GROUND WATER IN CALIFORNIA

The Experience of Antelope Valley

By

J. HERBERT SNYDER

With a Foreword by

S. V. CIRIACY-WANTRUP

Giannini Foundation
Ground Water Studies No. 2

UNIVERSITY OF CALIFORNIA • DIVISION OF AGRICULTURAL SCIENCES
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University of California
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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.

TABLE OF CONTENTS

TABLE OF CONTENTS (contd)

TABLES

FIGURES

APPENDIX TABLES

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 <u>per acre</u> 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

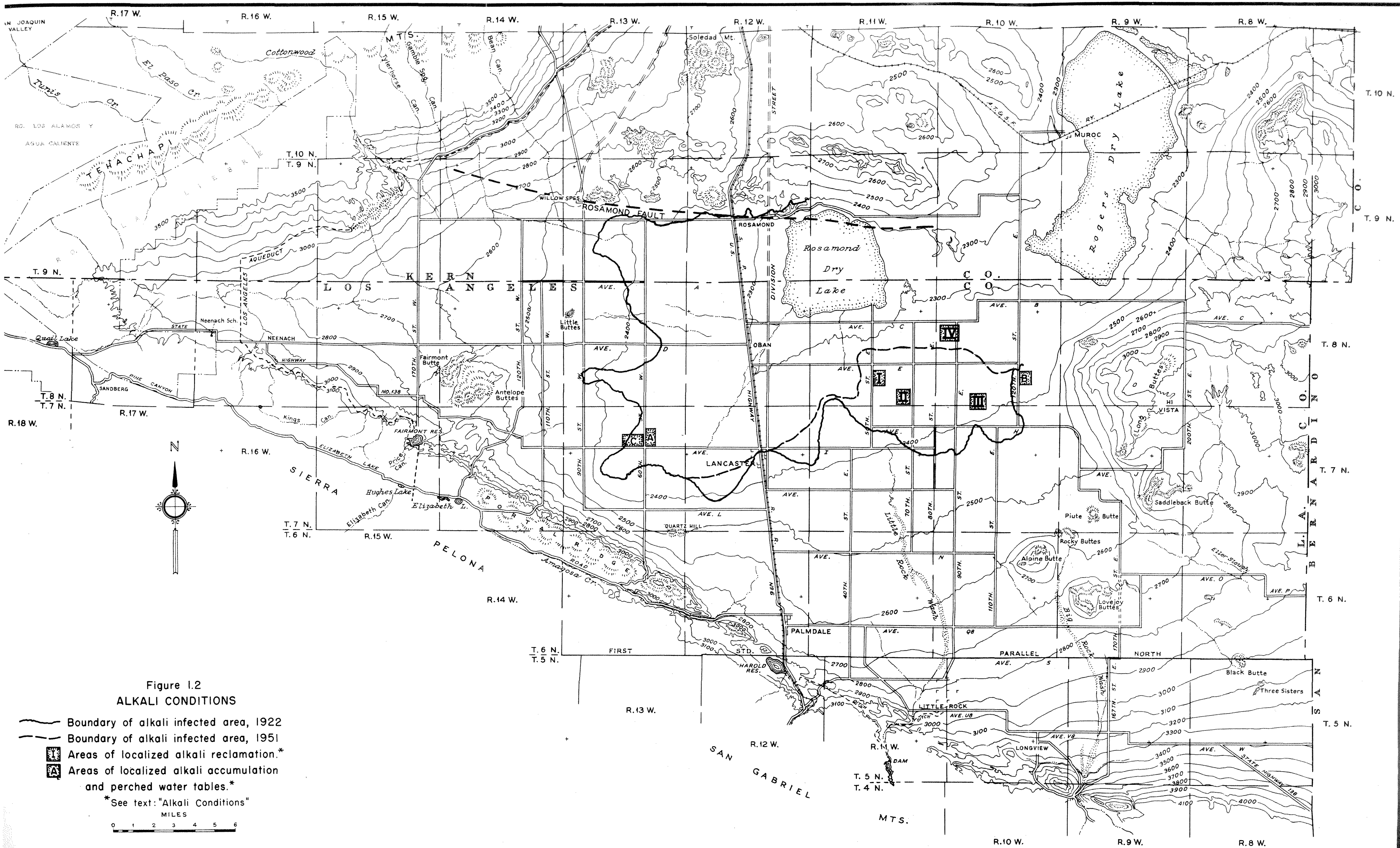

Figure 1.2

ALKALI CONDITIONS

- Boundary of alkali infected area, 1922
- Boundary of alkali infected area, 1951
- I Areas of localized alkali reclamation.*
- A Areas of localized alkali accumulation and perched water tables.*

*See text: "Alkali Conditions"

Revised 4-1-47, 4-7-47

This base map traced by [illegible]

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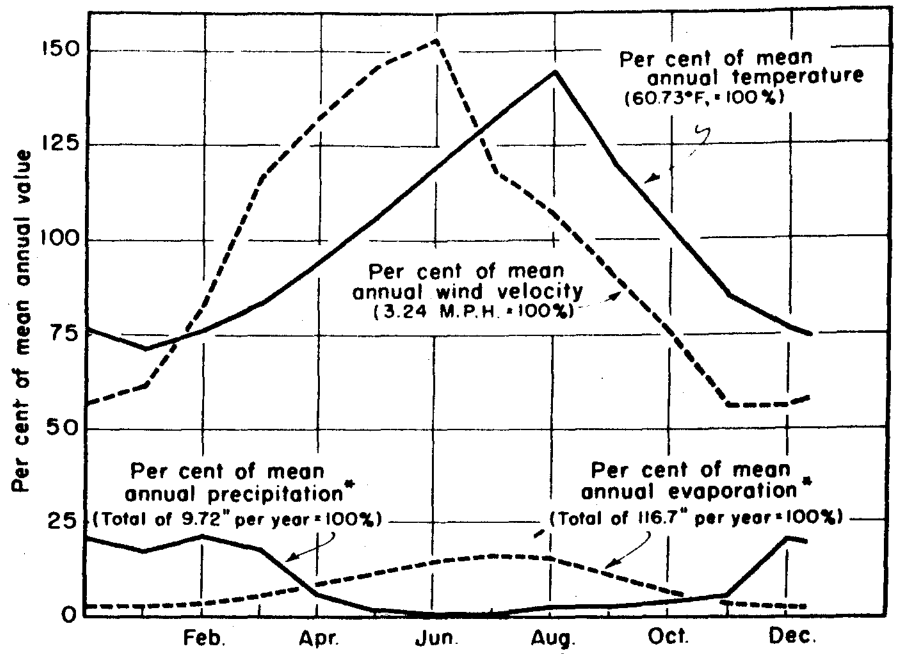
5/ The data are seasonal values (July 1 to June 30, inclusive).

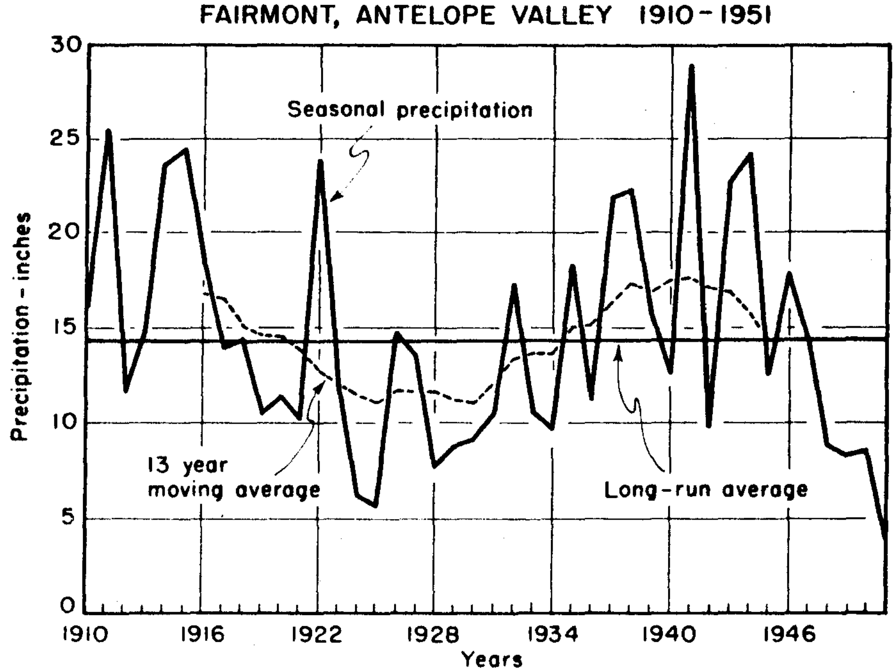
6/ The concept of cyclical variation in climatic phenomena is discussed at length in Chapter 3 under cyclical variation in recharge to ground water.

Figure 1.3 CLIMATIC VARIATIONS - ANTELOPE VALLEY



*Occurring in each calendar month.

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



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 plants[8/], 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 Conditions[9/]

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.

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.

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.

Location	Per cent soluble salt 1922	Per cent soluble salt 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.

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/

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.

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.

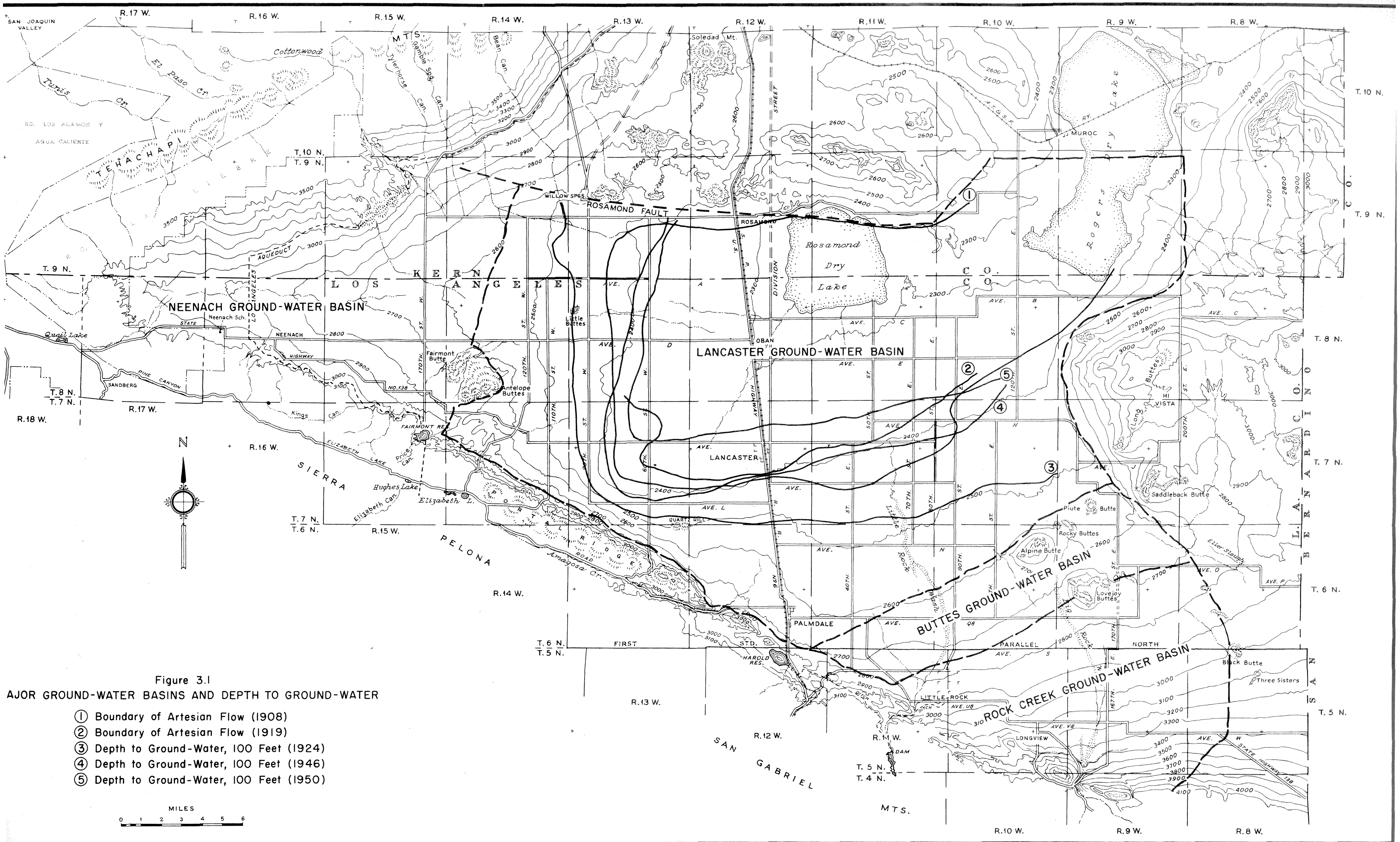

Figure 3.1
AJOR GROUND-WATER BASINS AND DEPTH TO GROUND-WATER

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)

Revised 4-1-47, 4-7-47
This base map traced by Ino A Parenti Feb 1947

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 group
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/]

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 inches	Runoff feet	Area acres	Runoff 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.

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.

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	Number of annual observations	Coefficient of determination for Rock Creek runoff	Number of annual observations
		r^2		r^2	
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

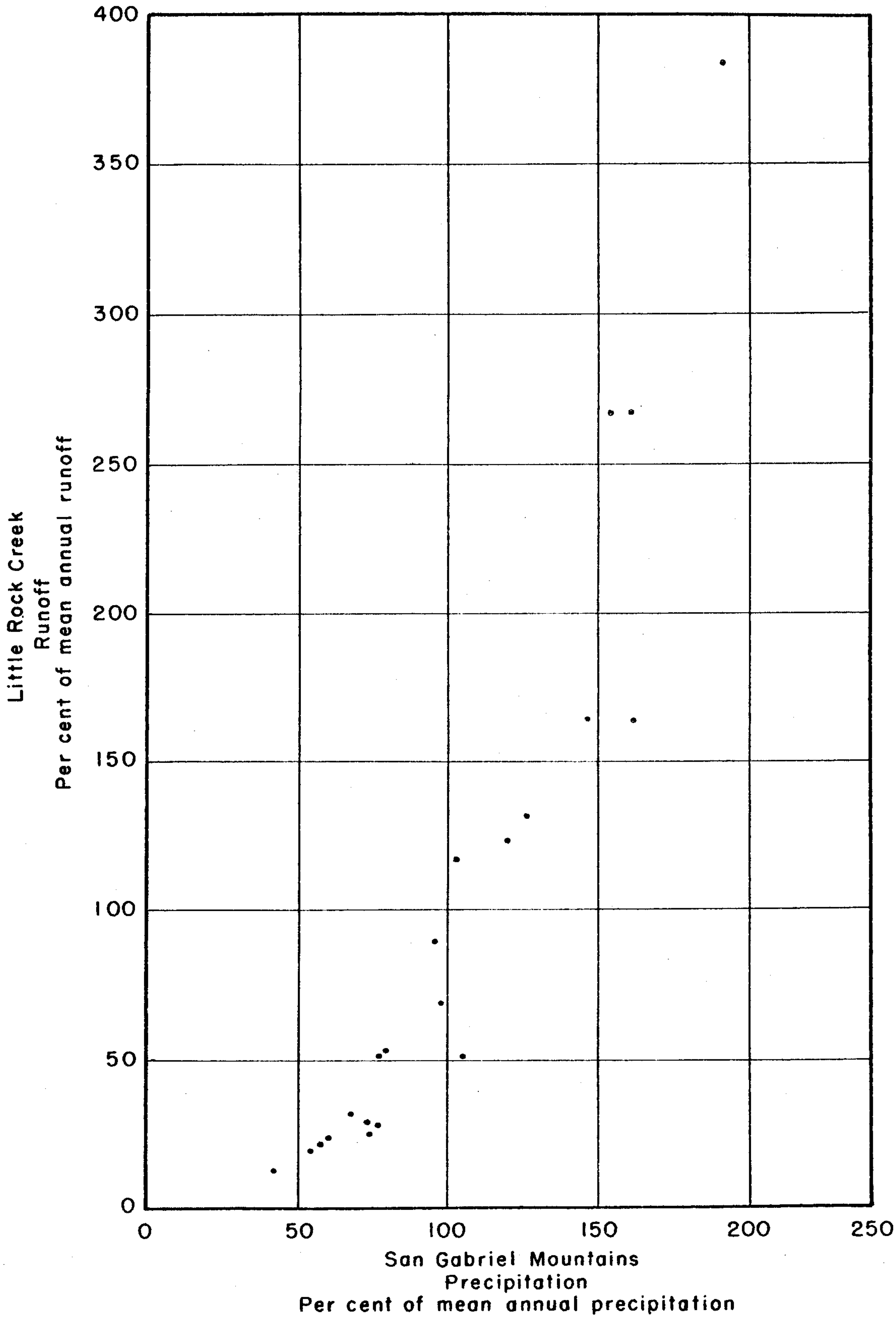
a/ This index series is based on the 75-year period, 1872-73 to 1948-49, with 28.16 inches per year equal to 100 per cent. The two values result from the use of different numbers of observations for the two correlations. The per cent values compare with long-time 75-year normal values of 100.

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 <u>not</u> 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." <u>The Annals of Mathematical Statistics</u>, 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.

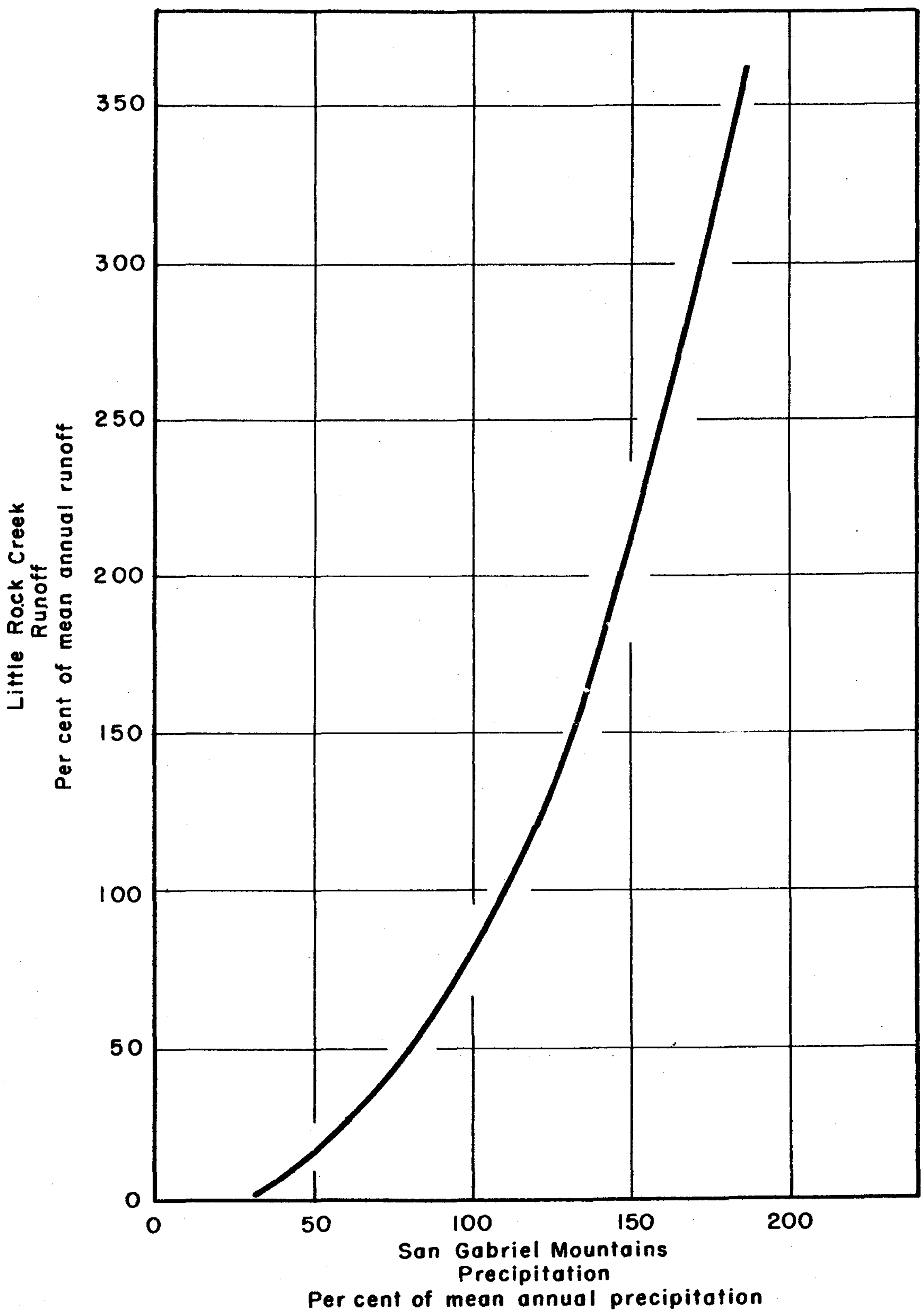
Second, a curvilinear relationship is indicated because, after soil moisture reaches field capacity, the greater the precipitation the greater the runoff, other things being equal. Interception and evapo-transpiration by plants will act to prevent the entire precipitation volume from becoming runoff. 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



ls.

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

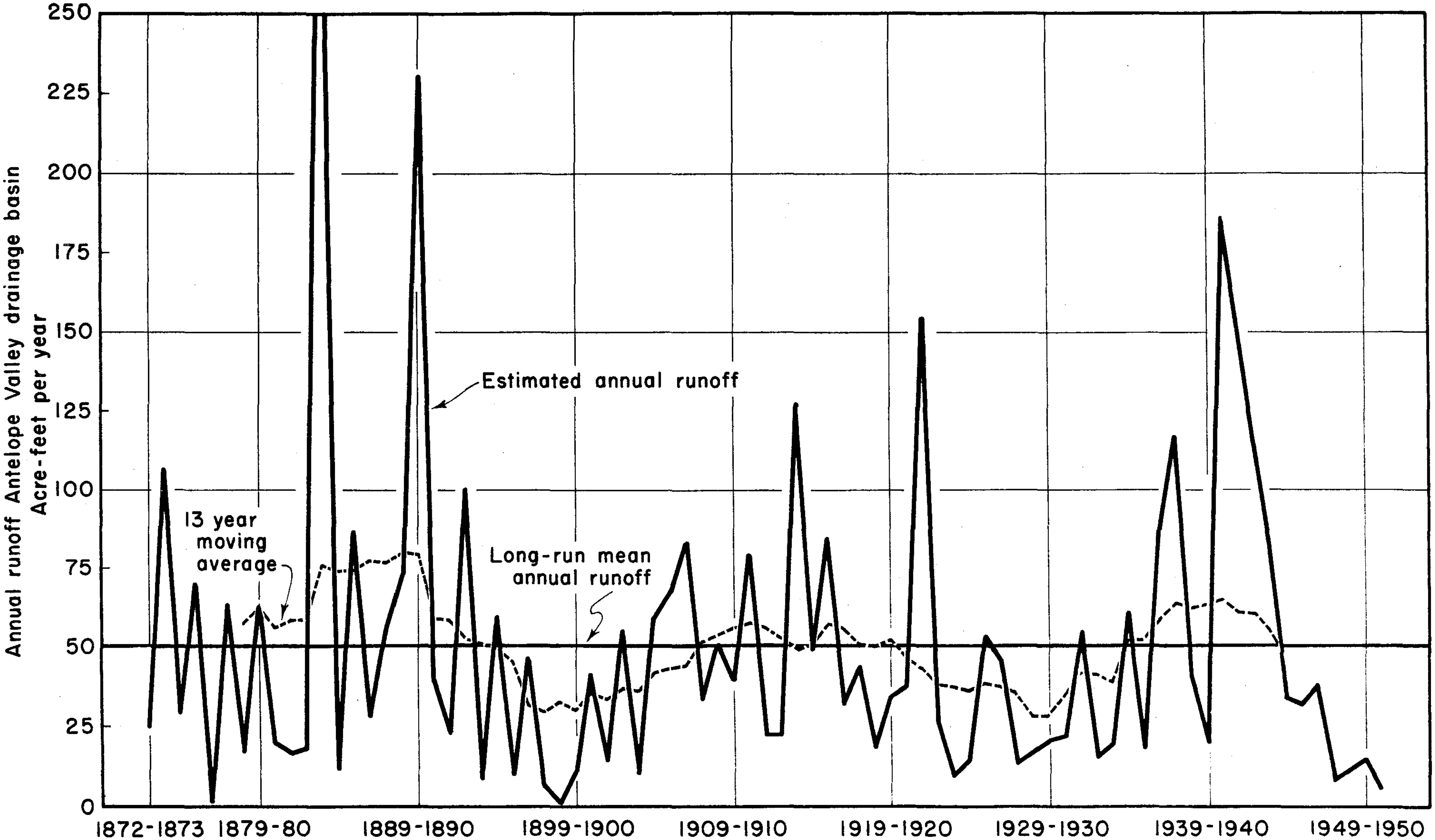
Estimate of Mountain Runoff Reaching Antelope Valley

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.

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.

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:

Year	Class of water consumer				
	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

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.

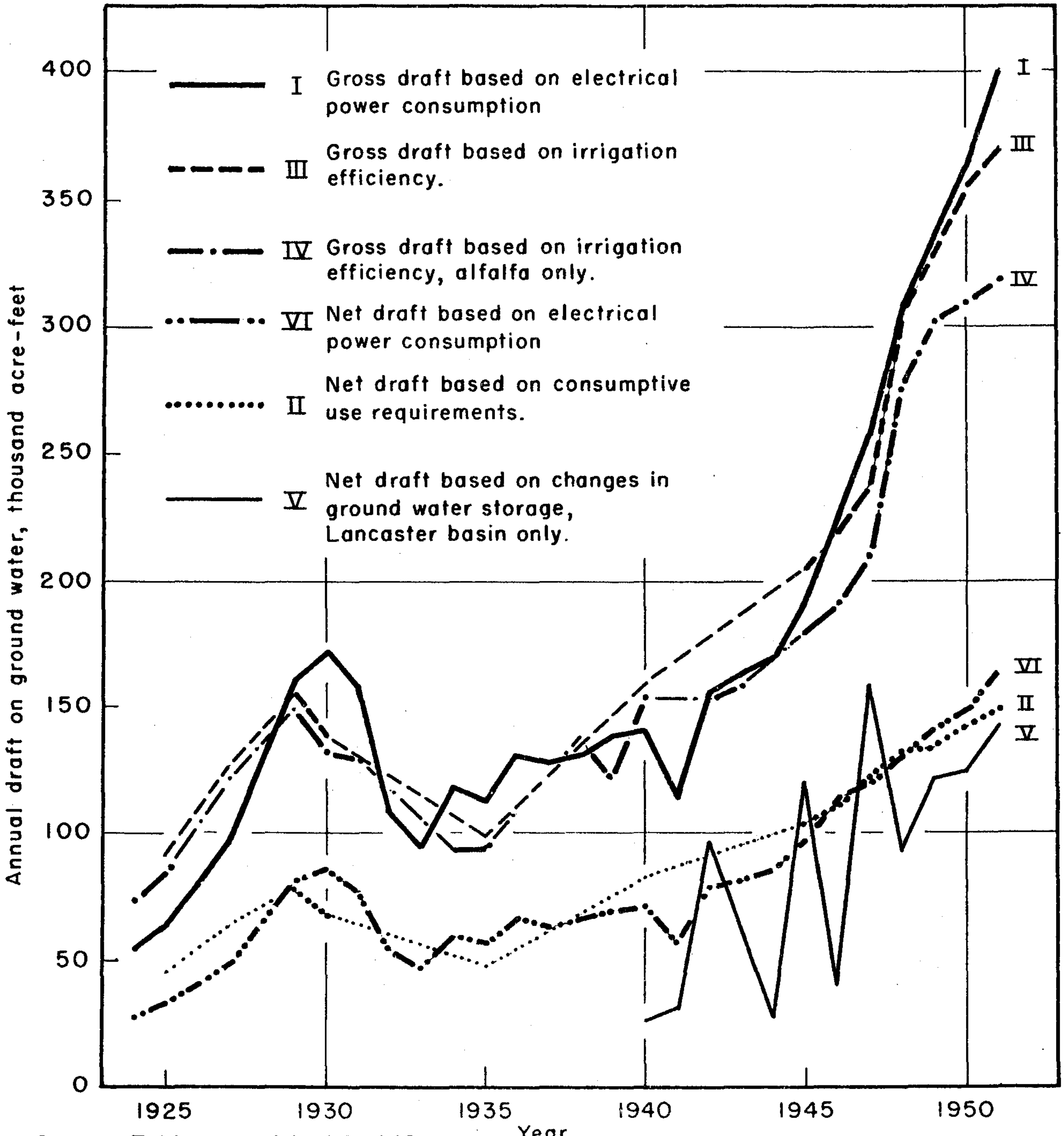
Certain assumptions have necessarily been made rather arbitrarily in this development of annual estimates of ground-water draft:

(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.

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.

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	Acre-feet per year: Consumptive use supplied by irrigation	Acre-feet per year: Waste	Acre-feet per year: Return flow	Per cent of water applied: Consumptive use	Per cent of water applied: Waste	Per cent of water applied: 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 $3\frac{1}{2}$ 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 underestimation 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

TABLE 3.1

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

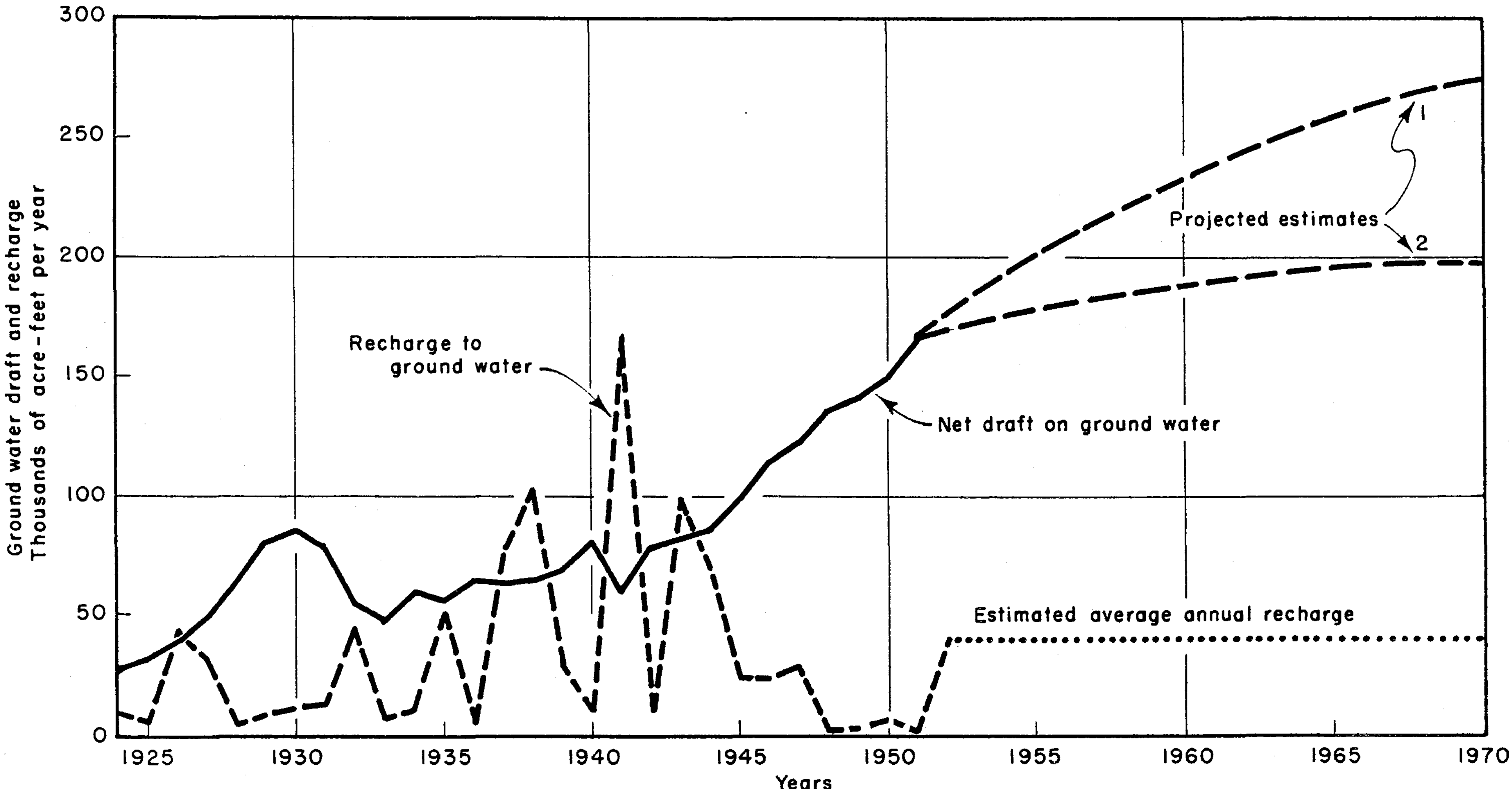
Year	Annual net draft on ground water			Annual recharge to ground water	Overdraft on ground water		Total pumping lift
	Agricultural	Nonagricultural[a/]	Total		Annual	Cumulative[b/]	
	acre-feet						feet
1924	27,000		27,000	9,000	18,000	518,000	89
1925	32,000		32,000	6,000	26,000	544,000	92
1926	41,000		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.

Figure 5.1

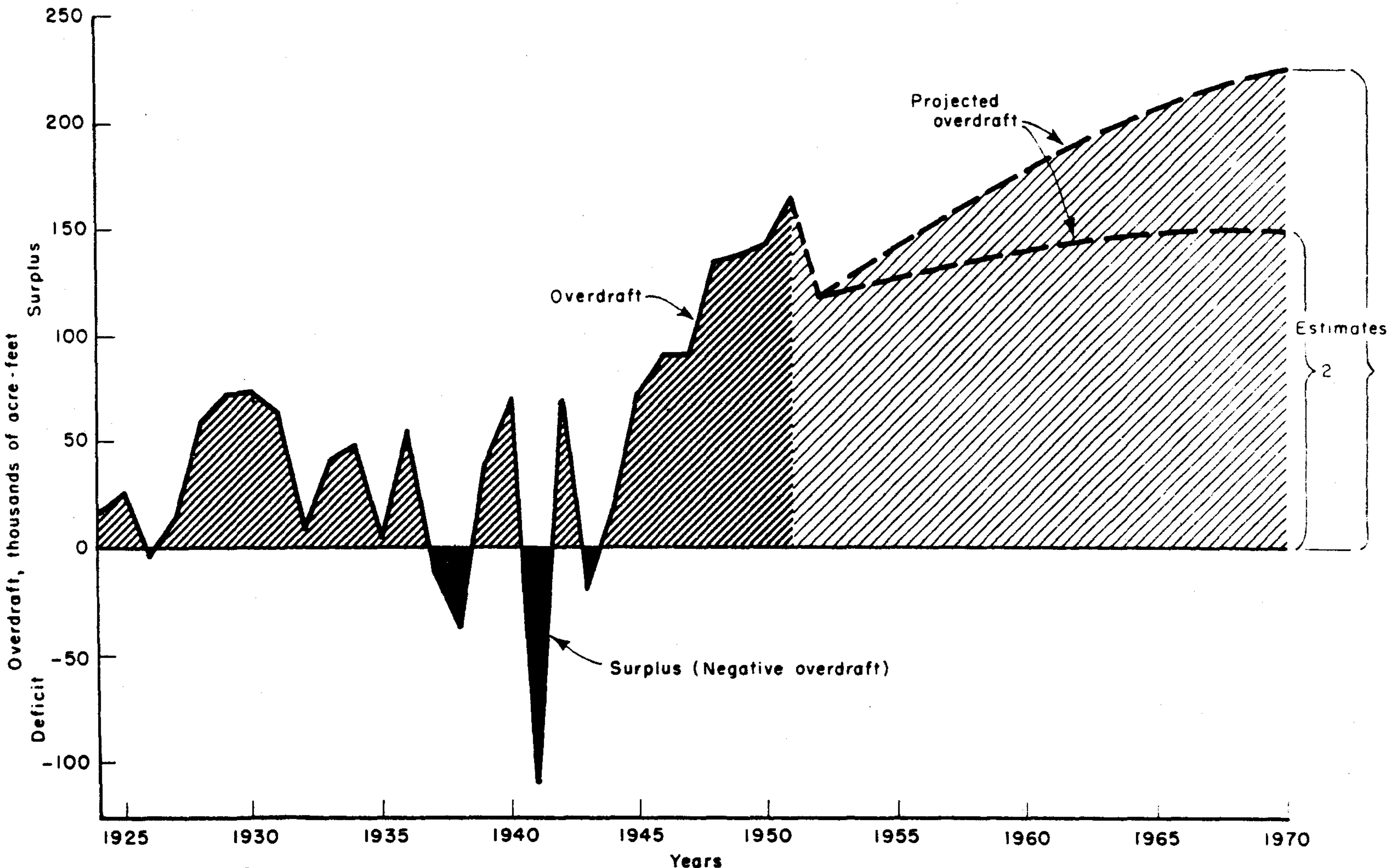
HISTORIC AND PROJECTED NET DRAFT AND RECHARGE
ANTELOPE VALLEY 1924 - 1970



Source: Table 5.1

Figure 5.2

HISTORIC AND PROJECTED OVERDRAFT
ANTELOPE VALLEY 1924 - 1970



Source: Table 5.1

Inherent problems in the measurement of overdraft have been fully covered in the earlier discussion of problems of measurement for recharge and draft. These difficulties should be borne in mind during the present discussion, but there is no need to restate them at this time. Unless otherwise specifically stated, when the term "draft" is used in the following discussion, net draft is implied.

Developmental Overdraft

Developmental overdraft involves removal of sufficient water from ground-water storage to permit the entire (average) annual recharge to enter storage and not be rejected as discharge. For an unconfined ground-water basin before development this would mean, depending on the extent of the basin, that relatively large volumes of ground water would need to be extracted. Prior to 1925, crop acreages and consequently ground-water draft in Antelope Valley were not sufficient to accomplish this necessary extraction. Yet many artesian wells had already ceased to flow, drops in ground-water levels had caused some concern about a possible future scarcity of ground water, and the natural discharge of ground water had decreased to a negligible proportion. Symptoms of developmental overdraft were clearly in evidence, but without apparent cause.

The explanation of this condition lies in the extensive artesian system in Antelope Valley. Most wells penetrating to depths greater than 80-100 feet are more or less subject to artesian pressure. Agricultural draft, combined with a wastage discussed earlier, reduced artesian pressure sufficiently to cause developmental overdraft in the area by about 1925. Thus, it is seen that either removal of large amounts of water or relatively small amounts of water coupled with pressure release from artesian aquifers can induce developmental overdraft.

For Antelope Valley this meant that as early as 1925 the volume of ground water in storage and artesian pressures had been reduced sufficiently to permit nearly complete utilization of the (average) annual recharge. It should be emphasized that this condition occurred at about the same time that sufficient acreage had been brought under irrigation to consume the (average) annual recharge. It was not necessary to induce developmental overdraft by expansion of acreage beyond a level that would, on the average, consume the safe yield of the ground-water reservoir: The condition of developmental overdraft had been created merely by pressure release from artesian aquifers. At this stage of utilization of the Antelope Valley ground-water resources (1926-1927), the ground-water economy could have been maintained at a relatively stable level with only relatively unimportant types of overdraft occurring--if the farmers had (1) been able to retain the irrigated acreage structure that existed and (2) wished to do so.

Seasonal (Annual) and Cyclical (Periodic) Overdraft

Little can be said about seasonal overdraft in Antelope Valley that has not already been said earlier, in the general discussion. Recharge normally occurs during November-March and draft during April-October. Draft will deplete water in the area of draft and cause an inflow of water from the area of recharge. The major replenishment of the recharge area occurs six months or so after the draft period, causing a seasonal lag in replenishment. Although hydrostatic pressures may be transmitted at a rapid rate from the recharge to the draft areas, there will be relatively slow flow of water between the two areas, due to low transmissibility of the aquifers. These factors produce seasonal overdraft, other things being equal, and ground-water levels fall during the pumping season and rise during the recharge season.

Cyclical overdraft may be noted for the period 1924-1940, when irrigated crop acreage fluctuated at a level that consumed the safe yield of the ground-water reservoir, or slightly above. During 1924 and 1925, draft exceeded recharge; in 1926, the reverse occurred. During 1928-1931, large expansions in irrigated acreage and low recharge levels resulted each year in a greater magnitude of overdraft than would have occurred with a stable crop acreage. During the relatively stable period of 1932-1943, overdraft occurred seven times and annual surplus (or negative annual overdraft) occurred four times. A rapid and consistent acreage expansion since 1943 has eliminated this rather stable oscillation, and annual overdraft appears to have merged into a more serious type.

It is possible to discern a tendency toward cyclical or periodic overdraft for the period 1923-1951 if certain assumptions are made. During 1923-1934 an extensive overdraft occurred, because of low recharge to ground water and expansions in irrigated crop acreage. Average annual ground-water draft during this period was only slightly above the physically determined safe yield value. This dominant recurrence of overdraft for a period of twelve years is called the deficit phase of cyclical overdraft. The reverse tendency during the next ten years (1935-1944) is called the surplus phase (or negative overdraft phase) of cyclical overdraft.

By comparing Figures 5.1 and 5.2 with Figure 3.4, it is evident that this tendency towards cyclical overdraft has been caused primarily by climatic fluctuations. From 1945 to 1951, assuming a constant acreage at or near the safe yield level, another deficit phase of cyclical overdraft would be observed. In fact, however, an increase in irrigated crop acreage induced a more serious type of overdraft.

Long-Run Overdraft--Past and Future

Since 1945, expansions in irrigated acreage in Antelope Valley have practically eliminated the possibility that annual recharge will ever again exceed annual draft. Even if this should happen occasionally, on the average the annual draft will exceed the annual recharge. Rejecting, for the moment at least, the possibilities of drastic reductions in future water consumption or large-scale importation of additional water, it can be stated that long-run overdraft has become the most important feature of the Antelope Valley ground-water economy.

Table 5.1 presented historical estimates of overdraft in Antelope Valley. Table 5.2 shows four hypothetical projections for the period 1952-1979, showing overdraft and the anticipated effect of this overdraft on the ground-water stock in terms of cumulative overdraft and pumping lift. From the beginning of agricultural development in the area up to 1951, it is estimated that overdraft (and waste) has been sufficient to remove nearly two million acre-feet from ground-water storage.[7/] This would be equivalent to a drop in ground-water levels of nearly 100 feet (see Table 3.1). Actually, the drop in water levels has been nearly double this amount, once again demonstrating the importance of artesian pressures in maintaining ground-water levels.

The first projection in Table 5.2 is based on an assumed continued growth in both agricultural and nonagricultural water use at about the rate observed during 1945-1951, with a gradual leveling off around 1965-1970 and relative stability achieved by 1975-1979. Population increase is assumed to reach about 135,000 people in Antelope Valley by 1975-1979 and remain

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7/ Estimated cumulative overdraft of 1,360,000 acre-feet plus estimated waste and pressure loss equivalent to 500,000 acre-feet.

TABLE 5.2

Hypothetical Draft, Overdraft, and Pumping Lift Projections for Antelope Valley, 1952-1979

	Net draft on ground water			Net recharge to ground water[a]	Overdraft on ground water		Increase in pumping lift during period[b]	Total pumping lift at end of period
	Agricultural	Non-agricultural	Total		For the period	Cumulative		
	acre-feet						feet	
1951 base	166,000	2,000	168,000	40,000	126,000	1,860,000	7	197
Projection No.1								
1952-1959	1,480,000	32,000	1,512,000	320,000	1,192,000	3,052,000	55	252
1960-1969	2,100,000	80,000	2,180,000	400,000	1,780,000	4,832,000	83	335
1970-1979	2,400,000	120,000	2,520,000	400,000	2,120,000	6,952,000	99	434
Projection No.2								
1952-1959	1,320,000	32,000	1,352,000	320,000	1,052,000	2,912,000	49	246
1960-1969	1,700,000	80,000	1,780,000	400,000	1,380,000	4,292,000	64	310
1970-1979	1,850,000	120,000	1,970,000	400,000	1,520,000	5,812,000	71	381
Projection No.3								
1952-1959	1,320,000	32,000	1,352,000	320,000	1,052,000	2,912,000	49	246
1960-1969	1,650,000	80,000	1,730,000	400,000	1,330,000	4,242,000	62	308
1970-1979	1,650,000	120,000	1,770,000	400,000	1,370,000	5,612,000	64	372
Projection No.4								
1952-1959	1,320,000	32,000	1,352,000	320,000	1,052,000	2,912,000	49	246
1960-1969	1,170,000	80,000	1,250,000	400,000	850,000	3,762,000	40	286
1970-1979	560,000	120,000	680,000	400,000	280,000	4,042,000	13	299

a/ Average annual recharge equals 40,000 acre-feet.

b/ It is estimated that permanent removal of ground water from storage in Antelope Valley will lower ground-water levels, on the average, at the rate of 100 feet per 2,150,000 acre-feet. See Table 3.1

TABLE 5.3

Hypothetical Annual Irrigated Acreage Projections
Antelope Valley, 1952-1979

	Alfalfa and irrigated pasture	Trees and vines	Vegetable crops	Hay and grain	Other field and miscellaneous crops	Total irrigated acreage
	acres					
Projection No. 1						
1952-1959	49,000	4,000	1,000	13,000	5,000	72,000
1960-1969	58,000	4,000	1,000	14,000	5,000	83,000
1970-1979	65,000	5,000	2,000	17,000	6,000	95,000
Projection No. 2						
1952-1959	45,000	3,000	1,000	10,000	4,000	63,000
1960-1969	47,000	3,000	1,000	11,000	4,000	65,000
1970-1979	49,000	4,000	2,000	13,000	4,000	72,000
Projection No. 3						
1952-1959	45,000	3,000	1,000	10,000	4,000	63,000
1960-1969	45,000	3,000	1,000	10,000	4,000	63,000
1970-1979	45,000	3,000	1,000	10,000	4,000	63,000
Projection No. 4						
1952-1959	45,000	3,000	2,000	10,000	3,000	63,000
1960-1969	20,000	1,000	20,000	1,000	9,000	51,000
1970-1979	5,000	---	14,000	1,000	6,000	26,000

relatively constant after that time. Gross per-capita water consumption is assumed to average 160 gallons per capita per day, with consumptive use one-half this amount.

Estimates of military-industrial water use are included in estimated nonagricultural draft.

Net ground-water draft by agriculture is assumed to reach a maximum of 240,000 acre-feet per year by 1970-1979. A projection of agricultural water use can be made by hypothesizing various combinations of acreages in irrigated crops by 1970-1979 and their relative growth to that time. One such set of estimates is given in Table 5.3 for the several projections of draft and overdraft. These acreage projections represent several possible alternatives for crop expansion and contraction. They represent possible developments and are formulated to demonstrate the effect that variations in irrigated acreage would have on the character of the ground-water stock figures shown in Table 5.2.

Projection No. 2 estimates net ground-water draft at 252,000 acre-feet per year by 1970-1979. Subtracting an average annual net recharge to ground water of 40,000 acre-feet per year, the average yearly overdraft will stand at 212,000 acre-feet per year. A cumulative overdraft of nearly 7,000,000 acre-feet would increase typical pumping lifts to 434 feet. All four physical projections of long-run overdraft assume that the economic limits of pumping will not have been reached by 1979; pumping could not otherwise continue at the rates projected. The economic forces that determine the economic limits of pumping will be considered at length in Chapters 6 and 7.

The second projection shown in Table 5.2 is based on a slightly different set of assumptions: The assumed nonagricultural use of water is the same, but agricultural use of water is assumed to expand at only about one-half the rate established during 1946-1951. A maximum net draft of 185,000 acre-feet per year will be reached by 1970-1979. This level of draft would create a cumulative overdraft of nearly 6,000,000 acre-feet and raise typical pumping lifts to a total of 381 feet by 1979.

Both projections assume increases in irrigated acreage that would not alter existing crop patterns in the Valley, while Projection No. 3 assumes relative stability in land and water use at about 1951 levels for agricultural purposes. The increases in nonagricultural draft assumed in the earlier projections are retained. In spite of the hypothesis of a static irrigated acreage, cumulative overdraft by 1979 would amount to over 5,600,000 acre-feet and typical pumping lifts would be about 372 feet.

The only methods by which the severity of long-run overdraft could be lessened, without large-scale importation of water, would be to curtail total irrigated acreage or meter pumpage volumes for the wells. Projection No. 4 assumes a marked decrease in net draft resulting from decreases in total acreage as well as in alfalfa acreage. In addition, large-scale shifts from alfalfa to vegetable crops and corn (which require less water) are a part of this projection (see pp. 123-126 for a discussion of economic factors associated with such shifts). Although cumulative overdraft and typical pumping lifts are raised above 1951 base conditions, the rate of increase is reduced significantly. Cumulative overdraft would total 4,000,000 acre-feet and typical pumping lifts would reach nearly 300 feet. It is obvious that long-run overdraft is present and probably will continue in Antelope Valley.

One way by which long-run overdraft could be eliminated in the Valley would be to curtail water use until annual net draft is in approximate balance with average annual recharge. This means drastic reduction in irrigated crop acreage, extensive shifts from crops that require large amounts of water to those with smaller requirements, and increased efficiency in the use of ground water for irrigation, or a combination of all of these. For example, approximate balance could be reach with a cut from the 1951 level of about 46,000 acres in alfalfa and irrigated pasture to about 13,250 acres in these same crops, or to 20,000 acres in field and vegetable crops, assuming maximum irrigation efficiency. Such reductions are highly unlikely.

A second theoretical solution to long-run overdraft in the Valley involves water importation from some other watershed area. Such a solution is perhaps likely for Antelope Valley and other deficit water areas, by importing Feather River or other water from northern California: Social and political institutions backed by engineering know-how and available capital have usually combined to solve this type of water shortage problem by transferring water from surplus to deficit areas. Regardless of the origin of imported water and regardless of whether it would be used for gravity diversion irrigation or diverted to underground storage for pumping at a later date, water importation to the Valley sufficient to curtail long-run overdraft is a definite possibility. Continued use of water at relatively high rates of consumption would be possible.

A third theoretical solution involves allowing economic and technological forces to impose severe reductions in pumping. Increase in pumping costs could, under appropriate conditions or assumptions, force farmers to abandon pumping when total lift exceeds, say, 500 feet. This process could gradually force farmers out of production until only a few of the most efficient operators were able to maintain their enterprises. In order to maintain an average total lift fluctuating around the 500-foot level, it would be necessary for average annual recharge to be in approximate balance with average annual draft. Thus, economic forces could create a condition where ground-water draft would equal the physically determined safe yield value, or draft and recharge would balance. The economic and technologic factors that influence the use of ground water in Antelope Valley will be considered in the following chapters.

Chapter 6

Pumping Costs and the Ground-Water Resource

It has been established that Antelope Valley agriculture is largely dependent upon the ground-water stock resource. Furthermore, annual draft rate in excess of annual recharge rate--ground-water mining--has created long-run overdraft. The next three chapters of the discussion examine the economic factors affecting ground-water resource use: chapter 6, a description and analysis of pumping costs; chapter 7, the influence of pumping costs on the selection of farm enterprises; and chapter 8, a discussion of the attempts made to combat overdraft in the Antelope Valley.

Determination of Pumping Costs

The annual water costs associated with ground-water utilization may be divided into two categories: (1) fixed annual charges--taxes and interest and depreciation on the original investment; (2) variable annual costs (operating costs)--determined by power (or fuel) consumption, lubricants, repairs, and attendance. The latter vary with the amount of water pumped. Pumping costs are also affected by the source of power or fuel used. The dominance of electricity in pumping ground water in the Valley permits the major emphasis to be placed on pumping costs using electricity as the power source; costs associated with other power sources will be introduced from time to time for purposes of comparison.

Fixed annual charges arise from the cost of well drilling, the cost of the pumping plant, and taxes. Appendix Table 9 shows, for several different installations in Antelope Valley in 1925 and 1951, the typical costs that determine fixed annual charges.[1/] These charges are "fixed" in that, regardless of the amount of water pumped each year, the total annual cost remains constant.

Variable annual costs vary with the number of hours of operation and reflect the number of acre-feet pumped during the year. The principal factor determining these costs is the cost of power or fuel. Table 6.1 summarizes estimated pumping costs from various lifts in Antelope Valley using electrical power.

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1/ These costs have not been corrected for changes in purchasing power.

TABLE 6.1

Cost of Pumping Water Per Acre-Foot, Antelope Valley[a/]

Year	Range of total lift					
	25 to 75 feet		75 to 150 feet		150 to 300 feet	
	Minimum[b/]	Maximum[c/]	Minimum[b/]	Maximum[c/]	Minimum[b/]	Maximum[c/]
	dollars					
1925	0.73	4.10	1.98	7.40		
1935 and 1945	0.41	2.35	1.24	4.42	2.27	8.35
1951	0.41	2.31	1.15	4.36	2.26	8.22

a/ A 45% over-all efficiency is assumed for 1925, and 60% for 1935-1951. If 60% efficiency is assumed for 1925 the calculated costs of pumping per acre-foot are:

25 to 75 feet, \$0.58 to \$3.58
75 to 150 feet, \$1.59 to \$6.54

b/ The minimum cost is associated with the smallest lift within the range and a gross pumpage of 2,000 acre-feet per year.

c/ The maximum cost is associated with the greatest lift within the range and a gross pumpage of 100 acre-feet per year.

Source: Snyder, J. Herbert. op. cit., pp. 396-403.

Because of lack of information, it is not possible to determine the costs of pumping ground water before 1920. As has been indicated, electrical power for pumping has been of dominant importance in the area since 1920. The costs of pumping water using electrical power are divided into three time periods, beginning with 1920 and continuing to the present (1953). The power schedule for agricultural use that was in effect in 1920 continued in substantially the same form until 1933, when a large reduction was made in both service charge and power charge. The second schedule continued in effect virtually unchanged until 1946, when a further, slight reduction in service charge was made.[2/] Costs of pumping water with the use of other

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2/ The power schedules selected were obtained from the Public Utilities Commission office in San Francisco. Only one agricultural schedule (PA-31) was selected for the 1951 rates although at least two are available for use by the farmer, depending upon the rated horsepower of the pumping installation he uses. For horsepower installations in excess of 100, a separate rate (PA-P2) is available, which, when large quantities of water are pumped, results in a substantial reduction of the cost of pumping per acre-foot. This seems to put a premium on pumping more water than may actually be necessary. The average rate charged for installations of less than 100 h.p. is about \$0.01 per kilowatt-hour, while the average rate for installations over 100 h.p. is about \$0.0085 per kilowatt-hour. See also Appendix Tables C.9 to C.12 inclusive. Snyder, J. Herbert, op. cit.

fuels may be determined on the basis of theoretical comparative efficiencies of different fuels.3/ Specific discussion of the factors affecting pumping costs is undertaken below (pp. 101-112).

Similar to power or fuel costs, expenditures for lubricants, repairs, and plant attendance depend upon the number of hours of operation or volume of water pumped. Table 6.2 shows typical costs for these items for both motor-driven (electric) and engine-driven pumping plants.

TABLE 6.2

Typical Unit Costs of Lubricants, Repairs, and Attendance

Item	Motor-driven plant per acre-foot	Engine-driven plant per acre-foot
	dollars	
Lubricants	0.05	0.15
Repairs	0.20	0.35
Attendance a/	0.00	0.40

a/ Electrically powered (motor-driven) plants require a negligible amount of attendance; engine-driven plants require a large amount. Attendance is the amount of labor involved in repairs and supervision necessary to provide continuous operation of the unit.

Source: Molenaar, A. op. cit., p. 4.

The most noticeable feature of these data is the increase in costs that has occurred over the period of record. Several factors--such as the increasing pumping lifts, the increasing sizes of wells, the changes in types of wells, and increasing depths of wells drilled--have been responsible for these increasing costs. These factors are discussed in later sections.

Previous to a discussion of the factors that influence pumping costs, one point must be made clear: For the most part, the costs presented above are theoretically determined; they are based on estimates of typical installations and typical plant operation. Because they have been worked out in cooperation with farmers, dealers, manufacturers, and ground water specialists, they are believed to be fairly representative. Specific research into pumping costs for various areas and types of installations would be useful in groundwater analyses such as this, and would strengthen the results.

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3/ "Brake horsepower tests on new tractor engines at the Nebraska Tractor Test Station indicate the following comparative efficiencies of liquid fuels:

Engines burning gasoline develop	9.72	H.P. hours per gallon.
Engines burning distillate develop	10.46	H.P. hours per gallon.
Engines burning diesel fuel develop	15.00	H.P. hours per gallon.

"By determining H.P. requirements for pumping an acre-foot of water, the gallons of fuel necessary can be computed from the above values for the different fuels. The fuel cost per acre-foot can then be calculated on the basis of prevailing fuel prices." Molenaar, A. Costs of Pumping Water for Irrigation, Davis, Univ. of Calif., Dept. of Irrigation, January, 1947. p. 3. Mimeographed.

Factors Affecting Water Costs

The important task in analyzing the factors that affect water costs is to separate them and examine each independently, insofar as possible. Among the more important variables are falling water table, number and size of pumping installations, power sources for pumping, volume of water pumped, and technological changes. As will be seen in the following discussion, these factors are not easily separated from each other: Water level declines have brought forth or been associated with changes in depth of well drilling, size of pumps used, type of pump used, etc.; each factor influences the cost of obtaining water, but seldom independently of other factors. In order to eliminate unnecessary confusion, each factor is discussed separately and its influence evaluated separately. Thus, although it is not possible to discuss the specific influence on water costs of multiple changes in multiple factors, the reader is cautioned to remember that a complicated relationship exists among the several factors.

Falling Water Table

A falling water table affects water costs by raising both the fixed annual charges and the variable pumping costs: Larger pumps and motors are required as pumping lifts increase; depth and size of well drilled may also be increased, as in Antelope Valley. The influence of these factors on total annual fixed charges is summarized in Table 6.1 for typical Valley pumping installations in 1925 and 1951. The increase in fixed charges for installations capable of supplying typical 40- and 80-acre alfalfa farms has been nearly fourfold.4/

Although the falling water table helped increase these costs, other factors were also important: Most irrigation wells drilled in the Valley since World War II have been gravel packed, a feature not prevalent in the interwar period, and well size has changed with respect to diameter as well as depth. Associated with these changes, a larger pumping unit (pump, motor, and accessories) has been necessitated both by increased lifts and the size of acreage typically irrigated from each well.

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4/ No comprehensive deflation of cost and price data has been undertaken in this study. As an illustrative example, however, components of the above-mentioned increase were deflated by both the "Purchasing Power of the Dollar" (U. S. Department of Commerce) and the "Index of Prices Paid by Farmers for Machinery" (U. S. Department of Agriculture). The results indicate a twofold increase, slightly less than one-half the above-indicated apparent increase.

Variable pumping costs may be calculated from two approaches: In the first method, cost estimates per acre-foot for various total pumping lifts may be based on the assumption of a uniform power rate per kilowatt-hour used.[5/] This method does not take into account the influence of such factors as variation in total volume of water pumped, and--as pumping lifts increase--the slight decrease in efficiency and the larger motors or engines required, which consume relatively greater amounts of kilowatt-hours per acre-foot of water pumped. This method of calculating variable pumping costs from estimates of pumping cost per acre-foot reduces to a straight-line formula of very limited value.

The second method of estimating pumping costs is based on the power schedule for electricity in the area, the volume of water pumped, and the rate of pumping. This method uses the procedure for determining kilowatt-hour requirements outlined above, but corrects the cost calculation to reflect both the volume of water pumped and the variations in power rates for different sizes of electrical motors. Table 6.3 presents typical pumping costs per acre-foot of water associated with three different sizes of pumping plants and four different amounts of water applied.

Either method of estimating pumping costs indicates an increase in pumping costs as water tables fall. But there are compensating variables: changes in efficiency, changes in electrical power rates over time, and a preferential bias in power charges for large (over 100 h.p.) pumping units. An improvement in efficiency of 10 per cent permits pumping at the same cost from a depth of 35 to 45 feet greater than before. It may be seen in Table 6.2 that changes in power rates and in efficiencies permit pumping from greater depths at no change in cost of pumping. Table 6.3 shows that a change from power schedule PA-31 to PA-P2 (permissible when demand horsepower exceeds 100 h.p.) permits pumping at the same cost from depths 100 to 250 feet greater than before.

Effect of Number and Size of Pumping Units

One feature of the Valley's ground-water stock resource (stressed in Chapter 3) is the large number of thin aquifers characteristically encountered

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5/ The number of kilowatt-hours theoretically required to left one acre-foot of water may be calculated from the formula:

$$\text{Kilowatt-hours} = 1.024 \; \frac{\text{Total lift in feet}}{\text{Over-all efficiency of the pumping plant}}$$

Average billing rates per kilowatt-hour are available for most areas.

TABLE 6.3

Typical Pumping Costs Per Acre-Foot for Variable Rate and Volume of Pumpage, Using Electrical Power a/

Rate and volume of water pumped	Total pumping lift										
	100 feet	150 feet	200 feet	250 feet	300 feet	350 feet	400 feet	450 feet	500 feet	550 feet	600 feet
	dollars										
450 gallons per minute on a 40-acre farm											
100 acre-feet (2.5 acre-feet per acre)	3.33	4.61	6.41	7.36	8.47	9.11	10.41	12.52	13.20	15.15	16.11
200 acre-feet (5.0 acre-feet per acre)	2.54	3.44	4.82	5.48	6.39	6.95	7.96	9.43	10.01	11.31	11.97
250 acre-feet (6.25 acre-feet per acre)	2.35	3.17	4.43	5.20	5.96	6.44	7.71	8.65	9.97	10.46	11.05
300 acre-feet (7.5 acre-feet per acre)	2.19	2.98	4.03	4.73	5.52	5.77	7.03	8.14	8.69	9.84	10.43
900 gallons per minute on an 80-acre farm											
200 acre-feet (2.5 acre-feet per acre)	3.34	4.36	5.95	7.03	7.97	8.61	5.08 b/	5.74	6.25	6.91	7.57
400 acre-feet (5.0 acre-feet per acre)	2.54	3.32	4.52	5.48	6.15	6.70	4.69 b/	5.28	5.75	6.37	6.95
500 acre-feet (6.25 acre-feet per acre)	2.35	3.08	4.18	5.09	5.69	6.30	4.61 b/	5.18	5.69	6.26	6.83
600 acre-feet (7.5 acre-feet per acre)	2.19	2.90	3.92	4.78	5.38	5.93	4.56 b/	5.12	5.63	6.19	6.75
1,800 gallons per minute on a 160-acre farm											
400 acre-feet (2.5 acre-feet per acre)	3.10	4.11	2.68 b/	3.28	3.94	4.49	4.99	5.63	6.14	6.79	7.36
800 acre-feet (5.0 acre-feet per acre)	2.39	3.20	2.49 b/	3.04	3.63	4.15	4.65	5.21	5.73	6.39	6.85
1,000 acre-feet (6.25 acre-feet per acre)	2.22	2.97	2.45 b/	3.00	3.57	4.08	4.58	5.14	5.65	6.21	6.74
1,200 acre-feet (7.5 acre-feet per acre)	2.09	2.81	2.42 b/	2.96	3.53	4.03	4.53	5.09	5.59	6.15	6.68

a/ Includes lubricant and repair charge of $0.25 per acre-foot. Assumes 60 per cent over-all efficiency of the pumping plant. Based on Power Rate Schedule PA-31 and PA-P1 of the Southern California Edison Company.

b/ At these lifts a change in Power Rate Schedules takes place because demand horsepower exceeds 100 h.p. at the pumping plant.

Source: Appendix Tables C.9 to C.12. Snyder, J. Herbert. op. cit.

in any single vertical section of the alluvial fill. It has also been stated that in Antelope Valley deep wells of large diameter have become necessary to assure that adequate amounts of water can be withdrawn as needed. It is true that large, deep wells satisfy this requirement, but so will several smaller, relatively shallow wells. Would not four wells pumping at rates of 450 gallons per minute supply the water for 160 acres of alfalfa more economically than one well pumping at a rate of 1,800 gallons per minute? The thin aquifers could certainly supply the smaller draft, and the initial cost of well drilling and the cost of a smaller pumping unit is much less. But, referring to Appendix Table 9, a comparison of the 450-gallon-per-minute unit with the 1,800-gallon-per-minute unit reveals a substantial saving in initial cost by using the larger unit. Four small units would cost $33,600 as compared with the cost of one large unit of $21,500. Furthermore, the cost of pumping per acre-foot of water would be less with the large unit than with the several small units. Referring to Table 6.3, it will be seen that, for a 450-gallon-per-minute unit pumping 5 acre-feet per acre from a 250-foot lift, the cost is $5.48 per acre-foot. For similar conditions, using the 1,800-gallon-per-minute unit, the cost per acre-foot is $3.04. Thus, both fixed and variable costs have influenced the shift from a large number of small pumps to a relatively smaller number of large pumps.[6/]

It is not easy to assess the influence on ground-water utilization of changes in the number and size of pumps. Theoretically, removal of a given volume of ground water from a specified volume of aquifer in a given period of time may be accomplished equally well by one large pump or several small pumps so long as the aquifer can supply the draft requirement of the large pump. Where many thin aquifers are present, as in Antelope Valley, large pumps may draw ground water from some of the aquifers more rapidly than the rate of replenishment within the aquifer, thus interrupting hydraulic continuity. This may, therefore, dry up, temporarily at least, the small, more shallow wells in the immediate vicinity. At the least the ground-water level (or the pressure surface) will show sudden and rapid declines during each pumping season.

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6/ An examination of available statistics for Antelope Valley indicates an average of 35 acres per pump unit in 1930, 40 acres per pump unit in 1940, and 50 acres per pump unit in 1950. The increase in average acreage per pump substantiates the statement of a shift from small pumps to larger pumps.

From a practical economic standpoint, the use of larger pumps and deeper wells not only allows a farmer to contend with rapidly and widely fluctuating water levels but also permits pumping from greater depths than when using small pumps and shallow wells. To pump 5 acre-feet from a depth of 200 feet at a rate of 450 gallons per minute costs $4.82 per acre-foot (Table 6.3). At the same cost, 5 acre-feet can be pumped from about 400 feet at a rate of 1,800 gallons per minute, based on power schedule PAP-1.

Differences in Power and Fuel Costs

Although electrically powered pumping units account for nearly all of the total annual draft on ground water in Antelope Valley, other energy sources are used to a small degree: A few diesel engines and a few gasoline engines still pump ground water for irrigation. At present, diesel-powered units do not compete favorably with electrically powered units. Gasoline-powered units compete even less favorably. In the period from 1920 to 1930, diesel- and gasoline-powered units were on a more favorable level of competition, but a general reduction in electrical power rates at the end of this period shifted the balance farther in favor of electrically powered units.

Electrically powered units possess at least two advantages: First, substantial economies of scale accrue to users of large amounts of electrical energy. The "block system" of decreasing charges per kilowatt-hour as larger amounts are used is not duplicated for users of diesel and gasoline fuels. Some saving may be obtained from volume purchases of these fuels, but nothing like that offered by the electrical block system. With diesel or gasoline fuels, the variable cost per acre-foot of water pumped remains relatively constant as volume increases; with electrical power, this cost goes down.

Second, the costs of repairs, lubricants, and attendance are higher for engine-driven units than for motor-driven units: The attendance cost is negligible for motor-driven units, but about $0.40 per acre-foot of water pumped for engine-driven units. Totals for the three items average about $0.25 per acre-foot for motor-driven units and about $0.90 per acre-foot for engine-driven units (Table 6.3). Storage facilities and timing of fuel deliveries present further problems for these units.

The possibility of using energy sources not currently used in the Valley should not be overlooked: Natural gas power and electrical energy derived from atomic fission or fusion may both be potential energy sources for pumping ground water.

A recent study at the University of Arizona compared the costs of using electrical energy with the costs of using natural gas in pumping ground water.7/ A cost advantage of natural gas over electric power was observed, varying from about $1.25 per acre-foot at 150-foot lifts to $4.25 per acre-foot at 300-foot lifts. This permits pumping--at a given cost--from lifts 100 to 150 feet greater with natural gas than with electrical power. The cost advantage of gas over electricity increased as the total pumping lift increased, within the range of pumping lifts studied.

Prior to December 1, 1951, natural gas was not available in Antelope Valley. On that date the Southern California Gas Company, by arrangement with the Pacific Gas and Electric Company, tied into the latter's 34-inch Texas line near Mojave, some 25 miles north of Lancaster. This made natural gas available to Lancaster and vicinity. Two factors prevent a major shift from electrically powered to natural-gas powered pumps by the agricultural sector, however. Not only would the cost of laying new gas mains to the various farms be prohibitive but the amount of natural gas permitted to any one customer is limited. It does not seem likely that natural gas will be appreciably used for pumping ground water in Antelope Valley in the near future. Furthermore, the cost differential between electrical power and natural gas is not so favorable in California as that observed in Arizona.

Although still in the pilot plant stage, the generation of electricity from atomic reactors has taken place.8/ Two major studies of economic and social aspects of atomic power have been undertaken and an extensive bibliography is accumulating in this field of study.9/ On the basis of varied

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7/ Rehnberg, Rex D. "Costs of Pumping Water Compared." Progressive Agriculture in Arizona. University of Arizona, vol. 4, no. 3, October, November, and December, 1952, pp. 3 and 12.

- - - - - "The Cost of Pumping Irrigation Water, Pinal County, 1951." Bulletin 246. Agricultural Experiment Station, Univ. of Arizona, Tucson. January, 1953. 27pp.

8/ The first known use of electric power generated from atomic energy took place at the Reactor Testing Station at Arco, Idaho, on December 20, 21, and 22, 1951. Power was generated at a rate in excess of 100 kw. U. S. Atomic Energy Commission. Eleventh Semiannual Report of the Atomic Energy Commission. Washington, Govt. Print. Off., January, 1952. p. 21.

9/ Schurr, S. H., and J. Marschak. Economic Aspects of Atomic Power. Cowles Commission and Princeton University Press. 1950. 289pp.

Isard, W., and V. Whitney. Atomic Power. New York, The Blakiston Co., 1952. 235pp.

Both of these books contain extensive bibliography lists.

assumptions, estimates of the cost of generating electrical energy vary from 4 to 14.5 mills per kilowatt-hour, as compared with existing costs for hydro- , oil- , and coal-powered electricity generation varying from 1+ (hydro) to 11 (coal) mills per kilowatt-hour.[10/] Generation of electrical energy from atomic energy at costs below coal- and oil-powered generation and at a comparable or slightly lower cost than hydro-powered generation would result in a decreased cost of electrical power to consumers. With respect to ground-water utilization, reductions in electrical power rates would permit pumping from increasingly greater depths.

The Volume of Pumpage

As pumpage volume increases, cost of pumping per acre-foot for a given lift and at a given rate will decrease when the energy source is electrical power. Table 6.4 presents typical pumping cost data for three rates of pumping and four volumes of pumpage with pumping lifts of 250 feet. The cost differential affects the marginal (added) cost of water significantly, though not enough to bring the total cost of pumping 6.25 acre-feet below the total cost of 5.0 acre-feet.

One of the unknown factors in plant-water relationships in Antelope Valley is the yield variation that may be expected when the amount of water applied to crops is varied. Sufficient investigation has taken place to enable the specification of minimum consumptive-use requirements (pp. 70 to 73). No satisfactory data are available on the quantitative variation in yield in arid areas if this minimum volume is increased.[11/] An investigation in the Salt River Valley of Arizona reveals an increase in alfalfa

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10/ Within the United States, existing costs vary from 1+ to 8 mills per kilowatt-hour, with an average of 5-6. Cf. footnote 9. See also:

Isard W., and J. B. Lansing. "Comparisons of Power Cost for Atomic and Conventional Steam Stations." The Review of Economics and Statistics, vol. XXXI, no. 3. August, 1949. pp. 217-228.

Shannon, R. H., J. D. Selby, and M. B. Dagan. "A study of electric power generation utilizing heat energy from power breeder reactors." AECD-3444. Oak Ridge, Tennessee, November 19, 1951. (U. S. Atomic Energy Commission, Tech. Inf. Service.) Photostatic copy. 21 p. Declassified, August 27, 1952.

11/ Some experimental studies in semi-arid areas indicate no significant total yield increase as soil moisture is increased above the permanent wilting percentage. An extensive review of the literature is contained in Soil Moisture in Relation to Plant Growth, Veihmeyer, F. J., and A. H. Hendrickson, Univ. of California, November, 1949. Mimeographed. 40 pp.

yield of about 1 ton per acre (from 7 to 8 tons) as the volume of water applied is increased from 5 to 6.25 acre-feet per acre.[12/]

TABLE 6.4

Influence of Volume of Pumpage on Cost of Pumping Ground Water [a/]

Rate of pumping	Volume of pumpage [b/]	Pumping cost (variable cost)	Overhead expense (fixed cost)	Total cost
gallons per minute	acre-feet	dollars per acre-foot		
450	100	7.36	6.77	14.13
450	200	5.48	3.38	8.86
450	250	5.20	2.70	7.90
450	300	4.73	2.26	6.99
900	200	7.03	5.85	12.88
900	400	5.48	2.93	8.42
900	500	5.09	2.34	7.43
900	600	4.78	1.95	6.73
1,800	400	3.28	4.33	7.61
1,800	800	3.04	2.17	5.21
1,800	1,000	3.00	1.73	4.73
1,800	1,200	2.96	1.44	4.40

a/ Figures presented are for electrically powered units with a total pumping lift of 250 feet. Power rate schedule is PA-31, except for the 1,800 g.p.m. unit, which is based on power rate schedule PA-P1

b/ The four volumes listed for each rate of pumping are equivalent to 2.5, 5.0, 6.25, and 7.5 acre-feet per acre. See Table 6.3, the column headed "Rate and volume of water pumped."

Sources: Appendix Table 9 and Table 6.3

If a similar situation exists in Antelope Valley, then decreased unit cost per acre-foot as pumpage volume is increased will result in an increased volume of pumpage by the individual farmer. For example, increasing alfalfa hay yield from 6.2 to 7.2 tons per acre would increase total production costs by $10.81 while total receipts would be increased by $23.75 (see Table 6.5)[13/]--a $12.94 excess of total returns over total cost that is attributable

12/ The Salt River Valley is climatically similar to Antelope Valley. Marr, J. C. "The use and duty of water in the Salt River Valley." Tucson, July 1, 1927. pp. 63-97. Cf. especially Figure 4, p. 78. (Ariz. Agr. Exp. Sta. Bul. 120.)

13/ This is applicable to a total pumping lift of 250 feet. It is assumed that increasing the amount of water applied from 5.0 to 6.25 acre-feet per acre would produce this increase in yield.

TABLE 6.5

Variations in Yield and Net Returns as Influenced by Increasing the Volume of Water Applied to Alfalfa in Antelope Valley[a]

	Case I: Water cost variable per acre-foot[b]		Case II: Water cost fixed per acre-foot[c]	
	Original level of application	Increased level of application	Original level of application	Increased level of application
	acre-feet per acre			
Volume of water applied	5.0	6.25	5.0	6.25
	tons per acre			
Alfalfa yield[d]	6.2	7.2	6.2	7.2
	dollars per acre			
Cost of production, excluding variable water cost	113.92	121.22	113.92	121.22
Variable water cost (pumping cost)	26.05	29.56	26.05	32.56
Total cost of production	139.97	150.78	139.97	153.78
Marginal cost of increasing production from 6.2 to 7.2 tons per acre	--	10.81	--	13.81
Total revenue at $23.75 per ton	147.25	171.00	147.25	171.00
Marginal revenue from increasing production from 6.2 to 7.2 tons per acre	--	23.75	--	23.75
Net revenue	7.28	20.22	7.28	17.22
Excess of marginal revenue over marginal cost with increased yield	--	12.94	--	9.94

a/ Hypothetical data, 160 acres in alfalfa.

b/ Based on Table 6.4.

c/ Assume $5.21 per acre-foot.

d/ The yield increase, as pumpage volume increases, is an assumption of this study.

Sources: Table 6.3 and text, pp. 107-110.

to irrigating for increased yield.[14] If no reduction in cost occurred as the volume of pumpage increased, the incentive to increase volume of pumpage would not be so great: The excess of total returns over total cost associated with the increased yield would be $9.94.

Controlled irrigation experiments in the Valley would reveal to what extent this yield-irrigation relationship exists and would also indicate points at which it would no longer be profitable to increase the volume of irrigation water applied. If the relationship is substantiated for arid areas, a clear conflict between conservation of water resources and economic utilization of the same resources will be established. Although minimum crop requirements (consumptive use plus application losses) may be less than 5 acre-feet per acre for alfalfa (Appendix Table 6), increased returns may easily predicate using larger volumes of irrigation water than the minimum.

This general cost-price-yield relationship further emphasizes the benefits gained by using electrically powered pumping units instead of diesel or gasoline units: Increasing the pumpage volume reduces water cost per acre-foot when using electrical energy, but similar economies do not result when using gasoline or diesel units. Such pumping cost reductions serve to extend the depth from which ground water may be pumped. This, in turn, increases the ability of ground-water users to deplete the ground-water stock resource.

Technology and Pumping Costs

In spite of the presence of overdraft, Antelope Valley water users have expanded agricultural production and intensified overdraft. The several factors discussed have combined to encourage this. So long as it remains profitable to pump ground water for irrigation of crops that consume large amounts of water, pumping will continue despite the declining water level.[15] The result has been the mining of a stock resource--the ground-water resource of Antelope Valley.

An element of technological change may be observed in the several factors influencing pumping costs (technology, as applied to the pumping

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14/ This is equivalent to saying that net profit per acre is $12.40 greater if 7.2 tons per acre are produced as compared with 6.2 tons per acre. Technically, it may be stated that the excess of marginal returns over marginal reserve is $12.40 per acre as the yield is increased from 6.2 to 7.2 tons per acre.

15/ The relationship of crops (and their water requirements) to the cost of pumping ground water will be discussed in the next chapter.

units, implies several features--such as pumping efficiency, size and number of pumps, and type of pumps):

The influence of pumping efficiency on water costs has been pointed out. Pumping efficiency arises from two sources: (1) the power unit, which may be a direct-connected unit (electric motor) or an indirect-connected unit (engines), with belt drive or gear head; and (2) the pump itself.16/ The greater the number of steps between power input and water output, other things being equal, the less efficient the pumping unit. Thus, direct-drive units have a higher efficiency than indirect-drive units. During the twenties, the majority of Antelope Valley pumping plants were indirect-drive units, and the majority of these were belt-driven plants. High speeds of operation resulted in belt slippage and further efficiency loss. The average over-all efficiency of belt-driven plants in Antelope Valley during this period was less than 40 per cent, with a maximum of about 50 per cent. A few gear-head units of slightly greater efficiency raised the average for all plants in the area to about 45 per cent. Belt-driven and gear-head plants are nearly extinct in the Valley. It is now estimated by Southern California Edison Power Company that a typical over-all efficiency for newly-installed large pumping plants is about 60 per cent, with 65-70 per cent efficiencies not uncommon.

The size of pumping unit (pump and motor) typical for a given installation has undergone a pronounced change in the period 1920-1950: Larger motors have become necessitated by the declining water table.

The type of pumping unit has also changed: In the early twenties, pit pumps were a common sight in Antelope Valley.17/ Simple centrifugal units were placed in pits dug to depths of 25 feet or more. As water levels continued to drop and the pits could not be economically deepened, a change was necessary. Fortunately, the deep-well turbine pump had become popular by then, and an easy shift from single-stage centrifugal pit pumps was possible.18/ Though the early deep-well turbine pumps were excessively heavy and not much more efficient than the pumps they replaced, pumping costs

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16/ Over-all pumping efficiency is the product of pump efficiency multiplied by motor (engine) efficiency.

17/ Personal interview, William Keller, Lancaster.

18/ Bennison, E. W. Ground Water. St. Paul, Minnesota, Edward E. Johnson, Inc., 1947. pp. 381-382.

were nevertheless reduced--and additional unit-cost reductions have resulted as improvements have been made.

Technological innovations in pumping have so far been able to keep slightly ahead of the pumping limits forecast from time to time. Several types of improvement in the pumping units themselves have combined with reductions in electrical energy rates to permit pumping from increasingly great depths. The ground-water stock resource is being "mined," and continued overdraft is the result. The cost of pumping is small enough relative to total cost of production that it is profitable and rational for the farmers to act as they have.

The biggest and most important question raised is: "How long will it continue to be profitable to mine the ground water?" The answer to this question is related to what may be called the economic limit of pumping, which is considered at length in the next chapter.

Chapter 7

Pumping Costs and the Selection of Farm Enterprises

The next step in considering the economic aspects of ground-water utilization is to relate various types of farm enterprises to the costs of ground-water utilization. Ideally, such a step would include detailed information, from farms in the area under study, covering the costs and returns associated with the most typical farm enterprises and detailed information on their pumping unit and ground-water setting. Such detailed field work was beyond the scope of this ground-water study. It has, therefore, been necessary to synthesize cost and return data for several farm enterprises and relate this to available information concerning the ground-water economy of Antelope Valley. Research providing such basic data would strengthen future ground-water studies.

Enterprise Selection

Research and experimentation in the selection of crops for the Valley have begun only in the last few years, at the Antelope Valley Field Station of the University of California. Various crops have been grown in an effort to discover those readily adaptable to the area. It has been found that with reliable irrigation nearly all major field and vegetable crops can be grown.1/ Extended studies have not been made on the economic suitability of various crops to the area, but preliminary indications tend to substantiate the trial and error process of early farmers that made alfalfa the primary crop grown in the Valley.

Not all crops grown at the Field Station are ideally adapted to the area: Watermelons and other melons are easily grown there, but are subject to serious competition from other major producing areas of the state. To meet this competition effectively, the timing of harvest operations should be so governed that Antelope Valley production arrives on the market between arrivals from other areas. This would be difficult to achieve.

Early potatoes are in a similar economic situation, with production from the Valley in direct competition with the potato producing area of the

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1/ A partial list of the crops successfully grown at the Field Station includes alfalfa, irrigated pasture, field corn, sweet corn, wheat, milo maize, broomcorn, melons, watermelons, squash, onions, carrots, sugar beets, cotton, strawberries, lettuce seed, clover seed, alfalfa seed, bush berries, castor beans, Lima beans, field beans, sweet potatoes, and potatoes.

southern San Joaquin Valley. Between 1941 and 1951, California state annual average prices have varied from $1.06 to $2.67 per hundredweight, with even greater fluctuations within a single season. An inelastic demand for this commodity leads to early market saturation.2/ Because of its perishable nature, the commodity cannot be stored and marked declines in market price therefore occur. High management incomes result if the product reaches the market at an appropriate time; otherwise substantial losses are incurred.

Castor beans appear to return a more than satisfactory management income, but two serious problems are found with this crop: First, the plant has a great tendency to shatter in harvest, which with a 30 per cent loss will reduce management income nearly to zero for most pumping lifts. Second, toxicity of castor beans to livestock constitutes a risk hazard.

For these reasons, the above three crops are not emphasized in the subsequent analysis. Few of the other crops grown at the Field Station have been included, because of a lack of appropriate technological knowledge on the part of the farmer or because of lack of suitable harvesting, processing, or marketing facilities.3/ Tree fruit crops have been omitted because of their relative unimportance in the Valley. Most of the land available for future agricultural development is not suitable for tree fruit production. Except for irrigated pasture for beef production, livestock enterprises have been omitted because of the insignificant consumption of water by livestock in the area. The enterprises selected represent single enterprise studies. That is, no intrafarm rotations or complementary-supplementary relationships are included. It is believed that such intrafarm combinations of enterprises would not materially affect the results obtained in the later sections of this chapter.

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2/ In 1950, so much "cotton land" in the southern San Joaquin Valley went into early potato production that the potato market "broke," because of the relatively low demand elasticity for this crop. "The heavy shipments [of early potatoes from Kern County] practically demoralized the market." U. S. Production Marketing Administration and California Department of Agriculture, Bureau of Market News. Marketing Kern District Early White Long Potatoes. Summary of 1950 Season. April, 1951. p. 1.

3/ Two examples to illustrate the point may be cited: The specialty truck crops, such as lettuce, lettuce seed, carrots, table beets, etc., require adequate technological knowledge on the part of the farmer and an adequate supply of stooped labor to provide cultural labor for the crops. Sugar beets have been grown, but delays in harvesting due to lack of equipment have caused farmers to suffer losses, because of post-maturity decline in the sugar content of the beets. Furthermore, sugar beets have suffered from "scalding" as a result of improper irrigation.

Economic Norms

Economic norms used in this portion of the study have been synthesized in the form of typical crop yields, prices received for crops, and costs of production. Table 7.1 summarizes this information.

Yield estimates are assumed to be the typical yields under average-to-good management that would be consistent with a minimum application of irrigation water--except for the alfalfa yield of 7.2 tons per acre, which is based on a typical irrigation application. The prices received for the various crops have been estimated by using 1946-1951 averages of the prices received by California producers. The prices received by farmers in Antelope Valley for alfalfa hay have traditionally averaged $1 to $2 per ton above the annual state average because of the higher quality of hay grown in the area.[4/] Because of lack of information on prices received by Antelope Valley growers for the other crops being considered, this differential was not included, making possible a more direct comparison between the prices received and resulting incomes from the several crops.

Costs of production are based on 1946-1951 average costs for materials and labor, and represent typical operations of 160-acre enterprises for that period in Antelope Valley.[5/] This period has been selected for use in this discussion because the cost-price relationships reflect the most recent methods of culture and the rather unstable but high-priced economy in which the farmer operates. The final entry in Table 7.1, management income plus fund for paying cost of pumping water, was derived by subtracting the total cost of production (excluding variable water costs) from the total receipts, on a per-acre basis.[6/] This sum includes return available to spend on pumping water for application to the crop, return to the operator for his managerial abilities, and payment for the risk and uncertainties incurred in agricultural production.

Income and the Falling Water Table: Alfalfa, 1920-1951

Historical variation in management income for Antelope Valley alfalfa enterprises is shown in Table 7.2 for four different periods. The periods

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4/ Alfalfa hay prices for Antelope Valley are available from the California Market News Service.

5/ Except for the dry-farmed wheat, which is based on an operation of 1,500 to 2,000 acres.

6/ Management income by itself is the payment allowed to the operator (manager) for his over-all farm investment, managerial activities, and risks and uncertainties incurred in agricultural production.

TABLE 7.1

Typical Yields, Costs, and Returns for Various Crops in Antelope Valley, Per-Acre Basis[a/]

	Alfalfa	Alfalfa (Contract baled)	Alfalfa	Castor beans	Field corn	Cotton	Milo maize	Irrigated pasture	Potatoes	Watermelons	Irrigated wheat (double cropped)	Dry-farm wheat
	Water application											
	5.0 acre-feet		6.25 acre-feet[b/]									
Crop yield per acre	6.2 ton	6.2 ton	7.2 ton	1.0 ton	50 cwt.	600 lb. lint	40 cwt.	600 lb. gain in weight	250 cwt.	10 ton	42 cwt.	5 cwt.
	dollars											
Returns per unit of production	23.75	23.75	23.75	180.00	2.75	0.295	2.55	0.20	2.05	20.00	3.16	3.16
Total returns	147.25	147.25	171.00	180.00	137.50	204.00[c/]	102.00	120.00	520.00[d/]	200.00	132.72	15.80
Costs of production												
Cash cost, excluding water	62.11	69.86	69.41	64.95	66.90	138.39	39.58	31.15	428.50	105.16	58.46	10.37
Non-cash cost	49.69	49.69	49.69	44.11	43.97	44.42	43.97	56.94	63.49	43.97	45.90	2.65
Total cost, excluding cost of water (variable pumping cost only)	111.80	119.55	119.10	109.06	110.87	182.81	83.55	88.09	491.97	149.13	104.36	13.02
Management income plus fund for paying cost of pumping water	35.45	27.70	51.90	70.94	26.63	21.19	18.45	31.91	28.03	50.87	28.36	2.78[e/]

a/ 160 acre units assumed for all crops except dry-farmed wheat, which is for 1,500-2,000 acre operation.

b/ See Table .

c/ This includes $27.00 from the sale of 900 pounds of cottonseed.

d/ This includes $7.50 from the sale of 50 sacks of cull potatoes.

e/ Because no irrigation water is used, this entire amount is management income.

have been selected rather arbitrarily to conform with information available on costs of production and electrical power costs for pumping irrigation water. Two sets of factors have been averaged in developing these sets of information, one temporal, the other managerial. The entries for each of the four periods are assumed to be typical for the period under consideration, with some incomes above and others below the stated level. Furthermore, managerial abilities represented by the given costs of production are assumed to be typical for Antelope Valley during the specified periods. The word typical is used in a median sense: It is assumed that approximately 50 per cent of the operators in the Valley would have greater costs of production than those herein specified, and 50 per cent would have lower costs of production.

TABLE 7.2

Typical Costs, Returns, and Management Income for Alfalfa Hay, Antelope Valley, 1925-1952 a/
(per acre basis)

	1920-1929 b/	1930-1939 b/	1940-1949 c/	1946-1952 c/
	feet			
Assumed total pumping lift d/	90	130	165	200
	dollars			
Cash costs of production, excluding pumping costs	36.60	29.15	35.25	62.11
Noncash costs and repair costs e/	14.00	15.00	28.50	49.69
Pumping cost	15.25	13.00	16.75	20.50
Total cost of production	65.85	57.15	80.50	132.60
Returns per ton alfalfa	15.00	10.50	19.75	23.75
Total returns (6.2 T/acre)	93.00	65.10	122.45	147.25
Management income	27.15	7.95	41.95	15.05

a/ Assume water application of 5 acre-feet per acre.

b/ Typical for 40- and 80-acre alfalfa units.

c/ Typical for 120- and 160-acre alfalfa units.

d/ Typical for the period indicated.

e/ Depreciation and interest on pump, well, and distribution system constitute more than one-half of the non-cash costs.

Study of this information reveals that pumping costs have increased as the water table has fallen. Closer study indicates that the importance of pumping cost relative to total production cost has decreased from an average high of 23 per cent in the period 1920-1929 to an average low of

15.5 per cent in the period 1946-1951. This indicates that despite long-run overdraft on the ground-water stock resource of Antelope Valley the effect of increased costs of pumping ground water has been more than compensated by other factors. Some of these factors have already been discussed, others are to follow.

The period from 1920-1929 was one of general prosperity, with development moving steadily forward in Antelope Valley. The major economic depression of the thirties fell hard upon the Valley alfalfa farmer and caused much acreage to be abandoned. The decade of the forties, except for one or two years, brought with it a time of war-induced prosperity and an opportunity for the Antelope Valley alfalfa farmer to erase his debts and strengthen the financial structure of his farm.

Postwar increases in labor and materials costs and declines in water levels have combined to decrease the management income received by the alfalfa farmer in Antelope Valley. But the price received for alfalfa hay has risen measurably during this period absorbing some of the increased costs of production. A sharp and prolonged decline in alfalfa hay prices similar to the short decline experienced in California in late 1949 and early 1950 could lead to abandonment of some alfalfa acreage in the area.

Alfalfa and Other Crops: Present and Future

A variation in operator's earnings as pumping lifts increase has been synthesized for alfalfa and other crops, as shown in Table 7.3. Assumptions underlying this table are several: (1) Size of enterprise is approximately 160 acres. (2) Average 1946-1952 cost-price relations. (3) The pump, motor, and assembly are capable of handling an increase in pumping lift of about 100 feet before replacement is necessary. (4) Replacement of the old pump and motor is a capital expenditure incurred about every 100 feet, making only a small addition to total annual fixed charges and resulting change in operator's earnings. This permits the problem to be considered as one of change in pumping costs, not of change in fixed plus variable costs.

Until total pumping lift exceeds 450 feet, all listed enterprises yield positive returns. The farmer receives greater returns per acre from alfalfa than from the other crops, with the exception of watermelons and castor beans. Because of the greater volume of water used for the several alfalfa enterprises and irrigated pasture than for the field crops, the rate of decrease in returns as pumping lift increases is greater with the alfalfa and pasture enterprises.

TABLE 7.3

Typical Management Income Associated with Variable Pumping Lifts for Several Crops in Antelope Valley a/

Crop	Water application	Yield	Total pumping lift, feet					
			100	200	300	400	500	600
	acre-feet per acre	per acre	dollars per acre					
Alfalfa	5.0	6.2T	23.50	23.00 b/	17.30	12.20	6.80	1.20
Alfalfa	6.25	7.2T	38.02	36.59 b/	29.59	23.27	16.59	9.77
Alfalfa (contract baled) c/	5.0	6.2T	15.75	15.25 b/	9.55	4.45	- 0.95	--
Castor beans	2.5	2,000 pounds	64.59	59.64	55.56	59.21 b/	56.56	53.56
Field corn	2.5	5,000 pounds	20.28	15.33	11.25	14.90 b/	12.25	9.25
Cotton	2.5	600 pounds	14.84	9.89	5.81	9.46 b/	6.81	3.81
Milo maize	2.5	4,000 pounds	12.10	7.15	3.07	6.72 b/	4.07	1.07
Irrigated pasture	5.0	600 pounds gain	19.96	19.46 b/	13.76	8.66	3.26	--
Potatoes	2.5	2,500 pounds	21.68	16.73	12.65	16.30 b/	13.65	10.65
Watermelons	2.5	10T	44.52	39.57	35.49	39.14 b/	36.49	33.49
Irrigated wheat (double cropped)	2.5	4,200 pounds	22.01	17.06	12.98	16.63 b/	13.98	10.98

a/ 1946-1951 average cost-price relationships assumed.

b/ Discontinuities occur as demand horsepower reaches a level of 100 H.P., which permits shifting to a more favorable power rate schedule.

c/ Two enterprises assume a water application of 5 acre-feet per acre per year; one of these is contract baled while the operator performs his own baling on the other. The third alfalfa enterprise assumes a water application of 6.25 acre-feet per acre per year, operator-performed baling, and a higher yield than the other two. This yield increase is based on an investigation in the Salt River Valley of Arizona in which a 1-ton increase in alfalfa yield occurred (from 7 to 8 tons) as the volume of water applied was increased from 5 to 6.25 acre-feet per acre. Marr, J. C. "The Use and Duty of Water in the Salt River Valley." Tucson, July, 1927. pp. 63-97. (Ariz. Agr. Exp. Sta. Bul. 120.)

On the basis of these relationships, it follows that rigid conservation of the ground-water stock resource--i.e., the exclusion of mining by restricting draft to the safe-yield volume--and maximization of individual farm incomes are not necessarily consistent long-run objectives.7/ Furthermore, maximum

7/ As used herein, conservation is defined in terms of ". . . changes in the intertemporal distribution of use. In conservation, the redistribution of use is in the direction of the future; . . ." Ciriacy-Wantrup, S. V. Resource Conservation, op. cit., pp. 51-53.

net social income over the long run is not necessarily consistent with rigid resource conservation.

Two factors bear directly upon this issue for Antelope Valley:

First, the hypothesis has been put forward that Valley farmers apply too much irrigation water to their alfalfa crops. That is, they exceed minimum theoretical requirements based on consumptive use (see Appendix Table 6). The corollary states that it will "soon" be uneconomic to pump irrigation water. Projecting the relationships and assumptions of Table 7.3 indicates that water levels can decline to a 400-600-foot level before negative returns are incurred, assuming no change in cost-price or technological relationships.

Second, the possible contradiction between rigid water conservation and maximization of farm income brought forth suggestions for shifts from alfalfa to crops that consume less water.8/ Excluding for the moment such specialty crops as watermelons and castor beans, theoretical transfers from alfalfa are not indicated until total pumping lift approaches 400 to 450 feet. Current experiments with field corn indicate a possible transfer at more shallow depths, especially for small farms with pumps discharging relatively small volumes of water.9/

In the Valley there is little incentive to transfer to crops that consume less water so long as alfalfa remains more profitable than most other crops currently grown there. Should transfer occur, the annual draft on ground-water stock resources that would be required to supply an estimated 65,000 acres10/ of low water-consuming crops would still exceed by three-fold the average annual recharge. The resource would be conserved by shifting the rate of use into the future, but overdraft would not be eliminated. The rates of overdraft and decline of ground-water levels would decrease, but favorable operator's earnings--decreasing differently for the several alternative crops--would continue to stimulate overdraft.

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8/ The term "duty of water" is not used in this discussion, for this reason: "The term duty of water . . . represents the relation between the area of land served and the quantity of water used. However, the term is somewhat confusing in its applications as a high duty of water represents a small amount of use and a low duty represents a large use." Etcheverry, B. A. and S. T. Harding. Irrigation Practice and Engineering. Vol. 1. Use of Irrigation Water and Irrigation Practice. p. 65.

9/ Experimental corn yields have exceeded 150 bushels per acre, but commercial yields approximate those indicated in Table 7.3.

10/ Estimated current total irrigated acreage in the Valley.

Price Variation and Enterprise Selection

A comparison of product-price variations and management incomes may be used to determine the price relationships necessary to make it profitable for a farmer to shift from alfalfa to crops that consume less water.[11/] Figure 7.1 has been constructed for alfalfa and four low-water-consuming enterprises--corn, potatoes, cotton, and double-cropped, irrigated wheat. In each comparison the diagonal line represents the positions of equal management returns per acre associated with the respective commodity prices. For example, a corn price of $3 per hundredweight will return to the operator the same management income as will an alfalfa price of $25 per ton for the standard alfalfa enterprise. The dots in each figure represent paired observations of average annual prices received by farmers for the crops.[12/] A dot falling below the line indicates that alfalfa was more profitable than the alternative enterprise; and above the line, vice versa. The dots plotted are for 1942-1951, inclusive. Figure 7.1 indicates that corn would have been more profitable than alfalfa two out of ten times, cotton and irrigated wheat three out of ten times, and potatoes eight out of ten times. The promise indicated for potatoes has already been discounted (see p. 114) because of unstable within-season demand and the perishable nature of the product.

Cotton, although not indicated as being more favorable than alfalfa for Antelope Valley, is an important factor in affecting the alfalfa situation in Antelope Valley. More important to Valley alfalfa growers than cotton grown in the area is the influence of cotton acreage allotments in other areas of California. In many areas of the San Joaquin Valley, cotton has replaced alfalfa because of the high price supports of the last two years (1951, 1952). Competition from San Joaquin and Imperial alfalfa in 1950, a year under cotton acreage allotments, accounted in large part for the severe drop in alfalfa prices received by Antelope Valley growers for that year. Alfalfa can be trucked to Los Angeles from southern San Joaquin Valley at approximately the same price it costs to truck from Antelope Valley.

Assuming the above-described price situation to have prevailed in Antelope Valley throughout most of its agricultural history, it is little wonder that alfalfa has been the favorite enterprise of the farmer. Even on an annual crop basis, alfalfa has consistently returned greater management income to farmers

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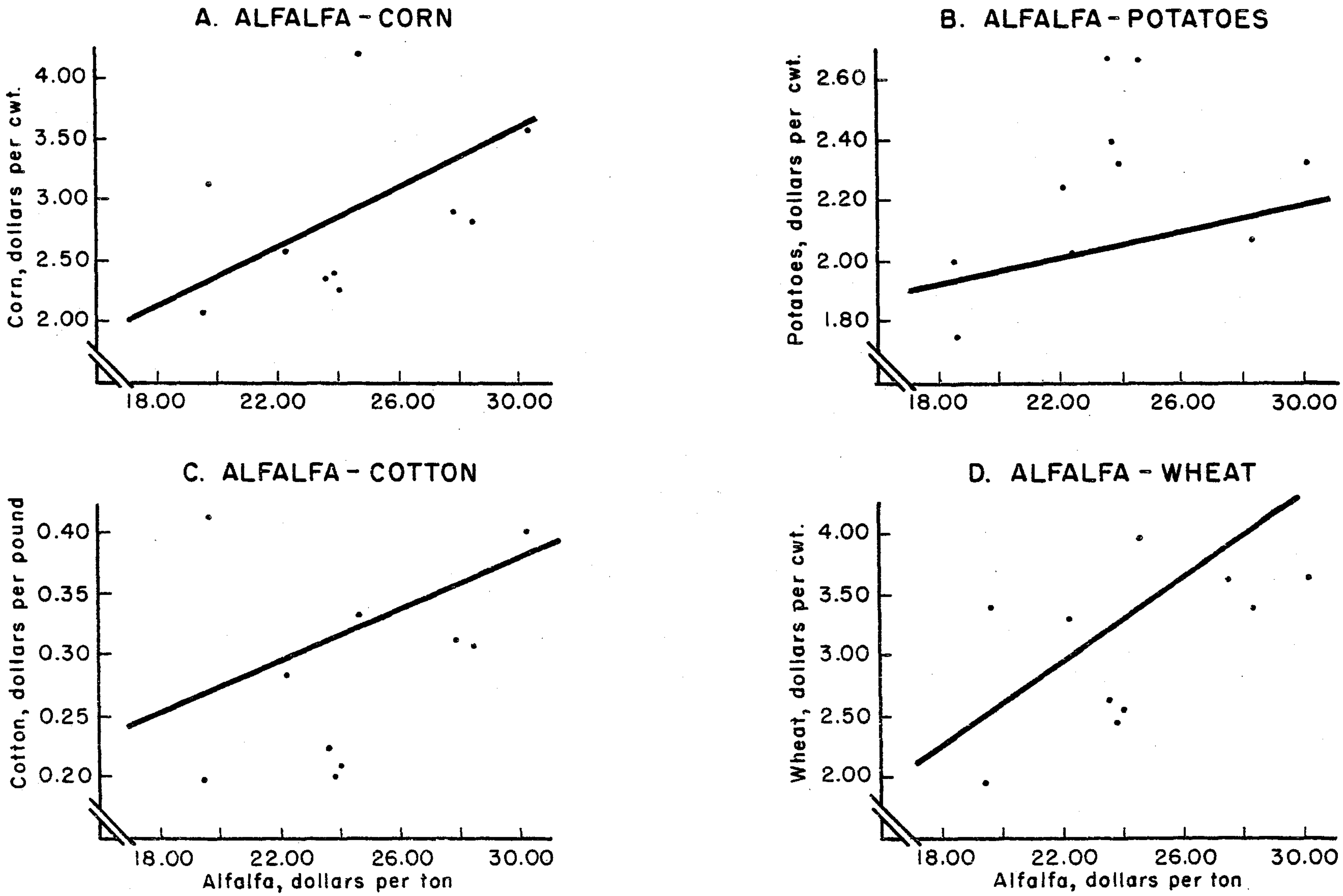
11/ The statements that follow relate only to the enterprises synthesized in this study.

12/ California state average annual prices received by farmer. See Appendix Table 10 .

Figure 7.1

MANAGEMENT INCOME AND COMMODITY PRICE VARIATION
ANTELOPE VALLEY 1942–1951[a]



a/ The line in each diagram represents prices of the crops which yield equal management income per acre.
Source: Table 7.5 Snyder, J. Herbert, op. cit.

than the low-water-consuming crops. Add to this the fact that alfalfa is a perennial crop that can be grown for five years or more without replanting and the already strong price advantage is improved.[13]

Acreage Variation and Overdraft

Changes in cost-price relationships may affect on-farm overdraft by bringing forth enterprise changes. If all farms in the Valley were to change, the total effect on overdraft would vary depending upon the type and extent of change. Shifts in enterprise acreage for the Valley could reduce overdraft and, under very strict circumstances, eliminate it.

Hypothetical shifts in crop acreage are assumed to evolve gradually from present acreages. In four cases, no change in total irrigated acreage (of approximately 65,000 acres) is anticipated for the Valley, while in one case reductions to 30,000 and 20,000 acres are assumed. The cost-price-yield relationships developed above are assumed for the period of projection, as are the relationships between management income and the water table, which declines from a 200-foot level in the several cases. Pumping plants in existence at the beginning of the period are assumed to be able to adjust to the increased pumping lifts. The only increase in cost that will occur is assumed to be in the variable pumping costs, as the pumping lift increases. Nonirrigated land use and incomes are assumed constant for the period. The projections are summarized in Table 7.4.

Case 1--No major changes in crop acreages. No major changes are assumed in crop acreages, and alfalfa remains the dominant crop. By 1963 the pumping lift will have increased about 69 feet beyond 1953 lift, as a result of a cumulative overdraft of 1,480,000 acre-feet for the period. Aggregate management income is estimated at $1,150,000 for 1963, a decrease of $110,000 from 1953 levels. The change is brought about entirely by increased costs of pumping, as the ground-water levels continue their decline. If the acreage under irrigation increases, overdraft and pumping lifts will increase and total earnings decrease.

Case 2-- Major shift from alfalfa to field corn. Major shifts from alfalfa to corn may occur because many small farms in the Valley are not equipped with pumping plants that can supply enough water to plant the entire farm to alfalfa. Large scale poultry enterprises in the Valley provide a

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13/ The individual farmer would hesitate to plow under a mature alfalfa stand in anticipation of a one-year price advantage for another crop, and then replant alfalfa.

Source: Table 7.5 Snyder, J. Herbert, op. cit.

TABLE 7.4

Projections of Antelope Valley Irrigated Agriculture for 1963

Case Number	Alfalfa	Field corn	Irrigated pasture	Miscellaneous fruit, field, and vegetable	Specialty vegetable	Total irrigated acreage	Estimated increase in pumping lift for 1954-1963	Total management income from all crops	Change in total management income compared with 1953
	acres						feet	dollars	
1	44,000	1,000	5,000	15,000		65,000	69	1,150,000	- 110,000
2	20,000	25,000	5,000	15,000		65,000	56	1,120,000	- 140,000
3_A	20,000	20,000	5,000	10,000	10,000	65,000	56	1,450,000	+ 190,000
3_B	5,000	20,000	5,000	10,000	25,000	65,000	47	1,950,000	+ 690,000
4		20,000		10,000	35,000	65,000	42	2,300,000	+1,040,000
5_A		10,000			20,000	30,000	33	1,200,000	- 60,000
5_B		5,000			15,000	20,000	24	860,000	- 400,000

local demand for feed that would be conveniently suppliable by local corn producers.[14]

It is assumed here that 25,000 acres are shifted from alfalfa to field corn. By 1963, the pumping lift will have increased only 56 feet and cumulative overdraft will be 1,200,000 acre-feet. Annual on-farm water savings will have amounted to about 1.2 acre-feet per acre. Total management income is estimated at $1,120,000, or $140,000 below 1953 levels. The difference is due to lower pumping costs resulting from a smaller increase in pumping lift, and lower earnings from corn than from alfalfa. The two factors act in opposite directions, but losses resulting from the shift will more than offset the gain from decreased pumping lifts.

Case 3--Major shifts from alfalfa to field corn and special vegetable crops. Two levels of shift are demonstrated, depending upon the degree of shift to specialty vegetable crops. Two factors combine to permit a supposition of shift to vegetable crops: First, rapid urbanization around Los Angeles is removing substantial acreage from commercial vegetable production. Second, the smog problem around Los Angeles area is hastening this abandonment of commercial vegetable crop acreage. Experiments at the Antelope Valley Field Station of the University of California indicate that such commercial vegetable crops as sweet corn, melons, watermelons, squash, bush berries, sweet potatoes, onions, carrots, beets, lima beans, and cucumbers can be grown successfully in Antelope Valley.

Case 3A assumes a shift of 10,000 acres to commercial vegetable crops of this type. By 1963, the pumping lift will have increased 56 feet beyond 1953 lift, as a result of a cumulative overdraft of 1,200,000 acre-feet. Total management income is estimated at $1,450,000 for 1963, or $190,000 above 1953 levels. This increase is primarily attributable to increased earnings associated with specialty vegetable crops. A slight contribution will also be made by decreased pumping costs associated with smaller increases in pumping lifts.

Case 3B assumes a shift to specialty vegetable crops of 25,000 acres and a corresponding reduction in alfalfa acreage. By 1963 the pumping lift will have increased 47 feet over 1953 lift, as a result of a cumulative overdraft of 1,020,000 acre-feet. Earnings are estimated at $1,950,000, or $690,000 above 1953 levels. This increase results from the increased earnings associated with specialty vegetable crops and smaller increases in pumping lift.

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14/ In 1953, Antelope Valley field corn production from 1,500 acres supplied less than 7 per cent of the annual feed-grain requirement of local poultry enterprises.

Case 4--Abandonment of alfalfa enterprises. If the volume of water that can be applied per acre is regulated by law and set at a level below the amount necessary to irrigate alfalfa, abandonment of alfalfa and irrigated pastures in Antelope Valley could result.[15/] It is assumed that specialty vegetable crops would absorb such acreage.

By 1963 the pumping lift will have increased 42 feet beyond 1953 lift, as a result of cumulative overdraft of 900,000 acre-feet. Total management income is estimated at $2,300,000, or $1,040,000 above 1953 levels. Greater earnings associated with specialty vegetable crops and lesser pumping costs associated with smaller increase in lifts combine to bring about aggregate earnings greater than those postulated in cases 1 to 3.

Case 5--Major reductions in irrigated crop acreage. Maintaining irrigated crop acreage in Antelope Valley at 65,000 acres will not reduce draft sufficiently to eliminate long-run overdraft at present levels of ground-water recharge. Case 5A assumes a reduction to 30,000 acres, all planted to field corn or specialty vegetable crops. By 1963 the pumping lift will have increased 33 feet beyond 1953 lift, as a result of a cumulative overdraft of 700,000 acre-feet. Total management income is estimated at $1,200,000, or $60,000 below 1953 levels. The severe reduction in acreage more than offsets the gains from shifting to specialty vegetable crops and pumping with more slowly declining levels.

Case 5B assumes a reduction to 20,000 irrigated acres, all planted to field corn or specialty vegetable crops. By 1963 the pumping lift will have increased only 24 feet beyond 1953 lift, as a result of cumulative overdraft of 510,000 acre-feet. Average annual draft and average annual recharge will finally be in balance, terminating the condition of long-run overdraft. Total earnings are estimated at $860,000, or a decrease of $400,000 from 1953 levels. For comparison, if all acreage is in alfalfa and the total acreage reduced until recharge equals draft, only 12,500 acres can be irrigated, reducing aggregate management income $1,030,000 below the 1953 levels--to $230,000 annually.

Any of the assumed shifts in crop patterns could occur in the Valley. It is unlikely, however, that acreage reductions sufficient to bring average annual recharge into balance with average annual draft will occur within the next ten years. Past experience indicates the profitability of mining the

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15/ A suggestion has been made to limit pumpage volume to 5 acre-feet per acre per year in Antelope Valley. This limitation would not cause major abandonment of alfalfa acreage. No official action has ever been taken on this recommendation, see p. 125.

ground-water resource. For example, using the ground-water stock at a safe yield rate (draft = recharge) and devoting the entire amount to alfalfa production, it is estimated that operators' earnings from alfalfa for the period 1927-1950 would have totaled less than $5,000,000. Actually, for only the period 1947-1950, alfalfa operators' earnings alone totaled $4,500,000. Thus income generated by mining the ground-water stock resource may easily exceed a perpetuity income resulting from maintaining balance between recharge and draft. Technologic and price changes have stimulated long-run overdraft through continued expansion of irrigated acreage.

Examination of historic price variation shows that, relative to many alternative crop possibilities, alfalfa has retained an advantage. Major shifts out of alfalfa would depend on satisfactory net returns from other crops, or restrictions on water use. One method by which the Valley can attain such an advantageous shift is to become a major producing area for specialty vegetable crops instead of a minor producing area competing with major areas. Thus, although major shifts in particular crops grown in the area may occur to conserve the ground-water stock resource and reduce overdraft, elimination of long-run overdraft is not a strong probability within the next ten years.

Economic Limits for Pumping Ground Water

Theoretical maximum expenditures for water can be forecast quite precisely, but the practical limit is less tangible. To specify the maximum water cost, all that needs to be done is to specify the minimum desired management income per acre, hold all other factors constant, and allow pumping costs to increase until the management income limit is reached: If it is assumed that the average present value of a 160-acre farm producing the irrigated crops analyzed in this chapter is $80,000 and that wages of management can be stipulated at 2 per cent of the value of the enterprise being managed, the necessary management income to produce this would be $10 per acre. Projecting 1946-1951 cost-price-yield relationships, this management income is associated with pumping lifts ranging from 200 to 600 feet and costs of pumping ranging from $13 to $43 per acre (or $7 to $15 per acre-foot of water), depending upon the crop.

This is not to say that Antelope Valley would cease to produce crops when the total pumping lift approached 600 feet, or that water costs in excess of $43 per acre would cause production to stop. Zero or even negative management incomes are frequently received by some enterprises. Management income is essentially a payment for encountering the risks and uncertainties of agricultural production. If the operator (who pays himself a variable labor wage, depending on the crop) is willing to forego this payment for risk and uncertainty, then total pumping lifts can be extended beyond the 600-foot limit.[16/] Furthermore, in periods of unfavorable prices, payments for depreciation and interest may be deferred and this money used to cover current cash costs. So long as cash costs in the short run are covered by enterprise returns, the operator will continue to produce.

Thus, the economic limit of pumping, or the limiting water cost, is a result of several factors--pumping cost per acre-foot, intensity of water application and crop grown, government acreage allotments, and supply-demand-generated price relationships among the several enterprises. The economic limit of pumping does not exist as a fixed concept: It is a changing concept over time, depending on actual and anticipated cost-price-technology relationships facing individual farmers and groups of farmers in a particular area.

With such complex situations, no simple statement of economic limits of pumping can be made. As a first approximation, and projecting the particular assumptions and findings of this paper, it appears that "mining" the ground-water stock resource will continue to be stimulated by economic pressures until total pumping lifts approximate 500 feet. Depending upon the rate of expansion or contraction in ground-water draft, these limits could be reached within 35 to 65 years. Periodic reexamination of the rate of depletion by "mining" and the level of revenues realized will be necessary because of changes in cost-price relations and technology.

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16/ In all probability, however, repair and maintenance costs, which increase very rapidly as pumping lifts exceed 300 feet, may serve to set economic pumping limits before even a 500-foot lift is reached.

Chapter 8

Action Programs for Combating Overdraft

Having concluded that economic forces have induced and perpetuated a condition of long-run overdraft in Antelope Valley, the discussion turns to a consideration of attempts to alleviate overdraft. Some activities discussed are not action programs but only investigations that may lead to positive action programs. All have influenced the battle against overdraft in the Valley.

In 1909 Johnson concluded that the area had not reached the limit of development of its underground waters, but he warned that all who had the interests of the region at heart must recognize its water limitations. He particularly warned about the abuse of artesian resources. In 1920 Thompson estimated that annual withdrawals had approached within 20 per cent of annual recharge (his estimate) and warned that future economic development might be limited. His advice was to keep average annual removal from ground water no more than average annual recharge. Since these early dates, local inhabitants have gradually recognized the presence of ground-water overdraft. This chapter presents the investigations and action programs undertaken in efforts to combat overdraft in Antelope Valley. Insofar as practical, chronological order is followed.

Investigational Programs and Activities

Activities of the Agricultural Extension Service and University of California relevant to combating overdraft have taken two forms: (1) sponsoring the Agricultural Program Building Conferences in 1940 and 1941, and (2) investigating suitable crops as alternatives to alfalfa. These were in response to requests for help by local farmers, as is the normal and logical procedure in State institutions.

The Antelope Valley Agricultural Program Building Conference

Meetings were called by the Agricultural Extension Service, one in 1940 and the second in 1941.[1/] The purpose was to plan for the best future development of Antelope Valley agriculture in cooperation with farmers presenting their

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1/ Most of the information on these meetings is from mimeographed reports issued by the Agricultural Extension Service, one at the conclusion of each conference: "Recommendations for the Agricultural Development of Antelope Valley by the Antelope Valley Agricultural Program Building Conference," Lancaster, March 20, 1940, and "Report of the Second Antelope Valley Agricultural Program Building Conference," Lancaster, April 16, 1941.

opinions as to the major agricultural problems affecting them. Representative farmers and businessmen attended the conferences together with representatives from the Soil Conservation Service, Agricultural Conservation Service, Farm Security Administration, Forest Service, and other agencies serving agriculture in the Valley. At all meetings the constantly lowering water table was considered of major importance.

At the conclusion of each conference, recommendations were adopted that the conferees believed would stimulate action in solving overdraft and other agricultural problems of the area. Three recommendations directly affected the overdraft problem:

> "(1) As a means of securing greater efficiency in irrigation, we recommend that a study be made of water use of all crops for maximum production, such study to take into account soil type, irrigation layout, and particularly the advantages and disadvantages of reservoirs.
>
> "(2) Since soil and water conservation is essential to permanent prosperity in the valley, we recommend that studies and demonstrations of soil and water conservation be continued, with the establishment of soil conservation demonstration farms, soil conservation districts, and that a special study of water spreading possibilities be made . . .
>
> "(6) Since the obtaining of long-term credit is often dependent upon water supplies, we recommend the keeping out of, or removing from irrigation, undeveloped or sub-marginal land by a program of acquisition by district formation or otherwise. . ."

In addition, search for an experimentation with new cash crops were recommended for the area, to provide more diversity in agriculture as well as the possibility of less water consumption. Recommendations (1) and (2) were adopted at both conferences, but recommendation (6) was not adopted at the second conference. No meetings have been held since 1941.

Activities growing out of these conferences have had only small influence in combating overdraft in the Valley. Farmers have become aware of their tendency to over-irrigate, but have not been satisfactorily informed as to the amount of over-irrigation.[2] The possibility is discussed above (pp. 107-110) that the crop-yield increases that result from applying more water than the minimum level may make rigid water conservation incompatible with profit maximization.

A direct outgrowth of recommendation (2) was the establishment, on July 22, 1941, of the Portal Ridge Soil Conservation District, comprising some

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2/ Recommendation (1) called for study to determine "water use of all crops for maximum production, . . ." As yet no comprehensive investigation to determine minimum water requirements has been made in Antelope Valley. Consumptive use requirements have been estimated from comparison with other areas.

40,000 acres. Experience gained led to organization of the Antelope Valley Soil Conservation District, on June 20, 1944, including nearly the entire remaining area of Antelope Valley in Kern and Los Angeles counties. The Portal Ridge and Antelope Valley districts were consolidated in June, 1947, so that almost the entire Valley is now covered by one soil conservation district. District activities are discussed below.

The recommendations designed to encourage search for and experimentation with new cash crops for the area led to establishment of the Antelope Valley Field Station, of the University of California. Studies there have provided new crop possibilities by demonstrating the wide variety of crops physically suited to the area. However, more study is needed to determine economic crop suitability.

Recommendation (6), which called for the removal of land from irrigation, was abandoned after the first conference. Such action would reduce water consumption, but this means of attaining the objective was more offensive to many residents of the community than could be offset by the gains obtained. Even greater objection came from persons residing outside the Valley who owned land in the area and were (and still are) hopeful of speculative gains to be made in real estate sales.

The net benefit from these conferences is difficult to assess: Resulting awareness of overdraft in most portions of the Valley has increased local desire to combat the problem; but the rapid rate of agricultural development in the Valley has more than offset any gains provided by local farmers in combating overdraft.

Experimental Crop Investigations

Studies by the Antelope Valley Field Station have covered a large number of crops--primarily those with lower water requirements than those of alfalfa. Whether stimulated by Field Station studies or some other factor, noticeable acreage increases in irrigated grains and field corn have occurred since 1946. Some of this acreage was transferred from alfalfa enterprises, thus permitting the saving of water for the farms involved of about 1.2 acre-feet per acre per year. No saving of water for the entire Valley has occurred, however, because expansion of total irrigated acreage has increased annual net draft every year since 1942.

The net effect of recommendations to transfer from alfalfa to crops that consume less water has been insignificant so far as reducing overdraft is concerned. It is suggested that these crops may not be so financially profitable as alfalfa until total pumping lifts reach the range of 350 to 600 feet--unless other factors stimulate earlier transfer (pp. 118-120).

Soil Conservation Service

Activities of the Soil Conservation Service were confined to a few demonstration farms prior to organization of the districts. Primary district activity has aimed at soil conservation problems, but some investigational projects have been undertaken in water-spreading and sprinkler irrigation.

Geological investigations in Antelope Valley have indicated that alluvial formations on the southern flank of the Valley would lend themselves to water spreading, done to recharge ground water.[3/] The problem of water-spreading resolved itself into one of economic feasibility, depending upon the water supply available. A study based on runoff of Big Rock Creek (the only major stream adaptable to spreading operations) from 1923-24 to 1941-42 revealed that in only six of the eighteen years would spreading have been of benefit. Because of the rareness of flood runoff from this stream, the spreading systems considered were designed for water spreading primarily, and for flood control only incidentally.

The estimated costs of constructing spreading facilities on Big Rock Creek did not differ significantly from the known costs for constructing other spreading grounds in southern California. However, the average annual runoff to be spread from this stream was so small that the cost of putting one acre-foot of water into underground storage ranged from $1 to $2.75--from two- to ten-fold greater than for similar spreading grounds. The study concluded that construction of such facilities would not be economically sound. The geological structure of Antelope Valley is such that natural spreading and percolation of runoff from streams debouching into the Valley take place nearly as well as if from man-made spreading grounds (pp. 4-5, and 46-48).[4/]

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3/ Muckel, Dean C. Feasibility of Spreading Water at Mouth of Rock Creek in Antelope Valley, California. September 12, 1944. Typed Manuscript. This study is summarized in Ewing, P. A. The Irrigation Development of Antelope Valley, California. Soil Conservation Service, Berkeley, California. 1945. 57 p. Mimeographed.

4/ This is further substantiated by the fact that runoff from Big Rock Creek and Little Rock Creek during the recently concluded wet water-year of 1951-52 at no time came closer than eight to ten miles to the dry lakes in the center of the Valley. The runoff was absorbed into the alluvial fans rapidly and at the cost of only minor flood damage.

Sprinkler Irrigation Trials

The effectiveness and efficiency of sprinkler irrigation in Antelope Valley were studied on several small plots of alfalfa by the Division of Irrigation and Water Conservation of the Soil Conservation Service.[5] One significant result of this study concerned the small evaporation loss between the time the water left the sprinkler and fell on the ground. This was in spite of the windy conditions under which most of the tests were performed. Loss due to interception and evaporation was estimated by the Soil Conservation Service to be less than 2 per cent (for 6-inch applications) and within the experimental error of measurement.

Evaporation losses from flooding, on the other hand, may exceed 10 per cent of the total water applied. In the irrigation of alfalfa an annual application of 5 acre-feet applied by flooding could result in evaporation waste of .5 acre-feet. The same amount of water applied by sprinkler would evaporate about .1 of an acre-foot--a saving of .4 acre-feet per acre per year. If like savings could have been accomplished on each acre irrigated from ground water in Antelope Valley in 1951, over 21,000 acre-feet would have been saved, cutting estimated overdraft in that year by nearly 13 per cent.

It was nevertheless concluded that sprinkler irrigation cannot yet be definitely recommended in the Valley, because strong and unpredictable winds distort the water distribution pattern, making uniform irrigation difficult. Some sprinkling units are in use in the Valley at the present time. A longer history of experience with this wind problem is necessary before sprinkling can be recommended in the Valley as a means of saving water.

Zoning, Water Law, and Overdraft

Zoning ordinances utilize the police powers of the state to protect and promote certain types of land use and restrict others. Zoning regulations

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5/ Litz, G. M., C. F. Bond, and W. W. Donnan. Sprinkler Irrigation Trials Antelope Valley Soil Conservation District. March, 1952. Typed Manuscript. A provisional report on irrigation investigations conducted by the Division of Irrigation and Water Conservation in cooperation with the Operations Division, Soil Conservice, and the Antelope Valley Soil Conservation District.

do not call for the performance of specific acts but keep individual initiative in the use of land and improvements in predetermined channels.6/ Before discussing zoning in Antelope Valley, it is necessary to consider how zoning affects and is affected by water rights and conservation.

Ground-Water Law

Laws applying to ground water tend to be less definite and have developed more slowly than those applying to surface waters.7/ Court decisions have classified ground waters as (1) definite underground streams and (2) percolating waters. Most cases dealing with ground water in California have involved percolating waters, including waters of artesian areas not shown to be parts of definite underground streams.8/ No definite underground streams exist in Antelope Valley (except in the relatively small underflow areas of the major streams before they emerge into the Valley) so that only laws applying to percolating water are considered. California law presumes all ground waters to be percolating unless proven otherwise.9/

Three general doctrines cover percolating water laws. The English or Common Law Rule of absolute ownership by the owner of the overlying land, applicable in California prior to 1903. But then the decision in Katz vs. Walkinshaw departed from this rule and adopted a modified form of the American Rule of Reasonable Use, which has come to be known as the California doctrine of correlative rights.10/ Court decisions since 1903 and noninterference by the legislature established the correlative rights doctrine as the

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6/ Solberg, E. D. "Rural Zoning in the United States." Agricultural Information Bulletin No. 59. Washington, D. C., U. S. Bureau of Agricultural Economics, 1952. p. 4.

Solberg differentiates between land-use regulations and zoning. Land-use regulations "may be either positive or negative. That is, they may prohibit using land in a specified way, or they may order the proprietor to carry out certain practices." Zoning, on the other hand, does "not affirmatively call for the performance of specific acts." Land-use regulations, as defined by Solberg, are characteristic regulatory powers of soil conservation districts.

7/ U. S. National Resources Planning Board. State Water Law in the Development of the West. Washington, Govt. Print. Off., 1943. p. 69. Some of the reasons given for slowness in this area: (1) lack of knowledge of the physical conditions under the surface of the earth where ground water occurs; (2) the more ready availability of surface water; and (3) the expense involved in digging wells and pumping water.

8/ The President's Water Resources Policy Commission. Water Resources Law Vol. 3. Washington, Govt. Print. Off., 1950. pp. 717-718.

9/ Legal citations given in Wells A Hutchins, "Selected Problems in the Law of Water Rights in the West." Misc. Pub. No. 418. U. S. Department of Agriculture. Washington, Govt. Print. Off., 1942. p. 192.

10/ Ibid.

law of percolating water in California.[11] This rule accords to owners of land overlying a common ground-water supply equal rights for use on or in connection with their overlying lands, each to have a fair and just proportion where the supply is not sufficient for all. The landowner's right extends only to the quantity of water necessary for use on his land; any surplus may be appropriated for distant use.[12] Rights associated with proper overlying use (reasonable needs for beneficial purposes) are paramount. "The right of an appropriator, being limited to the surplus, must yield to that of the overlying owner in the event of a shortage."[13]

The third doctrine applicable to percolating waters under California law is the Appropriation Doctrine. No statutory procedures govern appropriation of surplus percolating water, although definite underground streams are covered by statute.[14] Appropriation of surplus percolating water is effected by diversion and beneficial use.

Antelope Valley Zoning Experience: Prohibition of Well Drilling

During 1944 property owners in Antelope Valley, particularly those active in the Portal Ridge and Antelope Valley Soil Conservation districts, became alarmed at the receding water levels and requested the Los Angeles County Board of Supervisors to take action. The intention of the request was to prevent drilling of wells for purposes other than what might be termed "very essential" needs, and also to prevent any property owner from drilling more wells on his property than was "absolutely necessary for the maintenance and development of his ordinary crops." New water development and new plantings to crops were to be stopped, temporarily at least. Los Angeles County Ordinance 4457 N.S., adopted by the Board of Supervisors on February 20, 1945 and effective thirty days later, zoned the area against further

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11/ The President's Water Resources Policy Commission, op. cit., p. 718.

12/ For a summary of legal citations applicable to the California doctrine of correlative rights, see Ibid., footnotes 40 and 41, and Wells A Hutchins, "Selected Problems in the Law of Water Rights in the West," op. cit., pp. 192-204.

13/ ". . . unless the appropriator has gained prescriptive rights through the taking of nonsurplus waters." Pasadena vs. Alhambra, cited in the President's Water Resources Policy Commission, op. cit. The factors leading up to and associated with this decision are the subject of a special ground-water study (Raymond Basin) currently in progress by the Giannini Foundation of Agricultural Economics.

14/ State of California. Water Code, 1951. California Printing Division, Sacramento. See especially Division 2, Part 2, Chapter 1.

ground-water development unless specific exception is granted.

The main sections of the ordinance are as follows:

"Section 1. A person shall not drill any water well in . . . [defined area of Los Angeles County portion of Antelope Valley] until he first obtains a permit to do so from the Regional Planning Commission.

"Section 2. The Chief Engineer of the Regional Planning Commission shall grant a permit to drill a water well if:

(a) He finds that such well is to be used exclusively for domestic purposes or for watering livestock, including poultry or both, or
(b) He finds that such drilling of a water well is for the repair or replacement of existing wells and the water is to be used on land already under irrigation, or
(c) An exception has been granted . . . .

"Section 4. The provisions of this ordinance do not apply to any municipality, district, governmental agency, or other public body in existence on the effective date of this ordinance, but do apply to all such public agencies formed after such effective date . . . .

"Section 6. This ordinance is enacted in contemplation of the preparation of a precise plan of the Master Plan of Land Use or the preparation of a Master Conservation Plan and precise plans thereof, or both, which plans are to be adopted in conformity with the Planning Act . . . . The Board of Supervisors . . . finds that the water table in . . . [Antelope Valley] is now so low and continuing to drop so rapidly that if restrictions upon the drilling of further water wells are not effective within the next thirty days the whole of such . . . [area] will be rendered unfit for agricultural use . . . ." 15/

The ordinance as adopted was designed to preserve the status quo in Antelope Valley until a Master Plan of Land Use or Master Conservation Plan was prepared and adopted. The Los Angeles Regional Planning Commission had been conducting studies of Antelope Valley soil conditions with a view to working up a soil conservation plan. These studies were dropped, however, and "have not been resumed due to pressure of more urgent work."16/

Even before adoption of the ordinance, the Los Angeles County Counsel had warned the Board of Supervisors that such an ordinance would probably not be valid.17/ After the ordinance had been in effect for several months, it

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15/ Complete text of ordinance published in the Antelope Valley Ledger-Gazette, March 1, 1945.

16/ Communication from A. H. Adams, Director of Planning, the Regional Planning Commission to Victor W. Bruce, formerly Research Assistant, September 26, 1950.

17/ Letter dated November 15, 1944. A copy of this letter was procured for the present study by Mr. Bruce. The citation summarizing current legal opinion on this matter stated, ". . . if conservation be the end sought, it is not promoted by selecting a particular class of persons on an arbitrary basis and conferring special privileges on them and denying the same privileges to all others . . ." State ex rel. Bacich vs. Huse, 187 Wash. 75, 59 Pac.(2d) 1101, at 1105.

became evident that its constitutionality was being questioned. An action--Superior Court Case No. 506889 entitled Los Angeles County Farm Lands Company, a Corporation, Plaintiff vs. County of Los Angeles--was instituted for the purpose of testing the constitutionality of the ordinance.[18/] In view of the impending suit and the opinion of the Los Angeles County Counsel, the Board of Supervisors repealed the ordinance on April 16, 1946, and the suit was withdrawn.[19/] This ordinance was in effect slightly over a year during which time "many applications were made to the Regional Planning Commission for [well drilling] permits, most of which were granted." A few were denied, "on the grounds that the proposed use did not justify the drilling of an additional well."[20/]

Because the ordinance was short lived and most applications for new wells were approved, it had little effect in lessening overdraft in Antelope Valley. No reduction in the trend of estimated draft was observed for 1945 (Appendix Table 7 and Figure 4.1). Any effect in subsequent years (had it remained in force) would have depended entirely upon the policy of the Regional Planning Commission in granting permits to drill new wells.

This attempt to combat overdraft by restricting irrigation development was not successful, even on a pro tem basis. The existing legal framework will not permit enforcement of an ordinance discriminatory between those who have already begun to farm and those who wish to begin in the future.[21/]

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18/ Over 100 plaintiffs, all owners of farm land in Antelope Valley, participated in this suit. The Los Angeles County Farm Lands Company, which held a "considerable amount of property," was nominal plaintiff. "All of the plaintiffs were farmers in the valley or were workers whose livelihood was directly affected by the proposed ordinance"--Communication from Loyd Wright, attorney for the plaintiff, May 16, 1952.

The Los Angeles County Farm Lands Company was organized in 1913, at which time 25,000 acres of land near Lancaster and Palmdale were purchased for "speculative purposes." No improvements were ever made to the land, and none was ever rented. Land has been sold in large (farm sized) and small (lot sized) parcels until only 160 acres remain. When this last holding is sold, the company will, for all practical purposes, cease to exist. Communication from P. E. Neuschaefer, Los Angeles County Farm Lands Company, July, 1953.

19/ Ordinance No. 4659 N.S., which repealed Ordinance No. 4457 N.S., was adopted April 16, 1946, and became effective thirty days later. South Antelope Valley Press, Palmdale, California. April 25, 1946.

20/ Personal communication from A. H. Adams, Director of Planning, The Regional Planning Commission, to Victor W. Bruce, formerly Research Assistant, August 23, 1950.

21/ For the reader interested in the complexities of ground-water law, a summary of source materials and citations may be found in Bartz, P. M. Ground Water in California, op. cit., pp. 51-62.

A suggestion that land be retired from production so that a select area could be irrigated with the available ground water is not legally feasible, because it interferes with the property rights of land owners. Only if such land was owned by the state or some organization determined not to engage in irrigated agriculture but to sell ground water pumped from beneath the property for use on other lands would transfer of ground water from one area to another be possible. Presently existing patterns of ownership in Antelope Valley and the speculative interest in this land for future development make this possibility seem very unlikely.

Unless some change is made in the legal framework, it will remain impossible to bring all new developments in an area to a halt while methodical investigations of, and proposed solutions for, existing problems are determined. Comprehensive land and water surveys before an area is developed would permit regulated development (by zoning) at a pace and to such an extent that overdraft might be prevented entirely, or at least minimized.[22/]

Following the repeal of Ordinance No. 4457 N.S., residents of Antelope Valley, through the Board of Directors of the Antelope Valley Soil Conservation District, made to the Board of Supervisors a new proposal, consistent with the opinions of the County Counsel. The proposal was that a county ordinance be adopted that would restrict the amount of water that could be pumped in any one season to a maximum of 5 acre-feet per acre per year. No action was ever taken on this proposal, probably because of the difficulties of enforcement and that "pressure of more urgent work" referred to earlier.

The major portion of zoning activity in Antelope Valley since the repeal of the short lived, discriminatory ordinance has focused on land use, without direct concern or interest in water-use problems. This may imply that the Regional Planning Commission would rather let nature take its course as far as the use of ground water for agriculture is concerned. As yet, the Master Plan of Land Use applying to Antelope Valley applies only to a relatively narrow strip across the Valley from, and including, Palmdale to, and including, Lancaster. This is the strip within which residential, commercial, and industrial expansions are anticipated; it includes very little of the area in the Valley devoted to irrigated crop production. Zoning that has as its focus point the water problems of irrigated agriculture has, at least temporarily, been moved into the background.

22/ Each area investigated, however, could present different situations, depending on the quantitative relationships existing between the flow and stock components of the ground-water resource and irrigable acreage.

Zoning to Eliminate Overdraft?

Zoning to combat overdraft would necessarily be based on the amount of water available for apportionment on a per-acre basis. It has been estimated that the average annual recharge for this area is approximately 40,000 acre-feet per year (p. 49). If zoning should be based on this volume of water, it would mean that at ultimate development each acre of irrigable land (approximately 600,000 acres) would receive less than one inch of water per year. No intensive agricultural crop enterprise could be supported by this amount of water established by zoning for ultimate development. But that would be the effect of proposed zoning in Antelope Valley to lead toward a "balance between the acres of irrigated land and the average water supply available in the Valley."23/

One other method by which average annual recharge might be apportioned would be to reduce irrigated acreage in the Valley to a level that could be supported by this volume of water. The acreage that could be irrigated would, of course, depend upon the crop grown. Zoning could not dictate the crop to be grown.

As a first approximation, the high water-consuming crop of alfalfa may be used as a standard. Allowing 5 acre-feet per acre per year, average annual recharge would support 8,000 acres of alfalfa. This is less than one-quarter of the present alfalfa acreage in the Valley and means that ownership of nearly 600,000 acres of irrigable land would have to reside in the hands of the public in the form of governmental (state, county, etc.) or quasi-governmental (district) ownership; or if in private ownership, zoned against agricultural use. The volume of annual pumpage accorded to this large holding by its water rights could then be sold to the farmers operating the 8,000 acres of alfalfa.

Conversion to crops that consume small volumes of water might be brought about indirectly, by expanding the amount of land to be privately owned and cutting the amount of water sold (per-acre basis) to each farmer. For example, expanding the acreage from 8,000 to 16,000 would cut the amount of water sold annually to private holdings from 5 acre-feet per acre to about 2.5 acre-feet per acre. Such measures could make zoning effective in eliminating long-run overdraft in Antelope Valley, but associated

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23/ Letter from Los Angeles County Counsel, op. cit., p. 1.

difficulties appear to preclude it: Water available each year--the ground-water flow resource--is not sufficient to support a valley full of intensive agricultural enterprises dependent on irrigation; necessary supervision and metering to guarantee that draft on ground water would not exceed 40,000 acre-feet per year would be a barrier.

An alternate suggestion--cutting total irrigated acreage perhaps to less than 20,000 acres--is probably not feasible from a political point of view. It would be necessary to acquire public ownership of nearly 600,000 acres, which would entail enormous expenditures.[24/] Public ownership would be necessary to acquire the overlying water rights so that pumpage could be controlled effectively. If such acquisition could be accomplished, this plan would be feasible from a legal viewpoint. But economic infeasibility arising from a basic resource imbalance between water and land apparently preclude the adoption of government proprietorship as a tool of resource conservation.

It is concluded that zoning to eliminate long-run overdraft is not probable. The relation between irrigable acreage and recharge would not permit annual pumping at a volume approximately equal to average annual recharge. Thus, proposals to limit draft to the physically determined safe yield of this area (average annual recharge of 40,000 acre-feet) must be discounted if intensive irrigated agriculture is to remain in the Valley.

Zoning to Conserve Ground Water

Conservation is defined as ". . . changes in the intertemporal distribution of use. In conservation, the redistribution of use is in the direction of the future; in depletion, in the direction of the present."[25/]

A differentiation was made between the flow and the stock components of the Antelope Valley ground-water resource (Chapter 3). It has been suggested that relatively little can be done to affect the magnitude of the flow resource, which fluctuates according to climatic fluctuation. For the most part, it serves to recharge the stock component as efficiently as possible (pp. 41-44). It would seem that conservation measures must be directed at the stock component of the ground-water resources.

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24/ Private land is currently selling for $500 to $1,500 per acre, depending upon location and conditions and purpose of the sale.

25/ Ciriacy-Wantrup, S. V. Resource Conservation, Economics and Policies. Univ. of California Press, Berkeley, 1952. pp. 51-53.

Any measure to effect a redistribution of ground-water use rates of the stock resource in the direction of the future would be a conservation measure. This purpose could be served to a greater or lesser degree by several courses of action: reducing the volume of irrigation applied each year, changing to crops that use smaller volumes of water per acre, etc. In Antelope Valley none of these measures would have been sufficient of themselves to eliminate long-run overdraft; they would have been only conservation measures, shifting long-run overdraft into the future.

Zoning to conserve the ground-water stock resource is feasible within the existing legal framework. Zoning that specifies the amount of water to be used per unit area of land is possible, but the type of crop to be grown could not be regulated directly. A restriction as to the amount that each owner may pump would probably be justified under the police power as ". . . an adjustment of conflicting private rights and the apportionment of a common property right among the several owners. . . ."26/ Furthermore, a court has said, in upholding the constitutionality of an Orange County ordinance regulating the use of water from pumping wells and prohibiting the waste of water therefrom:

> "Legislation with respect to water affects the public welfare and the right to legislate in regard to its use and conservation is referable to the police power of the state. . . . [The ordinance] has for its purpose the conservation of subterranean waters, a legitimate field for the exercise of police power . . . it seeks to prevent the undue waste of the percolating waters within the County of Orange, thereby conserving said water and materially benefiting the public welfare. . . ." 27/

Assuming that intensive irrigated agriculture will remain in the Valley, zoning could specify a maximum volume of pumpage on a per-acre basis, thus giving all property owners an equitable share in the ground-water stock. The level could be set to control--indirectly--the crop grown (i.e., high water user or low water user). Such zoning would tend to cut down annual draft rates, shift the rate of use of the resource into the future, and thus be a conserving action.

Such zoning would have problems of enforcement. Maintaining pumpage volumes at the specified level would require adequate supervision and metering of volume of draft for each irrigation pump in the Valley. This would be expensive, both in terms of money and time.

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26/ People vs. New York Carbonic Acid Co., 196 N. Y. 421, 90 N. E. 441, at 448.

27/ In re Maas, 219 Cal. 422, 27 Pac. (2d) 373, at 424 and 425 of 219 Cal.

As a possible alternative to actual metering of pump draft, an enforcement agency could approximate the results by keeping crop acreage records for each property holding. If water allotments were set at 2.5 acre-feet per acre per year, a farmer operating 160 acres could grow one-third of this acreage in alfalfa, fallow the remainder, and be assumed to be within his permissible volume of pumpage.[28/] If the entire acreage were devoted to irrigated cereals or vegetable crops, it could be assumed the farmer was not pumping more than his allotted volume. This would not be as accurate as metering pump draft, but it could be operated at lower cost to the enforcement agency and would presumably not be greatly in error.

This type of zoning ordinance would probably not be instituted without some opposition, but it appears to be legally and technically feasible. Furthermore, it would serve to conserve the ground-water stock resource of Antelope Valley.

"Pay as You Pump"

Overdraft experience in Orange County, California,[29/] has centered around a localized problem similar to that of Antelope Valley: During the period of early settlement an abundant artesian ground-water resource was exploited until pressure was reduced to the point where pumping became necessary. As early as 1920 it became evident that more water was being extracted from the ground-water reservoir than was being replenished by natural recharge. By 1951 estimated annual net draft on ground water amounted to 203,000 acre-feet, while average recharge is 136,000 acre-feet per year.

Salt water from the ocean has infiltrated the ground water until nearly 5,000 acres of land along the coast are now underlain by ocean water. It has

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28/ In this situation, the farmer could apply as much as 7.5 acre-feet to each acre in alfalfa and still not exceed his allotment. If he were to apply only 5 acre-feet per acre to alfalfa, he could devote one-half of his acreage to this crop and fallow the remainder. Such situations, however, would not necessarily constitute economic units of operations.

29/ Information on Orange County ground-water problems is from the following reports: Browning, C. R. "Contribution of the Flow of Santa Ana River to Coastal Basin Replenishment or Beneficial Use in Acre-Feet." Tustin, Calif., August, 1952, 7 p. Processed. (Report by C. R. Browning, Consulting Civil Engineer.)

Miller, W. D. "To the Citizens Water Conservation Committee." Santa Ana, California, August, 1952. 8 p. Processed. (Report by W. D. Miller, Secretary of the Orange County Water District.)

Shafer, Ross A. "Statement to Joint Legislative Interim Committee on Water Problems, Re: The Proposed Plan for the Replenishment of the Coastal Basin of Orange County, California." Orange County Water District, Santa Ana, October, 1952. 8 p. Processed.

been estimated that restoration of 1920 water (and pressure) levels would halt further salt water encroachment. Restoring those levels would require a recharge volume to ground-water storage of about 375,000 acre-feet. Annual recharge importations must overcome this accumulated deficit (cumulative overdraft) as well as average annual overdraft. Geologic conditions are such that recharge can be accomplished without large-scale construction of spreading basins.

Two major problems were involved in this solution: (1) where to get the necessary volumes of water, and (2) how to pay for it? The first question was answered by obtaining water from the Metropolitan water district, which controls Colorado River water delivered to the Los Angeles and San Diego areas. A Metropolitan feeder line is conveniently located to discharge water into a natural percolation area. A new feeder line can be constructed to route water to an area where spreading grounds may be necessary.

Although the second question has defied answer for many years, the recent passage of Senate Bill 91, an amendment to the Orange County Water District Act, may not only solve the overdraft problem of Orange County but also set a pattern for solving some types of localized overdraft problems in other areas.[30/] The act sets forth its major purpose as the replenishment of the underground water supplies of the Orange County Water District.

Two methods are specified to provide payment for the water necessary to fulfill this objective:

The first method allows the district to levy a general tax not to exceed eight cents per $100 of assessed valuation of real property including improvements. The funds will be used to buy the necessary recharge volume of 375,000 acre-feet. Assessed valuations vary from less than $300 per acre for ordinary cropland to a top of about $1,300 for the best orange groves. Estimated total annual income to the district from the tax levy (agricultural and nonagricultural) would be about $280,000 per year. Water purchases from this tax fund may be used to overcome cumulative overdraft only, and are to be limited to 25,000 acre-feet in any one year and 375,000 acre-feet in aggregate. This will protect non-farm property owners from subsidizing payments for water necessitated by overdraft induced by farmers.

The second method allows the district to make a pumping assessment not to exceed $5.50 per acre-foot on ground water pumped within the district. This

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30/ California, Statutes of 1953, Chapter 770. Deering's California General Laws, No. 5683.

money will be used to import the water necessary to offset a continuing annual overdraft. Computing at the maximum pumping levy for an estimated annual pump draft of nearly 200,000 acre-feet, the district income from the pumping levy would exceed one million dollars. For the individual farmer, assumed to be pumping ground water at an average cost of $4.50 per acre-foot, total cost of pumping plus the levy would be $10.00 per acre-foot--or less if the pumping assessment is less than the maximum. The total water cost paid by the farmer will vary with crop, irrigation practice, soil type, cost-price and climatic variations, etc. But for most crops and "average" situations the figures of $8.50 to $10.00 per acre-foot are not unreasonable. Every well in the district must be registered on or before January 15, 1954. Water meters will be installed on all wells sometime after that date. It is hoped that the plan will be in full operation by 1955, when the first extraction tax will be available.[31]

District income from both the land tax and pumping levy may exceed one and one-quarter million dollars per year, which will be enough to wipe out accumulated overdraft in the Orange County Water District and to balance out continuing annual overdraft. One of the major advantages of this plan is that it does not, insofar as can be determined at the present, interfere with the water rights of individual property owners any more than does any ordinary property tax. Furthermore, it dictates payment in proportion to the amount of ground water used by each pumper. Each individual pays to overcome local overdraft to the extent that he contributes to it.

Can the Orange County Plan Work in Antelope Valley?

Many points of similarity exist between the Orange County ground-water economy and that of Antelope Valley. The major point of difference is the magnitude of overdraft: Current annual overdraft in Orange County is approximately one-half that in Antelope Valley. Restoring 1920 water levels would require 375,000 acre-feet in Orange County, but about 2,000,000 acre-feet in Antelope Valley.

The first problem to be solved would be to organize a district for Antelope Valley that would have the powers necessary to levy both an ad valorem land tax and a use-charge pumping assessment. The Antelope Valley Soil Conservation District does not possess such powers, but two county water districts (in the Los Angeles County and Kern County portions of Antelope Valley) could be organized with sufficient powers. They would have to work

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31/ Personal communication. W. D. Miller, Secretary, Orange County Water District. July 13, 1953.

closely in order to administer the activities involved in combating overdraft in the Valley. Perhaps a better district form would be a Water Storage and Conservation District that would encompass the entire Antelope Valley, thus minimizing administrative problems. If it is assumed that such a district can be formed in the Valley, are the other problems soluble?

What sources of water could be used to recharge the Antelope Valley ground-water stock resource?

The Owens Valley-Los Angeles Aqueduct crosses the western end of the Valley, transporting slightly more than 300,000 acre-feet per year. Water could be spilled into dry stream beds for natural recharge, or delivered by gravity through conduits to most areas of the Valley for direct irrigation. But the Los Angeles Department of Water and Power cannot provide water to Antelope Valley, for legal, physical, and economic reasons.[32]

Los Angeles' water rights in Inyo and Mono counties are appropriative and limited to the use of the City and its inhabitants unless surplus water exists--and none does. The exchange or sale of aqueduct water for use in the Valley would require the assent of two-thirds of the qualified voters of the City. Costs associated with the purchase and distribution of Metropolitan water, plus loss of revenue from power generation by aqueduct water below Antelope Valley, raise impassible economic barriers, even if the legal and physical obstacles could be overcome. Supplying water to Antelope Valley from the Los Angeles Aqueduct is not feasible.

Direct supply of water to the Valley from the Metropolitan Aqueduct (Colorado River water) is not technically feasible, because of differences in elevation--Antelope Valley being much higher than the Metropolitan outlets. The cost of lifting the water into the Valley, plus prior water rights by other areas of metropolitan Los Angeles, tends to exclude this water as a possible source of water for Antelope Valley agriculture.

Feather River Water is priced too high ($50.00 per acre-foot) for Valley farmers (pp. 51-52 and 127-128). Unless the cost to farmers is at least partially subsidized, Feather River water does not present a probable water supply for Antelope Valley agriculture.

If a firm water supply could be provided at prices Valley farmers could afford, a plan similar to the Orange County Water District Plan could stem long-run overdraft in the Valley. The only alternative is for Valley farmers to conserve their limited stock resource as efficiently as possible.

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32/ Communication, S. B. Morris, General Manager, Department of Water and Power, the City of Los Angeles. December 30, 1953.

State-wide Activity

The state of California has watched the water situation for many years. The Division of Water Resources has engaged in irrigation, drainage, and water-development investigations and programs, and is currently conducting cooperative investigations in Antelope Valley with the Los Angeles County Flood Control District and the U. S. Geological Survey.

The State Water Resources Board has been created to make state-wide investigations of water resources, their use, and their development. Recent land-utilization surveys made by the Division of Water Resources have been directed by the State Water Resources Board. The proposed Feather River Aqueduct, one of several developments from these investigations, appears to be one possible means of combating and perhaps eliminating overdraft in Antelope Valley and in other ground-water areas along its route that may be suffering from water shortages.

The California Division of Water Resources

Requested by House Resolution No. 101, adopted February 16, 1946, to survey the water supply of Antelope Valley and recommend means of assuring adequate water supply and underground water table conditions in Antelope Valley, the Division of Water Resources conducted a study and made recommendations as follows:

"1. Every effort should be made to reduce consumptive use in the Valley through the substitution of higher duty crops. [33/] Studies with this end in view are now being carried out by the Soil Conservation Service, County Farm Advisors and others, and the efforts of influential local organizations should be continued.

"2. Studies by the Soil Conservation Service and the University of California relative to improved irrigation practices and possible salvage of waste should be encouraged. The fact that this waste may be small does not justify neglecting it if it can be salvaged at a cost commensurate with the benefits derived.

"3. Measurements of depth to ground water made by the United States Geological Survey and Los Angeles County Flood Control District, and analysis by the Division of Water Resources based on these measurements should be continued, to augment crop data presented annually by the County Agricultural Commissioner in a periodic appraisal of the situation.

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33/ As used here, the term "higher duty" is synonymous with the term "lower water consuming."

"4. As lands go out of production because of economic pressure or from other causes, they should be acquired and held by a properly constituted public agency. Lands sold to the State for taxes should not again be put on the open market. If publicly owned, these lands could still be used under lease or permit, but with cropping and water use restricted."34/

Direct benefits from these recommendations have been small. The first three merely recommended the continuation of existing experimentation and research. The fourth recommendation is a synthesis of a recommendation arising from the 1940 Building Conference and certain legal opinions discussed previously. As far as can be determined, no specific action has ever been taken on recommendation 4.

The State Water Resources Board

This Board was organized in 1945 to investigate California's water resources. In 1947 the Board was authorized to make, and funds were appropriated for, a thorough state-wide water investigation.35/ The investigation continues to be conducted by the Division of Water Resources as requested and directed by the Board.36/ Antelope Valley is included as one of several areas in the state faced with the problem of a water supply inadequate to the needs of ultimate development.37/ The proposed Feather River Project is another State Water Resources Board activity. As a result of State Water Resources Board activities, actions have been taken that may ultimately alleviate southern California's water shortage in general and Antelope Valley's in particular.

In August, 1951, two applications were filed to appropriate 5,000,000 acre-feet of water annually and divert it from Feather River, Italian Slough, and Old River for use in "Areas south of Tehachapi Mountains" (i.e., southern California) and other areas south of the Sacramento-San Joaquin Delta area. The applications were filed on behalf of the Department of Finance of the

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34/ State of California, 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 Resolution 101 of February 16, 1946. Sacramento, Calif. State Print. Off., May, 1947. 22 p. Mimeographed.

35/ State Water Resources Board. "Water Resources of California." Bulletin No. 1. Sacramento, California, 1951.

36/ The Division of Water Resources conducts these investigations as requested and directed by the State Water Resources Board.

37/ Bulletin 2 of the State Water Resources Board will describe the relative imbalance between available water and water requirements when the various areas have expanded irrigated acreage to their maximum potential.

state of California by James S. Dean, Director of Finance, pursuant to Section 10500 of the Water Code of California.[38/] No specific amount of water has as yet been allocated to Antelope Valley under either of these applications or to other areas in the category covered by "Areas south of Tehachapi Mountains." The Feather River Project has not yet been authorized for construction; only preliminary investigations have been launched.

It has been suggested above (p. 145) that the initially listed sale price for Feather River Project water of $50.00 per acre-foot in areas south of the Tehachapi Mountains is more than agricultural users in Antelope Valley can pay. Thus far, water importations into southern California have been stimulated primarily by nonagricultural pressures. Urban users (residential, commercial, and industrial) have exhausted local water supplies, and can afford to pay the costs associated with water importations. For example, in the city of Los Angeles--during the period 1946-1949, inclusive--payments by residential water users amounted to $66.38 per acre-foot. Commercial water users during the same period made payments averaging $53.64 per acre-foot, while the few sales for agricultural irrigation averaged only $6.78 per acre-foot. The average billing for all classes of water users averaged $46.16 per acre-foot. These rates of payment for nonagricultural use are not out of line with the suggested sale price of $50.00 per acre-foot for Feather River water in areas south of the Tehachapi Mountains. The question that requires an answer in such situations is to what extent agricultural water-users should be subsidized by nonagricultural water-users--if at all.

Technology, ability to pay, need for water, and other institutional factors tend to favor solving water-shortage problems by transferring water from surplus to deficit areas. But the possibility is serious in some areas that such a solution may be temporary--even if economically, physically, and legally feasible.

Notwithstanding the obstacles to water importation, it became increasingly apparent during this study that in Antelope Valley the only permanent method whereby long-run overdraft can be materially reduced involves the importation of outside water. Sufficient acreage reduction to eliminate or even materially reduce long-run overdraft in the Valley cannot be attained unless economic pressures force out marginal producers as the economic limits of pumping are reached. Even then, political pressures might be brought to bear to force some other solution.

38/ Communication, A. E. Edmonston, State Engineer.

Combating Overdraft

Investigations and action programs launched in Antelope Valley have, for the most part, led to only slight gains in the battle against overdraft, although data on water use have been accumulated that are of value in analyzing overdraft. Agricultural development of the area has proceeded at such a rapid rate that individual on-the-farm gains have been more than offset by water use of new development. Zoning attempts have been either legally unsound or too difficult to enforce.

Specific actions and measures against long-run overdraft are seriously affected by two sets of conditions: First, the physical resources available and their potential balance or imbalance can easily make it extremely difficult to control or limit overdraft. Second, economic factors that dictate resource utilization may be so strong as to offset measures designed to combat overdraft.

If, as in Antelope Valley, the local economy is developed far beyond the capacity of the flow component of the ground-water resource, with consequent "mining," no simple solution to overdraft is in sight. If some form of a "pay as you pump" plan, similar to that of the Orange County Water District, could be developed for Antelope Valley, it is possible that overdraft might be controlled and eliminated. The enactment and enforcement of zoning measures to eliminate overdraft in the Valley is not probable. Unless a "pay as you pump" plan can be put into effect early, the best that can be done is to act so as to conserve the ground-water stock resource as long as possible.

Economic pressures will eventually bring about a more or less gradual shift out of agriculture as the economic limit of pumping is approached. Urbanization may soften the harshness of such a transfer and also act to subsidize the importation of water to the area. Such importation would increase the flow component either directly (water stored underground) or indirectly (importations substituting for ground-water draft). The magnitude of importation and the extent of urbanization would determine the degree to which overdraft would be decreased.

Chapter 9

ANTELOPE VALLEY--The Lessons Learned

The physical and historic backgrounds to overdraft in Antelope Valley have been presented, as well as the physical and economic aspects that have caused this problem and influenced its growth. Investigations and action programs developed in efforts to combat overdraft have been discussed and their effectiveness evaluated. This final chapter concludes the present study with a consideration of the implications of the experience in Antelope Valley--the lessons learned.

The earliest settlers in the Valley attempted large-scale developments of the surface streams and discovered that the water supply was inadequate to support proposed developments. Dry farming is dependent upon a variable and unpredictable rainfall. Extended dry spells forced abandonment of both dry-farmed and surface-irrigated developments. Pumping lifts around the border of the Valley were too great to permit irrigation of crops.

The discovery and development of flowing artesian wells prompted a rebirth of agriculture. After the warning from earlier failures, growth of the irrigated area in the center of the Valley proceeded slowly but steadily. The coincident location of artesian wells and alkali-infested soils restricted the area that could be developed initially. Although the ground-water stock resource was used at a rate less than the annual flow volume, wasteful (unrestricted) flow from the artesian wells brought about a gradual decline in artesian pressures and a shift to pumps in order to supply sufficient water to irrigate the crops. In spite of the falling water table, improved technology and favorable cost-price structures stimulated continuity of agricultural growth. Wells ceased to flow and the water table dropped. The more the area was developed, the more rapid was the decline in ground-water levels.

Residents of the Valley began to be concerned with the declining water table and requested that something be done to help them. Investigations and action programs have evolved, over the past twenty years, in various attempts to combat overdraft. These have added to stores of knowledge but have not materially affected overdraft. Long-run overdraft, continuing at an increasing rate, is the ever-present problem of Antelope Valley.

The Ground-Water Flow Resource

In studying ground-water problems on a regional basis, one of the first duties of the investigator is to inventory the resource. A complete inventory will take into account all elements contributing and affecting recharge and discharge (including draft). Early in this study a differentiation was made between the stock and flow components of the ground-water resource--a differentiation that made easier the subsequent analysis.

Early settlers in the Valley discovered that the flow resource or recharge component of the ground-water inventory was, in the form of stream flow for surface diversion, inadequate to maintain large agricultural development. Measurement of this component through the years has proven the settlers to be correct.

The measurements for Antelope Valley as discussed in this paper indicate that an easier and just as accurate form of measurement as those currently in use may be found in simple correlations between precipitation and runoff. These correlations presuppose hydrologic similarity between observation stations (precipitation and runoff), but do not seem to require geographic proximity. Thus, preliminary investigations for areas with scant precipitation and runoff data can be expected to yield reasonably accurate estimates of runoff by relating available data in the one area with long-run, reliable precipitation data in hydrologically similar areas. Only seasonal (yearly) data have been investigated in this study. Further refinement, involving shorter periods of time in order to determine flood-flow runoff characteristics in relation to precipitation, will be necessary before this relationship may be used for any period less than seasonal data.

The Ground-Water Stock Resource

The ground-water stock of an area (volume of ground water in storage) may be estimated, but not with great accuracy. One needs to determine the volume of alluvial fill that holds ground water, and then the percentage of pore space in this fill that is--or can be--occupied by water (specific yield measurements). The magnitude of the stock resource, as estimated in this paper, was found to be very large compared to the magnitude of the flow resource, and relatively large compared with the irrigated acreage in Antelope Valley. The situation becomes more complex if artesian pressures mislead the investigator. In some other areas, precise discrimination between artesian and nonartesian aquifers is possible, but not in Antelope Valley: All the aquifers at depths below eighty feet are subject to artesian pressure more or less, because of the pervasive interconnections between aquifers throughout the Valley alluvium. In attempting to estimate changes in volume of ground-water storage for the Antelope Valley, and thus estimate net draft on ground water, these artesian pressures and the scarcity of data combined to invalidate the computations.

Comparing characteristics and magnitudes of the flow and stock component of the ground-water resource, a most important physical fact is revealed: a small, highly variable flow resource has created a large stock resource that can be mined to provide water for agricultural and other uses.

Ground-Water Draft

The estimates of draft on ground water developed in this paper indicate that, although all estimates are more or less subject to error, those based on electrical power consumption are the most reliable. Not only do these estimates reflect acreage variation in an area, as do consumptive-use estimates of net draft, but they also reflect climatic and price-of-product variations, which consumptive-use estimates do not. In areas where the accounting zone for electrical power consumption coincides with the ground-water basin, this form of estimate may be made with relative reliability. The degree of reliability will depend upon the importance as a power source of electric energy relative to other forms of energy, and the availability of supplementary information in terms of pumping lift and efficiency of pumping.

If data are available on return recharge or irrigation efficiency in the area, then estimates of gross draft may be converted to estimates of net draft, the latter form of estimate being necessary in order to quantify and differentiate the several types of overdraft. Estimates of net draft are particularly difficult because of the problem of obtaining this information.

Types of Overdraft

A better understanding of the problem of overdraft is afforded by a logical, analytical differentiation of different types of overdraft. Overdraft *per se* may not be a "bad" element in ground-water utilization. Initial development of an area may necessitate developmental overdraft in order that ground-water storage space will be available to absorb recharge to ground water in years (or periods) of greater than normal runoff and recharge. By analogy, a farmer who observes a decline in water levels in his well during the course of the pumping season and a recovery during the season of nonuse will not be much concerned, although he is observing the manifestation of seasonal overdraft.

In an area where long-run average annual recharge and draft are in approximate balance, the occurrence of a declining water-table level over several years' time indicates only the presence of a cyclical overdraft. Cyclical overdraft is not cause for alarm, as water-table levels will rise again during the wet phase of the cycle. Thus, declining water levels in themselves are not necessarily an indication of long-run overdraft.

If, however, it is observed that water levels continue their recession during wet periods as well as dry, indicating that the acreage under irrigation consumes more water each year than is supplied to the stock under draft, then concern over the utilization of the resource is proper, because long-run overdraft is a feature of the ground-water economy. Long-run overdraft, as well as the other types differentiated, is present in Antelope Valley. It may well be that other areas, both in and out of California, are likewise suffering from long-run overdraft, but only careful consideration of the entire physical make-up of an area will prove this supposition. Declining water levels alone may be misleading.

Physical Factors and Economic Forces

No matter how exhaustive the study, a purely physical description and inventory of a ground-water problem-area is not apt to lead to action that will stem overdraft. For that matter, coupling intensive study of economic facts and factors with the physical study will not necessarily lead to elimination of overdraft. Antelope Valley has been the scene of both physical and economic studies, yet long-run overdraft appeared and is continuing at increasing rates. Overdraft has been stimulated and perpetuated by economic forces; and only their reversal or their cessation will eliminate overdraft in the Valley without some other intervention.

Pumping Costs and Overdraft

The factors that determine pumping costs have been pointed out as the prime reasons for continued agricultural development in Antelope Valley. A large stock of ground water served as the supply of irrigation water as soon as pumping became physically and economically possible. Removal of the stock has brought about declining water levels and increased pumping lift, which tend toward increased pumping costs, other things being equal.

But other things have not been equal. The average costs of pumping ground water have decreased relative to total costs of production for alfalfa, the leading crop in the Valley. Substantial decreases in the unit cost of electrical energy have permitted pumping from greater depths than initially, but an increase in electrical energy rates will reverse this trend. Shifts from gasoline and diesel fuels to electrical energy as power source have lowered the cost of pumping per acre-foot, thus permitting pumping from greater depths. The use of large motors (over 100-H.P. demand-horsepower rating), stimulated by a falling water table and large pumping volumes, permits pumping at lower cost than with small motors. Increasing the volume of pumpage per unit of land area may also lead to increased monetary returns, thus stimulating the application of greater than minimal amounts (consumptive use plus minimum allowance for wastage) of irrigation water.

Technological advancement is the phrase summarizing the factors that have served to offset the rising pumping costs associated with declining water levels. Changes in size, type, and efficiency of pumps, and changes in energy source and cost of the energy, have kept pumping costs down relative to total production cost. These factors serving to decrease relative pumping costs have also served to stimulate long-run overdraft. So long as technological innovation can keep ahead of the increasing costs associated with a declining water table, overdraft in this and similar ground-water economies will continue.

Under the conditions described in this study, the management income generated by mining the ground-water stock for only four or five years has exceeded the perpetuity income value that would be generated by maintaining a balance between recharge and draft. Income generated since initial development as a result of mining the stock probably exceeds the sustained income by many times. Economic forces have stimulated and perpetuated long-run overdraft in Antelope Valley. It is to be anticipated that these forces, as in the past, will similarly stimulate overdraft in other areas where an imbalance of resources permits overdraft to occur.

Economic Limits to Pumping

One solution to long-run overdraft in Antelope Valley may be the gradual elimination of irrigated farming enterprises as the limit of pumping (maximum economic total pumping lift) is approached. Under the set of assumptions used in this paper, a total pumping lift of about 500 feet represents the present limit. The economic pumping lift is not a static concept, however, and will change over time. It has been suggested that irrigation at or above current levels for the entire area may result in such an overdraft rate that these limits will be attained sometime after the year 2000. As this limit is approached, less-efficient operators will gradually be forced to abandon irrigation enterprises, leaving only the most efficient to maintain their activity, unless political pressures are brought to bear to subsidize the less-efficient operator. Such abandonment would tend toward a balance between recharge and draft, eliminating overdraft.

Predictions of the consequences of observed and postulated actions, and possible dates of the occurrence of these consequences, have been made. Such predictions are not as accurate as desirable, because of the necessity of using a series of static conditions to predict the outcome of a dynamic situation. Changing economic factors governing ground-water utilization have been pointed out in this paper. It is hoped that future developments and trends, as they are observed, will permit refinement of the prediction. It is possible that a changing environment (rural to urban) may solve the problem of overdraft because of a greater financial ability to import water to the Valley from areas with a water surplus. Regardless of how the features of the Antelope Valley ground utilization may change in future years, some change will occur. Only close and continued contact with a ground-water region will permit accurate appraisals of the ground-water problems. It is unlikely that a single, simple proposed solution to a given problem will stand for all time, because of the changing character of the problem and the factors that determine it. Determining the economic limits of pumping is a continuous research activity rather than an isolated observation in the flow of time.

Combating Overdraft

Specific actions and measures effective in eliminating long-run overdraft are affected by two sets of conditions: First, the physical resources available and their potential balance or imbalance can, as in Antelope Valley, make control of overdraft extremely difficult. Second, economic factors dictating resource use may be so strong as to offset any actions designed to combat overdraft.

If a ground-water flow resource is, or can be, modified to support an economically desirable agricultural economy, then the existing legal framework governing ground-water use can be effective in controlling overdraft. Some changes in type of farming may be necessary, but no great imposition would be placed upon an individual farm or farmer. No large-scale or sudden changes would occur that could necessitate an equally large-scale transfer of workers out of agriculture into other occupations, or an exodus from the area. Annual and cyclical variations in recharge would be absorbed by the ground-water stock and pumping lifts could be maintained at a relatively stable level.

If, as exists in Antelope Valley, a local economy is already developed far beyond the capacity of the ground-water flow resource, no simple solution is in sight. If a firm supply of imported water can be provided at a price that Valley agriculture can pay, some form of plan similar to the Orange County Water District Plan may reduce and eventually eliminate long-run overdraft. Enforcement of zoning measures necessary to eliminate overdraft in Antelope Valley is not feasible, unless imported water could be provided at a price Valley farmers could afford. Without a firm supply of inexpensive imported water the best that can be done--legally, economically, or politically--is to conserve the ground-water stock, allowing long-run overdraft to continue, though delayed.

Economic forces will bring about a more or less gradual shift out of agriculture as the economic limit of pumping is approached. Urbanization may not only soften the harshness of such a transfer but also act to subsidize, in part at least, the importation of water to the area. Importation from surplus to deficit areas--which is favored by technologic, economic, and political factors--would increase the ground-water flow-resource through direct addition to the stock each year or through use in direct surface diversion.

Further experience and research with a firm water import plan is necessary to determine what levels of water use would result in a balance of ground-water flow-resource (recharge plus imported water) and draft. Barring imported water, long-run overdraft in Antelope Valley and similarly characterized areas will continue until economic forces bring a balance between recharge and draft.

APPENDIX TABLE 1

Precipitation Summary[a]

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual average
Backus Ranch[b]													
Greatest monthly	3.90	5.63	5.19	1.74	0.72	0.54	0.47	0.63	1.62	1.26	2.67	6.14	
Mean monthly	0.91	1.57	1.51	0.28	0.10	0.06	0.03	0.11	0.27	0.28	0.40	1.63	7.15
Least monthly	0	0.17	0.22	0	0	0	0	0	0	0	0	T[c]	
Greatest daily	1.74	2.03	1.68	0.57	0.43	0.54	0.47	0.63	1.60	0.75	1.18	2.81	
Fairmont[d]													
Greatest monthly	13.77	11.10	9.50	5.69	2.10	0.53	0.28	1.30	2.63	2.30	6.41	12.06	
Mean monthly	3.17	3.36	2.52	0.89	0.32	0.05	0.02	0.12	0.24	0.49	0.88	2.93	14.99
Least monthly	T	0	T	0	0	0	0	0	0	0	0	0	
Greatest daily	7.60	4.50	4.00	2.10	1.00	0.36	0.28	1.07	1.37	1.85	3.36	5.30	
Llano[e]													
Greatest monthly	7.45	8.06	5.06	4.31	1.44	1.50	1.50	1.60	1.86	3.01	3.40	7.78	
Mean monthly	1.26	1.47	1.26	0.54	0.16	0.07	0.12	0.25	0.20	0.38	0.46	1.44	7.61
Least monthly	0	0	0	0	0	0	0	0	0	0	0	0	
Greatest daily	6.45	4.15	2.27	1.24	1.00	1.05	1.50	1.13	1.58	1.21	2.05	2.75	
Palmdale[f]													
Greatest monthly	5.59	7.24	4.92	2.37	0.40	0.21	0.22	1.38	1.89	1.63	3.37	7.55	
Mean monthly	1.36	1.89	1.69	0.46	0.12	0.03	0.02	0.32	0.22	0.38	0.48	2.15	9.12
Least monthly	0	0	T	0	0	0	0	0	0	0	0	0	
Greatest daily	2.40	2.43	2.39	0.68	0.40	0.15	0.22	1.05	1.02	1.63	1.63	3.43	

a/ Data in inches of precipitation.

b/ Length of record--14 years.

c/ Trace.

d/ Length of record--42 years.

e/ Length of record--35 years.

f/ Length of record--19 years.

Source: U. S. Dept. of Commerce Weather Bureau. "Climatological Summary." San Francisco. Mimeographed data supplied for each station.

APPENDIX TABLE 2

Temperature Summary[a]

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Backus Ranch[b]													
Highest	82	79	83	97	102	108	111	110	110	97	86	77	
Mean daily maximum	56.5	58.8	63.7	73.6	81.1	89.4	97.8	96.8	91.1	77.9	67.4	59.5	76.1
Mean daily	42.6	45.7	50.5	59.0	67.1	75.1	82.7	81.3	74.5	62.2	51.4	45.7	61.5
Mean daily minimum	28.7	32.5	37.3	45.3	53.0	60.8	67.6	65.8	58.0	46.4	35.5	32.0	46.9
Lowest	7	14	20	25	36	35	50	47	34	28	16	14	
Fairmont[c]													
Highest	78	80	87	92	98	108	109	109	106	96	86	87	
Mean daily maximum	52.3	55.0	59.8	66.2	72.8	81.5	90.7	90.2	84.9	73.7	63.7	54.5	70.4
Mean daily	43.7	46.3	50.5	56.3	62.7	71.0	79.7	78.8	73.2	62.7	52.8	45.9	60.3
Mean daily minimum	35.1	37.6	41.2	46.4	52.6	60.4	68.6	67.4	61.5	51.8	42.6	37.3	50.2
Lowest	11	16	19	26	32	39	48	48	42	31	18	19	
Llano[d]													
Highest	77	75	90	93	100	108	112	109	105	96	89	78	
Mean daily maximum	54.2	58.1	63.7	71.0	79.2	88.3	95.4	94.4	88.0	76.2	64.3	56.1	74.1
Mean daily	43.1	46.4	50.5	56.5	63.6	71.5	79.0	77.9	71.9	61.8	51.7	45.0	59.9
Mean daily minimum	32.1	34.6	37.3	42.0	48.0	54.8	62.7	61.3	55.8	47.4	39.2	34.0	46.5
Lowest	8	14	20	22	28	35	39	38	36	25	15	13	
Palmdale[e]													
Highest	81	78	89	97	107	109	112	112	111	100	86	83	
Mean daily maximum	56.3	59.2	65.6	73.3	80.3	88.1	97.2	96.4	90.7	78.9	67.6	58.6	76.0
Mean daily	43.6	46.8	52.0	58.6	65.1	72.3	81.1	79.9	73.6	63.2	52.3	45.9	61.2
Mean daily minimum	30.8	34.3	38.5	43.9	49.9	56.4	65.0	63.5	56.6	47.5	37.0	33.1	46.4
Lowest	9	16	21	28	31	40	43	44	36	27	19	14	

a/ Data in °F.

b/ Length of record, 14 years.

c/ Length of record, 29 years.

d/ Length of record, 32 years.

e/ Length of record, 19 years.

Source: U. S. Dept. of Commerce. Weater Bureau. "Climatological Summary." San Francisco. Mimeographed data supplied for each station.

Source: U. S. Dept. of Commerce. Weater Bureau. "Climatological Summary." San Francisco. Mimeographed data supplied for each station.

APPENDIX TABLE 3

Histories of Irrigation Districts in Antelope Valley

Name of district and subsequent organizations	Date of organization	Area in district acres	Purpose of original organization	Extent of operations	Date of disorganization
Palmdale Irrigation District	February 3, 1890	50,000	Nonspeculative	Organization held null and void by the courts before construction started.	July 10, 1891
Southern Antelope Valley Land Company	1895	—	Nonspeculative	Negligible, because of prolonged drought period and lack of storage facilities.	1912
Palmdale Water Company	1912	3,000	Nonspeculative	Negligible, because of prolonged drought period and lack of storage facilities.	1918
Palmdale Irrigation District	July 9, 1918	4,756	Nonspeculative	Lined and unlined ditches; concrete distribution lines for irrigation water, iron pipe lines for domestic water. Little Rock and Harold reservoirs to store irrigation water, wells to supply domestic water.	Very strong and active at present.
Big Rock Creek Irrigation District	July 14, 1890	30,000	Speculative	Some small ditches constructed.	1897
Mescal Land and Water Company	1900	--	—	Some ditches constructed, and a half-mile tunnel into bed of Big Rock Creek.	1902-03
Llano del Rio Company	1914	--	Socialistic colonization	Ditches constructed and some storage developed; small community constructed, designed to be self-supporting.	1917

(Continued on next page.)

Appendix
Table 3 continued.

Name of district and subsequent organizations	Date of organization	Area in district acres	Purpose of original organization	Extent of operations	Date of disorganization
Manzana Irrigation District	December 5, 1891	3,000	Speculative	Negligible, because of surface water lack.	1896
Little Rock Creek Irrigation District	March 28, 1892	4,200	Speculative	Ditches, flumes, and orchards; pumping plant installed during drought. District weakly active from 1895 to 1909. Abortive attempt to form a mutual water company in 1909. Since then, a gradual expansion of facilities and service, including construction of Little Rock Dam jointly with Palmdale District.	Strong and active at present.
Neenach Irrigation District	May 5, 1893	3,840	Nonspeculative	None.	1894
Armagoza Irrigation District	January 31, 1895	5,000	Nonspeculative	None.	1896

Source: Snyder, op. cit. Appendix A. Based on information contained in:

Adams, F. Histories of Irrigation Districts in California Organized Under Wright Act of 1887, 1887-1893. Irrigation Investigations, Office of Experiment Stations, USDA. Berkeley, 1915. 160p. Typewritten manuscript.

Adams, F. "Irrigation Districts in California, 1887-1915." Bulletin No. 2. State of California Dept. of Engineering. Sacramento, California. 151p.

Adams. F. Irrigation Districts in California. 1929 421p. (Calif. Dept. Pub. Works, Bul. 21).

Palmdale Irrigation District. "Open Letter to all Members of the Palmdale Irrigation District." Palmdale, 1950. Unpaged. Processed.

Personal interviews with secretaries of the Palmdale and Little Rock Creek Irrigation Districts, 1952.

Personal interviews with secretaries of the Palmdale and Little Rock Creek Irrigation Districts, 1952.

APPENDIX TABLE 4

Irrigated Crop Acreage in Antelope Valley

Year	Alfalfa	Tree fruits and vines	Irrigated grain and pasture	Miscellaneous crops	Gravity irrigated crops	All crops irrigated from ground water	Total irrigated crop acreage
1910	2,500						
1912							4,629
1916							10,000
1919	7,155	4,655[a]			3,100	8,710	11,960
1920	7,400	4,900[a]			2,950	9,350	12,300
1922	7,000	4,700[a]				10,000	
1924	12,000	4,780[a]			2,600	14,180	16,780
1925	14,000						
1927	20,250						
1929	25,000						31,420
1930	22,000				2,996[c]		
1931	21,700				2,509[c]		
1932					1,708[c]		
1933					1,736[c]		
1934	15,317[b]				1,810		23,800
1935	16,000				1,765		
1937					1,750		
1938	23,000				2,047		
1939	20,000				2,027		
1940	24,202[b]	1,950	1,113	1,023			
1941							
1942	25,500[b]						

(Continued on next page.)

Appendix
Table 4 continued.

Year	Alfalfa	Tree fruits and vines	Irrigated grain and pasture	Miscel-laneous crops	Gravity irrigated crops	All crops irrigated from ground water	Total irrigated crop acreage
1943	26,000[b]				2,052		
1944					2,200		
1945	29,600	1,870[b]	5,850[b]	475[b]	2,236	35,559[d]	37,795
1946	31,500	1,902[b]	5,590[b]	1,035[b]	2,393	37,634[d]	40,027
1947	34,700	2,067[b]	8,612[b]	971[b]			
1948	37,700	2,027	10,011[b]	1,312[b]			
1949	38,900	2,382	10,460[b]	755[b]	1,567	50,930[d]	52,497
1950	38,525	2,375	13,022[b]	744[b]	1,158	53,508[d]	54,666
1951	39,845	2,376	11,291[e]	943[b]	1,061	53,394[d]	54,455

a/ These acreages include some private stream diversions of unknown amount as well as acreage prepared for irrigation but never irrigated.

b/ Los Angeles County only. No information available for Kern County. Potato and melon acreage in Kern County estimated to average 675 acres for period 1945-1951. Other acreages small.

c/ These are acreages served by Palmdale and Little Rock Creek Irrigation districts. Individual diversions unimportant.

d/ Total Irrigated Crop Acreage less Gravity Irrigated Crop acreage.

e/ Includes 1,126 acres of cotton in Los Angeles and Kern Counties. This is the first major introduction of cotton into the area.

Source: Compiled from:

Adams, F., et al. Reports on the Irrigation Resources of California. Irrigation Investigation Off. of Exp. Sta., USDA. California State Printing Office, Sacramento. 1912.
Thompson, D. G. WSP no. 578.
Baugh, R. E. The Antelope Valley. MA Thesis. Clarke University. 1926.
Annual Crop Reports of Los Angeles County Agricultural Commissioner for Antelope Valley.
Estimates of the Kern County Agricultural Commissioner for Rosamond and Willow Springs area.
Field Survey by the Soil Conservation Service of Antelope Valley in 1945.
Field Survey by the California State Division of Water Resources in 1950-51.
Annual Reports of Palmdale and Little Rock Creek Irrigation Districts to the Securities Exchange Comm.
Pacific Rural Press, vol. 131, p. 406, and vol. 137, p. 326.

Appendix Table 5

Precipitation and Stream Flow; Antelope Valley, 1923-1951

	Seasonal precipitation		Precipitation as percent of mean annual rainfall			Seasonal stream flow discharge or runoff[b]		Stream flow as percent of mean annual runoff
						Rock Creek	Little Rock Creek	
	Fairmont	Llano	San Gabriel Mts. Watershed area[a]	Fairmont	Llano	Drainage area: 23.0 square miles	Drainage area: 49.0 square miles	Little Rock Creek Area
	inches per season		percent			acre-feet		percent
1923-24	6.35	5.66	55.1	46.9	72.7	4,180		
1924-25	5.76	4.72	65.4	42.5	60.6	2,860		
1925-26	14.71	7.36	119.3	108.6	94.5	12,200		
1926-27	13.60	8.62	110.9	100.4	110.7	16,000		
1927-28	7.84	6.86	63.0	57.9	88.1	5,470		
1928-29	8.85	4.11	69.3	65.4	52.8	3,870		
1929-30	9.20	7.94	76.5	67.9	101.9	6,160		
1930-31	10.54	6.99	78.9	77.8	91.8	4,270	3,620	52.5
1931-32	17.41	12.08	119.4	128.6	158.7	15,700	16,700	123.5
1932-33	10.69	5.23	67.5	78.9	68.7	5,950	4,170	31.0
1933-34	9.73	2.12	75.8	71.9	27.9	4,760	3,760	27.9
1934-35	18.38	8.50	125.7	135.7	111.7	17,800	17,640	131.0
1935-36	11.39	4.11	72.7	84.1	54.0	5,000	3,320	24.6
1936-37	21.97	8.95	145.4	162.3	117.6	22,630	21,950	163.0
1937-38	22.34	8.95	161.0	165.0	117.6	25,000[c]	22,000[c]	163.4
1938-39	15.92	9.89	104.9	117.6	130.0	10,660	6,800[c]	50.5
1939-40	12.77	8.95	75.8	94.3	117.6	8,660	7,000	52.0
1940-41	29.13	15.39	190.1	215.1	202.4	36,420	51,620	382.3
1941-42	9.98	5.65	72.7	73.7	74.3	7,000	5,140	38.2
1942-43	22.76	15.61	160.0	168.1	205.1	30,740	35,870	266.4
1943-44	24.24	19.02	142.3	179.0	249.9	24,120	35,940	266.4
1944-45	12.77	6.36	96.6	94.3	83.6	10,450	9,250	68.7
1945-46	17.87	7.48	94.5	132.0	98.3	14,560	12,110	89.9
1946-47	14.44	9.08	101.8	106.6	119.3	16,040	15,850	117.7
1947-48	9.02	5.73	53.0	66.6	75.3	4,640	2,450	18.2
1948-49	8.54	5.80	59.2	63.1	76.2	4,180	3,170	23.6
1949-50	8.75	3.56	57.1	64.6	46.8	3,390	2,470	18.1
1950-51	4.17	3.51	45.7	30.8	46.1	1,380	430	3.2

(Continued on next page.)

Appendix Table 5 continued.

a/ Adapted from Seasonal Railfall Index for San Gabriel Mountains contained in Los Angeles County Flood Control District. Biennial Report on Hydrologic Data, Seasons of 1949-50 and 1950-51.

b/ Seasonal figures are for October 1-September 30, inclusive; for example, seasonal runoff for Rock Creek, October 1, 1923-September 30, 1924, was 4,180 acre-feet.

c/ Estimated by Los Angeles County Flood Control District.

APPENDIX TABLE 6

Water Requirements of Crops in Antelope Valley

Crop	Growing season	Consumptive use: Total Annual	Consumptive use: Supplied by precipitation	Consumptive use: Supplied by irrigation	Minimum amount of irrigation water necessary to supply consumptive use[a]	Estimates of typical irrigation applications in Antelope Valley
		Acre-feet per acre				
Alfalfa	April 1-October 31	3.37	0.35	3.02	4.31	5.75-7.5
Permanent pasture	April 1-October 31	3.18[b]	0.35	2.83	4.04	5.75-7.5
Orchard (deciduous)	April 1-October 31	2.60	0.35	2.25[c]	3.21[c]	2.25-2.75
Hay and grain (irrigated)	December 1-June 1	1.33	0.35	0.98	1.40	1.75-2.25
Field crops (miscellaneous)	May 1-August 31	1.95	0.35	1.60	2.29	3.0-3.5
Cotton[d]	April 1-October 31	2.46	0.35	2.11	3.02	4.0-4.5
Truck crops (miscellaneous)	April 1-July 31	1.92	0.35	1.57	2.24	3.0-3.5
Sugar beets	April 1-September 30	2.54	0.35	2.19	3.13	4.0-4.5

a/ Assuming 70 per cent irrigation efficiency (cf. footnote 16, p.). Information obtained from R. L. Forsyth, Antelope Valley Field Station, University of California, tends to substantiate this column. The 30 per cent not used consumptively represented water evaporating from free water surfaces (either in storage reservoirs on the farm or as water floods over the checks) plus an amount required as necessary return flow.

b/ Estimates by Farm Advisors and Antelope Valley Experiment Station indicate that permanent pasture will use as much water as alfalfa, and possibly more.

c/ These values are in excess of current irrigation practice in the area.

d/ Adapted from State Department of Public Works. Division of Water Resources. "Irrigation Requirements of California Crops." Sacramento, Calif. State Print. Off., 1945. (Bul. 51) p. 79.

Sources: State Department of Public Works, Division of Water Resources. "Water Utilization and Requirements, Antelope Valley Basin." Bryte, California, June 1, 1951. (Mss. by T. C. Mackey. Preliminary information subject to revision.) California Agricultural Extension Service and U. S. Dept. of Agric. Alfalfa Cost and Management Study, Antelope Valley, 1950. Office of the Farm Advisor, Los Angeles, Calif. 1950 [and earlier issues], Mimeo. variable paging. California Agricultural Extension Service and U. S. Dept. of Agric. 1947 and 1948 Sugar Beet Production, Cost and Management Study, Antelope Valley. Office of the Farm Advisor, Los Angeles, Calif. 1948. 7pp. Mimeo. California Agricultural Extension Service. Information leaflets on growing corn, mild maize, irrigated wheat, and castor beans in Antelope Valley.
Personal interviews.

APPENDIX TABLE 7

Annual Draft on Ground Water Antelope Valley
Based on Electrical Power Consumption

Year	Estimated average depth to static ground water level	Estimated average drawdown, friction, loss, etc.	Estimated total pumping head	Estimated over-all efficiency of pumping plants	Estimated KWH necessary to pump one acre-foot of water	Total annual power sales to agriculture, Lancaster District a/	Estimated annual gross draft on ground water by electric pumping plants	Estimated annual net draft on ground water by electric pumping plants
	feet			per cent		KWH	acre-feet	
1924	59	30	89	45.0	202.6	11,100,000	54,788	27,000
1925	62	30	92	45.5	207.1	13,413,229	64,767	32,000
1926	66	30	96	46.0	213.7	17,389,599	81,374	41,000
1927	70	30	100	46.5	220.2	21,575,387	97,981	49,000
1928	72	30	102	47.0	222.3	28,604,011	128,673	64,000
1929	75	30	105	47.5	226.4	36,545,046	161,418	81,000
1930	79	30	109	48.0	232.5	40,127,057	172,590	86,000
1931	83	30	113	48.5	238.5	37,574,421	157,545	79,000
1932	86	30	116	49.0	242.4	26,452,939	109,129	55,000
1933	88	30	118	49.5	244.1	23,342,419	95,627	48,000
1934	92	35	127	50.0	260.1	31,029,494	119,298	60,000
1935	95	35	130	50.5	263.6	29,756,145	112,884	56,000
1936	98	35	133	51.0	267.1	35,033,094	131,161	66,000
1937	102	35	137	51.5	272.4	34,693,969	127,364	64,000
1938	105	35	140	52.0	275.7	36,103,543	130,952	65,000
1939	110	35	145	52.5	282.9	38,807,103	137,176	69,000
1940	111	35	146	53.0	282.2	39,804,883	141,052	82,000
1941	112	35	147	53.5	281.5	31,937,315	113,454	58,000
1942	117	35	152	54.0	288.2	44,790,903	155,416	79,000
1943	120	35	155	54.5	291.4	47,412,334	162,705	82,000
1944	121	40	161	55.0	300.1	50,813,056	169,320	86,000
1945	127	40	167	55.5	308.4	59,363,778	192,490	97,000
1946	129	40	169	56.0	309.1	69,746,931	225,645	114,000
1947	136	40	176	56.5	319.1	82,537,667	258,658	122,000
1948	140	40	180	57.0	323.3	99,760,942	308,571	136,000
1949	145	40	185	57.5	329.5	109,857,984	333,408	141,000
1950	150	40	190	58.0	335.5	121,624,753	362,518	149,000
1951	157	40	197	58.5	344.9	138,249,080	400,838	166,000

a/ Southern California Edison Company. Unpublished annual reports filed with California Public Utilities Commission, State Office Building, San Francisco, California, 1924-1951 inclusive.

APPENDIX TABLE 8

Net Draft on Ground Water in Antelope Valley
(Consumptive Use)

Water use category	1919	1920	1925	1927	1929	1930	1935	1940	1945
Agricultural use									
Crops									
Alfalfa	21,600	22,300	42,300	61,200	75,500	66,400	48,300	76,100	89,400
Permanent pasture)								1,400	5,900
Irrigated grain)								700	3,800
Miscellaneous field and truck)	10,500	11,000	6,000	4,500	4,500	4,500	3,000	1,600	1,800
Cotton)								—	—
Tree fruits and vines)								4,400	4,500
Livestock	100	100	100	100	200	200	200	300	300
Total agricultural	32,200	33,400	48,400	65,800	80,200	71,100	51,500	84,500	105,700
Nonagricultural use									
Residential-commercial	—	—	—	—	—	—	—	—	800
Military-industrial	—	—	—	—	—	—	—	—	400
Total nonagricultural	200	200	300	300	400	400	400	600	1,200
Estimated net water consumption	32,400	33,600	48,700	66,100	80,600	71,500	51,900	85,100	106,900
Less estimated net water consumption for gravity-irrigated crops[a]	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Total estimated net draft on ground water in Antelope Valley	29,400	30,600	45,700	63,100	77,600	68,500	48,900	82,100	103,900

(Continued on next page.)

Appendix Table 8 continued

Water use category	1946	1947	1948	1949	1950	1951	Future estimates	
							1955	1960
Agricultural use								
Crops								
Alfalfa	95,100	104,700	113,900	117,500	116,300	120,300		
Permanent pasture	5,200	4,500	5,600	5,400	8,600	12,100		
Irrigated grain	3,900	4,700	4,500	5,200	10,200	6,300		
Miscellaneous field and truck	4,200	3,900	4,400	2,000	2,100	2,800		
Cotton	—	—	—	—	300	2,400		
Tree fruits and vines	4,600	4,800	4,800	5,500	5,500	5,500		
Livestock	400	400	500	500	600	700		
Total agricultural	113,400	123,000	133,700	136,100	143,600	150,100	182,000	225,000
Nonagricultural use								
Residential-commercial	900	900	1,000	1,100	1,200	1,400	3,000	5,000
Military-industrial	300	200	200	200	300	600	1,200	1,600
Total nonagricultural	1,200	1,100	1,200	1,300	1,500	2,000	4,200	6,600
Estimated net water consumption	114,600	124,100	134,900	136,400	145,100	152,100	186,200	231,600
Less estimated net water consumption for gravity-irrigated crops[a]	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Total estimated net draft on ground water in Antelope Valley	111,600	121,100	131,900	133,400	142,100	149,100	183,200	228,600

a/ Divert 7,500 acre-feet per year, of which 1,500 acre-feet are assumed to be evaporated from storage, leaving 6,000 acre-feet to be delivered to crops. Assuming 50 per cent irrigation efficiency, 3,000 acre-feet will be used consumptively each year.

Source: Table 2.2, Table 4.3, Snyder, J. Herbert, op. cit.

APPENDIX TABLE 9

Typical Costs of Pumping Installations, Antelope Valley

	Initial cost	Average value b/	Expected life c/	Fixed annual charges per year a/ (overhead charges)			Total annual fixed charges per year
				Interest at 5 per cent	Taxes and insurance at 2 per cent	Deprecia-tion d/	
	dollars		years	dollars			
1925 e/							
To pump 450 gal. per min. with 20 h.p. electric motor from 350-ft. well f/							
Well and casing	1,002	501	25	25.05	10.02	40.80	
Electric motor and pump assembly	1,200	600	20	30.00	12.00	60.00	
Total	2,202	1,101	--	55.05	22.02	100.80	177.87
To pump 900 gal. per min. with 40 h.p. electric motor from 450-ft. well g/							
Well and casing	1,665	833	25	41.65	16.65	66.60	
Electric motor and pump assembly	1,800	900	20	45.00	18.00	90.00	
Total	3,465	1,733	--	86.65	34.65	156.60	277.90
1951 h/							
To pump 450 gal. per min. with 40 h.p. electric motor from 500-ft. gravel-packed well f/							
Well and casing	3,500	1,750	25	85.00	35.00	140.00	
Electric motor and pump assembly	4,900	2,450	20	122.50	49.00	245.00	
Total	8,400	4,200	--	207.50	84.00	385.00	676.50

Continued -

Appendix Table 9 (Continued)

	Initial cost	Average value[b]	Expected life[c]	Fixed annual charges per year[a] (overhead charges): Interest at 5 per cent	Taxes and insurance at 2 per cent	Depreciation[d]	Total annual fixed charges per year
	dollars		years	dollars			
To pump 900 gal. per min. with 75 h.p. electric motor from 750-ft. gravel-packed well[g]							
Well and casing	6,375	3,188	25	159.40	63.75	255.00	
Electric motor and pump assembly	8,150	4,075	20	203.75	81.50	407.50	
Total	14,525	7,263	--	363.15	145.25	662.50	1,170.90
To pump 1,800 gal. per min. with 150 h.p. electric motor from 1,000-ft. gravel-packed well[i]							
Well and casing	9,500	4,750	25	237.50	95.00	380.00	
Electric motor and pump assembly	12,000	6,000	20	300.00	120.00	600.00	
Total	21,500	10,750	--	537.50	215.00	980.00	1,732.50

a/ Annual rate of charge based on A. Molenaar, "Costs of Pumping Water for Irrigation," 1947, Univ. of Calif. Dept. of Irrigation, Davis, California. Processed.

b/ Average value is assumed to be one-half the initial cost.

c/ Expected life for motor and pump assembly depends upon total hours of use and whether or not water level is falling rapidly. Periodic replacement of bowls (due to cavitation, mechanical wear, or suspended material) or extension of the pumping column (due to a falling water table) will shorten the estimated expected life and increase total annual fixed charges slightly.

d/ It is assumed that pump, motor, and assembly are capable of handling an increase in pumping lift of about 100 feet before replacement becomes necessary. Replacement of old pump and motor is a capital expenditure to be incurred about every 100 feet. The addition to total annual fixed charges when such a change occurs will be small when compared to the total.

e/ Installations capable of pumping average volumes indicated for a range of pumping lift of 75-200 feet.

f/ Capable of supply a 40-acre alfalfa unit.

g/ Capable of supplying an 80-acre alfalfa unit.

h/ Installations capable of pumping average volumes indicated for a range of pumping lift of 200-350 feet.

i/ Capable of supplying a 160-acre alfalfa unit.

Source: Interviews with well drillers and farmers in Antelope Valley.

APPENDIX TABLE 10

Prices Received by California Producers, 1920-1951

Year	Alfalfa[a/]	Antelope Valley alfalfa[b/]	Field corn	Wheat	Grain sorghum (includes milo)	Cotton	Beef cattle
	dollars per ton		dollars per hundredweight			cents per pound	
1920	22.35		1.73	3.68	1.68	13.60	9.20
1921	12.35		1.55	2.03	1.38	16.97	6.40
1922	14.65		1.63	1.83	1.95	23.97	6.40
1923	15.75		1.95	1.77	1.88	31.43	6.10
1924	20.35		2.40	2.23	2.43	23.78	6.50
1925	16.15		1.80	2.53	1.75	19.77	6.90
1926	14.45		1.85	2.17	1.70	13.75	6.90
1927	14.35		2.07	2.11	1.93	19.97	7.40
1928	16.85		2.05	2.05	1.64	18.93	9.50
1929	17.75		1.82	1.95	1.89	17.24	9.40
1930	13.75	13.50	1.28	1.50	1.27	9.59	7.90
1931	12.35	11.90	1.03	.97	.89	6.15	5.60
1932	8.85	9.48	.90	.88	.80	7.09	4.50
1933	9.85	11.25	1.07	1.30	.98	10.86	4.05
1934	11.55	13.22	1.65	1.32	1.39	12.98	4.35
1935	10.45	13.50	1.32	1.30	1.05	11.65	6.50
1936	14.05	15.58	1.90	1.55	1.57	12.65	6.10
1937	14.45	16.54	1.25	1.58	1.18	8.75	7.20
1938	10.55	11.60	1.18	1.08	.95	9.05	6.30
1939	11.05	13.31	1.35	1.27	1.23	9.60	7.00

(Continued on next page.)

Appendix Table 10 continued.

Year	Alfalfa a/	Antelope Valley alfalfa b/	Field corn	Wheat	Grain sorghum (includes milo)	Cotton	Beef cattle
	dollars per ton		dollars per hundredweight			cents per pound	
1940	9.60	12.71	1.45	1.28	1.09	11.97	7.40
1941	14.70	18.86	1.67	1.71	1.50	17.31	8.60
1942	19.50	24.45	2.08	1.90	1.70	19.22	10.50
1943	23.80	26.50	2.38	2.45	2.64	20.34	12.20
1944	24.00	25.75	2.26	2.55	2.09	20.89	11.60
1945	23.60	25.57	2.37	2.63	2.66	22.12	12.70
1946	28.40	32.41	2.83	3.38	2.79	30.94	14.60
1947	24.60	27.16	4.65	4.00	4.13	33.31	18.50
1948	27.80	31.21	2.90	3.62	2.66	31.35	22.60
1949	22.20	23.34	2.58	3.33	2.59	28.17	19.10
1950	19.70	24.10	3.12	3.40	2.61	41.30	22.60
1951	30.20	35.87	3.58	3.66	3.08	40.10	28.60

a/ Baling premiums of $2.35 per ton arbitrarily added to prices received for loose alfalfa for period 1920-1939. Baled hay prices begin 1940.

b/ Begins May 1 each uear and carries to April 30 the year following.

Source: California Crop and Livestock Reporting Service. "Prices Received by California Producers for Farm Commodities, 1909-1951."