequently, the next well, HT-2(3), was completed only in Aquifer 3a. Aquifer 2 (figs. 5.4 and 5.5) has been subdivided into Aquifer 2a and the underlying Aquifer 2b. Wells HT-1b, HT-2a, HT-2b, and HT-5 are finished in Aquifer 2a. Aquifers 2 and 1 were hydraulically tested in test holes HT-1 and HT-2 before the holes were completed in other aquifers. Only well HT-6 was completed in Aquifer 2b, and well HT-1a was completed in both Aquifers 2a and 2b. HT-4 is the only well completed in Aquifer 1.

The water-level rise in well HT-1(3) (1963) and in well HT-2(3) (1962) is the result of cleaning the drilling fluids by pumping the wells. Water levels after these rises probably represent the true head of Aquifer 3. The decline of water level in well HT-2(3) during 1965 is the result of the pumping and sampling program following the Salmon Event. The Salmon and Sterling Events had no permanent effect on the water levels

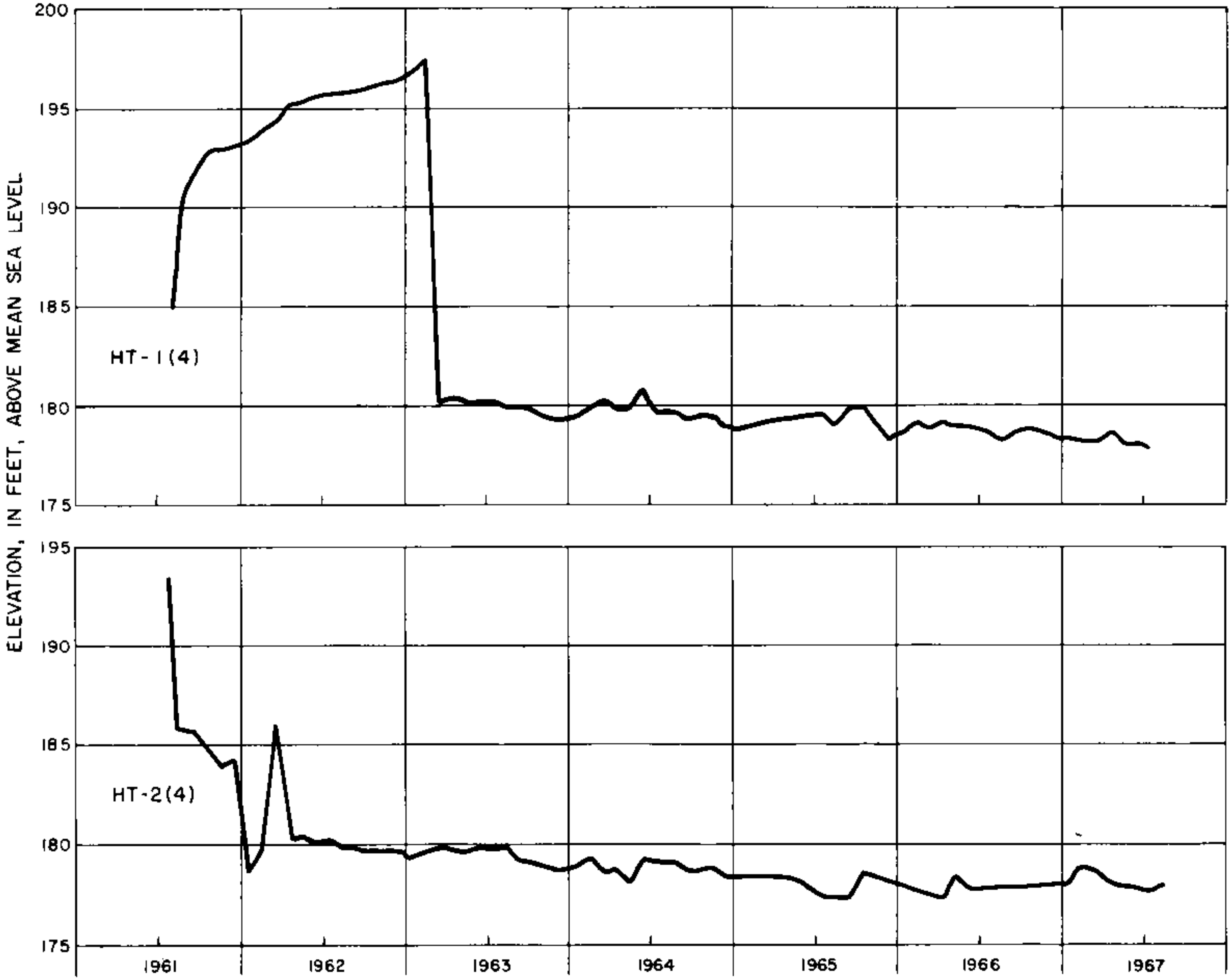


Figure 5.2 Hydrographs for wells HT-1(4) and HT-2(4) in the Vicksburg Group (Aquifer 4).

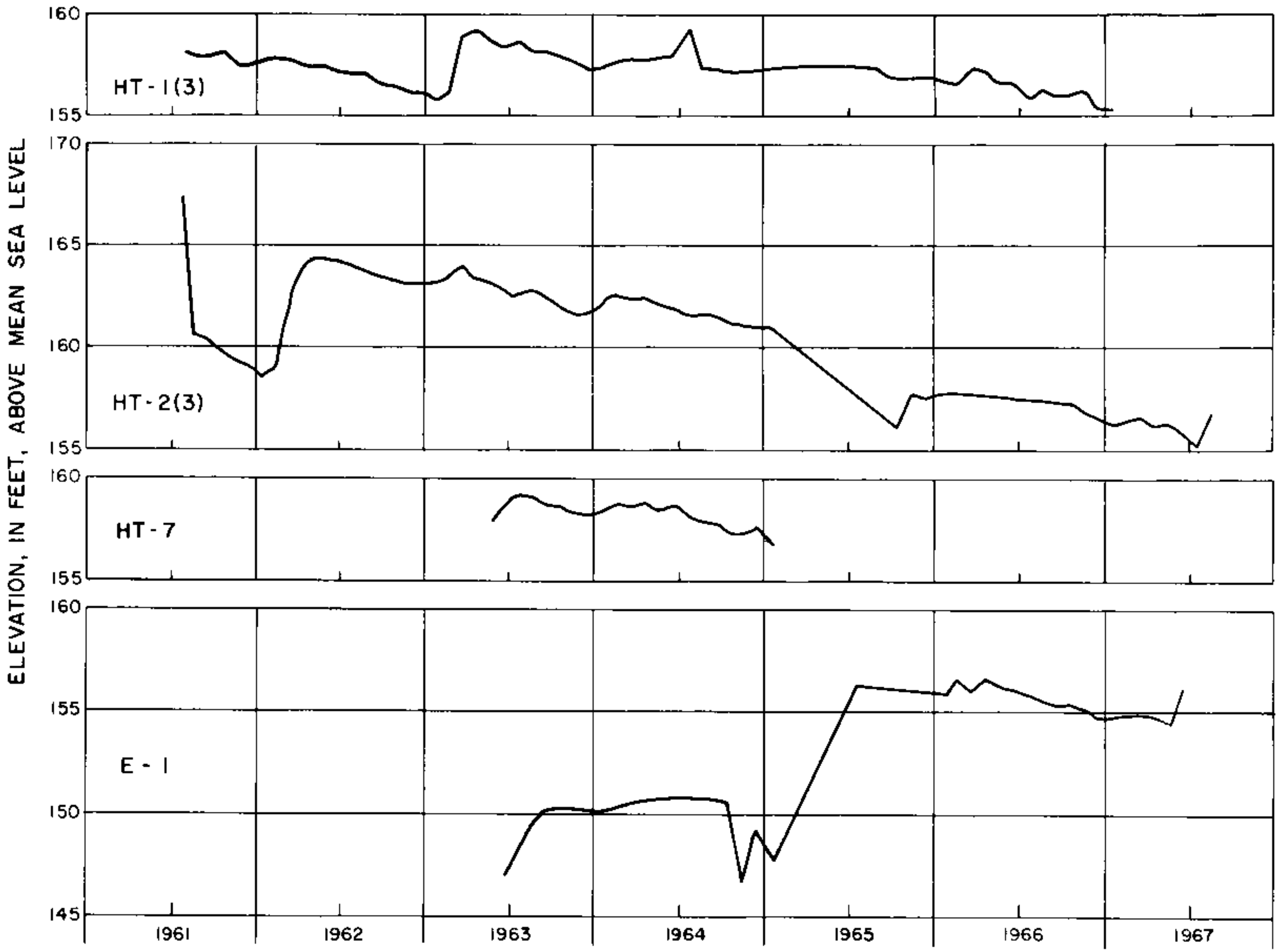


Figure 5.3 Hydrographs for wells HT-1(3), HT-2(3), HT-7, and E-1 in the Catahoula Sandstone (Aquifer 3).

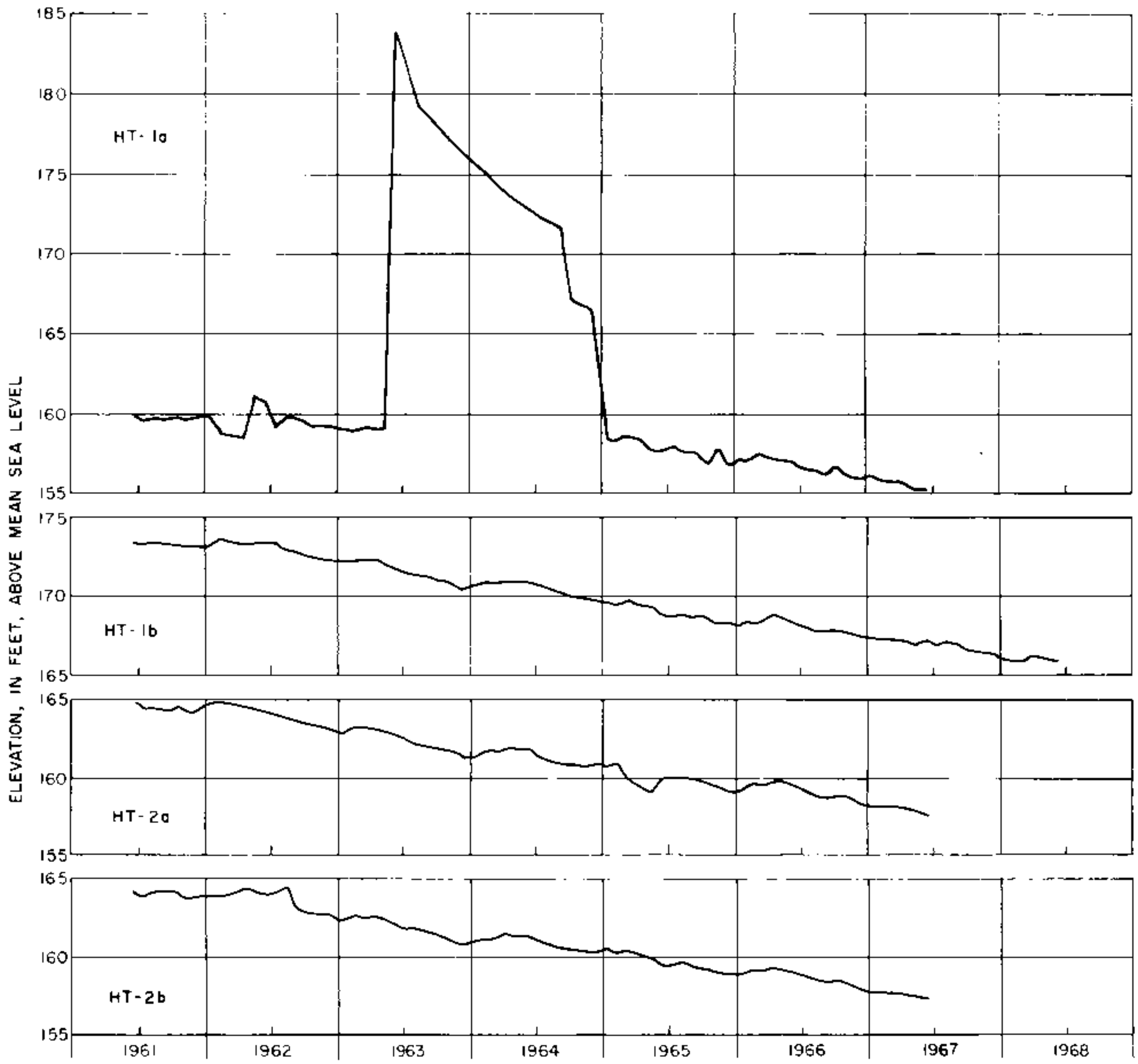


Figure 5.4 Hydrographs for wells HT-1a, HT-1b, HT-2a, and HT-2b in the Pascagoula and Hattiesburg Formations (Aquifer 2).

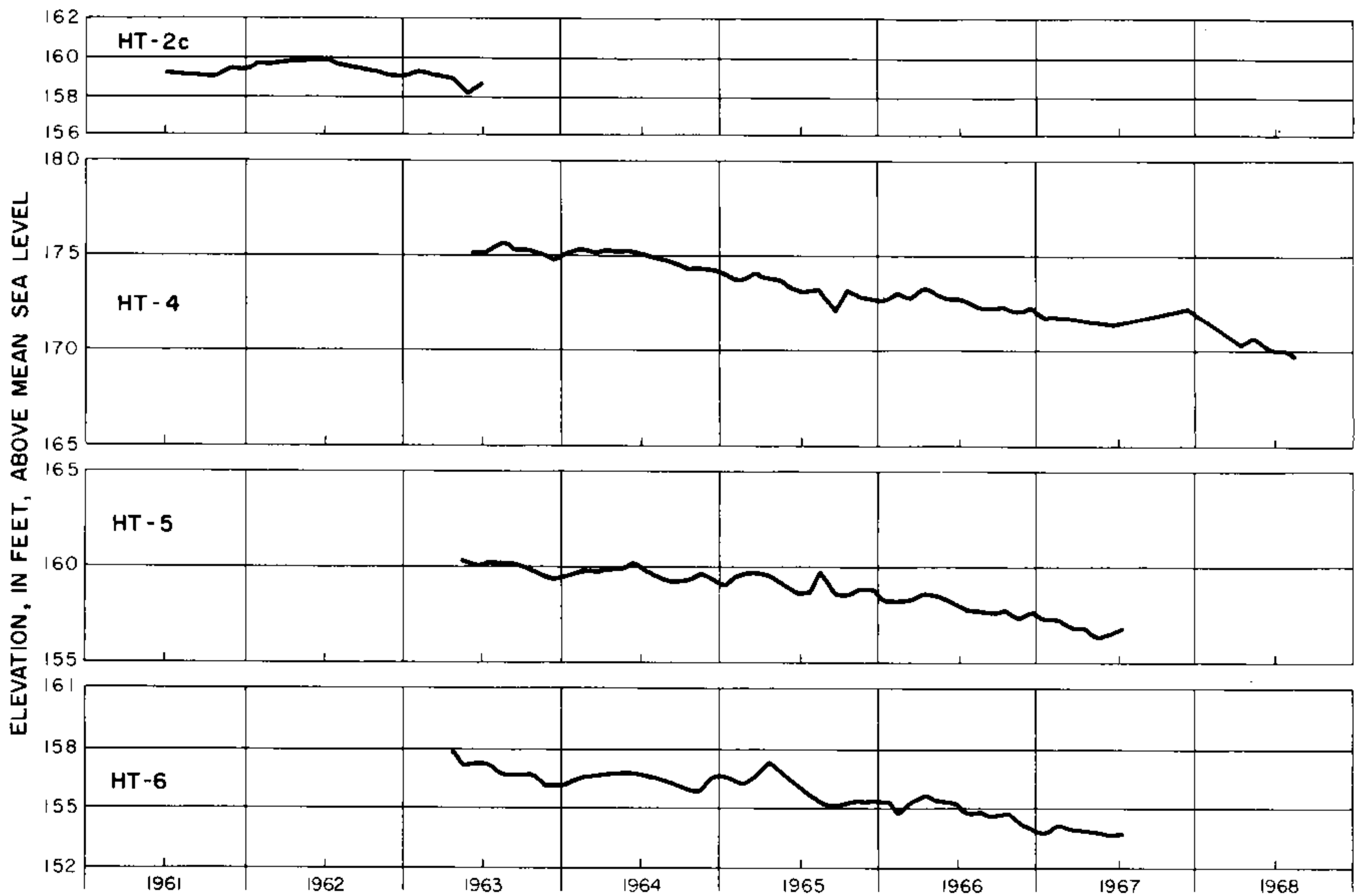


Figure 5.5 Hydrographs for wells HT-2c, HT-4, HT-5, and HT-6 in the Pascagoula and Hattiesburg Formations (local aquifer, Aquifers 1 and 2).

in wells HT-1(3) and HT-2(3). The water levels in HT-7 and E-1 rose and remained 1 and 3 feet higher, respectively, after the Salmon Event. Posttest water levels probably represent true formation head, which had been depressed because of drilling fluid and pretest pumpage. The average water-level decline of Aquifer 3 at the Tatum dome is about 1 foot per year. Temporary water-level decline in 1965 at well HT-2(3) is the result of the pumping and sampling program.

The water-level anomaly of Aquifer 2 in well HT-1a, recorded during 1963 and 1964, is a result of the injection and removel of water from the well. If the anomaly is ignored, the general water-level trend can be followed to June 1967. Although the hydrograph shows an annual cyclic trend, the basic water-level trend is a decline of about 1 foot per year. The Salmon and Sterling Events had no permanent effect on the water levels in wells finished in Aquifer 2.

The water-level fluctuation of Aquifer 1 in well HT-4 shows a decline similar to the other sand aquifers of Miocene age. The Salmon and Sterling Events had no permanent effect on the water level in well HT-4.

The water level of the local aquifer was measurable only in well HT-2c. Since this aquifer is also of Miocene age, the water-level fluctuations would probably be similar to those of Aquifers 1, 2, and 3.

5.4 SURFICIAL AQUIFER

Water-level fluctuations of 10 observation wells in the surficial aquifer are shown in figures 5.6 to 5.8. The

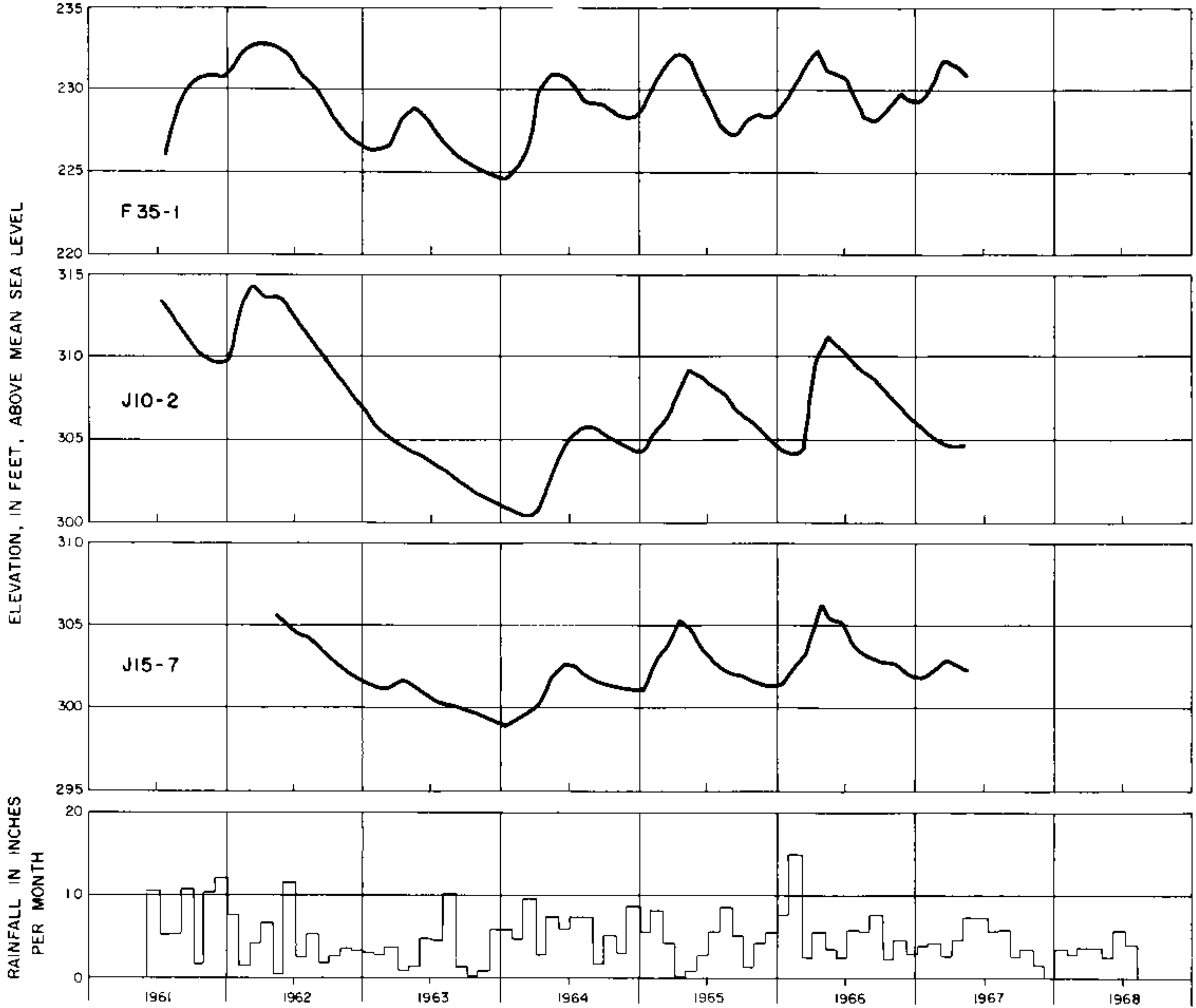


Figure 5.6 Area precipitation and hydrographs for wells F35-1, J10-2, and J15-7 (surficial aquifer).

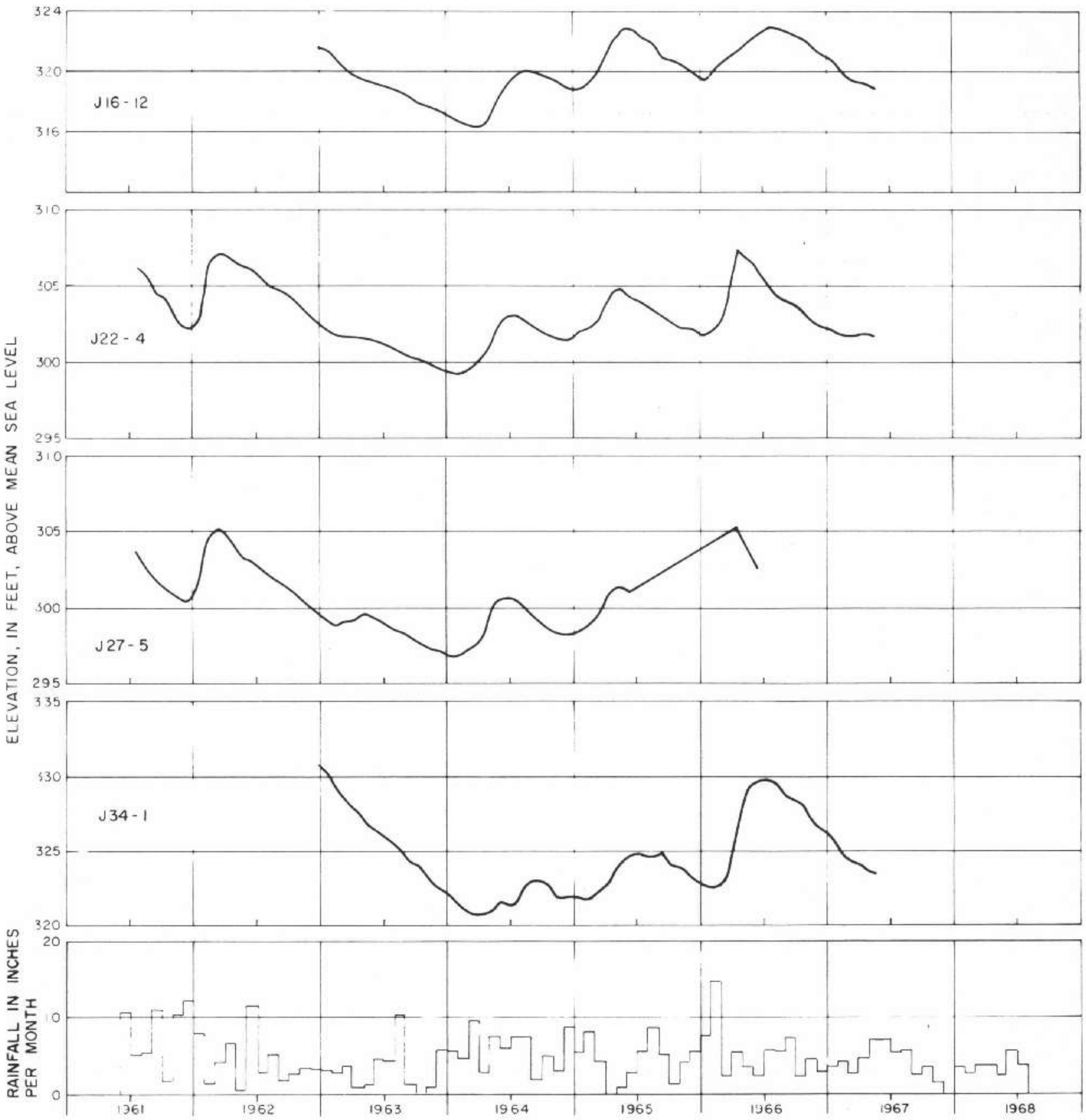


Figure 5.7 Area precipitation and hydrographs for wells J16-12, J22-4, J27-5, and J34-1 (surficial aquifer).

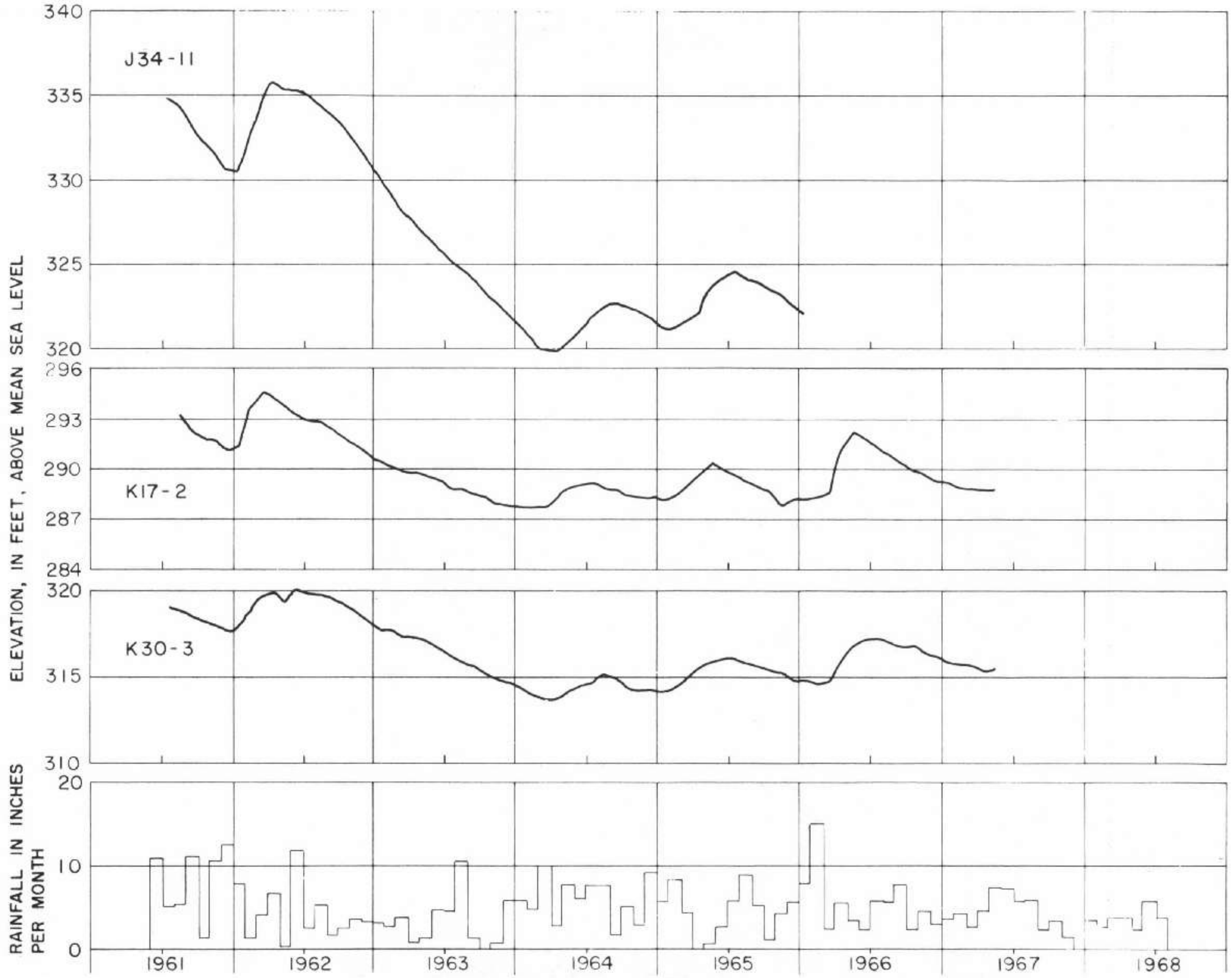


Figure 5.8 Area precipitation and hydrographs for wells J34-11, K17-2, and K30-3 (surficial aquifer).

fluctuations show an annual cyclic trend. In 1963, the water-level cyclic trend was either absent, as in wells J10-2 and J34-11, or barely evident, as in wells J15-7 and J22-4. The 1963 water-level recovery in well F35-1 is evident because the well is in bottomland and the water level is shallow.

Water-level fluctuations in the surficial-aquifer wells are a direct result of local rainfall and recharge. Most of the recharge to the surficial aquifer occurs in the months of December, January, February, and March when rainfall is steady, temperature is low, cloud coverage is great, and plants are dormant. Heavy rainfall that occurs sporadically in summer does not contribute as much water because of evapotranspiration and runoff. At higher elevations wells are deeper in the surficial aquifer and have greater water-level fluctuations, greater tendency to follow seasonal fluctuation as opposed to weekly or monthly fluctuation, and greater lag time when alternating the direction of fluctuation, than the shallow bottomland wells. The highest water levels during the period of recorded data for most of the wells occurred in early 1962, although some wells attained a similar or higher water level in 1966. Rainfall was deficient in 1962 and 1963 but excessive in 1964. Rainfall during the winters of 1964-65 and 1965-66 was sufficient for the water levels to recover so that the water level of each succeeding year (1964-66) was higher than the preceding year. Rainfall for the winter of 1966-67 was not enough for a significant water-level recovery early in the year as expected with the annual cyclic trend. The Salmon and Sterling Events had no permanent effect on water levels in the surficial aquifer.

5.5 CALCITE CAPROCK AQUIFER

Water-level fluctuations of the caprock aquifer are best indicated by the hydrographs for wells E-7 and HT-3 (figs. 5.9 and 5.10). The general water-level trend has been downward at a rate of about 1 foot per year. The water level in well E-9 did not represent true aquifer head until after reworking and clean up in 1963, after which the water level declined similarly to that in wells E-7 and HT-3. In Station 3 Vent the water level is greatly depressed because of the high density of the water. The general water level rise in Station 3 Vent probably is caused by a change in water character--a combination of settling out of suspended matter and accumulation of rainwater.

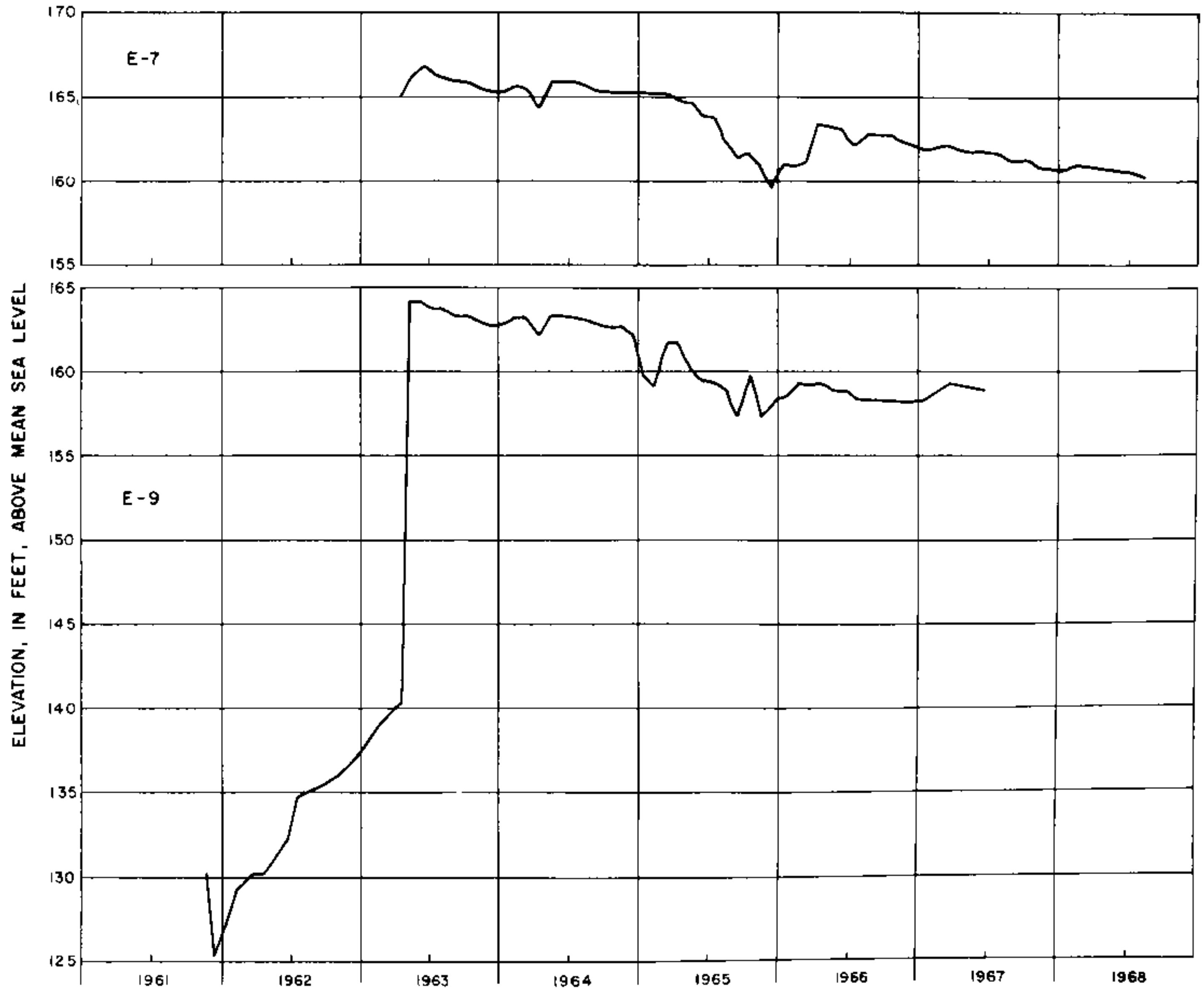


Figure 5.9 Hydrographs for wells E-7 and E-9 (calcite caprock aquifer).

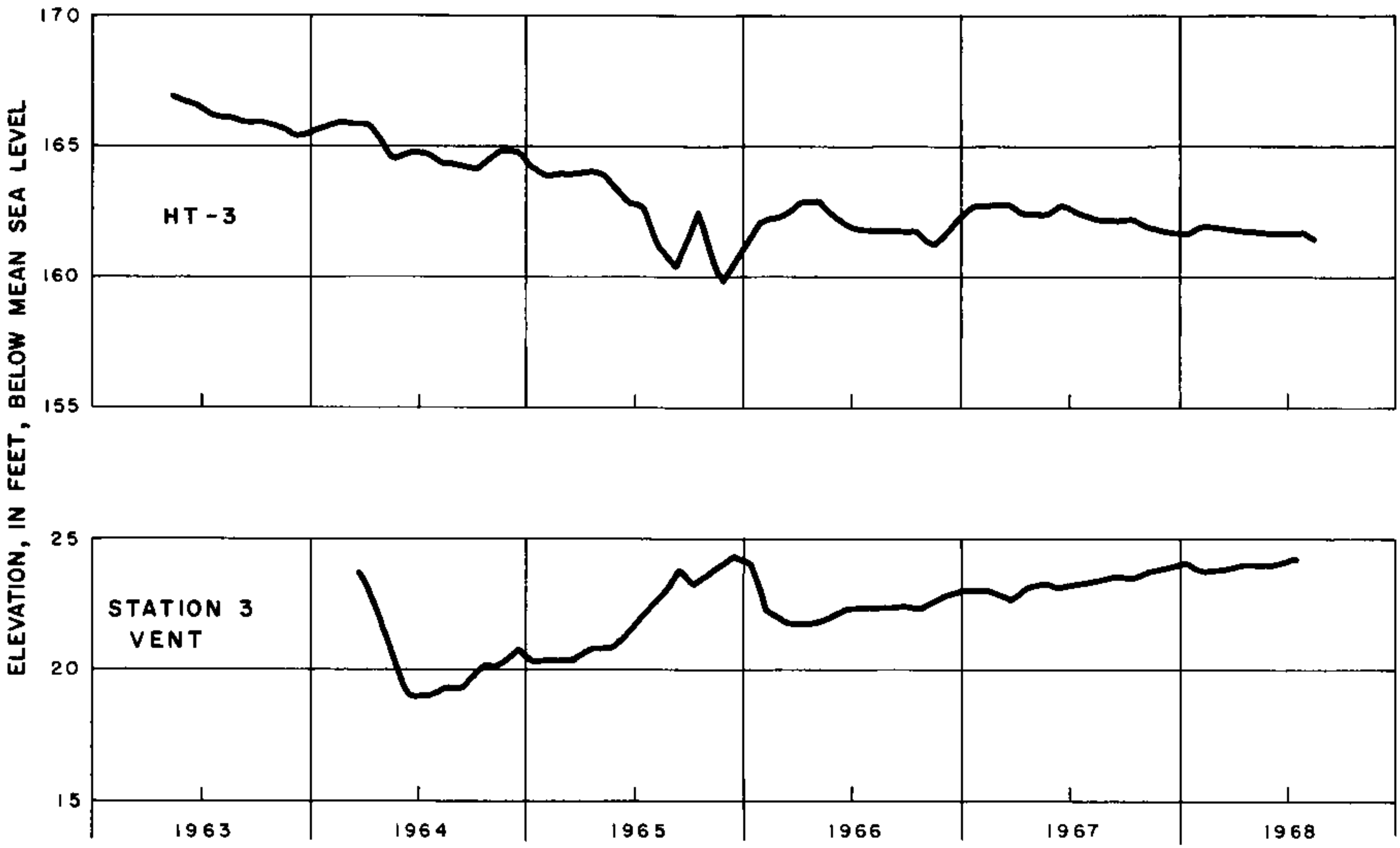


Figure 5.10 Hydrographs for wells HT-3 and Station 3 Vent (calcite caprock aquifer).

CHAPTER 6

HYDRAULIC CHARACTERISTICS

Results of 16 pumping tests, conducted from 1961 to 1967, are summarized in table 6.1. The hydraulic characteristics of Aquifer 5 were calculated from U.S. Bureau of Mines data and are included. When wells HT-1 and HT-2 were drilled, casing was installed and cemented, and each aquifer was tested by gun perforating the casing adjacent to the aquifer, pumping the well between packers, and proceeding to the next higher aquifer. After these tests were completed, the perforations connecting Aquifers 1 and 2 with the test holes were cemented shut and the test holes were completed in Aquifers 3, 4, and 5 using multiple-casing strings. The other aquifer tests were conducted with the completed multiple-casing well open to a specific aquifer. Thicknesses of clay beds in the aquifer and sand beds not connected with the producing interval were subtracted from the total aquifer thickness to obtain the effective aquifer thickness.

Some of the test results may not represent true aquifer characteristics due to: (1) partial development of the aquifer interval, (2) excessive discharge of sand, (3) sand filling the casing and thus decreasing the effective perforated interval, (4) cement partially sealing the aquifers, especially the

Table 6.1. Aquifer and well characteristics.

Aquifer	Well	Depth (ft)	Effective aquifer thick-ness (ft)	Hydraulic coefficients: Transmiss-ivity (gpd per ft)	Hydraulic coefficients: Perme-ability (gpd per sq ft)	Specific capacity (gpm per ft at end of 1 day)	Pumping rate (gpm)
Surficial	J136	200	103	[a]100,000	970	6.2	171
Local	HT-2c	366	45	45,000	1,000	1.4	27
1	HT-1(1)	782	55	4,500	82	1.8	75
	HT-2(1)	820	100	5,600	56	4.8	91
	HT-4	474	95	18,300	195	.9	125
2a	HT-2(2)	1,000	170	[b]166,000	970	55	182
	HT-5	680	85	80,000	940	3	250
2b	HT-1(2)	1,130	80	[b]70,000	875	3.8	225
	HT-6	762	45	26,000	580	1	100
3a	HT-1(3)	1,310	95	6,900	73	4.3	160
	HT-2(3)	1,400	195	13,800	71	4.8	75
	HT-7	860	35	71	2	.2	26
4	HT-1(4)	1,880	215	7,000	33	1.5	157
	HT-2(4)	1,959	150	8,300	55	2.5	95
5	HT-1(5)	2,420	150	[c]1,500	10	--	--
	HT-2(5)	2,616	200	[c]2,000	10	--	--
Caprock	HT-3	1,040	105	[d]8,000	76	.8	150
	E-14b	1,025	84	[d]7,000	83	50	52

a Probably combination of Citronelle Formation and underlying Miocene sedimentary rocks.

b Coefficient of storage is 2.9×10^{-4} for HT-1(2) and 3.0×10^{-4} for HT-2(2).

c Calculated from U.S. Bureau of Mines data (Riggs, Heath, and Ward, 1962).

d Coefficient of storage is 1×10^{-4} for HT-3 and 6×10^{-5} for E-14b.

limestones in Aquifer 4, and (5) effects of gases in the water.

The low transmissivity of Aquifer 1 is a result of the fine sand and clay associated with this aquifer. The low transmissivities computed from tests at other wells may be due to underdevelopment as a result of retention of drilling mud and fine sediments in an aquifer. An example of extreme underdevelopment of a well is HT-5 (Aquifer 2a). A pumping test in 1963 indicated a transmissivity of about 10,000 gpd (gallons per day) per foot. In 1965 the well was acidized and a second pumping test indicated a transmissivity of 80,000 gpd per foot. The pumping test at well HT-1(2) suggests that only the lower part of Aquifer 2 was effectively open and that the transmissivity shown in table 6.1 represents only Aquifer 2b. If a well were open to all of Aquifer 2, test data indicate that the transmissivity would be more than 200,000 gpd per foot. Possible explanations for the lower permeability for Aquifer 2b at well HT-6 than at well HT-1(2) are that well HT-6 is finished in finer-grained sediments and is not fully developed. Aquifer 3a is very poor (fine-grained, lignitic sediments) at well HT-7, and the well did not produce much water.
Both conditions contributed to the extremely low transmissivity indicated by the pumping test. Aquifer 3b reportedly did not produce water during an attempted pumping test at well HT-1(3). The cause of the difference in permeability for Aquifer 4 at wells HT-1(4) and HT-2(4) is that the perforations are in different intervals in the test wells. The U.S. Bureau of Mines determined from field and laboratory studies that the average

hydraulic conductivity of Aquifer 5 is approximately 10 gpd per square foot. The transmissivity determined in the pumping tests of wells HT-1(5) and HT-2(5) were obtained by multiplying this average hydraulic conductivity by the aquifer thickness at the respective well.

Transmissivities of 7,000 and 8,000 gpd per foot were obtained from two pumping tests of the calcite caprock aquifer. However, there are conflicting results and disagreement on the hydraulic characteristics of this aquifer, and the test results shown in table 6.1 represent minimum values. The specific capacity of 50 gpm (gallons per minute) per foot of drawdown, observed in the test of well E-14b, indicates a transmissivity greater than 100,000 gpd per foot, provided that the effective diameter of the well was the diameter shown by the well record. Fractures and brecciated zones (some filled with sedimentary rocks of Miocene age), solution cavities (including a 9-foot hole at well HT-3), and all the fluid and solids lost in the calcite caprock indicate that this aquifer should have a transmissivity greater than the values in table 6.1. However, the heterogeneous nature of the calcite caprock indicates that the expected high hydraulic values are only local and that the pumping test results represent the average values for the aquifer.

Pumping test at the four closely spaced wells (HT-4 through HT-7) showed hydraulic communication between the aquifers. Pumping from one aquifer caused drawdown in the water level of the other aquifers.

CHAPTER 7

GROUND-WATER MOVEMENT

The regional trend of ground-water movement is down-dip, or to the southwest. This trend has been modified locally in the Tatum dome area for the water in the aquifer of the Cook Mountain Limestone and the principal aquifers of Miocene age. The water levels in the major aquifers at the dome are depicted in figure 7.1 and a summary of water movement is presented in table 7.1. Locally, the direction of water movement can be determined only approximately, because good data are limited. Early data were not necessarily representative of actual conditions, because the wells had not been adequately developed. Most of the measurements used for the following calculations of water movement were made in 1965 and 1966, after the wells had been pumped extensively.

Injection of brine into the Cook Mountain Limestone (Aquifer 5) has locally modified the movement of ground water. The water level is higher in well HT-1(5) than in well HT-2(5) after density correction is applied for the difference in brine concentrations. The wells are miles up-dip from the brine injection site but the pressure is insufficient at the dome to cause the water to move in a northeasterly direction in the vicinity of Tatum salt dome at this time.

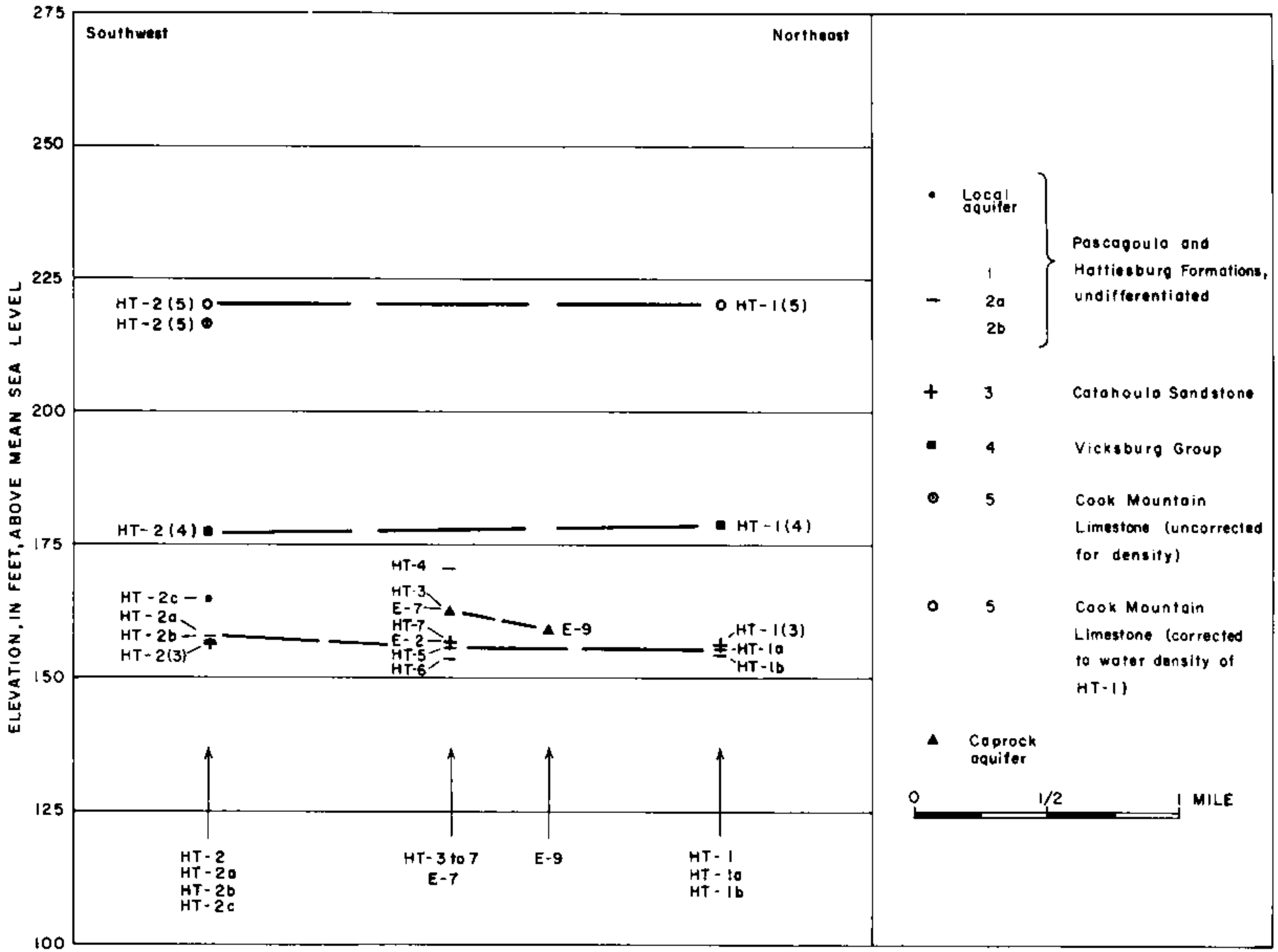


Figure 7.1 Water levels in the major aquifers at Tatum salt dome.

Table 7.1. Rate and direction of ground-water movement.

Aquifer	Coefficient of permeability (gpd per sq ft)	Hydraulic gradient (ft per ft)	Effective porosity (percent)	Rate of water movement		Direction of movement
				(ft per day)	(ft per year)	
1 1/	56	0.0004	30	0.01	4	southwest
2a	940	.0001	30	.04	15	northeast
3a	71	.00002	30	.0002	.07	Do.
4	33	.00002	25	.0004	.1	southwest
5	10	.00005	25	.0003	.09	Do.

1/ From water level measurements taken prior to completion of test holes HT-1 and HT-2 in 1963.

Water in the Vicksburg Group (Aquifer 4) follows the regional trend of movement to the southwest. The water density is similar at wells HT-1(4) and HT-2(4), so that a density correction is not needed.

Direction of ground-water movement in the Catahoula Sandstone (Aquifer 3) is to the northeast. The data presented have not been corrected for density. If a density correction was applied, it would merely indicate an increase in the rate of water movement to the northeast.

Water in the Pascagoula and Hattiesburg Formations, undifferentiated, (Aquifer 2), is moving either eastward or northeastward against the regional trend. The cause of the high water level in well HT-1b is unknown, and the water level is not used in the calculations.

The direction of water movement in the same formations for Aquifer 1 probably follows the regional southwesterly trend.

Withdrawal from this aquifer has not been sufficient to reverse the direction of movement as have the heavy withdrawals of water from the deeper aquifers of Miocene age to the east and northeast.

Only one well is finished in the local aquifer of Miocene age; therefore, the direction and rate of water movement is unknown. However, as this aquifer is not extensively used as a source of water, the direction of water movement is probably southwestward.

Water in the caprock aquifer is moving eastward. However, because of the head difference between the caprock aquifer and Aquifer 3a, more water is probably moving upward into the overlying rocks than laterally in the caprock.

CHAPTER 8

NUCLEAR-TEST EFFECTS

8.1 WATER WELLS

Water wells have been inventoried in and beyond the Tatum dome area since 1961 (fig. 8.1). Inventories of all water wells within a 5-mile radius of the Tatum dome were conducted prior to the Salmon and Sterling Events in order to ascertain the condition of each well, its equipment, and chemical quality of the water before each nuclear detonation. The inventory for the Salmon Event listed 360 wells, and the inventory for the Sterling Event accounted for 46 new or revised water-well systems.

Following the Salmon Event October 22, 1964, a total of 139 inquiries and complaints were filed on 142 wells and 1 spring. The reporting of these complaints was spread over a period of 13 months. Figure 8.2 shows the cumulative increase of complaint reports during the investigative period after the nuclear test. The plot does not represent the actual dates that reports were received but is the cumulative number at the time of a weekly administrative report (usually submitted on Friday). Thus, the reporting date of a complaint is not more than 7 days from the plotted point.

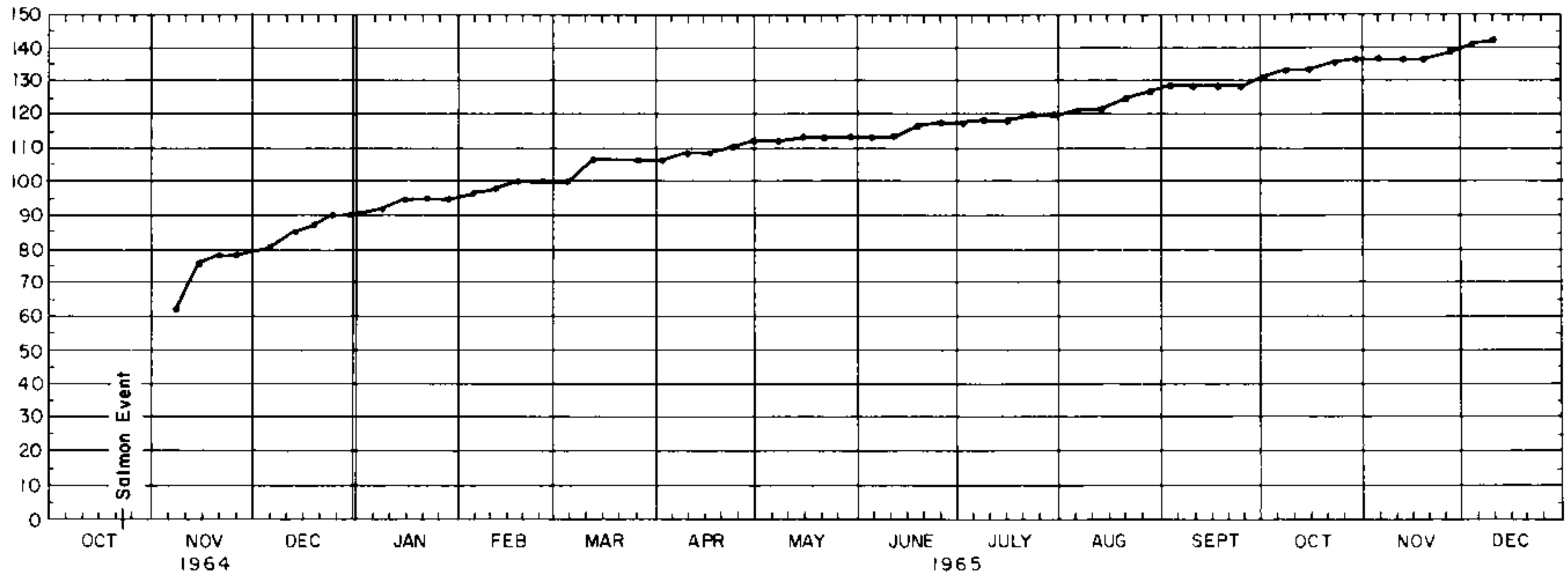


Figure 8.2 Cumulative number of inquiries and complaints on water-supply systems as a result of Salmon Event.

Seventy-six complaints (53 percent of the total) had been reported by November 13, 1964, 22 days after the detonation. Fewer reports were received after November 13, and in 26 of the next 56 weeks no reports were received. Sixty of the 142 wells are within the Tatum dome area and are shown on figure 8.1 as a circle around the well number. The Sterling Event, a detonation on December 3, 1966, had a considerably smaller yield than the Salmon Event and produced only eight water-well complaints. Six of the complaints were received by January 25, 1967, and the last complaint on August 31, 1967. Five of the complaints are in the Tatum dome area and are shown on figure 8.1 as a triangle around the well number.

Atomic Energy Commission-sponsored investigators of water-well complaints after the two nuclear tests found no evidence of direct structural damage to closed wells (closed-well pipe system and screen). The pretest water-well inventory revealed that some wells were already in disrepair. After the test, casing and screen in 44 closed wells (31 percent of all complaints) were removed for inspection. All the wells were in various stages of normal deterioration; namely, rust accumulation in and on well components, corrosion of screen and pipe, sediment accumulation in the screen, and encrustation on the screen. Deterioration through corrosion or encrustation commonly results where an iron pipe and a multimetal sandpoint or screen are immersed in a ground-water environment.

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Eargle, D. H., 1964, Surface and subsurface stratigraphic sequence in southeastern Mississippi: U.S. Geol. Survey Prof. Paper 475-D, p. D43-D47.

Riggs, C. H., Heath, L. J., and Ward, D. C., 1962, Salt Disposal Study, Project Dribble, Tatum Dome area, Lamar County, Miss.: U.S. Bureau of Mines Special Report, 47 p.

TECHNICAL AND SAFETY PROGRAM REPORTS SCHEDULED FOR ISSUANCE BY AGENCIES PARTICIPATING IN PROJECT DRIBBLE

SAFETY REPORTS

Agency	Report No.	Subject or Title
USWB	VUF-1020	Weather and Surface Radiation Prediction Activities
USPHS	VUF-1021	Final Report of Off-site Surveillance
USBM	VUF-1022	Pre and Post-Shot Safety Inspection of Oil and Gas Facilities Near Project Dribble
USGS	VUF-1023	Analysis of Geohydrology of Tatum Salt Dome
USGS	VUF-1024	Analysis of Aquifer Response
REECo	VUF-1025	On-Site Health and Safety Report
RFB, Inc.	VUF-1026	Analysis of Dribble Data on Ground Motion and Containment - Safety Program
H-NSC	VUF-1027	Ground-Water Safety
FAA	VUF-1028	Federal Aviation Agency Airspace Advisory
H&N	VUF-1029	Summary of Pre and Post-Shot Structural Survey Reports
JAB	VUF-1030	Structural Response of Residential-Type Test Structures in Close Proximity to an Underground Nuclear Detonation
JAB	VUF-1031	Structural Response of Tall Industrial and Residential Structures to an Underground Nuclear Detonation.

NOTE: The Seismic Safety data will be included in the USC&GS Technical Report VUF-3014

TECHNICAL REPORTS

Agency	Report No.	Subject or Title
SL	VUF-3012	Free-Field Particle Motions from a Nuclear Explosion in Salt - Part I
SRI	VUF-3013	Free-Field Particle Motions from a Nuclear Explosion in Salt - Part II
USC&GS	VUF-3014	Earth Vibration from a Nuclear Explosion in a Salt Dome
UED	VUF-3015	Compressional Velocity and Distance Measurements in a Salt Dome

LRL	VUF-3016	Vent-Gas Treatment Plant
LRL	PNE-3002 *	Response of Test Structures to Ground Motion from an Underground Nuclear Explosion
SRI	VUF-3017	Feasibility of Cavity Pressure and Temperature Measurements for a Decoupled Nuclear Explosion
LRL	VUF-3018	Background Engineering Data and Summary of Instrumentation for a Nuclear Test in Salt
WES	VUF-3019	Laboratory Design and Analyses and Field Control of Grouting Mixtures Employed at a Nuclear Test in Salt
LRL	VUF-3020	Geology and Physical and Chemical Properties of the Site for a Nuclear Explosion in Salt
EG&G	VUF-3021	Timing and Firing

* This report number was assigned by SAN

In addition to the reports listed above as scheduled for issuance by the Project DRIBBLE test organization, a number of papers covering interpretation of the SALMON data are to be submitted to the American Geophysical Union for publication. As of February 1, 1965, the list of these papers consists of the following:

Title	Author(s)	Agency(s)
Shock Wave Calculations of Salmon	L. A. Rogers	LRL
Nuclear Decoupling, Full and Partial	D. W. Patterson	LRL
Calculation of P-Wave Amplitudes for Salmon	D. L. Springer and W. D. Hurdlow	LRL
Travel Times and Amplitudes of Salmon Explosion	J. N. Jordan W. V. Mickey W. Helterbran	USC&GS AFTAC UED
Detection, Analysis and Interpretation of Teleseismic Signals from the Salmon Event	A. Archambeau and E. A. Flinn	SDC
Epicenter Locations of Salmon Event	E. Herrin and J. Taggart	SMU USC&GS
The Post-Explosion Environment Resulting from the Salmon Event	D. E. Rawson and S. M. Hansen	LRL
Measurements of the Crustal Structure in Mississippi	D. H. Warren J. H. Healy W. H. Jackson	USGS

All but the last paper in the above list will be read at the annual meeting of the American Geophysical Union in April 1965.

LIST OF ABBREVIATIONS FOR TECHNICAL AGENCIES

BR LTD	Barringer Research Limited Rexdale, Ontario, Canada
ERDL	Engineering Research Development Laboratory Fort Belvoir, Virginia
FAA	Federal Aviation Agency Los Angeles, California
GIMRADA	U. S. Army Geodesy, Intelligence and Mapping Research and Development Agency Fort Belvior, Virginia
H-NSC	Hazleton-Nuclear Science Corporation Palo Alto, California
H&N, INC	Holmes & Narver, Inc. Los Angeles, California Las Vegas, Nevada
II	Isotopes, Inc. Westwood, New Jersey
ITEK	Itek Corporation Palo Alto, California
JAB	John A. Blume & Associates Research Division San Francisco, California
LRL	Lawrence Radiation Laboratory Livermore, California
NRDL	U. S. Naval Radiological Defense Laboratory San Francisco, California
REECo	Reynolds Electrical & Engineering Co., Inc. Las Vegas, Nevada
RFB, INC.	R. F. Beers, Inc. Alexandria, Virginia
SDC	Seismic Data Center Alexandria, Virginia
EG&G	Edgerton, Germeshausen & Grier, Inc. Las Vegas, Nevada
SL	Sandia Laboratory Albuquerque, New Mexico
SMU	Southern Methodist University Dallas, Texas
SRI	Stanford Research Institute Menlo Park, California
TI	Texas Instruments, Inc. Dallas, Texas
UA	United Aircraft El Segundo, California
UED	United Electro Dynamics, Inc. Pasadena, California
USBM	U. S. Bureau of Mines Washington, 25, D. C.
USC&GS	U. S. Coast and Geodetic Survey Las Vegas, Nevada
USGS	U. S. Geologic Survey Denver, Colorado
USPHS	U. S. Public Health Service Las Vegas, Nevada
USWB	U. S. Weather Bureau Las Vegas, Nevada

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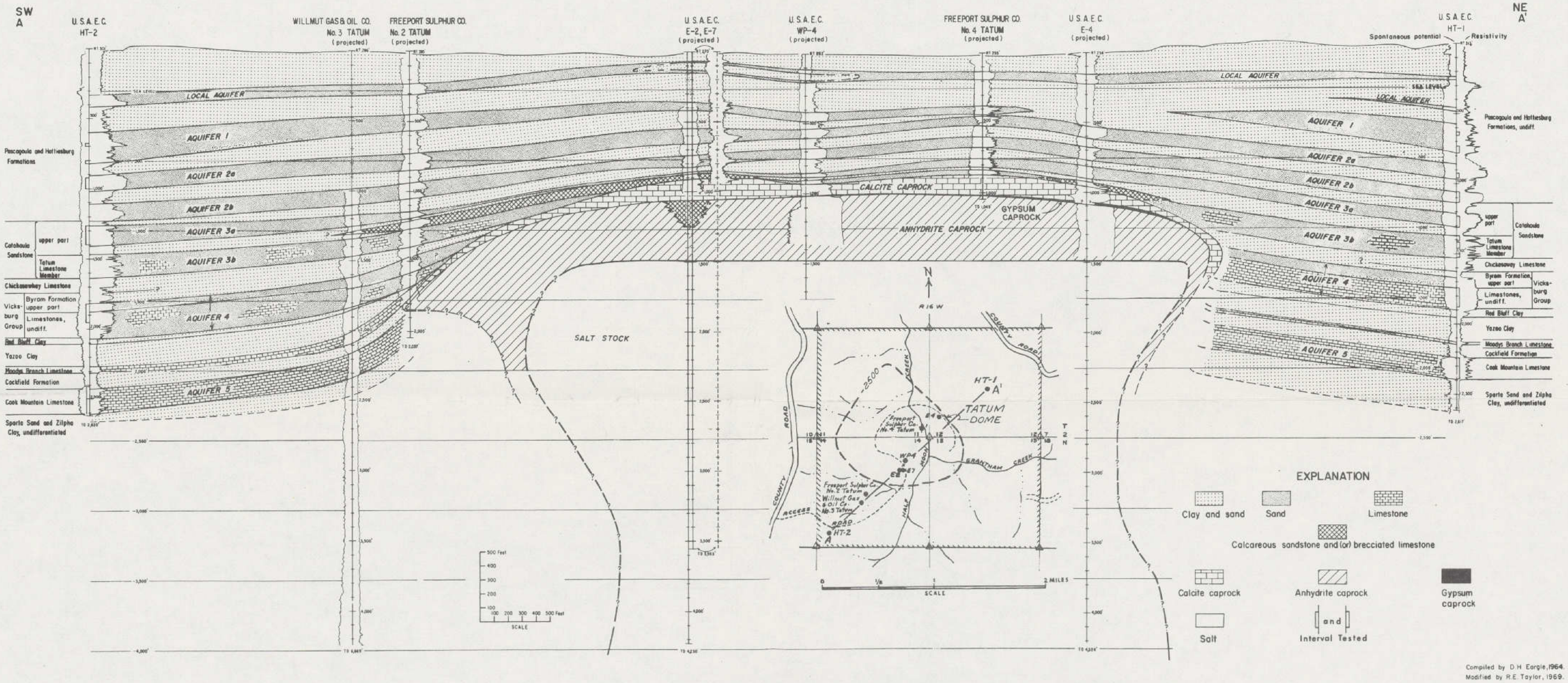
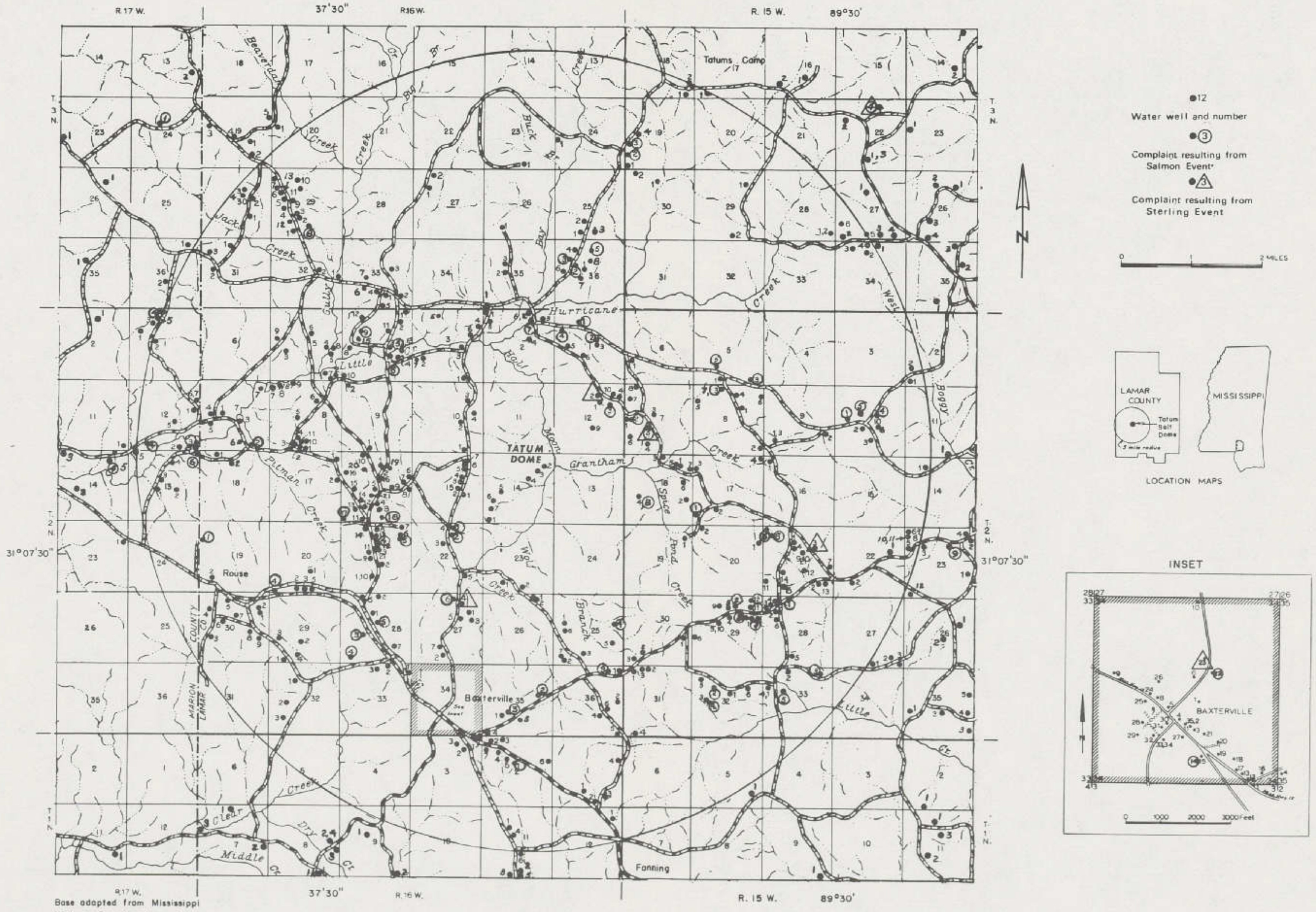


FIGURE 2.1 - SOUTHWEST - NORTHEAST SECTION THROUGH TATUM SALT DOME



Base adapted from Mississippi Highway Department county map, 1960.

Figure 8.1--Water wells in the Tatum salt dome study area.