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GROUND WATER IN CALIFORNIA

THE EXPERIENCE OF ANTELOPE VALLEY

by

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With a Foreword by

S. V. Ciriacy-Wantrup

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A listing of the persons and agencies that have helped in this study could not adequately describe the assistance, service, and encouragement received. And such a list would be inordinately long. The author can only say he is grateful for the help in gathering information that has come to him, by letter and interview, from these sources--too numerous to mention, however deserving.

But several individuals and agencies must be singled out, because of the especial importance of their aid and encouragement. I acknowledge my indebtedness to the Committee in Charge of the doctoral dissertation underlying this study, who were most generous with their time and energy: Professors S. V. Ciriacy-Wantrup, D. Weeks, and P. F. Wendt. The Chairman of the Committee, Professor Wantrup, stimulated and assisted the author during the actual period of writing by giving freely of his ideas and experience. The California Division of Water Resources, U. S. Geological Survey, Los Angeles County Flood Control District, Los Angeles County Agricultural Commissioner (Lancaster Office), Agricultural Extension Service, and Soil Conservation Service have made available much of the basic data required for this study. In addition, the Division of Water Resources has generously supplied the base map of Antelope Valley, used in Figures 1.2 and 3.1. Miss Marcia McClain and Mr. Victor Bruce, formerly Research Assistants on the Giannini Foundation of Agricultural Economics, uncovered some of the primary sources of information, thereby hastening this study. In 1950, Mr. Bruce prepared a short seminar report that was useful in formulating parts of Chapters 1, 2, and 8 of the present study. The charts and diagrams were prepared by Mrs. Katherine Eardley.

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FOREWORD

by

S. V. Ciriacy-Wantrup[1]

This paper is the second of a series of ground water studies being undertaken by the Giannini Foundation of Agricultural Economics of the University of California. The first paper[2] explained the current need for investigations focusing on the economic and social problems arising from the great dependence on ground water in this state. With the present paper, we commence these investigations.

Economic analysis of ground water problems stands between physical investigation on one side and legal studies on the other. In a sense, economic analysis is the connecting link between the two. Present laws affecting ground water have their historical roots in an economic environment in which ground water did not play a conspicuous role. During the last generation this role has changed greatly. It is largely economic pressure which leads to changes of laws and which determines their social acceptance. The physical problems of ground water, although complex and interesting by themselves, lead to legal issues only after increasing demand has transformed physical problems into economic ones.

The economic implications of ground water hydrology and ground water law are best developed through detailed studies of the experience in selected ground water basins. Each ground water basin represents an individual case in terms of its physical and economic conditions. In the economics of ground water, special caution is indicated when the attempt is made to generalize.

On the other hand, generalizing is a necessary part of the tools and the objectives of research. To solve this dilemma, it appeared best to select for detailed study individual ground water basins in such a way as to afford the best laboratory to analyze broader themes. Each basin study, therefore, has

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1/ Professor of Agricultural Economics and Agricultural Economist in the Experiment Station and on the Giannini Foundation.

2/ Bartz, Patricia McBride, Ground Water in California: The Present State of Our Knowledge (with a foreword by S. V. Ciriacy-Wantrup) (Berkeley: University of California, College of Agriculture, Agricultural Experiment Station, 1950), 67p. (Giannini Foundation Ground Water Studies No. 1.) 2nd Edition.

some special major theme of its own. None of these studies contains the "whole story" of the economic and social implications of ground water use. Each is intended to be a part of a whole. On the other hand, each is a distinct unit with respect to its major theme.

The present study has as its major theme the "mining" of ground water in a strictly arid and hydrologically self-contained basin. A small flow resource (recharge), which is highly variable over time, has created a large, dependable, and easily accessible stock resource (volume of ground water in storage) which can serve as the basis for a flourishing agricultural and urban development--for a limited and foreseeable period of time.

The objective of the study is to understand the economic forces such as water demand and pumping costs, which affect ground water mining, to trace its historical development, its consequences, and to probe into its future. No simple "solution" is offered. But the economic implications of possible remedial actions are thoroughly considered and compared with those of laissez-faire. Such actions are, for example, educational activities to change crop patterns and water application, local zoning ordinances to limit and reduce draft, state ground water laws, and water importation.

Frequently, the suggestion is made that a major policy objective of ground water conservation in this and other states is to limit draft to the "safe yield" of a basin. This is a physical but not necessarily an economic objective. Even if it is assumed that such an objective is politically feasible, Dr. Snyder's study raises doubts that it is economically desirable if the quantitative relations between stock and flow components of the ground water resource are such as in the Antelope Valley. This quantitative relation prevails in many ground water basins in arid regions in California and in other western states. The study, therefore, sheds light on some pressing issues which are significant far beyond the boundaries of Antelope Valley.

Although the major theme of the study has broader significance and some generalizations are permissible from the economic analysis of this theme, there is one aspect which is typical for large and important areas of the south coastal region of California and for smaller areas in other western states, but which is not typical for all ground water basins in which the above quantitative relation between flow and stock prevails. This aspect is rapid urbanization and industrialization.

The change from a mainly agricultural to a mainly urban and industrial economy is of major significance for possible "solutions" of overdraft problems. This is especially true for a ground water basin in which mining of the ground water stock resource has been the basis for economic growth.

Gross use of water per acre is generally less for an urban and industrial area than for intensive irrigation agriculture. In terms of net use (consumptive use) the difference is even greater. Through development of better facilities for reuse--largely through better treatment of sewage effluent from urban and industrial areas--this difference can be further increased. In irrigation agriculture, on the other hand, a major portion of water applied is consumed. Increasing the reuse of that relatively small portion of water that is not consumed has definite technological limits in arid regions. At present, urban and industrial use of water in the Antelope Valley is only a small--although steadily increasing--portion of total use (5 per cent in terms of consumptive use). The flow component of the ground water resource alone could support four times the present urban and industrial use if it were devoted exclusively to these uses.

For individual farmers and for the community, urbanization and industrialization would in many ways ease an attempt to adjust the Antelope Valley economy to its permanent water base--the flow component of the ground water resource. This, however, is not the only reason why urbanization is of major significance for a "solution." Urbanization and industrialization make it economically easier to supplement the permanent water base through water imports. Irrigation agriculture alone could not pay for this development. Most agricultural enterprises could not survive a water charge of $10 per acre-foot or even less. Urban use in southern California supports water charges of $60 an acre-foot and more. The most likely sources for water imports are discussed by Dr. Snyder. Nobody, however, can tell with certainty which sources, or combination of sources, will be tapped, or when imports will be available to the Antelope Valley.

Even with water imports, serious problems remain. How should the high costs of imported water be allocated between various uses--for example, between residential and agricultural? To what extent should imported water be used to recharge the local ground water reservoir? By whom should such a scheme be administered and benefits and costs distributed? Dr. Snyder's discussion of the "Orange County Plan" is of interest in this connection.

In spite of these problems, urbanization and industrialization will make a balance between economic growth and available water easier in the Antelope Valley than in many other arid basins where similar relations between flow and stock of ground water occur. To generalize, therefore, from the experience of Antelope Valley, tends to give a too optimistic picture of the economic implication of ground water mining. In other ground water basins, earlier and more decisive remedial action will be needed to bring irrigation agriculture into balance with its permanent water base.

Chapter 1
Physical Background

The Antelope Valley is an area in which environment--physical and historical as well as economic--has dictated a predominately irrigated agricultural development. The value of all crop production for the area in 1953 was more than $10,000,000. Of this amount, more than 87 per cent was accounted for by irrigated crops. Ground water presently supplies more than 95 per cent of the water used.

Antelope Valley, indicated in Figure 1.1, is located in the southwestern portion of the Mojave Desert, about 40 miles north of Los Angeles. About two-thirds of the area is in Los Angeles County and the remainder in Kern and San Bernardino counties. The 1950 Census of Population mentioned only two urban developments of importance--Lancaster (population 3,594) and Palmdale (population 978).1/ Since that time, population growth has been rapid. Estimates for mid-year 1952 indicate: Lancaster and vicinity, 12,300; Palmdale and vicinity, 3,800; other portions of Antelope Valley, 7,000; total for the Valley, 23,100.2/ The major centers of urban development are convenient to railroad and highway facilities (see Figure 1.2).

Antelope Valley is not, as its name suggests, a true valley; it is a closed basin, with no surface drainage outlets. Physical barriers enclosing the area vary from rugged mountains on the south, west, and northwest, to smooth buttes and gently sloping alluvial fans on the north and east. Mountain and foothill land within the Valley totals about 596 square miles. The relatively flat valley and alluvial fan land totals about 1,820 square miles. The floor of the Valley ranges in elevation from 2,300 to nearly 3,500 feet above sea level, thus lying at a higher elevation than most of the nearby desert valleys and considerably above the coastal plain to the south and the San Joaquin Valley to the west.

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1/ U. S. Bureau of the Census. Census of 1950, Population, California.

2/ Combination of estimates supplied by the Los Angeles Chamber of Commerce and Southern California Edison Company. Personal interviews.

FIGURE 1.1

LOCATION OF THE ANTELOPE VALLEY

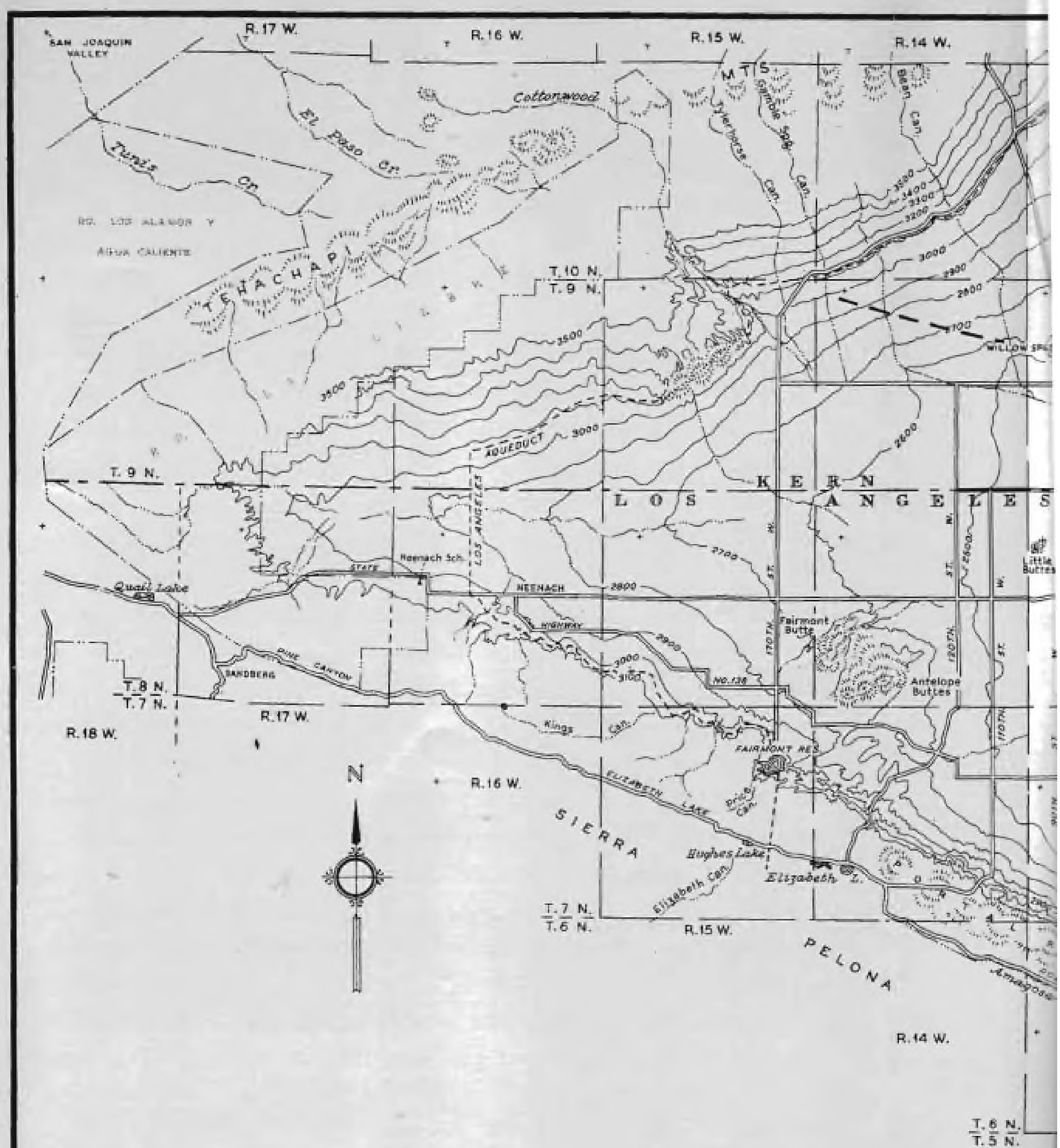
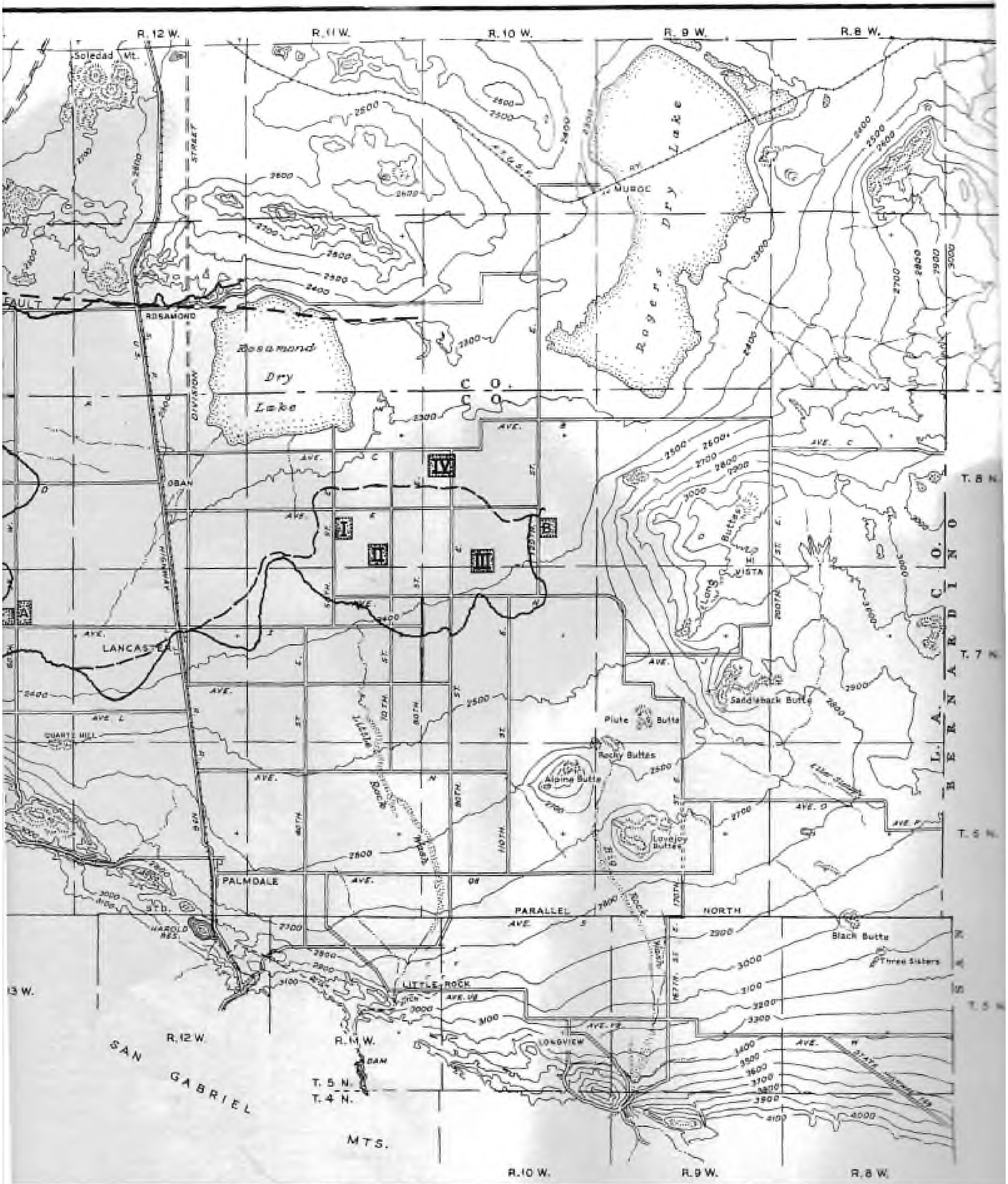


Figure 1.2
ALKALI CONDITIONS

Boundary of alkali infected area, 1922
Boundary of alkali infected area, 1951
Areas of localized alkali reclamation.*
Areas of localized alkali accumulation and perched water tables.*
*See text: "Alkali Conditions"
MILES
0 1 2 3 4 5 6


R. 12 W.
R. 11 W.
R. 10 W.
R. 9 W.
R. 8 W.
Soledad Mt.
FAULT
ROSAMOND
Rosamond Dry Lake
DIVISION STREET
MUROC
Rogers Dry Lake
C O.
C O.
OBAN
LANCASTER
QUARTZ HILL
PALMDALE
HAROLD RES.
LITTLE ROCK
LONGVIEW
DAM
HI VISTA
Saddleback Butte
Piute Butte
Rocky Buttes
Alpine Butte
Lovejoy Buttes
Black Butte
Three Sisters
PARALLEL
NORTH
T. 8 N.
T. 7 N.
T. 6 N.
T. 5 N.
T. 4 N.
L. A. CO.
SAN BERNARDINO
SAN GABRIEL MTS.

Geology and Land Forms

The present features of Antelope Valley are of comparatively recent geological origin.[3/] Severe crustal disturbances several million years ago changed the area from one of gentle relief to one with abrupt topographic boundaries. The greater altitude differential between mountains and valley plus the accompanying increased rainfall caused stream dissection to become the dominant geologic process. During the millions of years following the disturbance, streams have carried alluvial debris into the basin, building up the present Valley floor and almost obliterating the pre-deformation relief. The thickness of the alluvial debris is highly variable. The log of one well drilled to a depth in excess of 2,000 feet failed to reveal other than sedimentary deposits.[4/]

Sediments from the mountains were deposited in typical alluvial fans at the mouths of each canyon entering the Valley. These gradually coalesced to form a more or less continuous alluvial slope, stretching from the mountains to the center of the Valley. Continuing changes in slope, precipitation, and runoff have caused the different particle sizes of the alluvium to be transported varying distances into the basin, creating a deposition of alternating lenticular beds of clay, sand, and gravel. Void spaces within this alluvium provide storage for the ground-water resource of Antelope Valley.

Torrential runoff reaches the central portion of the Valley from time to time, carrying in suspension the finest particles picked up by the erosive action. A lake is formed, which usually contains only a few inches of water and soon evaporates, leaving a deposit of clay, silt, and salt. This flat-floored bottom of the undrained desert basin is known as a playa, of which there are three in Antelope Valley. Such silt-clay-salt deposits, with high pore-space but low specific yield, do not contain appreciable amounts of ground water, but their extensions intermix with the water bearing strata (aquifers) and often serve as

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3/ Thayer, W. N. Geologic Features of Antelope Valley, California. Los Angeles County Flood Control District. October, 1946. 20 p. Processed.

4/ Simpson, Edward. "Geology and Mineral Deposits of the Elizabeth Lake Quadrangle, California." California Report of the State Mineralogist. California Department of Natural Resources, Division of Mines, vol. 30, no. 4, August-October, 1934. p. 415.

confining barriers to the subsurface movement of ground water, thus creating artesian (pressure) conditions. Such a situation exists in Antelope Valley.

Climate

Precipitation data from four weather stations in the Valley are summarized in Appendix Table 1 and the average presented graphically in Figure 1.3. These data show certain characteristic features. First, a distinct seasonal distribution occurs, with the major amounts of precipitation in the winter months. Second, precipitation (greatly affected by topography) differs in different parts of the Valley, generally being slightest in the low, central part of the Valley and greatest in the high mountains. Third, mean annual precipitation in most of the Valley is less than ten inches--so small an amount that irrigation is necessary for the successful culture of most agricultural crops.

Figure 1.4 summarizes seasonal precipitation recorded at Fairmont during 42 years, the longest period of continuous record to be found in the Valley.[5/] Construction of moving averages revealed a long-run cycle of about 25 years in the data, but any effort to predict a long-run cycle would be misleading, because of variations within the dry and wet periods. For example, during the "dry" phase there are three years with greater than average rainfall; and during the "wet" phase there are four years with less than average rainfall.[6/]

Temperature data for the four weather stations are summarized in Appendix Table 2 and Figure 1.3. High temperatures are common in summer, exceeding 100° F. on many days in each season. The air at this high altitude usually cools rapidly after sunset, creating a daily temperature range of 30° to 45° F., summer and winter. For example, winter temperatures frequently rise to 60° or 70° F. during the day and drop below freezing at night. Length of growing (frost-free) season has ranged from 175 to 323 days. The average is 215-245 for most of the Valley, long enough for the majority of the crops grown in the area. Extended periods of killing frost are sufficiently rare that little damage is ever done.

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5/ The data are seasonal values (July 1 to June 30, inclusive).

6/ The concept of cyclical variation in climatic phenomena is discussed at length in Chapter 3 under cyclical variation in recharge to ground water.

Figure 1.3 CLIMATIC VARIATIONS - ANTELOPE VALLEY

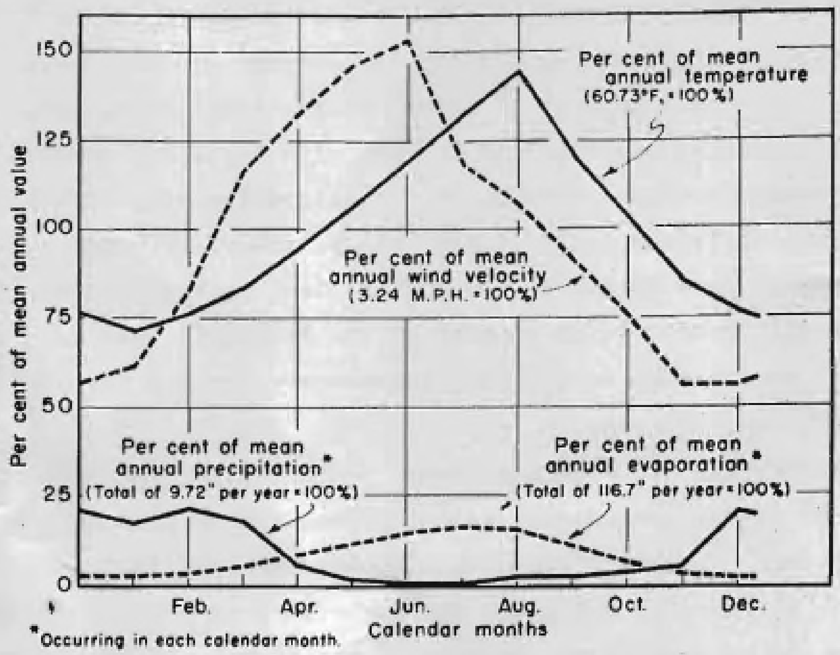
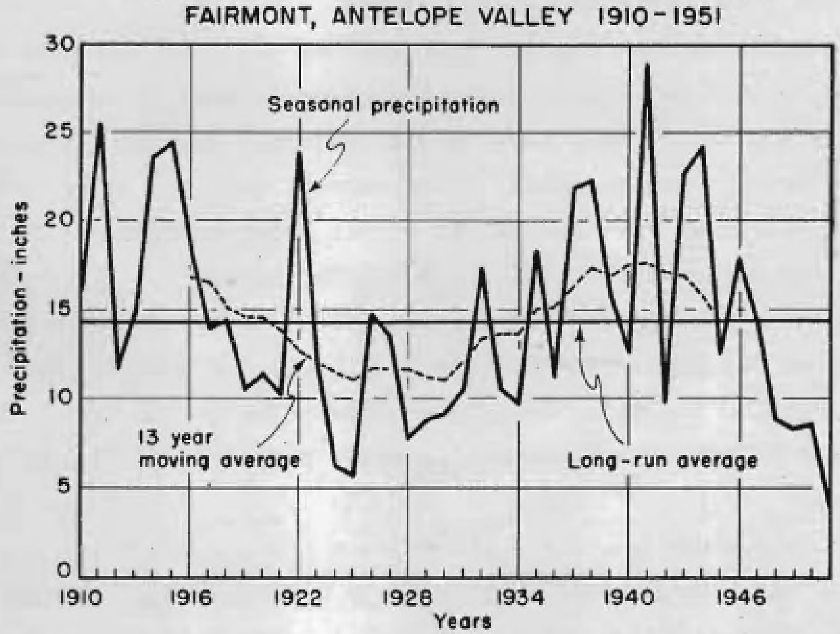


Figure 1.4 ANNUAL AND CYCLICAL PRECIPITATION FAIRMONT, ANTELOPE VALLEY 1910-1951



PWS-0069-0018

Wind movement and evaporation are the other forms of climatic data presented in Figure 1.3. Wind movement is important in the Valley, because of wind erosion as well as wind's effect on water use. Wind erosion problems--the blowing of soil and accumulation of wind-driven sand on irrigated lands--are confined to the western portion of the Valley. Wind affects water consumption of plants by moving away water-laden air and moving in air of lesser moisture content.7/ If other conditions are equal, water-use by plants will be greater in areas of moderate wind velocity than in areas of low wind velocity.

Three factors--high temperature, high wind velocity, and low air moisture content--combine to make the annual evaporation at Backus Ranch Weather Station in Antelope Valley the highest recorded for California by the Weather Bureau. Although no hard and fast relationship exists between the amount of water evaporated from an evaporation pan and the amount of water used by plants8/, it can be said that the amount of water used by a particular plant will normally be greater in areas where evaporation from a pan is high than in areas where evaporation is low. It may be concluded, other things being equal, that the use of water by plants in Antelope Valley is higher than in most sections of California.

Soil and Alkali Conditions9/

The alluvial soils of the Valley may be divided by age, or stage of development, into two broad groups: The older soils, which since deposition have undergone marked change in their physical characteristics, are found in the central portions of the Valley and on the alluvial fans. The newer, alluvial soils, consisting of unaltered deposits in the process of accumulation or deposited in very recent time, are found on the upper portion of the alluvial slopes and near active stream channels.

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7/ Plants transpire water as a vapor through small openings (stomata). The respired air is rich in moisture in contrast with the air they take in. No relative humidity values (to measure the moisture content of air) are available for Antelope Valley. Because of high altitude and high temperature ranges, relative humidity in Antelope Valley is presumably low.

8/ State Department of Public Works. Division of Water Resources. "Use of Water by Native Vegetation." Sacramento, Calif. State Print. Off., 1942. (Bul. 50) p. 154.

9/ A complete description of the soil and alkali conditions of Antelope Valley as surveyed in 1922 may be found in Soil Survey of the Lancaster Area, California, by Carpenter, E. J. and S. W. Cosby. U. S. D. A. Bureau of Soils and Calif. Ag. Exp. Sta., 1926. pp. 663-720.

As part of a recent, state-wide inventory of California land, the Soil Conservation Service conducted a reconnaissance survey in Antelope Valley.[10/] Approximately 600,000 acres were classified as suitable for irrigation, but about one-half of this land was classed as "problem land" because of erosion tendencies or alkali conditions.[11/] The California Division of Water Resources estimates 609,000 acres as ultimate irrigated acreage in the same area.[12/] Much of the difference is accounted for by difference in viewpoint between the two organizations. For example, land devoted to irrigated pasture may be on slopes too steep for the routine cultivation (by Soil Conservation Service standards) required for more intensive types of crop development. At the present time, less than 100,000 acres in Antelope Valley are under cultivation in any 1 year, and less than 60,000 of these receive irrigation water. Whichever estimate of potential acreage is accepted, it is apparent that ample acreage exists for future agricultural development.

Soils between Lancaster and Rosamond and toward the east, as shown in Figure 1.2, contain excess soluble salts. In the absence of reclamation, this tends to prevent profitable crop production. In the greater part of this area, natural drainage is sufficient to permit reclamation of much of the alkali land simply by good cultural practices.

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10/ Wohletz, L. R., and E. F. Dolder. Know California's Land. State Department of Natural Resources and U. S. Department of Agriculture, Soil Conservation Service. Sacramento, Calif. State Print. Off., 1952. 43 p. 2 maps.

11/ About 320,000 acres were classed as cultivable, and the remainder as irrigable for such things as pasture. The definition of cultivable land on the part of the Soil Conservation Service tends to be conservative. Some of the land in Antelope Valley classified as non-cultivable is nevertheless under cultivation, and will probably remain so, by choice of the individual farmer.

12/ State Department of Public Works. Division of Water Resources. "Water Utilization and Requirements, Antelope Valley Basin." Bryte, California, June, 1951. (Manuscript by T. C. Mackey--preliminary information, subject to revision.)

The extent of alkali reclamation in this area since 1922 is also shown in Figure 1.2.[13/] Relatively favorable drainage and the cultivation of irrigated, salt-tolerant crops--such as alfalfa, sugar beets, cotton, Barley, melons, and irrigated pasture grasses and clovers--have facilitated this reclamation. With poor drainage the solution is more difficult and the alkali condition worsens with irrigation. Some acreage in the Valley has been rendered unusable in this way. The area affected by this problem is small in relation to the total cultivable area of the Valley. Three such small areas are indicated in Figure 1.2.

To this arid but fertile Valley, the early settlers came to develop an agricultural economy dependent upon rainfall and surface stream diversions. A consideration of these attempts and the gradual evolution of agriculture dependent upon ground water is presented next.

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13/ Communication from Chester A. Coover, Work Unit Conservationist, Soil Conservation Service, Lancaster. 1952.

Alkali indications, as determined in the form of soluble salts from conductivity measurements, are shown in Figure 1.2 for 4 locations as they have changed from 1922 to 1950-51. The compared samples were not taken from identical spots, but nevertheless give an idea of the extent of alkali reclamation during the period.

	Per cent soluble salt	
Location	1922	1950-51
I	.64/ .57	.2 / .5
II	1.94/1.70	.7 / .2
III	.82/ .72	.10/ .05
IV	.68/1.06	.3 / .9

The numerator of the fraction expresses the per cent of soluble salt in the first foot of the soil profile, and the denominator that of the entire profile to a depth of approximately six feet.

Chapter 2

Historical Background

The early history of other areas of the Mojave Desert region is scattered throughout reports of early explorations and the diaries of travelers. A historical sketch of the region has been given by Thompson.1/ Antelope Valley, however, was mentioned only occasionally during the period before 1880, and then merely as an area through which one needed to travel in order to get somewhere else.

Livestock Production

The earliest official recognition of agricultural activity in the Valley is a Mexican Land Grant of eleven leagues of land, known as La Liebre, to Jose M. Flores in 1846.2/ The grant was confirmed much later, by the Land Commission and court adjudication, and patented on June 21, 1875.3/ Little is known of the use of the land during the period 1846-1861, although it is likely that cattle were then grazed there.4/ In 1861 the property was purchased from the original grantee for the stated purpose of raising cattle and has continued in this use, among others, since that time.

Winter and spring grazing of ranch stock expanded in the Valley until 1894, when an extended dry phase of the climatic cycle began. By 1900, the area was almost depleted of livestock.5/ For nearly forty

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1/ Thompson, D. G. The Mohave Desert Region, California. A Geographic, Geologic, and Hydrologic Reconnaissance. U. S. Department of Interior, Geological Survey. Washington. Govt. Print. Off., 1929. pp. 9-26. (Water Supply Paper 578.) pages 289-371, inclusive, are devoted to the Antelope Valley.

2/ Bancroft, H. H. "History of California" (vol. V, 1846-1848). The Works of Hubert Howe Bancroft, vol. XXII. San Francisco, The History Company, 1886. 784 p.

3/ Stratton, J. S. "Report of Spanish or Mexican Land Grants in California." Appendix to California Senate and Assembly Journal. 1881. p. 4.

4/ A diary account of W. A. Wallace, editor of the Los Angeles Star, was published in that newspaper on July 1, 1854, describing a journey from Los Angeles to Tejon or Sebastian Indian Reservation. The entry for June 4 reads in part: "At noon we turned into a beautiful little green valley with good water and timber--La Liebre--the former abode of a rancheria of Indians . . . ." Cited in Giffen, H. S. and A. Woodward, The Story of El Tejon. Dawson's Book Shop, Los Angeles, 1942. p. 76.

5/ California Agricultural Extension Service and U. S. Department of Agriculture. Recommendations for the Agricultural Development of Antelope Valley by the Antelope Valley Agricultural Program Building Conference. Lancaster, California, March, 1940. 10 p. mimeographed.

years, the livestock population of the Valley continued to fluctuate, sometimes violently, parallelling changes in rainfall. The introduction of feed lots for cattle and sheep has brought some measure of stability to the livestock industry in the area.

From the standpoint of value of production, the poultry industry is the most important livestock enterprise in the Valley. In 1951, over 75 per cent of the total value of livestock production was turkeys and chickens.6/ Turkey production has been relatively important to the area since the early 1930's, when production was fairly stable at about 100,000 birds per year. This figure was tripled during the period 1945-1951. During the same period the fryer industry experienced a tenfold expansion, to the current level of 8,000,000-10,000,000 birds each year.

The value of production from the livestock industries in the Los Angeles County portion of Antelope Valley in 1951 amounted to $14,688,026. The value of production from crop agriculture for this year was only $8,611,060. Nearly 60 per cent of the total value of production arose from livestock. During 1951, crop agriculture consumed nearly 98 per cent of the ground water used in Antelope Valley, while livestock directly consumed less than 1 per cent. Livestock consumption of water contained in crops (irrigated pasture and alfalfa hay) may increase this figure to perhaps 10 per cent, which is still in dramatic contrast to the greater value of livestock production.

Dry-Land Crop Agriculture

In the late 1870's and early 1880's a number of ranchers began to dry-farm grain in the western end of the Valley. Then, as today, success depended on winter rains, which are variable. As many as 60,000 acres of wheat and barley were dry-farmed in the Valley during the period 1880-1893.7/ The drought that began in 1894 forced farmers in that area to abandon their holdings, leaving little activity until after 1905.

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6/ Information on livestock in Los Angeles County portion of Antelope Valley are from communication of C. E. Wictor, D. V. M., Livestock Inspector, Los Angeles County Livestock Department.

7/ Recommendations for the Agricultural Development of Antelope... op. cit.

Before the drought, some acreage had been set out to fruit trees, with the expectation that natural rainfall would provide sufficient moisture for growth. Most of these plantings were along the southern flank of the Valley. Some acreage actually came into bearing before the drought hit, when most of this acreage was abandoned.

Redevelopment of the dry-farming belts since 1905 has been gradual. By 1940, acreage devoted to dry-farmed grain averaged 25,000-30,000 acres, and by 1951, nearly 90,000 acres.[8/] Since 1940, the dry-farmed fruit acreage has remained fairly stable, at about 500-700 acres, devoted primarily to almonds and vines. In recent years, estimated value of production for dry-farmed crops ranged from a high of 20 per cent of total estimated value of Valley crops, in 1945, to a low of 2 per cent, in 1951.

The Evolution of Irrigated Agriculture

Settlers in Antelope Valley and the southwest in general did not realize that the arid and semi-arid climate of the area would make them dependent upon water resources supplemental to precipitation. Most of them came from regions where water was plentiful, from rainfall, stream flow, and underground sources readily tapped though usually not needed. They were not prepared for a climate where it is usual for no significant amount of rain to fall during a 6-8 month period each year and where, particularly in the south and west portions of the Valley, the depth to ground water frequently exceeded 100 feet. Painful experience soon established that supplemental water supplies were essential to significant agricultural production.

Irrigation from Streams

The earliest stream diversions were to irrigate fruit trees planted in the late 1880's and early 1890's by land companies interested in selling

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8/ Ibid., and Agricultural Commissioner's Crop Report for the Antelope Valley portion of Los Angeles County, 1951.

At present, only about one-half of the land devoted to dry-farmed grain is planted at any one time, strip or contour fallow occupying the remainder. In 1951, when 90,000 acres were devoted to grain farming, 45,000 acres were planted butonly 7,000 acres harvested, due to crop failure caused by low rainfall.

land to settlers.[9] Large sums of money were spent on irrigation systems, and crops were planted without definite knowledge of the adequacy and availability of water--which proved to be totally inadequate when the drought period came. For example, Hinton stated that in 1891 in Antelope Valley:

> ". . .it is estimated that in all 50,000 acres are now under ditch. The surface supply is obtained from mountain streams, stored in three reservoirs, with a total capacity of 30,000,000 gallons . . . The main ditches are 50 miles in length, 5 feet wide at the top. There is an equal mileage of distributing and lateral ditches." 10/

This at least indicates intentions to develop large areas of the Valley in the late 1880's, for the total irrigated acreage in the Valley in 1951 was only 54,455 acres, even with present-day advances in pumped agriculture. A storage capacity of only 92 acre-feet given by Hinton, if accurate, is strong evidence of inadequate knowledge of the available water supply and the water needs of crops.

In the late 1880's, a natural interest in irrigation and a recognition that the community must act as a whole produced a wave of schemes for land settlement and development in the western states. In California, developments of this type were favored by the passage, in 1887, of the Wright Act, which sought:

> "to confer on farming communities powers of municipalities in the purchase or construction and the operation of irrigation works." 11/

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9/ "The Fairmont Land and Water Company set out 500 acres of deciduous fruit trees in 1891. The same company set out over 1,000 acres in 1892. The total acreage of deciduous fruit trees is expected to be nearly 5,000 acres by the end of 1892 for the entire Antelope Valley." Pacific Rural Press, vol. 44, August 13, 1892. p. 132.

"1,300 acres have been planted to almond trees this spring by the Manzana Plantation." Pacific Rural Press, vol. 45, March 4, 1893. p. 196.

10/ Hinton, R. J., "Progress Report of Irrigation in the United States, 1891." Washington, Govt. Print. Off., 1893, p. 50. (52d Congress, 1st Session. Senate. Executive Document 41, Part I).

11/ Adams, F. Irrigation Districts in California, 1887-1915. State Department of Engineering, Sacramento, California State Print. Off., p. 8. (Bulletin 2.)

In Antelope Valley, six irrigation districts were organized under the Act between 1890 and 1895. All located on the upper slopes of the alluvial fans along the southern boundary of the Valley, they planned to obtain their water by gravity flow from the streams emerging from the mountains. Appendix Table 3 presents condensed histories of these districts. The speculative nature of three of the districts and the limitations in available water and financing combined to play a dominant role in their failure.12/ Today, the sole survivor of the early projects is the Little Rock Creek Irrigation District. The Palmdale Irrigation District, in operation since 1918, was created by reorganization of one of the earlier districts. Its financial stability today has been helped by the residential and commercial developments that have taken place in the vicinity. Until recently the Little Rock district was the only one that had been financially successful.

The drought that began in 1894 caused the loss of most of the acreage developed. The survival of the Little Rock district during this period was principally due to the installation of a water pump. Pumps were not then in general use in this area. This was something of an experiment, and the experiment was a success. Both the Little Rock Creek and Palmdale districts have continued to supplement their gravity supply with pumped water.

Fruit acreage in the Valley rose to a peak of nearly 7,500 acres during the 1920's, but the depression of the 1930's cut this by more than half. Only a slight upward trend has been observed since that time. The ratio of irrigated fruit acreage to total fruit acreage has remained fairly constant, at about 75 per cent. There has been a shift from dependence upon water supplied by irrigation districts to ground water pumped by the individual farmers. District-supplied water diverted to irrigation has been relatively unimportant in comparison to the total water consumed by irrigation in the Valley. Since 1945, it has averaged less than 5 per cent.

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12/ Adams (ibid.) considered a district to be speculative if the original organization of the district was primarily for the purpose of selling land and not a "grass roots" development.

Irrigation from Ground Water

The development of irrigation systems dependent upon surface streams failed to provide a stable, reliable source of water for agriculture in Antelope Valley. Concurrent with the above-described attempts at surface irrigation, the discovery of flowing artesian ground water in the central portion of the Valley pointed toward another source of irrigation water. The history of irrigation from ground water in the Valley (gathered from a variety of sources) is reflected by the irrigated crop acreage statistics of Appendix Table 4 and Figure 2.1.

Although 266 artesian wells had been drilled in Antelope Valley prior to 1908, the primary purpose seems to have been to secure patent to government land, for only 93 of the wells were listed by Johnson as having been put to definite use.13/ The drilling of wells on property that was not thereafter developed may have been in some cases honest attempts to farm land that proved subject to adverse alkali conditions. Thompson, in 1920, stated that the quantity of water from flowing wells applied to irrigation was probably not great; for the most part, wells with head sufficient to yield adequate water without pumping were located in areas of alkali land.14/ The importance of flowing artesian wells to Antelope Valley irrigation has not been great.

A strong and steady irrigation development of the area began with the pumping of ground water, shortly after 1912, and continued until the

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13/ Use of Flowing Artesian Wells

Use of Well	Number of Wells
Irrigation	62
Irrigation and domestic	10
Domestic	17
Stock watering	4
Abandoned	26
No use specified a/	147
Total	266

a/ As far as can be determined, the majority of these wells were abandoned prior to 1908.

Source: Johnson, H. R. Water Resources of Antelope Valley, California. U. S. Department of Interior, Geological Survey. Washington, Govt. Print. Off., 1911. (Water Supply Paper 278.) pp. 70-89.

14/ Thompson, D. G. The Mohave Desert Region, California. op. cit. p. 326.

beginning of the depression of the 1930's. Table 2.1 presents a summary of the development of Antelope Valley ground-water resources as reflected by number of pumps. The interrupted growth in irrigated acreage resumed in 1934-35, but did not become marked until after 1940. Irrigated acreage seems to have approached relative stability after 1949.

Alfalfa has remained the most important crop, by virtue of acreage as well as gross income to the area. Alfalfa has occupied about 60-75 per cent of the irrigated acreage and has, since 1945 at least, contributed between 60 and 70 per cent of the gross income from all crops. Whether or not proportionate stability has been reached will not be obvious for several more years. Irrigated grains, field corn, and permanent pasture are newcomers that may play an important role in the future pattern of water and land utilization.

Urban Developments

The activity of aircraft industries and military airports incident to World War II and the Korean conflict has stimulated population growth and non-agricultural development in Antelope Valley. Secondary commercial enterprises have expanded, to supply the consumer needs of the expanding population. Except for urban water users, individuals have developed their own domestic water supply, from the ground-water reservoir. The Los Angeles County Water District Number Four, private water companies, and the irrigation districts provide water for residential, commercial, military, and light industrial use.[15]

The future ratio of agricultural to non-agricultural water use cannot yet be accurately predicted. For some time agriculture will continue to consume the major portion of the Valley's output. If population pressures in southern California become strong enough, however, the area could well become a second San Fernando Valley. Value of building permits issued for the area increased from a pre-war average value of $200,000-$500,000 per year to about $12,000,000 per year in 1952.[16] Most of this building is for residential and commercial

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15/ In this and later sections of the discussion, the non-agricultural water users are segregated into two classes: Residential-Commercial and Military-Industrial. The available records do not permit further subdivision. In addition, the Military-Industrial water users (airport, final assembly, and test installations) are so closely interconnected that such separation is not possible.

16/ Interview. Los Angeles County, Division of Buildings and Safety. Lancaster Office. 1952.

TABLE 2.1

Development of Ground-Water Resources in Antelope Valley

Year	Pumped wells, electric	Pumped wells, other a/	All wells
1920	200	50	250
1925	362	50	412
1930	784	70	854
1935	559	70	629
1940	522	85	607
1945	669	65	734
1946	718	57	775
1947	804	46	850
1948	891	40	931
1949	942	35	977
1950	1,014	25	1,039
1951	1,074	15	1,089

a/ Includes diesel, gasoline, and "some" wind-powered pumps.

Source: Compiled from:
(1) Baugh, op. cit. The Antelope Valley, Worcester, Mass. Clarke University, June, 1926. 237 pp. (M. A. Thesis)
(2) Thompson, op. cit. Thompson, D. G. The Mohave Desert Region, California. A Geographic, Geologic, and Hydrologic Reconnaissance. U. S. Dept. of Interior, Geological Survey. Washington. Govt. Print. Off., 1929. pp. 9-26. (Water Supply Paper 578.) Pages 289-371, inclusive, are devoted to the Antelope Valley.
(3) Carpenter and Cosby, op. cit. Soil Survey of Lancaster Area, California. U. S. Bureau of Soils and California Agr. Exp. Sta., 1926. pp. 663-720.
(4) Communication from L. D. McCorkindale, Senior Agricultural Inspector, Lancaster, California.

construction and primarily for subdivision activity.

Urban activities have been progressing rapidly during the last 5 to 6 years, and the general impression of the Valley is one of mixed agricultural, urban, and military-industrial development. But the greater importance of agriculture will probably continue for many years. The Valley is still a scene of predominantly agricultural activity.

Chapter 3

The Ground-Water Resource and Its Recharge

The statement has been made that ground water in Antelope Valley has become subject to overdraft. Criteria for evaluating this contention are needed. In this paper ground-water inventory of the area reveals the effects on the resource of its use. Physical factors are shown to set absolute limits on recharge and draft of the resource. A discussion of proposed water importations shows their probable effect on the natural ground-water economy of the Valley.

Ground-Water Resources of Antelope Valley

Water resources of the Valley are of three kinds: rainfall on the Valley floor, surface streams, and ground water. Some rain may percolate into the ground-water supply, but precipitation averages less than eight inches annually. Since most of this inconsiderable volume is probably evaporated or directly consumed by plants, most authorities feel that the contributions of rain to ground-water resource are negligible.[1/]

Surface stream diversions, primarily by the two irrigation districts, seldom exceed 6,000 acre-feet per year.[2/] Ground water supplies more than 90 per cent of irrigation water used in the Valley.

The Stock Resource and the Flow Resource

The penetrable alluvium of the Valley through the years has received, absorbed, and stored most of the runoff from the surrounding mountains, accumulating water until the entire basin became filled more or less to capacity. This volume of ground water is a stored flow resource, as annual recharge acts to maintain or replenish the store. In the absence of use of the resource, natural processes of discharge act to maintain

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1/ State Department of Public Works. Division of Water Resources. Report to the Assembly of the State Legislature on Water Supply of Antelope Valley in Los Angeles and Kern Counties. Pursuant to House Res. 101 of February 16, 1946. Sacramento, Calif. State Print. Off., May, 1947. 22 p. Mimeographed.

2/ Annual reports filed by the districts with the Securities Exchange Commission, San Francisco.

approximate balance between inflow (recharge) and outflow (discharge). The stock resource, as the stored flow will herein be called, was maintained in pre-irrigation times at or near the capacity level of the ground-water reservoir. The volume stored did not increase significantly with time.3/

The flow resource is that water which flows into the reservoir each year. Some quantity is available every year, although subject to considerable annual variation. Recharge volume in any one year has no effect upon the flow in future years. This annual and varying recharge to ground water, making different units available in different time intervals, is the ground-water flow resource.4/

Relative Size of the Resources

The early settlers, blessed with flowing artesian wells in this desert region, concluded that ground water was inexhaustible, originating in areas outside the Valley. Such beliefs have long since been refuted.5/ Economic forces (to be discussed in Chapters 6 and 7) have combined with a false impression of the nature and extent of the resource to deplete this generous natural reservoir of ground water. It took hundreds of years for a relatively small flow resource to build up the large stock resource, which has since been drawn upon at rates exceeding rates of recharge.

The Ground-Water Reservoir--The Stock

A variation among the static water levels in the Valley indicates that the ground water is contained in more than a single basin. Thayer has charted one large, central ground-water basin and six small sub-basins, the most important of which are shown in Figure 3.1.6/ The inclination of ground-water contour-slopes toward the central basin indicates the gradual movement of surplus water from the sub-basins into the central (or Lancaster) ground-water basin. The ground-water reservoir of the

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3/ Resources are defined as stock if "their total physical quantity does not increase significantly with time." Ciriacy-Wantrup, S. V., Resource Conservation, Economics and Policies. Berkeley, University of California Press, 1952. p. 35.

4/ Ibid. p. 37.

PWS-0069-0031

5/ Johnson, H. R. Water Resources of Antelope Valley, California. U. S. Department of Interior, Geological Survey. Washington, Govt. Print. Off., 1911. pp. 59-62. (Water Supply Paper 278.)
Thompson, D. G. The Mohave Desert Region, California, op. cit. pp. 315-317. (Water Supply Paper 578.).

6/ Thayer, W. N. Geologic Features of Antelope Valley, California. Los Angeles County Flood Control District, 1946. 20 p. Mimeographed.

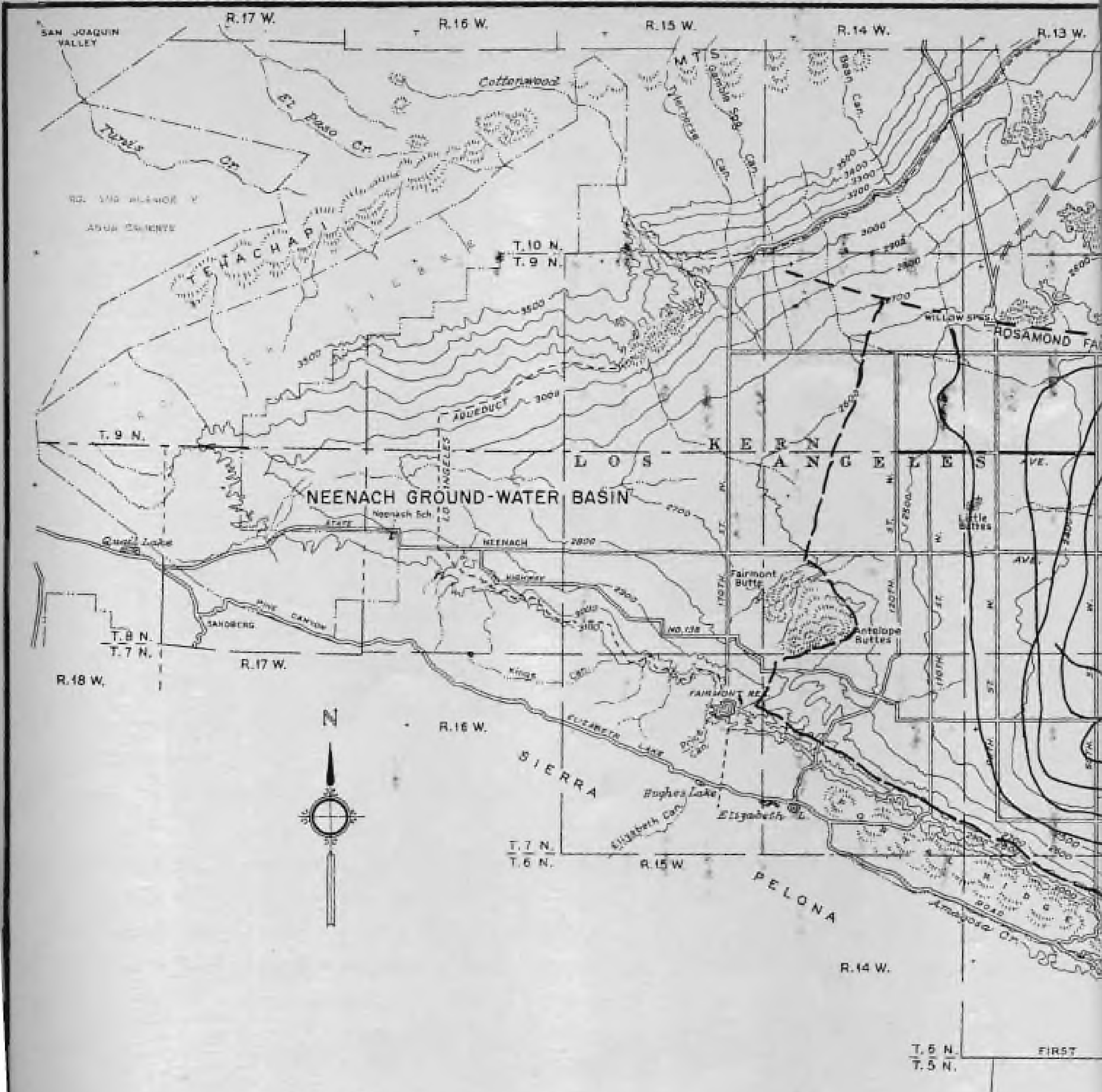

Figure 3.1

MAJOR GROUND-WATER BASINS AND DEPTH TO GROUND-WATER

① Boundary of Artesian Flow (1908)
② Boundary of Artesian Flow (1919)
③ Depth to Ground-Water, 100 Feet (1924)
④ Depth to Ground-Water, 100 Feet (1946)
⑤ Depth to Ground-Water, 100 Feet (1950)

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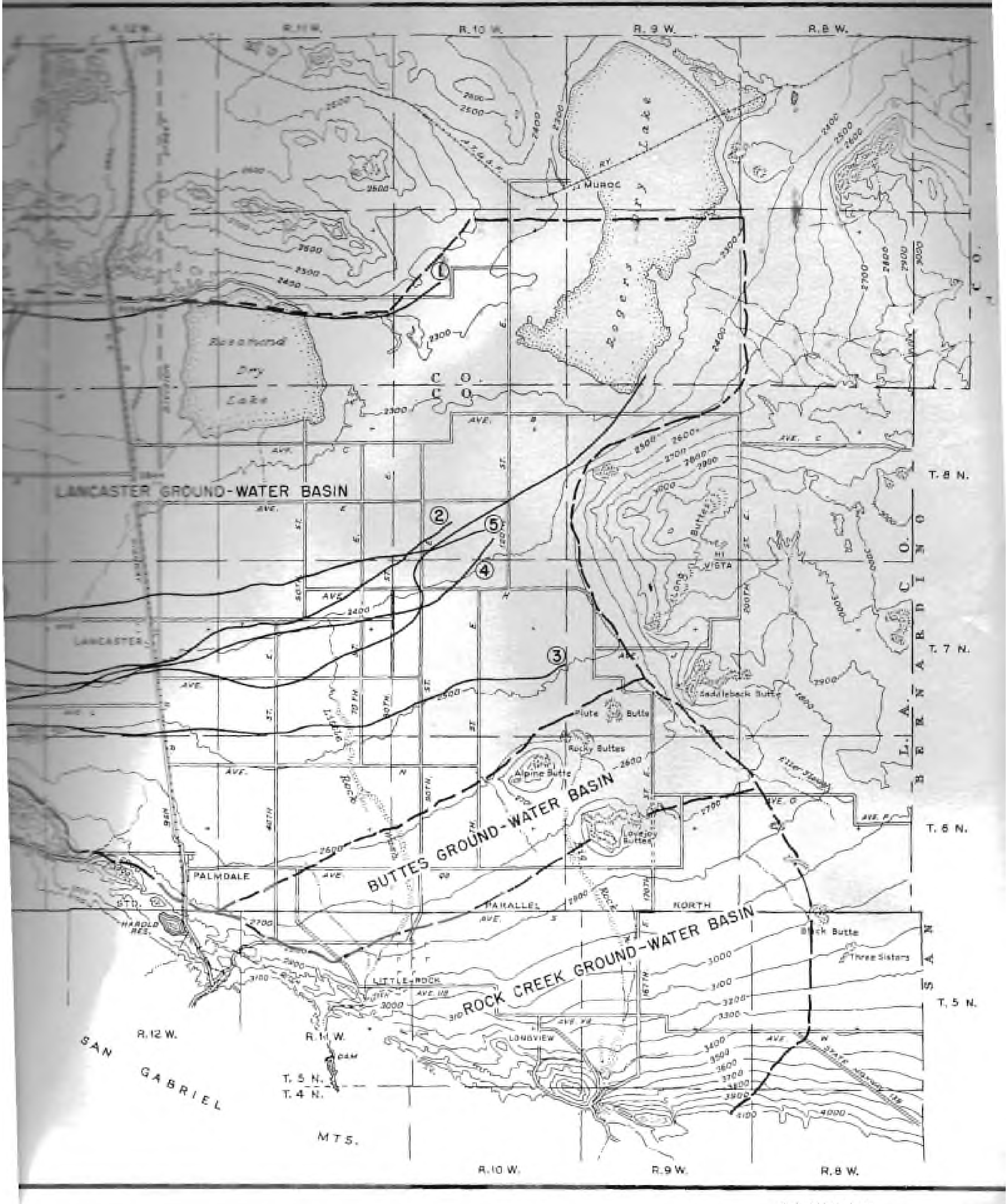

Revised 4-1-47, 4-7-49
This base map traced by Jno. A. Parent Feb.

Valley is generally considered to consist of this central basin, and the discussion here will logically center on it. The logic of this treatment is further enforced by the fact that irrigated crop production is concentrated within its boundaries.

Measuring the Stock

The volume of a ground-water stock resource, before it is drawn upon, is of course equivalent to the capacity of the ground-water reservoir containing the stock. It is probable that the capacity of a reservoir decreases as the stock diminishes through use, because of compaction of the containing aquifers--water-containing geological formations. (See below, pp. 28 to 29 for discussion of compaction.) The stock resource of Antelope Valley is here estimated in terms of the untapped capacity of the reservoir.

Determining above-ground reservoir capacity of course requires measurement of length, width, and depth. Determining ground-water reservoir capacity requires the additional measurement (usually computed by test) of specific yield--the per cent of total volume that may be occupied by water.[7/]

The surface area of the Lancaster ground-water basin, shown in Figure 3.1, was determined by planimeter. The specific yields for the various areas of this basin were determined by the California Division of Water Resources for a zone extending from about 100 feet above the static water table level of January, 1945 to about 100 feet below.[8/] The volume of ground-water storage capacity is estimated, by combining area and specific yield measurements, to average about 2,000,000 acre-feet per 100-foot depth of alluvium, as shown in Table 3.1.

No extensive measurements of the depth of alluvium in the area have been made. Depth of existing wells varied from a few feet to over 1,500 feet. These are usually drilled without ever reaching the granite basement,

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7/ Specific Yield: "The ratio of the volume of water a rock or soil will yield by gravity to its own volume." Tolman, C. F. Ground Water. New York and London, McGraw-Hill Book Company, Inc., 1937. p. 563.

8/ State Department of Public Works. Division of Water Resources. Report to the Assembly. . . op. cit. pp. 11-12 and plate 8. Typical static water level varied between 100 and 150 feet below the ground surface.

TABLE 3.1

Determination of the Size of a Portion of the Ground-Water Reservoir in Lancaster Basin for a Zone Averaging 100 Feet Each Way from Static Ground-Water Level of January, 1945[a]

Specific yield sectors determined from base map	Area in each sector	Volume of sediments 100 feet either side of static ground water level of January, 1945[b]	Specific yield assigned to each sediment group [c]	Volume of storage space in each sediment grou
per cent	acres	acre-feet	per cent	acre-feet
4	66,761	13,352,200	4	534,088
4-6	96,553	19,310,600	5	965,530
6	61,512	12,302,400	6	738,144
6-8	72,764	14,552,800	7	1,018,696
8-10	42,543	8,508,600	9	765,774
10	5,251	1,050,200	10	105,020
10-12	6,536	1,307,200	11	143,792
12	1,178	235,600	12	28,272
Total	353,098	70,619,600		4,299,316[d]

a/ Typical static water levels varied between 100 and 150 feet below the ground surface.

b/ Total width of zone in 200 feet.

c/ Mean specific yield for the basin may be estimated by the equation:

$$\text{M. S. Y.} = \frac{\Sigma(\text{Specific Yield})\ (\text{Acreage})}{\Sigma(\text{Acreage})} = \frac{2,149,658}{353,098} = 6.08798$$

d/ In each 100-foot band of alluvial sediments, there are about 2,000,000 acre-feet of water stored or 4,299,316 ÷ 2 = 2,149,658.

Source: Division of Water Resources. "Report to the Assembly ..." op. cit. Plate 8.

unless located near the mountains or buttes of the Valley. One oil test hole drilled in the central portion of Lancaster basin pierced 2,100 feet of alluvium without reaching the granite basement.[9/] Geological reports on the area do not specify depth of alluvium other than to indicate that it is probably great.[10/] Maps accompanying the reports of Simpson and Wiese merely estimate that depths of alluvium in the central portion of the Valley vary from 500 to over 2,000 feet. These estimates are based primarily on surface geological indications; greater accuracy would require test holes.

This geological information permits making certain assumptions about alluvial depth variation in the Lancaster ground-water basin. It is assumed that the specific yield values determined in the 200-foot band of alluvium are representative of the entire basin, to depths of 600-700 feet. The log of the oil test-hole mentioned above indicates fine sediments at depths beyond 1,500 feet but coarse material for the first 1,200-1,400 feet. Economic considerations in Chapters 6 and 7 indicate that the present economic limits of large pumping plants are 500-600 feet. (Current pumping lifts typically range from 175 to 250 feet.) Using 500 feet as a conservative assumption of the depth factor for the Lancaster ground-water basin, it is estimated that the original stock ground-water resource, to a depth of 500 feet, amounted to about 10,000,000 acre-feet.

Changes in the specific yield values would of course alter the estimate of total volume in the same direction, as would changes in the depth factor. Changes in the economic factors, considered at length in Chapters 6 and 7, would have similar effects.

Pressure Zones

Artesian conditions complicate the measurement of ground-water stock resource. This should be mentioned, although it is not possible to quantify pressure effects. Alternating layers of aquifers and confining strata extend from the central portion of the Valley toward recharge areas near

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9/ Simpson, Edward. "Geology and Mineral Deposits of the Elizabeth Lake Quadrangle, California." California Report of the State Mineralogist. California Department of Natural Resources, Division of Mines, vol. 30, no. 4, August-October, 1934. p. 415.

10/ Ibid., and Wiese, J. H. "Geology and Mineral Resources of the Neenach Quadrangle, California." California Department of Natural Resources, Division of Mines, 1950. 53 pp. (Bul. 153.)

the mountains, creating artesian conditions. Pressure in a particular aquifer is generated by elevation difference between some point of recharge, where confinement in the aquifer begins, and the outlet point or points of natural draft. When tapped, artesian water is under sufficient pressure to rise above the zone of saturation. Whether it flows above the ground surface will depend on the elevation differences.

Johnson's geologic investigation in Antelope Valley stressed the general fact of many thin aquifers and a high degree of intercalation.11/ These conditions will not interfere with the transmission of pressure within any aquifer so long as its hydraulic flow continuity is maintained. They will, however, restrict the volume of water that can flow between points of recharge and draft within a given time interval. If relative draft rate exceeds the transmission rate of ground water through the entire aquifer, hydraulic continuity can be interrupted. Thus, removal of only a relatively small volume of ground water from a well drawing solely on an artesian aquifer could cause the well to "go dry." Furthermore, even if only a part of the well's water is supplied from such an aquifer, pressure drop in the aquifer from water removal could cause a marked decline in the well's water level.

According to Johnson and Thompson, artesian water has been tapped (historically) at depths ranging from 80-1,800 feet.12/ By tapping artesian aquifers at depths below 500 feet and using water from these aquifers, the volume of estimated available ground water is increased by the coefficient of storage.13/ The stock thus consists of water stored in aquifers to the 500-foot depth plus that made available by

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11/ Johnson, H. R. Water Resources of Antelope Valley, California. pp. 36-46.

12/ Artesian water mentioned at depths greater than 800 feet is usually called "warm water." No indication is given of the height to which such water rose when the wells were drilled. Johnson, op. cit. p. 92, well nos. 240 and 242.

Wells recently drilled in the Roosevelt area to depths in excess of 1,000 feet tapped artesian water, which rose to within 250 feet of the ground surface. Some of this water was called "warm water" by local well drillers, and may have been of low quality.

13/ Defined as "the usable storage capacity of an artesian aquifer," which is computed from "the fraction of a cubic foot of water released from storage in a vertical column of the aquifer one-foot square when the head is lowered one foot." McGuiness, C. L. "The Water Situation in the United States with Special Reference to Ground Water." Washington, D. C., U. S. Department of Interior, Geological Survey. June, 1951. Processed. (Geological Survey Circ. 114) p. 14.

artesian pressure from aquifers at greater depths. Water in aquifers above the 500-foot level is subject to varying degrees of artesian pressure, but the entire volume of water is accounted for in the specific yield estimate. Water in artesian aquifers below the 500-foot level which pushes above that level is a volume in addition to the specific yield estimate for the 0-500 foot band of alluvium.

Because of interconnections between aquifers that are natural or arise from well drilling, it is not possible to determine meaningful values for the coefficient of storage of artesian aquifers in Antelope Valley. Because of these difficulties, no quantitative expression of the amount of artesian water available from depths below 500 feet is possible. It can only be concluded at this point that the original ground-water stock resource, to a depth of 500 feet, exceeded 10,000,000 acre-feet.

As ground-water levels decline and the pressure surface is reduced to levels below successive confining layers, artesian aquifers become unconfined aquifers and can be included in specific yield data for estimating the volume of ground water in storage.

Ground-Water Recharge and Its Measurement--The Flow

The major contribution to ground-water recharge comes from stream runoff. The two principal streams in the area (Rock Creek and Little Rock Creek) contribute from 35-47 per cent of total runoff, yet drain less than 15 per cent of the total watershed area surrounding the Valley. The majority of the remaining contribution comes from ephemeral streams along the south, west, and north boundaries of the Valley. Other contributions to recharge are minor, and will be discussed but briefly here before considering the contributions from stream runoff.

Contributions From Other Areas

Mountain formations surrounding the Valley are rocky and nearly impervious, preventing direct percolation through from other areas. Faulting along the southern boundary may have shattered the rock ridges separating the Valley from other watershed areas and water, permitting some percolation into Antelope Valley alluvium from these closed valleys.

But this is improbable; lakes and swamps mark these valleys as largely undrained. Possible contributions to ground-water recharge from this source may be neglected.[14]

Contributions From Return Recharge

Return recharge from excess irrigation occurs when water applied to crops exceeds their needs--the consumptive use requirement.[15] Reliable investigators assume 70 per cent to represent typical irrigation efficiency for Antelope Valley.[16] Thus, if the consumptive use requirement of a particular crop is 7 inches of water, an additional 3 inches must be applied to ensure that the crop will receive the required amount. Implicit in the concept of irrigation efficiency is the recognition that a certain amount of over-irrigation is necessary. Unavoidable losses, ranging from 5 to 40 per cent of total water applications, arise from evaporation of water stored in open on-farm reservoirs and farm laterals, seepage losses from farm laterals, surface runoff at the end of irrigation checks, and deep percolation accompanying necessary over-irrigation at the head end of the checks.

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14/ Thompson, op. cit. p. 322.

15/ Consumptive Use: "The sum of the volumes of water used by the vegetative growth of a given area in transpiration and building of plant tissue and that evaporated from adjacent soil, snow, or intercepted precipitation on the area in any specified time, divided by the given area. If the unit of time is small, the consumptive use is expressed in acre-inches per acre or depth in inches, whereas, if the unit of time is large, such as a crop-growing season or a twelve-month period, the consumptive use is expressed as acre-feet per acre or depth in feet or inches." Blaney, H. F. "Consumptive Use of Water." Proceedings, ASCE, vol. 77, separate no. 91, Oct. 1951. p. 2.

During the process of evolution of the term, many different interpretations have been given but, at the present, this definition has general acceptance. Ibid. pp. 2-4.

16/ "Irrigation Efficiency: The percentage of irrigation water delivered to the farm. . . that is available in the soil for consumptive use by the crops." State Department of Public Works. Division of Water Resources. "Irrigation Requirements of California Crops." Sacramento, California State Print. Off., 1945. (Bul. 51) p. 10.

Typical irrigation efficiency of 70 per cent in Antelope Valley is assumed by Division of Water Resources. Ibid. p. 71.

The 70 per cent figure is based on the concrete-constructed underground distribution systems in widespread use in Antelope Valley and assumes "good" management practices on the part of the farmer. Ewing, P. A. (ed.) The Irrigation Development of Antelope Valley, California. A compilation based on various reports by members of the staff of the Division of Irrigation, Soil Conservation Service. Berkeley, California, October, 1945. Mimeographed. p. 44.

In addition to unavoidable losses, some investigators believe that it is necessary to apply water above consumptive use requirements in order to prevent salt accumulation, from salts in the irrigation water added to those already dissolved in the soil:

> "In such case, rigid conservation of irrigation water is incompatible with soil conservation. A substantial amount of irrigation water must be wasted by liberal application as a necessary means of preventing increased salinity of the soil." 17/

There is a certain minimum level of over-irrigation necessary to prevent saline-alkali accumulation. This level may be 9-25 per cent above consumptive use requirements, depending upon water quality and salt content and balance of the soil.[18/] It is estimated that the over-irrigation necessary to prevent saline accumulation in Antelope Valley will vary within the above limits.[19/] Allowing an additional 5-10 per cent for unavoidable losses maximum possible irrigation efficiency could not exceed 80 per cent--with 70 per cent a safe level for most parts of the Valley.

Estimates of return recharge volume are necessarily linked with estimates of draft, which is discussed in detail in Chapter 4. The discussion at that point states that perhaps 50 per cent of the ground water applied to crops percolated back to ground water as return recharge in 1951, a volume estimated at over 200,000 acre-feet.

Water originally from deep aquifers that returns to ground water will usually not reach the stratum from which removed, being intercepted and retained by impervious strata. It is made available for reuse by

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17/ Kelley, W. P., B. M. Laurance, and H. D. Chapman. "Soil Salinity in Relation to Irrigation." Hilgardia, vol. 18, no. 18, January, 1949. Berkeley, Calif. Agr. Exp. Sta. p. 660.

18/ Scofield, C. S. "Salt Balance in Irrigated Areas." Jour. Agric. Res., vol. 61, July-December, 1940. Washington, Govt. Print. Off., 1941. pp. 17-39. For irrigation water containing about 1,000 p. p. m. soluble salts, irrigation should exceed crop requirements by about 22½ per cent.

Broadbent, F. E., and H. D. Chapman. "A Lysimiter Investigation of Gains, Losses, and Balance of Salts and Plant Nutrients in an Irrigated Soil." Proceedings, Soil Science Society of America, vol. 14, 1949. p. 267. For water containing about 350 p. p. m., irrigation should exceed crop requirement by about 9 per cent.

19/ Communication from W. P. Kelly, University of California.

Typical water analyses indicate that ground-water quality in Antelope Valley varies between the limits of 150-900 p. p. m. State Water Resources Board. "Water Resources of California." Sacramento, Calif. State Print. Off., 1951. (Bul. 1) pp. 522-523.

pumping units that draw on strata closer to the surface. This form of recharge is man-induced and is no more than the transfer of a portion of the stock resource from one part of the storage reservoir to another. It is not a perennial recharge and does not build up the stock. It is controllable, and can be reduced to a minimum that is considered necessary because a lesser return flow contains too high salt content, from soil leaching, and is unsuitable for reuse. Depending upon the relative sizes of return flow and the aquifers being recharged, pollution by this salty return flow may reach a point where the entire stock becomes unsuitable for use.

Contributions From Compaction

Tolman reported studies of ground-water hydrology in Livermore Valley (Alameda County, California) and Santa Clara Valley (Santa Clara County, California) in which release of water from aquifers as a result of compaction was considered to be a recharge to ground water.[20/] This implies that ground water thus released is a quantity above and beyond the specific yield of the aquifers involved. Tolman speaks of this as "excess water produced by compaction..." [21/] Surface subsidence, which indicates compaction, is equal in volume to the amount of water released in excess of specific yield. Actually, compaction is seldom great, and storage space of the reservoir is therefore affected to only a relatively small degree. An opposing viewpoint states that ground water released by compaction is only a portion of that available as the specific yield of the aquifer. Kelley states that super-saturation is not possible: that clays cannot contain more than the specific yield volume of water.[22/] Void spaces of the alluvium are compacted by the weight of the overlying material as the aquifers are unwatered, thus reducing specific yield and reservoir storage space.[23/]

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20/ Tolman, C. F. Ground Water. McGraw-Hill Book Co., New York and London. 1937. pp. 341-346 and 495-498.

21/ Ibid. p. 498.

22/ Communication from W. P. Kelley, Berkeley, California.

23/ Terzaghi, C. cited by Tolman, C. F. op. cit. p. 498.

The importance of compaction lies not in ground water, per se, but in ground-water storage. If release of water by compaction is above the specific yield values it is a small bonus accruing to users of the resource. It is perhaps more important that ground-water storage space is not affected significantly. If, as seems more probable, water released by compaction comes only from the void spaces of the aquifers, then compaction destroys ground-water storage. Thus, ground-water storage capacity, regarded as a flow resource, possesses a critical zone in that compaction of aquifers renders restoration of this capacity impossible.[24]

From neither standpoint does it seem reasonable to consider contributions from compaction as recharge to ground water. Water released belongs in a "once and for all" category, and can be considered as a part of the stock resource. From the first standpoint, it increases the stock resource by a small amount; from the second, it is included in the initial estimate.

Because of large draft volumes existing in Antelope Valley, it is likely that release of ground water by compaction does occur. No measurements have been taken to substantiate its presence, however. It is assumed that the volume of water thus released has been included in the estimated size of the stock. If at a later date it becomes necessary to determine the volume of storage lost by compaction, determination of subsidence or release of ground water by compaction may become necessary. The important fact to remember is that there probably is no contribution to recharge by compaction, although pumping conditions may have been changed where and if compaction has occurred.

Contributions From Stream Runoff

Stream runoff is partly evaporated or used by plants, and the remainder percolates through the alluvium until it reaches ground water. Antelope Valley is a closed basin and no water leaves the area by surface streams. In very wet years runoff reaches the playas, where it evaporates without percolation.

Several estimates have been made of the average annual contribution of runoff to ground-water recharge. These estimates (summarized in Table 3.2) range from 33,280 to 81,400 acre-feet per year, and are all admittedly based

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24/ Ciriacy-Wantrup, S. V. Resource Conservation, Economics and Policies. op. cit. p. 39. See also Critical Overdraft, Chapter 5 of this paper.

TABLE 3.2

Historic Estimates of Ground-Water Recharge to the Antelope Valley Ground-Water Reservoir

Year	Area of drainage basin	Runoff[a/]	Recharge[b/]
	square miles	acre-feet	acre-feet
1912	260	--	33,280[c/]
1919	558	75,300	50,000
1924	558	104,450	81,400
1928	483	86,430	68,800
1947	558	66,404	
1951	--	66,000	

a/ The runoff estimates represent the amount of precipitation that leaves the drainage basin area after supplying the plants with their annual water requirements and wetting the soil, which of course is dry at the beginning of the wet season. It is inflow to the area.

b/ The recharge estimates represent that portion of runoff which is free to percolate into the ground-water reservoir. Deductions from the amount of average annual runoff are necessary to account for evaporation from the surface of streams and from the soil, for stream wash that is wetted by inflow, and possibly for some water that becomes lost through being perched above the true aquifer.

c/ If Adams had used the figure that Thompson later used for the area of the drainage basin and his other assumptions had remained the same, the earlier estimate of recharge would have been raised to 71,424 acre-feet per year.

Sources:

1912: Adams, F., S. T. Harding, R. D. Robertson, and C. E. Tait. Reports on the Irrigation Resources of California. Irrigation Investigations, Office of Experiment Stations, U. S. Department of Agriculture. Sacramento, Calif. State Print. Off. 1912. 243 pp. 3 maps.

1919: Thompson, D. G. The Mohave Desert Region, California. A Geographic, Geologic, and Hydrologic Reconnaissance. U. S. Dept. of Interior, Geological Survey. Washington, Gov. Print. Office. 1929. 759 pp. 15 maps. (Water Supply Paper 578).

1924: Wright, R. V. Report on Agricultural, Economic and Ground-Water Situation, Antelope Valley, California. Federal Land Bank of Berkeley. November 6, 1924. 115 pp. Typewritten.

1928: Backman, A. E. Supplemental Report on Antelope Valley, California. Federal Land Bank of Berkeley. March 21, 1928. 29 pp. Typewritten.

1947: Dept. of Public Works. Div. of Water Resources. Report to the Assembly of the State Legislature on Water Supply of Antelope Valley in Los Angeles and Kern Counties. Pursuant to House Resolution No. 101 of February 16, 1946. Sacramento, Calif. State Print. Off. May 7, 1947. 22 pp. Mimeographed.

1951: State Water Resources Board. Water Resources of California. Sacramento, Calif. State Print. Off. 1951. 648 pp. (Bul. 1) This estimate was made by the Div. of Water Resources.

TABLE 3.3

Estimate of Mountain Runoff Reaching Antelope Valley

Area	Precipitation	Runoff	Area	Runoff
	inches	feet	acres	acre-feet
Area east of Rock Creek	17	0.17	28,800	4,896
Rock Creek (above gauging station)[a]	33	.79	14,720	11,720
Rock Creek (below gauging station)	20	.21	17,280	3,628
Between Rock Creek and Little Rock Creek	16	.15	12,800	1,920
Little Rock Creek (above gauging station)[a]	27	.39	31,360	12,080
Little Rock Creek (below gauging station)	19	.20	14,080	2,816
Between Little Rock Creek and Amargosa Creek	10	.07	25,600	1,792
Leonis Valley-Amargosa Creek	15	.14	25,600	3,584
Portal Ridge	13	.11	16,000	1,760
West side. Sawmill, Liebre, and Tehachapi Ranges. Not including Oak, Cottonwood, and a few other small creeks	15	.14	128,000	17,920
North side. Oak, Cottonwood, Minetos, and other small creeks	12	.10	42,880	4,288
Total			357,120	66,404

a/ Runoff based on stream flow measurements.

Source: State of California, Division of Water Resources. Report to the Assembly . . . op. cit. p. 10.

on inadequate data. The early estimates were based on meager data on stream flow and rainfall; the latest estimate--that of the Division of Water Resources--had the benefit of longer series of data and of observations at several locations, although area coverage is still not adequate.

Division of Water Resources Estimate

The Division of Water Resources of the State Department of Public Works has done much to develop comprehensive estimates of water supply for various areas of California. Table 3.3 shows the Division's estimate of runoff for Antelope Valley. From the value of 66,404 acre-feet was deducted 3,320 acre-feet, to allow for direct evaporation and stream-bed wetting, giving an estimated "mean annual net supply from mountain runoff. . . of about 63,000 acre-feet."25/

Stream flow and rainfall data were compared for the two most important drainage basins in the Valley (Rock Creek and Little Rock Creek), to establish a long-time relation. Where stream flow records were incomplete, they were filled in on the basis of comparison with the stream flows of other streams with headwaters in the same general area for which records existed. Average annual stream flow in each basin during the period from 1923-24 to 1941-42, inclusive, was assumed to equal the long-time mean annual stream flow. Long-time mean annual precipitation for the mountain area tributary to Antelope Valley was estimated from a 70-year (1872-1942) rainfall map prepared by the Los Angeles County Flood Control District. A curve of mean annual precipitation (70-year period) versus mean annual runoff (19-year period) was constructed, using stream flow-precipitation relations at Rock Creek and Little Rock Creek as controlling points. From this curve, runoff per acre was read directly from precipitation values and converted to acre-feet for the 11 areas shown in Table 3.3.

Certain elements used in this estimate appear to be worthy of further examination.

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25/ Department of Public Works. Division of Water Resources. Report to the Assembly. . . op. cit. p. 15.

If an additional allowance is made for surface diversion and storage losses from the irrigation districts, the resultant volume is equivalent to the term "average annual recharge to ground water" used in this paper. See Table 3.6.

First--Are the selected time periods suitable for use as norms? Comparing 70-year and 19-year mean values would at first seem to promise inaccuracies: A 70-year period seems long enough to establish representative long-time precipitation values; but 19 years of stream flow data would seem insufficient, leading to either under- or over-estimates of runoff. Nevertheless, an examination of annual rainfall indexes prepared by the Los Angeles County Flood Control District[26] indicates that the 19-year time period selected was a prudent choice for comparison with the long-time precipitation data: The 19-year average of the rainfall indexes for the Rock Creek and Little Rock Creek areas, after weighting by the acreages they represent, yields 98.36, which compares favorably with the 70-year mean of 100.

Second--Stream flow measurements were available for only two watersheds of the general area. The curve drawn would have been more reliable if more observations had been available. Actual measurements of precipitation within the drainage basins would have been more realistic than long-time averages. The curve constructed presents the average relationships existing between precipitation and runoff for different drainage basins within the same general watershed area. The basic assumption of this curve is that runoff is primarily a function of precipitation per unit area per time period. (This assumption is investigated in the following section.) The general shape of the curve agrees with curves obtained from precipitation-runoff for individual watersheds.[27] It is this very point, however, that weakens and complicates the curve presented by the Division of Water Resources. A preconceived notion forces the curve through only two points and into a particular shape. A small change in this curve could create a large change in the runoff estimate. It would seem that this curve would have been improved by more observations (admittedly impossible) or a different method of construction.

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26/ Los Angeles County Flood Control District. Hydraulic Division. Biennial Report on Hydrologic Data, Seasons of 1949-50 and 1950-51. Los Angeles, August, 1952. 388 pp. Processed.

27/ For example, a study by Lee indicates curvilinear relations in the initial portions of the curve and straight-line relationship as rainfall increases to 20-50 inches. Slight variability results for various watershed-climate-geology combinations. Lee, C. H. "Total Evaporation for Sierra Nevada Watersheds by the Method of Precipitation and Runoff Differences." Transactions-American Geophysical Union, Part I, 1941. pp. 50-66.

Third--It is possible that stream flow measurements may underestimate the quantity of water yielded by a watershed. Rowe and Colman state that as much as 75 per cent of annual water yield may leave a watershed as underflow, through extensively faulted rock underlying the canyon.28/ The possibility and extent of similar conditions underlying Rock Creek and Little Rock Creek canyons above the gauging stations is unknown, and no accurate statement of underflow can be made. Stream flow measurements provide the only measure of watershed water yield and must be used as indicators of total runoff, although they are subject to the probability that they understate the total.

Finally, relationships between stream-flow and precipitation can only be handled as broad aggregates. Specific relationships between runoff and such variables as vegetation, soils, geology of the water course, seasonal distribution of precipitation, humidity, wind velocity, etc., can only be implied. Furthermore, specific relationships are not easily evaluated. Even with the high degree of control in the study of Rowe and Colman, inductive reasoning and aggregation were necessary. Any future research that concentrates on specific runoff relations should, of course, improve runoff estimates.

Precipitation--Runoff Correlations

The assumption that runoff is primarily a function of precipitation per unit area per unit of time was tested by correlating annual precipitation and stream flow for Antelope Valley and adjoining areas, in terms of per cent of mean annual values.29/ The ordinary least-squares coefficients of determination (r^2) are presented in Table 3.4 and an example of the resulting general scatter diagrams is given in Figure 3.2. The main purpose underlying this examination was to see if a method for estimating Antelope Valley watershed runoff could be developed that would be more simple and rest upon at least as firm a foundation as those discussed above.

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28/ Shown for a small canyon on the south side of the San Gabriel Mountains, to the south and east of Antelope Valley watersheds. Rowe, P. B. and E. A. Colman. "Disposition of Rainfall in Two Mountain Areas of California." Washington, D. C., U. S. Department of Agriculture, 1951. pp. 69-79. (Technical Bul. 1048)

29/ Representative precipitation and stream flow data are presented in Appendix Table 5.

TABLE 3.4

Precipitation-Runoff Correlations Antelope Valley Watershed

Precipitation station	Mean annual precipitation	Coefficient of determination for Little Rock Creek runoff r^2	Number of annual observations	Coefficient of determination for Rock Creek runoff r^2	Number of annual observations
San Gabriel Mountains	96.2 per cent	0.86	21	--	--
Index of seasonal precipitation a/	91.4 per cent	--	--	0.94	28
Big Pines Park	26.06 inches	0.77	21	0.86	21
Sawmill Mountain	21.65 inches	0.77	21	0.83	21
Rouff Ranch b/	15.48 inches	0.64	21	0.70	21
Table Mountain b/	14.19 inches	0.46	21	0.55	21
Fairmont	13.54 inches	0.86	21	0.92	28
Little Rock Creek	10.19 inches	0.76	21	0.78	21
Palmdale	8.91 inches	0.86	19	0.84	19
Llano	7.79 inches	0.76	21	0.70	28
Lancaster	7.68 inches	0.76	21	0.71	21
Backus Ranch	7.28 inches	0.69	15	0.61	15

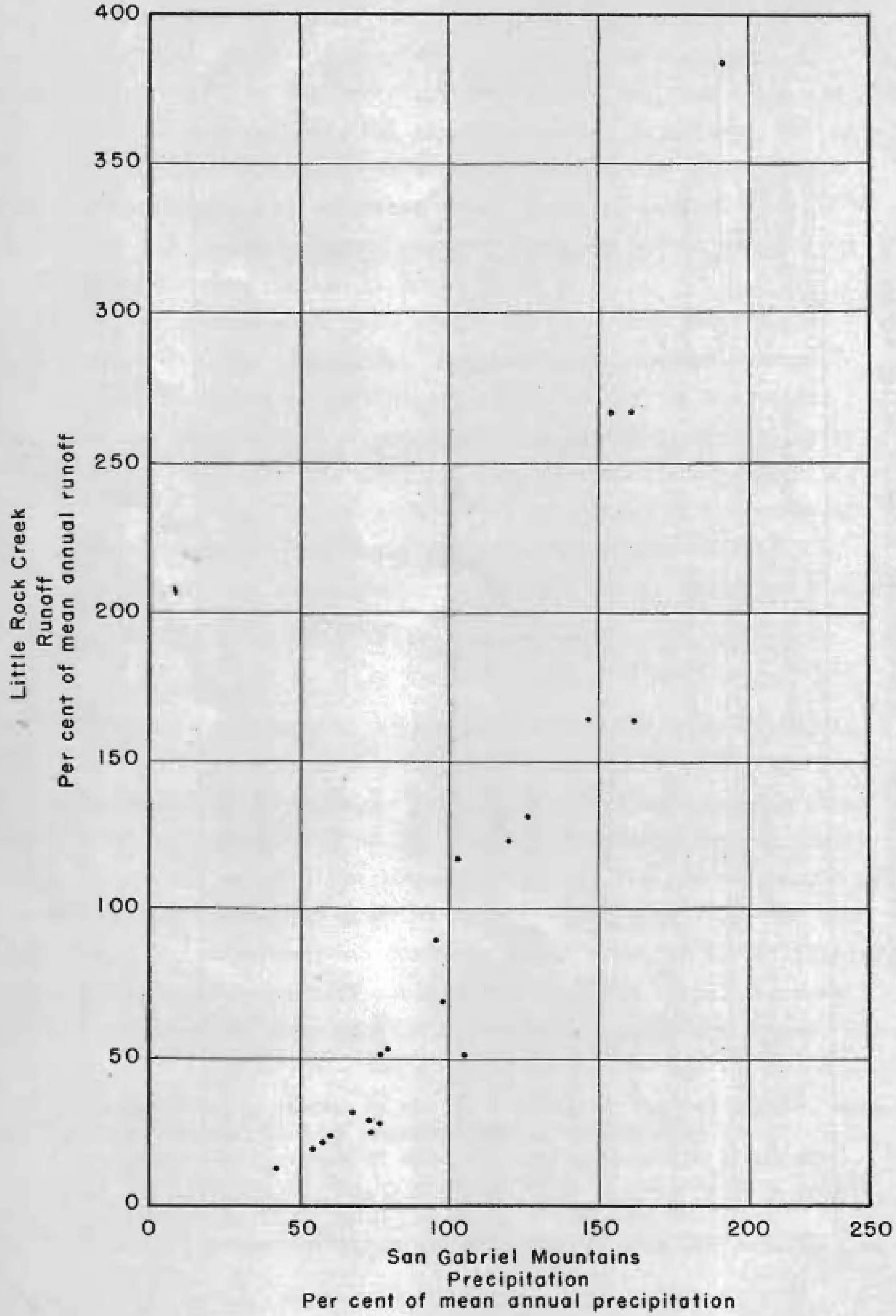
a/ This index series is based on the 75-year period, 1872-73 to 1948-49, with 28.16 inches per year equal to 100 per cent. The two values result from the use of different numbers of observations for the two correlations. The per cent values compare with long-time 75-year normal values of 100.

b/ Poor record because of changes in location of station.

Source: Appendix tables. Snyder, J. Herbert. op. cit.

Figure 3.2

RUNOFF PRECIPITATION RELATIONS
LITTLE ROCK CREEK – SAN GABRIEL MOUNTAINS



Precipitation in a watershed is the only source of runoff from that watershed, assuming there is no surface or subsurface inflow from other watersheds. One would therefore expect a high correlation between runoff at one station and precipitation at any other one of selected stations within the watershed. That expectation receives strong support from the scatter diagrams and significant coefficients of determination obtained in this study.

One could furthermore expect that any observed correlation would become greater the more nearly climatic conditions at the precipitation station correspond to climatic conditions within the drainage basin in which runoff is measured. Fairmont station is more than 30 miles from the Little Rock Creek watershed. A higher correlation between Little Rock Creek runoff and precipitation is observed at Fairmont station than at either Llano or Little Rock Creek precipitation stations, both of which are within 10 miles of the watershed. Although geographically removed, Fairmont station is hydrologically more similar to the watershed area producing the runoff than is either of the nearer stations.

Seasonal distribution of rainfall for small watersheds of the Antelope Valley type will be similar for all stations, with only total annual values varying significantly. Because of relatively high annual precipitation within the area producing runoff, a relatively greater runoff correlation is statistically predictable for high precipitation stations, regardless of their proximity to the watershed. This tendency is demonstrated in Table 3.4, especially if Rouff Ranch and Table Mountain stations are disregarded.[30/] Furthermore, the tendency is substantiated significantly when subjected to statistical test.[31/] In estimating runoff from precipitation, it is necessary to relate runoff and rainfall from hydrologically similar areas. Similarity alone is apparently sufficient to permit estimating runoff; geographic proximity is not required.

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30/ These stations may be omitted because locations of the rain gauges were shifted several times.

31/ The hypothesis that the paired observations are not from the same population (that is, ranked in the same order) is rejected at the 99-per cent level of significance. Olds, E. G. "Distributions of Sums of Squares of Rank Differences for Small Numbers of Individuals." The Annals of Mathematical Statistics, vol. IX, no. 2, June, 1938. pp. 133-148.

To be useful in estimating runoff, the runoff-precipitation correlation needs to be refined into a curve describing the relationship.

First, such a curve must allow for the fact that some precipitation is necessary before any runoff can result. During the dry season, plants in the watershed will use up most of the available water within the root zone. Precipitation will replenish this water before runoff occurs unless precipitation intensity exceeds the infiltration rate of the soil. If the latter condition holds, runoff will occur regardless of the moisture content of the soil.

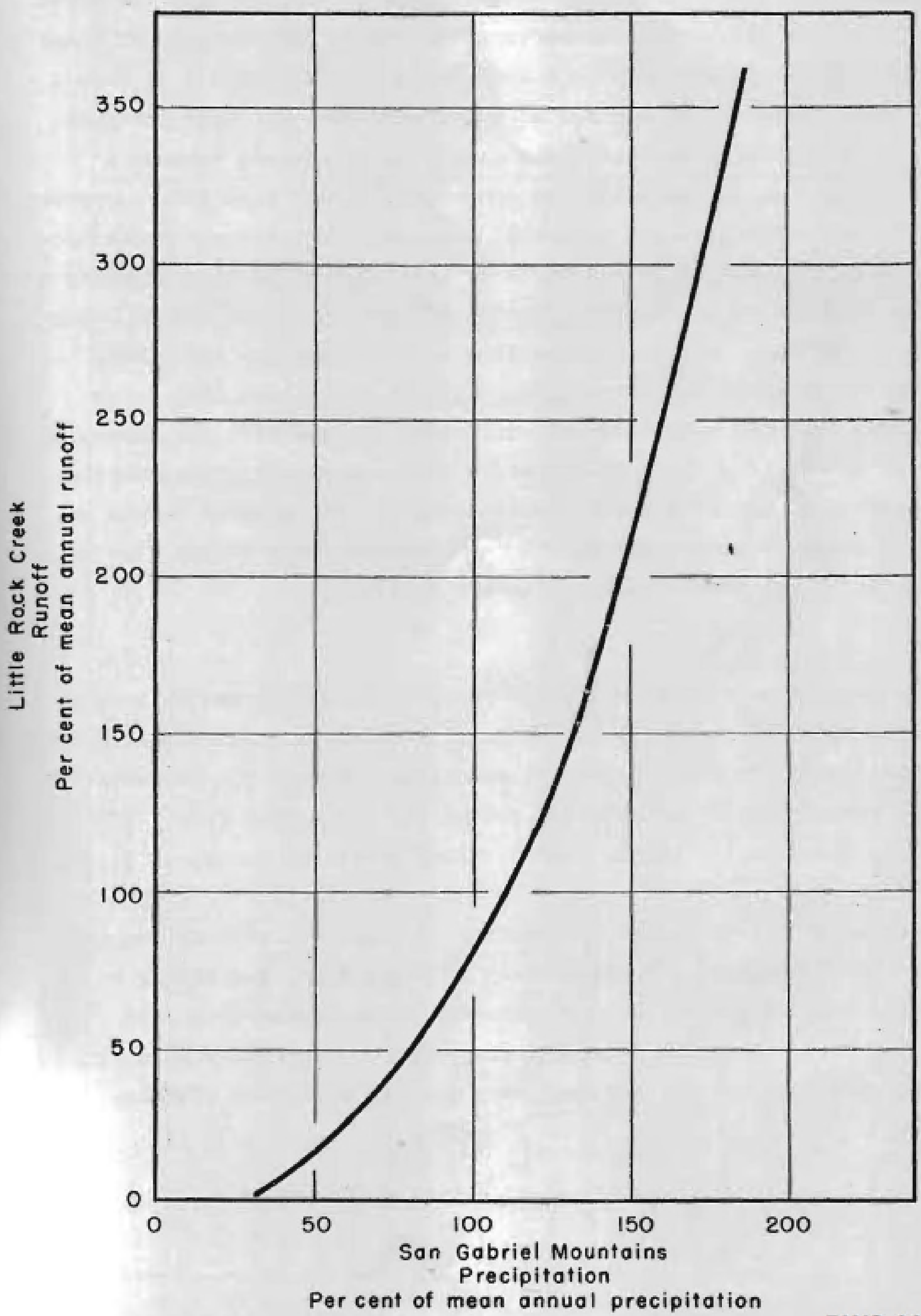
Second, a curvilinear relationship is indicated because, after soil moisture reaches field capacity, the greater the precipitation the greater the runoff, other things being equal. Interception and evapo-transpiration by plants will act to prevent the entire precipitation volume from becoming runoff. The relationship is probably curvilinear throughout its entire range, although it may approach a straight line, asymptotically, as annual rainfall exceeds 36 inches.

Such a curve (see Figure 3.3) has been developed for Antelope Valley, and is based primarily on the scatter diagram of Little Rock Creek runoff and San Gabriel Mountain precipitation shown in Figure 3.2. The Little Rock Creek drainage area was selected because geologic, vegetative, and climatic conditions found there are typical of the entire Antelope Valley watershed area. All runoff-precipitation data used in this study were converted to values expressed as per cent of mean annual figures. This allowed direct comparison of the several watersheds studied. Superimposing the general curve on each of the scatter diagrams showed the curve to be a valid representation of the relations of each paired set of data. The curve was further satisfactorily tested against three diagrams for streams flowing from the San Gabriel mountains out to the Pacific Ocean and scatter diagrams for San Joaquin River (above Friant Dam) and Kaweah River watersheds.

Although this demonstration cannot be accepted as conclusive proof, it is strong corroborative evidence substantiating the assumption under examination. Surface runoff from a drainage area can be assumed to be primarily a function of precipitation per unit area per unit of time. Furthermore, a single precipitation curve can be used to describe the relationships existing for several drainage areas within one general watershed, so long as climate, vegetation, geology, topography, exposure, etc., are similar.

Figure 3.3

GENERALIZED RUNOFF PRECIPITATION RELATION
LITTLE ROCK CREEK - SAN GABRIEL MOUNTAINS



The general curve can be used to estimate meand annual runoff for Antelope Valley, in a manner similar to that used by the Division of Water Resources. Estimated mean annual runoff is 51,110 acre-feet per year (Table 3.5) from a 318,220-acre watershed, an average of 0.161 acre-feet per acre per year. This compares closely with the Division of Water Resources runoff estimate of 66,404 acre-feet per year (Table 3.3) from a 357,120-acre watershed, an average of 0.186 acre-feet per acre per year.

Which estimate is more accurate cannot be determined without a longer history than is now available concerning stream flow data supported by metered estimates from the ephemeral streams. The estimate presented here rests on at least as firm a basis as that of the Division of Water Resources (determined by only two points) and has the advantage of being more simply derived. Actual observations on precipitation and runoff determine the shape of the curve throughout its range, and only a few observations from the watershed are sufficient to establish the placement of the curve. It is subject to the major shortcoming, discussed earlier, of aggregation of specific runoff relationships. The general method of estimating runoff may be quite useful for areas in which stream flow data are fragmentary but precipitation data are available.

Cyclical Variation in Runoff

The general precipitation-runoff curve (Figure 3.3) can be used to demonstrate cyclical runoff in the Valley. A rainfall index beginning in 1872 is available for the San Gabriel mountains. Figure 3.4 presents estimated annual runoff for Antelope Valley for the period from 1872-73 to 1950-51, based on the annual runoff value, developed above, of 51,100 acre-feet per year.

A definite but irregular periodicity is observed, with alternate "wet" and "dry" periods of approximately 13 years each, completing a "cycle" in about 26 years. A 13-year moving average describes this periodicity better than did five-, seven-, nine-, or eleven-year moving averages. Although neither the frequency nor the amplitude of these

TABLE 3.5

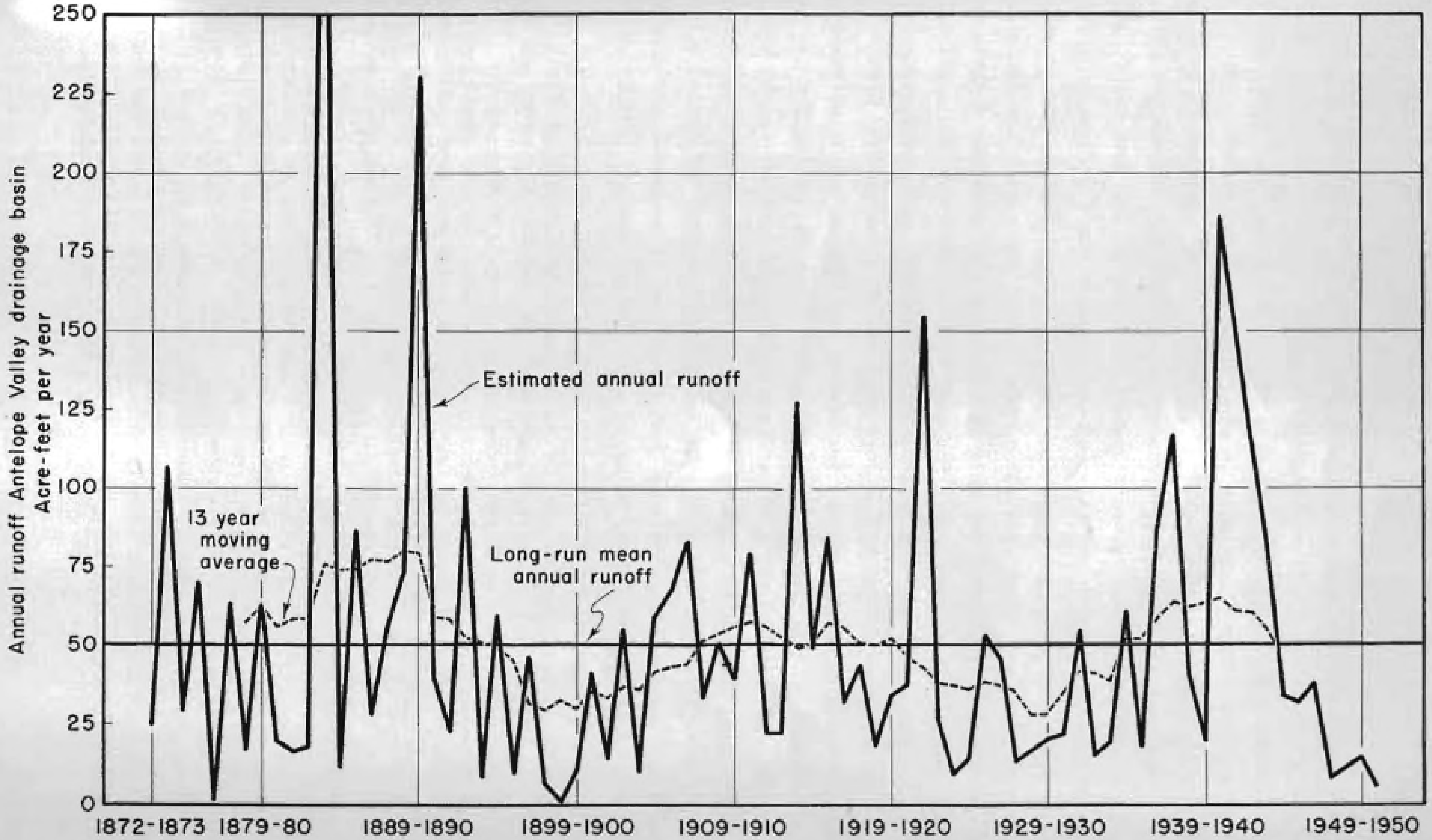
Estimate of Mountain Runoff Reaching Antelope Valley

Area	Precipitation		Runoff		Area	Total runoff
	Average depth, inches per year	Per cent of normal	Per cent of normal	Acre-feet per acre per year	acres	acre-feet
East of Rock Creek	16.635	59	24	0.1392	28,800	4,010
Rock Creek (above gauging station)	30.162	107	93	0.5395	14,720	7,940
Rock Creek (below gauging station)	16.282	58	22	0.1275	17,200	2,190
Between Rock Creek and Little Rock Creek	13.999	50	17	0.0986½	12,800	1,260
Little Rock Creek (above gauging station)	27.675	98.2	74	0.429	31,400	13,470
Little Rock Creek (below gauging station)	19.806	70	36	0.2087	13,000	2,710
Between Little Rock Creek and Portal Ridge	13.000	46	11	0.0638	30,000	1,920
Portal Ridge	12.000	43	8	0.0464	11,000	510
Between Portal Ridge and Kern County Line	14.702	52	18	0.1043	77,700	8,100
Tehachapi (Kern County portion)	15.223	54	19	0.1102	81,600	9,000
Total					318,220	51,110

Source: Figure 3.3.

Figure 3.4

ANNUAL AND CYCLICAL RUNOFF
ANTELOPE VALLEY 1872-1951



Source: Table 3.7 Snyder, J. Herbert, op. cit.

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periods is constant, for want of a better term they are called cycles.32/ They are nevertheless of value, because of the much greater variation in runoff that can occur from year to year and over a period of several years.

Historically, when several years of subnormal runoff occurred, the economy of Antelope Valley suffered. For example, the drought period centering around 1899 caused abandonment of farms, as has been mentioned (pp. 10-12 and 14). Since 1920, direct dependence of most farmers upon the ground-water stock resource has lessened the direct influence of periodic variation in climate. Pumping technology has made this stock available for use during dry periods when sufficient water was not obtainable otherwise. Besides this advantage in time the stock provided advantage in location, obviating any need of long and expensive diversion canals to transport water from streams to individual farms.

This cyclic variation has important policy implications in any consideration of the possibility of storing surplus runoff (greater than mean annual volume). Figure 3.4 demonstrates the probability of wide fluctuations around the mean value that would produce two or three times the mean runoff in any one year, together with a tendency of greater than mean runoff to occur for several years together. This must be anticipated by a ground-water economy in such a way that cumulative excess runoff can be stored during the wet, or surplus, phase of the cycle for subsequent use

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32/ Although commonly spoken of as cycles, modern climatologists stress the randomness of climatic fluctuations, e.g.,:

Comparison with variation in major drainage basins in other portions of the United States showed that the Antelope Valley cycles were "in phase" during the first complete cycle, but "out of phase" during the second. Hoyt, W. G., et al. Studies of Relations of Rainfall and Runoff in the United States. U. S. Department of Interior, Geological Survey. Washington, Govt. Print. Off., 1936. 301 pp. (Water Supply Paper 722)

"Though firm advocates of climatic cycles will sharply disagree, such facts as we possess today neither definitely demonstrate nor disprove the existence of any real cycle. Such climatic variability as has been observed may be explained as resulting wholly from random fluctuations." Mascart, Jean. Cited in U. S. Department of Agriculture, "Climate and Man." Yearbook of Agriculture, 1941. Washington, Govt. Print. Off., 1941. p. 92.

Brooks, in discussing climatic oscillations varying in length from millions of years to less than 100 years, carefully avoids using the word "cycle" but stresses the randomness in fluctuations of the factors that cause climatic variation. Brooks, C. E. P. Climate Through the Ages. 2d ed. London, Ernest Benn, Ltd., 1949. 395 pp.

during the dry, or deficit, phase of the cycle. In Antelope Valley, the natural recharge area is great enough in extent that most of the surplus runoff will percolate to ground water without man-made recharge basins.33/

Problems in Estimating Recharge

Some difficulties in estimating the sequence of precipitation to runoff to ground-water recharge have been discussed above. In Antelope Valley, the problem of estimating ground-water recharge reduces to a problem of estimating runoff, for contributions to ground water from other sources are not significant. The exclusion of such items as possible underflow, however, may tend to make estimates of recharge that are based on runoff alone to be somewhat conservative.

Thomas defines reservoir problems (herein called recharge problems) as those that pertain to entire ground-water reservoirs where replenishment rate is inadequate to the continuing demand for ground water.34/ Antelope Valley is in such situation, with use of ground water exceeding rate of recharge, with consequent mining of the ground-water stock.

In this area the heart of the recharge problem is a satisfactory determination of recharge volume--the amount of water that may be withdrawn--annually and indefinitely--from ground-water storage without significantly altering the character of the stock resource. It is equivalent to the physically determined safe yield of the basin (a concept to be discussed in the next section).

The magnitude of ground-water recharge is less than runoff because of losses in stream-bed wetting, consumptive use by vegetation near stream channels, surface diversions by irrigation districts, evaporation from irrigation districts' reservoirs, and evaporation from the playas. Because there is no surface outflow from the area, runoff less these deductions is the recharge to ground water. Two estimates of average annual recharge for Antelope Valley are presented in Table 3.6. Both are based on an average annual runoff of 51,100 acre-feet, as developed in this paper.

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33/ Muckel, D. C. Feasibility of Spreading Water at Mouth of Rock Creek in Antelope Valley, California. Soil Conservation Service, Irrigation Office, Berkeley, September, 1944. Typed manuscript.

34/ Thomas, H. E. The Conservation of Ground Water. New York, McGraw-Hill Book Company, Inc., 1951. (Sponsored by the Conservation Foundation.)

TABLE 3.6

Average Annual Recharge to Ground Water
Antelope Valley

	Acre-feet
Estimate 1	
Estimated average annual runoff	51,100
Less 6.5 per cent wetting loss[a/]	3,320
Less annual surface diversions and evaporation from storage (irrigation district reservoirs)[b/]	7,500
Estimated average annual recharge to Antelope Valley ground water	40,280
Estimate 2	
Estimated average annual runoff	51,100
Less 60 per cent wetting loss, evaporation from flowing water, and consumptive use by native vegetation[c/]	30,660
Less annual surface diversion and evaporation from storage[b/]	7,500
Estimated average annual recharge to Antelope Valley ground water	12,940

a/ Division of Water Resources. "Report to the Assembly . . . ," op. cit.

b/ Irrigation district records and interview with W. O. Wagner, Consulting Hydraulic Engineer for Palmdale Irrigation District.

c/ White, W. N., "Preliminary report on the ground-water supply of Mimbres Valley, New Mexico." Contributions to the Hydrology of the United States, 1930. U. S. Department of the Interior, Geological Survey. Washington, Govt. Print. Off. 1931. 220 pp. (Water Supply Paper 637)

The first estimate deducts 3,320 acre-feet[35/] from average annual runoff, for wastes that include stream-bed wetting and evaporation from the playas. Percolation measurements underlying this deduction indicate the necessity of very great rainfall intensities before runoff reaches the playas. Runoff wasting to the playas during the single water year 1937-38 amounted to 82 per cent of the total recorded waste for the 18-year period from 1923-24 to 1941-42. For that year, waste was 45 per cent of total runoff; during the other years of the period, annual measured waste only once exceeded 5 per cent of total estimated annual runoff. The infrequent occurrence of large runoff volumes and the high permeability of the recharge area make 3,320 acre-feet a sufficient allowance for wastes from stream-bed wetting and evaporation from the playas. (This is approximately 6.5 per cent of average annual runoff.) Evaporation from the surface of flowing streams is less than the margin of error for measuring stream flow, and may consequently be ignored.

A second deduction from runoff must be made: An allowance of 7,500 acre-feet for annual surface diversions and evaporation from storage is based on records and estimates of the irrigation districts. There may be a small return flow from irrigation district diversions, but the variable and unpredictable water supply of the Valley has taught thrift in water application, and usable return flow can be assumed to be negligible.

The remainder after the deductions discussed above is 40,280 acre-feet--which is one estimate of average annual recharge to Antelope Valley ground water. Except for the surface diversions and evaporation from storage deducted above, nearly the entire runoff volume is recharge. Estimates of yearly recharge made for the area with the above procedure indicate that in years of very low runoff nearly the entire runoff volume is probably diverted by the irrigation districts, reducing recharge to negligible proportions.[36/]

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35/ Measured waste from Rock Creek and Little Rock Creek during the period from 1923-24 to 1941-42 averaged 2,317 acre-feet per year. An additional 1,003 acre-feet was considered an ample allowance for waste from the smaller streams. Division of Water Resources. Personal communication.

36/ For example, during the period from 1947-48 to 1950-51 the estimated recharge averaged less than 3,000 acre-feet per year, because most of the runoff from Little Rock Creek was diverted by the irrigation districts. Snyder, J. Herbert. Factors Affecting the Ground-Water Economy of the Antelope Valley, Los Angeles County, California. Unpublished doctoral dissertation. University of California, Berkeley. 1953. Table 3.7.

A report on the Mimbres Valley, in New Mexico, indicates that recharge to ground water in that area may average only about 40 per cent of mean annual runoff.[37] The factors that were stressed as accounting for this low value include the carrying of large amounts of silt and debris in the stream runoff and the extensive use of water by plants growing near the broad stream channels.

The second estimate of recharge given in Table 3.6 is based on White's research in the Mimbres Valley--similar in character to the Antelope Valley. White's 60-per-cent deduction for stream-bed wetting, evaporative waste, and consumptive use by native vegetation in and near stream channels or recharge areas, when applied to the Antelope Valley runoff of 51,100, gives a runoff waste of 30,660 acre-feet. An allowance of 7,500 acre-feet for surface diversion and evaporation from storage is further made, as before. The remainder of 12,940 acre-feet per year is the second estimate of average annual recharge to Antelope Valley ground water that is made here.

The extreme difference between the two recharge estimates arises primarily from differences in the degree of permeability between the two recharge areas. Because the first estimate is based on actual percolation measurements in Antelope Valley, the resulting estimate of average annual recharge of 40,280 acre-feet appears to be the better.

Safe Yield

Average annual recharge to ground water is essentially the same as the safe yield of a ground-water basin, which is physically determined. The problems of estimating recharge are also the problems of estimating safe yield. Safe yield may be something less than recharge if transmission problems are present in the ground-water basin.[38] The presence of this

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37/ White, W. N. op. cit., pp. 69-90. This area is similar to Antelope Valley with respect to climate and topography. The main points of dissimilarity are in the permeability and extent of the recharge area, that of Antelope Valley being greater in both respects.

38/ Transmission or pipeline problems are defined by Thomas as those that arise because of the inability of water to move rapidly enough through earth materials to supply the demands of wells, even though the ground-water reservoir as a whole may have an adequate supply of water. Thomas, op. cit. p. 4.

problem in Antelope Valley was mentioned as a possibility earlier herein (p. 23, Pressure Zones), but its actuality has not been demonstrated. For this reason, and because this type of problem is minor when compared to the serious recharge (or reservoir) problem, transmission problems are assumed to be insignificant in Antelope Valley, leaving average annual recharge equivalent to the physically determined safe yield.[39/]

The phrase "physically determined" is used, because only physical variables such as runoff, surface diversions, evaporation, consumptive use, etc., enter into the determination of safe yield. Annual draft limited to safe yield does not necessarily become a policy goal for ground-water use, because of the lack of economic considerations. As will be shown later, annual draft on ground water in the Valley exceeded safe yield as much as four-fold in one year, and has consistently exceeded it since 1925. Since that time, ground-water levels (and pressure levels) have declined 50 to 200 feet, and the mining the ground-water stock resource continues because it is profitable (see Chapters 6 and 7).

Does this mean that an "economically determined" safe yield can be specified? Theoretically it can, because it represents the "optimum state of conservation" of the ground-water stock resource.[40/] It could be formulated as the time distribution of use rates of the ground-water stock that maximized the present value of the flow of expected net revenues from the use of the resource. From a practical standpoint, however, such specification of use rates cannot be attained, because of the never-ceasing fluctuations in the very factors that determine maximized net revenues. In a study such as this, the best that can be done is to recognize that the physically determined safe yield may be exceeded, and to estimate whatever magnitudes might be involved.

As with runoff, cyclical variation in recharge is a fact that must be considered. If the average annual recharge (or flow resource) is to be used to its full extent, it is necessary that the ground-water storage

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39/ An additional problem that may need investigation in the future centers around the fact that in a closed basin, such as Antelope Valley, the quality of the ground-water stock resource will gradually deteriorate.

40/ "The optimum state of conservation" is defined and discussed in Ciriacy-Wantrup, S. V. Resource Conservation, Economics and Policies. op. cit. pp. 76-93.

reservoir be in such condition that no recharge will be rejected in years of greater than average recharge. As a result of mining the ground-water stock, the volume of ground water in storage has been reduced enough that even in years of high recharge little or none of the flow is rejected. The Antelope Valley ground-water economy can absorb the average annual recharge or safe yield volume of water--estimated to be about 40,000 acre-feet per year.

Water Importations

Experience in many western ground-water regions has shown that importation of water will be necessary to meet present and anticipated levels of water use. Ground water or surface streams may be adequate for large-scale initial development--or appear to be--but maintaining long-time use at the developed level may nevertheless require supplementation of the annual flow (particularly of ground water). The Central Valley of California demonstrates this situation.

Antelope Valley was selected for this study because of its virtual isolation from outside water and its status as a self-contained drainage unit. This does not mean, however, that it is impossible to deliver water to the area from regions outside the Valley.

The western portion of the Valley is crossed by the Owens Valley-Los Angeles Aqueduct, which in the past has supplied some water to this area. The Feather River and associated projects have been proposed as elements of a master water plan for California.[41/] The proposed southern California conduit of the Feather River Project could supply water to Antelope Valley water users as it passes along the southern flank of the Valley. As far as can be determined at this time there are no other projects that can in the near future provide additional water for southern California or Antelope Valley water users.[42/] The Klamath, Trinity, and Columbia rivers

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41/ This master plan provides for transfer of water from regions with excess available water to those deficient in water. Part of the system is in operation and other parts are under construction.

42/ Only Feather River water has yet been filed on for use in areas "south of the Tehachapi Mountains," (i.e., southern California). Personal communication, A. D. Edmonston, State Engineer, Sacramento, 1953.

are possible future sources of water, either for surface-diversion gravity-irrigation or for recharge to the ground-water stock.

The Owens Valley-Los Angeles Aqueduct

The Los Angeles Aqueduct, operated by the Department of Water and Power of the City of Los Angeles, crosses western Antelope Valley to transmit water from Owens Valley and Mono Basin to reservoirs in San Fernando Valley, for distribution to various parts of greater Los Angeles. Routine testing and cleaning of the aqueduct during the period 1938-1945 caused about 27,420 acre-feet of water to be discharged into Antelope Valley.43/ No discharge of any significance occurred prior to 1938.

During 1945, the Portal Ridge Soil Conservation District constructed a 40-acre spreading basin in Kings Canyon below this aqueduct. During 1946 and 1947 this spreading basin was favored with "wasted water" from the aqueduct when "operational convenience was served thereby," a total of 9,309 acre-feet being discharged in the 2 years.44/

A total of about 36,729 acre-feet was discharged from the aqueduct in Antelope Valley during the period 1938-1947, only because the aqueduct carried "surplus water above City requirements, but within Aqueduct capacity," which water was released along the course of the aqueduct. Since 1947, municipal demands have increased to the point where the "City will be unable to remove from Owens Valley any waters in excess of its requirements, since full capacity is necessary to meet municipal demands." No discharge has taken place since 1947 and no future discharge is anticipated.45/

The capacity of the spreading basin in Kings Canyon is approximately 50 cubic feet per second. Probably 15,000-18,000 acre-feet could be spread during a year, allowing for "rest" periods to improve infiltration rates. The probability of this ever happening is very remote: Past contributions from the aqueduct have been relatively unimportant, and no future contributions are anticipated.

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43/ Communication from Samuel B. Morris, General Manager, Department of Water and Power of the City of Los Angeles.

44/ Ibid.

45/ Ibid.

Feather River Water[46]

The California State Water Resources Board has proposed the Feather River and associated projects as part of the State's master water plan to provide for transfer of water from "surplus" to "deficit" areas.[47] The project involves a multiple-purpose dam on the Feather River and a 566.6 mile diversion conduit, beginning near the conflux of the Sacramento and San Joaquin rivers and terminating in San Diego County. The proposed conduit enters Antelope Valley about 300 miles from the intake diversion. Three major turnout structures could divert water in the Valley. The 3,000 foot elevation of the conduit would permit delivery of water by gravity to most of the arable portions of the Valley.

The project is still in the investigational stage and some of the recently proposed features will probably be modified before the project is constructed. There is no doubt, however, that some project will be constructed to deliver water to southern California. The availability to the Central Valley of Trinity River and Klamath River water helps free Feather River water for use in southern California. Antelope Valley is but a very small part of the State water plan, and routing the conduit through the Valley would be only incidental to the objective of transmitting water to the parched metropolitan areas of southern California. The Feather River Project may be changed so as to by-pass Antelope Valley entirely, although it is assumed herein that the route through the Valley will be the final choice.

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46/ The majority of this section is based on: State Water Resources Board. Report on Feasibility of Feather River Project and Sacramento-San Joaquin Delta Diversion Projects Proposed as Features of the California Water Plan. Department of Public Works, Division of Water Resources. Sacramento, California State Print. Off., May 1951. 127 pp. Mimeographed.

The State Water Resources Board has been created to make state-wide investigations of water resources and their use and development. The Board, however, is supervisory in nature. The actual work and investigation are undertaken by the Division of Water Resources, which reports to the State Water Resources Board. From the standpoint of the present discussion, the two agencies may be considered synonymous. State Water Resources Board. Water Resources of California. Sacramento, Calif. State Print. Off., 1951.

47/ Section 11260 of the Water Code of the State of California states that the Feather River and associated projects are a part of the Central Valley project but are to be constructed, maintained, and operated by the State Water Project Authority as units of the Central Valley Project "separate and apart from any or all other units thereof."

Based on 1950 cost estimates, capital repayable costs of bringing the project into southern Kern County would be $529,513,000. Additional costs of transporting water south of the Tehachapi Mountains would be $603,948,000. Using a 2-per cent interest rate on outstanding long-term and short-term debts, the annual cost incurred to deliver water to southern California would be $74,356,100 per year. Using a 3-per cent interest rate, it would be $77,528,800.

Additional revenue provided by water users in southern California--using $50 per acre-foot, as proposed by the Division of Water Resources--would be $75,100,000 per year.48/ Using the 2-per cent interest rate, that part of the project that provides water to southern California would yield a $743,900 surplus each year. Using the 3-per cent rate, it would suffer an annual deficit of $2,428,800. For the entire project, the 2-per cent interest rate would yield a $3,866,200 surplus each year and the 3-per cent interest rate would create an annual deficit of $1,898,400.

The revenue estimates from which the above surpluses and deficits are calculated include sale of water to areas south of the Tehachapi Mountains at $50 per acre-foot. It will be shown in later chapters that it is impossible for farmers in Antelope Valley to pay such a price for irrigation water, either for gravity diversion or ground-water recharge. Only residential or commercial water users can afford such prices.49/

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48/ See footnote 45, supra.

49/ For example, average billing price per acre-foot in metropolitan Los Angeles is:

	Class of water consumer				
Year	Residential	Commercial	Intermittent irrigation	Combined irrigation and residential	All classes combined
	dollars per acre-foot				
1946	66.04	52.79	6.84	34.15	44.91
1947	66.39	53.88	6.80	33.63	46.04
1948	66.17	53.88	6.75	33.32	46.65
1949	66.56	54.01	6.75	34.41	47.04

Source: Calculated from data presented in: Los Angeles Board of Water and Power Commissioners. 46th Annual Report, 1947 and 48th Annual Report, 1949.

Other issues to be settled include conflict between the State of California and the federal government as to what authority each shall have and under what limitations the project shall be constructed. Additional time is also needed to complete investigational activities and obtain financing of the project.

It is apparent that no water importation to Antelope Valley can be expected in the near future. Until such time as importation may be made, the safe yield of the ground-water basin remains as previously calculated: 40,000 acre-feet per year. If and when water is imported, the safe yield value will of course be raised by the magnitude of the imports. It is immaterial whether one postulates the imported water to be for direct gravity diversion--which will allow some agricultural units to stop pumping ground water--or for ground-water recharge--which will tend to increase the size of the ground-water stock. In either instance, the effect will be to slow or reverse the decline in ground-water levels.

Chapter 4

Discharge and Draft of the Ground-Water Resource

Consideration of the physical aspects of ground water and its recharge was the first step in this inventory of Antelope Valley ground water. The second phase will review the means by which water is removed from ground-water storage--both naturally and artificially--and will estimate the quantities. Natural discharge of ground water has become unimportant in Antelope Valley as a result of the intensive irrigated agriculture.1/

Natural Discharge of Ground Water

Average annual recharge to ground water over an extended period of time will about equal average annual discharge when there is no large-scale interference by man. Processes of natural discharge of ground water are most important when the reservoir is filled to capacity. In an unsaturated reservoir, natural discharge tends to be less than recharge while the available capacity for storage still exists. When it becomes filled, processes of natural discharge act to maintain balance between recharge and discharge. This does not imply static ground-water levels around which forces of recharge and discharge fluctuate. The seasonal and cyclical components of the recharge-discharge process combine to permit wide variation in recharge and discharge, and, consequently, in water levels. Natural discharge occurs primarily in three ways: (1) underground percolation from the area, (2) evaporation from soil and water surfaces, and (3) transpiration from plants. Use of ground water by man tends to upset the natural balance by removal of water in the form of crops and increasing the volume of evaporation and transpiration by irrigating in periods when lack of natural precipitation would curtail these sharply.

Although no surface runoff leaves Antelope Valley today, there is reason to believe that underground percolation from the area occurred in the past. Thompson described sloping ground-water conditions in northeastern Antelope Valley as indicating probable ground-water percolation toward the north in former times.2/ When the ground-water reservoir of Antelope Valley

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1/ Although the word discharge is sometimes restricted to mean flow in a liquid state, it is used here to include water loss in the vapor state as well.

2/ Thompson, D. G., The Mohave Desert Region . . . op. cit.

was still filled to near capacity levels, subsurface percolation may have been quite extensive. At present, with ground-water levels considerably lower than for many years, subsurface percolation from the area may be neglected.

Large areas of alkali soil indicate a past discharge of ground water by evaporation from ground surfaces in the central part of the Valley. When the ground water reservoir was saturated so that water rose to the surface by capillary action, it was free to evaporate. But evaporation involves only water, precipitating dissolved solids--alkali and nonalkali salts--out of solution at or near the ground surface. During periods when natural discharge approximately balanced recharge, as much as 29,000 to 170,000 acre-feet of water may have been lost by evaporation from the soil surface of the alkali area in any single year.[3/] This discharge could not continue each year (unless average recharge figures closely approximated the value) because natural discharge could not continually exceed recharge. Thompson, in 1919, described former loss of ground water from the area by this means as being "substantial," but gave no quantitative estimates.[4/]

Investigations by Lee and others indicate that discharge of ground water by direct evaporation is not a factor when water levels are below 10-12 feet.[5/] Since ground-water levels have been reduced well below this depth in all parts of the Valley, there is probably no discharge of

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3/ Lee determined average annual evaporation to be about ten inches from soil with water levels seven feet below ground surface. The estimates were based on experimental work carried out in Owens Valley, California, which has a climate similar to that of Antelope Valley. If the water table is assumed to have averaged seven feet beneath the ground surface, annual discharge by evaporation from this approximately 150 square-mile area could have been about 80,000 acre-feet in a year. If the water table is assumed to have been five feet below the ground surface, an average annual evaporation of about 170,000 acre-feet per year would be possible. Lee, C. H., An Intensive Study of the Water Resources of a Part of Owens Valley, California. U. S. Dept. of Interior, Geological Survey. Washington, Govt. Print. Off. 1912. 135 pp. (Water Supply Paper 294) and Lee, C. H. "The Determination of the Safe Yield of Underground Reservoirs of the Closed-Basin Type." ASCE Transactions, vol. 78, 1915. pp. 148-218.

Similar determinations by Veihmeyer at Davis, Sacramento Valley, Calif., set lower discharge rates and would indicate evaporation of 28,900 acre-feet from a 150 square mile area for a saturation level 4.8 feet below the ground surface. Veihmeyer, F. J., "Evaporation from Soils and Transpiration." Trans., Amer. Geophys. Un. Vol. 19, 1918. p. 616.

4/ Thompson, D. G., The Mohave Desert Region . . . op. cit. p. 324.

5/ Lee, C. H., op. cit. Mclaughlin, W. W., "Capillary Movement of Soil Moisture." U. S. Dept. of Agriculture Bul. 835, 1920. Shaw, C. F. and A. Smith, "Maximum Height of Capillary Rise, Starting with Soil at Capillary Saturation." Hilgardia, Vol. 2, Univ. of Calif., 1927, pp. 399-409.

ground water from this source. In a few small sections, there has been a development of water tables sufficiently close to the surface to create minor problems of drainage and salt and alkali accumulation (pp.

In Antelope Valley, discharge of ground water from free water surfaces is not important--and never has been, so far as can be determined. The meager information available concerning discharge from springs in the Valley indicates that such discharge to the atmosphere is not a significant part of total discharge--at least, not since agricultural development.[6/] Because heavy pumping has significantly reduced ground-water levels and artesian pressures in most of the Valley it is reasonable to assume that natural discharge from soil and water surfaces is insignificant at present.

Discharge of ground water by transpiration or by guttation takes place only when plant roots reach ground water or the capillary fringe above it.[7/] Even the roots of desert plants do not ordinarily penetrate to depths of more than 10 feet. Thus, discharge of ground water by plants can take place only where ground-water levels are no deeper than 15-25 feet below the ground surface (cf. footnote 2, supra). Of Antelope Valley land that is irrigated or suitable for irrigation, less than 3,500 acres are underlain by ground water close enough to the surface to be discharged directly by plants.[8/] It is therefore assumed that no significant amount of ground water can be directly lost by transpiration or guttation. In any case, guttation is substantial only in areas of high humidity, and would therefore be negligible in the Valley.

Before development of intensive irrigated agriculture in Antelope Valley, natural discharge of ground water may have exceeded 100,000 acre-feet in a given year. Now, direct evaporation or transpiration can take place in only a few small areas. Natural discharge of ground water has been suppressed by lowered ground-water levels and pressure surfaces over the entire Valley, and is assumed to be negligible.

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6/ Snyder, op. cit. pp. 132-136.

7/ Water discharged by transpiration escapes as vapor while that lost by guttation is in liquid form. The water is discharged primarily by plant leaves, from the epidermis, through the stomata.

8/ Measurements made by the Division of Water Resources in 1946 indicate that of land irrigated or prepared for irrigation in the immediate future, 3,500 acres had depth to ground water of less than 50 feet; 19,000 acres had depth of 50-100 feet; 29,000 acres had depth greater than 100 feet. This land is on the floor of the Valley proper and does not include the upper portions of the piedmont slope. State Department of Public Works. Division of Water Resources. Report to the Assembly . . . op. cit. p. 19.

Ground-Water Draft--Utilization by Man

Early settlers in Antelope Valley knew little or nothing about developing arid lands; later settlers recognized the limitations imposed on the area by nature or soon learned. Physical and economic forces brought about growth of irrigated agriculture and led to intensive water and land use. Draft on the ground-water stock currently exceeds the removal from storage of the early waste, draft, and natural discharge combined.

Nonagricultural Use of Ground Water

Only minor volumes of surface water are supplied to nonagricultural users by the Little Rock Creek and Palmdale irrigation districts. Other organizations and individuals are entirely dependent upon ground water to supply nonagricultural needs. It is assumed that the entire amount of water estimated to be consumed for nonagricultural uses is removed from ground-water storage.

Gross urban water use during 1945-1951 has been compared for Lancaster and Pasadena.[9] In Lancaster, gross per-capita water-use (residential, commercial, and industrial) for an average population density of 2.61 persons per acre ranged from 129 to 145 gallons per day. In Pasadena, gross per-capita consumption for an average population density of 7.60 persons per acre ranged from 132 to 161 gallons per day for all uses combined. This is equivalent to 0.17 to 0.50 acre-feet per acre per year for Lancaster, and from 1.00 to 1.42 acre-feet per acre per year for Pasadena. The lower values for Lancaster are due to a lower population density.

Consumptive or net use of irrigation water for agricultural purposes in the Lancaster area varied from one to three acre-feet per acre per year, and gross use from two to eight acre-feet per acre per year, depending upon the crops grown (see Appendix Table 6). Areas devoted to such crops as alfalfa and irrigated pasture use more water than urban areas. Such low water-using crops as irrigated grains consume water in the same order of magnitude as do urban areas. Extensive (as opposed to intensive) agriculture,

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9/ Sources: Pasadena Water Department. Annual Reports. Pasadena. (Annual Series) Report Nos. 12, 17, 22, 27, and 32-38 inclusive.
W. J. Fox, County Engineer, County of Los Angeles. Personal communication.

such as dry-farmed grains, uses less water than urban areas. The foregoing illustrates the tendency for nonagricultural purposes to use less water than does intensive agricultural development.

Within Antelope Valley, there has been no attempt to separate domestic, commercial, or light industrial consumption of water. Present (1951-52) gross consumption of water for residential-commercial use for the entire Antelope Valley is estimated to be about 2,843 acre-feet per year and consumptive use or net use about half this value.10/

Division of Water Resource estimates of consumptive use requirement of mixed residential-commercial-industrial areas in the South Coastal Basin range from 1.0 to 1.8 acre-feet per acre per year.11/ This range is of the same order of magnitude as the estimated gross use for Pasadena. It is expected that gross use would be nearly double consumptive use. Considerable error is introduced in this comparison by including rainfall in the consumptive use estimates. Additional error may arise from an inability to estimate population density accurately within the area served by the Pasadena Water Department. In any event, the data demonstrate the smallness of water requirements for an urban area compared to those of intensively cultivated agricultural areas.

During World War II the United States Army Air Force and certain private aircraft manufacturers developed training and testing facilities in the Valley. Estimates of water consumption of these military-light industrial installations have been supplied by the Air Force and the U. S. Army Corps of Engineers. It is estimated that the annual water consumption of these installations is presently (1951-52) about 785 acre-feet per year.

The Edwards Field installation is located on nonagricultural land in the northeastern part of the Valley. Palmdale Airport, on the other hand, is located on 4,870 acres of land that has been mapped as excellent-to-fair

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10/ Sewage effluent constitutes the major portion of the difference between gross and net use. Consumptive use is assumed to be 50 per cent of gross use. For the military-industrial sector, 80 per cent is assumed because of the large amount of evaporation resulting from washing airplanes, hangar aprons, etc. State Department of Public Works. Division of Water Resources. "South Coastal Basin Investigations," op. cit.

11/ Ibid. Detailed estimates of average annual consumptive use for various cultural classifications in the western unit of the Raymond Basin (includes Pasadena) are given in this bulletin. Table 27, p. 100.

agricultural land. This permits some direct area comparisons of water use for agricultural and nonagricultural purposes. Estimated 1951-52 water consumption at Palmdale Airport was approximately 400 acre-feet per year. According to a survey by the Los Angeles Regional Planning Commission in October, 1951, approximately 1,500 acres of land, within what are now the boundaries of the airport, were devoted to agriculture, primarily alfalfa. Consumptive use of this acreage in alfalfa was about 4,530 acre-feet of water. Had the entire acreage been devoted to alfalfa culture, the estimate would exceed 14,000 acre-feet per year. This demonstrates a tendency for nonagricultural use of water to be less than agricultural use.[12/]

Nonagricultural use of water in the Valley has been unimportant relative to agricultural use (see Appendix Table 8), ranging from a low of 0.93 per cent of estimated total consumptive use, in 1929, to a high of 2.35 per cent, in 1951. Future nonagricultural water use is dependent upon urbanization, growth of military and light industrial installations, and supporting commercial development. Estimates of population by the end of 1960 range from 60,000 to 75,000. Present plans of the United States Air Force call for an expansion to about double 1951-52 facilities by the end of 1954. Expansion, or even possible contraction, of military-light industrial installations after that date has not been determined. Estimates indicate that the relative importance of nonagricultural water use may be expected to increase. Nonagricultural water use is estimated to account for about 4 per cent of estimated total consumptive use in 1955 and 5 per cent in 1960, (see Appendix Table 8). If population increases more rapidly, if the military-light industrial installations are enlarged, or if agricultural development does not continue its present rate of expansion, the relative importance of nonagricultural water use will increase correspondingly. The converse also holds true.

Competition Between Agricultural and Nonagricultural Land Use

Recent surveys by the Soil Conservation Service indicate that there are approximately 650,000 acres of irrigable land in Antelope Valley.[13/]

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12/ This tendency was also demonstrated by Thomas, who showed that transfer of a portion of a watershed area from agriculture to heavy industry created more available water for agricultural use than existed previously. Thomas, H. F., The Conservation of Ground Water. op. cit., pp. 80-82.

13/ Estimate based on maps contained in: Wohletz, L. R., and E. F. Dolder, Know California's Land. State Department of Natural Resources and U. S. Department of Agriculture, Soil Conservation Service. Sacramento, Calif. State Print. Off. 1952. 43pp.

The Division of Water Resources estimates 606,000 acres for ultimate irrigation acreage in the same area.[14] At the present time, less than 100,000 acres in Antelope Valley are under cultivation in any one year and less than 60,000 receive irrigation water. It is apparent that there is land for expansion of both nonagricultural and agricultural uses for many years to come. The question, however, is whether agricultural use of land can continue to expand in competition with nonagricultural expansion.

As will be brought out in a later chapter (see pp. 98-99), the 1951-52 cost of water to agriculture was about $4.00-$6.00 per acre-foot. It is possible that agriculture may be able to pay two or three times this amount for water. On the other hand, urban users of water are currently paying $66.00 an acre-foot for water in Los Angeles (see p. 52). Clearly, non-agricultural users can afford to pay much more for water than agricultural. In areas suffering from water shortages, certain institutional and political factors have tended to favor importing water from surplus areas. Large concentrations of urban developments with need for water, ability to pay for it, and available capital and engineering skill have prompted the construction of the Owens Valley and Colorado River aqueducts. If population expansion continues in southern California to such an extent that Antelope Valley becomes primarily an urban area and not an agricultural area, it may no longer be possible for agricultural land use, which is dependent upon relatively inexpensive water for irrigation, to expand. It is possible that, as in much of southern California, agricultural land use in Antelope Valley may contract and eventually disappear, but this last is only a remote probability. Agricultural land and water use will continue their relative importance in Antelope Valley.

Agricultural Ground-Water Use

The relative unimportance of flowing ground water in Antelope Valley agriculture has been established (see p. 15). Wells drilled at the edge of the area of original flowing ground water (see Figure 3.1) began to be developed in large numbers shortly before 1920. Data presented in Table 2.1 indicate a steady growth in the number of electrically pumped

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14/ State Department of Public Works. Division of Water Resources. "Water Utilization and Requirements, Antelope Valley Basin." Bryte, Calif. June, 1951. (Manuscript by T. C. Mackey--preliminary information, subject to revision.)

wells since that time. Only during the depressed years of the early thirties did the number of electrically pumped wells decline.

Coincident with this growth in pumping was a relatively steady increase in pumping lift or distance to ground water. Thompson's investigations revealed a significant decrease before 1919 in pressure and flow of flowing wells, but no significant decline in ground water levels of nonflowing wells. Between 1919 and 1927, "moderate" declines were observed in some wells.[15/] These declines were small, but sufficient to generate interest in their significance. Data began to be accumulated that permit various estimates of the removal of ground water from storage.

Measurement of Ground-Water Draft

Three general methods may be used to estimate ground-water draft: (1) as a function of electrical power consumed, (2) as a function of consumptive use and acreage irrigated, and (3) as a function of changes in ground-water storage as developed from changes in water levels. Ground-water draft is the removal of ground water from storage by man for his use. Dissatisfaction with existing estimates has prompted the use of available techniques to make additional estimates of ground-water draft

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15/ Thompson, D. G., The Mohave Desert Region, California. op. cit., pp. 333-335 and 364-371.

in the Valley, based on these three methods.[16/] Estimates of nonagricultural use of water (discussed above) are included in the final estimates given in the tables and chart that follow. Available estimates lack comparability over time, and are too few to permit examination of the year-to-year impact

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16/ Published Estimates of Ground-Water Utilization in Antelope Valley:

Year	Area irrigated	Water applied or delivered	Consumptive use
	acres	acre-feet	
1919 a/	8,710	31,000	
1924 a/	14,180	66,700	
1939 b/	30,982	176,433	
1945 c/	42,000 f/		106,000 h/
1947 c/	50,000 f/		125,000 h/
1949 d/	53,147	g/	
1951 e/	70,900 f/		198,000 h/

a/ Thompson, D. G., The Mohave Desert Region, California. op. cit. 1929.

b/ U. S. Bureau of the Census. Irrigation of Agricultural Lands. Sixteenth Census of the United States: 1940.

c/ State Department of Public Works. Division of Water Resources. Report to the Assembly . . . op. cit. 1947.

d/ U. S. Bureau of the Census. U. S. Census of Agriculture: 1950. Vol. III, Irrigation of Agricultural Lands, Part 3, California. 1952.

e/ State Department of Public Works. Division of Water Resources. "Water Utilization and Requirements, Antelope Valley Basin." op. cit. 1951.

f/ These acreage estimates are considerably greater than those given in Table 2.2. See also pp.

g/ No estimates made of water use in Antelope Valley by Census in 1949.

h/ To cover surface diversions, a 3,000 acre-feet allowance has been deducted from original estimates. See Table 4.4, footnote a/.

of man's utilization on the character of the ground-water resource.[17/]

Electrical Power Consumption and Draft

Electrically powered pumping plants in Antelope Valley have ranged from an estimated low, in 1920, of 80 per cent to the 1951 level of 99 per cent of all pumping plants (Table 2.1). Because of their relative importance and the difficulty of estimating volume of draft by nonelectric pumping plants, this estimate is based entirely on electrically powered pumping plants.

Southern California Edison Company supplies electrical power to the Antelope Valley and files annual reports with the California Public Utilities Commission covering its operational activities. Since 1924, these reports detail total annual sales of electrical power for agricultural pumping in the Lancaster District. The Lancaster District is approximately equal in size to the Antelope Valley drainage basin. These annual power sales, assumed to represent consumption of electrical power for pumping ground water in Antelope Valley, are presented in Appendix Table 7, together with other information necessary to transform the power consumption figures to draft on ground water. Figure 4.1 gives a graphic presentation of estimated annual draft on ground water for the period 1924-1951, inclusive.

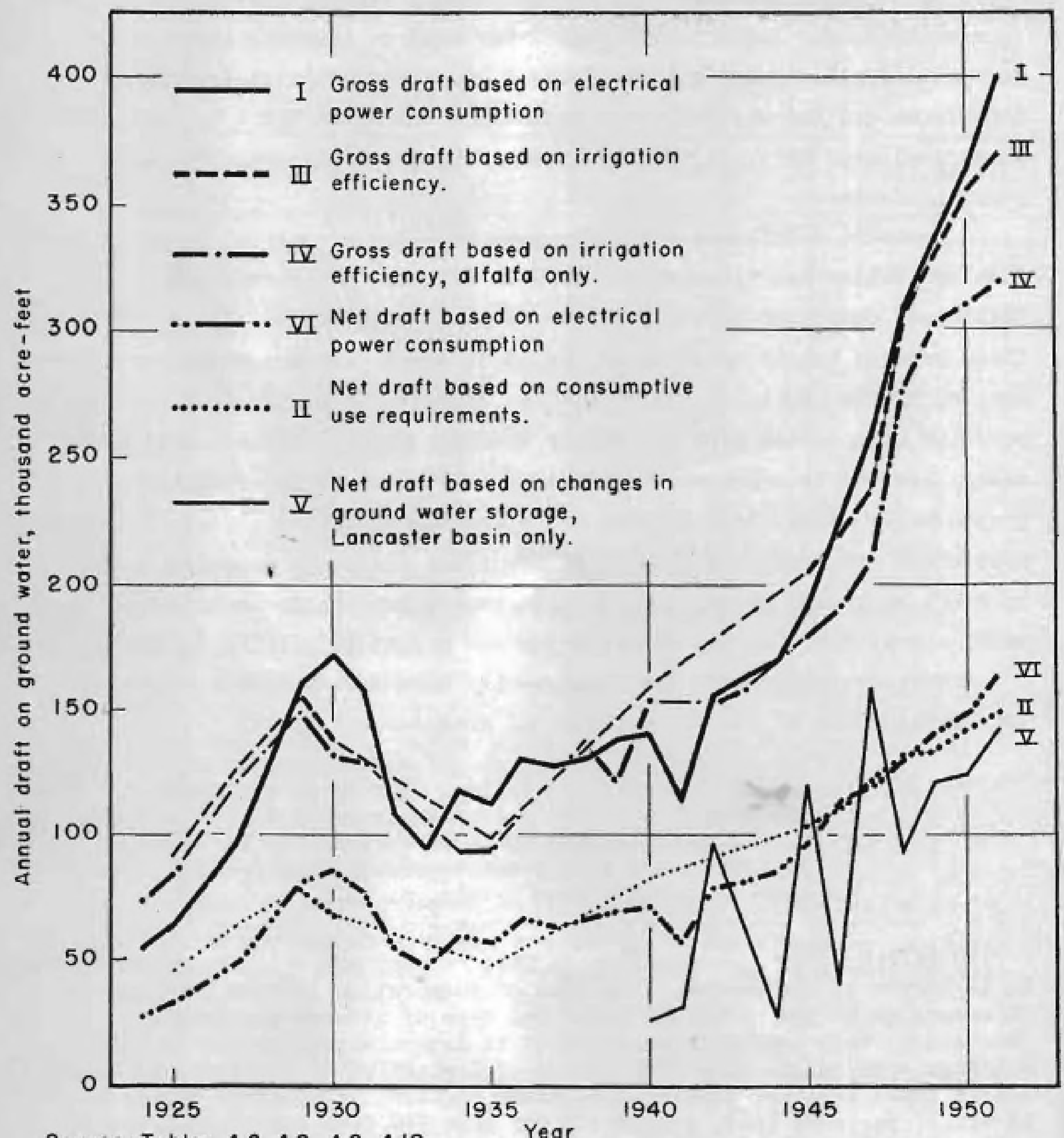
Certain assumptions have necessarily been made rather arbitrarily in this development of annual estimates of ground-water draft:

(1) Estimated depth to static ground water level is representative for the entire Antelope Valley. Estimates are based on fragmentary water level measurements prior to 1940. Since 1940, they are believed to be as accurate as any average figure can be for such a heterogeneous measurement. (See Declines in Ground-Water Levels, p. 74.)

17/ Particularly disappointing in this respect are data presented by the U. S. Bureau of the Census. The area of enumeration changes from census to census as do the questions asked and type of information presented. Frequently, very poor samples are used to determine values for an entire drainage area, e.g.: The 1950 Census of Irrigation of Agricultural Lands states total cost per acre-foot of water to farms in Antelope Valley in 1949 as $16.27 per acre foot, supposedly for some 568 farm enterprises reported in the Valley. This is obtained, however, by dividing per-acre irrigation cost of 568 farms by average quantity of water applied per acre on 6 farms, 4 of which received their water from surface sources and not from ground water. These farms receiving their water from surface sources applied an average of 1.5 acre-feet, which is less than one-fourth the amount typically applied on alfalfa farms (more than 400 of the 568 farms raise alfalfa).

Figure 4.1

GROUND-WATER DRAFT
ANTELOPE VALLEY 1924 - 1951[a]



Source: Tables 4.6, 4.8, 4.9, 4.10
Snyder, J. Herbert, op. cit.

a/ Includes nonagricultural water use.

(2) An increment must be added to depth to static ground water to allow for drawdown, friction losses, and height of delivery above ground surface. Three different values split the series into approximately equal thirds. Estimates are based on fragmentary pump-test measurements made in 1940 for the Los Angeles Farm Advisor's Office 18/ and "recollections" of farmers and well drillers who reside in the area. Changes are necessitated by the falling water table and installation of pumps with greater capacity and hence greater pull (drawdown) on the ground water.

(3) Estimates of average over-all efficiency show a gradual increase from 1924-1951. Those for 1924-1929 are consistent with estimates made by Bryan and Hunt in making similar determinations for the Santa Clara Valley, Santa Clara County, California. 19/ The estimate for 1940 is consistent with pump test findings cited earlier. Estimates for 1950-51 are believed to be typical for Antelope Valley. 20/ In order to eliminate sharp changes in draft estimates, changes in efficiency over time are assumed to be gradual and continuous.

(4) Estimated kilowatt hours necessary to pump one acre-foot of water are based on the formula:

$$KWH = 1.024 \frac{H}{E}$$

where 1.024 represents a constant, H total pumping lift in feet, and E over-all efficiency of the pumping plant expressed decimally. 21/

(5) Annual power sales are assumed to be uniformly distributed throughout those portions of Antelope Valley in which pumping of ground water for agricultural purposes occurs.

Examination of the results obtained, as presented in Figure 4.1 (curve I) and Appendix Table 7, reveals several facts. First, the general shape of the curve reflects the acreage of irrigated crops--particularly alfalfa--in Antelope Valley, as given in Table 2.2, and the price received by Antelope

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18/ "Report of the Second Antelope Valley Agricultural Program Building Conference," Lancaster, California. 1941. 19 pp. Mimeographed.

19/ State Department of Public Works, Division of Water Resources, "Santa Clara Investigation, 1933," Sacramento, Calif. State Print. Off. 1933. 271 pp. (Bul. 42). This publication assumes an over-all efficiency of 50 per cent.
Hunt, G. W., "Description and Results of the Operation of the Santa Clara Valley Water Conservation Districts' Project." Trans. Am. Geophys. Un. 1940, pp. 13-23. This publication assumes an over-all efficiency of 40 per cent.

20/ Communications from Southern California Edison Company and statements of pump dealers in Antelope Valley.

21/ Brown, J. B., "Pumping Problems." Agricultural Extension Service, College of Agriculture, Davis, California. 10 pp. Mimeographed. (Revised 1951 by L. J. Booher.)

Valley growers for their product. During 1930, the price received for alfalfa hay tumbled from an average of $20-25 per ton f.o.b. to an average of $10-19. The price received for alfalfa hay remained fairly stable within this lower range until 1940-41, when increasing prices brought forth a rapid increase in hay acreage that lasted until 1949, when price changes once again caused a leveling off in acreage. Three sharp departures from the general trend are noticed, however--in 1935, 1941, and the period 1948-1951--which points to a second fact:

Although there is correlation between crop acreage (itself greatly influenced by the prices received) and draft, draft is also influenced by marked departures from normal rainfall. In 1935, and even more in 1941, rainfall in the spring months permitted postponement of pumping for 3-8 weeks, depending on location, soil type, and the year.[22] This is reflected by sharp declines in 1935 and 1941 from a line that would smoothly connect the drafts in the years prior and subsequent. The reverse tendency is observed during the period of 1948-1951, a four-year period of extremely low rainfall. During this period, draft on ground water was considerably greater than that anticipated on the basis of irrigated crop acreage alone. Estimates of annual draft only can be developed for Antelope Valley at present, although power records usually permit estimates of monthly draft. Such estimates would show more clearly the relations between climate and draft. The typical pumping season in Antelope Valley begins during the first two weeks in April and ends about the last week in September, influenced of course by year-to-year variations in rainfall and temperature.

Estimates of ground-water draft based on electrical power consumption are not without problems. First, such estimates can be only as reliable as the underlying assumptions--which may be in error, though they are as accurate a description of Antelope Valley conditions as possible. For example, if the assumption of the 1951 over-all pumping plant efficiency is merely lowered from 58.5 to 53.5 per cent, the resulting estimated draft is decreased by as much as 30,600 acre-feet. Or if total lift assumption is increased only 5 per cent (from 197 to 206 feet), estimated draft is lowered by 17,600 acre-feet.

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22/ Farms located nearest the foothills in the south and west of the Valley and those with medium-textured soil types would receive the greatest postponement, other things being equal. Similarly, postponement in 1941 would have been greater than that in 1935.

A second difficulty arises from different electrical power-rate schedules for agricultural pumping. Since 1937, power records show a decline in power use by pumping installations of under 100 h.p. rating in comparison to those with ratings greater than 100 h.p. Of all agricultural pumping power sold in Lancaster District in 1937, 97 per cent was sold to installations of less than 100 h.p. This declined to 56 per cent by 1951. Larger installations are required as pumping lifts increase (see Chapter 6) and as shifts in farm organization require greater volumes of water per unit of time. Use of larger pump installations tends to increase the kilowatt-hours necessary to pump an acre-foot of water, which in turn tends to decrease draft estimates, other things being equal. On the other hand, newer installations employ more modern equipment, representing technological advances, which increases over-all efficiency of the pumping plant, thus increasing estimated draft. Specific quantitative effect of these opposing factors on the total ground-water draft in Antelope Valley cannot be determined at present, but since they tend to offset one another the estimates presented are assumed to be accurate. Further influence of differential power rate schedules will be examined in the economics chapters (Chapters 6 and 7).

A third difficulty concerns the failure to measure water permanently removed from ground-water storage. These draft estimates represent total volume of water pumped from storage each year but do not indicate how much water percolates back to ground water (i.e., in excess of consumptive use, see p. 68). Because of complex stratification of water-bearing and impermeable strata, the depth to which return recharge can percolate varies with location. In the Roosevelt area, for example, water removed beneath the 300-600 foot levels probably never returns to aquifers from which removed, because of thick layers of heavy blue clay at these depths. The excess water will be available to pumps that remove water from aquifers above the blue clay layers.

Thus, estimates of annual draft on ground water based on electrical power consumption can only indicate the total volume of ground water pumped each year, or as it will be called herein, gross draft. These estimates are comparable over time and reflect the general development of irrigated agriculture in Antelope Valley. Because the figures do not represent permanent removal from storage--net draft on ground water--it is necessary to examine other possible means of estimating this volume of water.[23] Accurate overdraft determination requires reliable net draft estimates. Three forms of such an estimate for Antelope Valley may be based on (1) gross draft less return flow, (2) consumptive use requirements, and (3) changes in volume of ground water in storage. The first of these, based on electrical power consumption, is considered next.

Net Draft and Electrical Power Consumption

The advantages of draft estimates based on electrical power consumption have been discussed above. The major weakness was that net draft was not measured. If satisfactory data on return flow exist, net draft estimates based on electrical power consumption can be made. Estimates of return flow expressed as a per cent of applied water (assumed to be equal to total draft per acre) are presented in Table 4.1. The data are based on enterprise cost and management studies of the Agricultural Extension Service for alfalfa and sugar beets for the years indicated, and consumptive use estimates are from Appendix Table 6.[24] Waste estimates are set arbitrarily at 10 per cent of the difference between water applied and consumptive use.[25] The following assumptions, based on Table 4.1, are made concerning return flow and waste in Antelope Valley:

(1) For 1924-1946: a return flow of 45 per cent of gross draft for all crops, waste of 5 per cent.

(2) For 1947: a return flow of 47.1 per cent of gross draft (a weighted average based on acreage in alfalfa and irrigated pasture as opposed to all other crops); waste of 6 per cent.

(3) For 1948: a return flow of 50.3 per cent of gross draft (a weighted average); waste of 6 per cent.

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23/ The tern "net draft" on ground water is used to describe that portion of gross draft that is used by the plants directly or evaporated from the ground surface. It does not percolate back through the soil to become available for reuse at a later time and is thus differentiated from the gross draft estimates yielded by electrical power consumption data.

24/ Consumptive use, cf. footnotes 27 and 28 infra.

25/ Because most of the farm irrigation systems are buried concrete pipes, there is little or no loss in the farm irrigation system. Some evaporation takes place from on-the-farm storage reservoirs, and this is the "waste" item above. The balance of the water pumped is allocated between consumptive use and return flow.

(4) For 1949: a return flow of 52.0 per cent of gross draft (a weighted average); waste of 6 per cent.

(5) For 1950 and 1951: a return flow of 53.2 per cent of gross draft (a weighted average based on 1950 water use data only); waste of 6 per cent.

TABLE 4.1

Return Flow as a Per Cent of Applied Water

Year	Crop	Acre-feet per year: Average annual application	Consumptive use supplied by irrigation	Waste	Return flow	Per cent of water applied: Consumptive use	Waste	Return flow
1931	Alfalfa	6.05	3.02	.30	2.73	49.9	5.0	45.1
1940[a]	Alfalfa	6.00	3.02	.30	2.68	50.3	5.0	44.7
1947	Alfalfa	6.70	3.02	.37	3.31	45.0	5.5	49.5
1947	Sugar beets	3.82	2.19	.16	1.47	57.3	4.2	38.5
1948	Alfalfa	7.30	3.02	.43	3.85	41.4	5.9	52.7
1948	Sugar beets	4.04	2.19	.19	1.66	54.1	4.7	41.2
1949	Alfalfa	7.77	3.02	.48	4.27	38.9	6.2	54.9
1950	Alfalfa	8.03	3.02	.50	4.51	37.6	6.2	56.2

a/ The 1940 Census of Irrigation reveals an average annual application of water to all crops of 5.8 acre-feet for Antelope Valley.

Sources: California Agricultural Extension Service and U. S. Department of Agriculture. 1947 and 1948 Sugar Beet Production, Cost and Management Study, Antelope Valley. Office of the Farm Advisor, Los Angeles, California. 1948. 7 pp. Mimeographed.

California Agricultural Extension Service and U. S. Department of Agriculture. Alfalfa Cost and Management Study, Antelope Valley, 1950. Office of Farm Advisor, Los Angeles, California. 1950 [and earlier issues]. Mimeographed. Variable paging.

On the basis of these assumptions and the estimates of gross draft (based on electrical power consumption) estimates of annual net draft have been calculated and are included in Appendix Table 7 and Figure 4.1.

The resulting estimates of net draft possess the advantages and limitations discussed earlier for gross draft based on electrical power consumption, but further weakened or strengthened by the reliability of the estimates of consumptive use, return flow, and waste. Because the Agricultural Extension Service endeavors to select representative farms for its enterprise cost and management studies, it is believed that the assumptions made concerning return flow and waste are not in serious error.

Consumptive Use and Net Draft

Two forms of data are necessary to estimate consumptive use: (1) irrigated crop acreage estimates and (2) consumptive use estimates for crops per unit area. Antelope Valley acreage estimates are based on Appendix Table 4, and obtained primarily from the Office of the Los Angeles County Agricultural Commissioner.[26/] Consumptive use by crops in Antelope Valley are presented in Appendix Table 6. These estimates are based primarily on experimental research carried out in San Fernando Valley by the Soil Conservation Service, and were transposed to Antelope Valley by means of climate and irrigation correlations between the two areas.[27/]

Estimates of consumptive use of water (net draft) for agricultural and nonagricultural sectors of Antelope Valley at various intervals during the period 1925-1951 are presented in Appendix Table 8 and shown graphically (curve II) in Figure 4.1. To arrive at consumptive use of ground water, an allowance is made for consumptive use from surface diversion by deducting 3,000 acre-feet per year from the total consumptive use estimates. This

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26/ Census data are available for Antelope Valley only in 1939, 1944, and 1949. The Agricultural Commissioner's estimates check within 5 per cent of the Census data and are thus considered to be reliable for the portions of Antelope Valley in Los Angeles County. Acreage estimates for the Kern County portion of the Valley have been obtained from the Kern County Commissioner's Office, the Los Angeles County Commissioner's Office, the Soil Conservation Service, the Antelope Valley Hay Grower's Association, and local appraisers. The acreage estimates prepared by the Division of Water Resources appear to be too high for the area.

27/ State Department of Public Works. Division of Water Resources. "Irrigation Requirements of California Crops." Sacramento, Calif. State Print. Off. 1945. p. 71. (Bul. 51.)

State Department of Public Works. Division of Water Resources. "Water Utilization and Requirements, Antelope Valley Basin." op. cit.

A few of the recent publications on the determination of consumptive use and water requirements in an area are:

Blaney, H. F., "Consumptive Use of Water." Proceedings, A. S. C. E., Vol. 77, Separate No. 91, October, 1951. 6 p.

Blaney, H. F. and W. D. Criddle. Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data. Washington, D. C., U. S. Dept. of Agriculture. Soil Conservation Service. August, 1950. 40 p. Processed.

Criddle, W. D., "Consumptive Use of Water on Irrigated Land." Proceedings A. S. C. E., Vol. 77, Separate No. 98, November, 1951. 10 p.

State Dept. of Public Works. Division of Water Resources. "Use of Water by Native Vegetation." Sacramento, Calif. State Print. Off. 1942. 160 p. (Bul. 50.)

State Dept. of Public Works. Division of Water Resources. "South Coastal Basin Investigation." Sacramento, Calif. State Print. Off. 1947. 256 p. (Bul. 53.)

allowance may be low for the period prior to 1930, but later declines in gravity-diverted irrigated acreage effect a self-cancellation.

The data reveal an increase in consumptive use from 1925 to 1929, a decrease from then until 1935, and an increase since that time. The qualitative relationship thus established is consistent with earlier findings. The quantitative aspects deserve further consideration as to significance and reliability.

Estimates of ground-water draft that are based on consumptive use have several advantages:

First, the estimates represent permanent removal of ground water from storage. It is assumed that water applied in excess of consumptive use requirements, although initially removed from storage, will ultimately return to some aquifer and will thus be available for reuse.[28/] Consumptive use estimates thus permit determination of net draft on ground water, as distinguished from gross draft.

Second, consumptive use estimates may be derived from acreage surveys. They are not dependent upon particular boundaries--such as the Lancaster District--from which electrical power consumption data can be obtained to calculate ground-water draft. Estimates can be developed for an individual farm, county, drainage basin, state, or group of states, so long as acreage estimates are available.

Third, consumptive-use data for crops on a unit-area basis are available for most agricultural regions. Where actual data are not available, they can be estimated from climatological data.[29/]

On the other hand, certain drawbacks to this method of determining net draft must be recognized:

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28/ Most of the poultry farms and the residential areas outside of Lancaster, Palmdale, Little Rock, Quartz Hill, and Rosamond are dependent upon shallow (typically, not over 100 feet in depth) wells for their water supply. Much of this water comes from return recharge resulting from over-irrigation. The magnitude of this over-irrigation has been large enough for the quality of water in these aquifers to remain good.

29/ Consumptive use may be calculated from the formula U = KF. U is the consumptive use, K is an empirical consumptive use coefficient for the particular crop, and F is the sum of monthly consumptive use factors for the growing period (based on monthly temperature and per cent of day time hours). See: Blaney, H. F. and W. D. Criddle. Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data. Washington, D. C., U. S. Department of Agriculture, Soil Conservation Service. August, 1950. p. 15.

First, the estimates can be no more accurate than the basic acreage estimates. For example, the Division of Water Resources' estimate of consumptive use in Antelope Valley for 1951 (footnote 16, supra) is about 25 per cent, or 49,000 acre-feet, greater than the estimate given in Appendix Table 8. This is slightly above estimated long-time average annual recharge to the Valley of 40,000 acre-feet and arises from the differences in the acreage estimates used.

Second, unless a satisfactory historical series of acreage data is available, annual variations in draft cannot be demonstrated satisfactorily. Annual draft observations are necessary if one is to establish a relationship between ground-water draft and such factors as climate and the prices received for the agricultural commodities. Although available acreage data yield a relatively satisfactory series of annual observation in the Valley, previous estimates based on consumptive use do not reflect annual variation in either climate or price relationships. Consumptive use estimates are based on water use requirements of crops for a typical or long-run average year. During years with higher temperatures and longer growing (irrigation) seasons than average, consumptive use requirements of crops will be above average.[30/] The reverse also holds true. During a series of dry years when acreage in crops is expanding, as in Antelope Valley during 1947-1951, consumptive use estimates of net draft are probably less than actually experienced. But the reverse also holds true, and errors will tend to be self-compensating under conditions of relative long-run stability in crop acreage and type of crop.

Whether one uses consumptive-use net-draft estimates or estimates based on electrical power consumption will depend on the availability of data and the purpose for which an estimate is desired. For Antelope Valley, estimates of net draft that are based on electrical power consumption appear to be more useful and more reliable than consumptive-use estimates.[31/]

Consumptive Use and Gross Draft

Estimates of gross draft can also be based on consumptive use data and irrigation efficiency data. A series of such estimates, depicted graphically in Figure 4.1 (curve III), has been developed--for purposes of comparison only, for net draft, not gross, is the important variable in evaluating overdraft.

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30/ Ibid. p. 15

31/ Reliable in the sense that measurement of more variables is possible for this method of estimating draft.

The acreage estimates, irrigation efficiency assumptions, and estimates of gross water use for nonagricultural purposes are the same as used earlier.

The series reveals a general agreement with estimates of gross draft that are based on electrical power consumption. Enough observations are not available for the period 1925-1944 to demonstrate whether peaks and troughs coincide as well as do the general shapes and positions of the two series. Exact conformity is not anticipated, because this method does not reflect climatic or price influences on the use of water as does that based on electrical power consumption.

This method of estimating gross draft on ground water depends upon reliable estimates of crop acreages and irrigation applications to crops or consumptive use and irrigation efficiency data. To be useful, the method requires year-to-year observations on the basic data. Only a few observations over time may provide a check of this method against other methods of estimation. It is subject to the defect common to gross draft estimates: It does not indicate the volume of water permanently removed from ground water storage.

A decrease in irrigation efficiencies for alfalfa during 1948-1951 has been largely responsible for keeping this estimate of gross draft in close agreement with that based on electrical power consumption. During this period, Antelope Valley climate was characterized by longer growing seasons, higher temperatures, and lower rainfall than normal. These conditions led to more liberal applications of irrigation water to crops, despite the fact that at any one time the soil, within the zone of root development, can absorb and hold for use by plants only a limited amount of water.[32] It is also interesting to note that although amount applied increased, the number of irrigation applications remained stable in comparison with 1931, a year climatically similar to the period 1947-1950.

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32/ Antelope Valley Alfalfa Cost and Management Studies reveal the following information (averages for the farms studied):

Year	Number of farms studied	Number of irrigation applications during the year	Depth applied, inches each irrigation	Total acre-feet applied during the year per acre
1931	14	13.0	4.6	6.05
1947	8	15.5	4.9	6.70
1948	6	16.3	5.7	7.30
1949	7	15.1	6.1	7.77
1950	7	15.3	6.4	8.03

The importance of alfalfa to the Antelope Valley ground-water economy may be demonstrated by estimating gross draft from alfalfa use alone. Curve IV in Figure 4.1 shows gross draft by alfalfa in the Valley. This curve is only slightly below the gross draft curve for all uses for the period 1924-1940. During the period 1940-1945, the importance of alfalfa decreased relative to total use because of the introduction of irrigated pastures in the area. More complete acreage data for alfalfa permitted the construction of a more complete curve than had been possible for the total gross draft curve. This demonstrates the possibility of constructing a reliable curve for gross draft on ground water from acreage of a single crop if use of water in the area is determined primarily by acreage devoted to one crop.

Declines in Ground-Water Levels

Increased draft on the stock resource has brought about declines in ground-water levels observed in Antelope Valley. (A large decrease in artesian pressure and the gradual disappearance of flowing artesian wells from Antelope Valley have already been mentioned.) The area of one-time artesian flow is (1951 datum) approximately bounded by the line representing an average depth to ground water of 100 feet (see Figure 3.1).

Average ground-water level declines in Antelope Valley have been estimated annually by the Geological Survey since 1938. Because of great variability found in alluvial deposits inthe Valley, such calculations cannot represent the average change in levels of ground water for the area, or even for the main ground water basin. There is no average depth to static water level that is typical for an area of significant extent. The range of measurements in the Valley over the last 10 years varies from 0 to 300 feet from ground surface to water level. Deposition of alluvial sediments on an already well-defined drainage system implies that aquifers so formed will not be closely interconnected or possess any great degree of uniformity. Measurements taken in the fall season of each year indicate an over-all average decline for the period extending from 1937-38 to 1950-51 of nearly 3½ feet per year.[33] During the first half of this period the

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Water Year:	1937-38	1938-39	1939-40	1940-41	1941-42	1942-43	1943-44
Decline (feet)	1.5	5.5	2.0	1.5	4.0	2.8	1.2
	1944-45	1945-46	1946-47	1947-48	1948-49	1949-50	
	4.9	1.5	4.3	4.2	3.1	5.1	

U. S. Dept. of Interior, Geological Survey. Water Levels and Artesian Pressures in Observation Wells in the United States in 1950. Part 6. Southwestern States and Territory of Hawaii. Washington, Govt. Print. Off., 1953. 279p. (Water Supply Paper 1170) and earlier issues.

average amount of decline was exceeded only twice, while during the second half five out of seven seasons registered declines exceeding the over-all average.

In spite of data weaknesses, two facts are evident: First, there has been a continuing drop in ground-water levels, indicating (though not proving) a removal from ground-water storage of water that is not being replaced. Second, the rate of decline appears to be increasing during recent years.

Two forces have combined to cause this increase in rate of decline: First, the cyclical or periodic variation in recharge to ground water was at a low level during these years, and this drought period brought about increased draft on ground water as well as decreased recharge. Second, a rapid and steady increase in acreage devoted to crops that consume large amounts of water has characterized the Valley's agriculture thereby increasing draft.

The increase in rate of decline may have been influenced more directly by the period of drought than by any other factor. A sufficient lapse of additional time may establish another period of wet years and perhaps a relatively stable crop acreage pattern, permitting the influence of climate on ground-water draft to be more precisely evaluated.

A discussion of declining water levels cannot omit mention of the problem created by artesian pressures in the measurement of decline, which is even more important than the influence they have on determining the extent of the ground-water reservoir, discussed earlier.

It has been previously suggested that the removal of a relatively small amount of ground water from the artesian aquifers may create a marked decline in artesian flow and pressure (see p. 24). Continued pumping from artesian aquifers could cause large drops in the ground-water level if the aquifers were small in size or if a discontinuity in hydraulic pressure existed between the area of recharge and the point of pumping, or both. Because most wells in Antelope Valley are subject to artesian pressure, it must be realized that some portion of the drop in ground-water levels is accounted for by pressure changes. This means that, for a given decline in depth to ground water, only a part of the drop is actually accounted for by removal from storage, with the remainder due to pressure decline. There is thus a bias toward overestimating draft if it is based on declining ground-water levels in an area subject to artesian pressures.[34/] If artesian and nonartesian aquifers can be separated the difficuly is overcome by using coefficients of storage (p. 24) instead of specific yield values. But the intermingling of aquifers in the Valley prevents such a procedure.

A second bias develops from standard and unavoidable--but distorting--assumptions concerning topography of ground-water basins. An assumption of average ground-water level declines is based on a further assumption that the topography of the basin is essentially level. Yet the land form underlying the recent alluvium of Antelope Valley is one of a well-advanced drainage system with hills, valleys, and water courses.[35/] It is of course possible that this underground topography may be random enough to establish a real average level nearly corresponding to the assumed level. This possibility seems to be invalidated by the concentration of wells in the central portion of Antelope Valley: The underground topography of a small area is less likely to be randomly distributed. The degree--and even the direction--of the bias introduced by this condition is not yet known. Its determination awaits future drilling of wells and test holes extending to the bottom of the basin.

A third bias develops from the widespread variation in specific yield values of various sediments. Specific yield values are known to vary widely for a particular well. Not only are there variations within an aquifer, but even greater variations exist between the several aquifers penetrated. Variability in the nonwater-bearing sediments further complicates the problem. In addition, considerable differences between specific yield values are typical for wells drilled within a short distance of each other.

Specific yield variations of a more general nature also complicate the picture. It is likely that coarseness of the Valley alluvium will increase as one penetrates from the ground surface toward bedrock or tertiary alluvium. This factor would tend to increase the specific yield values in general as one penetrates deeper into the water-bearing strata. But as a contrary force

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34/ This bias has equally important consequences in a contrariwise manner. Complacency about rate of draft may be suddenly revealed as unjustified by the unexpected decline of water levels below the "economic pumping limit" before the people using the resource are aware of what has happened.

35/ Thayer, W. N., Geologic Features of Antelope Valley, California. Los Angeles County Flood Control District. October, 1946. Processed. p. 12.

the weight of the alluvium, as it piles up in deeper and deeper layers, tends to pack down the underlying strata and reduce pore space in the sediments. The assumption made earlier that specific yield determinations made by the Division of Water Resources are accurate in the horizontal direction and may be extended to depths of 500 feet below the ground water surface depends on the further assumption that these biases are self-canceling. If specific yield values actually increase, on the average, as the ground-water level drops, then the above assumptions will tend to yield an underestimate of the volume of ground water actually removed for a given drop in ground water.

Although information on seasonal variation in water levels is potentially useful, such information is scant for Antelope Valley: In 1949, the U. S. Geological Survey in Antelope Valley listed 142 wells, only 25 of which were reported as being measured more than once during the year, and only 9 more than four times. There is a wide variation among wells in seasonal decline--from $1\frac{1}{2}$ to 23 feet for the same year. Where sufficient observations are available, the data show an expectable seasonal fluctuation in water level--high in the spring, before pumping begins, and low in the fall, at the end of the pumping season.

Measuring Net Draft from Changes in Ground-Water Levels

A series of net draft estimates can be developed from changes in ground-water levels. Sufficient data are not available to permit calculations for any years prior to 1940. Even since that time, it is admittedly difficult to make calculations that can be assumed to be either comparable over time or statistically reliable.

The biases, pitfalls, and necessary assumptions discussed above indicate, for Antelope Valley at least, that this method of estimating net draft is probably the least reliable of the three general methods discussed herein. In spite of these difficulties, however, Table 4.2, based on average specific yield and average yearly changes in water levels, has been prepared. Estimates of net draft on ground water based on electrical power consumption are also presented for purposes of comparison (see Figure 4.1, curve V).

Estimated mean annual draft for 1940-1951 is of the same order of magnitude for the two methods, with that based on electrical power consumption slightly larger than that based on changes in ground-water levels. Estimates for individual years prior to 1948 show considerable variation between the two series. There are several reasons for the large degree of variation of the estimates based on changes in water levels.

First, the estimates are based on the average annual declines in water levels observed in the Lancaster ground-water basin, but these observations were made on only 11 wells in 1940, on 15 in 1941, and on 16 in 1942. Only after 1946 does the number of observed wells exceed 25. Clearly, the observations are too few to describe an "average" decline in water levels for an area exceeding 350,000 acres. Furthermore, no single well was observed for each year during the period 1940-1951, thus introducing a high degree of inconsistency into the data.

TABLE 4.2

Net Draft on Ground Water
(Permanent Removal from Storage)

Year	Estimates based on changes in ground-water levels	Estimates based on electrical power consumption
	acre-feet	
1940	25,989	70,526
1941	31,234	56,727
1942	96,990	77,708
1943	62,639	81,352
1944	27,472	84,660
1945	119,023	96,245
1946	39,467	112,822
1947	157,974	121,311
1948	92,239	134,845
1949	120,442	140,031
1950	123,645	147,907
1951	142,862	163,542
Mean annual draft for twelve-year period	86,665	107,306

Second, locations of the wells for which observations are available may not be representative of the area: In 1947 only 3 out of 34 wells observed (about 9 per cent of the sample) were located within a three and one-half mile radius of Roosevelt, where between 30 and 40 per cent of the total alfalfa crop of the Valley in that year was produced. This would tend toward an underestimate of ground-water draft. On the other hand, about 65 per cent of the observation wells for 1947 were located in areas with mean specific yield of subsurface sediments greater than the value for the entire Lancaster ground-water basin. This would tend toward an overestimate of ground-water draft. Which of the factors is dominant, and to what extent they are self-canceling, cannot be determined.

Third, timing of observations varies from year to year for individual wells: A water level reading of a particular well may be taken in November one year, December the next year, October or even September the third year, and so forth. Other things being equal and assuming November to be the month when well readings are usually taken, this would result in an under-estimation of decline for the second year, and an overestimation for the third.

Finally, artesian pressures tend toward an overestimate of draft. What has been estimated in Antelope Valley is in fact some combination of change in storage and change in pressure. The violent fluctuations observed are primarily a function of variations in pressure. The result is not at all useful as a measure of changes in ground-water storage for this area, in which artesian and nonartesian conditions are intermingled. Any attempt to compensate for this bias would merely introduce another source of error into an estimating procedure already encumbered with error-producing complications.

It is possible to relate some of the variation in these estimates to variation in runoff. This relation indicates relatively rapid transmission of ground-water pressure from the area of recharge to the area of discharge, suggesting that hydraulic continuity exists between the wells in the discharge area and the area of recharge. For example, the large runoff for 1940-41 can be associated with small discharge from storage. A low runoff in the next year is associated with a relatively large discharge estimate. Greater than average runoff during 1943 and 1944 is associated with relatively small discharge estimates. Since 1945 the low runoff estimates have been associated with relatively large discharge estimates, except for the year 1946, in which the reverse association is observed.

On the basis of the foregoing it must be concluded that an estimate of net draft that is based on water level declines is not reliable for areas in which artesian aquifers are widespread. An estimate of seasonal variation in draft made on the same basis would be even less reliable. Measurements on a well located near another well that is being pumped at the time of observation will yield an overestimate of water removal. The degree of error will depend on proximity of the two wells, volume of water being removed from the nearby well, specific yield of the sediments being pumped, etc.

Draft on Antelope Valley Ground Water

In spite of severe limitations in basic data, several facts concerning ground-water draft in Antelope Valley have been clarified. It is apparent that draft on ground water in the Valley increased more than threefold during the period 1924-1951. By comparing the several estimates of ground-water draft, some light is shed on quantitative aspects of this increase.

The first general method of estimation (based on electrical power consumption) traces the rise, decline, and current rise in both gross and net draft. Annual variations from the general trend are observable. The results suggest that draft is less in years with greater than average recharge. Increased draft resulting from high prices received for agricultural products is likewise suggested. The second method (based on consumptive use) produces curves of the general form produced by the first method. The tendency toward over-irrigation is also demonstrated. The two methods produce estimates of both gross and net draft that are reliable and useful. The accuracy of the estimates depends upon the completeness of the basic data. The third general method of estimating ground-water draft (based on changes in ground-water levels) has been rejected for Antelope Valley as being too full of weaknesses, biases, and pitfalls because of the imprecise data available.

The series of estimates based on electrical power consumption will be herein combined with the consumptive use estimates of nonagricultural draft to make an evaluation of the effect on ground water of man's use of the resource. These estimates will be used in the next chapter, in which recharge (Chapter 3) will be compared with discharge and draft (Chapter 4) to evaluate overdraft in Antelope Valley.

Chapter 5

Overdraft of the Ground-Water Resource

The several ground-water problems found in Antelope Valley may be grouped together as "overdraft." The foregoing discussion of recharge and draft can be evaluated in terms of different types of overdraft.[1]

Overdraft is the volume of ground water removed in excess of recharge from aquifers within a particular geographic area and for a specified period of time. Both natural and man-induced recharge and discharge are included. The area under consideration is, in this case, the Antelope Valley. Different time periods associated with variable stages of ground-water development determine various types of overdraft. At least five types of overdraft may be isolated for purposes of discussion. Before this is done, however, a discussion of pseudo-overdraft is appropriate.

Pseudo-Overdraft

Noticeable declines in ground-water levels continuing for a period of years are almost certain to bring forth the cry of "overdraft." Although a normal companion to overdraft they are not necessarily or uniquely associated with overdraft. Overdraft is present only if water removed from ground-water storage continually exceeds recharge to ground water, but declining water levels may still occur when recharge exceeds draft on ground water. Such a possibility exists with pipeline or transmission problems, when ground water is unable to move through aquifers rapidly enough to supply draft even though for the ground-water reservoir as a whole, recharge may equal or exceed draft.[2]

For example, estimated annual ground-water draft in Antelope Valley prior to 1926 was less than average annual recharge. Even before 1920, however, concern was expressed in the Valley about falling water levels and decreased artesian flow.[3] The symptom of overdraft was present in

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1/ The differentiation of different types of overdraft as an analytical tool in the analysis of ground-water problems was undertaken at the suggestion of S. V. Ciriacy-Wantrup, Professor of Agricultural Economics, Univ. of California, Berkeley.

2/ Thomas, H. E., The Conservation of Ground Water. op. cit. pp. 4-5, 98-100.

3/ Thompson, D. G., The Mohave Desert Region, . . . op. cit. pp. 326-342.

the Valley before overdraft itself actually occurred. Removal of relatively small amounts of ground water together with pressure release brought about marked decreases in water levels (see pp. 75-79). Similar conditions may be widespread in other areas largely dependent upon ground water. Under such conditions, it is likely that the cry of "overdraft" is usually raised long before the condition actually exists. This may be advantageous, however, because of the human inertia that characteristically must be overcome in combating problems associated with resource utilization.

This "false overdraft" problem should be recognized, if encountered, and differentiated from "real overdraft" problems, for it requires a different approach to its solution--though not necessarily an easier one. The problem centers around an inadequate transmissibility of aquifers supplying the discharge or draft area. In order to stem declining water levels, inflow (replenishment) to the discharge area must balance discharge or draft--either by decreasing draft or increasing replenishment, or both. Pumping within the discharge area tends to increase the rate of movement from the recharge area to wells, by increasing the hydraulic gradient. Such a solution would not be satisfactory if it required pumping lifts so great as to make water costs prohibitive or if the aquifer would be unwatered in the process of establishing a favorable hydraulic gradient.

The extent of transmission problems cannot be evaluated easily. The possible presence in Antelope Valley of physical conditions associated with this type of problem has been mentioned earlier (see pp. 23-25). For the area as a whole the problem is relatively unimportant. In ground-water studies the possible presence of transmission problems must at least be examined. If they prove to be unimportant they may be placed in proper perspective and the more important problems of "real overdraft" emphasized. Thus, consideration of "pseudo-overdraft" and differentiation of the several types of "real overdraft" constitute a tool of analysis or a method of studying ground-water problems.

Developmental (Short-Run) Overdraft

During initial development of a ground-water stock resource, developmental overdraft often must take place if annual recharge (ground-water flow resource) is to be fully utilized. Without the influence of man's actions, average annual discharge of ground water from an area over a period of years must equal average annual recharge. Complete use of the flow component of the ground-water resource requires elimination of natural discharge and entry of the entire (average) annual recharge into the ground-water reservoir. Draft on the stock that lowers the water table enough to prevent natural discharge and permit utilization of the entire potential recharge volume (average annual) as actual recharge constitutes developmental overdraft.[4/]

Developmental overdraft is a necessary stage in ground-water utilization if man is to take full advantage of both the stock and flow components. The volume of draft that will result in the necessary degree of developmental overdraft will vary, depending upon the length of time during which such overdraft is to take place, the extent of the ground-water stock resource developed, and the relative sizes of the flow and stock.

Developmental overdraft may or may not be a necessary forerunner of other types of overdraft, depending on the ability to control total ground-water draft both during initial phases of development and after ultimate development. Control could take the form of limitations on type and acreage of crops grown or metered control of the volume of water pumped from wells. This important limiting procedure will be discussed further in Chapter 8.

Where control of ground-water draft exists, the types of overdraft observed will not usually cause a perpetual drain on the stock resource. Relatively minor variations in ground-water levels or artesian flow and pressure will result from seasonal and cyclical overdraft.

Seasonal (Annual) and Cyclical (Periodic) Overdraft

Rates of annual ground-water use equivalent to the naturally determined safe yield of an area will not maintain ground-water levels at a specified point. Other things being equal, variation around a mean value will be observed: First, within each pumping season the water levels will decline, the extent depending upon the relative sizes of the draft volume and the volume (specific yield and transmissibility) of the aquifers being tapped. Second, from one year to the next--or for a period of several years--water

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4/ Within a ground water basin beset with transmission problems and apparent or "pseudo" overdraft development, overdraft at the point of ground water withdrawal serves to increase recharge to the site by increasing the hydraulic gradient. It does not increase recharge to the entire basin, however. The elimination of natural discharge in Antelope Valley is much more important than localized increases in recharge.

levels may fall or rise, depending upon draft volume and whether actual recharge in a particular year is less or greater than the average annual recharge. Such variations, covering periods from one to several years, may be observed for both the "dry" and "wet" phases of the cycle (see pp. 41-44).

Seasonal (annual) overdraft will be accompanied by the first-named variation in water levels. Overdraft would be entirely seasonal if water levels at the beginning of the pumping season remained the same from year to year and declined only during the pumping season. The pumping season does not usually coincide with that part of the year during which precipitation produces recharge. In most parts of California, water level declines begin about April or May of each year, and begin to rise about October or November.

Seasonal overdraft is common throughout most irrigated areas, varying only in degree. It may occur in an area characterized by serious types of overdraft as well as in those in which only the unimportant types of overdraft occur. The most important factor determining seasonal overdraft is the relative size of the volume of draft and the volume (specific yield and transmissibility) of the aquifers being tapped. Wells drawing on an aquifer with high specific yield will show a smaller seasonal overdraft than if the aquifer were characterized by a low specific yield, other things being equal.[5/]

Cyclical (periodic) overdraft occurs when total draft on ground water for a period of one to several years exceeds total recharge for the same period. This type of overdraft will result in year-to-year declines in ground-water levels for a span of several years. The number of years included in this periodic decline may be highly variable. Cyclical overdraft can be recognized in periodic variations in the balance of total recharge and total draft cumulated over a period of years. In a particular area it may take on a negative value during the "wet" phase of the cycle if annual draft during these years does not greatly exceed the safe yield volume. In both cyclical and annual overdraft, climate (i.e., recharge) is the important variable. Other things being equal, the magnitude of overdraft is determined by the discrepancy between draft and recharge cumulated over a period of years.

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5/ Specific yield: "The ratio of the volume of water which a rock or soil [aquifer] will yield by gravity to its own volume." Tolman, C. F., Ground Water, op. cit., p. 563.

These two types of overdraft are considered to be relatively unimportant to the ground-water economy of an area. In each there exists a state of overdraft without perennial depletion of the stock resource: Over a long period of time there is approximate balance between draft and recharge. When, however, draft is so greatly in excess of recharge that the ground-water levels move only down, a more serious type of overdraft is at work.

Long-Run (Secular) Overdraft

Long-run overdraft, or secular overdraft, is a result of "mining" the ground-water stock resource. When draft is so great that long-run overdraft is in existence, the seasonal and cyclical overdrafts are in evidence only as minor variations on the over-all trend. Total draft in a particularly "wet" year may be less than total recharge, but when cumulated over an entire "wet" cycle, draft exceeds recharge.

Long-run overdraft is a consequence of what may be called, from a strictly physical and hydrological point of view, overdevelopment of the ground-water resources of an area. Such a situation may develop when nature endows a region with land suitable for agriculture but neglects to provide sufficient water (ground water--stock and flow--or surface water) to enable even a small portion of the area to be cultivated perennially.

The limits of long-run overdraft are set by the physical extent of the ground-water stock resource, economic factors, technological innovations, and social institutions. These factors will be discussed at length in later chapters.

Critical Overdraft

Long-run overdraft frequently leads to another condition in the ground-water economy, which may be called critical overdraft. The word critical assumes the presence of a flow resource possessing a critical zone.[6] Ground-water storage capacity may be regarded as a flow resource. If sustained overdraft has led to compaction of clay aquifers, the restoration of storage capacity becomes economically and technologically impossible. The level of overdraft that causes this condition may be termed critical overdraft.

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6/ Ciriacy-Wantrup, S. V., Resource Conservation, Economics and Policies. pp. 37-40, 256. "Critical zone means a more or less clearly defined range of rates below which a decrease in flow cannot be reversed economically under presently foreseeable conditions." p. 39.

Critical overdraft can conceivably occur before real overdraft takes place. Pseudo-overdraft or overdraft localized to a small discharge area may result in compaction of clay aquifers before draft exceeds recharge for the area as a whole. Critical overdraft is probable during the "dry" phase of cyclical overdraft if draft has removed sufficient ground water relative to the pressures bearing upon the clay aquifers to permit compaction. Thus, critical overdraft is possible at nearly all levels of ground-water utilization within a specified area, depending upon physical and climatic characteristics of the area.

If preserving the ground-water storage capacity of an area is important, a careful and accurate examination of the relation of draft and recharge is necessary at all levels of ground-water utilization. Critical overdraft may be ignored and attention focussed on problems of long-run overdraft when the amount of storage capacity destroyed by critical overdraft relative to total available storage capacity can be assumed to be small or unimportant.

Overdraft in Antelope Valley

Having categorized criteria for the evaluation of different types of overdraft, discussion returns to the problem posed at the beginning of this chapter: Does overdraft exist in Antelope Valley? If so, what type or types can be observed, and what is the magnitude of any overdraft?

The basic definition of overdraft specifies that draft must exceed recharge for a certain time and area. The first symptom of the existence of overdraft is found in the decline of ground-water levels, although (as has been stated earlier) presence of this symptom does not guarantee the existence of overdraft. Declines in ground-water levels have been shown to be great throughout Antelope Valley, particularly in the last twenty-five years. Estimates of recharge and draft have been prepared herein, which can now be compared to quantify the presence and magnitude of overdraft in Antelope Valley.

Figure 5.1 presents a graphic comparison of draft and recharge in Antelope Valley for the period 1924-1951, including two levels of projection to 1970. Overdraft in Antelope Valley for the same period is given in Figure 5.2, based on the annual differences between estimated annual recharge and estimated annual net draft. Tables 5.1 and 5.2 present these data in tabular form.

TABLE 5.1

Ground-Water Inventory and Overdraft, Antelope Valley, 1924-1951

Year	Annual net draft on ground water			Annual recharge to ground water	Overdraft on ground water		Total pumping lift
	Agricultural	Nonagricultural[a]	Total		Annual	Cumulative[b]	
	acre-feet						feet
1924	27,000		27,000	9,000	18,000	518,000	89
1925	32,000		32,000	6,000	26,000	544,000	92
1926	41,000		41,000	43,000	- 2,000[c]	542,000	96
1927	49,000		49,000	35,000	14,000	556,000	100
1928	64,000		64,000	5,000	59,000	615,000	102
1929	81,000		81,000	8,000	73,000	688,000	105
1930	86,000		86,000	12,000	74,000	762,000	109
1931	79,000		79,000	13,000	66,000	828,000	113
1932	55,000		55,000	44,000	11,000	839,000	116
1933	48,000		48,000	7,000	41,000	880,000	118
1934	60,000		60,000	11,000	49,000	929,000	127
1935	56,000		56,000	50,000	6,000	935,000	130
1936	66,000		66,000	10,000	56,000	991,000	133
1937	64,000		64,000	75,000	- 11,000	980,000	137
1938	65,000		65,000	102,000	- 37,000	943,000	140
1939	69,000		69,000	31,000	38,000	981,000	145
1940	82,000		82,000	11,000	71,000	1,052,000	146
1941	58,000		58,000	167,000	-109,000	943,000	147
1942	79,000		79,000	10,000	69,000	1,012,000	152
1943	82,000		82,000	99,000	- 17,000	995,000	155
1944	86,000		86,000	69,000	17,000	1,012,000	161
1945	97,000	1,000	98,000	24,000	74,000	1,086,000	167
1946	114,000	1,000	115,000	23,000	92,000	1,178,000	169
1947	122,000	1,000	123,000	29,000	94,000	1,272,000	176
1948	136,000	1,200	137,200	1,000	136,200	1,408,200	180
1949	141,000	1,300	142,300	3,000	139,300	1,547,500	185
1950	149,000	1,500	150,500	6,000	144,500	1,692,000	190
1951	166,000	2,000	168,000	d/	168,000	1,860,000	197

a/ Less than 1,000 acre-feet per year until after 1945.
b/ Cumulative overdraft should include the waste and overdraft which occurred before adequate records became available. An allowance of 500,000 acre-feet is made for this volume.
c/ "Negative overdraft" arises when recharge exceeds draft.
d/ Less than 1,000 acre-feet.

Source: Figures 3.3 and 3.4, Appendix Tables 7 and 8.