UNITED STATES
DEPARTMENT OF THE INTERIOR
Geological Survey
Water Resources Division

ESTIMATED SUBSIDENCE IN THE CHINO-RIVERSIDE AND BUNKER HILL-YUCAIPA AREAS IN SOUTHERN CALIFORNIA FOR A POSTULATED WATER-LEVEL LOWERING, 1965-2015

OPEN-FILE REPORT

Prepared in cooperation with the
California Department of Water Resources

Sacramento, California
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ILLUSTRATIONS

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ABSTRACT

One of the alternate plans for water utilization being considered by the California Department of Water Resources in the Chino-Riverside and Bunker Hill-Yucaipa areas in southern California involves partial mining of ground water during the period 1965-2015, and consequent substantial lowering of water levels. The Department wants to know whether land subsidence would be a problem as a result of the postulated lowering. To answer this question, to the extent that leveling control permits, the present study has been made at the request of and in cooperation with the State of California.

At a few locations in the Chino-Riverside and Bunker Hill-Yucaipa areas, comparable water-level decline and subsidence data are available from which rough estimates can be made of subsidence that would occur as a result of the postulated lowering from 1965 to 2015. Limited leveling control, and apparent discrepancies in the data, preclude accurate determination of amounts of subsidence caused by historic water-level decline.

Based on 1965-2015 water-level changes postulated by the California Department of Water Resources and on available subsidence/head decline ratios, as much as 6 feet of subsidence might occur northeast of the San Jacinto fault between Loma Linda and San Bernardino, in an area of more than 350 feet of projected water-level decline. Also, as much as 1.5 feet of subsidence might occur in the vicinity of Ontario.

INTRODUCTION

At the request of Ernest M. Weber of the Southern District of the California Department of Water Resources, Joseph F. Poland and Ben E. Lofgren of the U.S. Geological Survey met with Messrs. Weber, Kiyoshi Mido, and William Harley on February 19, 1969, in Los Angeles. Mr. Weber advised us that the Department of Water Resources, as part of its water-utilization studies, is considering several alternative plans of water supply. One alternative plan involves partial mining of ground water to the year 2015 and consequent substantial lowering of water level. The Department wants to know whether land subsidence would be a problem as a result of this lowering.

Accordingly, the Department requested an appraisal by the U.S. Geological Survey of evidence of subsidence in the Chino-Riverside and Bunker Hill-Yucaipa (San Bernardino-Yucaipa) areas that could be used to predict possible subsidence under the assumed future pumping-stress conditions. The Chino-Riverside area is to the west of the San Jacinto fault and the Bunker Hill-Yucaipa area is to the east (fig. 1). It was agreed that the appraisal would be based on a review of existing leveling data. The Department provided maps showing gross changes in water level for the two areas for the 1933-34 to 1960 period, and also the postulated change in water level for the 1965 to 2015 period. Based on these data, the Department would like to know:

1. Has there been any subsidence due to water-level decline to date, and can this be used to estimate future subsidence?

2. What is the estimate of subsidence that would occur as a result of the postulated water-level lowering 1965 to 2015? It was agreed that no attempt would be made to estimate the magnitude of subsidence in areas where no leveling control is available, as this would require an investigation of a scope far beyond the time and funds available.

DATA AVAILABLE

Visits were made to various agency offices in San Bernardino and Riverside Counties to determine the extent of leveling control available, and to obtain control data where repeat leveling indicates subsidence caused by declining water levels. In general, most of the local leveling done by city and county agencies consists of short runs tied to floating bench marks. The only leveling in the areas of concern which: (1) tied to stable bench marks, (2) extended across areas of suspected subsidence, and (3) had repeat leveling for computing subsidence, was that done by the U.S. Coast and Geodetic Survey, for which chronologic elevation changes for each bench mark is in published form. Figure 1 of this report shows

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Figure 1 following here.

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the extent of the Coast and Geodetic Survey level control in the combined area of interest. Unfortunately, relatively few of the bench marks along these lines have repeat leveling spanning a long enough period to give definitive evidence of the magnitude of subsidence, if any, that can be correlated with contemporary water-level decline.

Figure 1 also shows level lines being run by County survey crews during 1968-69 as part of "The Southern California Cooperative Level Program" in cooperation with the U.S. Coast and Geodetic Survey. Data from this 1968-69 leveling were supplied to us in the form of unadjusted field notes indicating elevation differences between bench marks, and were used in preparing two of the figures discussed later (figs. 4 and 5). When adjusted elevations are available for these lines, probably 1 to 2 years hence, more accurate changes in elevation can be computed for bench marks along these lines that were leveled earlier by the Coast and Geodetic Survey.

Water-level data available for this interpretation comprised the following water-level maps supplied by the Department of Water Resources:

(a) Water-level maps of Chino-Riverside area, fall 1933 and fall 1960

(b) Water-level maps of Bunker Hill-Yucaipa area, fall 1934 and fall 1960

(c) Water-level change, Chino-Riverside area, 1933-60

(d) Water-level change, Bunker Hill-Yucaipa area, 1934-60

(e) Postulated water-level change 1965-2015 for both areas, as determined by mathematical model. The contours of water-level change, shown in figure 3, contain obvious irregularities, chiefly due to imperfectly known ground-water barriers that could not be shown on a map at this scale. Others, such as the -50-foot contour south of Colton, are inconsistent, but do not affect the findings of this report.

INTERPRETATION OF DATA

Figure 2 is a hydrograph of well 1N/4W-35L1, 3 miles northeast

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Figure 2 following here.

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of San Bernardino in the study area (Calif. Dept. Water Resources, 1965, fig. 13, p. 30). It is assumed that this hydrograph more or less typifies the general trend of water levels in the region although the range of water-level fluctuation in the eastern part of the Chino-Riverside area is much less. At well 35L1, the water level recovered until about 1915 from an earlier drought, and then declined to another drought low in 1936, at which time the drawdown did not appreciably exceed the level of 1905. In 1945, water levels were not much lower than during the 1910-1922 high period. Since 1945, water levels have declined almost continuously, and since about 1950, the depth to water in most of the study area probably exceeded any previous low. At well 35L1, the water level declined about 80 feet from 1950 to 1960. Most of the subsidence that has occurred since 1905, therefore, is probably caused by water-level declines since 1950. The 1933-34 to 1960 period for which the change in ground-water levels has been mapped is shown in figure 2.

Several of the Coast and Geodetic Survey lines (fig. 1) had leveling control prior to the broad coverage in 1961. At only a few locations, however, was leveling and releveling available that was comparable in its time span with the water-level change time-span of 1933-34 to 1960. Inasmuch as little change in elevation of bench marks probably occurred before 1950 (and this is supported by sparse leveling data), the bench-mark subsidence computed as differences between pre-1950 elevations and 1961 elevations was considered as caused by water-level changes from 1933 to 1960.

Figure 3 shows the locations where changes in bench-mark elevation

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Figure 3 following here.

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from pre-1950 leveling to the 1961 releveling are available for comparison with 1933-34 to 1960 water-level changes. At these locations, subsidence/head-decline ratios were computed (fig. 3), which, when multiplied by the projected 1965-2015 water-level change shown in figure 3, give a rough estimate of the subsidence that would result from the 1965-2015 stress change. Estimates of subsidence from 1965 to 2015 at the few locations where subsidence/head-decline ratios could be computed are also shown in figure 3. These estimates do not include subsidence that might have occurred prior to 1965.

Detailed analysis of published Coast and Geodetic Survey leveling data suggests that discrepancies of as much as 0.2 foot may exist in the absolute elevation of many of the bench marks during the period of record. For example, bench marks located on or near bedrock outcrops appear to be subsiding; also, elevations for certain years indicate a net rise of the land surface over broad areas where little or no rebound is anticipated, suggesting problems of datum controls and adjustment problems. In many instances, the apparent discrepancies in the published data may be larger than the absolute changes in elevation we are trying to detect. Also, possible tectonic subsidence, especially northeast of the San Jacinto fault near San Bernardino, may account for some of the change in bench-mark elevation and, if so, would reduce the subsidence actually caused by water-level declines. In the subsidence computations of figure 3, all observed subsidence has been attributed to water-level decline.

In the Chino-Riverside area, meaningful subsidence/head-decline ratios are largely limited to the vicinity of Ontario, Claremont, and Colton (fig. 3). For most of the area, there is no leveling control to determine the amount of subsidence that occurred during the 1933-60 period of ground-water development. Reported subsidence of bedrock bench marks 3 miles northwest of Claremont indicates leveling uncertainties of as much as 0.2 foot in the 1923-61 period. This raises concern as to the magnitude of such discrepancies in other parts of the area. In the Colton area, also, the reported subsidence of bench marks that should have remained stable introduces uncertainties of several tenths of a foot. In both the Ontario-Claremont and Colton areas, however, the estimated subsidence for postulated 1965-2015 water-level changes, based on the indicated subsidence/head-decline ratios, is small--about 1.5 feet near Ontario and 0.2 foot near Colton.

In the Bunker Hill-Yucaipa area, not only are postulated water-level declines large adjacent to the San Jacinto fault, but also, subsidence/head-decline ratios are the largest in the study area. This is the general area of original artesian flow as shown by Mendenhall (1905, pl. VIII). Probably, fine-grained compressible beds are more abundant in this area of confined aquifers than elsewhere in the region. As much as 5.8 feet of subsidence near Loma Linda, and from 3 to 5 feet of subsidence in the San Bernardino area enclosed by the -300-foot water-level-decline contour are estimated for the postulated water-level change 1965-2015. Subsidence in most of the remainder of the Bunker Hill-Yucaipa area probably would not exceed 1-2 feet. It might exceed 2 feet in the vicinity of the -250-foot contour immediately south of the Crafton Hills, which also was originally an area of artesian flow. Locally, where an increase in water levels is indicated in figure 3, no subsidence would be anticipated.

Two subsidence profiles are presented to show the magnitude of apparent subsidence across the San Jacinto fault in the vicinity of Colton, through the one locality in the combined area where significant subsidence would probably result from the postulated 2015 water-level conditions. In order to show maximum measured subsidence on these profiles, data are plotted for the full period of record to 1961. The beginning dates for leveling at available bench marks of long record vary from bench mark to bench mark. Therefore, the beginning date of the leveling record is shown above the pre-1950 base line for each bench mark. Hence, the plotted subsidence from the pre-1950 base line to 1961 is not for a common period of time. In spite of this discrepancy, the graphic representation of subsidence at the bench marks shown is useful in indicating the general magnitude of subsidence that has occurred.

Figure 4 shows the subsidence that occurred during two periods of

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Figure 4 following here.

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record along line A-A' (for location, see fig. 1) from north of Riverside to San Bernardino. In the upper graph, the change in bench-mark elevations from pre-1950 leveling to 1961, based on published data of the Coast and Geodetic Survey, shows a marked difference across the San Jacinto fault. The uniform apparent subsidence of about 0.15 foot from 1949 to 1961 of bench marks south of the fault may be due in part to changes in elevation of bench marks assumed to be stable in the survey data adjustments. Nevertheless, definite subsidence has occurred north of the fault where water-level declines have been large. It is possible that a small part of this subsidence may be due to tectonic movement. In this analysis, however, all of the subsidence is attributed to compaction due to water-level decline. The lower graph shows the apparent change along the same profile from 1961 to 1968, and is based on published 1961 elevations of the Coast and Geodetic Survey and accumulated differences in bench-mark elevations of the 1968-69 County surveys, assuming bench mark Z38 to be stable during this period. Since some subsidence probably occurred at bench mark Z38, other bench marks along the line would be lowered by this same unknown amount. The marked subsidence north of the San Jacinto fault persists during the 1961 to 1968-69 period. Although water-level control is not available for this later period, the continued subsidence trend lends support to the subsidence/head-decline ratios computed for the 1933-34 to 1961 period.

Figure 5 shows the subsidence that has occurred during the same

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Figure 5 following here.

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pre-1950 to 1961 and 1961 to 1968-69 periods along line B-B' (for location, see fig. 1), extending east and southeast from Colton. The sharp subsidence trough east of the San Jacinto fault is seen for both periods of record, and even though an uncertainty of as much as 0.15 foot in the absolute datums for the several surveys may exist, the profiles supply a rough measure of the amount of subsidence that has occurred. Along this profile also, all observed subsidence is attributed to increased stresses caused by declining water levels. Maximum observed subsidence is immediately east of the San Jacinto fault near Loma Linda, and has been about 1.3 feet from about 1943 to 1968-69.

CONCLUSIONS

1. Observed subsidence was less than 0.2 foot through most of the area of leveling control. Indicated subsidence greater than 0.2 foot is in the Ontario-Claremont and the San Bernardino-Redlands areas. Maximum observed subsidence is immediately east of the San Jacinto fault near Loma Linda and has been about 1.3 feet from about 1943 to 1968-69.

2. A rough estimate of future subsidence can be made at only a few locations in the combined Chino-Riverside and Bunker Hill-Yucaipa areas, where bench-mark subsidence and water-level change are known for comparable periods. Because of gross geologic differences in thickness and physical characteristics of the water-bearing deposits, no attempt is made herein to extrapolate beyond the available data.

3. Discrepancies in leveling control preclude accurately determining actual amounts of subsidence caused by water-level decline. Not only may some of the changes in elevation be due to tectonic adjustments, particularly east of the San Jacinto fault, but apparent problems of absolute datums for the various surveys suggest that discrepancies of possibly as much as 0.2 foot of indicated elevation changes in parts of the combined areas may not be real.

4. Because of slow drainage from fine-grained aquitards, not all of the ultimate subsidence caused by the 1933-34 to 1960 water-level decline would have occurred by 1961. Possibly as much as 25 percent of the ultimate subsidence would lag the leveling control, and thus would not be included in the subsidence/head-decline ratios used in our data analysis. This lag component is not known, and probably varies considerably in both time and space.

5. Analysis of leveling data in areas where little or no subsidence is expected, that is, where little or no water-level decline has occurred or where bench marks are located on bedrock outcrops, suggests that published data indicate more subsidence than actually has occurred. In parts of the combined area, a discrepancy of more than 0.15 foot of unreal subsidence probably exists in the pre-1950 to 1961 leveling data. If tectonic subsidence has occurred, it would tend to reduce the subsidence attributed to water-level change. Also, because of lag complications, less subsidence probably occurred during the pre-1950 to 1961 period used in this study than would ultimately result from contemporaneous water-level changes. There is little basis for estimating the significance of these uncertainties in our subsidence interpretation. They would, however, tend to counteract each other in their net effect.

6. In the Chino-Riverside area, postulated 1965-2015 water-level declines are largest (300 to 400 feet) in the vicinity of Ontario where some control is available (fig. 2). Projected trends for the 1965-2015 change, based on 1933-60 ratios, indicate that as much as 1.5 feet of subsidence might occur in this area. Uniformly spaced water-level decline contours suggest that subsidence would be more or less uniform over broad areas, and sharp differential changes are not anticipated. In the vicinity of Colton, southwest of the San Jacinto fault, very little subsidence would be anticipated. No leveling data are available for estimating future subsidence in the vicinity of Fontana.

7. For the Bunker Hill-Yucaipa area, as much as 6 feet of subsidence might result if postulated 1965-2015 water-level changes are imposed. Subsidence would be most intense immediately northeast of the San Jacinto fault, between Loma Linda and San Bernardino, within the -350-foot water-level decline line. No data are presently available for estimating future subsidence in the Beaumont-Yucaipa subarea. However, the postulated water-level decline is less than 150 feet in most of that subarea, and it is not anticipated that subsidence would be appreciable.

REFERENCE CITED

California Department of Water Resources, 1967, Hydrologic data: 1965, Vol. V: Southern California, App. C: Ground water measurements, fig. 13: California Dept. Water Resources, Bull. 130-65.

Mendenhall, W. C., 1905, Hydrology of the San Bernardino Valley, California: U.S. Geol. Survey Water-Supply Paper 142, 124 p.

Figure 1

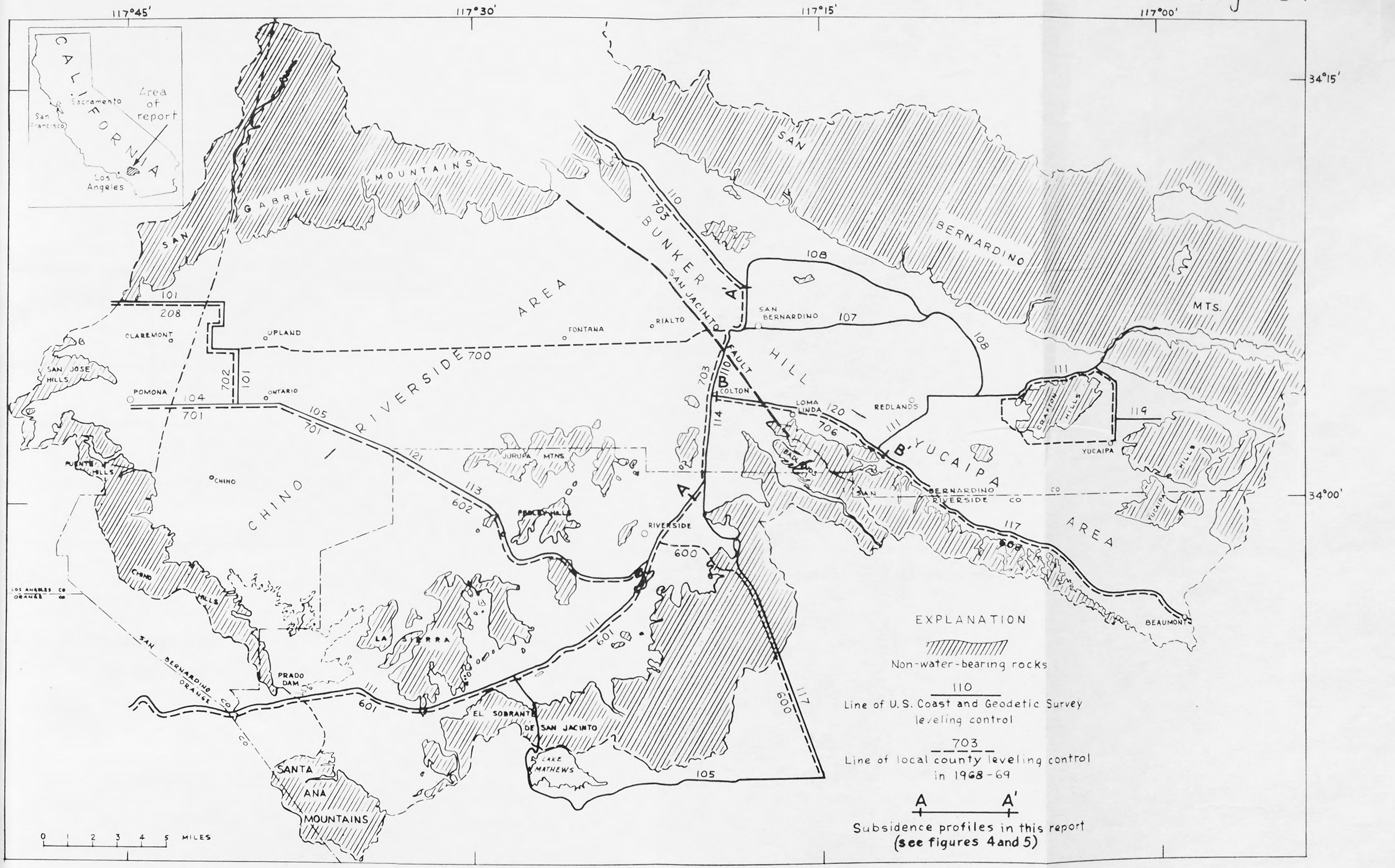

FIGURE 1.—Leveling control in the Chino-Riverside and Bunker Hill-Yucaipa areas, Riverside and San Bernardino Counties, California, and locations of subsidence profiles.

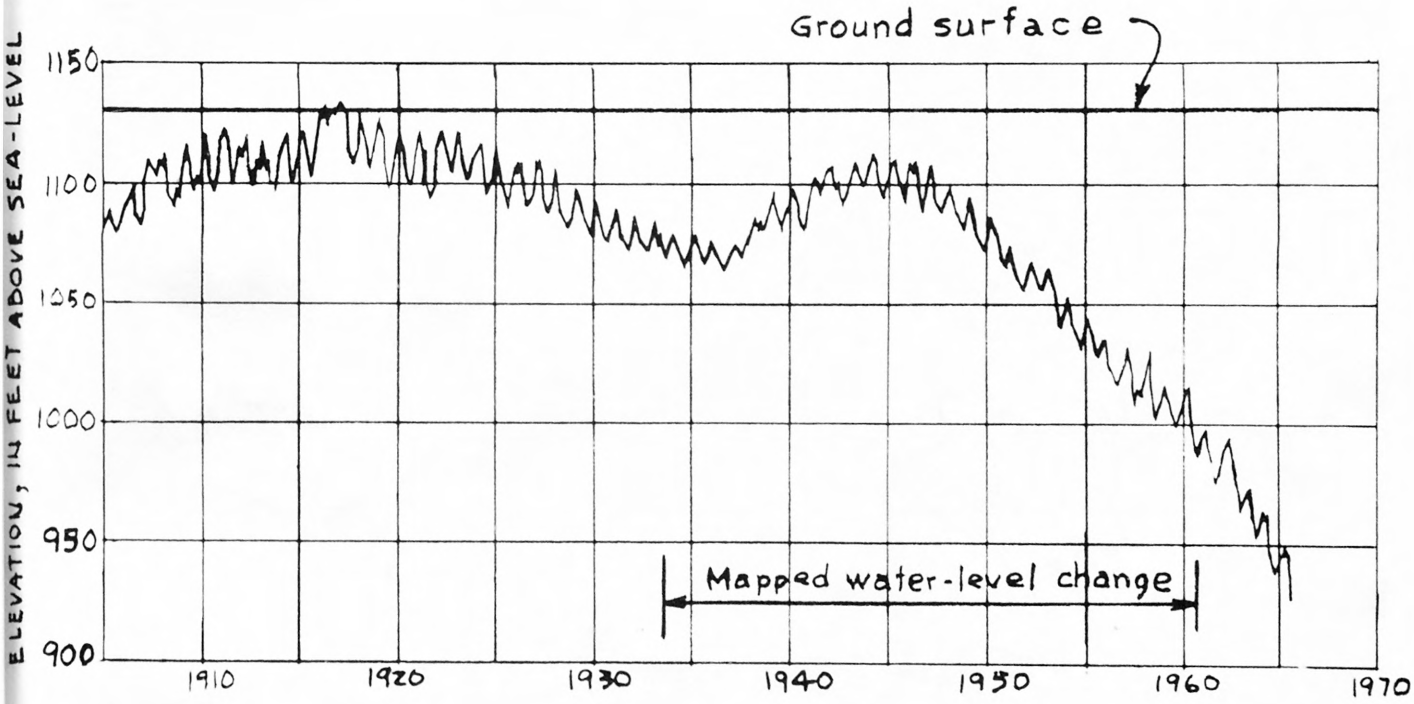

Figure 2.—Hydrograph for well 1N/4W-35L1, 3 miles northeast of San Bernardino

Figure 3

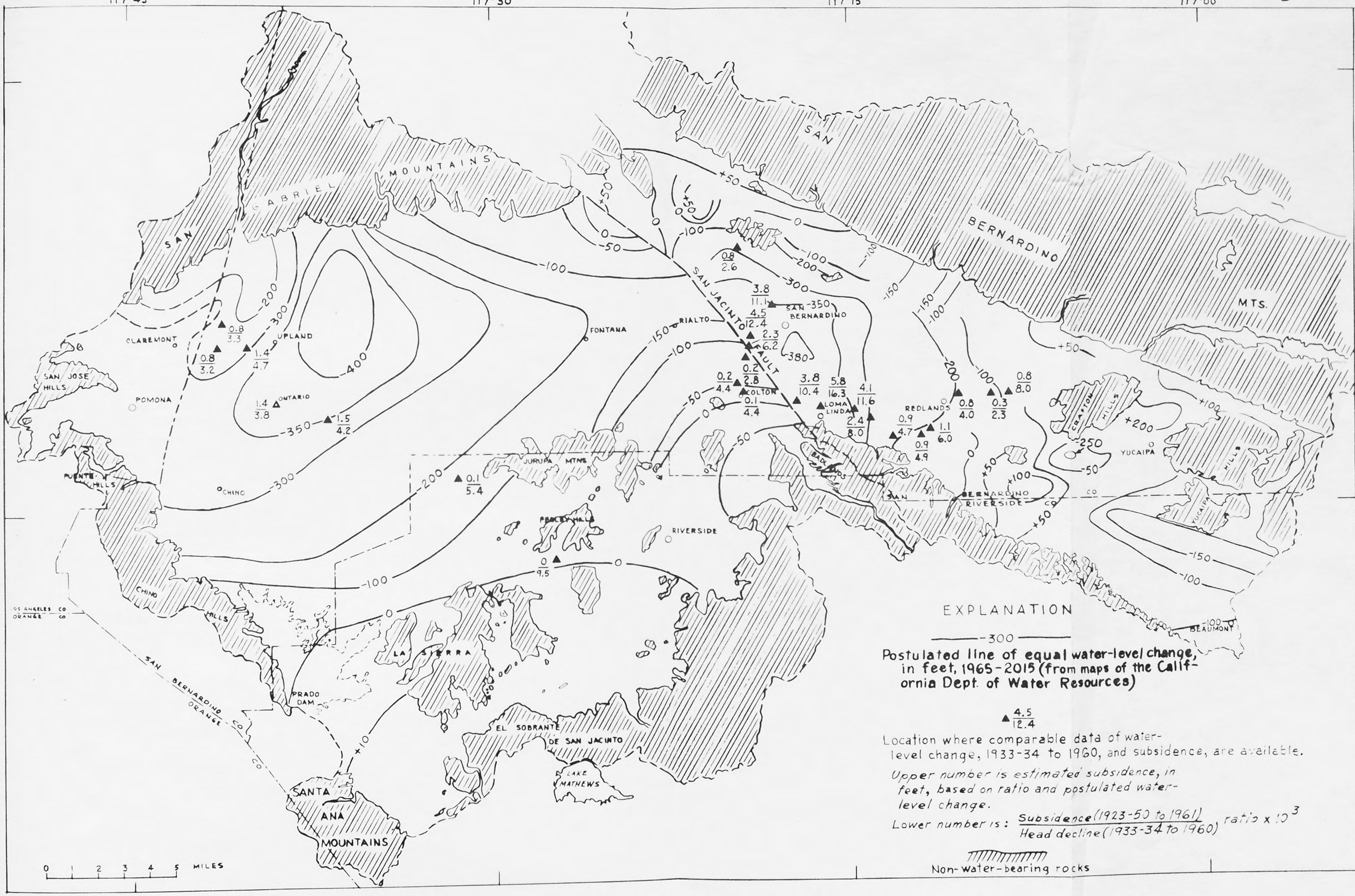

FIGURE 3.— Postulated water-level change and estimated subsidence, 1965—2015, in the Chino-Riverside and Bunker Hill-Yucaipa areas, Riverside and San Bernardino Counties, California

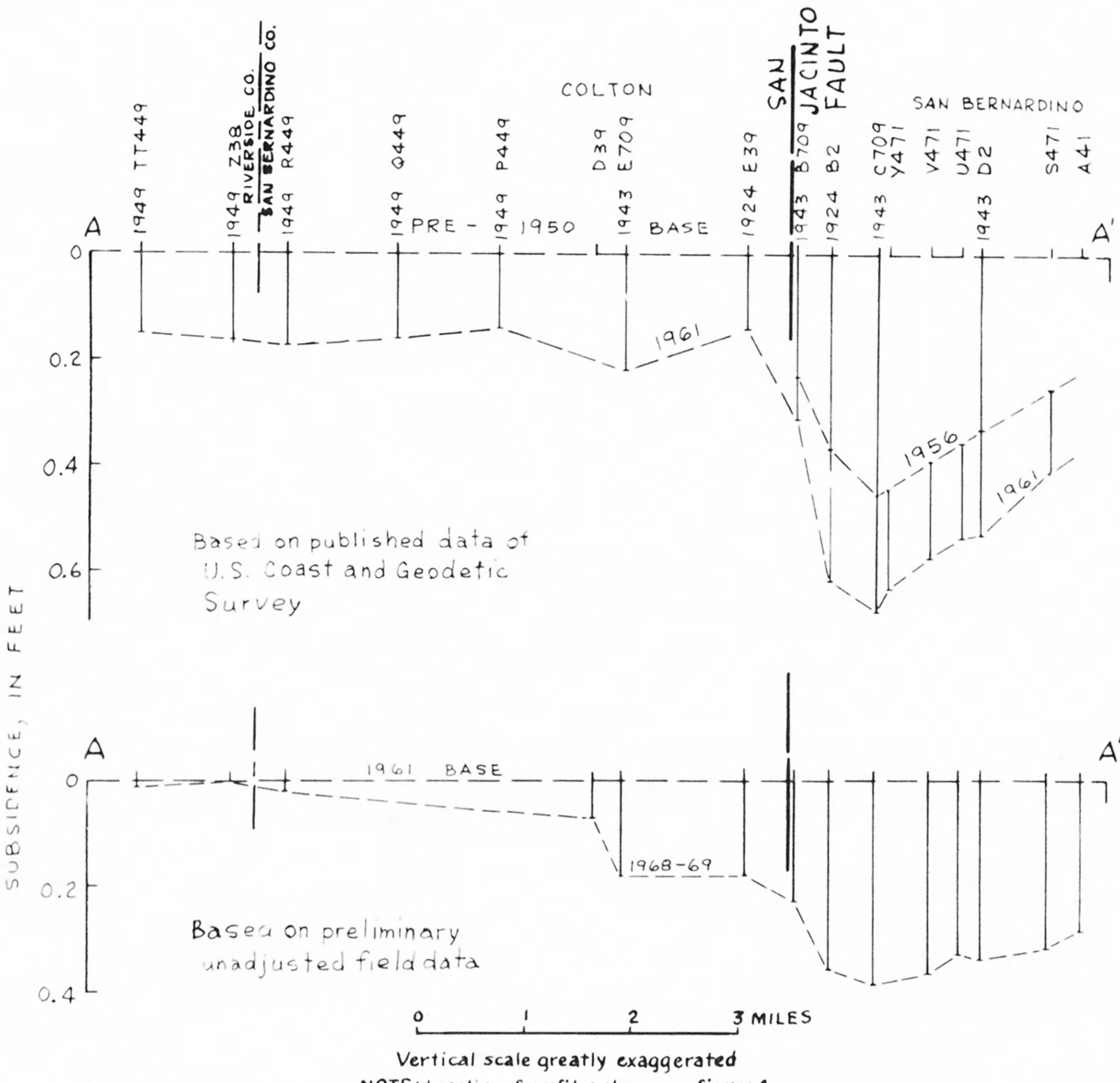

FIGURE 4.—Subsidence profiles from north of Riverside to San Bernardino.

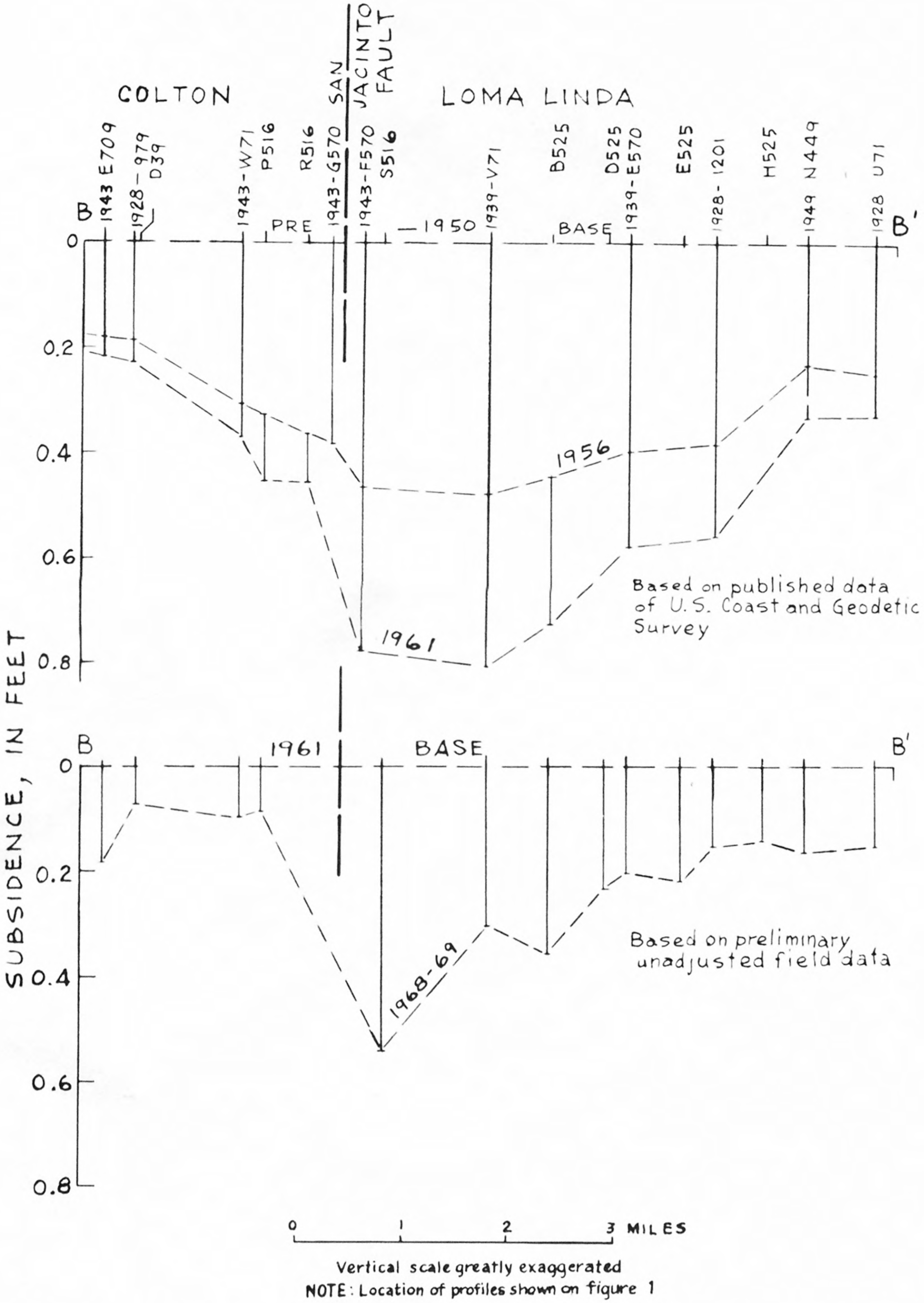

FIGURE 5.—Subsidence profiles southeast from Colton.