UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRELIMINARY REPORT ON LAND-SURFACE SUBSIDENCE IN THE AREA OF BURNETT, SCOTT, AND CRYSTAL BAYS NEAR BAYTOWN, TEXAS

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73-374

Prepared by the U.S. Geological Survey
in cooperation with the
U.S. Army Corps of Engineers

February 1973

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ABSTRACT

Removal of water, oil, and gas from the subsurface in Harris County has caused declines in fluid pressures which in turn have resulted in subsidence of the land surface. One critical area of subsidence is in the area of Burnett, Scott, and Crystal Bays near Baytown. Much of this area is now subject to inundation by high tides.

Production of oil and gas from the Goose Creek Field at the southern edge of Baytown had caused as much as 3.25 feet of subsidence by 1925. The subsidence bowl is restricted to the area of production and has not extended to the area of Burnett, Scott, and Crystal Bays.

Withdrawals of water from large-capacity industrial wells, which resulted in declines in artesian pressure, began about 1918; as much as 250 feet of water-pressure decline has occurred in the Evangeline aquifer. Significant subsidence of the land surface probably began about 1920 or later. Possibly as much as 7.5 feet of subsidence had occurred in the area by 1971.

The study of subsidence in the area of the three bays included the collection of undisturbed clay samples for laboratory analyses, collection of water-level records, and installation and monitoring of pressure transducers in clays and of observation wells in sands.

Probable future subsidence was calculated for two loading situations. Case I provided that the artesian pressure in both the Alta Loma Sand of Rose (1943) and Evangeline aquifer would continue to decline at a rate of 6 feet per year until 1980 and then cease. Case II provided that artesian pressure in the Alta Loma Sand would continue to decline at a rate of about 6 feet per year until about 1995, when the potentiometric head would reach the top of the Alta Loma Sand. The artesian pressure in the Evangeline aquifer would also decline about 6 feet per year until 1995.

The ultimate subsidence expected for the assumed conditions of case I and case II is 11.2 feet and 14.5 feet, respectively. However, only 1.8 feet of subsidence below present land surface would occur if artesian pressures were maintained at their present levels.

To halt subsidence in the near future, artesian pressure must be increased. The most logical method of increasing artesian pressure is by decreasing pumpage rather than repressurization by artificial recharge.

INTRODUCTION

The pumping of vast quantities of ground water to meet the increasing demands for industrial use, irrigation, and municipal supply in Harris County has caused significant declines in artesian pressures. The removal of water that has resulted in declines in artesian pressures has caused critical subsidence of the land surface in parts of the county. One such locality of critical land-surface subsidence is in the area of Burnett, Scott, and Crystal Bays near Baytown in the eastern part of Harris County (figure 1).

The land surface in this area has subsided several feet since development of ground water began, and some parts have been inundated by sea water. Driveways, streets, and some homes along the waterfront are flooded regularly by normal high tides. Unusually high tides, such as those produced by Hurricane Carla in 1961, flood everything at an elevation less than about 13 feet above mean sea level.

At the request of the U.S. Army Corps of Engineers, the U.S. Geological Survey began an investigation in March 1972 of land-surface subsidence in the area of Burnett, Scott, and Crystal Bays. The objectives of this investigation are:

1. To determine the amount of subsidence due to the withdrawal of oil and gas and the amount due to the withdrawal of water.

2. To determine the rates of subsidence due to each cause and to relate the rate of land-surface subsidence to the decline in artesian pressure.

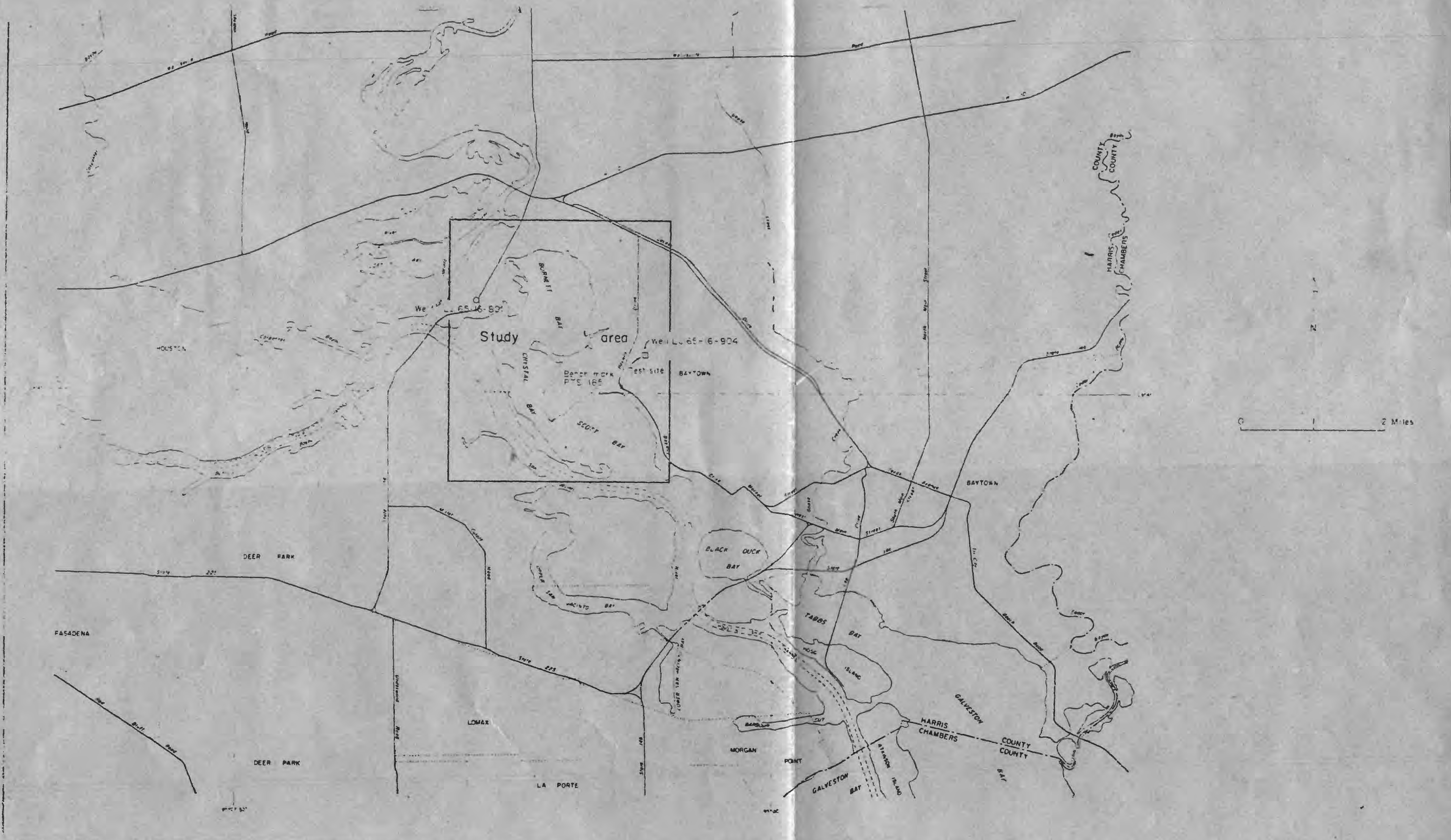

FIGURE 1. - Location of Burnett, Scott, and Crystal Bays

3. To predict the decline in artesian pressure during the next 50 years.

4. To predict the rate of subsidence caused by each type of fluid withdrawal.

5. To predict the maximum subsidence to be expected during the next 50 years.

The purpose of this report is to present the preliminary findings of the investigation. The author gratefully acknowledges the assistance of Mr. Spencer Buchanan and Mr. Robert Bigham of Spencer J. Buchanan and Associates, Inc.; Mr. Jerry Dvorak and Mr. Andy Braswell of the Humble Oil and Refining Co.; and Mr. C. M. Floyd, Consulting Engineer. The city of Baytown, through Mr. Jack Morton, Director of Public Works, furnished the site for installation of monitoring equipment.

CAUSES OF SUBSIDENCE

In the Baytown area, there are two primary causes of land-surface subsidence--the withdrawal of oil and gas and the pumping of ground water.

As early as 1918, subsidence due to oil and gas production was noticed at the Goose Creek Field on the southeastern edge of Baytown. According to Pratt and Johnson (1926), the subsidence "bowl" was about 2.5 miles long and 1.5 miles wide by 1925. Subsidence at the center was 3.25 feet. No data are available on changes in elevations in the field since 1925.

In 1925, oil and gas were produced from depths between 1,000 and 4,100 feet below land surface. Presently (1972), production is from 23 separate zones between 1,500 and 5,000 feet. The production is from traps that probably have little hydraulic continuity; therefore, the declines in pressure are restricted principally to the zones of withdrawal; and subsidence of the land surface is restricted to the area of the field.

Because the distance from Scott Bay to the west edge of the Goose Creek Field is about 2.5 miles, none of the subsidence in the area of the bays can be attributed to oil and gas production.

Ground-water withdrawals from large-capacity industrial wells began in the Baytown area about 1918. The pumpage increased from about 5 mgd (million gallons per day) in 1919 to about 9 mgd in 1927. From 1928 to 1946 the average was about 15 mgd; from 1946 to 1960, the pumpage gradually increased to about 22 mgd. The withdrawal rate remained at about 22 mgd until 1969, when it increased to about 28 mgd.

Most of the withdrawals in the area are from wells completed in the Alta Loma Sand (lower unit of the Chicot aquifer), but the declines in artesian pressures are not due to production of ground water in the Baytown area alone. Large-scale production of ground water from the Alta Loma Sand and the underlying Evangeline aquifer in the Pasadena area a few miles southwest (see fig. 1) has caused regional pressure declines that extend to the Baytown area.

The decline in artesian pressure in the Evangeline aquifer at Baytown is principally the result of ground-water pumping at Pasadena. The decline in artesian pressure in the Alta Loma Sand is the result of pumping at Pasadena and at Baytown. In addition, the pumpage of approximately 600 mgd in all of Harris County and parts of the adjoining counties has contributed to the declines in artesian pressures at Baytown.

The pressure declines are illustrated by the hydrographs of two wells in or near the Baytown area (fig. 2). Well LJ-65-16-801, west of Burnett Bay, is between the cones of depression at Baytown and Pasadena. This hydrograph provides measurements at the closest point to the monitoring site for which a long record is available. It shows the same pattern of decline after 1952 as the hydrograph of water levels in well LJ-65-16-904 at the monitoring site. However, water levels in the well at the monitoring site are consistently 40 feet deeper. The rate of water-level decline determined from regional contour maps is about 6 feet per year; the rate indicated by the hydrographs is about 5 feet per year.

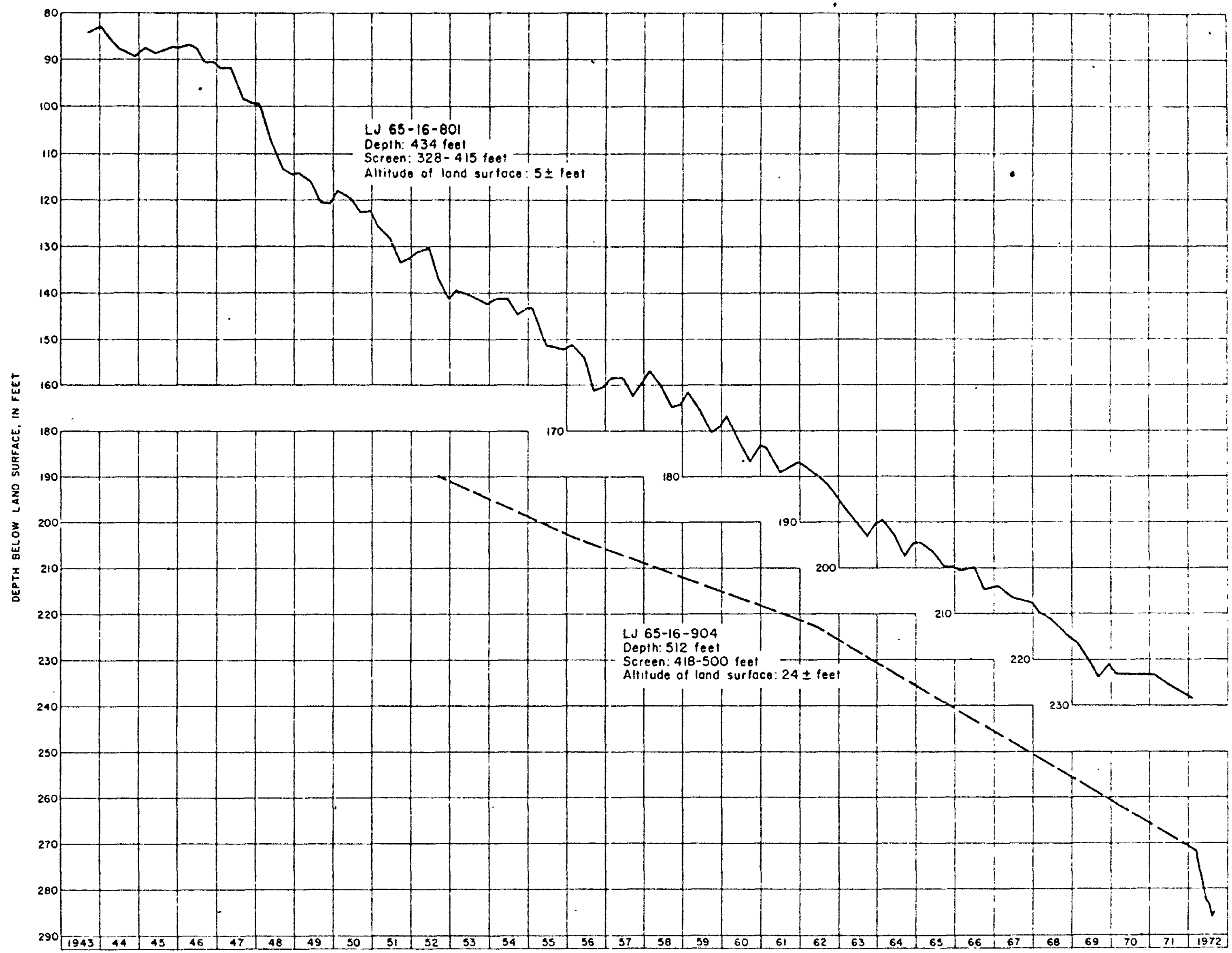

FIGURE 2. - Hydrographs showing changes in water levels in wells completed in the Alta Loma Sand

SUBSIDENCE AT BURNETT, SCOTT, AND CRYSTAL BAYS

Winslow and Doyel (1954) were probably the first to assemble data on subsidence in the Houston-Galveston region. Winslow and Wood (1959) added to the earlier findings when data became available. Gabrysch (1969) presented an analysis of subsidence in the region on the basis of the most recent (1964) releveling of bench marks by the U.S. Coast and Geodetic Survey. Releveling of bench marks in the Baytown area was completed by the Corps of Engineers in 1971. This releveling and all other available data were used to prepare the map of land-surface subsidence presented as figure 3.

Subsidence between 1943 and 1971 ranged from about 3 feet to more than 6 feet. Possibly as much as 7.5 feet of subsidence has occurred at bench mark PTS 185 on the northern edge of Scott Bay, but probably no more than this amount has occurred elsewhere in the Baytown area. Data show that some subsidence occurred before 1943, but the information is too meager to permit preparation of a map.

The relationship between the decline in artesian pressure and subsidence of the land surface is shown on figure 4. The original artesian pressure for both the Alta Loma Sand and the Evangeline aquifer is an assumed value. The assumptions for the Evangeline aquifer are based on interpretations of published and unpublished water-level maps because there are no suitable observation wells in the area.

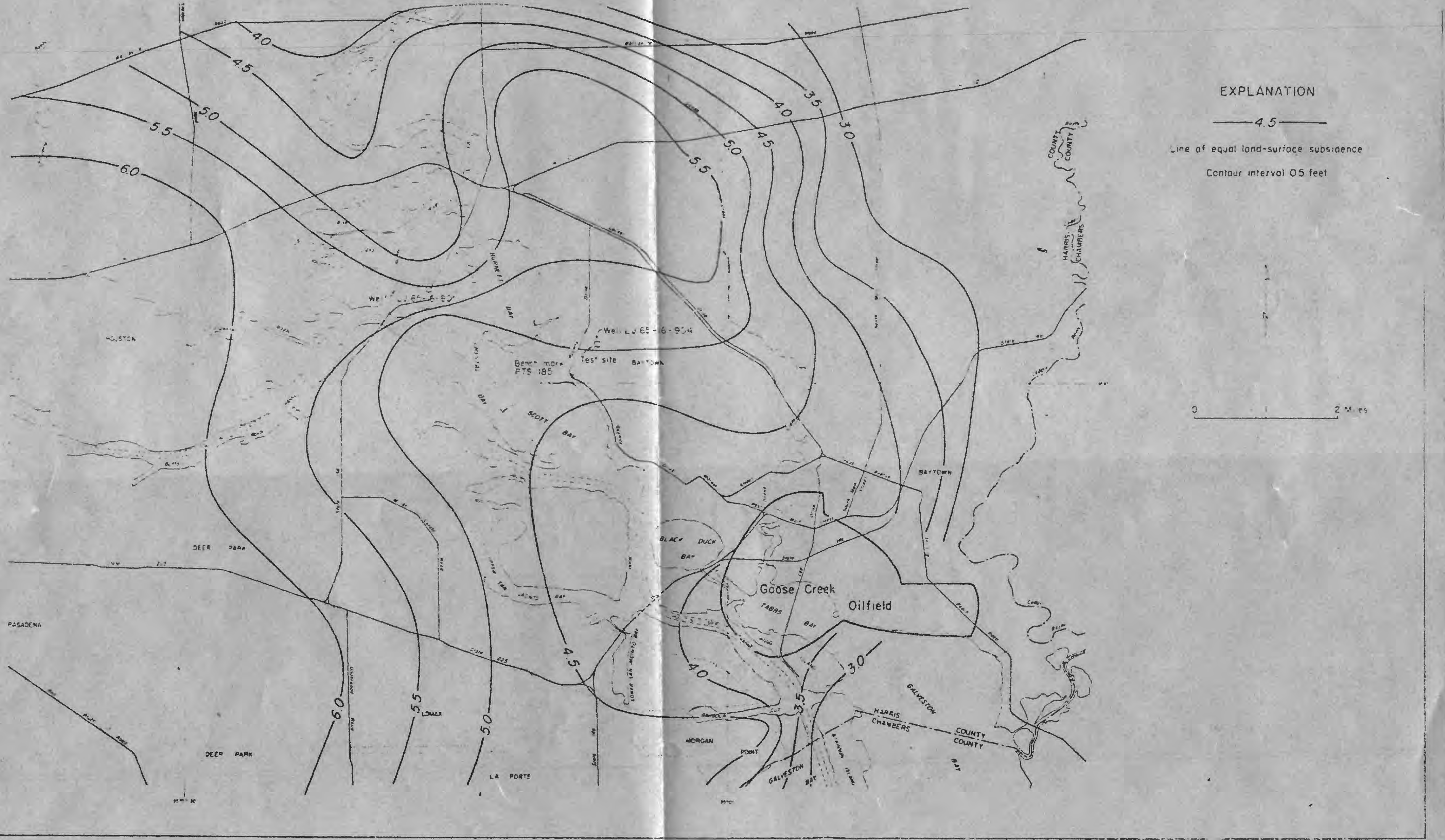

FIGURE 3. - Approximate subsidence of the land surface, 1943 - 71

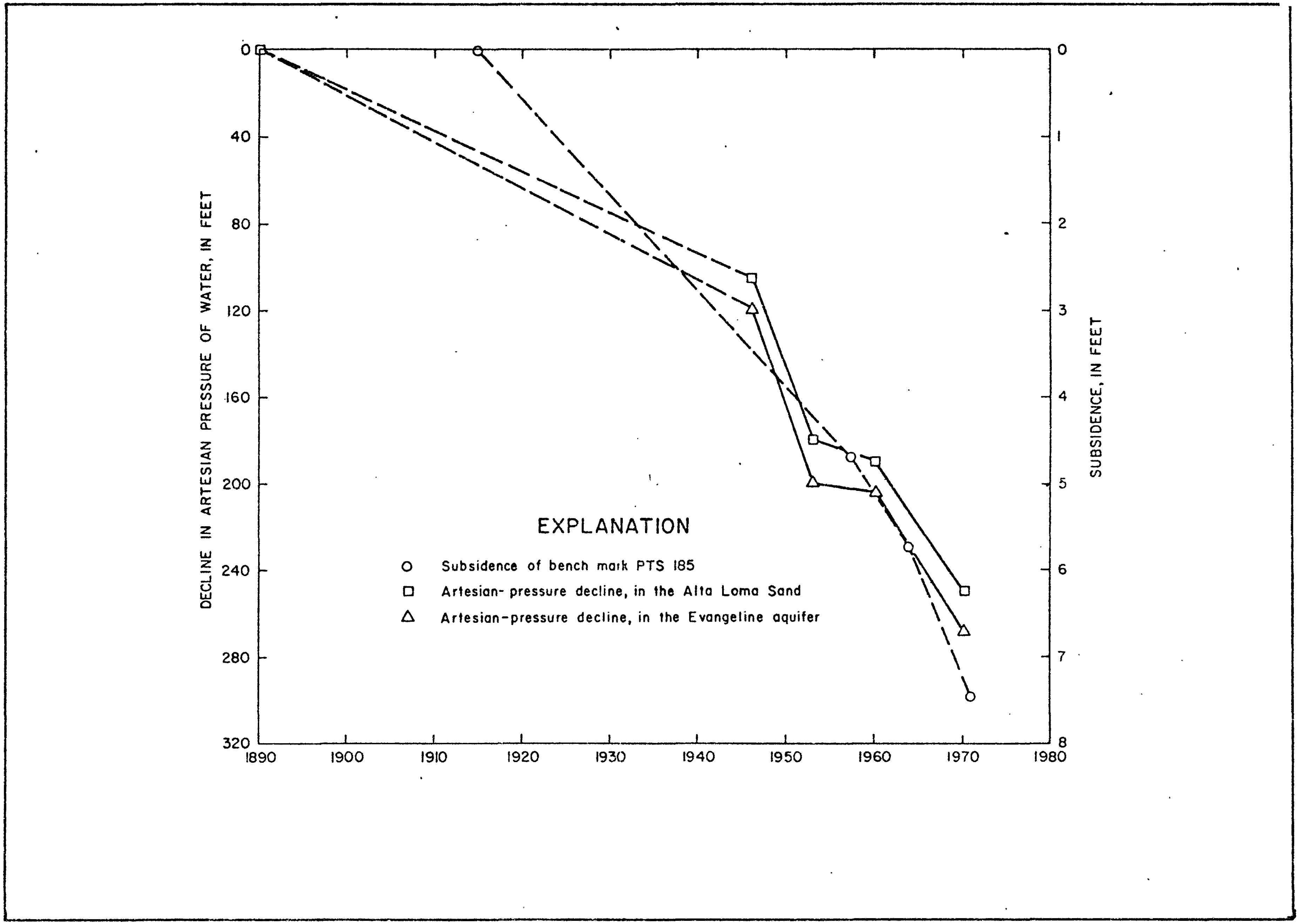

FIGURE 4. - Relation between land-surface subsidence and artesian-pressure decline

Care must be exercised, however, in the projection of subsidence curves on the basis of pressure declines only. The ratio of subsidence to the decline of water levels in wells is not constant. For example, Gabrysch (1969, fig. 10) showed a range of 0.5 foot to more than 2.5 feet of subsidence per 100 feet of water-level decline in the Houston-Galveston region. The variation in the ratio is caused by the differences in total clay thickness, individual clay-bed thickness, and clay characteristics. The depth of the overburden and the amount of load to which the material has been previously subjected are also necessary considerations.

Data collected at a site 12 miles south of the Baytown area indicate that as much as two-thirds of the subsidence is the result of compaction of the shallow (less than 750 feet deep) clay beds. Therefore, less subsidence (clay compaction) may be expected to result from a pressure decline in the Evangeline aquifer than from an equal pressure decline in the Alta Loma Sand.

DATA COLLECTION AND ANALYSIS

Because compaction of the subsurface material is dependent on the characteristics of the fine-grained material (clay) that is being compacted and the load to which the material is being subjected, undisturbed clay samples were collected at various depths. The samples were then analyzed by the U.S. Geological Survey in Denver, Colorado, to determine Atterburg limits, moisture content, and unit weights. Consolidation tests were made, and the permeability of each sample was calculated as well as measured.

The four samples analyzed in this study were taken from the clay layers above the Alta Loma Sand, the top of which is about 390 feet below land surface at the sampling site. Data for the stratigraphic section below the Alta Loma Sand at the sampling site were not available; therefore, test results from a well drilled on the campus of the University of Houston, about 19 miles west of the site, were utilized.

Electrical logs were used to determine the thickness of the clay beds. On the basis of these logs, the clays from the land surface to a depth of 1,900 feet were grouped into 43 layers. It is assumed that compaction below 1,900 feet is negligible. Data from the laboratory analyses of the clay samples and data from the test well at the University of Houston were used to assign characteristics to the 43 layers.

The laboratory consolidation tests were used to relate the changes in loads imposed on a sample to the changes in voids in the sample material. By imposing several different loads, a curve of void ratio (ratio of voids to solids) versus load is obtained. This curve is then used to estimate the changes that would occur due to loading in the natural environment. By using the void-ratio versus loading curves and the loading due to declines of artesian pressure, each clay layer was analyzed for its change in thickness according to the procedure outlined by Terzaghi and Peck (1948) and by Taylor (1948). Corrections for incremental continuous loading rather than instantaneous loading was made according to the procedures outlined by Taylor (1948, p. 291).

Gross approximations of the declines in artesian pressures in the Alta Loma Sand and the Evangeline aquifer were made from historical data in published and unpublished maps of potentiometric surfaces for the periods 1890-1946, 1946-53, 1953-60, and 1960-70. Loading of the clays was estimated for the assumed original conditions, and changes in loading were computed from the maps showing changes in pressure. The current (1972) loading profile for the material above the Alta Loma Sand is based on measurements in four observation wells and on data from four pneumatic pressure transducers installed in clay beds especially for this study.

The observation wells are completed in sands at depths of 110, 170, 234, and 324 feet below land surface. The transducers are installed to measure pore pressure in clays at depths of 71, 126, 259, and 344 feet below land surface. In addition, water-level measurements are being made in a production well (owned by the city of Baytown) in the Alta Loma Sand. Instrumentation at the monitoring site will also permit calculation of the time lag between loading and drainage of the clays.

The following assumptions were used to predict the rate of subsidence and the maximum amount of subsidence:

1. The potentiometric surface in 1920 was the same as the original surface in 1890, and no subsidence occurred before 1920.

2. Artesian-pressure declines in the Alta Loma Sand and Evangeline aquifer will continue at a rate of 6 feet per year until 1980. Thereafter, no further pressure declines will occur (case I).

3. Artesian-pressure declines in the Alta Loma Sand will continue at a rate of 6 feet per year until the potentiometric surface reaches the top of the Alta Loma Sand in 1995. Thereafter, no further pressure declines will occur (case II); and artesian-pressure declines in the Evangeline aquifer will continue at a rate of 6 feet per year from 1970 to 1995 and then cease.

PREDICTED SUBSIDENCE

The principal results of this study are given in the two graphs, figures 5 and 6. Figure 5 shows the calculated subsidence for the period 1920-75. For comparison, figure 5 includes a graph of the altitude of bench mark PTS 185 beginning in 1915. The computed values for a long period of time and under several different loading conditions correlate well with the measured changes in the altitude of the bench mark.

The ultimate amount of subsidence was calculated, on the basis of current loading, to be 9.3 feet. That is, if artesian pressures were maintained at their present level, it could be expected that about 1.8 feet of additional subsidence would occur in addition to the 7.5 feet that has already occurred.

The difference between calculated subsidence and measured subsidence was 0.3 foot in 1971. This difference is 4 percent of the total 7.5 feet that has occurred. The maximum difference, which occurred in 1925, was 0.8 foot. The true difference is probably less because significant changes in the altitude of the bench mark probably did not occur until after 1920. Actual subsidence by 1925 was probably less than 1.1 feet shown by fig. 5.

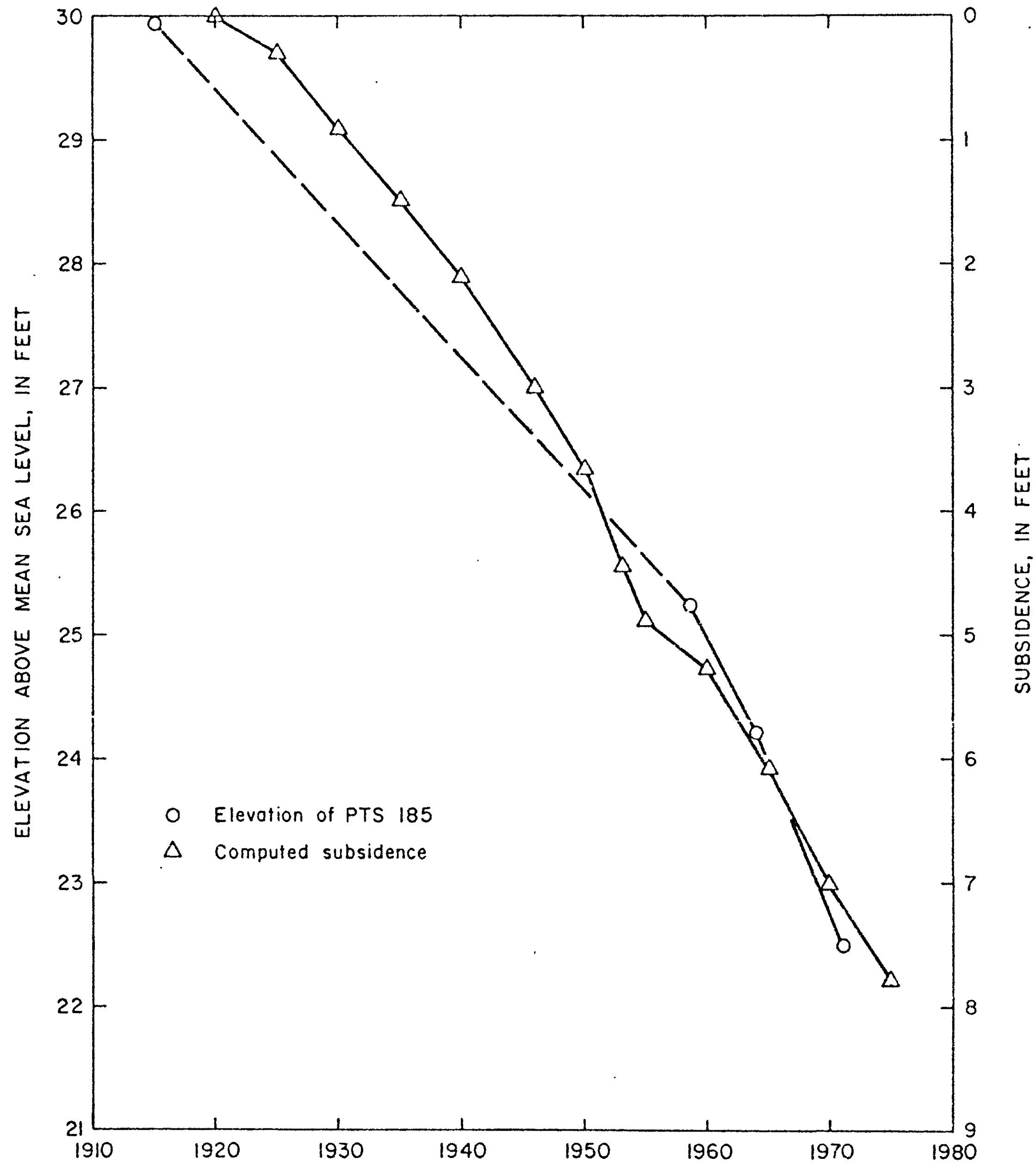

FIGURE 5. - Calculated land-surface subsidence, 1920-75

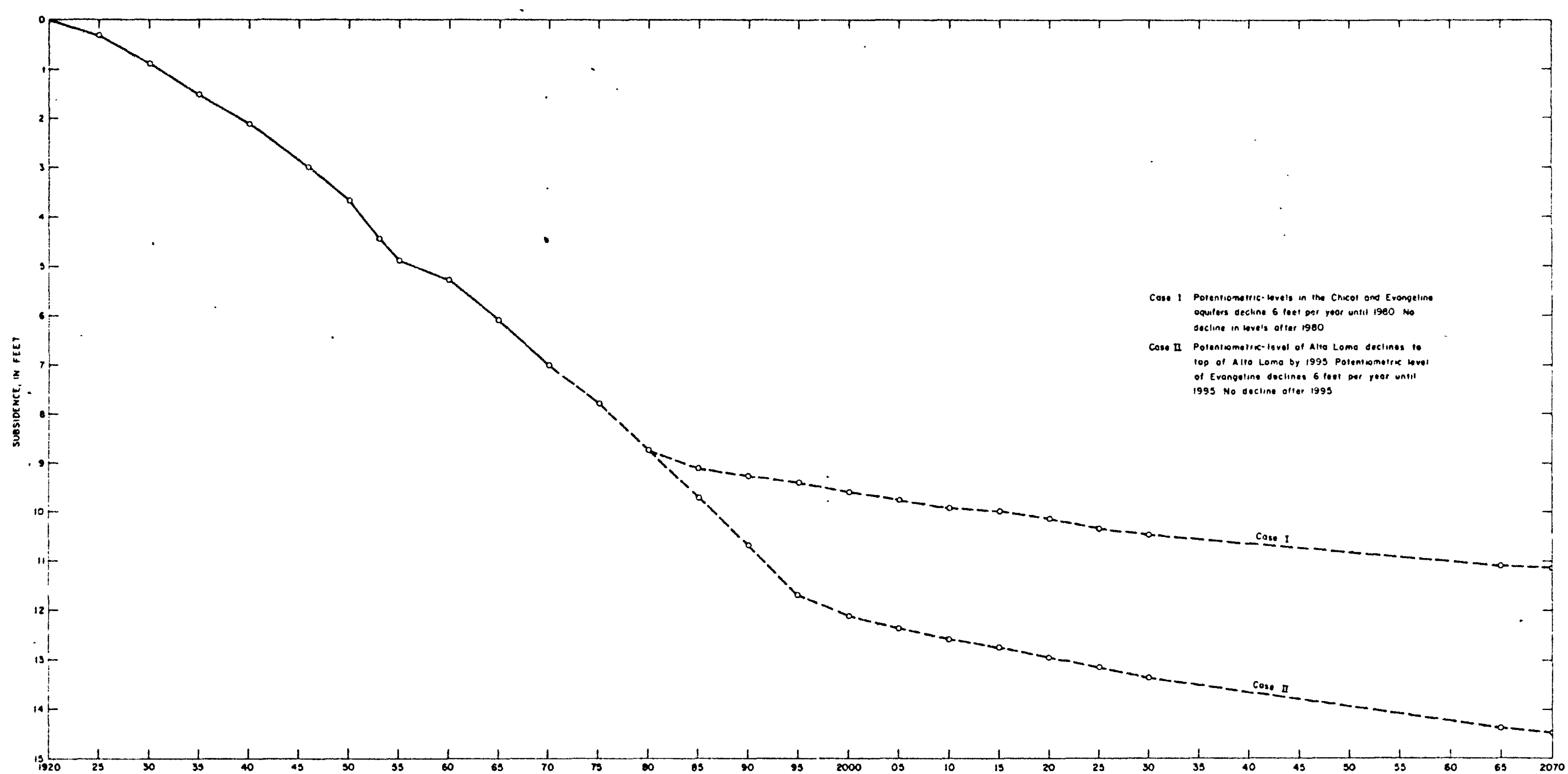

FIGURE 6. - Calculated land-surface subsidence in the Burnett, Scott, and Crystal Bays area, 1920-2070

These comparisons indicate that the assumptions, data translations, and interpretations are valid and may be used for prediction of the rate and amount of subsidence that can be expected in the future.

Figure 6 shows the subsidence calculated on the basis of estimated loading for the period 1920-70 and the subsidence calculated on the basis of two cases of assumed loading for the years 1920-2070. Case I is the most likely situation, but case II is not unreasonable.

The total amount of subsidence that could be expected if pressure declines ceased in 1980 (case I) is 11.2 feet. The total amount of subsidence that could be expected if pressures continue to decline at the rate of about 6 feet per year until 1995 (case II) is 14.5 feet.

CORRECTIVE MEASURES

Subsidence of the land surface in the Baytown area will continue until pore pressures in the clays equal the pressure in the adjacent sands. Therefore, even if artesian pressure is maintained at the present (1972) level, compaction of the clay layers would continue for some time but at a decreasing rate.

According to measurements made in the clay layer at a depth of 345 feet at the monitoring site, the Alta Loma Sand would have to be repressurized about 63 psi (pounds per square inch) to arrest the compaction. This increase in pressure is equal to raising the artesian head about 145 feet. However, the pore pressure in the clay is declining at a rate of about 0.5 psi per week, and the measurement is probably not representative of the pore pressure at some distance from the borehole. To halt compaction in the near future, the artesian pressure in the sands must be raised to a value equal to the pore pressure in the adjacent clay beds.

Two methods of repressurizing are: (1) Decreasing the rate of groundwater pumpage in the area, and (2) artificial recharge of the aquifer. Artificial recharge would require that the injected water be of a quality suitable for future use and be compatible with the native ground water and associated water-bearing material. These requirements would probably require treatment of any available surface water to a quality suitable for immediate use.

Although at least a dozen wells drilled for the disposal of liquid waste are in operation in Harris and surrounding counties, no large-scale fresh-water injection is underway or planned. There is additional fresh water available to Harris County from both the ground and from nearby lakes. A decrease in pumpage would cause artesian pressure to increase by natural means and is probably the most logical solution to the problem of artesian-pressure declines and land-surface subsidence.

Experience in other areas, notably in California, where the hydrology and clay mineralogy are similar to that of the Texas Gulf Coast region, demonstrates that recovery of the land surface by repressurizing would probably be less than 5 percent of subsidence. According to Mayuga and Allen (1969), repressurizing of the oil field at Wilmington, California, caused as much as 1.1 feet of land-surface rise where 29 feet of subsidence had occurred. Subsidence at Wilmington was probably a result of compaction of siltstone interbeds in the oil-producing zones.

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