

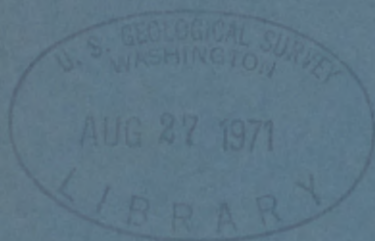
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

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ESTIMATED SUBSIDENCE IN THE RAYMOND BASIN, LOS ANGELES
COUNTY, CALIFORNIA, FOR A POSTULATED WATER-LEVEL
LOWERING, 1970-2020

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By Ben E. Lofgren



Prepared in cooperation with the
California Department of Water Resources

OPEN-FILE REPORT

Sacramento, California
1971

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ESTIMATED SUBSIDENCE IN THE RAYMOND BASIN,
LOS ANGELES COUNTY, CALIFORNIA,
FOR A POSTULATED WATER-LEVEL LOWERING, 1970-2020

By Ben E. Lofgren

ABSTRACT

One of the alternate plans for water utilization being considered by the California Department of Water Resources in the Raymond Basin in southern California involves partial mining of ground water during the period 1970-2020, 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 existing leveling data permit, the present study has been made at the request of and in cooperation with the Department of Water Resources.

Water levels in the Raymond Basin declined to historic low levels in the mid-thirties, then rose and remained above these lows during most of the forties, fifties, and early sixties. Thus, no additional hydraulic stresses were imposed on the water-bearing deposits during this latter period to induce subsidence.

Bench-mark control for the 27-year period, 1933-34 to 1961, suggested 0.2 foot of subsidence for most bench marks in and near the basin. This is attributed to network-adjustment problems rather than actual subsidence. At none of the bench marks studied is there a basis for directly relating subsidence to water-level decline. Limited leveling control during the 1961-68 period is also inconclusive. Unfortunately, no leveling control is available for the pre-1933 period of major water-level decline.

Based on subsidence/head-decline ratios of nearby areas, it is concluded that subsidence in Raymond Basin would be small if Plan D pumping stresses were effected. Maximum subsidence, occurring where pumping stresses were the greatest and unconsolidated deposits are the thickest, would probably be less than 1 foot. Subsidence would occur so slowly and over such a broad area that no problems should result.

The Department of Water Resources provided water-level maps of the Raymond Basin for the years 1933, 1960, and 1969, and also a map showing the postulated change in water level under Plan D for the 1970 to 2020 period. The Department would like to know, based on existing data:

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 estimated magnitude and extent of subsidence that would occur as a result of postulated water-level lowering of 1970-2020?

If it was agreed that where available data are inadequate or inconclusive, no estimates would be made as this would involve an investigation of

INTRODUCTION

At the request of the California Department of Water Resources, and in financial cooperation with their Southern District, the U.S. Geological Survey investigated the possibility of subsidence that might occur in Raymond Basin under a postulated future pumping stress. The Department of Water Resources, as part of its water-utilization studies, is considering several alternative plans of water supply. One alternative, Plan D, involves the extensive lowering of ground-water levels between 1970 and 2020. The crux of this study is the extent to which land subsidence would be a problem if these pumping stresses were imposed.

The Department of Water Resources provided water-level maps of the Raymond Basin for the years 1933, 1960, and 1969, and also a map showing the postulated change in water level under Plan D for the 1970 to 2020 period. The Department would like to know, based on existing data:

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 estimated magnitude and extent of subsidence that would occur as a result of postulated water-level lowering of 1970-2020?

Figure 1.-- Map of the Raymond Basin showing the location of long-term hydrographs and leveling control.

It was agreed that where available data are inadequate or inconclusive, no estimates would be made as this would involve an investigation of a scope far beyond the time and funds available.

and from several smaller streams discharging from the San Gabriel Mountains comprise the principal water-bearing deposits of the Basin.

The bedrock basement underlying Raymond Basin is highly irregular thus the wedge of overlying Quaternary alluvial deposits that comprise ground-water reservoir varies considerably in thickness. As shown in geologic sections (Div. Water Resources, 1943, pl. 6), these unconsolidated deposits range in thickness from a maximum of about 1,000 feet in the south-central part of the basin to zero on the northern and western margins and at Monk Hill (fig. 1). Although these deposits are principally sands and gravels, and, for the most part, highly productive to water, some fine-grained confining beds occur in the depositional sequence, particularly in the southern part of the basin along the Raymond fault. In no part of the basin are there indications of contiguous confining strata although artesian conditions prevailed locally in the early days.

NATURE OF THE PROBLEM

Raymond Basin is a highly urbanized alluvial valley, bounded on the north by the San Gabriel Mountains and on the south by the hydrologically and topographically conspicuous Raymond fault (fig. 1).

Figure 1.--Map of the Raymond Basin showing the location of long-term hydrographs and leveling control.

Detrital alluvial fans, derived principally from Arroyo Seco, Eaton Wash, and from several smaller streams discharging from the San Gabriel Mountains, comprise the principal water-bearing deposits of the Basin.

The bedrock basement underlying Raymond Basin is highly irregular, thus the wedge of overlying Quaternary alluvial deposits that comprise the ground-water reservoir varies considerably in thickness. As shown in geologic sections (Div. Water Resources, 1943, pl. 6), these compressible unconsolidated deposits range in thickness from a maximum of about 1,000 feet in the south-central part of the basin to zero on the northern and western margins and at Monk Hill (fig. 1). Although these deposits are principally sands and gravels, and, for the most part, highly productive to water wells, some fine-grained confining beds occur in the depositional sequence, particularly in the southern part of the basin along the Raymond fault. In no part of the basin are there indications of continuous confining strata, although artesian conditions prevailed locally in the early days.

Raymond fault, throughout its length, is an effective hydrologic barrier. Water levels are persistently higher north of the fault. Before extensive developments lowered the ground-water levels throughout the region, a narrow belt of swamps and flowing wells north of the fault gave evidence of the diked ground-water basin.

In 1902, 141 wells were listed for the Raymond Basin (Mendenhall, 1908). The earliest of these wells was constructed in 1881, and many were shallow and of small production. Exploitation of the ground-water basin was rapid during the early decades of the century, with heavy demands by numerous expanding municipalities and water companies putting severe stress on the resource. By 1920, some alarm was felt concerning the overdraft of the basin and the persistent decline of ground-water levels. Several reservoirs were built on the principal streams, and distribution systems were improved by various agencies attempting to augment local supplies and enhance the ground-water conditions.

In 1939, an intensive appraisal of the ground-water resources of the Raymond Basin by the California Division of Water Resources was ordered by the court in anticipation of an adjudication of the water rights of the basin. By the early forties, rigid controls were imposed on withdrawals from the ground-water reservoir and water levels began to rise throughout much of the area.

Figure 2 is an east-west section north of the Raymond fault showing

Figure 2.--Profiles of bedrock and water table just north of Raymond fault. (From California Division of Water Resources, 1943, plate 8; plate references are to that publication.)

the configuration of the bedrock, and the approximate position of the water table in the fall of 1902 and the spring of 1937. Figure 3 shows the long-

Figure 3.--Fluctuations of the water table in selected wells in the Raymond Basin.

term water-level trends of eight observation wells in the basin through 1945. As shown, there was an extended water-level decline from 1916 to about 1937 throughout the area, followed by a distinct rising trend. This marked reversal in water-level trend was apparently directly related to a period of increased precipitation, beginning in 1934-35, and a decrease in withdrawal after 1934 (Div. Water Resources, 1943, table 3).

Figure 4 shows the measured precipitation at Los Angeles for 90 years

Figure 4.--Representative precipitation characteristics for Los Angeles. (Modified from Calif. Dept. Water Resources, 1970.)

observation wells through 1965 (for location, see figure 1). The water of record, and the cumulative deviation from mean precipitation for the level in well 1N/12W-20B1, located 0.8 mile south-southwest of Mont Hill, attained a low level during the drought terminating in the mid-thirties interest in this study, from 1933-34 to 1961 and from 1961 to 1968, during which bench-mark leveling control was available for interpretation. As indicated by the cumulative graph (fig. 4), precipitation was generally above normal from 1933-34 to 1944, and below normal during the later part of the control period. Cumulative precipitation for the 28-year period of leveling control (1933-34 to 1961) was somewhat above normal. Levels in wells 1N/11W-21C4, C5, in the Sierra Madre area, showed a much greater seasonal fluctuation and were more responsive to several years of excessive precipitation. In this part of the basin, the water level throughout the 1933-34 to 1961 control period remained above the low of the early thirties, except for a few summer months of 5 years between 1949 and 1957. A comparison of the hydrograph of well 1N/12W-20B1 with the precipitation graph of figure 4 suggests that many of the ground-water fluctuations in this part of the basin are climatically induced.

Figure 5 shows the long-term hydrographs of two representative

Figure 5.--Long-term hydrographs of representative wells in the Raymond Basin. From California Department of Water Resources (1970).

observation wells through 1968 (for location, see figure 1). The water level in well 1N/12W-20B1, located 0.8 mile south-southwest of Monk Hill, attained a low level during the drought terminating in the mid-thirties then rose and remained relatively stable for 15 years, due to excess precipitation to 1944 and regulated ground-water withdrawals thereafter. A renewed decline in water-level trend began in 1956 in this area. It was not until about 1963, however, considerably after the first period of leveling control, that the head was drawn below the 1933 low level. Water levels in wells 1N/11W-21C4, C6, in the Sierra Madre area, showed a much greater seasonal fluctuation and were more responsive to several years of excessive precipitation. In this part of the basin, the water level throughout the 1933-34 to 1961 control period remained above the low of the early thirties, except for a few summer months of 6 years between 1949 and 1957. A comparison of the hydrograph of well 1N/12W-20B1 with the precipitation graph of figure 4 suggests that many of the ground-water fluctuations in this part of the basin are climatically induced.

LEVELING DATA AVAILABLE FOR ESTIMATING FUTURE SUBSIDENCE

The most direct method for estimating future subsidence uses a subsidence/head-decline ratio calculated for periods of historic water-level decline. Thus, if at a given location, X feet of subsidence occurred for each 10 feet of additional water-level decline to new low levels during a period of historic record, it is probable this same relationship will continue in the future. Because of slow drainage of the fine-grained aquitards, not all of the ultimate subsidence caused by a given water-level change occurs during the period of the change. Estimates of future subsidence are thus minimum values, and may be 25-50 percent less than the ultimate. Although the subsidence/head-decline ratio may vary from one locality to the next due to hydrogeologic differences, at a given location this ratio is a rough measure of the compression characteristics of the aquifer system and its response to induced pumping stresses.

Numerous water-level maps and long-term hydrographs are available for the area from which hydraulic changes in the ground-water basin can be approximated. In general, these indicate that water levels declined appreciably prior to the mid-thirties, then rose considerably during the late thirties and early forties. A comparison of the October 1960 water-level contours with the corresponding October 1933 contours indicates almost no change during the 27-year period. Water levels in 1960 locally were as much as 25 feet above or below the corresponding 1933 elevations. Throughout most of the basin, however, differences were less than 10 feet at the end of this 27-year period.

The only leveling control usable for estimating long-term subsidence is: (1) leveling tied to stable bench marks outside the subsiding area, and (2) level lines with repeated leveling at a later date so that changes in elevation can be computed. Most of the leveling in the basin by city and county agencies consists of short runs tied to floating bench marks, and thus is not usable for computing subsidence. Figure 1 shows the location of about three dozen bench marks in the basin that meet above requirements. Table 1 gives the apparent elevation change for these bench marks during various periods of leveling control.

Table 1.--Apparent elevation change of bench marks in Raymond Basin

[Computed from adjusted data of the U.S. Coast and Geodetic Survey. Bench-mark designations have been shortened in figure 1.]

Bench mark	Elevation change			Bench mark	Elevation change		
	1952-63	1963-66	1966-68		1931-2 to 1933-4	1933-4 to 1961	1961 to 1968
24-35	+ .00	- .10	- .19	X172 (reset)		- .18	- .05
24-37	- .03	- .10	+ .01	Y172		- .15	- .03
24-38	- .00	- .10	+ .00	Z172		- .13	- .31
24-41	- .01		- .19	A173		- .16	+ .03
	1931-2 to 1933-4	1933-4 to 1961	1961 to 1968	C173 (reset)		<u>1</u> /	- .87
T172		- .19	- .21	S65 (USGS)	- .08	- .14	- .19
U172		- .21	- .17	F171		- .15	- .21
V172 (reset)		- .20	- .17	G171		- .30	- .21
W172 (reset)		- .19	- .19	Ohio No. 5 well (C of P)		- .18	- .25
				S64 (USGS)		- .17	- .21

1/ Bench mark reset in 1942. Change based on published data for this bench mark not correct.

Table 1.--Apparent elevation change of bench marks in Raymond Basin--Continued

Bench mark	Elevation change		Bench mark	Elevation change	
	1931-2 to 1933-4	1933-4 to 1961		1931-2 to 1933-4	1933-4 to 1961
828.30 (USGS)		- .18	868 (C of P)	- .12	- .18
896 (C of P)	- .10		L171 (reset (C of P)		- .18
S96 and reset	- .08	- .18	M171		- .18
H171		- .18	N171		- .20
J171 (reset)		- .19	892.4 (USGS)		- .31
S69	- .09	- .19	U171		- .20
K171		- .19	Copelin (C of P)		- .87
S68 (reset)		- .21	V171		- .19
836 (C of P)	- .11	- .17	W171		- .21
R96	- .11	- .17	X171		- .21
857 (reset) (C of P)	- .11	- .19	Z171		- .25
S63 (USGS)	- 12	- .19	B172		- .21
			D172		- .21

1/ Bench mark reset in 1942. Change based on published data for this bench mark not correct.

INTERPRETATION OF DATA

Only four bench marks listed in table 1 showed 0.25 foot of subsidence or more for the 28-year period 1933-34 to 1961. Most of the bench marks and Geodetic Survey (lines 13 and 14, quadrangle 341182). These lines showed about 0.2 foot of subsidence during this period--this apparent traverse Raymond Basin from south to north, and are tied to reference elevation change probably being related to adjustment computations outside bench marks outside the Basin. Not all of the computed changes in the study area for either the 1933-34 or 1961 leveling control. Bench marks elevation along these lines (table 1) are caused by hydrogeologic changes S65 (USG6) and T172, south of the Raymond Basin (fig. 1), show nearly 0.2 within the Basin, however, All of the bench marks, within the Basin and foot of subsidence between 1933-34 and 1961, and bench mark D172 on the beyond, have a component of subsidence which apparently is related to bedrock of the San Gabriel Mountains showed slightly more than 0.2 foot leveling adjustments or discrepancies outside the Basin. The measure of of subsidence during this period. Actually, only 3 of the 40 bench marks actual subsidence related to water-level changes in the Basin, therefore, with vertical control in 1933-34 and 1961 showed deviations of more than is assumed to be the amount that bench marks in areas of water-level 0.05 foot from the 0.20 foot difference for the period. Two of these showed decline have settled in excess of the settlement of unaffected bench marks less than the 0.20-foot change and three showed more. By assuming an in surrounding areas of no decline. Thus, if all bench marks--those in 0.20-foot correction for all bench marks in the area, and subtracting this heavily pumped areas and those in unpumped areas--experienced the same amount from the 1933-34 to 1961 differences (table 1), the differences apparent subsidence, the common difference is probably not caused by the differences of table 2 are obtained for the three bench marks showing pumping.

significant subsidence, apparently due to local influences. Also, table 1 shows the approximated water-level changes at the three locations from October 1933 to October 1960.

Only four bench marks listed in table 1 showed 0.25 foot of subsidence or more for the 28-year period 1933-34 to 1961. Most of the bench marks showed about 0.2 foot of subsidence during this period--this apparent elevation change probably being related to adjustment complications outside the study area for either the 1933-34 or 1961 leveling control. Bench marks S65 (USGS) and T172, south of the Raymond fault (fig. 1), show nearly 0.2 foot of subsidence between 1933-34 and 1961, and bench mark D172 on the bedrock of the San Gabriel Mountains showed slightly more than 0.2 foot of subsidence during this period. Actually, only 5 of the 40 bench marks with vertical control in 1933-34 and 1961 showed deviations of more than 0.05 foot from the 0.20 foot difference for the period. Two of these showed less than the 0.20-foot change and three showed more. By assuming an 0.20-foot correction for all bench marks in the area, and subtracting this amount from the 1933-34 to 1961 differences (table 1), the adjusted differences of table 2 are obtained for the three bench marks showing significant subsidence, apparently due to local influences. Also, table 2 shows the approximated water-level changes at the three locations from October 1933 to October 1960.

Table 2.--Bench marks indicating measurable subsidence due to

water-level decline

Bench mark	Location	Indicated subsidence ^{1/} 1933-34 to 1961 (feet)	Water-level ^{2/} change 1933 to 1960 (feet)
G171	3.5 mi due south of Monk Hill; north of fault.	0.10	0
892.4 (USGS)	1.2 mi due south of Monk Hill.	.11	+ 15
Copelin	0.8 mi south-southwest of Monk Hill.	.67 ^{3/}	+ 20

^{1/} Based on published Coast and Geodetic Survey data, adjusted as described above.

^{2/} Based on October 1933 and October 1960 water-level maps prepared by the California Department of Water Resources.

^{3/} Nearby bench mark U171 showed no subsidence (after adjustment) during this period.

Three bench marks had leveling control for the 1961 to 1968 period (table 1). One of these showed a net rise, and two a net subsidence. During the 27-year period, 1933-34 to 1961, water levels generally remained above their mid-thirties lows. Thus, in general, no additional hydraulic stresses were imposed on the aquifer system in the vicinity of bench marks X172 (reset) and Y172, where 0.05 and 0.03 foot of subsidence, respectively, was observed between 1961 and 1968, water levels showed a net rise of 10 to 20 feet from October 1960 to October 1969. Unfortunately, bench mark C173 (fig. 1), located on the mountain block north of Altadena and ideally situated as a reference tie outside the ground-water basin, was reset in 1934 and its published 1961 elevation cannot be related to the 1933-34 elevation.

Figure 6 shows the postulated change in ground-water levels that

Figure 6.--Postulated change in ground-water elevations, 1970-2020, in the Raymond Basin under Plan D (decreed right plan).

Most of the apparent subsidence observed for bench marks throughout the basin (table 1) is probably related to network-adjustment problems outside the study area. Several of the bench marks may have been disturbed during the 1933-34 to 1961 period, which is probably the cause of the large settlement of bench mark Copelin (table 1). As shown, water levels throughout the basin would be lowered from 30 to more than 300 feet. Heads throughout half the basin would be lowered more than 100 feet, with the most severe declines occurring immediately north of the Raymond fault.

CONCLUSIONS

1. During the 27-year period, 1933-34 to 1961, water levels generally remained above their mid-thirties lows. Thus, in general, no additional hydraulic stresses were imposed on the aquifer system during this period to induce subsidence. If subsidence did occur in the Basin during this interval, as suggested by a few scattered bench marks, it was probably of only local extent or was not related to water-level declines.
2. The hydrograph of well 1N/12W-20B1 (fig. 5) suggests that after 1961 water levels in centers of heavy pumping may have declined below their mid-thirties lows. Little leveling control is available, however, to record subsidence that may have occurred. The 1961-68 record of elevation changes for three bench marks listed in table 1 is inconclusive in relating subsidence to head change.
3. Most of the apparent subsidence observed for bench marks throughout the basin (table 1) is probably related to network-adjustment problems outside the study area. Several of the bench marks may have been disturbed during the 1933-34 to 1961 period, which is probably the cause of the large settlement of bench mark Copelin (table 1).

4. At none of the bench marks studied is there a basis for directly relating subsidence to water-level decline. During the pre-1935 period of extensive water-level decline, no leveling control was available; also, during the declines since 1961, the limited control is inconclusive. Apparently, estimates of future subsidence cannot be derived from pre-1969 subsidence/head-decline ratios as has been conveniently done for other areas.
5. Estimates of subsidence for postulated water-level lowering could be made from detailed studies of the hydrogeologic parameters of the basin. Thus, knowing the thickness and compressibility of the water-bearing deposits throughout the basin, and the changes in effective stress that would result from the postulated water-level change, the magnitude and extent of future subsidence could be approximated. However, a detailed study of these parameters for Raymond Basin was beyond the scope of this investigation.
6. Water levels in 1969 were at about the all-time low levels of the mid-thirties throughout most of the basin. Continued decline in many areas should cause effective stresses greater than the pre-consolidation stresses of the mid-thirties. Thus, some subsidence should be expected if water levels are drawn down much below their 1969 levels.

7. In general, the geologic setting of Raymond Basin and the nature of the alluvial fan deposition in the Basin are quite similar to the nearby Claremont-Upland area previously investigated (Lofgren, 1971). Perhaps the subsidence/head-decline ratios of the Claremont-Upland area, ranging from 3.2 to 4.7×10^{-3} foot of subsidence per foot of additional head decline are not unrealistic for the Raymond Basin. If so, 0.3 to 0.5 foot of subsidence could be expected for each 100 feet of water-level decline below the previous low levels.
8. Inasmuch as subsidence/head-decline ratios are directly related to the thickness and compressibility of the aquifer system, this ratio would undoubtedly vary considerably throughout Raymond Basin. Maximum subsidence, if Plan D pumping stresses (fig. 6) were imposed on the Basin, would probably occur in the southern part of the Basin where postulated stresses are the greatest and the unconsolidated deposits are the thickest.
9. It is concluded that if Plan D pumping stresses (fig. 6) were imposed in Raymond Basin subsidence would be small. Maximum subsidence would probably be less than 1 foot, and would occur so slowly and over such a broad area that it should not cause problems.

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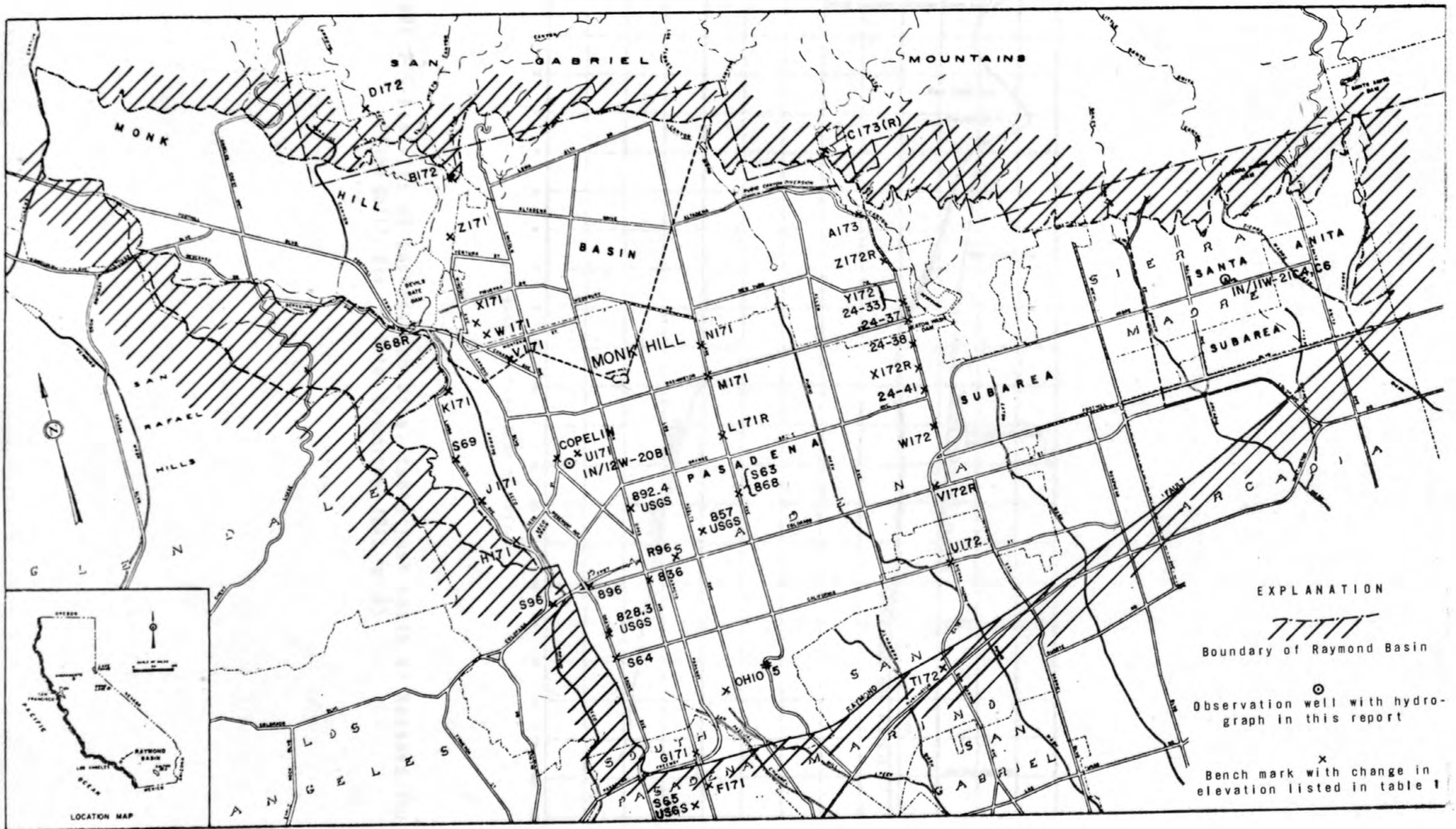


FIGURE 1-- Map of the Raymond Basin showing location of wells with long-term hydrographs and leveling control.

ELEVATION IN FEET ABOVE OR BELOW MEAN SEA LEVEL

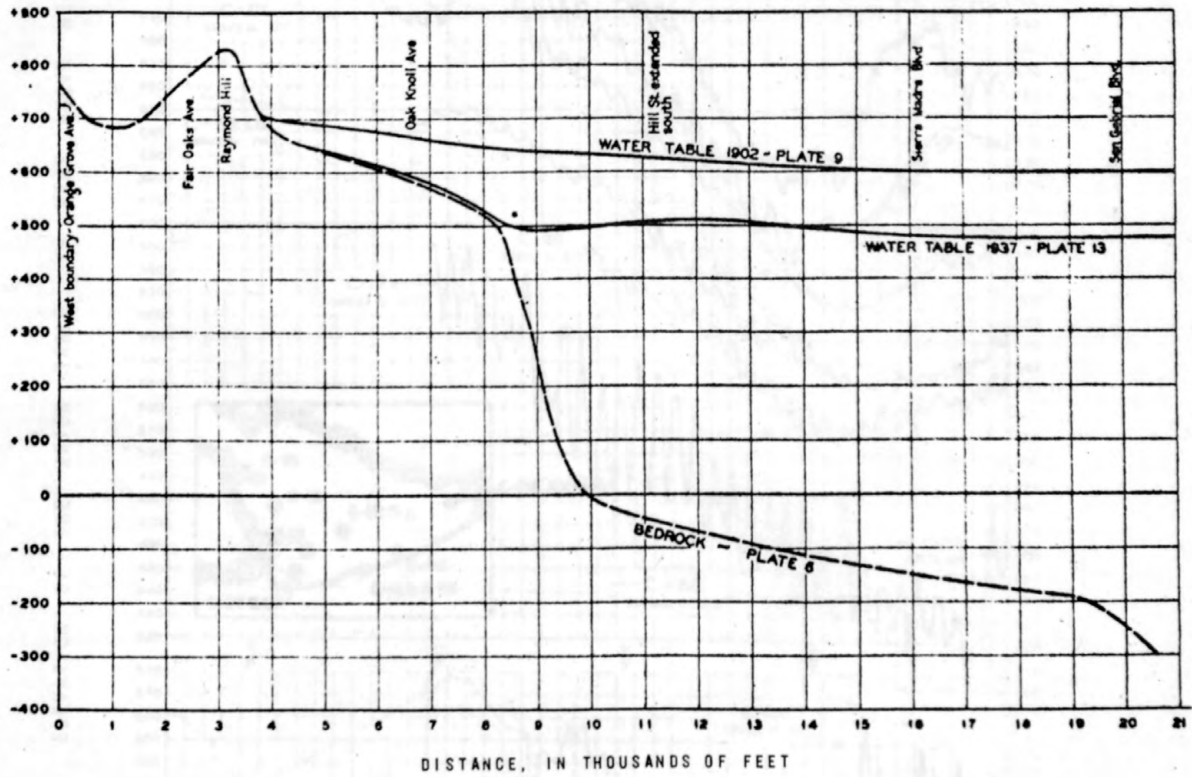


FIGURE 2.--Profiles of bedrock and water table just north of Raymond fault. (From Calif. Div. of Water Resources, 1943, pl.8)

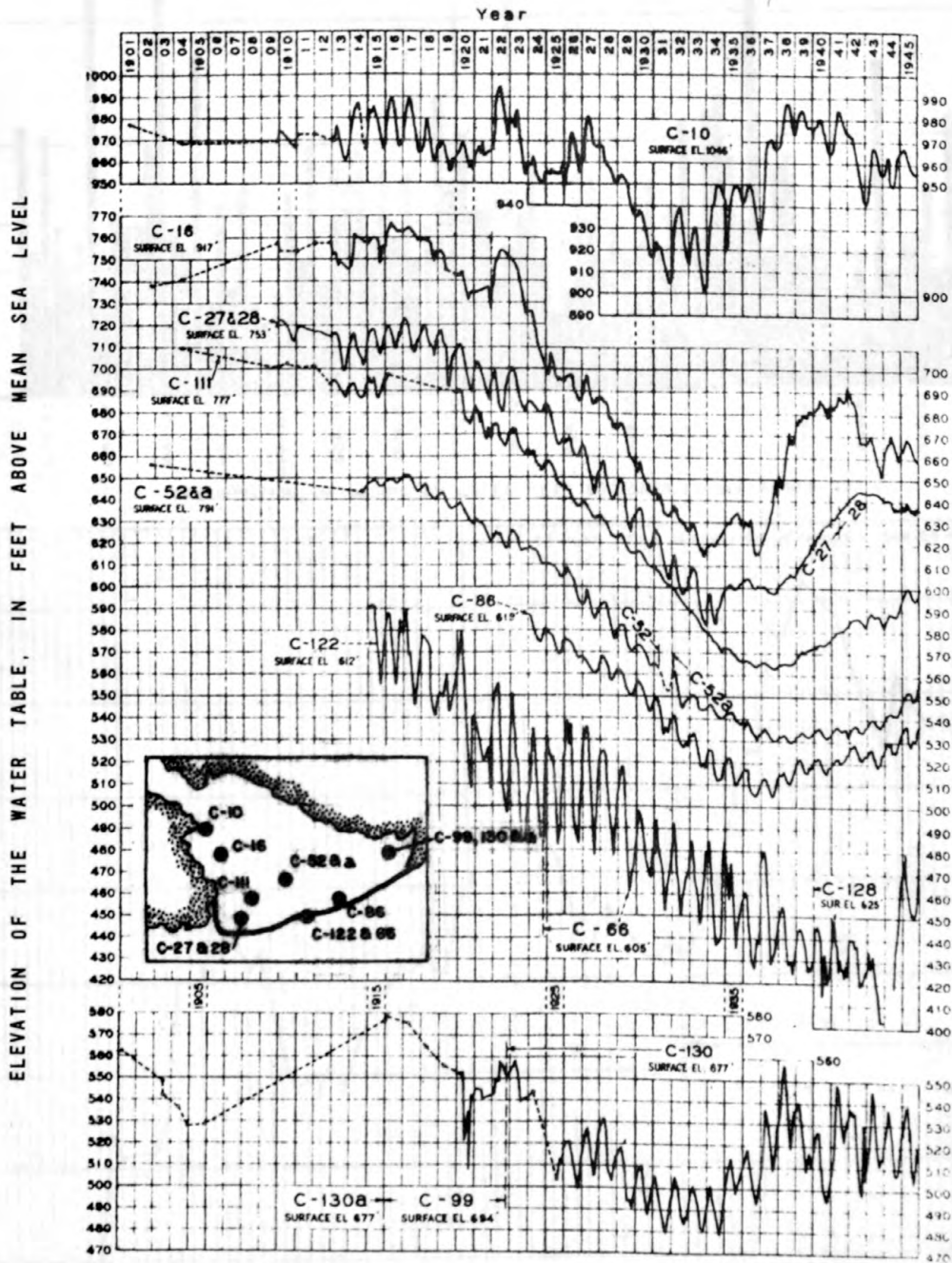
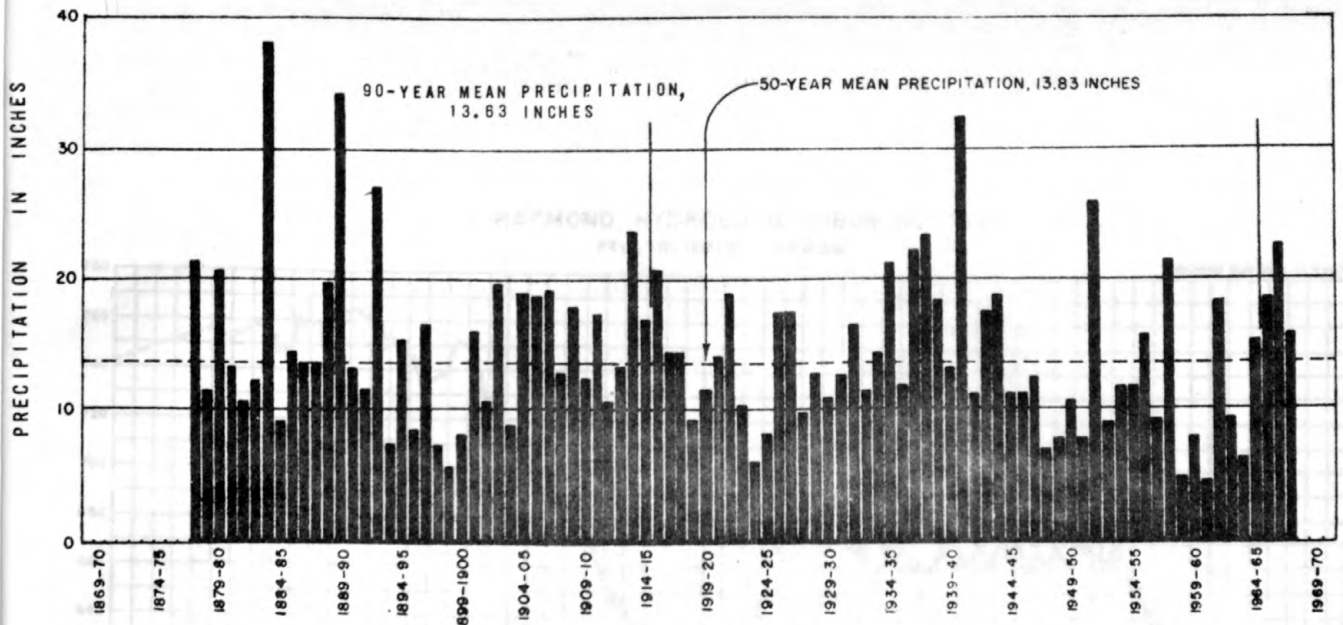
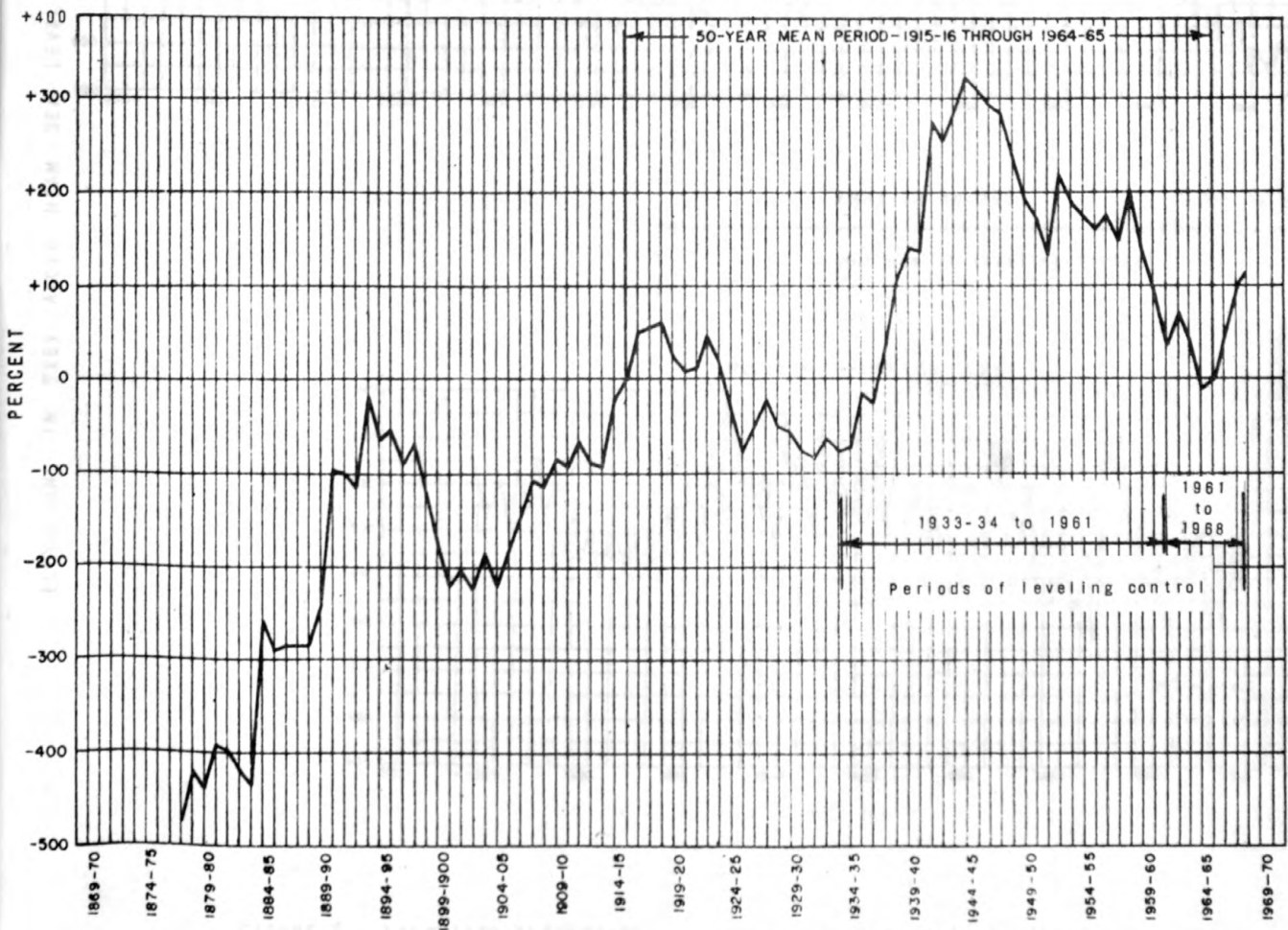


FIGURE 3.--Fluctuations of the water table in selected wells in the Raymond Basin.
 (From Calif. Div. of Water Resources, 1947, pl.9)



PRECIPITATION, IN INCHES, BY WATER YEAR (OCTOBER 1 - SEPTEMBER 30)



CUMULATIVE DEVIATION FROM MEAN PRECIPITATION AS A PERCENT OF MEAN

FIGURE 4.--Representative precipitation characteristics for Los Angeles (Modified from Calif. Dept. Water Resources, 1970, p.5)

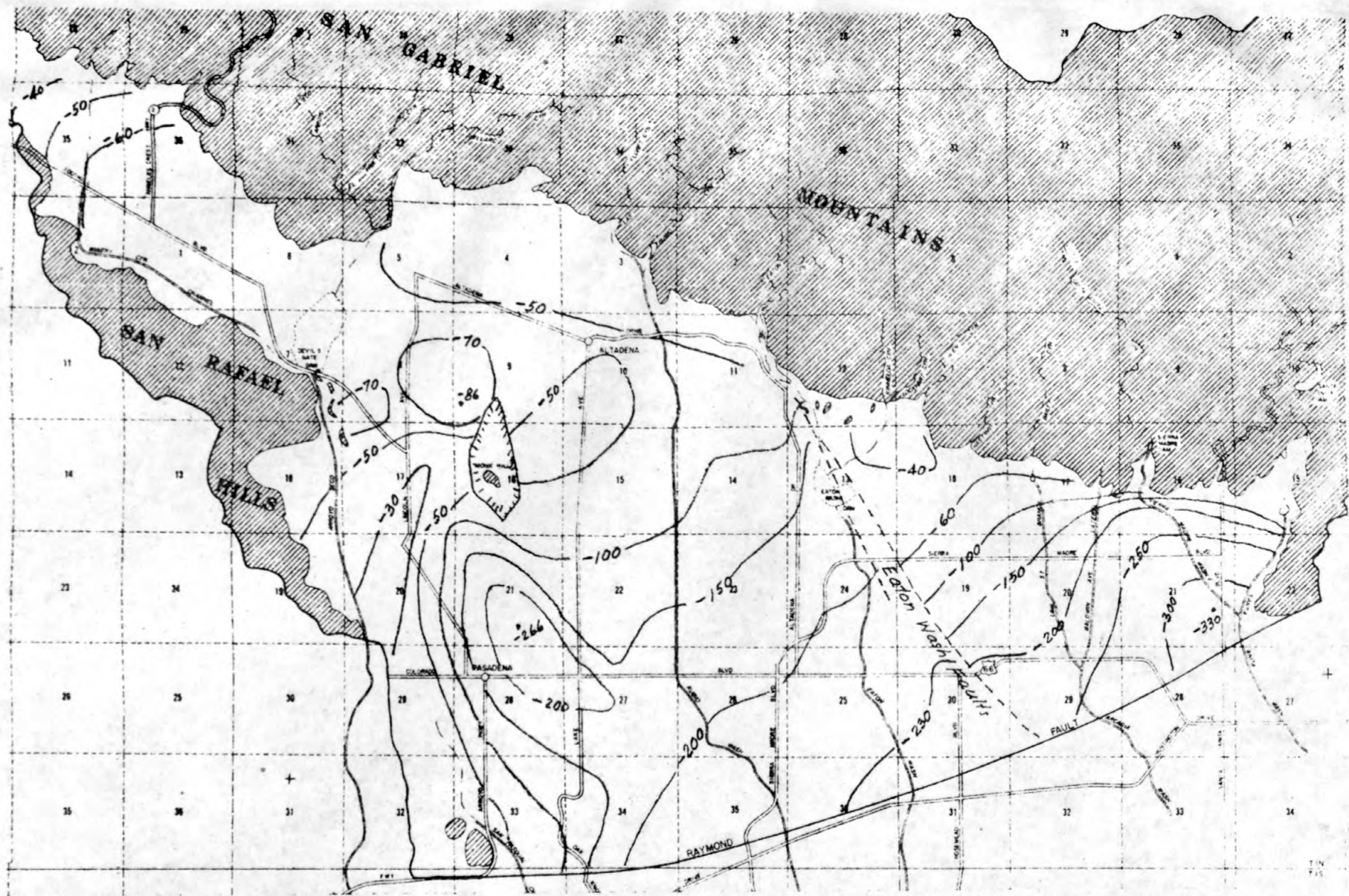


FIGURE 6--Postulated change in ground-water elevations, 1970-2020, in the Raymond Basin under Plan D (decreed right plan).

Map prepared by California Department of Water Resources.

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