A PRELIMINARY ASSESSMENT OF LAND-SURFACE SUBSIDENCE IN THE EL PASO AREA, TEXAS

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4155

Prepared in cooperation with the
U.S. BUREAU OF RECLAMATION

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By L.F. Land and C.A. Armstrong

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Austin, Texas

1985

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
649 Federal Building
300 E. Eighth Street
Austin, TX 78701

Copies of this report can
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METRIC CONVERSIONS

For those readers who may prefer to use the International System (SI) of units rather than inch-pound units, the conversion factors for the terms used in this report are given below:

From	Multiply by	To obtain
acre-foot (acre-ft)	0.001233	cubic hectometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer

Milligrams per liter (mg/L): A unit expressing the concentration of a chemical constituent in solution as weight (milligrams) of solute per unit volume (liter) of water. One mg/L equals 1,000 micrograms per liter.

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ABSTRACT

The northeast and southeast parts of the El Paso area are underlain by Hueco bolson deposits as much as 9,000 feet thick. The deposits consist of lenses of gravel, sand, silt, and clay. In the Rio Grande Valley, about 400 to 450 feet of these deposits have been eroded and replaced with as much as 200 feet of alluvium. Ground water in the shallow alluvial aquifer in the Rio Grande Valley and in the Hueco bolson aquifer outside the valley is under water-table conditions, whereas ground water in the bolson aquifer in the valley is under leaky artesian conditions. Maximum water-level declines in the Hueco bolson aquifer are 110 feet east of the Franklin Mountains and 150 feet in the downtown El Paso area. For the shallow aquifer, the maximum declines have been 125 feet in the downtown area. Compressable materials in the freshwater zone of the aquifer range from 50 to 450 feet.

Recharge from the Rio Grande to the shallow alluvial aquifer has increased from an estimated 15,000 acre-feet during 1968 to 30,000 acre-feet during 1983, an increase of about 1,000 acre-feet per year. Leakage from the Rio Grande is expected to continually increase in the near future because of a continued decline in ground-water levels. The amount of leakages from the canals is much less than from the river.

Releveling of bench marks along lines to the northeast and the southeast of the Rio Grande, and along its channel commonly show land subsidence of about 0.2 foot. The maximum measured subsidence is 0.41 foot along the river in the Chamizal zone. No subsidence was detected at the Riverside Diversion Dam. A comparison of subsidence, water-level declines, and clay thickness along the three survey lines shows the expected correlation of greater subsidence with thicker accumulated clay material for a given decline in water levels. The preconsolidation stress was expected to range from 85 to 115 feet of water-level decline on the basis of subsidence studies in Arizona and California. A study of specific-unit compaction along the three survey lines shows that the values usually range between 1.0 to 2.5 x 10^{-5} feet per feet squared. These values are comparable to the ones computed in the Tulare-Wasco, California, and Houston-Galveston, Texas, areas following the exceedance of the local preconsolidation stress. Because of this comparability, the specific-unit compaction for future periods in the El Paso area probably will not increase dramatically when the preconsolidation stress is exceeded, if it has not already been exceeded.

In addition to regional subsidence, local subsidence is indicated by observable surface fractures but has not been verified by precise leveling. These local areas coincide with areas that historically were swamps along the Rio Grande.

INTRODUCTION

Each of the many municipal, industrial, military, and agricultural water users in the El Paso area (fig. 1) is concerned about the continued availability of their freshwater supplies. Often, protecting one user's supply has an adverse effect on another user's supply. The case of interest in this report involves the farmers in the El Paso Valley in their attempt to get a full allocation of Rio Grande water to their fields. The most significant step in approaching this goal is to decrease the losses of the water-delivery system, and the U.S. Bureau of Reclamation is making advanced planning studies to determine the environmental, social, economic, and cultural impacts of: (1) Constructing a 13-mi concrete extension to the present American Canal and reconstructing a 1.4-mi section; (2) discontinuing the use of 5.25 mi of the Franklin Canal; and (3) reconstructing the Ascarate Wasteway as a feeder lateral (fig. 2). The purpose of the actions is to decrease the loss of water by river and canal seepage, and thus to increase the volume of water available for delivery to farmers who are holders of surface-water rights in the Rio Grande. The proposed actions will cause the Rio Grande to have little or no flow between the International and Riverside Diversion Dams, and there is concern that the decreased recharge to the aquifers beneath the river may cause additional declines in ground-water levels that are sufficient to activate local or regional land-subsidence.

Purpose and Scope

Because of concern about increased potential for land subsidence that may result from the proposed changes in the delivery system, the U.S. Geological Survey was asked by the U.S. Bureau of Reclamation to study the effects of such changes on the ground-water system. The Geological Survey proposed a study to accomplish the following objectives: (1) Estimate the quantity of recharge to the ground-water system through seepage from the river and canals; (2) define the thickness of compressible material in the depth interval subject to compaction; (3) determine the magnitude of subsidence, if any, that has occurred; (4) estimate the relationship between the change in water levels and land-surface subsidence; (5) predict water-level changes that would occur with anticipated pumpage, and with and without decreased infiltration from the river and canals; (6) predict subsidence; and (7) describe the possible detrimental effects of subsidence and where they are likely to occur. The study has been divided into two phases. Phase one addresses the first four objectives. Phase two, which will ultimately address the remaining objectives, will require the collection of additional data. This report documents the findings of phase one. Studies needed to document, understand, and predict subsidence are identified at the end of this report and are based on objectives 5-7 and the results of this study.

The study area includes the nonmountainous area north of the Rio Grande near El Paso, Texas (fig. 1). Because of the limited data documenting subsidence in the El Paso area, the conclusions are based mainly on the transfer of data from similar areas where subsidence has occurred, primarily the Houston-Galveston region, Texas, and Arizona and California. The transfer of data from an area with a similar hydrogeologic framework still has considerable uncertainty because of the possibility of a large variation in preconsolidation conditions.

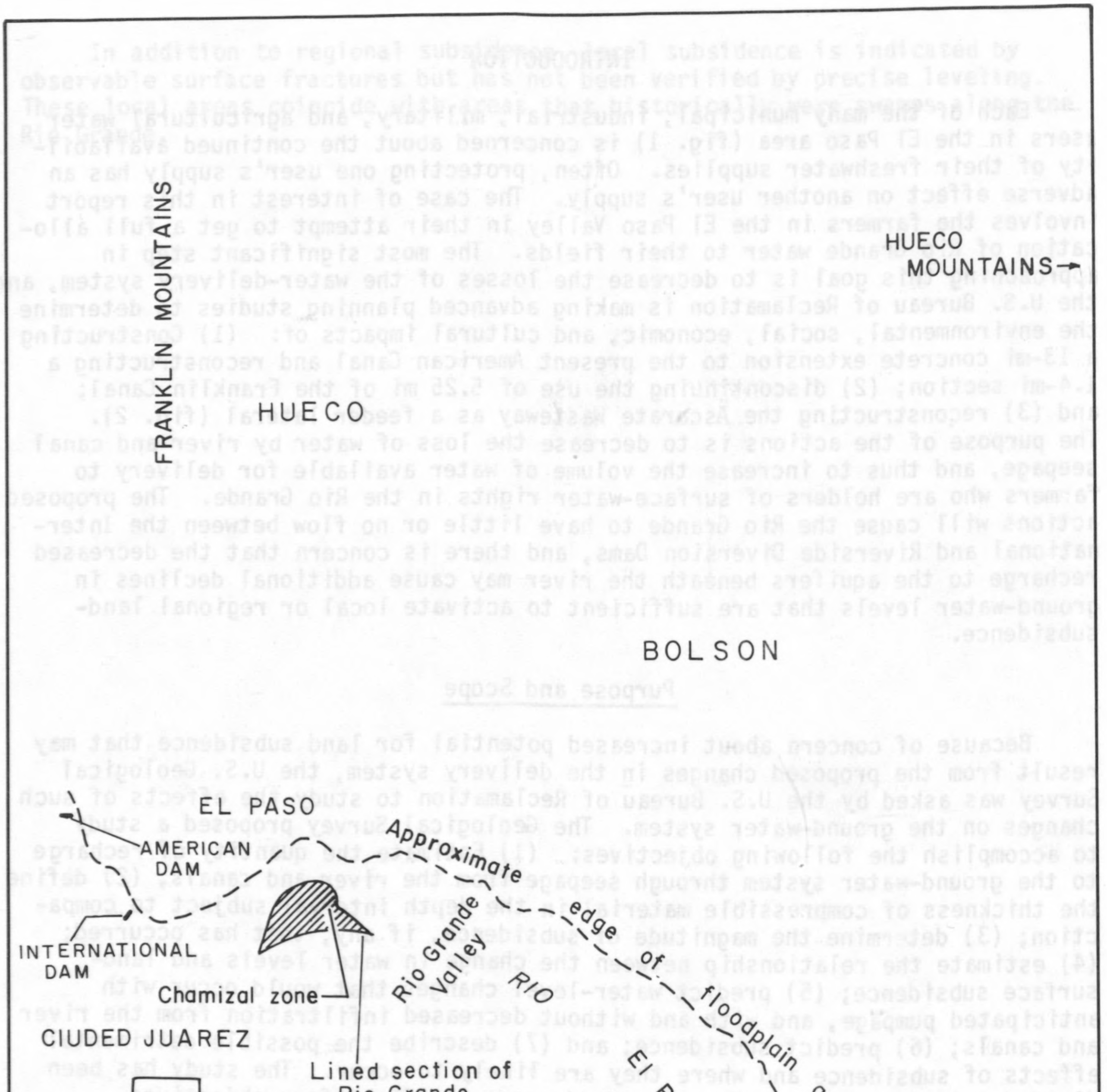
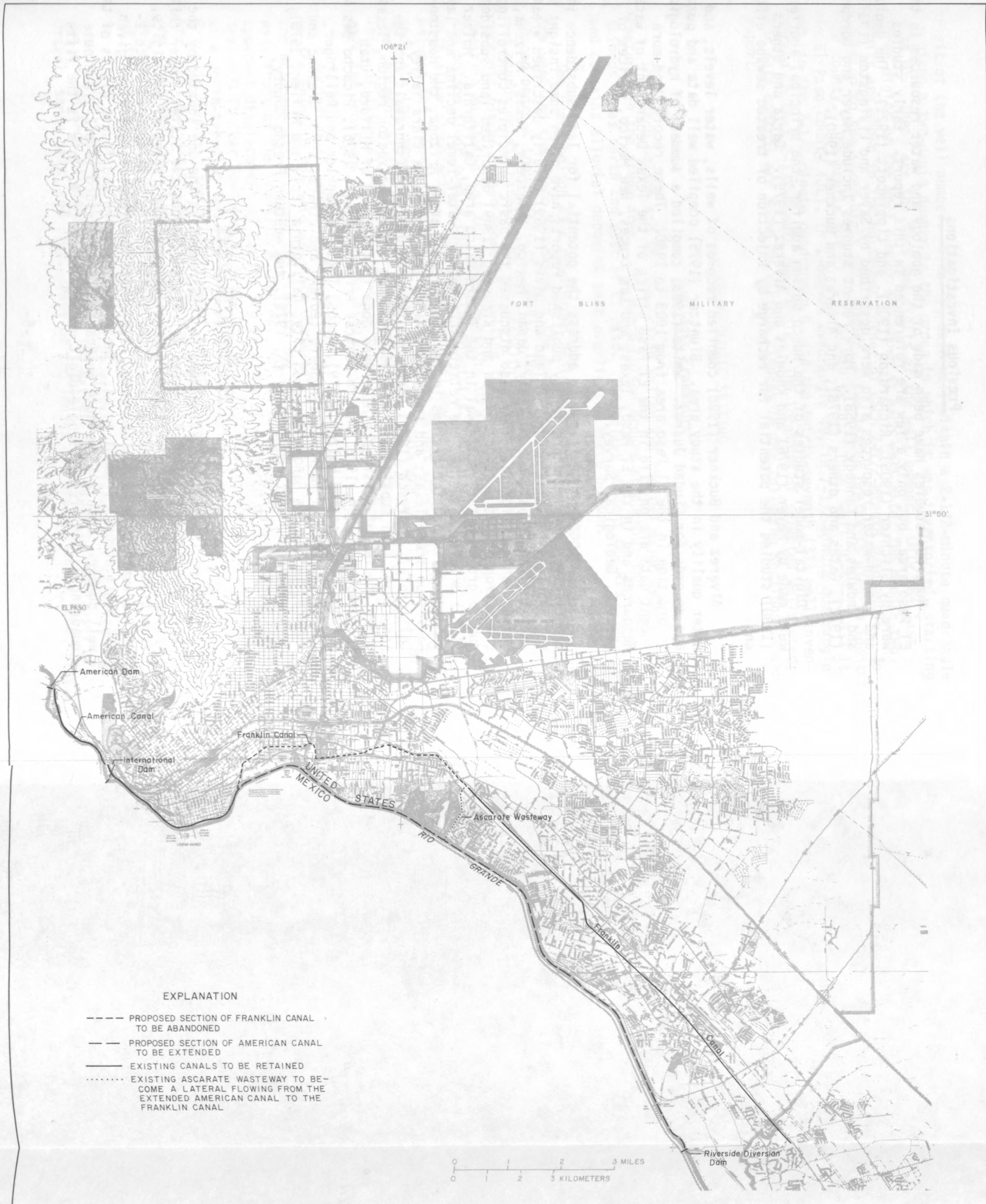


Figure 1.--Location and physiography of El Paso area.



Base from Texas Department of Highways and Public Transportation General Highway Map

Modified from U.S. Bureau of Reclamation, written commun, 1984

Figure 2.--Proposed changes to canal system by the U.S. Bureau of Reclamation.

Previous Investigations

Numerous studies have been made of the geology and water resources in the El Paso area, but only a few are referenced in this report. Early studies were by Slichter (1905), Richardson (1909), and Lippincott (1921). The geology and ground-water resources also were described by Sayer and Livingston (1937), and Knowles and Kennedy (1958). More recent studies include Meyer and Gordon (1972), Gates and others (1978), and Alvarez and Buckner (1980).

Digital-model studies of the Hueco bolson aquifer, the principal aquifer, were made by Meyer (1976) and Knowles and Alvarez (1979). Garza and others (1980) studied the potential for recharge by injection of treated sewage effluent.

Alvarez and Buckner (1980) compiled records of wells, water levels, and water quality in the study area. Bluntzer (1975) compiled well data and pumpage records for Ciudad Juarez. White (1983) compiled a summary of hydrologic information in the El Paso area from 1903 to 1980. These records and more recent data are on file in the El Paso office of the Texas Department of Water Resources and in the El Paso, Texas, and Las Cruces, New Mexico, offices of the U.S. Geological Survey.

This report is the first to address the potential for land subsidence in the El Paso area. The previously published reports have given some insight to the problems that may occur. Poland and Davis (1969) briefly described areas of major land subsidence in Italy, Japan, Mexico, Venezuela, Texas, Arizona, Nevada, and California. They also discussed the basic principles controlling compaction of sediments. Lofgren and Klausing (1969) described land subsidence due to ground-water withdrawal in the Tulare-Wasco area, California. Holzer (1981) briefly described the relationship between water-level decline and land subsidence in aquifer systems in the Eloy-Picacho area, Arizona; the Houston-Galveston area, Texas; and the Tulare-Wasco area and Santa Clara Valley, California. Gabrysch (1982) described the ground-water withdrawals and the associated land subsidence for 1906-80 in the Houston-Galveston region, Texas. Other studies of subsidence have been done in the areas of Milford, Utah (Cordova and Mower, 1976), south-central Arizona (Laney, 1976), Picacho Basin, Arizona (Jachens and Holzer, 1979), Pecos, Texas (Rosepiler and Reilinger, 1977), San Joaquin Valley, California (Poland and others, 1975; Ireland and others, 1982), Los Banos-Kettleman City, California (Bull and Miller, 1975), Arvin-Maricopa, California (Lofgren, 1975), and western Fresno County, California (Bull, 1964).

Well-Numbering System

The well-numbering system used in this report is the one adopted by the Texas Department of Water Resources for use throughout the State. Under this system, each 1-degree quadrangle is given a number consisting of two digits, from 01 to 89. These are the first two digits in the well number. Each 1-degree quadrangle is divided into 7-1/2-minute quadrangles, which are given two-digit numbers from 01 to 64. These are the third and fourth digits of the well number. Each 7-1/2-minute quadrangle is subdivided into 2-1/2-minute quadrangles and given a single-digit number from 1 to 9. This is the fifth digit of the well number. Finally, each well within a 2-1/2-minute quadrangle is given a two-digit number in the order in which it was inventoried, starting with 01. These are the last two digits of the well number. Only the last three digits of the well number are shown at each well site; the middle two digits are shown in the northwest corner of each 7-1/2-minute quadrangle. In addition to the seven-digit well number, a two-letter prefix is used to identify the county. The prefix for El Paso County is JL. Thus, well JL-49-13-837 is in El Paso County (JL), in 1-degree quadrangle 49, in 7-1/2-minute quadrangle 13, in the 2-1/2-minute quadrangle 8, and the thirty-seventh (37) well inventoried in that 2-1/2-minute quadrangle. The location of selected wells used for data control are shown in various figures in the following sections of the report.

HYDROGEOLOGIC SETTING

Geologic Framework

The Hueco bolson and the Rio Grande Valley are the two major hydrogeologic features in the study area. The Hueco bolson occurs throughout the nonmountainous areas north and east of El Paso. The valley borders the Rio Grande and contains alluvial deposits that overlie the Hueco bolson.

The Hueco bolson is a downthrown basin between the Franklin Mountains on the west and the Hueco Mountains on the east (fig. 1). The basin forms a V-shaped bedrock trough (Cliett, 1969). The lowest part of the trough is near and approximately parallel to the Franklin Mountains. It was formed when tectonic forces caused sporadic faulting that resulted in uplifting of the Franklin Mountains and the Hueco Mountains to a lesser extent, and tilting of the bolson floor toward the Franklin Mountains. The bolson then was filled with alluvial material. The total vertical movement along the fault or faults between the Franklin Mountains and the bolson is not known, but subsurface data indicate that movement was more than 9,000 ft (Davis and Leggat, 1967, p. 8). The pediment at the east edge of the Franklin Mountains is covered with an apron of alluvial material, so the precise locations of the fault scarps that mark the locations of the faults also are not known.

According to Harbour (1972, p. 76, pl. 1), the latest structural features in the Franklin Mountain area are Quaternary faults that vertically displace the Holocene alluvium and the Pleistocene gravel and caliche rimrock along the east front of the Franklin Mountains. In the El Paso area, a fault has an apparent displacement of 200 to 300 ft a few miles north of El Paso to more than 400 ft near downtown El Paso. Harbour (1972) also noted the occurrence of a north-trending fault in the Hueco bolson about 2 to 3 mi east of the Franklin Mountain front. This fault extends from a point about 4 mi south of the Texas-New Mexico State line to about 2 mi north of the line, is curved, and downthrown to the east. Sayre and Livingston (1945, pl. 2) also have delineated several north-trending faults in the Hueco bolson immediately east of the downtown El Paso area.

The bolson deposits are composed of fluvial and lacustrine material that was eroded from adjacent mountains. The material was deposited as lenses of gravel, sand, silt, and clay. Many of the lenses are predominantly sand, clay, or silt, but others are poorly sorted and contain a secondary lithology. For example, a sand lens may contain enough clay to be described as a clayey sand, or a clay lens may contain enough sand or silt to be described as a sandy clay or silty clay.

At some time after the Hueco bolson aggraded to its present level, the Rio Grande breached the gap between the southern end of the Franklin Mountains and the adjacent mountains in Mexico. Southeast of the gap at the southern end of the Franklin Mountains, the Rio Grande eroded a valley in the bolson deposits, which is locally known as the El Paso Valley on the north side of the river in the United States and the Juarez Valley on the south side of the river in Mexico (fig. 1). The surface of the Rio Grande Valley is 200 to 250 ft lower than the surface of the Hueco bolson. According to Davis (1967, p. 5), the Rio Grande has deposited alluvium as much as 200 ft thick in the valley. The Rio Grande alluvium and the underlying bolson deposits have not been differentiated because of the similarity in the visual characteristics of the two deposits; thus, the base of the alluvial deposits generally is not known. Because of head and water-quality considerations, however, two aquifers have been designated--the Hueco bolson aquifer and the shallow aquifer, which is believed to generally coincide with the Rio Grande alluvium.

Hueco Bolson Aquifer

The Hueco bolson aquifer is the principal source of freshwater for municipal, military, and industrial users in the El Paso area. The location of the major municipal and industrial water-supply wells in 1979 are shown in figure 3. The development of ground water is shown in figure 4 in terms of withdrawals and population in the El Paso-Fort Bliss metropolitan area in Texas.

Ground water occurs under water-table conditions throughout most of the areal extent of the Hueco bolson aquifer, except in the Rio Grande Valley where it ocurs under leaky artesian conditions. In the Rio Grande Valley, alluvium overlies the Hueco bolson aquifer and in some areas the alluvium is a leaky confining bed. These confining conditions in both the Hueco bolson and shallow aquifers are caused by a large number of discontinuous clay beds that decrease the vertical hydraulic conductivity with respect to the horizontal hydraulic conductivity.

Before ground-water development began at the beginning of the 20th century, the areas or sources of recharge to the Hueco bolson aquifer in Texas were: (1) The inflow of ground water from the Hueco bolson in New Mexico, (2) the infiltration of runoff from the Franklin and Hueco Mountains, and (3) the infiltration of precipitation through the land surface of the Hueco bolson and the Rio Grande alluvium. The largest contribution came from the infiltration of runoff from the Franklin Mountains.

As indicated by a predevelopment (1903) water-level map (fig. 5a), ground-water flow in the Hueco bolson aquifer was southward toward the Rio Grande Valley; in the valley, flow was toward the southeast. Significant flow moved upward into the shallow aquifer and either became flow in the Rio Grande or was lost to evapotranspiration in the flood plain (Meyer, 1976). By 1980, the ground-water flow was primarily toward two large cones of depression

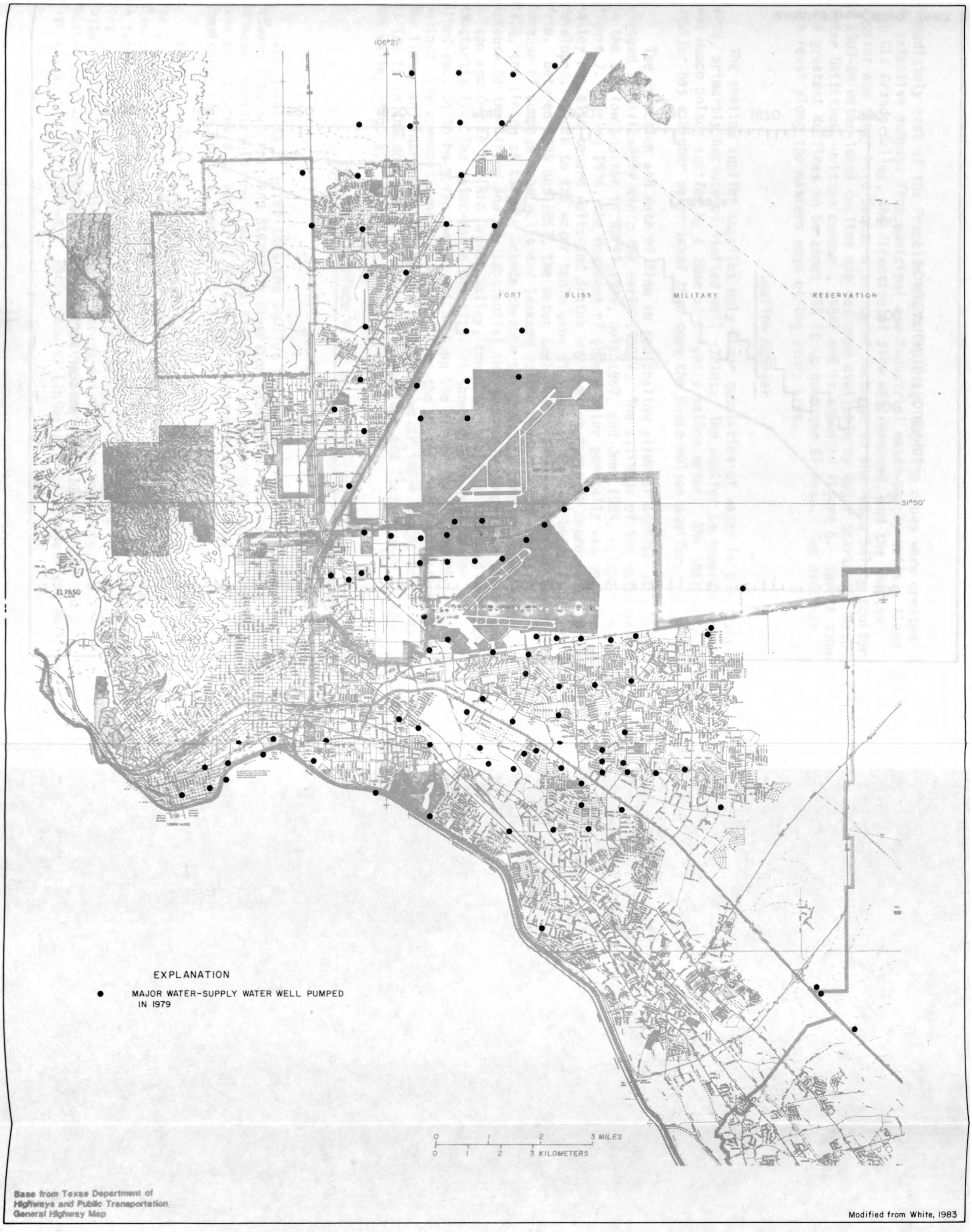
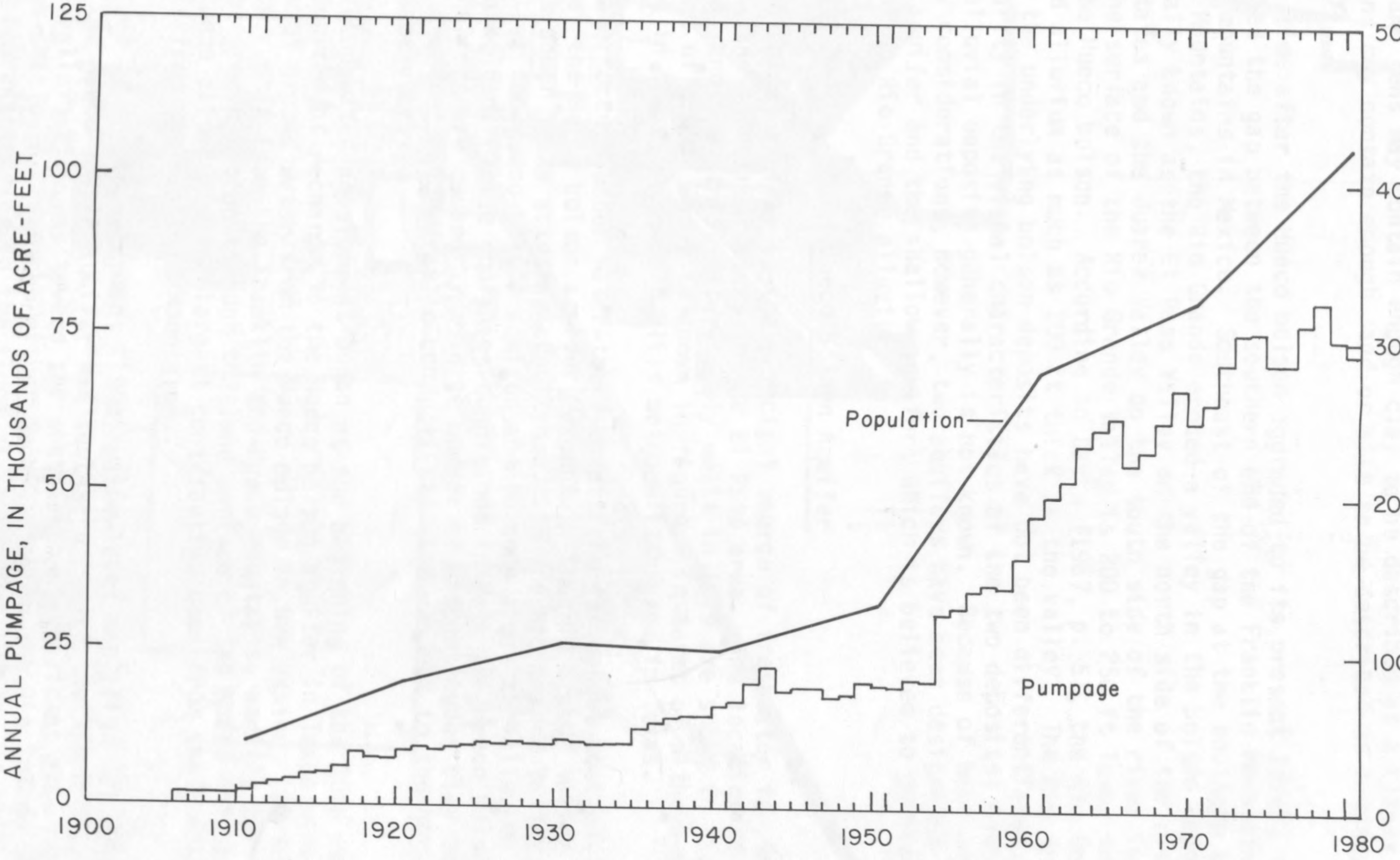


Figure 3.--Location of major water-supply wells compiled in Hueco bolson aquifer, 1979.



Modified from White, 1983

immediately east of the Franklin Mountains (fig. 5b); the cones were created by extensive pumpage from municipal and industrial water-supply wells. Along the Rio Grande Valley, the direction of flow was reversed, and the shallow aquifer and river have become a source of recharge to the Hueco bolson aquifer. A 1903-84 water-level decline map was made available by Roger Sperka (El Paso Water Utilities, written commun., 1984) and is shown in figure 6. Sperka shows the greatest declines to be about 150 ft in downtown El Paso. The declines are least along the eastern edge of the study area.

Shallow Aquifer

The shallow aquifer supplies only minor quantities of water in the study area, primarily because of limited well yields. The aquifer is separated from the Hueco bolson aquifer by a zone of slightly saline water. The shallow aquifer has a higher water level than does the Hueco bolson aquifer.

The direction and rate of flow in the shallow alluvial aquifer also has changed significantly since the early 1900's. The altitude of the water-table in the shallow aquifer in April 1936, July 1967, and June 1984, is shown in figure 7. During 1936, the movement of ground water generally was down the valley but also toward wells and drains where minor cones of depression had developed. Depth to the water table generally was a few feet below land surface. Between 1936 and 1967, the water table declined as much as 20 feet because of pumpage from wells and leakage to the Hueco bolson aquifer. In 1968, the lining of the Rio Grande through the Chamizal zone was completed. Because of the lining and the substantial increase in pumpage from the Hueco bolson aquifer in the Rio Grande Valley, the water table in 1984 had declined substantially. The water-table map (fig. 7) shows ground water under the lined section to be moving west, which is up the river. Where the river is unlined, the movement generally is away from the river. The combination of the lining and increased pumping has caused the water table to decline as much as 125 ft in the downtown area since 1936; declines are less than 20 ft down the valley (fig. 8).

Leakage of Surface Water to Aquifer System

Rio Grande

The quantity of water that the aquifer system receives from the Rio Grande between International and Riverside Diversion Dams is of considerable interest to water managers in the area. Data have been collected and computations have been made by the U.S. Bureau of Reclamation, International Boundary and Water Commission, and the U.S. Geological Survey.

For operational purposes, the Bureau prepared an annual water budget for 1959-83 of the measured inflows and outflows between International and Riverside Diversion Dams, and calculated a net loss. These data are presented in table 1 (U.S. Bureau of Reclamation, written commun., 1984). This budget does not include storm runoff in the intervening reach nor does it identify losses to unauthorized diversions, to evaporation, or to evapotranspiration. Another water-budget estimate was made by the Commission, which conducted a river-loss study for 1981-83. Their results (International Boundary and Water

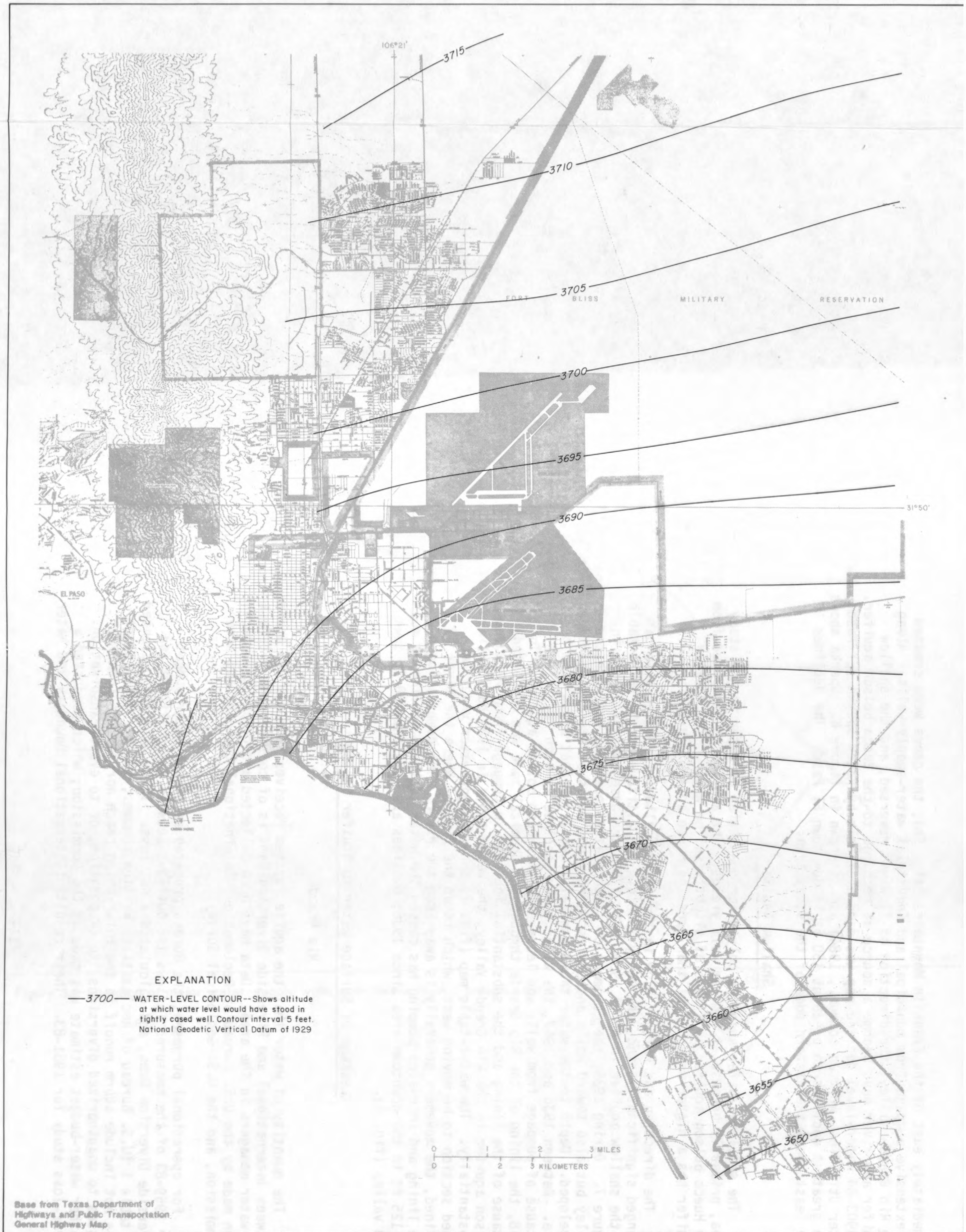


Figure 5a.--Approximate altitude of water levels in the Hueco bolson aquifer, 1903.

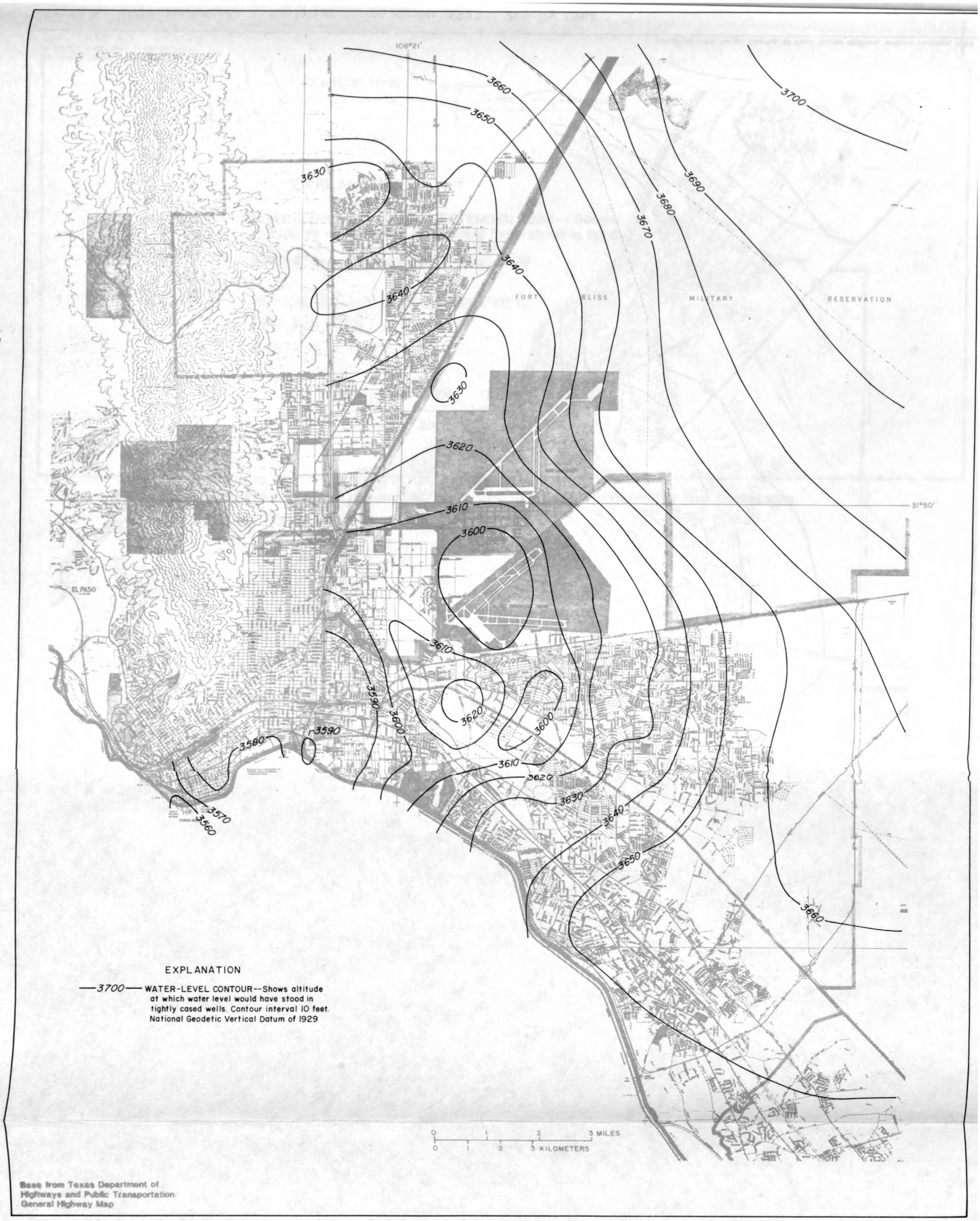


Figure 5b.--Approximate altitude of water levels in the Hueco bolson aquifer, January 1980.

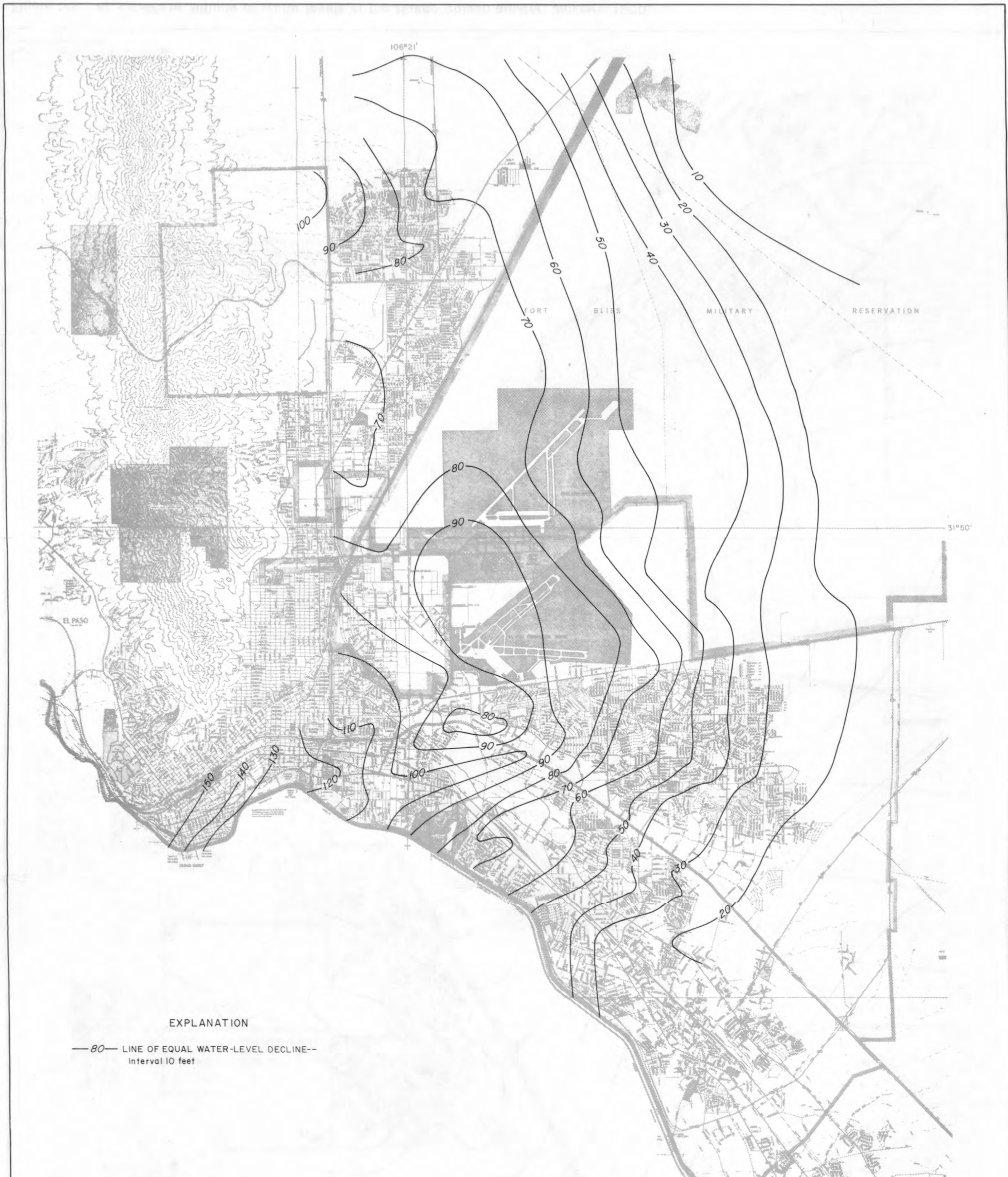


Figure 6.--Water-level decline in the Hueco bolson aquifer, 1903 to January 1984

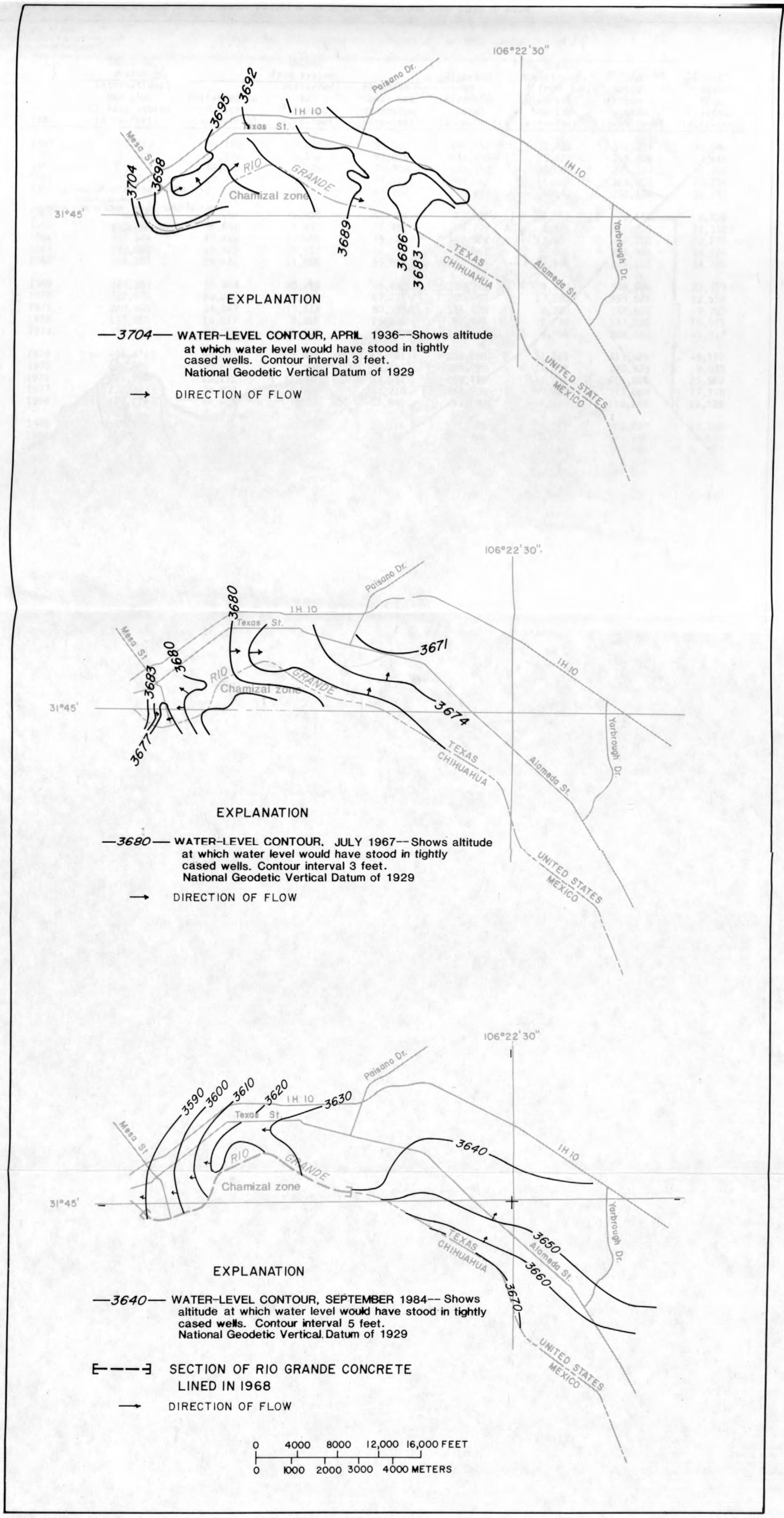


Figure 7.--Approximate altitude of the water level in the shallow aquifer in the downtown El Paso-Chamizal area, 1936, 1967, and 1984.

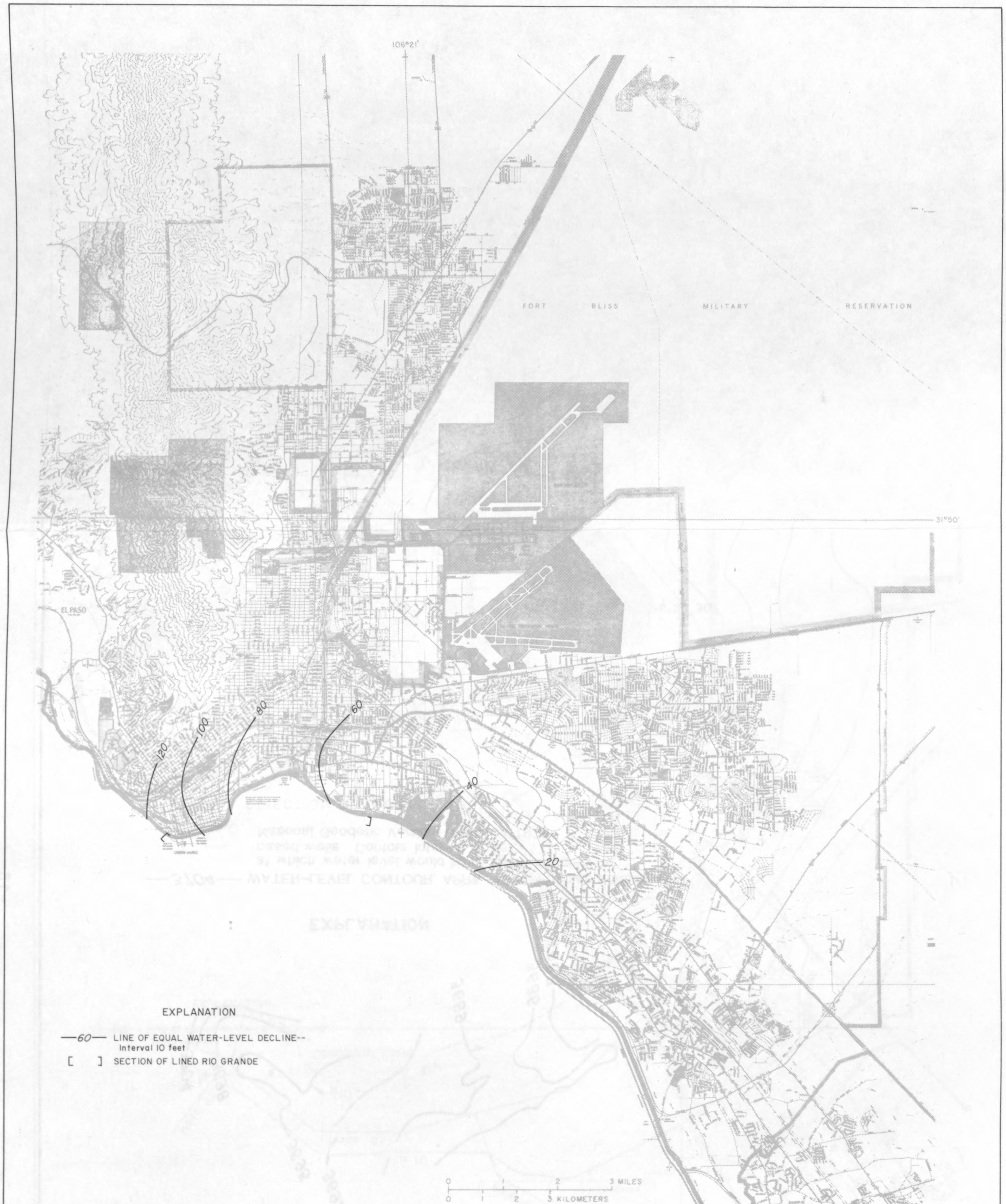


Figure 8.--Water-level decline in the shallow aquifer in the El Paso-Chamizal area, 1936 to 1984

Table 1.--Rio Grande water budget, International Dam to Riverside Diversion Dam

[Data from U.S. Bureau of Reclamation, written commun., 1984]

Year	Input to system 1/	Output from system						
	International Dam plus El Paso sewage (acre-feet)	Delivered to Mexico (acre-feet)	Delivered to El Paso (acre-feet)	Franklin Canal net diversion (acre-feet)	Diverted to Riverside Canal (acre-feet)	Rio Grande downstream from Riverside heading (acre-feet)	Total output from system (acre-feet)	Net loss from system (acre-feet)
1959	405,310	60,110	9,042	95,835	194,896	12,431	372,314	32,996
1960	397,402	60,320	8,393	92,815	202,906	15,522	379,956	17,446
1961	320,529	48,610	7,328	76,200	139,183	8,006	279,327	41,202
1962	396,584	60,057	9,093	77,443	205,265	16,992	368,850	27,734
1963	284,357	39,693	9,971	67,257	130,637	4,542	252,100	32,257
1964	86,207	6,653	3,805	41,703	23,160	4,151	79,472	6,735
1965	225,383	36,658	6,451	57,487	106,199	6,256	213,051	12,332
1966	332,344	49,618	12,051	75,228	159,568	13,605	310,070	22,274
1967	253,622	29,829	15,517	57,391	131,601	5,008	239,346	14,276
1968	284,303	39,677	11,865	55,591	124,394	7,990	239,517	44,786
1969	384,893	59,884	23,016	65,648	206,300	4,132	348,980	35,913
1970	382,079	60,065	14,044	67,234	200,998	17,180	359,521	22,558
1971	268,505	34,847	15,518	50,138	155,920	2,380	258,803	9,702
1972	153,959	16,077	9,368	25,199	84,474	2,270	137,388	16,571
1973	323,456	60,000	16,406	53,743	190,250	4,969	325,368	-1,912
1974	406,471	60,050	17,909	66,441	235,980	31,249	411,629	-5,158
1975	384,968	60,052	18,309	55,351	228,020	14,303	375,935	9,033
1976	427,414	60,172	14,887	64,551	259,470	2,765	401,845	25,569
1977	238,247	24,824	9,368	41,210	134,900	767	211,069	27,178
1978	179,777	14,903	7,229	31,846	97,180	7,095	158,253	21,524
1979	339,617	60,055	14,569	57,916	177,170	16,727	326,437	13,180
1980	380,636	60,033	20,058	57,160	226,510	12,205	375,966	4,670
1981	359,538	60,262	20,020	45,768	174,940	26,851	327,841	31,697
1982	354,049	59,257	17,387	56,943	184,982	21,198	339,767	14,282
1983	360,920	60,621	20,992	46,417	173,895	26,618	328,543	32,377
25-year total	7,844,363	1,175,674	318,791	1,440,812	4,125,638	280,961	7,341,876	502,487
25-year average	313,775	47,026	12,752	57,632	165,026	11,238	293,674	20,099

1/ Inflow from urban runoff is unaccounted.

Commision, written commun., 1984) for the reach downstream from the lined section to and Riverside Diversion Dam (fig. 1) are as follows:

Year	Inflow (acre-feet)	Outflow (acre-feet)	Loss (acre-feet)
1981	201,100	174,700	26,400
1982	229,300	196,300	33,000
1983	229,500	193,200	36,300

The Commission estimated that there were about 620 acre-ft per year of unmeasured water diversions to the irrigated lands along the river in Mexico and that 884 acre-ft per year of water evaporated. A third estimate of water entering the aquifer system by seepage from the river above Riverside Diversion Dam was made in a ground-water-modeling study by the Survey (Meyer, 1976, table 1). These singular values of seepage are presented in table 2 and suggest gradually increasing losses from the river into the aquifer.

In an attempt to quantify the recharge to the ground-water system from the river, the losses shown in tables 1 and 2 are plotted in figure 9. The annual flow past International Dam plus El Paso sewage (total inflow) and annual precipitation also are plotted in an attempt to identify a correlation. A brief discussion of the graphs and data sets follow:

1. U.S. Bureau of Reclamation - The graphs show major fluctuations in losses with little or no correlation with inflow and rainfall. A poorly defined trend is a gradual decrease in seepage for several years after the lining of the river channel in 1968 and a substantial increase in the last 10 years (from a small gain to about 30,000 acre-ft per year). Again, no accounting was made for storm runoff entering the stream between the gaging stations.

2. International Boundary and Water Commission - The water budget uses streamflow records at the ends of the reach between the end of the lined section and Riverside Diversion Dam and the major tributary inflow (Ascarate Wasteway). This tributary includes a large percentage of the storm runoff. Because of fewer diversions and points of inflow and more local gaging, these results are believed to be substantially more accurate than the other two determinations. Also, this analysis includes estimates of evapotranspiration and evaporation.

3. U.S. Geological Survey - These simulated results (Meyer, 1976) do not reflect time-varying conditions but are long-term averages. The losses after 1973 are projections made in the mid-1970's. Because of the model limitations and the lack of data for calibration, the results have a limited value for the purposes of this report.

Before further interpretation of these data, a comment on typical errors associated with stream-gaging records is in order. Daily-discharge records published by the Geological Survey are classified as "excellent," "good," and "poor" and are expected to have errors of 5, 10, and greater than 15 percent 95

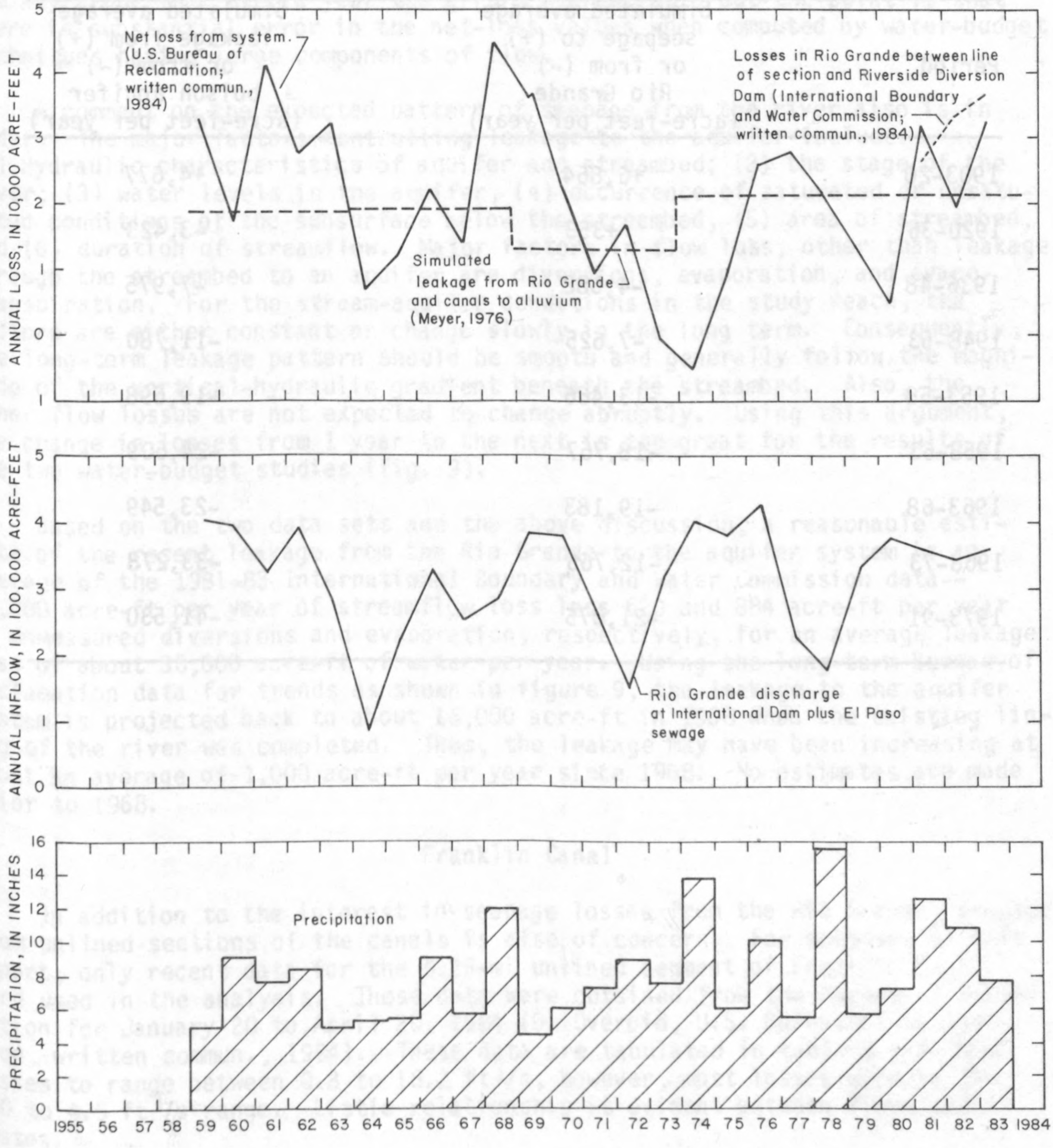


Figure 9.--Annual net loss from and inflow to Rio Grande and precipitation at El Paso, 1953-83

Table 2.--Simulated average annual seepage to or from the Rio Grande and canals and average leakage between aquifers as computed by a digital model

[From Meyer, 1976, table 1]

Period	Simulated average seepage to (+) or from (-) Rio Grande (acre-feet per year)	Simulated average leakage from (+) or from (-) bolson aquifer (acre-feet per year)
1903-20	+6,864	+4,677
1920-36	+353	-3,423
1936-48	-4,588	-7,975
1948-53	-7,625	-11,780
1953-58	-13,466	-19,698
1958-63	-18,767	-24,609
1963-68	-19,183	-23,549
1968-73	-12,765	-33,278
1973-91	-21,075	-41,530

percent of the time. Because of this source of error and the small difference between the inflow and outflow, the actual net loss easily can be within the error range. Using the 25-year average in table 1 as an example, a 5-percent error of the inflow and outflow produces ranges of 298,086 to 329,464 acre-ft and 278,990 to 308,358 acre-ft, respectively. Based on the above ranges of inflow and outflow, the range in net losses is from -10,272 to 50,474 acre-ft. One may argue that over a year the errors average out, but the point is that there is substantial error in the net-loss values when computed by water-budget techniques having large components of flow.

A comment on the expected pattern of seepage from the river also is in order. The major factors controlling leakage to the aquifer include: (1) Hydraulic characteristics of aquifer and streambed; (2) the stage of the river; (3) water levels in the aquifer, (4) occurrence of saturated or unsaturated conditions of the subsurface below the streambed, (5) area of streambed, and (6) duration of streamflow. Major factors in flow loss, other than leakage through the streambed to an aquifer are diversions, evaporation, and evapotranspiration. For the stream-aquifer conditions in the study reach, the factors are either constant or change slowly in the long term. Consequently, the long-term leakage pattern should be smooth and generally follow the magnitude of the vertical-hydraulic gradient beneath the streambed. Also, the other flow losses are not expected to change abruptly. Using this argument, the change in losses from 1 year to the next is too great for the results of the two water-budget studies (fig. 9).

Based on the two data sets and the above discussion, a reasonable estimate of the recent leakage from the Rio Grande to the aquifer system is an average of the 1981-83 International Boundary and Water Commission data--31,900 acre-ft per year of streamflow loss less 620 and 884 acre-ft per year to unmeasured diversions and evaporation, respectively, for an average leakage loss of about 30,000 acre-ft of water per year. Using the long-term Bureau of Reclamation data for trends as shown in figure 9, the leakage to the aquifer system is projected back to about 15,000 acre-ft in 1968 when the existing lining of the river was completed. Thus, the leakage may have been increasing at about an average of 1,000 acre-ft per year since 1968. No estimates are made prior to 1968.

Franklin Canal

In addition to the interest in seepage losses from the Rio Grande, seepage from unlined sections of the canals is also of concern. For purposes of this report, only recent data for the 5.25-mi unlined segment of Franklin Canal were used in the analysis. These data were obtained from the Bureau of Reclamation for January 20 to April 20, 1984 (D. Overoid, U.S. Bureau of Reclamation, written commun., 1984). These data are tabulated in table 3 and show losses to range between 0.8 to 18.2 ft^3/s; however, most losses were in the 1.0 to 4.5 ft^3/s range. Little relationship is evident between flows and losses.

Table 3.--Water-loss data for unlined section of Franklin Canal, January-April 1984

(Data from: U.S. Bureau of Reclamation, written commun., 1984)

Date	Upstream discharge (cubic feet per second)	Downstream discharge (cubic feet per second)	Decrease in discharge (cubic feet per second)
Jan. 20, 1984	48.2	46.8	1.4
24	47.5	47.0	.5
26	50.0	47.4	2.6
31	44.6	40.4	4.2
Feb. 14	78.2	74.3	3.9
22	100.2	99.2	1.0
25	110.2	103.3	6.9
27	104.0	100.4	3.6
Mar. 6	105.0	102.1	3.9
16	158.9	153.6	5.3
23	190.1	185.9	4.2
27	182.4	169.3	13.1
30	190.5	187.2	3.3
Apr. 3	181.0	178.4	2.6
6	182.5	168.3	18.2
10	188.6	184.8	3.8
13	188.8	188.0	.8
17	181.5	180.4	1.1
20	186.2	185.0	.6

Determination of the occurrence of an Unsaturated Zone Below Streambeds

Leakage from a surface-water body into a hydraulically connected ground-water system is directly proportional to the hydraulic gradient at the streambed which is influenced by the hydraulic gradients in the vertical and horizontal directions immediately below the streambed. In the case where the regional water table is gradually lowering, these hydraulic gradients continue to increase until an unsaturated zone develops between the surface-water body and the main saturated section of the aquifer. The unsaturated section should logically occur at the top of a very permeable section that is immediately below a section of lesser permeability. When an unsaturated zone develops, the maximum downward leakage rate is reached. As long as the unsaturated conditions exist, this maximum leakage rate is expected to be maintained.

To determine if saturated or unsaturated conditions existed below the streambed of the Rio Grande and Franklin Canal, the Bureau of Reclamation drilled test holes by air rotary method, collected lithologic and geophysical data, and installed clusters of piezometers at five locations near the river (fig. 10). At each site, a test hole was drilled to below the regional water table; a lithologic description of the subsurface was obtained; and natural-gamma and neutron-geophysical logs were collected. One to four piezometers were installed at the site, each in a separate hole. In most cases, two were installed near the river and a third one about 200 ft away. The lithologic descriptions are given in table 8 (at the end of this report). The well data are tabulated in table 4.

Rio Grande

Site 1R is about 0.2 mi downstream from the end of the lined section of the Rio Grande. The regional water table has an altitude of about 3,640 ft, which is about 55 ft below the land surface. Using the lithologic data, geophysical logs, and profile of water levels shown in figure 11, the section above the well depth of about 30 ft and below about 50 ft is saturated, whereas the intermediate 20-ft section appears to be unsaturated. The moisture content begins in the unaturated zone near the base of a sand bed below a clay bed and has even less moisture at the top of the gravel bed.

At the next downstream site (2R), the regional water table occurs at an altitude of 3,665 ft or from 20 to 25 ft below land surface. Based on the lithologic data, geophysical logs, and profile of water levels in figure 12, the hydrogeology of this site is dissimilar to site 1R in that the alluvium less than 20 ft deep is mainly unsaturated with a possible exception in a thin perched zone at a depth of 10 ft as indicated by the neutron log. Although lithologic logs are not clear and consistent among the four test holes as to the occurrence of a clay bed(s) at shallow depths, materials having little hydraulic conductivity are believed to exist and limit the downward movement of water. The section below a depth of 20 ft is saturated.

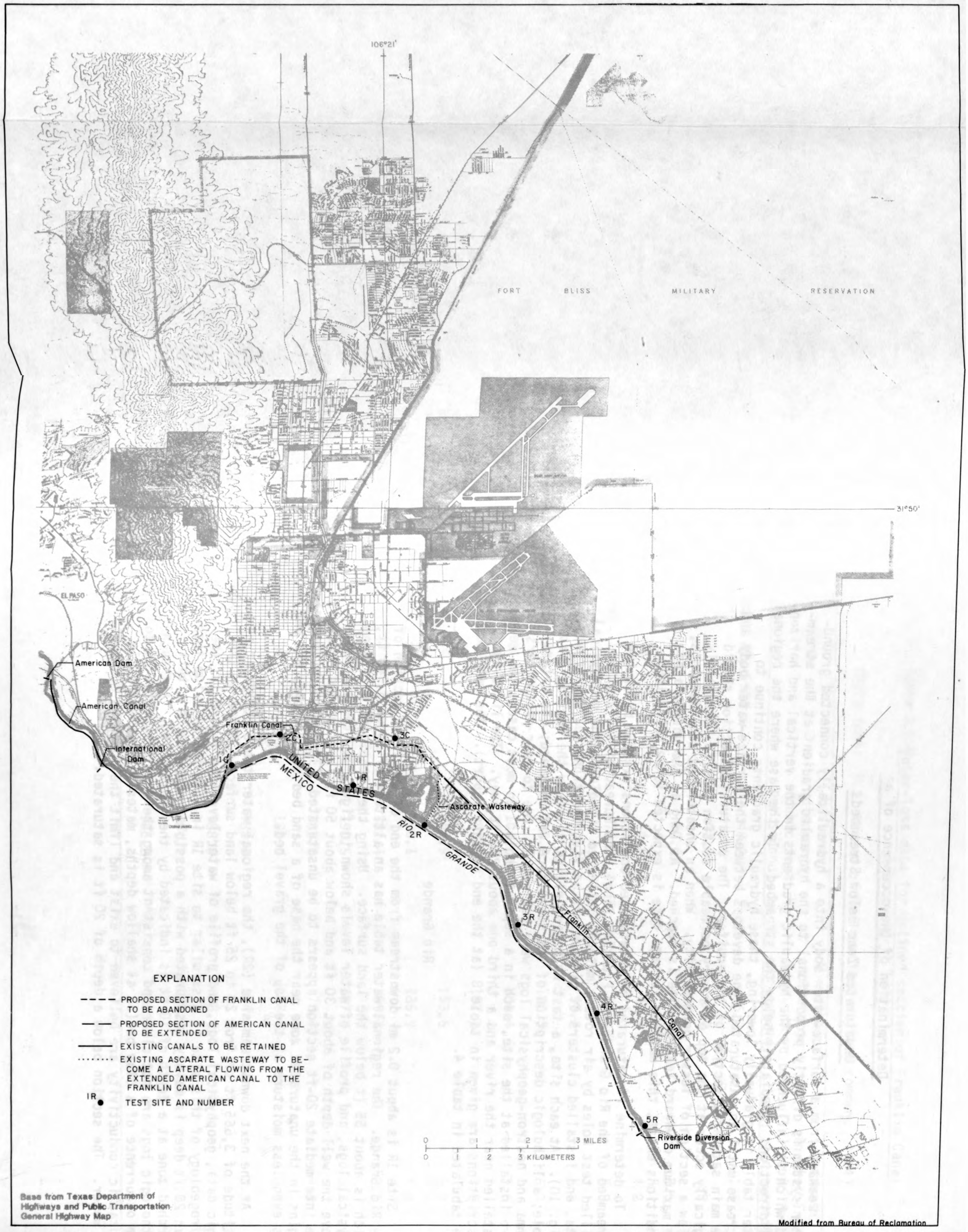


Figure 10.--Location of test sites drilled along the Rio Grande and Franklin Canal in 1984.

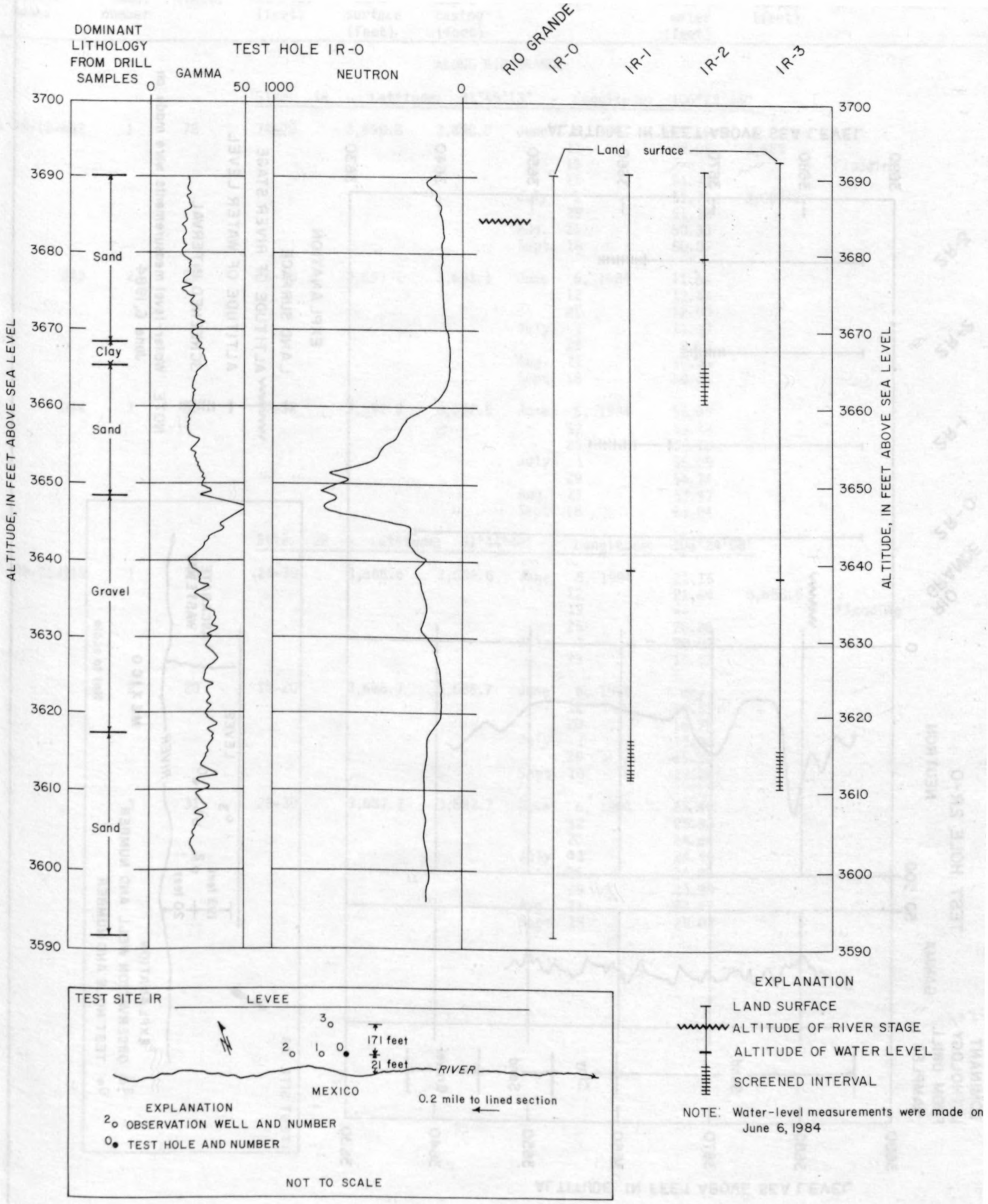


Figure 11.--Lithologic, geophysical, well-completion, and water-level data for test site 1R.

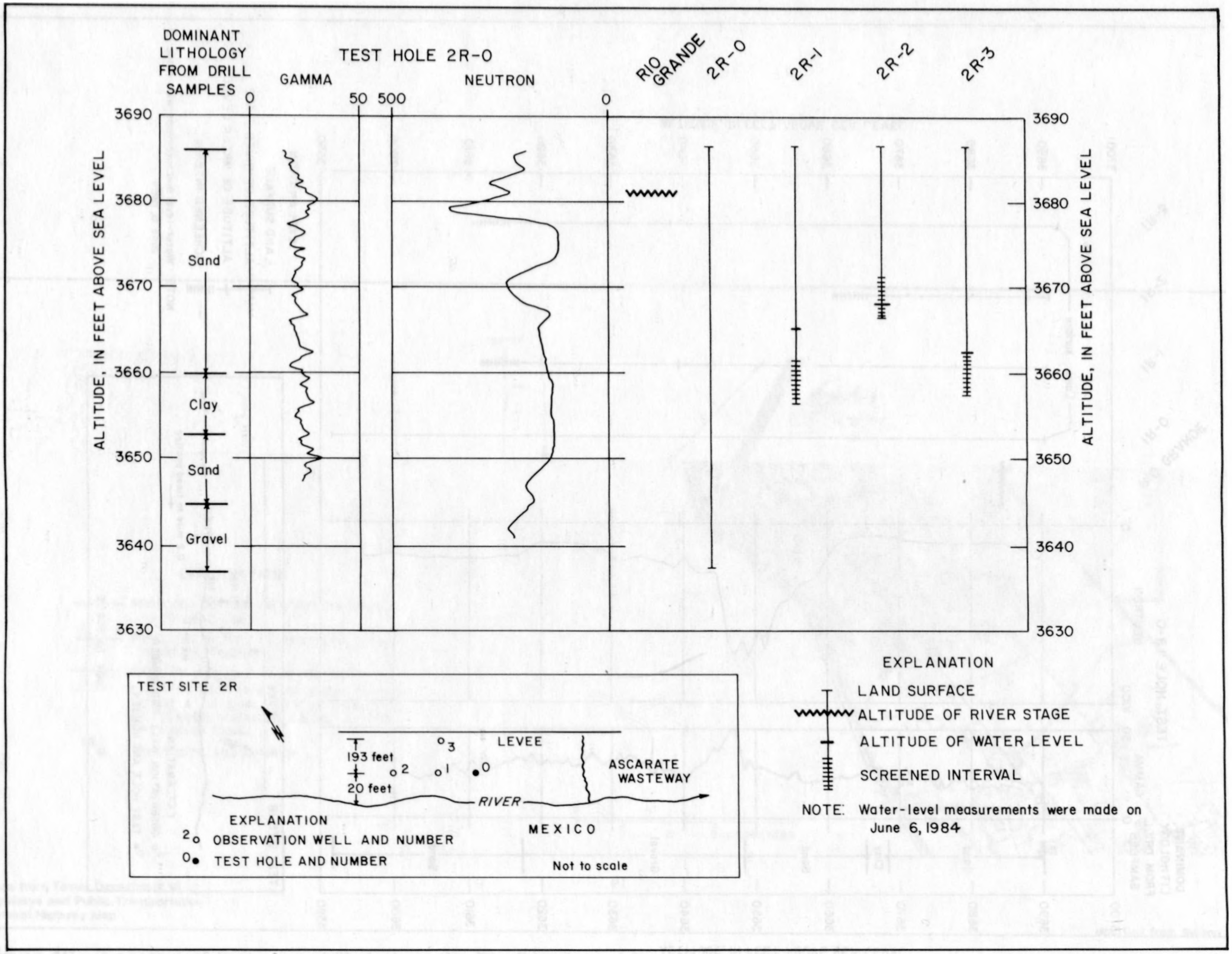


Figure 12.--Lithologic, geophysical, well-completion, and water-level data for test site 2R.

Table 4.--Well records of test drilling along Rio Grande and Franklin Canal in 1984

Well identification		Depth (feet)	Screen interval (feet)	Altitude of land surface (feet)	Altitude of top of casing (feet)	Water-level measurements		Altitude of water surface (feet)	Remarks
State number	Local number					Date	Depth to water (feet)		
					ALONG RIO GRANDE				
			Site: 1R - Latitude: 31°45'13" - Longitude: 106°25'35"						
JL 49-13-842	1	78	74-79	3,690.8	3,690.8	June 6, 1984	52.16		
						12	52.08	3,684	
						19	--		Flooding
						25	51.71		
						July 1	51.71	3,685.5	
						29	51.18		
						Aug. 21	50.33		
						Sept. 18	50.07		
843	2	29	25-30	3,691.1	3,691.1	June 6, 1984	11.64		
						12	12.44		
						25	12.03		
						July 1	11.17		
						29	9.13		
						Aug. 21	10.34		
						Sept. 18	10.04		
844	3	80	77-82	3,692.5	3,692.5	June 6, 1984	55.39		
						12	55.48		
						25	55.15		
						July 1	55.09		
						29	54.74		
						Aug. 21	53.97		
						Sept. 18	53.84		
			Site: 2R - Latitude: 31°44'40" - Longitude: 106°24'08"						
JL-49-21-313	1	26	25-30	3,686.6	3,686.6	June 6, 1984	21.15		
						12	21.44	3,680.6	
						19	--		Flooding
						25	20.26		
						July 1	20.02		
						29	19.52		
	2	20	15-20	3,686.7	3,686.7	June 6, 1984	dry		
						12	18.55		
						20	16.79		
						July 1	15.88		
						29	15.26		
						Sept. 18	17.24		
	3	31	25-30	3,687.7	3,687.7	June 6, 1984	25.40		
						12	25.53		
						20	24.64		
						July 1	24.46		
						26	24.08		
						29	23.99		
						Aug. 21	23.67		
						Sept. 18	25.02		

Table 4.--Well records of test drilling along Rio Grande and Franklin Canal in 1984--Continued

Well identification: State number	Well identification: Local number	Depth (feet)	Screen interval (feet)	Altitude of land surface (feet)	Altitude of top of casing (feet)	Water-level measurements: Date	Water-level measurements: Depth to water (feet)	Altitude of water surface (feet)	Remarks
			Site: 3R - Latitude: 31°43'01" - Longitude: 106°22'24"						
JL 49-22-136	1	23	18-23	3,679.3	3,679.3	June 1, 1984	10.8		
						7	11.10		
						12	11.19	3,674.8	
						19	--		Flooding
						25	10.19		
						July 1	9.83	3,675.7	
						29	8.83		
						Aug. 21	9.13		
						Sept. 18	9.32		
137	2	16	10-15	3,679.4	3,679.4	June 1, 1984	10.9		
						7	11.19		
						12	11.28		
						25	10.27		
						July 1	9.92		
						29	8.88		
						Aug. 21	9.17		
						Sept. 18	9.39		
138	3	25.5	20-25	3,680.5	3,680.5	June 1, 1984	12.8		
						12	13.05		
						25	12.15		
						July 1	11.92		
						29	11.21		
						Aug. 21	10.74		
						Sept. 18	10.81		
			Site: 4R - Latitude: 31°41'11" - Longitude: 106°20'37"						
JL 49-22-409	--	15	10-15	3,671.8	3,671.8	June 1, 1984	4.3		
						7	4.68		
						12	4.69	3,668.3	
						19	--		Flooding
						25	4.02		
						July 1	3.50	3,669.1	
						29	2.02		
						Aug. 21	3.82		
						Sept. 18	3.79		
			Site: 5R - Latitude: 31°39'31" - Longitude: 106°19'45"						
JL 49-22-841	--	18	10-15	3,665.5	3,665.5	June 7, 1984	8.21		
						12	8.22	3,663.0	
						19	--		Flooding
						25	7.16		
						July 1	7.36	3,664.0	
						29	6.73	3,664.9	
						Sept. 18	7.72	3,663.9	

Table 4.--Well records of test drilling along Rio Grande and Franklin Canal in 1984--Continued

Well identification: State number	Well identification: Local number	Depth (feet)	Screen interval (feet)	Altitude of land surface (feet)	Altitude of top of casing (feet)	Water-level measurements: Date	Water-level measurements: Depth to water (feet)	Altitude of water surface (feet)	Remarks
ALONG FRANKLIN CANAL									
Site: 1C - Latitude: 31°45'40" - Longitude: 106°28'03"									
JL 49-13-729	1	119	102-122	3,707.0	3,707.0	June 1, 1984	80.1		Storm runoff on June 9.
						6	79.81		
						12	79.75	3,704+	
						20	79.62		
						July 1	79.58		
						29	79.43		
						Aug. 21	79.18	3,702.3+	
						Sept. 18	78.99		
Site: 2C - Latitude: 31°46'15" - Longitude: 106°27'07"									
JL 49-13-837	1	93	91-96	3,703.3	3,703.3	June 6, 1984	74.46		
						12	74.52	3,701.3	
						20	74.58		
						July 1	74.66	3,701.2	
						29	74.85		
						Aug. 21	75.01		
						Sept. 18	75.15		
838	2	46.3	41-46	3,703.6	3,703.6	June 6, 1984	dry		
						12	dry		
						20	dry		
						July 1	dry		
						29	dry		
						Aug. 21	dry		
						Sept. 18	dry		
839	3	17.5	15-20	3,703.7	3,703.7	June 6, 1984	dry		
						12	dry		
						20	dry		
						July 1	17.3		
						29	17.2		
						Aug. 21	17.3		
						Sept. 18	17.3		
840	4	94.5	92.5-97.5	3,699.6	3,699.6	June 6, 1984	72.67		
						12	72.55		
						20	72.63		
						July 1	72.68		
						29	72.89		
						Aug. 21	73.04		
						Sept. 18	73.16		

Table 4.--Well records of test drilling along Rio Grande and Franklin Canal in 1984--Continued

Well identification: State number	Well identification: Local number	Depth (feet)	Screen interval (feet)	Altitude of land surface (feet)	Altitude of top of casing (feet)	Water-level measurements: Date	Water-level measurements: Depth to water (feet)	Altitude of water surface (feet)
			Site: 3C - Latitude: 31°46'07" - Longitude: 106°24'47"					
JL 49-13-945	1	109	100-105	3,696.9	3,696.9	June 6, 1984	60.05	
						12	60.48	3,693.5
						20	60.50	
						July 1	60.55	3,695.8
						29	60.54	3,695.7
						Aug. 21	60.34	3,693.6
						Sept. 18	60.09	3,694.6
946	2	48	41-46	3,697.2	3,697.2	June 6, 1984	dry	
						12	dry	
						20	dry	
						July 1	dry	
						29	dry	
947	3	19	15-20	3,697.2	3,697.2	June 6, 1984	17.89	
						12	16.64	
						20	15.70	
						July 1	14.63	
						29	14.85	
						Sept. 18	14.57	
	4	104	102-107	3,695.1	3,694.6	June 6, 1984	58.17	
						12	58.21	
						27	58.30	
						July 1	58.37	
						29	58.28	
						Aug. 21	58.12	
						Sept. 18	58.68	

At the third downstream site (3R), the regional water table is at an altitude of 3,668 ft or about 10 ft below the land surface. The neutron log in figure 13 indicates a possible unsaturated section at about 8 ft, which is beneath a saturated section at about the level of the stream. In any case, the seepage is expected to be limited because of the clay immediately below the streambed.

Test sites 4R and 5R were located farther downstream. As expected, data from these sites indicate saturated conditions beneath the streambed.

In conclusion, it appears that leakage from the Rio Grande has reached a maximum in about the first 2 mi below the lined section but will continually increase as long as saturated conditions prevail in the lower reach because of continued decline in ground-water levels. The maximum leakage along the Rio Grande probably will not exceed the previous rate of a 1,000-acre-ft increase each year.

Franklin Canal

For site 1C, the lithologic, geophysical and water-level data shown in figure 14 are not sufficient for a conclusive delineation of saturated and unsaturated zones. However, the data do indicate saturated conditions in the silt and clay sections above a depth of 32 ft, unsaturated conditions at the base of the clay and at the top of the gravel, and saturated conditions in the remainder of the gravel. The saturated section in the gravel is believed to be perched on the relatively thick clay bed. Of interest, the neutron log is similar to the one from test hole 1R-0 (fig. 11).

For sites 2C and 3C, the lithologic, geophysical, and water-level profiles are shown in figures 15 and 16, respectively. At both sites, the data indicate that the section above the regional water table is unsaturated except immediately below the canal. An unexplained anomaly is observed at site 3C in the zone between 60 and 80 ft. The neutron log indicates this section to be unsaturated, but the water-level data from the deep observation wells indicate this section should be saturated.

LAND SUBSIDENCE

Land subsidence has occurred in many places throughout the world. Most cases of land-surface subsidence have been related to decrease of fluid pressure caused by the removal of gas, oil, or water from the subsurface. Land-surface subsidence in mining areas also has been recorded. A few cases of land-surface subsidence have been caused by the addition of water, a process called hydrocompaction. In the El Paso area, practically all land-surface subsidence is expected to be caused by ground-water pumpage and the accompanying water-level decline. However, there is a possibility of land-surface subsidence caused by fault movement in the Quaternary deposits. The status of fault activity is unknown, but it is assumed to have been inactive for the past 80 years. However, it is possible that the faults may be activated in response to a lowering of water levels.

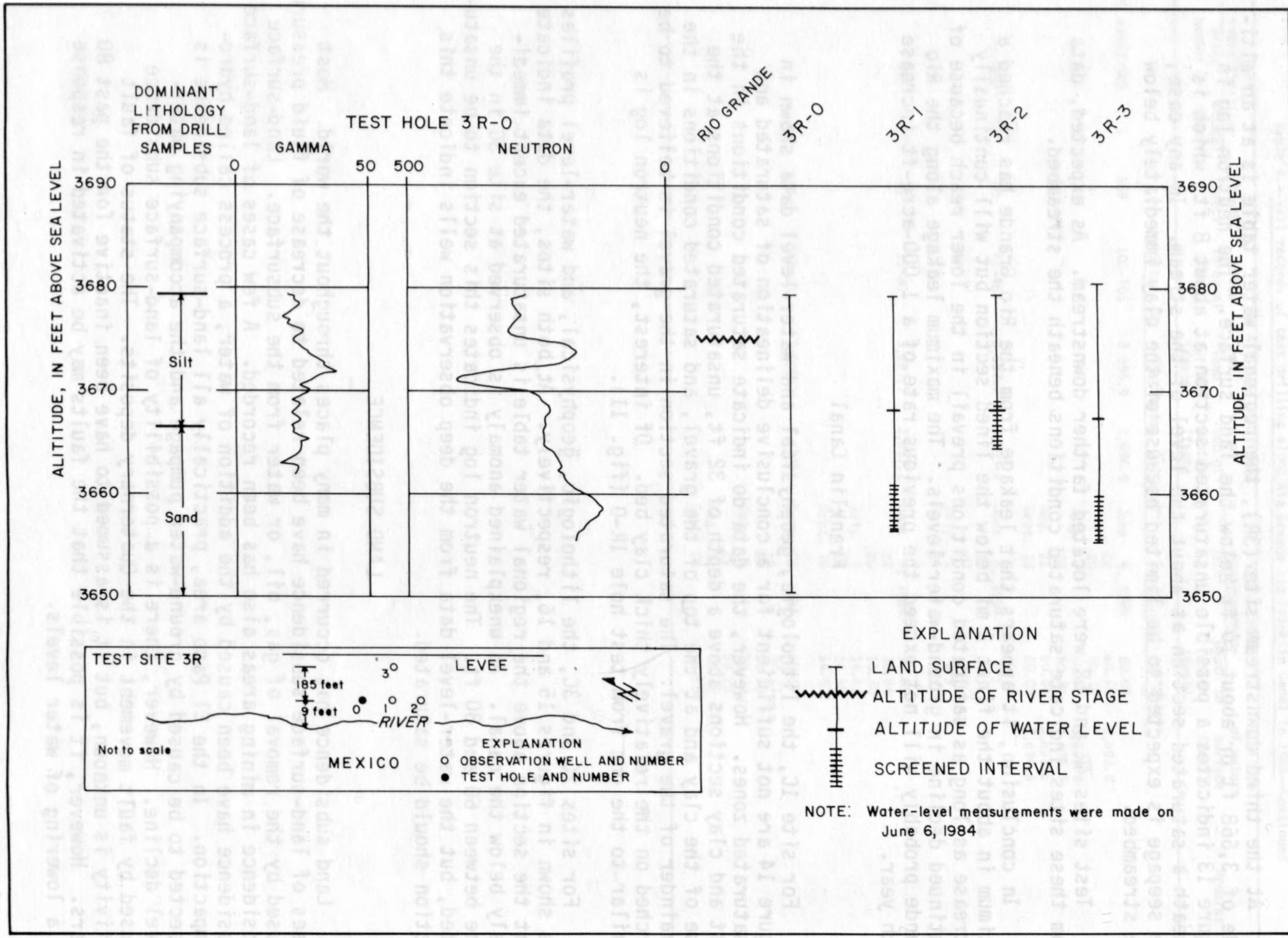


Figure 13.--Lithologic, geophysical, well-completion, and water-level data for test site 3R.

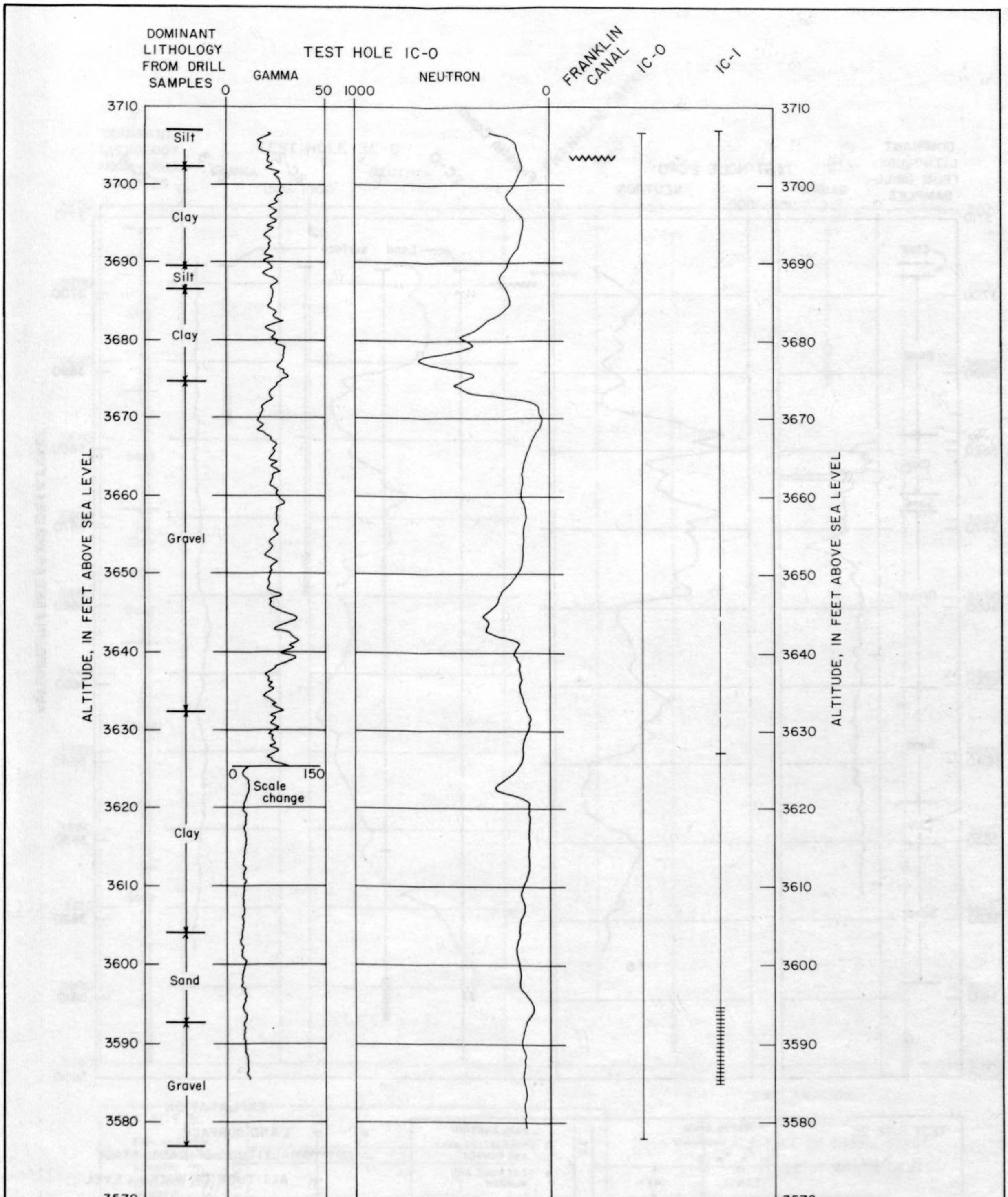


Figure 14.--Lithologic, geophysical, well-completion, and water-level data for test site 1C.

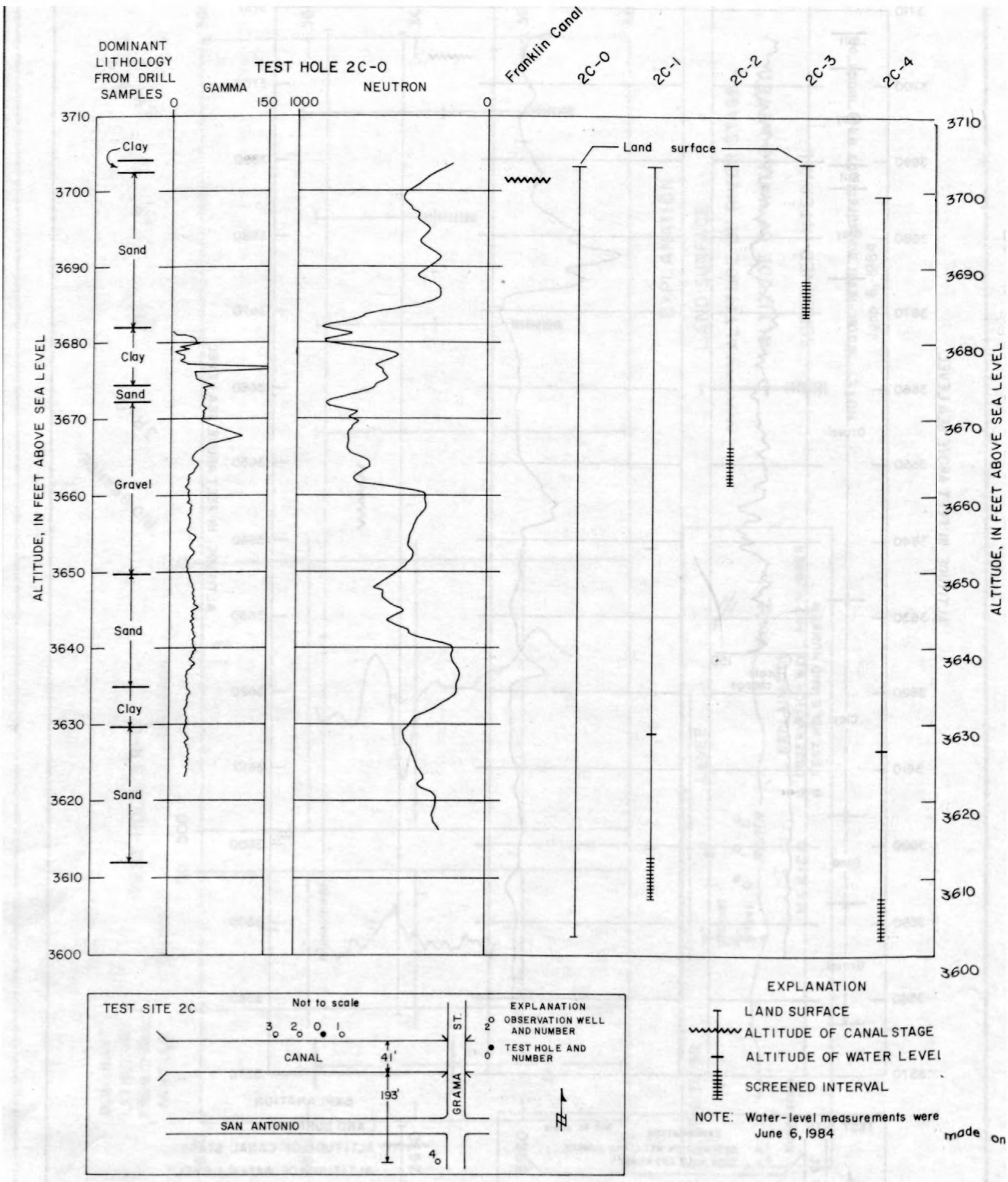


Figure 15.--Lithologic, geophysical, well-completion, and water-level data for test site 2C.

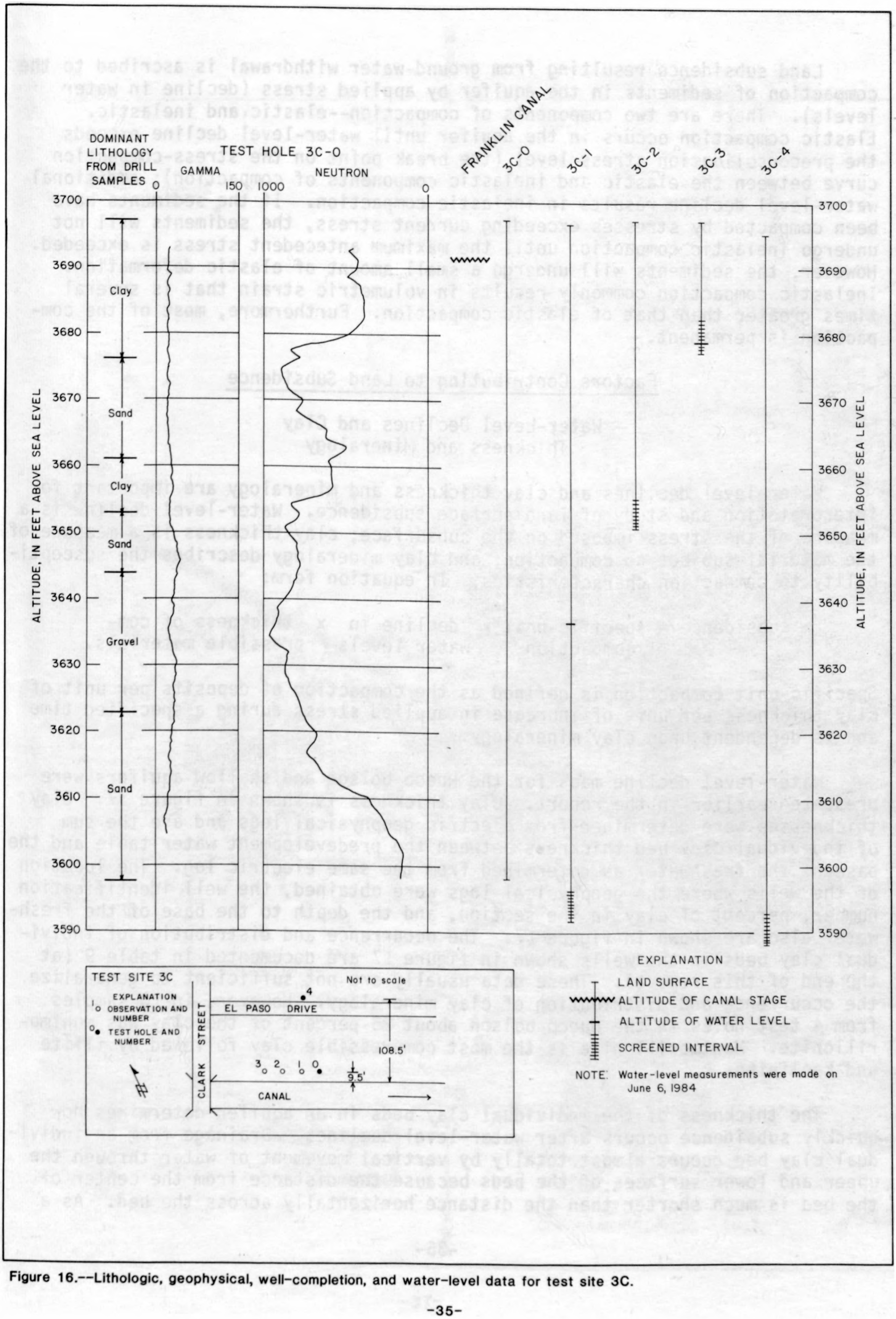


Figure 16.--Lithologic, geophysical, well-completion, and water-level data for test site 3C.

Land subsidence resulting from ground-water withdrawal is ascribed to the compaction of sediments in the aquifer by applied stress (decline in water levels). There are two components of compaction--elastic and inelastic. Elastic compaction occurs in the aquifer until water-level decline exceeds the preconsolidation stress level (the break point on the stress-compaction curve between the elastic and inelastic components of compaction); additional water-level decline results in inelastic compaction. If the sediments have been compacted by stresses exceeding current stress, the sediments will not undergo inelastic compaction until the maximum antecedent stress is exceeded. However, the sediments will undergo a small amount of elastic deformation. Inelastic compaction commonly results in volumetric strain that is several times greater than that of elastic compaction. Furthermore, most of the compaction is permanent.

Factors Contributing to Land Subsidence

Water-Level Declines and Clay Thickness and Mineralogy

Water-level declines and clay thickness and mineralogy are important for interpretation and study of land-surface subsidence. Water-level decline is a measure of the stress imposed on the subsurface; clay thickness is a measure of the material subject to compaction; and clay mineralogy describes the susceptibility to compaction characteristics. In equation form:

subsidence = specific-unit compaction x decline in water levels x thickness of compressible materials.

Specific-unit compaction is defined as the compaction of deposits per unit of clay thickness per unit of increase in applied stress during a specified time and is dependent upon clay mineralogy.

Water-level decline maps for the Hueco bolson and shallow aquifers were presented earlier in the report. Clay thickness is shown in figure 17. Clay thicknesses were determined from electric geophysical logs and are the sum of individual clay bed thickness between the predevelopment water table and the base of the freshwater as determined from the same electric log. The location of the wells where the geophysical logs were obtained, the well identification number, percent of clay in the section, and the depth to the base of the freshwater also are shown in figure 17. The occurrence and distribution of individual clay beds in the wells shown in figure 17 are documented in table 9 (at the end of this report). These data usually are not sufficient to generalize the occurrence and distribution of clay mineralogy. However, in 10 samples from 4 test holes in the Hueco bolson about 25 percent of the clay was montmorillonite. Montmorillonite is the most compressible clay followed by illite and kaolinite.

The thickness of the individual clay beds in an aquifer determines how quickly subsidence occurs after water-level declines. Drainage from an individual clay bed occurs almost totally by vertical movement of water through the upper and lower surfaces of the beds because the distance from the center of the bed is much shorter than the distance horizontally across the bed. As a

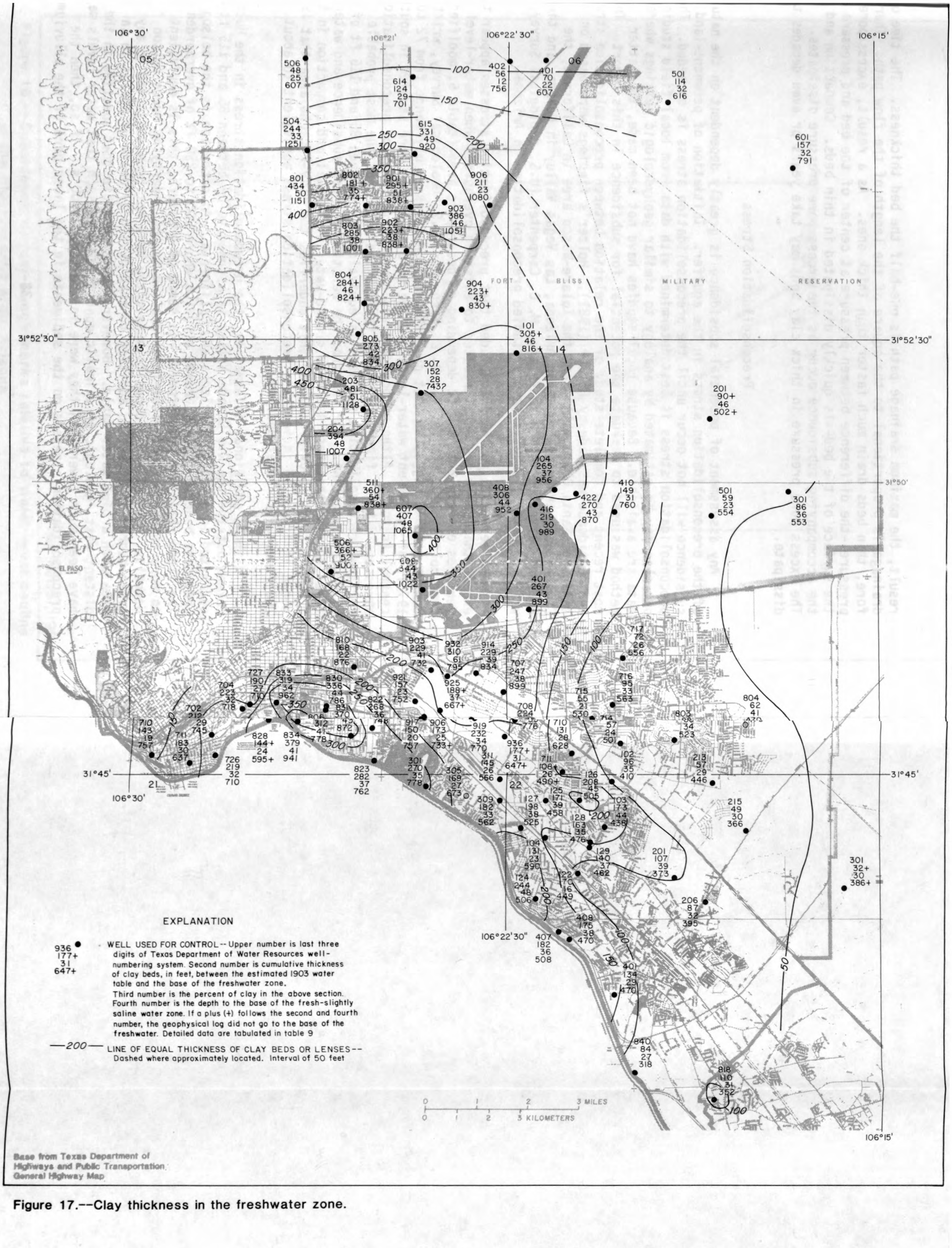


Figure 17.--Clay thickness in the freshwater zone.

result, the maximum drainage path is one-half the bed thickness. The time of drainage is proportional to the square of the length of the flow path. Therefore, thin beds drain much faster than thick ones. As a result, excess pore pressure--the difference between pressure at center of the bed and pressure at the surface of the bed--is quickly dissipated in thin beds. Compaction and the accompanying subsidence occur as the excess pore pressure dissipates. The excess pore pressure in thick clay beds may take years or even decades to dissipate.

Preconsolidation Stress

Any assessment of potential subsidence is greatly dependent on the nature of the preconsolidation stress in the aquifer. Initiation of permnent-land subsidence will not occur until the preconsolidation stress is exceeded. The preconsolidation stress is best determined with data from local field studies but also may be estimated by analogy to similar geohydrologic settings where data are available. Because local studies have not been made, the latter method was used to evaluate the potential for subsidence in this report. The most recent and complete study of the relation between preconsolidation stress and subsidence was made by Holzer (1981). Holzer's findings were based on data from Santa Clara Valley and the Tulare-Wasco area in California, the Eloy-Picacho and Bowie areas in Arizona, Las Vegas Valley in Nevada, and the Houston-Galveston region in Texas. M. C. Carpenter (U.S. Geological Survey, written commun., 1984) also has studied preconsolidation in Arizona.

Holzer (1981, p. 693) concluded that preconsolidation stresses appear to exceed that which can be attributed to existing overburden when water-level declines exceed 52 to 207 ft depending on geographic area (table 5, modified from Holzer, 1981, table 1). M. C. Carpenter (U.S. Geological Survey, written commun., 1984) suggested that preconsolidation stresses may range from 72 to 197 ft of equivalent water-level decline in basins that were studied in south-central Arizona. Although both writers gave a wide range of preconsolidation stresses, data in figure 18 and in table 5 indicate that the most probable range for the preconsolidation stresses is equivalent to between 85 and 115 ft of water-level decline. For example, the relation between subsidence and water-level decline that resulted from ground-water withdrawal and compaction in the 2,500-ft thick alluvial aquifer that underlies the Eloy-Picacho area that is shown in figure 18 indicates a preconsolidation stress equivalent to about 100 ft of water-level decline.

Without additional information, the preconsolidation stress in the Hueco bolson outside the Rio Grande Valley is assumed to be between 85 and 115 ft as estimated in studies in Arizona and California. An exception is the bolson sediments beneath the Rio Grande alluvium where 200 to 250 ft of overburden in the flood plain has been eroded. In terms of pressure, this is equivalent to more than 500 ft of water-level decline in the underlying Hueco bolson deposits. The alluvial deposits apparently have not been subjected to any great degree of stress in addition to that caused by depth of burial in an area with a high water table. However, it is possible that sometime in the distant past, geologic or climatic conditions were such that water levels may have been much lower than they were in the early 1900's. If so, then the preconsolidation stresses on the sediments in the lower part of the alluvium

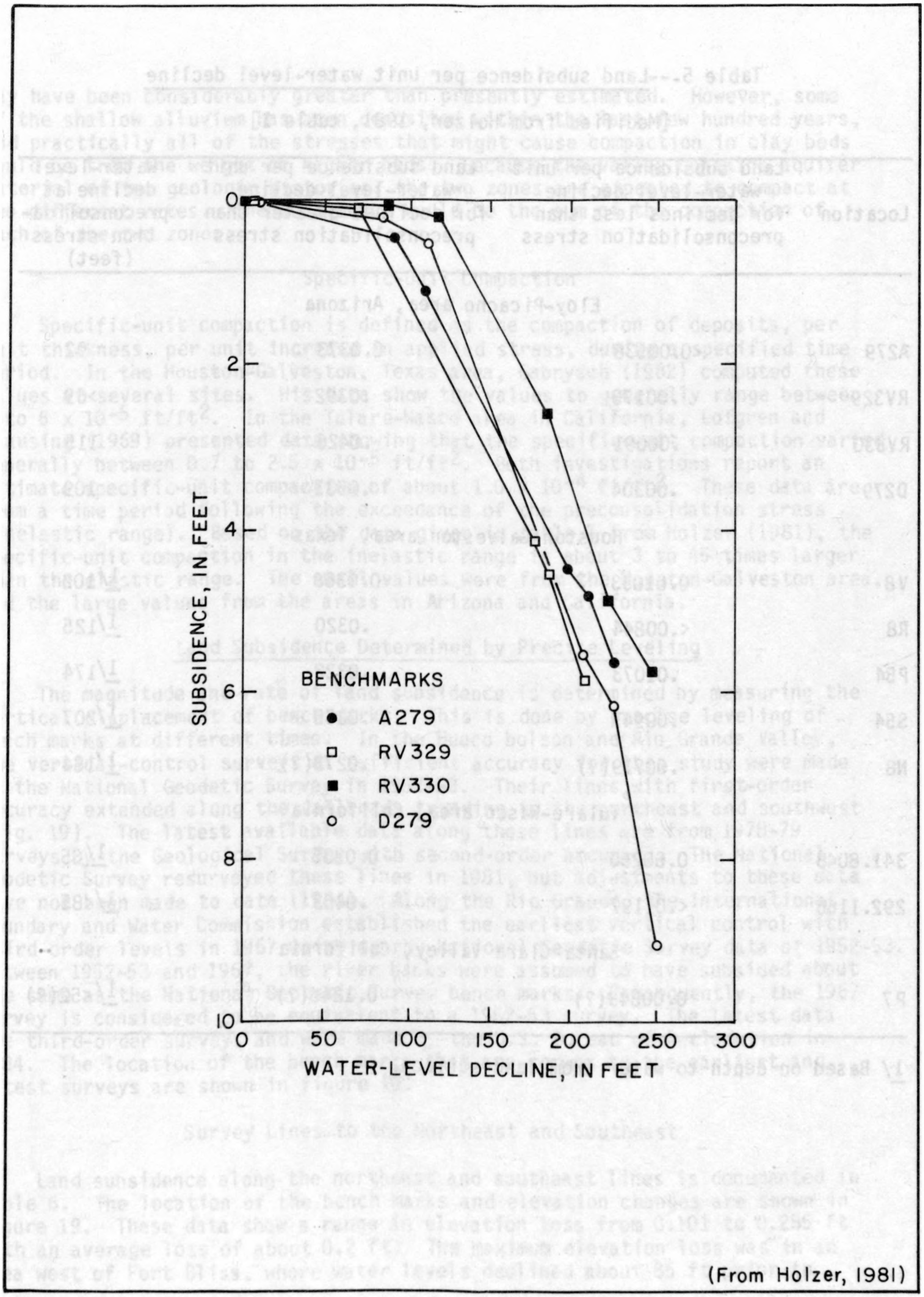


Figure 18.--Subsidence of four bench marks relative to water-level decline in the Eloy-Picacho area, Arizona

Table 5.--Land subsidence per unit water-level decline

[Modified from Holzer, 1981, table 1]

Location	Land subsidence per unit water-level decline for declines less than preconsolidation stress	Land subsidence per unit water-level decline for declines greater than preconsolidation stress	Water-level decline at preconsolidation stress (feet)
		Eloy-Picacho area, Arizona	
A279	<0.00538	0.0373	92
RV329	.00175	.0392	>69
RV330	.00091	.0426	115
D279	.00304	.0531	109
		Houston-Galveston area, Texas	
V8	0.01033	0.0358	1/102
R8	<.00844	.0320	1/125
P54	.01073	.0322	1/174
S54	.00947	.0355	1/207
N8	.00719(?)	.0273(?)	1/184
		Tulare-Wasco area, California	
341.804B	0.00250	0.0335	1/85
292.116B	<.01197	.0463	1/<85
		Santa Clara Valley, California	
P7	0.00849(?)	0.1245(?)	1/<52(?)

1/ Based on depth to water from land surface.

may have been considerably greater than presently estimated. However, some of the shallow alluvium has been deposited within the last few hundred years, and practically all of the stresses that might cause compaction in clay beds would be from the weight of higher beds. Because the valley contains aquifer material of two geologic histories, the two zones are expected to compact at two different rates. The subsidence would be the sum of the compaction of each of the two zones.

Specific-Unit Compaction

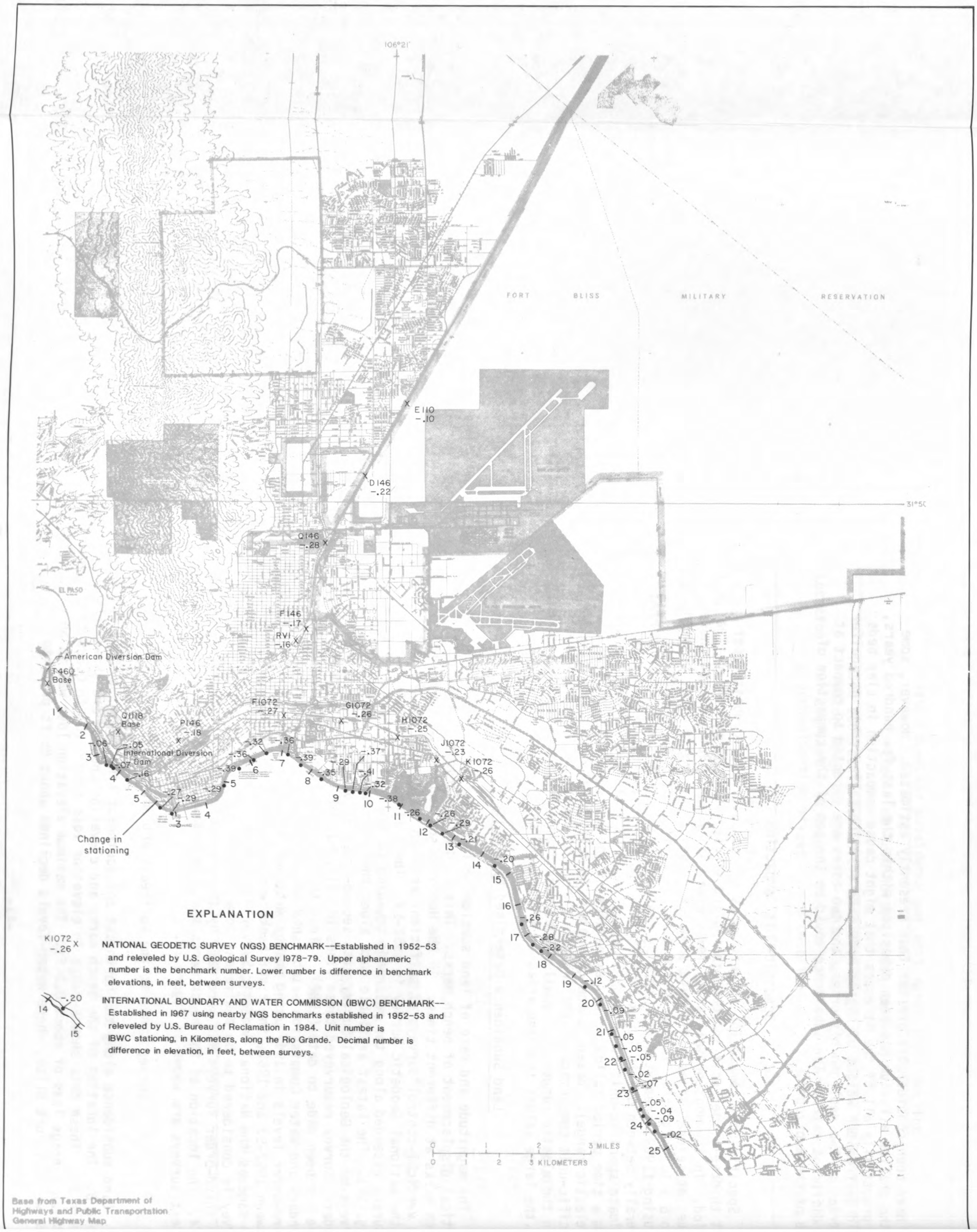
Specific-unit compaction is defined as the compaction of deposits, per unit thickness, per unit increase in applied stress, during a specified time period. In the Houston-Galveston, Texas area, Gabrysch (1982) computed these values at several sites. His data show the values to generally range between 1 to 6 x 10^{-5} ft/ft^2. In the Tulare-Wasco area in California, Lofgren and Klausing (1969) presented data showing that the specific-unit compaction varied generally between 0.7 to 2.5 x 10^{-5} ft/ft^2. Both investigations report an ultimate specific-unit compaction of about 1.0 x 10^{-4} ft/ft^2. These data are from a time period following the exceedance of the preconsolidation stress (inelastic range). Based on the data given in table 5 from Holzer (1981), the specific-unit compaction in the inelastic range is about 3 to 45 times larger than the elastic range. The small values were from the Houston-Galveston area, and the large values from the areas in Arizona and California.

Land Subsidence Determined by Precise Leveling

The magnitude and rate of land subsidence is determined by measuring the vertical displacement of bench marks. This is done by precise leveling of bench marks at different times. In the Hueco bolson and Rio Grande Valley, the vertical-control surveys of sufficient accuracy for this study were made by the National Geodetic Survey in 1952-53. Their lines with first-order accuracy extended along the railroads trending to the northeast and southwest (fig. 19). The latest available data along these lines are from 1978-79 surveys by the Geological Survey with second-order accuracy. The National Geodetic Survey resurveyed these lines in 1981, but adjustments to these data have not been made to date (1984). Along the Rio Grande, the International Boundary and Water Commission established the earliest vertical control with third-order levels in 1967 using nearby National Geodetic Survey data of 1952-53. Between 1952-53 and 1967, the river banks were assumed to have subsided about the same as the National Geodetic Survey bench marks. Consequently, the 1967 survey is considered to be equivalent to a 1952-53 survey. The latest data are third-order surveys and were made by the U.S. Bureau of Reclamation in 1984. The location of the bench marks that are common to the earliest and latest surveys are shown in figure 19.

Survey Lines to the Northeast and Southeast

Land subsidence along the northeast and southeast lines is documented in table 6. The location of the bench marks and elevation changes are shown in figure 19. These data show a range in elevation loss from 0.101 to 0.285 ft with an average loss of about 0.2 ft. The maximum elevation loss was in an area west of Fort Bliss, where water levels declined about 85 ft prior to



Base from Texas Department of
Highways and Public Transportation
General Highway Map

Table 6.--Elevation of bench marks and difference in elevation between surveys along the northeast and southeast survey lines

Bench mark (date set)	Elevations (feet) National Geodetic Survey 1952-53 (adjusted 1954)	Elevations (feet) U.S. Geological Survey 1978-79 (adjusted 1980[1/])	Change in elevation (feet)
Q1118 (1958)	3,857.280	3,857.280	Base
P146	3,740.784	3,740.604	-0.18
		Northeast line	
RV-1	3,820.601	3,820.443	-.16
F146 (1954)	3,836.647	3,836.473	-.17
Q146 (1954)	3,722.198	3,721.913	-.28
D146 (1954)	3,874.295	3,874.072	-.22
E110 (1932)	3,883.372	3,883.271	-.10
		Southeast line	
F1072 (1956)	3,702.448	3,702.188	-.27
G1072 (1956)	3,697.467	3,697.211	-.25
H1072 (1956)	3,698.284	3,698.035	-.25
J1072 (1956)	3,695.144	3,694.915	-.23
K1072 (1956)	3,691.739	3,691.476	-.26

1/ The control points for the Geological Survey 1978-79 levels were at the ends of the northwest (near Texas-New Mexico Stateline), northeast (E110), and southeast (K1072) lines. Because these control points were in areas of possible subsidence, the elevations were recomputed by using bench mark Q1118 as the only control point. This bench mark is on rock outcrop at the foot of the Franklin Mountains and is believed to be stable.

1984. No survey data are available in the airport area where water level declines are greatest (about 90 feet).

Survey Lines Along the Rio Grande

Subsidence along the Rio Grande is summarized in table 7. As stated earlier, the leveling was completed by the International Boundary and Water Commission in 1967 using National Geodetic Survey, U.S. Bureau of Reclamation data, the U.S. Bureau of Reclamation in 1984, and the U.S. Geological Survey in 1978. The stationing for Commission bench marks originally was based on the distance in meters from the bench mark at the Texas-New Mexico boundary, but when the Chamizal Treaty with Mexico established a permanent course for the Rio Grande, a new set of bench marks were established starting a short distance downstream from the International Dam. Bench-mark number 2+020.19 in the new set is the same bench mark as 5+464.44 in the old numbering system.

The difference in elevations shown in table 7 indicate that all Commission bench marks except the ones at and downstream of the Riverside Diversion Dam were lower in 1984 than in 1967. In the upper reach between Commission marks 3+467.94 to 3+706.19, the aquifer is thin. Based on the position of the area with respect to the mountains, the aquifer material also is believed to be composed largely of coarse-grained material, especially at depth. Consequently the subsidence was small in comparison to other areas (less than 0.07 ft). The subsidence was greater than 0.25 ft for nearly all bench marks between 2+020.19 and 17+315.67. The maximum subsidence along this line was 0.41 ft at bench mark 9+650.01, which is located about 1,000 ft downstream from the end of the lined section of the Rio Grande. Water-levels have declined from 50 to 150 ft in the Hueco bolson aquifer and from 25 to 125 ft in the shallow aquifer in this area; the cumulative thickness of the clay beds in the two aquifers averages about 250 ft. In the section 5+000 to 11+000, the subsidence was consistently in the 0.32- to 0.41-ft range except at bench mark 9+145. Of interest, a 1923-24 topographic map shows this reach to be characterized by meanders and swampy areas. In the reach between stations 17+500 and 24+500, subsidence decreases from about 0.25 to 0.02 ft. Downstream from the Riverside Diversion Dam, a slight rise in elevation is indicated (table 7). As of 1984, the ground-water levels in this area have remained stable or only decreased slightly. Slight variations in elevations are expected because of the variation of the moisture content of soils above the water table.

Relationship Between Land-Surface Subsidence, Water-Level Declines, and Clay Thickness

Survey Lines to the Northeast and Southeast

In an attempt to establish the relationship between land-surface subsidence, water-level declines, and clay thickness, profiles of the three were drawn along survey lines (fig. 19) from the base bench mark (Q1118) to the northeast (fig. 20) and southeast (fig. 21). The northeast line is on the Hueco bolson, and the southeast line is on the alluvium but very near the boundary with the Hueco bolson. For the northeast line, the subsidence shows

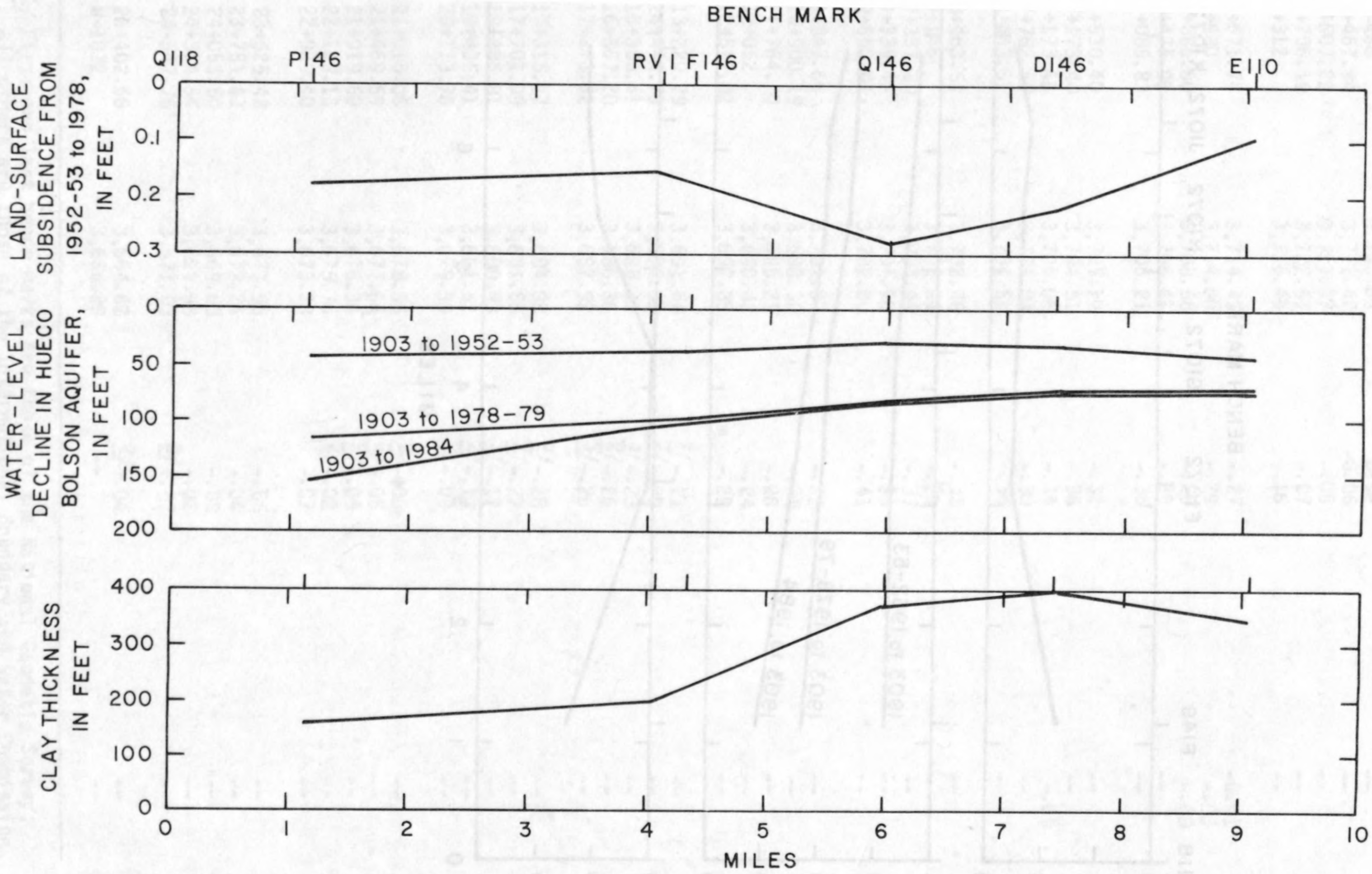


Figure 20.--Profiles of land-subsidence, water-level decline, and clay thickness along the northeast survey line.

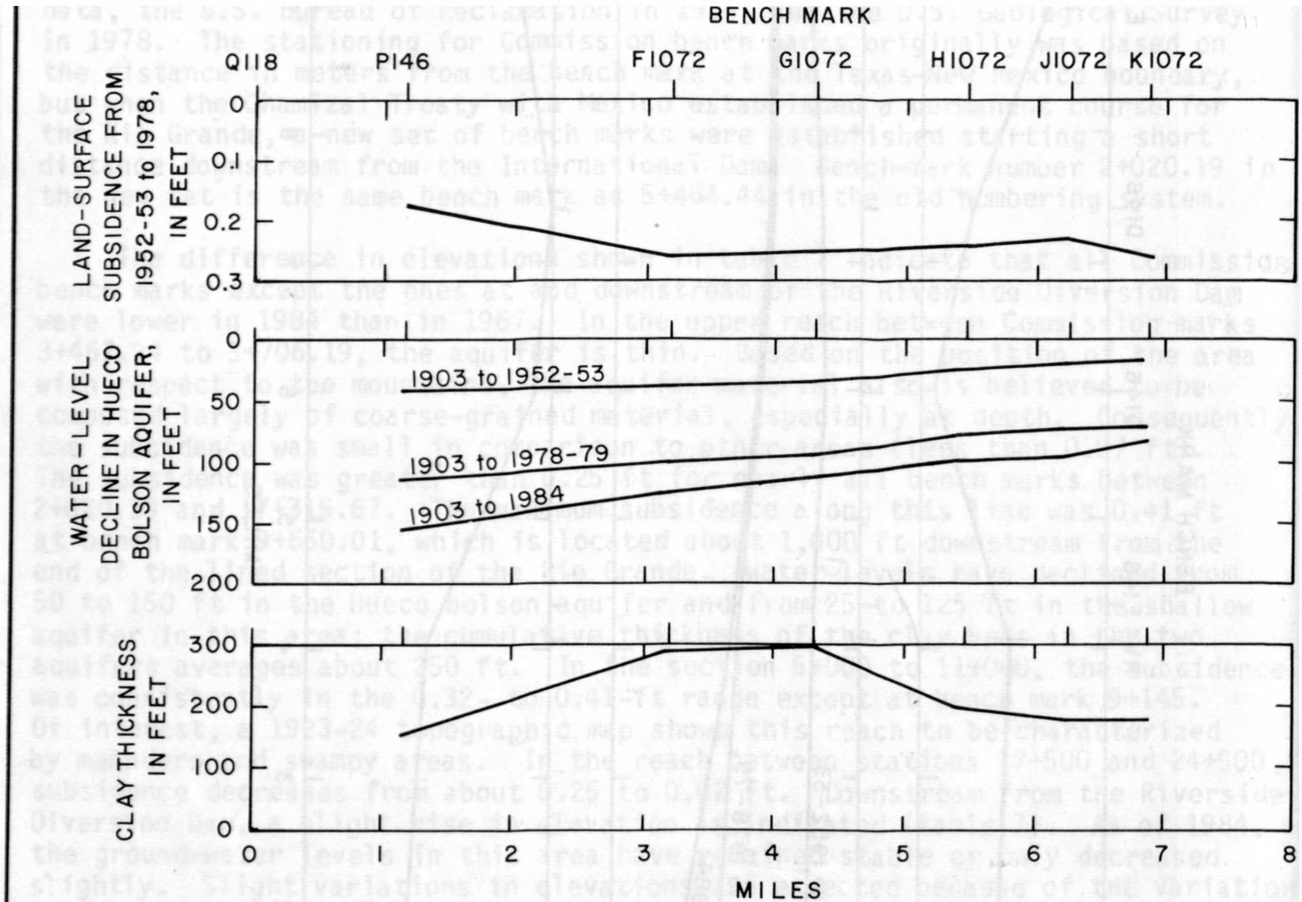


Figure 21.--Profiles of land-surface subsidence, water-level decline, and clay thickne along the southeast survey line.

Table 7.--Elevation of bench marks and difference between surveys along the Rio Grande Valley

Bench-mark number 1/	U.S. Bureau of Reclamation (1984) adjusted elevation (feet)	Difference in elevation (feet): International Boundary and Water Commission 1967 survey using National Geodetic Survey 1952-53 data	Difference in elevation (feet): U.S. Geological Survey 1978
T-460	3,733.89	Base	--
3+467.94	3,721.42	-0.06	--
3+607.22	3,717.37	-.05	--
3+706.19	3,722.51	-.07	--
4+312	3,716.45	-.16	--
2+671.74	3,714.41	-.27	-0.01
2+980	3,714.00	-.29	-.03
4+886.60	3,708.56	-.29	-.00
5+475.96	3,706.41	-.39	--
6+085.83	3,705.21	-.36	--
6+530.40	3,705.19	-.32	--
7+173.40	3,704.51	-.36	--
7+173.48	3,706.05	-.34	-.05
7+782.59	3,704.04	-.39	--
8+463.51	3,704.51	-.34	--
8+463.51	3,702.46	-.35	--
9+145	3,702.84	-.29	--
9+337.20	3,703.49	-.37	--
9+339.45	3,701.98	-.35	--
9+650.01	3,702.60	-.41	--
9+847.66	3,701.80	-.32	--
10+900.19	3,698.30	-.38	--
11+764.70	3,695.21	-.26	--
12+052	3,690.42	-.24	--
12+517.02	3,692.85	-.29	--
13+220.79	3,691.68	2/ -.21	--
14+444.79	3,690.09	2/ -.20	--
15+385.41	3,688.37	3/ -.23	--
16+567.20	3,686.36	2/ -.26	--
17+273.62	3,682.92	3/ -.26	--
17+315.67	3,684.08	2/ -.28	--
17+701.09	3,681.58	2/ -.22	--
18+485.81	3,680.93	3/ -.17	--
19+435.41	3,681.52	2/ -.12	--
20+113.76	3,679.99	2/ -.09	--
21+015.06	3,678.58	2/ -.05	--
21+469.59	3,677.65	2/ -.05	--
21+919.59	3,676.34	2/ -.05	--
22+129.13	3,675.76	2/ -.02	--
22+929.40	3,673.38	-.07	--
23+525.42	3,671.96	-.05	--
23+751.43	3,672.24	-.04	--
24+053.50	3,669.63	-.09	--
24+314.64	3,669.58	-.02	--
24+547.76	3,671.03	3/ +.07	--
26+402.56	3,664.62	2/ +.04	--
W-1072	3,656.28	--	--

1/ First and last bench marks are those of the National Geodetic Survey; all others are those of the International Boundary and Water Commission.
2/ Bench mark monument raised in 1978. Base was 1967 elevation.
3/ Bench mark monument raised in 1981. Base was 1967 elevation.

a correlation with clay thickness between bench marks RV-1 and E110. Between bench marks Q146 to D146, where the clay thickness is nearly constant, the subsidence shows a decrease with a decrease in water-level decline (fig. 20). These findings support the principles discussed earlier. The cause-and-effect relationship for the southeast line is not as evident (fig. 21). The profiles again illustrate a maximum subsidence in the area of maximum clay thickness.

In an attempt to determine if the preconsolidation stress has been exceede the specific-unit compaction is computed at each data point along the profiles (figs. 20 and 21). A comparison of these specific-unit compaction data with the values listed earlier from other areas may indicate if the preconsolidation stress had been exceeded. The specific-unit compaction during 1952-53 to 1978-79 for these two profiles are tabulated below:

Bench mark (fig. 20)	Specific-unit compaction (foot per foot squared)	Bench mark (fig. 21)	Specific-unit compaction (foot per foot squared)
RV-1	1.4×10^{-5}	P146	1.6×10^{-5}
F146	1.4×10^{-5}	F1072	1.4×10^{-5}
Q146	1.5×10^{-5}	G1072	1.3×10^{-5}
D146	1.5×10^{-5}	H1072	2.2×10^{-5}
E110	1.0×10^{-5}	J1072	2.4×10^{-5}
		K1072	2.7×10^{-5}

Comparing data along lines shows variations by a factor of slightly more than 2 or less. This magnitude is not as large as one would expect between the two stages of stress. However, this alone is not conclusive because both stages may have been in effect during the period of any or all the bench marks. Additional comparisons can be made by comparing the change in water-level and land-surface elevations shown in figures 21 and 22. During the period of measured subsidence, the ranges of water-level declines below predevelopment levels were from 45 to 115 ft at P146 and from 20 to 70 ft at K1072. These ranges are not markedly different than the previously estimated 85 to 115-foot range of preconsolidation stress.

Comparing the specific-unit compaction data tabulated above with the data mentioned earlier shows the El Paso data are comparable to the Tulare-Wasco area and in the low range of the data given in the Houston-Galveston area. As stated earlier, these data from the outside areas are for a period following the exceedance of the preconsolidation stress.

In conclusion, comparing water-level declines implies that preconsolidation stress has not been exceeded, however, calculated spcific-unit compaction values fall in the range of inelastic compaction. In any case, the specific-unit compaction should not increase dramatically as water levels continue to decline.

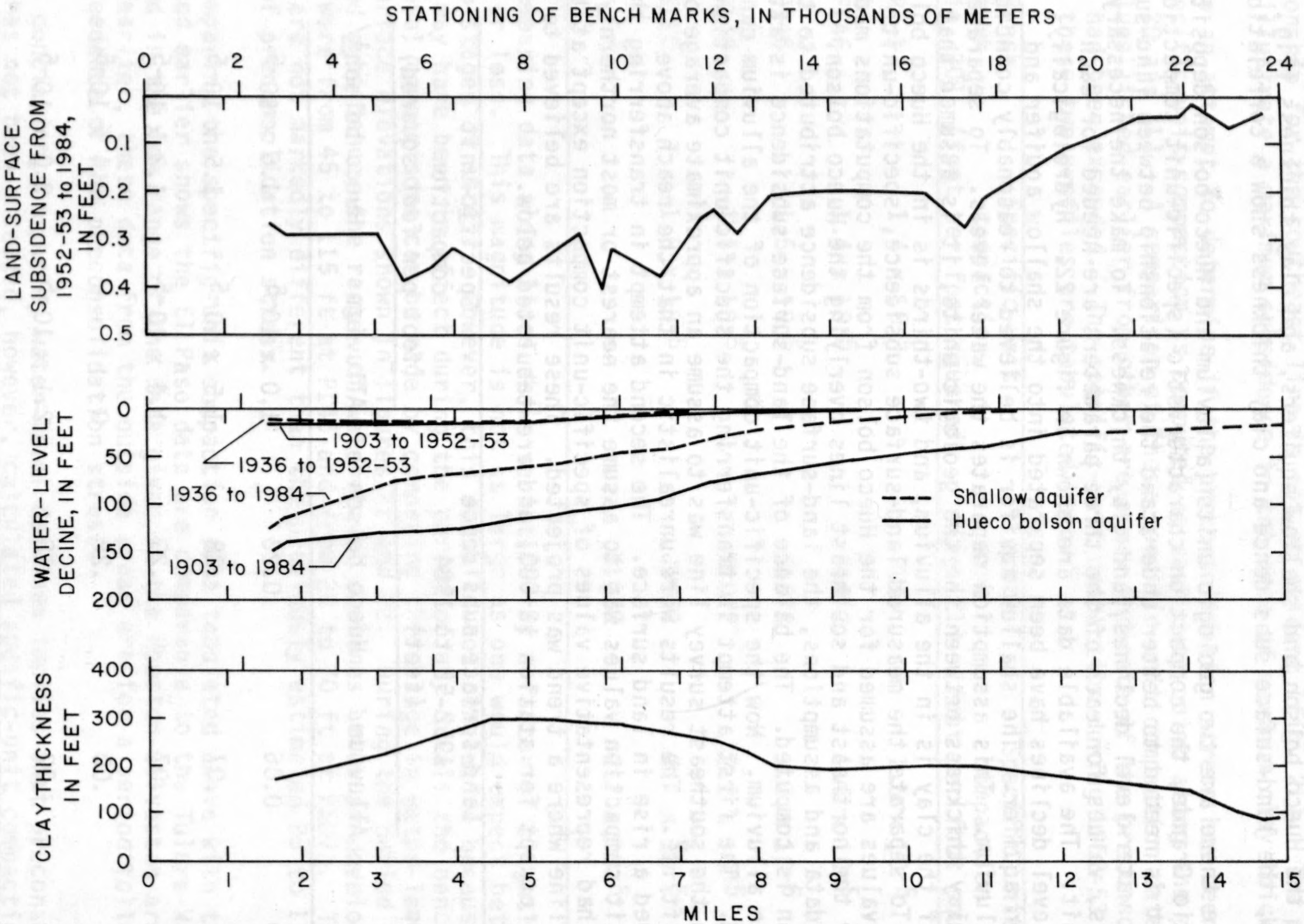
Survey Line Along Rio Grande

As was done for the survey lines to the northeast and southeast, profiles along the Rio Grande were drawn for land-surface subsidence, water-level declines in the Hueco bolson and shallow aquifers, and clay thickness (fig. 22). Again, the land-suface subsidence and clay thickness show a correlation.

Because there are two geologic units (alluvium and Hueco bolson deposits) along the Rio Grande, the compaction characteristic (specific-unit compaction) of each unit is needed to better understand the relationship between land-surface subsidence, water-level declines, and clay thickness. To make the necessary computations, values for each of the three parameters are needed for each geologic unit. The available data are shown in figure 22. Hydrologically, the water-level declines have been separated into the shallow aquifer and Hueco bolson aquifer. The shallow aquifer is believed to reasonably coincide with the alluvium. This assumption separates the water levels. To separate the total clay thickness between the two geologic units, it is assumed that one-third of the clay is in the alluvium, and two-thirds is in the Hueco bolson deposits. To separate the measured land-surface subsidence, specific-unit compaction values are assumed for the Hueco bolson from the computations made earlier for the northeast and southeast lines overlying the Hueco bolson. With these data and assumptions, the land-surface subsidence attributed to the Hueco bolson is computed. The balance of the land-surface subsidence is attributed to the alluvium. Now the specific-unit compaction of the alluvium can be computed. The first attempt in transferring the specific-unit compaction values from the southeast survey line was to assume an approximate average of 2.0×10^{-5} ft/ft^2. The results were unrealistic in that the reach above 10+000 showed a rise in land surface. The second attempt in transferring the specific-unit compaction values was to assume the nearest or most northernly bench mark had representative values of specific-unit compaction except at the end of the line where a trend was projected. These results are believed to be reasonable, except for station 12+000, and are tabulated below.

Station	Land-surface subsidence 1952-53 to 1984 (feet)		Specific-unit compaction (foot per foot squared)	
	Alluvium	Hueco bolson	Alluvium	Hueco bolson 1/
3+000	0.06	0.23	1.0×10^{-5}	1.6×10^{-5}
6+000	.07	.28	1.5×10^{-5}	1.5×10^{-5}
9+000	.07	.25	1.6×10^{-5}	1.3×10^{-5}
12+000	.00	.28	0	2.4×10^{-5}
15+000	.02	.18	2.1×10^{-5}	3.0×10^{-5}

1/ Estimated.


STATIONING OF BENCH MARKS, IN THOUSANDS OF METERS
0
2
4
6
8
10
12
14
16
18
20
22
24
LAND-SURFACE SUBSIDENCE FROM 1952-53 to 1984, IN FEET
0
0.1
0.2
0.3
0.4
0.5
WATER-LEVEL DECINE, IN FEET
0
50
100
150
200
1903 to 1952-53
1936 to 1952-53
1936 to 1984
1903 to 1984
Shallow aquifer
Hueco bolson aquifer
CLAY THICKNESS IN FEET
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
MILES

The conclusions are the same as reached earlier for the northeast and southeast lines that are predominantly or totally underlain by the Hueco bolson. That is, the preconsolidation stress probably has not been reached and the specific-unit compaction will not increase dramatically when the preconsolidation stress is exceeded.

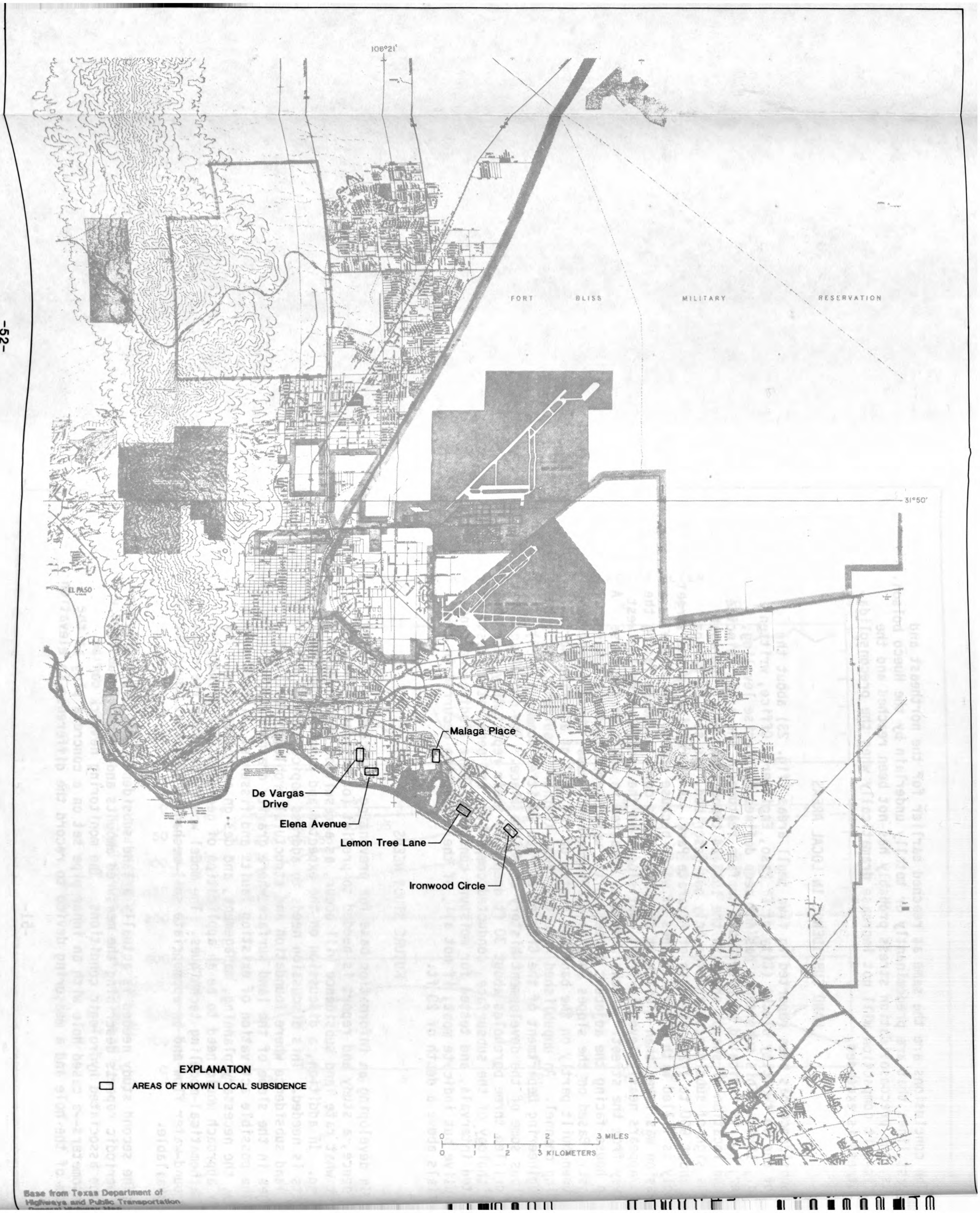
LAND SUBSIDENCE IN LOCAL AREAS

Subsidence has been reported in five small areas (fig. 23) about the size of one to two city blocks (City of El Paso, Engineer's Office, written commun., 1984). This subsidence has not been defined by precise leveling, however, but is indicated by observable surface features. The areas coincide with the location of swamps shown in the 1923-24 topographic map. The most obvious sign of subsidence, and the only one described, was seen on Malaga Place about 900 to 1,200 ft north of Ascarate Park. A depression in the street commonly is filled with several inches of water because the bottom of the depression was lower than a ditch at the base of the curb. A house facing the street appears nearly level in front, but slopes in the rear towards the west and away from the street. Cracks have been repaired in walls of the house. A second house facing the adjacent street to the west seemed to slope towards the east. Based on the slopes and the old topographic maps, these houses may have been built partly on the bank and partly on the fill of a buried north-trending channel. An unpublished report by Ruba-Kistner Consultant, Inc., to the Engineering Department of the City of El Paso (written commun., 1983) describes some of the development history at Malaga Place. The consultant also drilled three boreholes about 30 ft deep. In their report they describe the lithology of the subsurface, conducted compaction and penetration tests at selected intervals, and tested for moisture content. Their findings were not conclusive but indicate most, if not all, of the compaction occurred in clay materials above a depth of 20 ft.

FUTURE STUDY NEEDS

In developing an information base for preventing or accomodating land subsidence, a study and report is needed to predict (or estimate) how much, and at what rate land subsidence will occur, as a result of ground-water pumpage. In addition, a discussion on the expected and possible detrimental effects is needed. This discussion needs to address topics such as differential land subsidence where foundation and structural problems are likely, changes in the slope of the land surface where gravity drains would be affected, and the possible activation of existing faults and fissures. Without such a study, the necessary planning, management, and design cannot be done. The study approach would need to be an application of geohydrologic principles and mathematical-modeling techniques. The model would integrate the equation of ground-water flow and an appropriate soil-mechanics equation. Such models are available.

The second study needed is actually a land subsidence monitoring program with periodic reports describing the measured amounts and rates of subsidence and the associated hydrologic conditions. The monitoring network can be extensometers--a cased hole with an inner pipe set on a concrete plug at the bottom of the hole and a measuring device to record the difference in elevation



Base from Texas Department of Highways and Public Transportation between the top of the rod and a floating concrete pad or lines of bench marks that are periodically resurveyed. In the valley area, two extensometers at a site would be desirable. A deep one would be set below the base of the freshwater to record total compaction and the shallow one at the base of the alluvium to record compaction of the shallow aquifer. Another means of measuring subsidence is periodic releveling of bench marks. Results need to relate the land-subsidence to water levels in the aquifer and attempt to establish the preconsolidation stress in the alluvium and Hueco bolson and coefficients to subsidence/water-level declines/clay thickness equations for elastic and inelastic compaction.

A third study needed is the development of an engineering tool to determine the proportion of subsidence that can be attributed to a water-resources development or management action. Such a tool would have been most useful to the Bureau of Reclamation in determining the proportion of subsidence that could be attributed to the elimination of leakage from the canals and Rio Grande. As in the first study, modeling techniques would be most appropriate. The model developed in the first study may be suitable for this engineering tool.

SUMMARY

The northeast to southeast El Paso area is underlain by Hueco bolson deposits that are as much as 9,000 ft thick. The bolson is filled with fluvial deposits that were eroded from the surrounding mountains and predominantly consist of lenses of gravel, sand, silt, and clay or a mixture of the lithologies. After the basin filled with sediments to about its present level, the Rio Grande breached a gap at the end of the Franklin Mountains and mountains in Mexico and eroded a valley that now contains as much as 200 ft of alluvium whose surface is about 200 to 250 ft lower than the old bolson surface.

Throughout most of the bolson, ground water occurs under water-table conditions. In the El Paso Valley, however, ground water is under water-table conditions in the Rio Grande alluvium, locally known as the shallow aquifer, and under leaky artesian conditions in the underlying bolson deposits. Within this valley area, the freshwater in the bolson deposits is overlain by slightly saline water and underlain by slightly saline and saline water. The water in the shallow aquifer generally is fresh to slightly saline. The clay beds in the deposits of the bolson are discontinuous lenses, and the vertical hydraulic conductivity is substantially less than the horizontal hydraulic conductivity because of these clay beds. The sum of clayey materials in the freshwater part of the aquifer ranges from 50 to 450 ft.

Water levels in the El Paso area have declined as a result of pumping for the area's water supply. Water-level declines since development began are as much as 150 ft in the bolson deposits beneath the downtown area of El Paso and locally as much as 110 ft within 2 mi of the front of the Franklin Mountains. Water levels in the shallow aquifer have declined about 125 ft in the downtown El Paso area.

One of the sources of recharge to the aquifer system is leakage from the Rio Grande and canals. Since 1968, the estimated leakage to the ground-water system from the river has increased from 15,000 to 30,000 acre-ft per year, which is an increase of about 1,000 acre-ft per year. Ground-water withdrawal is the largest contributing factor to this increase. The annual rate of leakage is expected to continue to gradually increase in the near future. Leakage from the canals is small in comparison to that from the river.

Releveling of bench marks along lines to the northeast, southeast, and along the Rio Grande commonly show land-surface subsidence of about 0.2 ft. The maximum measured land-surface subsidence is 0.41 ft along the river in the Chamizal zone. A comparison of land-surface subsidence, water-level declines, and clay thickness along the three survey lines shows the expected correlation of greater land-surface subsidence for thicker accumulated clay material for a given decline in water levels. The preconsolidation stress is estimated to be the equivalent of from 85 to 115 ft of water-level decline on the basis of land-surface subsidence studies in similar hydrologic areas in Arizona, California, and Texas. A study of specific-unit compaction along the three survey lines shows that the values usually range between 1.0 to 2.5 x 10^{-5} ft/ft^2. These values are comparable to the ones computed in the Tulare-Wasco, California, and Houston-Galveston, Texas, areas following the exceedance of the local preconsolidation stress. Because of this comparability, the specific-unit compaction for future periods in the El Paso area probably will not increase dramatically when the preconsolidation stress is exceeded, if it has not already done so. In addition to regional subsidence, local subsidence has been reported in historical swamp areas near the Rio Grande.

Future study needs include predicting the occurrence, timing, and detrimental effects of subsidence, data collection and analysis, and development of engineering tools to estimate the effects of any major water-resources development or management plan.

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Table 8.--Lithology of test holes drilled along Rio Grande and Franklin Canal in 1984

(ft, feet; in., inch)

Test hole: 1R-0

0.0-22.0 ft. Sand.
Predominantly fine sand with a trace of fine gravel. Maximum size: 1 in.

22.0-25.0 ft. Clay.
Predominantly high plasticity fines.

25.0-30.0 ft. Sand.
Predominantly fine sand with a trace of fine gravel. Maximum size: 1 in.

30.0-42.0 ft. Sand.
Prdominantly fine sand with minor fine gravel. Maximum size: 1 in.

42.0-73.0 ft. Gravel.
Predominantly fine to coarse subrounded gravel: With a trace of fine sand. Maximum size: 3 in.

73.0-99.0 ft. Sand.
Same as interval 0.0-22.0 ft.

Test hole: 1R-1

0.0-4.5 ft. Sand.
Mostly fine sand with some nonplastic fines.

4.5-6.0 ft. Clay.
Mostly medium plasticity fines with some fine sand.

6.0-26.0 ft. Sand.
Same as interval 0.0-4.5 ft.

26.0-30.0 ft. Clay.
Predominantly high plasticity fines.

30.0-44.0 ft. Sand.
Same as interval 0.0-4.5 ft.

44.0-62.0 ft. Gravel.
Mostly fine to coarse subrounded gravel with some predominantly coarse sand.

62.0-68.0 ft. Sand.
Predominantly coarse sand.

68.0-69.5 ft. Clay.
Same as interval 4.5-6.0 ft.

Table 8.--Lithology of test holes drilled along Rio Grande and Franklin Canal in 1984--Continued

Test hole: 1R-1--Continued

69.5-70.0 ft. Gravel.
Same as interval 44.0-62.0 ft.

70.0-79.0 ft. Sand.
Mostly fine sand with interbeds of silt and clay.

Test hole: 1R-2

0.0-4.5 ft. Silt.
Predominantly nonplastic fines.

4.5-8.0 ft. Clay.
Mostly low plasticity fines of low toughness with some fine sand.

8.0-9.0 ft. Silt.
Mostly nonplastic fines with some fine sand.

9.0-25.0 ft. Sand.
Predominantly fine sand with minor nonplastic fines.

25.0-28.0 ft. Sand.
Mostly fine sand with some medium plasticity fines: trace fine gravel.

28.0-30.0 ft. Clay.
Predominantly high plasticity fines.

Test hole: 1R-3

0.0-8.0 ft. Silt.
Predominantly nonplastic fines of low dry strength: trace fine to medium sand.

8.0-10.0 ft. Clay.
Mostly low plasticity fines with some fine sand.

10.0-31.0 ft. Silt.
Predominantly nonplastic fines: trace fine to coarse sand.

19.0-23.0 ft. Clay.
Predominantly high plasticity fines.

31.0-33.0 ft. Clay.
Same as interval 19.0-23.0 ft.

33.0-41.0 ft. Sand.
Predominantly coarse sand.

Table 8.--Lithology of test holes drilled along Rio Grande and Franklin Canal in 1984--Continued

Test hole: 1R-3--Continued

41.0-68.0 ft. Gravel.
Mostly fine gravel with some coarse sand. Maximum size: 3/4 in.

68.0-76.0 ft. Clay.
Same as interval 19.0-23.0 ft.

76.0-82.0 ft. Silt.
Same as interval 10.0-31.0 ft.

Test hole: 2R-0

0.0-26.0 ft. Sand.
Predominantly fine sand with no detectable fines.

26.0-33.0 ft. Clay.
Predominantly high plasticity fines with no detectable sand.

33.0-41.0 ft. Sand.
Same as interval 0.0-26.0.

41.0-46.0 ft. Gravel.
Predominantly fine to coarse subrounded gravel. Maximum size: 2-1/2 in.

46.0-49.0 ft. Gravel.
Mostly fine to coarse gravel with some high plasticity fines. Maximum size: 2-1/2 in.

Test hole: 2R-1

0.0-30.0 ft. Sand.
Predominantly fine sand: trace nonplastic fines.

Test hole: 2R-2

0.0-5.0 ft. Silt.
Predominantly nonplastic fines.

5.0-20.0 ft. Sand.
Predominantly fine sand.

16.0-17.0 ft. Clay.
Predominantly high plasticity fines.

Table 8.--Lithology of test holes drilled along Rio Grande and Franklin Canal in 1984--Continued

Test hole: 2R-3

0.0-2.0 ft. Silt.
Predominantly nonplastic fines.

2.0-7.0 ft. Sand.
Predominantly fine sand: trace nonplastic fines.

7.0-10.0 ft. Clay.
Mostly medium plasticity fines of low toughness with some fine sand.

10.0-21.0 ft. Sand.
Same as interval 2.0-7.0 ft.

21.0-24.0 ft. Clay.
Predominantly high plasticity fines.

24.0-30.0 ft. Sand.
Same as interval 2.0-7.0 ft.

Test hole: 3R-0

0.0-13.0 ft. Silt.
Mostly nonplastic fines with some fine sand. Some interbeds of high plasticity fines.

13.0-29.0 ft. Sand.
Predominantly fine sand with minor nonplastic fines.

Test hole: 3R-1

0.0-13.0 ft. Silt.
Mostly nonplastic fines with some predominantly fine sand.

13.0-25.0 ft. Sand.
Predominantly fine sand: trace nonplastic fines.

Test hole: 3R-2

0.0-10.0 ft. Silt.
Predominantly nonplastic fines.

10.0-15.0 ft. Sand.
Predominantly fine sand: trace nonplastic fines.

Table 8.--Lithology of test holes drilled along Rio Grande and Franklin Canal in 1984--Continued

Test hole: 3R-3

0.0-7.0 ft. Silt.
Predominantly nonplastic fines.

7.0-9.0 ft. Clay.
Predominantly high plasticity fines.

9.0-25.0 ft. Sand.
Predominantly fine sand: trace nonplastic fines.

Test hole: 4R-1

0.0-2.0 ft. Silt.
Predominantly nonplastic fines.

2.0-3.0 ft. Clay.
Predominantly high plasticity fines.

3.0-15.0 ft. Sand.
Predominantly fine sand: trace nonplastic fines.

Test hole: 5R-1

0.0-2.0 ft. Silt.
Predominantly nonplastic fines.

2.0-15.0 ft. Sand.
Predominantly fine sand: trace nonplastic fines.

Test hole: 1C-0

0.0-4.5 ft. Silt.
Mostly nonplastic fines with some fine sand.

4.5-17.0 ft. Clay.
Predominantly high plasticity fines: minor find send.

17.0-20.0 ft. Silt.
Mostly nonplastic fines with some fine sand.

20.0-32.0 ft. Clay.
Mostly high plasticity fines: some predominantly fine sand and minor fine to medium subrounded gravel. Maximum size: 2 in.

Table 8.--Lithology of test holes drilled along Rio Grande and Franklin Canal in 1984--Continued

Test hole: 1C-0--Continued

32.0-74.0 ft. Gravel.
Mostly fine to coarse subrounded gravel with some coarse sand. Maximum size: 2-1/2 in.

74.0-102.0 ft. Clay.
Predominantly high plasticity fines. Minor interbedded gravel layers.

102.0-113.0 ft. Sand.
Mostly fine sand with some nonplastic fines.

113.0-129.0 ft. Gravel.
Mostly fine to coarse subrounded gravel with some fine to coarse sand. Maximum size: 3 in.

Test hole: 1C-1

0.0-5.5 ft. Silt.
Mostly nonplastic fines with some fine sand.

5.5-10.0 ft. Clay.
Predominantly high plasticity fines with some fine sand.

10.0-25.0 ft. Silt.
Mostly nonplastic fines with some fine sand.

25.0-27.0 ft. Clay.
Mostly medium to high plasticity fines of medium toughness with some fine sand and minor fine gravel.

27.0-28.0 ft. Sand.
Predominantly fine sand.

28.0-31.0 ft. Clay.
Predominantly high plasticity fines: trace fine sand.

31.0-36.0 ft. Clay.
Mostly high plasticity fines of medium to high toughness with some fine sand.

36.0-38.0 ft. Sand.
Predominantly fine sand: trace fine gravel.

38.0-73.0 ft. Gravel.
Mostly medium subrounded gravel with some predominantly coarse sand. Maximum size: 1 in.

Table 8.--Lithology of test holes drilled along Rio Grande and Franklin Canal in 1984--Continued

Test hole: 1C-1--Continued

73.0-99.0 ft. Clay.
Predominantly high plasticity fines: minor fine sand: trace fine gravel.

99.0-113.0 ft. Sand.
Mostly fine sand with some nonplastic fines.

113.0-122.0 ft. Gravel.
Mostly fine subrounded gravel with some medium plasticity fines.

Test hole: 2C-0

0.0-11.0 ft. Clay.
Predominantly high plasticity fines: minor fine sand.

11.0-31.0 ft. Sand.
Predominantly fine sand.

31.0-39.0 ft. Clay.
Mostly medium to high plasticity fines: some fine sand: trace fine gravel. Maximum size: 3/4 in.

39.0-41.0 ft. Sand.
Predominantly coarse sand.

41.0-63.0 ft. Gravel.
Mostly subangular to subrounded, fine to coarse gravel; some predominantly coarse sand. Maximum size: 3 in.

63.0-78.0 ft. Sand.
Predominantly coarse sand with minor medium gravel. Maximum size: 1 in.

78.0-83.0 ft. Clay.
Mostly medium to high plasticity fines: some fine sand. Maximum size: fine sand.

83.0-101.0 ft. Sand.
Mostly coarse sand with some fine gravel. Maximum size: 3/4 in.

Test hole: 2C-1

0.0-9.0 ft. Clay.
Predominantly high plasticity fines of medium to high toughness: minor fine sand.

9.0-29.5 ft. Sand.
Predominantly fine sand.

Table 8.--Lithology of test holes drilled along Rio Grande and Franklin Canal in 1984--Continued

Test hole: 2C-1--Continued

29.5-34.0 ft. Clay.
Mostly medium to high plasticity fines with some predominantly fine sand and a trace of fine gravel.

34.0-70.0 ft. Gravel.
Mostly medium subrounded gravel with some predominantly coarse sand. Maximum size: 2-1/2 in.

70.0-79.0 ft. Sand.
Mostly coarse sand with some predominantly fine gravel. Maximum size: 1 in.

79.0-84.0 ft. Clay.
Mostly medium plasticity fines of medium toughness with some fine sand.

64.0-100.0 ft. Sand.
Mostly coarse sand with some fine gravel. Maximum size: 1 in.

Test hole: 2C-2

0.0-11.0 ft. Clay.
Predominantly high plasticity fines: trace fine sand.

11.0-43.0 ft. Sand.
Predominantly fine sand with trace fines.

43.0-46.0 ft. Gravel.
Mostly fine subrounded gravel with some predominantly coarse sand. Maximum size: 1 in.

Test hole: 2C-3

0.0-11.0 ft. Clay.
Predominantly high plasticity fines: trace fine sand.

11.0-20.0 ft. Sand.
Predominantly fine sand: trace fines.

Test hole: 2C-4

0.0-3.0 ft. Silt.
Predominantly low plasticity fines.

3.0-7.0 ft. Clay.
Predominantly high plasticity fines of high toughness.

Test hole: 2C-4--Continued

7.0-19.0 ft. Sand.
Predominantly fine sand.

19.0-30.0 ft. Clay.
Mostly medium plasticity fines.

22.0-28.0 ft. Sand.
Predominantly fine sand.

30.0-40.0 ft. Clay.
Mostly medium plasticity fines of medium toughness with some fine to coarse sand: minor gravel. Maximum size: 1 in.

40.0-65.0 ft. Gravel.
Mostly fine to coarse subrounded gravel with some predominantly coarse sand. Maximum size: 2-1/2 in.

65.0-70.0 ft. Sand.
Predominantly coarse sand with minor gravel. Maximum size: 1 in.

70.0-86.0 ft. Clay.
Same as interval 30.0-40.0 ft.

86.0-100.0 ft. Sand.
Mostly fine sand with some nonplastic fines.

Test hole: 3C-0

0.0-21.0 ft. Clay.
Predominantly high plasticity fines: trace fine sand.

21.0-36.0 ft. Sand.
Predominantly fine sand with minor nonplastic fines. Subangular gravel at 26.0 ft. Maximum size: 1 in.

36.0-44.0 ft. Clay.
Predominantly high plasticity fines. Minor predominantly coarse sand and trace fine gravel. Maximum size: 1 in.

44.0-53.0 ft. Sand.
Predominantly fine sand with minor fine gravel. Maximum size: 1 in.

53.0-74.0 ft. Gravel.
Mostly fine gravel with some coarse sand. Subangular to subrounded.

74.0-99.0 ft. Sand.
Mostly coarse sand with some fine subangular to subrounded gravel. Maximum size: 1/2 in.

Table 8.--Lithology of test holes drilled along Rio Grande and Franklin Canal in 1984--Continued

Test hole: 3C-1

0.0-22.0 ft. Clay.
Predominantly high plasticity fines: minor fine sand.

22.0-31.0 ft. Sand.
Predominantly fine sand with a trace of fines and a trace of gravel. Maximum size: 1 in.

31.0-42.0 ft. Clay.
Predominantly high plasticity fines of high toughness: minor coarse sand: trace of fine gravel.

42.0-80.0 ft. Gravel.
Mostly fine subangular to subrounded gravel: some predominantly coarse sand.

80.0-108.0 ft. Sand.
Predominantly fine sand with a trace of fine gravel.

108.0-109.0 ft. Clay.
Predominantly medium to high plasticity fines of medium to high toughness: trace sand: trace gravel. Maximum size: 1 in.

Test hole: 3C-2

0.0-23.0 ft. Clay.
Predominantly high plasticity fines: trace fine sand.

23.0-34.0 ft. Sand.
Predominantly fine sand with minor nonplastic fines.

34.0-35.0 ft. Clay.
Same as interval 0.0-23.0 ft.

35.0-37.0 ft. Sand.
Mostly fine sand with some medium subrounded gravel. Maximum size: 2 in.

37.0-43.0 ft. Clay.
Same as interval 0.0-23.0 ft.

43.0-46.0 ft. Gravel.
Predominantly medium subrounded gravel. Maximum size: 2 in.

Test hole: 3C-3

0.0-20.0 ft. Clay.
Predominantly high plasticity fines of high toughness: trace fine sand.

Table 8.--Lithology of test holes drilled along Rio Grande and Franklin Canal in 1984--Continued

Test hole: 3C-4

0.0-7.0 ft. Sand.
Mostly fine sand with some nonplastic fines: trace coarse sand.

7.0-9.0 ft. Sand.
Predominantly fine sand with minor coarse sand.

9.0-11.0 ft. Clay.
Mostly medium to high plasticity fines of medium toughness with some predominantly fine sand: trace fine gravel.

11.0-14.0 ft. Sand.
Same as interval 0.0-7.0 ft.

14.0-20.0 ft. Sand.
Same as interval 7.0-9.0 ft.

20.0-25.0 ft. Clay.
Predominantly medium plasticity fines of medium toughness with minor fine sand.

25.0-35.0 ft. Sand.
Mostly fine sand with some medium plasticity fines of low toughness.

35.0-43.0 ft. Clay.
Mostly medium plasticity fines of medium toughness with some fine sand.

43.0-48.0 ft. Sand.
Predominantly coarse sand with minor fine gravel. Maximum size: 3/4 in.

48.0-85.0 ft. Sand and gravel.
Coarse sand and fine gravel. Maximum size: 1 in.

85.0-89.0 ft. Clay.
Same as interval 35.0-43.0 ft.

89.0-109.0 ft. Sand and gravel.
Predominantly coarse sand and predominantly fine gravel. Maximum size: 1 in.

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells

Well number: JL 49-05-207
Estimated 1903 water level: 391 feet

Interval, in feet below land surface	Thickness, in feet
403-411	8
422-427	5
433-441	8
464-470	6
514-517	3
534-540	6
562-564	2
576-580	4
589-591	2
610-612	2
651-563	2
656-658	2

668 (Base of fresh water)

Well number: JL 49-05-504
Estimated 1903 water level: 417 feet

Interval, in feet below land surface	Thickness, in feet
417-420	3
440-558	8
455-458	3
459-474	15
484-486	2
497-499	2
512-515	3
538-544	6
578-592	14
600-613	13
648-659	11
663-672	9
697-721	24
728-748	20
760-766	6
772-774	2
777-778	1
787-799	12
816-818	2
829-830	1
848-856	8
860-878	18
908-916	8
921-931	10
978-986	8
1,010-1,012	2
1,033-1,036	3
1,056-1,064	8
1,070-1,088	18
1,104-1,106	2
1,112-1,117	5

1,151 (Base of fresh water)

Well number: JL 49-05-506
Estimated 1903 water level: 418 feet

Interval, in feet below land surface	Thickness, in feet
421-427	6
435-438	3
448-462	14
468-473	5
504-508	4
526-530	4
545-548	3
555-560	5
575-579	4

607 (Base of fresh water)

Well number: JL 49-05-614
Estimated 1903 water level: 276 feet

Interval, in feet below land surface	Thickness, in feet
313-333	20
344-350	6
356-366	10
372-376	4
410-429	19
444-448	4
454-462	8
512-526	14
532-546	14
551-556	5
632-642	10
650-654	4
665-668	3
672-676	4

701 (Base of fresh water)

Well number: JL 49-05-615
Estimated 1903 water level: 245 feet

Interval, in feet below land surface	Thickness, in feet
249-274	25
286-298	12
323-354	31
359-363	4
380-393	13
398-402	4
407-419	12
438-440	2
449-463	14
488-490	2

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-05-615--Continued

Interval, in feet below land surface	Thickness, in feet
493-502	9
504-511	7
519-521	2
525-554	29
593-607	14
622-628	6
636-641	5
650-664	14
678-713	35
718-720	2
724-728	4
739-749	10
757-759	2
774-779	5
790-805	15
814-823	9
828-830	2
833-841	8
849-851	2
866-890	24
901-904	3
906-910	4

920 (Base of fresh water)

Well number: JL 49-05-801
Estimated 1903 water level: 381 feet

Interval, in feet below land surface	Thickness, in feet
384-393	9
398-407	9
410-422	12
438-448	10
457-458	1
467-470	3
498-505	7
508-511	3
528-531	3
541-546	5
557-561	4
569-574	5
576-580	4
594-607	13
635-643	7
646-658	12
660-667	7
690-694	4
704-716	12
722-742	20
750-762	12
781-805	24
811-825	14
834-840	6
858-912	54

Well number: JL 49-05-801--Continued

Interval, in feet below land surface	Thickness, in feet
916-932	16
955-966	11
972-982	10
988-1,002	14
1,008-1,010	2
1,017-1,032	15
1,047-1,068	21
1,070-1,082	12
1,086-1,090	4
1,103-1,105	2
1,122-1,138	16
1,145-1,170	25
1,189-1,195	6
1,203-1,217	14
1,241-1,246	5
1,248-1,261	13

1,241 (Base of fresh water)

Well number: JL 49-05-802
Estimated 1903 water level: 264 feet

Interval, in feet below land surface	Thickness, in feet
290-294	4
300-301	1
316-323	7
327-333	6
341-357	16
362-363	1
378-389	11
421-423	2
430-436	6
443-452	9
456-466	10
488-489	1
513-530	17
560-564	4
583-592	9
616-624	8
639-653	14
659-661	2
670-686	16
688-705	17
710-712	2
727-745	18

774 (Base of fresh water)

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-05-803
Estimated 1903 water level: 250 feet

Interval, in feet below land surface	Thickness, in feet
264-270	6
282-296	14
323-333	10
356-362	6
385-387	2
430-448	18
471-486	15
516-519	3
541-570	29
590-596	6
624-642	18
646-662	16
666-674	8
678-679	1
690-697	7
701-717	16
720-727	7
732-740	8
782-800	18
813-815	2
832-850	18
851-870	19
884-890	6
922-934	12
952-972	20

1,001 (Base of fresh water)

Well number: JL 49-05-804
Estimated 1903 water level: 204 feet

Interval, in feet below land surface	Thickness, in feet
204-209	5
228-243	15
255-261	6
274-281	7
285-297	12
274-281	7
283-295	12
309-318	9
328-333	5
345-347	2
352-356	4
376-391	15
410-411	1
428-434	6
458-465	7
470-498	28
520-535	15
560-570	10
575-581	6
589-596	7

Well number: JL 49-05-804--Continued

Interval, in feet below land surface	Thickness, in feet
608-622	14
630-639	9
660-673	13
694-720	26
754-762	8
787-813	26

824 (Total depth)

Well number: JL 49-05-805
Estimated 1903 water level: 188 feet

Interval, in feet below land surface	Thickness, in feet
217-220	3
225-228	3
248-280	32
297-343	46
354-357	3
374-376	2
406-418	12
487-507	20
514-546	32
560-568	8
577-591	14
602-614	12
625-631	6
646-659	13
664-684	20
696-709	13
737-763	26
765-773	8

834 (Base of fresh water)

Well number: JL 49-05-901
Estimated 1903 water level: 238 feet

Interval, in feet below land surface	Thickness, in feet
250-269	19
274-293	19
309-322	13
328-335	7
348-354	6
358-386	28
388-398	10
401-406	5
410-415	5
417-423	6
446-450	4
456-461	5
470-471	1
484-497	13
512-516	4

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-05-902--Continued

Interval, in feet below land surface	Thickness, in feet
519-535	16
543-553	10
559-566	7
572-587	15
608-610	2
641-646	5
660-663	3
675-683	8
712-718	6
725-739	14
742-776	34
786-804	18
817-829	12

838 (Total depth)

Well number: JL 49-05-902
Estimated 1903 water level: 230 feet

Interval, in feet below land surface	Thickness, in feet
230-236	6
251-257	6
264-275	11
288-292	4
297-312	15
329-341	12
358-364	6
381-384	3
398-418	20
430-450	20
470-472	2
488-512	24
550-556	6
574-587	13
600-601	1
626-628	2
661-663	2
676-700	24
714-718	4
727-736	9
750-772	22
782-784	2
811-816	5
820-826	6

838 (Total depth)

Well number: JL 49-05-903
Estimated 1903 water level: 204 feet

Interval, in feet below land surface	Thickness, in feet
212-230	18
249-260	11
287-300	13
315-320	5
326-332	6
346-374	28
407-438	31
442-472	30
475-496	21
500-504	4
513-526	13
543-553	10
564-572	8
589-597	8
624-658	34
669-673	4
701-713	12
717-720	3
721-752	31
753-768	15
782-786	4
800-802	2
815-820	5
824-829	5
835-839	4
892-903	11
920-932	12
940-976	36
986-988	2
1,051-1,068	17
1,079-1,094	15
1,113-1,122	9
1,141-1,147	6
1,169-1,183	14
1,187-1,196	9
1,218-1,229	11
1,233-1,241	8

1,051 (Base of fresh water)

Well number: JL 49-05-906
Estimated 1903 water level: 214 feet

Interval, in feet below land surface	Thickness, in feet
214-223	9
232-252	20
266-273	7
344-346	2
349-351	2
354-361	7
394-396	2
420-423	3
430-432	2
448-449	1

Well number: JL 49-05-906--Continued

Interval, in feet below land surface	Thickness, in feet
504-510	6
540-541	1
543-560	17
565-568	3
572-576	4
597-601	4
634-637	3
675-678	3
683-685	2
706-710	4
716-718	2
726-728	2
738-749	11
781-785	4
793-810	17
838-840	2
853-854	1
860-878	18
910-914	4
948-960	12
962-968	6
976-988	12
991-998	7
1,003-1,004	1
1,009-1,010	1
1,019-1,022	3
1,081-1,087	6
1,096-1,104	8

1,080 (Base of fresh water)

Well number: JL 49-06-101
Estimated 1903 water level: 309 feet

Interval, in feet below land surface	Thickness, in feet
318-326	8
338-346	8
358-361	3
362-363	1
375-379	4
408-433	25
438-447	9
452-453	1
468-469	1
480-481	1
486-496	10
514-516	2
524-526	2
546-548	2
594-600	6
619-622	3
631-633	2
648-652	4
668-670	2

684 (Base of fresh water)

Well number: JL 49-06-102
Estimated 1903 water level: 328 feet

Interval, in feet below land surface	Thickness, in feet
340-353	13
370-378	8
400-403	3
413-420	7
434-453	19
468-480	12
520-539	19
543-545	2
550-555	5
564-570	6
598-602	4

641 (Base of fresh water)

Well number: JL 49-06-104
Estimated 1903 water level: 318 feet

Interval, in feet below land surface	Thickness, in feet
342-358	16
437-442	5
453-456	3
471-472	1
485-486	1
499-501	2
507-520	13

550 (Base of fresh water)

Well number: JL 49-06-201
Estimated 1903 water level: 278 feet

Interval, in feet below land surface	Thickness, in feet
285-309	24
316-318	2
329-331	2
338-357	19
361-363	2
398-406	8
418-441	23
471-478	7
522-526	4
538-558	20
596-624	28

644 (Base of fresh water)

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-06-401
Estimated 1903 water level: 285 feet

Interval, in feet below land surface	Thickness, in feet
291-299	8
304-306	2
307-329	22
377-383	6
454-458	4
462-463	1
478-482	4
498-499	1
502-503	1
512-514	2
532-536	4
540-543	3
553-557	4
565-572	7
588-589	1
607-609	2
614-615	1
621-622	1
624-629	5
632-640	8
652-661	9
680-683	3
735-737	2

607 (Base of fresh water)

Well number: JL 49-06-402
Estimated 1903 water level: 307 feet

Interval, in feet below land surface	Thickness, in feet
340-348	8
359-373	14
399-402	3
495-498	3
530-531	1
573-576	3
603-614	11
616-619	3
650.5-651.5	1
665-666	1
670-671	1
674-679	5
694-696	2

756 (Base of fresh water)

Well number: JL 49-06-501
Estimated 1903 water level: 262 feet

Interval, in feet below land surface	Thickness, in feet
272-279	7
292-300	8
356-368	12
376-398	22
408-416	8
430-432	2
438-440	2
449-455	6
500-506	6
510-516	6
529-544	15
565-573	8
588-589	1
594-605	11
616-620	4
633-636	3
645-648	3
661-663	2
669-672	3

616 (Base of fresh water)

Well number: JL 49-06-601
Estimated 1903 water level: 301 feet

Interval, in feet below land surface	Thickness, in feet
303-308	5
313-330	17
360-366	6
371-377	6
405-409	4
414-422	8
436-443	7
468-480	12
502-520	18
558-560	2
574-578	4
584-593	9
598-607	9
615-617	2
629-635	6
642-664	22
672-674	2
705-708	3
722-724	2
727-728	1
751-760	9
769-771	2
782-783	1

791 (Base of fresh water)

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-07-803
Estimated 1903 water level: 35 feet

Interval, in feet below land surface	Thickness, in feet
70-73	3
118-155	37
175-177	2
188-210	22
253-261	8
264-300	36
317-326	9
342-414	72
430-438	8
454-520	66
532-556	24
559-565	6
611-644	33

661 (Base of fresh water)

Well number: JL 49-13-203
Estimated 1903 water level: 182 feet

Interval, in feet below land surface	Thickness, in feet
183-190	7
212-216	4
223-233	10
256-276	20
293-298	5
300-303	3
327-332	5
338-340	2
348-349	1
356-368	12
380-410	30
413-418	5
430-434	4
437-449	12
463-472	9
475-488	13
500-523	23
524-530	6
551-567	16
582-592	10
593-597	4
605-641	36
665-703	38
707-708	1
739-780	41
788-809	21
835-837	2
842-850	8
855-888	33
893-895	2

Well number: JL 49-13-203--Continued

Interval, in feet below land surface	Thickness, in feet
900-915	15
934-940	6
947-975	28
1,000-1,002	2
1,012-1,025	13
1,040-1,060	20
1,085-1,092	7
1,105-1,114	9

1,128 (Base fresh water)

Well number: JL 49-13-204
Estimated 1903 water level: 182 feet

Interval, in feet below land surface	Thickness, in feet
189-190	1
203-220	17
228-234	6
257-270	13
273-275	2
282-285	3
289-297	8
298-301	3
308-323	15
330-331	1
337-343	6
361-369	8
371-373	2
382-395	13
406-410	4
426-450	24
463-470	7
473-474	1
475-476	1
495-508	13
515-527	12
545-550	5
587-596	9
611-613	2
615-622	7
625-658	33
667-683	16
698-715	17
745-747	2
750-757	7
770-775	5
778-800	22
817-831	14
835-859	24
865-870	5

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-13-204--Continued

Interval, in feet below land surface	Thickness, in feet
872-873	1
875-882	7
892-895	3
910-966	56
1,007-1,012	5
1,022-1,030	8
1,035-1,045	10
1,050-1,062	12
1,075-1,080	5
1,082-1,084	2
1,085-1,086	1
1,088-1,089	1
1,098-1,100	2

1,007 (Base fresh water)

Well number: JL 49-13-307
Estimated 1903 water level: 198 feet

Interval, in feet below land surface	Thickness, in feet
198-200	2
201-202	1
212-217	5
219-223	4
232-234	2
235-240	5
256-258	2
270-276	6
282-284	2
337-339	2
344-346	2
358-359	1
366-376	10
380-382	2
394-396	2
409-411	2
428-437	9
449-462	13
471-472	1
498-505	7
508-513	5
530-531	1
552-556	4
557-558	1
568-572	4
573-574	1
576-577	1
598-606	8
626-650	24
661-663	2

Well number: JL 49-13-307--Continued

Interval, in feet below land surface	Thickness, in feet
666-668	2
683-686	3
688-694	6
719-729	10

743 (Base of fresh water)

Well number: JL 49-13-506
Estimated 1903 water level: 198 feet

Interval, in feet below land surface	Thickness, in feet
198-200	2
214-223	9
232-240	8
242-249	7
255-258	3
262-267	5
274-291	17
303-309	6
314-316	2
322-325	3
327-333	6
334-342	8
349-362	13
384-393	9
400-409	9
412-423	11
427-436	9
438-442	4
444-453	9
456-461	5
464-493	29
496-504	8
519-525	6
540-551	11
573-601	28
608-628	20
630-636	6
640-643	3
660-670	10
682-706	24
709-712	3
722-727	5
741-750	9
757-775	18
786-793	7
804-818	14
855-872	17
891-896	5

902 (Total depth)

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-13-511
Estimated 1903 water level: 177 feet

Interval, in feet below land surface	Thickness, in feet
177-199	22
202-205	3
211-227	16
231-247	16
263-274	11
286-300	14
310-325	15
338-345	7
347-355	8
361-371	10
373-384	11
410-430	20
432-442	10
456-459	3
466-478	12
482-488	6
504-508	4
520-532	12
540-562	22
592-597	5
600-602	2
610-620	10
622-628	6
630-663	33
664-682	18
692-698	6
718-725	7
728-733	5
748-765	17
774-787	13
790-795	5
799-802	3
810-812	2
816-822	6

838 (Total depth)

Well number: JL 49-13-607
Estimated 1903 water level: 220 feet

Interval, in feet below land surface	Thickness, in feet
260-280	20
312-322	10
330-333	3
355-393	38
408-438	30
448-460	12
465-473	8
480-498	18
505-527	22
536-545	9

Well number: JL 49-13-607--Continued

Interval, in feet below land surface	Thickness, in feet
580-597	17
640-643	3
650-657	7
676-695	19
705-715	10
730-739	9
741-778	37
810-835	25
865-890	25
893-915	22
935-942	7
946-954	8
972-1,020	48

1,065 (Base of fresh water)

Well number: JL 49-13-608
Estimated 1903 water level: 222 feet

Interval, in feet below land surface	Thickness, in feet
222-250	28
262-275	13
298-311	13
317-323	6
347-352	5
360-365	5
372-380	8
394-398	4
404-422	18
446-461	15
464-476	12
480-483	3
498-510	12
519-527	8
539-540	1
545-547	2
549-572	23
580-600	20
620-630	10
692-702	10
717-727	10
740-752	12
755-771	16
774-786	12
790-801	11
842-858	16
872-876	4
917-924	7
939-955	16
964-983	19
1,001-1,007	6

1,022 (Total depth)

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-13-702
Estimated 1903 water level: 19 feet

Interval, in feet below land surface	Thickness, in feet
87-89	2
90-105	15
210-220	10
235-247	12
268-276	8
278-300	22
306-313	7
316-323	7
325-335	10
355-395	40
480-482	2
570-592	22
611-629	18
640-645	5
672-675	3
685-691	6
715-723	8

745 (Base of fresh water)

Well number: JL 49-13-704
Estimated 1903 water level: 13 feet

Interval, in feet below land surface	Thickness, in feet
57-62	5
70-75	5
95-96	1
102-112	10
178-183	5
200-207	7
219-253	34
263-292	29
320-350	30
355-360	5
384-398	14
463-475	12
482-505	23
536-542	6
560-576	16
598-614	16
648-650	2
681-682	1

718 (Base of fresh water)

Well number: JL 49-13-710
Estimated 1903 water level: 14 feet

Interval, in feet below land surface	Thickness, in feet
32-38	6
44-47	3
70-82	12
88-89	1
114-122	8
134-136	2
150-151	1
183-184	1
216-217	1
226-227	1
234-235	1
240-242	2
266-268	2
269-274	5
281-283	2
304-308	4
311-315	4
331-332	1
341-342	1
355-357	2
381-383	2
384-388	4
389-390	1
392-393	1
413-414	1
421-424	3
438-439	1
466-472	6
486-488	2
490-504	14
548-555	7
606-634	28
656-666	10
730-733	3

757 (Base of fresh water)

Well number: JL 49-13-711
Estimated 1903 water level: 24 feet

Interval, in feet below land surface	Thickness, in feet
46-64	18
84-88	4
108-112	4
157-171	14
164-167	3
188-194	6
216-224	8
270-274	4
296-298	2
300-302	2

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-13-711--Continued

Interval, in feet below land surface	Thickness, in feet
319-326	7
332-337	5
356-365	9
369-377	8
398-412	14
419-423	4
431-432	1
435-436	1
440-456	16
468-473	5
477-478	1
482-483	1
486-490	4
496-501	5
506-525	19
556-570	14
573-587	14

637 (Base of fresh water)

Well number: JL 49-13-726
Estimated 1903 water level: 20 feet

Interval, in feet below land surface	Thickness, in feet
48-57	9
94-108	14
124-128	4
134-137	3
167-169	2
173-181	8
193-194	1
204-209	5
212-220	8
233-240	7
244-260	16
282-300	18
309-312	3
341-343	2
379-381	2
395-412	17
429-439	10
467-468	1
472-496	24
497-504	7
511-526	15
544-545	1
572-586	14
594-596	2
597-599	2
612-624	12
652-654	2
663-668	5
710-713	3
734-741	7

Well number: JL 49-13-726--Continued

Interval, in feet below land surface	Thickness, in feet
755-758	3
796-806	10
824-825	1
830-834	4
838-846	8

710 (Base of fresh water)

Well number: JL 49-13-727
Estimated 1903 water level: 14 feet

Interval, in feet below land surface	Thickness, in feet
35-42	7
92-98	6
135-143	9
172-176	4
187-195	8
222-230	8
232-241	9
250-263	13
265-272	7
300-325	25
368-371	13
441-454	13
460-469	9
471-481	10
505-516	11
534-544	10
565-584	19
629-633	4
664-668	4
685-686	1

710 (Base of fresh water)

Well number: JL 49-13-806
Estimated 1903 water level: 20 feet

Interval, in feet below land surface	Thickness, in feet
45-48	3
82-85	3
106-109	3
130-135	5
137-145	8
160-177	17
199-220	21
242-248	6
257-280	23
303-324	21
349-357	8
370-384	14
399-418	19
419-421	2
423-425	2

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-13-806--Continued

Interval, in feet below land surface	Thickness, in feet
431-438	7
458-474	16
490-498	8
506-531	25
555-561	6
579-581	2
617-627	10
646-660	14
684-691	7
725-730	5
735-761	26

778 (Base of fresh water)

Well number: JL 49-13-810
Estimated 1903 water level: 97 feet

Interval, in feet below land surface	Thickness, in feet
108-109	1
110-113	3
114-116	2
117-121	4
122-123	1
147-149	2
150-158	8
186-188	2
191-192	1
193-195	2
202-203	1
205-206	1
230-235	5
241-242	1
250-253	3
261-263	2
269-271	2
274-279	5
298-299	1
300-302	2
304-311	7
328-334	6
344-353	9
359-360	1
369-370	1
376-379	3
390-394	4
396-406	10
416-425	9
439-441	2
459-474	15
527-530	3
531-535	4
545-546	1
547-548	1

Well number: JL 49-13-810--Continued

Interval, in feet below land surface	Thickness, in feet
549-551	2
553-554	1
556-558	2
574-578	4
590-592	2
622-628	6
651-652	1
689-690	1
711-715	4
732-737	5
763-767	4
796-797	1
801-802	1
821-824	3
830-831	1
849-851	2
855-856	1

876 (Base of fresh water)

Well number: JL 49-13-822
Estimated 1903 water level: 13 feet

Interval, in feet below land surface	Thickness, in feet
111-124	13
153-176	23
179-182	3
184-198	14
214-222	8
229-235	6
239-242	3
279-299	20
307-311	4
340-343	3
347-367	20
400-429	29
436-442	6
484-496	12
498-500	2
512-514	2
518-550	32
563-568	5
581-582	1
588-594	6
599-601	2
604-606	2
624-626	2
631-639	8
646-658	12

Well number: JL 49-13-822, Continued

Interval, in feet below land surface	Thickness, in feet
667-669	2
695-697	2
707-712	5

748 (Base of fresh water)

Well number: JL 49-13-823
Estimated 1903 water level: 14 feet

Interval, in feet below land surface	Thickness, in feet
76-82	6
94-102	8
132-141	9
148-156	8
171-182	11
197-222	25
247-263	16
276-282	6
306-317	11
345-362	17
389-397	8
406-420	14
431-438	7
449-460	11
480-488	8
498-518	20
535-543	8
550-564	14
583-596	13
615-627	12
642-653	11
675-678	3
716-728	12
762-768	6

762 (Base of fresh water)

Well number: JL 49-13-828
Estimated 1903 water level: 13 feet

Interval, in feet below land surface	Thickness, in feet
48-86	38
178-246	68
265-275	10
385-392	7
576-595	19

600 (Total depth)

Well number: JL 49-13-830
Estimated 1903 water level: 16 feet

Interval, in feet below land surface	Thickness, in feet
65-69	4
74-78	4
86-89	3
97-112	15
140-150	10
160-163	3
176-184	8
203-223	20
262-282	20
308-336	28
354-362	8
380-390	10
394-403	9
409-449	40
462-478	18
490-499	9
512-534	22
543-545	2
555-563	8
578-582	4
620-629	9
652-656	4
669-678	9
690-692	2
701-711	10
712-716	4
726-766	40
786-794	8
795-802	7
818-824	6
830-838	8
841-842	1
845-848	3
856-862	6

786 (Base of fresh water)

Well number: JL 49-13-831
Estimated 1903 water level: 13 feet

Interval, in feet below land surface	Thickness, in feet
42-49	7
68-75	7
82-86	4
96-106	10
118-124	6
150-181	31
182-199	17
210-222	12
230-236	6
249-257	8

Well number: JL 49-13-831, Continued

Interval, in feet below land surface	Thickness, in feet
271-273	2
274-298	24
307-311	4
326-330	4
342-348	6
359-372	13
380-387	7
410-416	6
422-434	12
445-457	12
468-471	3
488-504	16
529-559	30
566-572	6
582-585	3
600-603	3
611-616	5
631-647	16
657-673	16
686-701	15
714-716	2
722-729	7
748-754	6
772-776	4
780-782	2
786-800	14
825-829	4
834-840	6

872 (Base of fresh water)

Well number: JL 49-13-833
Estimated 1903 water level: 14 feet

Interval, in feet below land surface	Thickness, in feet
61-80	19
148-162	14
187-192	5
202-221	19
227-258	31
276-288	12
314-350	36
395-403	8
413-416	3
432-442	10
453-464	11
482-511	29
524-531	7
536-538	2
552-556	4
598-602	4
612-622	10
632-656	24
661-662	1
678-682	4

Well number: JL 49-13-833--Continued

Interval, in feet below land surface	Thickness, in feet
706-708	2
719-722	3
738-748	10
764-772	8
787-790	3
798-801	3
810-812	2
823-826	3
836-852	16
866-868	2
872-875	3
894-896	2
904-907	3
929-931	2
936-940	4

962 (Base of fresh water)

Well number: JL 49-13-834
Estimated 1903 water level: 17 feet

Interval, in feet below land surface	Thickness, in feet
54-60	6
70-73	3
79-96	17
99-102	3
114-118	4
131-135	4
150-164	14
175-177	2
204-206	2
220-246	26
268-270	2
280-300	20
328-349	21
353-363	10
374-378	4
390-392	2
400-408	8
419-427	8
460-466	6
484-499	15
509-513	4
530-552	22
566-576	10
577-582	5
587-599	12
627-641	14
651-669	18
680-686	6
709-716	7
734-740	6

Well number: JL 49-13-834--Continued

Interval, in feet below land surface	Thickness, in feet
753-761	8
763-774	11
787-795	8
799-810	11
821-836	15
841-845	4
866-872	6
879-900	21
915-924	9

941 (Base of fresh water)

Well number: JL 49-13-903
Estimated 1903 water level: 179 feet

Interval, in feet below land surface	Thickness, in feet
181-191	10
196-212	16
220-222	2
235-239	4
296-306	10
317-322	5
342-345	3
353-375	22
378-380	2
388-392	4
412-415	3
426-428	2
439-447	8
467-499	32
502-507	5
530-535	5
536-550	14
563-565	2
566-568	2
584-588	4
594-597	3
627-631	4
642-656	14
662-682	20
684-717	33

732 (Base of fresh water)

Well number: JL 49-13-906
Estimated 1903 water level: 38 feet

Interval, in feet below land surface	Thickness, in feet
130-133	3
145-153	8
180-184	4
204-209	5
220-229	9

Well number: JL 49-13-906--Continued

Interval, in feet below land surface	Thickness, in feet
262-292	30
318-338	20
342-346	4
360-362	2
382-384	2
397-405	8
421-426	5
438-443	5
455-475	20
510-523	13
562-566	4
629-638	9
650-651	1
673-677	4
689-693	4
705-708	3

733 (Total depth)

Well number: JL 49-13-914
Estimated 1903 water level: 250 feet

Interval, in feet below land surface	Thickness, in feet
255-258	3
276-281	5
290-295	5
296-298	2
300-311	11
312-323	11
338-348	10
357-373	16
374-385	11
389-390	1
396-398	2
413-416	3
423-426	3
441-442	1
448-451	3
459-488	29
517-518	1
525-537	12
550-558	8
566-568	2
591-592	1
606-609	3
620-624	4
636-640	4
646-657	11
672-690	18
714-740	26
742-752	10
754-756	2
763-766	3

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-13-914, Continued

Interval, in feet below land surface	Thickness, in feet
780-782	2
803-805	2
821-822	1

834 (Base of fresh water)

Well number: JL 49-13-917
Estimated 1903 water level: 20 feet

Interval, in feet below land surface	Thickness, in feet
54-57	3
127-128	1
138-139	1
173-178	5
179-188	9
202-204	2
214-218	4
239-240	1
263-265	2
296-316	20
321-322	1
353-363	10
386-388	2
391-392	1
395-396	1
405-406	1
409-411	2
417-418	1
423-424	1
426-427	1
442-448	6
449-452	3
489-491	2
504-526	22
566-578	12
581-582	1
607-609	2
612-614	2
622-623	1
628-630	2
642-649	7
677-681	4
695-702	7
706-710	4
722-729	7

757 (Base of fresh water)

Well number: JL 49-13-919
Estimated 1903 water level: 97 feet

Interval, in feet below land surface	Thickness, in feet
100-102	2
103-109	6
113-117	4
118-120	2
122-129	7
145-151	6
156-157	1
159-160	1
162-163	1
165-180	15
181-182	1
184-188	4
191-203	12
204-217	13
227-230	3
241-250	9
260-262	2
265-281	16
310-335	25
368-375	7
408-413	5
418-421	3
422-423	1
424-425	1
431-433	2
435-436	1
450-452	2
474-478	4
490-500	10
510-519	9
520-529	9
564-569	5
622-624	2
635-639	4
640-644	4
647-650	3
653-654	1
660-661	1
662-663	1
669-672	3
691-697	6
714-719	5
722-723	1
729-730	1
733-735	2
742-749	7
758-760	2

770 (Total depth)

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-13-921
Estimated 1903 water level: 64 feet

Interval, in feet below land surface	Thickness, in feet
68-76	8
82-86	4
98-103	5
108-109	1
140-142	2
149-150	1
159-160	1
167-168	1
172-173	1
181-182	1
185-186	1
211-212	1
214-219	5
222-224	2
239-240	1
259-261	2
279-281	2
287-289	2
291-301	10
303-304	1
307-309	2
324-332	8
342-350	8
383-384	1
392-396	4
412-414	2
441-443	2
452-454	2
470-472	2
483-489	6
511-512	1
550-568	18
582-586	4
602-612	10
628-637	9
652-654	2
660-664	4
665-667	2
676-677	1
690-700	10
737-738	1
740-742	2
748-750	2

752 (Base of fresh water)

Well number: JL 49-13-925
Estimated 1903 water level: 77 feet

Interval, in feet below land surface	Thickness, in feet
102-108	6
136-155	19
178-184	6
186-191	5
208-234	26
237-254	17
294-304	8
330-359	29
372-374	2
394-409	15
456-469	13
475-482	7
516-518	2
530-547	17
558-567	9
582-585	3
598-602	4
620-625	5
630-632	2
638-643	5
650-654	4
656-660	4

667 (Total depth)

Well number: JL 49-13-932
Estimated 1903 water level: 189 feet

Interval, in feet below land surface	Thickness, in feet
230-238	8
242-246	4
248-270	22
275-284	9
295-302	7
312-359	47
363-370	7
403-406	3
410-420	10
436-469	33
480-488	8
495-499	4
504-518	14
531-540	9
551-553	2
578-592	14
614-642	28
656-686	30
712-762	50

795 (Base of fresh water)

Well number: JL 49-13-936
Estimated 1903 water level: 74 feet

Interval, in feet below land surface	Thickness, in feet
94-100	6
122-136	14
168-170	2
190-204	14
208-213	5
221-225	4
228-239	11
242-244	2
263-269	6
272-278	6
303-304	1
317-325	8
336-340	4
344-360	16
388-417	29
456-458	2
461-475	14
497-508	11
556-578	22
642-646	4

647 (Total depth)

Well number: JL 49-14-101
Estimated 1903 water level: 160 feet

Interval, in feet below land surface	Thickness, in feet
168-181	13
188-197	9
220-226	6
263-276	13
280-289	9
300-306	6
318-328	10
336-347	11
367-383	16
393-406	13
416-460	44
464-467	3
486-526	40
558-567	9
579-606	27
628-638	10
643-647	4
650-659	9
684-686	2
702-718	16
734-736	2
742-744	2
752-778	26

816 (Total depth)

Well number: JL 49-14-104
Estimated 1903 water level: 254 feet

Interval, in feet below land surface	Thickness, in feet
275-278	3
290-296	6
301-323	22
327-333	6
373-385	12
399-401	2
411-412	1
423-443	20
452-468	16
483-491	8
508-528	20
574-579	5
584-586	2
603-617	14
631-647	16
671-694	23
740-752	12
775-780	5
790-802	12
818-830	12
856-874	18
877-881	4
893-901	8
912-916	4
930-944	14

956 (Base of fresh water)

Well number: JL 49-14-201
Estimated 1903 water level: 310 feet

Interval, in feet below land surface	Thickness, in feet
310-334	24
377-379	2
398-433	35
443-457	14
465-471	6
477-485	8

502 (Total depth)

Well number: JL 49-14-301
Estimated 1903 water level: 314 feet

Interval, in feet below land surface	Thickness, in feet
314-328	14
338-346	8
357-359	2
380-389	9
422-423	1

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-14-301--Continued

Interval, in feet below land surface	Thickness, in feet
427-443	16
476-491	15
504-516	12
537-546	9

553 (Base of fresh water)

Well number: JL 49-14-401
Estimated 1903 water level: 272 feet

Interval, in feet below land surface	Thickness, in feet
280-296	16
302-310	8
321-322	1
369-409	40
431-442	11
468-482	14
512-549	37
566-582	16
594-596	2
598-616	18
627-630	3
632-648	16
654-672	18
686-687	1
702-709	7
726-730	4
750-760	10
773-781	8
799-800	1
804-808	4
818-824	6
829-841	12
866-874	8
883-889	6

899 (Base of faresh water)

Well number: JL 49-14-408
Estimated 1903 water level: 252 feet

Interval, in feet below land surface	Thickness, in feet
252-267	15
275-282	7
284-298	14
315-330	15
337-338	1
345-357	12
377-391	14
394-408	14
410-438	28
445-477	32

Well number: JL 49-14-408--Continued

Interval, in feet below land surface	Thickness, in feet
493-501	8
509-510	1
522-526	4
534-539	5
552-555	3
570-574	4
584-592	8
602-612	10
617-623	6
662-678	16
720-732	12
750-751	1
759-764	5
781-826	45
850-852	2
892-915	23
932-933	1

952 (Base of fresh water)

Well number: JL 49-14-410
Estimated 1903 water level: 276 feet

Interval, in feet below land surface	Thickness, in feet
300-317	17
331-342	11
358-365	7
381-408	27
432-434	2
475-477	2
485-495	10
521-528	7
567-577	10
607-632	25
638-645	7
664-670	6
684-696	12
706-712	6

760 (Base of fresh water)

Well number: JL 49-14-416
Estimated 1903 water level: 254 feet

Interval, in feet below land surface	Thickness, in feet
260-264	4
286-292	6
320-329	9
363-376	13
385-397	12

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-14-416--Continued

Interval, in feet below land surface	Thickness, in feet
400-402	2
417-425	8
438-453	15
455-460	5
462-464	2
492-493	1
500-501	1
515-520	5
532-540	8
567-577	10
579-588	9
599-605	6
649-650	1
652-654	2
655-660	5
663-667	4
700-722	22
749-750	1
768-783	15
789-807	18
822-826	4
851-853	2
891-906	15
931-933	2
952-954	2
962-963	1
967-974	7
980-982	2

989 (Base of fresh water)

Well number: JL 49-14-422
Estimated 1903 water level: 242 feet

Interval, in feet below land surface	Thickness, in feet
250-264	14
268-278	10
296-298	2
308-310	2
324-348	24
352-358	6
366-376	10
399-401	2
417-434	17
467-473	6
479-530	51
585-588	3
618-628	10
630-635	5
651-665	14
681-694	13
701-726	25
738-740	2
753-768	15
776-791	15

Well number: JL 49-14-422--Continued

Interval, in feet below land surface	Thickness, in feet
798-801	3
808-812	4
818-824	6
844-855	11

870 (Base of fresh water)

Well number: JL 49-14-501
Estimated 1903 water level: 294 feet

Interval, in feet below land surface	Thickness, in feet
294-296	2
309-312	3
333-338	5
353-361	8
370-372	2
397-402	5
413-419	6
426-433	7
440-442	2
470-476	6
513-515	2
520-526	6
540-545	5

554 (Base of fresh water)

Well number: JL 49-14-707
Estimated 1903 water level: 224 feet

Interval, in feet below land surface	Thickness, in feet
251-253	2
257-269	12
285-288	3
301-303	2
316-331	15
336-343	7
350-357	7
360-373	13
379-381	2
392-394	2
396-402	6
416-427	11
430-440	10
476-479	3
502-504	2
530-540	10
542-544	2
545-557	12
595-598	3
607-615	8

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-14-707--Continued

Interval, in feet below land surface	Thickness, in feet
635-641	6
649-657	8
671-674	3
677-691	14
710-712	2
737-740	3
746-756	10
766-779	13
785-788	3
792-802	10
803-813	10
823-844	21
857-863	6
864-870	6

899 (Total depth)

Well number: JL 49-14-708
Estimated 1903 water level: 128 feet

Interval, in feet below land surface	Thickness, in feet
153-164	11
172-178	6
188-191	3
195-202	7
245-250	5
256-268	12
274-291	17
324-335	11
338-345	7
360-366	6
400-404	4
439-442	3
447-468	21
491-502	11
516-530	14
536-547	11
548-551	3
587-594	7
597-605	8
609-617	8
631-635	4
638-642	4
659-671	12
678-684	6
690-697	7
713-715	2
722-724	2
730-734	4
748-754	6
766-768	2

776 (Base of fresh water)

Well number: JL 49-14-710
Estimated 1903 water level: 156 feet

Interval, in feet below land surface	Thickness, in feet
167-172	5
183-185	2
229-240	11
272-281	9
285-289	4
311-324	13
370-374	4
388-394	6
398-406	8
424-438	14
469-491	22
552-562	10
571-574	3
589-592	3
603-611	8
616-624	8

628 (Base of fresh water)

Well number: JL 49-14-711
Estimated 1903 water level: 82 feet

Interval, in feet below land surface	Thickness, in feet
98-102	4
110-117	7
125-133	8
142-148	6
158-171	13
194-206	12
215-217	2
244-251	7
253-258	5
282-284	2
288-290	2
311-322	11
351-352	1
400-402	2
404-415	11
425-430	5
444-454	10

490 (Total depth)

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-14-714
Estimated 1903 water level: 266 feet

Interval, in feet below land surface	Thickness, in feet
266-267	1
272-274	2
278-279	1
296-298	2
299-313	14
328-329	1
330-337	7
344-349	5
353-354	1
402-408	6
412-413	1
437-439	2
441-442	1
469-470	1
472-474	2
478-488	10

501 (Base of fresh water)

Well number: JL 49-14-715
Estimated 1903 water level: 264 feet

Interval, in feet below land surface	Thickness, in feet
285-299	14
326-334	8
341-344	3
360-372	12
403-404	1
417-419	2
425-426	1
428-429	1
436-437	1
439-444	5
451-453	2
488-492	4
496-498	2

530 (Base of fresh water)

Well number: JL 49-14-716
Estimated 1903 water level: 279 feet

Interval, in feet below land surface	Thickness, in feet
279-280	1
284-296	12
314-316	2
329-351	22
352-361	9

Well number: JL 49-14-716--Continued

Interval, in feet below land surface	Thickness, in feet
372-378	6
381-382	1
410-419	9
430-432	2
434-442	8
474-486	12
498-504	6
518-523	5

563 (Base of fresh water)

Well number: JL 49-14-717
Estimated 1903 water level: 278 feet

Interval, in feet below land surface	Thickness, in feet
308-332	24
392-396	4
397-415	18
417-426	9
449-450	1
455-466	11
515-517	2
518-520	2
525-526	1

556 (Base of fresh water)

Well number: JL 49-14-802
Estimated 1903 water level: 256 feet

Interval, in feet below land surface	Thickness, in feet
268-270	2
311-312	1
338-339	1
347-348	1
358-364	6
377-378	1
383-386	3
438-452	14
458-472	14

538 (Base of fresh water)

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-14-803
Estimated 1903 water level: 261 feet

Interval, in feet below land surface	Thickness, in feet
262-287	25
303-310	7
343-353	10
360-368	8
385-389	4
410-424	14
450-453	3
493-510	17

523 (Base of fresh water)

Well number: JL 49-14-804
Estimated 1903 water level: 319 feet

Interval, in feet below land surface	Thickness, in feet
326-331	5
334-348	14
362-383	21
398-413	15
456-458	2
460-465	5

470 (Base of fresh water)

Well number: JL 49-21-301
Estimated 1903 water level: 13 feet

Interval, in feet below land surface	Thickness, in feet
67-83	16
103-106	3
116-126	10
136-145	9
171-187	16
192-200	8
216-241	25
246-258	12
281-290	9
295-299	4
309-310	1
329-335	6
348-350	2
356-369	13
379-390	9
410-418	8
420-421	1
424-438	14
457-460	3
470-478	8

Well number: JL 49-21-301--Continued

Interval, in feet below land surface	Thickness, in feet
493-510	17
505-513	8
555-563	8
587-592	5
612-619	7
628-636	8
656-660	4
682-685	3
690-696	6
701-706	5
736-742	6
750-752	2
756-770	14

778 (Total depth)

Well number: JL 49-21-305
Estimated 1903 water level: 10 feet

Interval, in feet below land surface	Thickness, in feet
60-67	7
70-73	3
90-98	8
104-105	1
107-110	3
130-140	10
145-148	3
162-177	15
221-226	5
244-247	3
255-281	26
307-309	2
320-322	2
350-356	6
361-367	6
381-382	1
387-399	12
425-429	4
441-445	4
458-459	1
473-478	5
491-493	2
511-514	3
532-540	8
549-551	2
555-557	2
569-575	6
598-601	3
619-621	2
628-632	4
640-650	10
661-663	2

673 (Total depth)

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-21-309
Estimated 1903 water level: 12 feet

Interval, in feet below land surface	Thickness, in feet
69-71	2
82-90	8
106-108	2
128-132	4
136-144	8
147-148	1
166-174	8
202-209	7
218-232	14
240-244	4
252-253	1
264-266	2
270-278	8
282-285	3
302-310	8
326-328	2
330-334	4
346-370	24
387-390	3
392-403	11
441-445	4
458-466	8
490-495	5
500-512	12
514-520	6
524-526	2
530-538	8
542-548	6

562 (Base of fresh water)

Well number: JL 49-21-311
Estimated 1903 water level: 13 feet

Interval, in feet below land surface	Thickness, in feet
48-58	10
60-63	3
84-85	1
87-88	1
104-108	4
125-132	7
136-142	6
150-154	4
168-174	6
180-188	8
204-210	6
229-232	3
246-252	6
263-265	2
280-301	21

Well number: JL 49-21-311--Continued

Interval, in feet below land surface	Thickness, in feet
312-318	6
333-338	5
346-360	14
394-405	11
427-429	2
438-443	5
465-469	4
528-533	5
535-538	5

566 (Base of fresh water)

Well number: JL 49-22-102
Estimated 1903 water level: 138 feet

Interval, in feet below land surface	Thickness, in feet
138-149	11
170-180	10
182-189	7
193-194	1
204-205	1
220-243	23
263-274	11
293-294	1
296-297	1
301-304	3
322-334	12
357-360	3
363-377	14

410 (Base of fresh water)

Well number: JL 49-22-103
Estimated 1903 water level: 46 feet

Interval, in feet below land surface	Thickness, in feet
98-100	2
124-126	2
146-152	6
158-166	8
168-178	10
204-228	24
258-260	2
265-274	9
294-300	6
304-340	36
365-370	5
380-404	24
417-420	3
424-426	2

438 (Base of fresh water)

Well number: JL 49-22-104
Estimated 1903 water level: 13 feet

Interval, in feet below land surface	Thickness, in feet
78-84	6
96-107	11
146-154	8
197-200	3
223-230	7
264-266	2
271-278	7
303-311	8
340-346	6
370-373	3
397-406	9
414-420	6
434-440	6
454-478	24
506-509	3
532-542	10

590 (Base of fresh water)

Well number: JL 49-22-122
Estimated 1903 water level: 14 feet

Interval, in feet below land surface	Thickness, in feet
46-65	19
80-85	5
94-97	3
113-116	3
126-130	4
164-166	2
178-181	3
221-224	3
236-238	2
268-269	1
290-292	2
296-302	6
322-326	4
327-330	2
361-362	1
384-386	2
402-405	3
413-414	1
416-430	14

449 (Base of fresh water)

Well number: JL 49-22-124
Estimated 1903 water level: 7 feet

Interval, in feet below land surface	Thickness, in feet
22-44	22
66-187	127
221-224	3
233-251	18
263-270	7
275-301	26
309-311	2
322-327	5
334-346	12
393-403	10
440-442	2
474-479	5
490-495	5

506 (Base of fresh water)

Well number: JL 49-22-125
Estimated 1903 water level: 12 feet

Interval, in feet below land surface	Thickness, in feet
75-90	15
101-120	19
158-160	2
171-172	1
178-180	2
196-198	2
202-217	15
226-232	6
245-248	3
254-273	19
301-302	1
306-312	6
327-345	18
364-380	16
390-395	5
400-412	12
413-418	5
433-445	12
450-452	2

458 (Base of fresh water)

Well number: JL 49-22-126
Estimated 1903 water level: 38 feet

Interval, in feet below land surface	Thickness, in feet
41-48	7
71-80	9
93-132	39
140-161	21
188-192	4

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-22-126--Continued

Interval, in feet below land surface	Thickness, in feet
196-209	13
220-222	2
230-247	17
255-273	18
274-280	6
290-292	2
300-314	14
350-358	8
378-388	10
407-415	8
432-450	18
471-482	11

505 (Base of fresh water)

Well number: JL 49-22-127
Estimated 1903 water level: 13 feet

Interval, in feet below land surface	Thickness, in feet
28-52	24
58-62	4
83-91	8
100-103	3
107-115	8
138-140	2
143-146	3
155-158	3
178-182	4
188-209	21
212-217	5
240-254	14
256-266	10
275-282	7
284-289	5
296-302	6
312-323	11
339-342	3
356-364	8
396-402	6
406-412	6
426-446	20
455-458	3
474-481	7
497-502	5
503-505	2

525 (Base of fresh water)

Well number: JL 49-22-128
Estimated 1903 water level: 11 feet

Interval, in feet below land surface	Thickness, in feet
24-44	20
57-61	4
91-97	6
104-108	4
117-126	9
135-139	4
158-162	4
186-188	2
195-206	11
214-221	7
241-244	3
260-263	3
268-272	4
274-291	17
300-302	2
308-312	4
327-330	3
346-369	23
399-402	3
405-414	9
419-430	11
436-439	3
445-448	3
454-458	4

476 (Base of fresh water)

Well number: JL 49-22-129
Estimated 1903 water level: 86 feet

Interval, in feet below land surface	Thickness, in feet
92-96	4
106-116	10
126-133	7
139-143	4
169-178	9
186-188	2
206-231	25
247-249	2
270-280	10
284-289	5
311-323	12
332-337	5
351-357	6
367-374	7
380-394	14
401-405	4
414-416	2
424-427	3
432-434	2
441-448	7

462 (Base of fresh water)

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-22-201
Estimated 1903 water level: 100 feet

Interval, in feet below land surface	Thickness, in feet
130-138	8
176-178	2
190-198	8
213-226	13
230-233	3
243-267	24
276-287	11
295-297	2
305-320	15
335-338	3
346-364	18

373 (Base of fresh water)

Well number: JL 49-22-206
Estimated 1903 water level: 120 feet

Interval, in feet below land surface	Thickness, in feet
123-140	17
162-180	18
187-190	3
195-200	5
217-221	4
246-253	7
261-269	8
283-287	4
303-306	3
330-336	6
344-356	12

395 (Base of fresh water)

Well number: JL 49-22-213
Estimated 1903 water level: 247 feet

Interval, in feet below land surface	Thickness, in feet
247-259	12
273-279	6
296-305	9
348-355	7
361-362	1
368-373	5
382-386	4
420-425	5
427-435	8

446 (Base of fresh water)

Well number: JL 49-22-215
Estimated 1903 water level: 205 feet

Interval, in feet below land surface	Thickness, in feet
217-230	13
241-244	3
258-266	8
272-278	6
294-304	10
312-321	9

366 (Base of fresh water)

Well number: JL 49-22-301
Estimated 1903 water level: 280 feet

Interval, in feet below land surface	Thickness, in feet
290-300	10
308-309	1
317-320	3
324-328	4
333-339	6
340-342	2
345-346	1
350-351	1
354-356	2
368-369	1
377-378	1

386 (Base of fresh water)

Well number: JL 49-22-401
Estimated 1903 water level: 8 feet

Interval, in feet below land surface	Thickness, in feet
122-128	6
170-176	6
192-202	10
208-218	10
264-279	15
282-296	14
305-308	3
333-340	7
352-364	12
391-393	2
410-415	5
426-430	4
444-452	8

470 (Base of fresh water)

Table 9.--Occurrence and Thickness of Clay Lenses Penetrated in Selected Wells--Continued

Well number: JL 49-22-407
Estimated 1903 water level: 6 feet

Interval, in feet below land surface	Thickness, in feet
25-28	3
40-42	2
62-69	7
89-99	10
118-121	3
143-155	12
164-170	6
186-198	12
208-214	6
220-222	2
229-232	3
238-246	8
256-272	16
277-284	7
298-317	19
336-342	6
360-370	10
391-396	5
408-417	9
434-446	12
456-462	6
463-467	4
479-481	2
492-496	4

508 (Base of fresh water)

Well number: JL 49-22-408
Estimated 1903 water level: 6 feet

Interval, in feet below land surface	Thickness, in feet
74-89	15
102-104	2
128-150	22
174-179	5
189-192	3
194-202	8
221-226	5
232-259	27
276-282	6
289-291	2
309-318	9
338-345	7
362-374	12
386-391	5
397-410	13
416-420	4
424-429	5
433-435	2
440-445	5

470 (Base of fresh water)

Well number: JL 49-22-818
Estimated 1903 water level: 5 feet

Interval, in feet below land surface	Thickness, in feet
106-112	6
132-141	9
165-173	8
180-186	6
195-199	4
207-214	7
234-241	7
251-255	4
272-278	6
282-284	2
294-300	6
310-312	2
316-317	1
325-331	6
335-340	5
346-350	4

352 (Base of fresh water)

Well number: JL 49-22-840
Estimated 1903 water level: 8 feet

Interval, in feet below land surface	Thickness, in feet
65-73	8
83-87	4
110-117	7
139-143	4
175-186	11
212-230	18
242-245	3
252-259	7
288-296	8
308-311	3

318 (Base of fresh water)