Suitability of Irrigation Water and Changes in Ground-Water Quality in the Lompoc Subarea of the Santa Ynez River Basin Santa Barbara County California

By R. E. EVENSON

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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SUITABILITY OF IRRIGATION WATER AND CHANGES IN GROUND-WATER QUALITY IN THE LOMPOC SUBAREA OF THE SANTA YNEZ RIVER BASIN, SANTA BARBARA COUNTY, CALIFORNIA

By R. E. Evenson

ABSTRACT

Analyses of water samples collected since 1934 from some of the irrigation wells in the Lompoc subarea of the Santa Ynez River valley have shown a gradual deterioration in the chemical quality of the water.

Most of the ground water pumped in the subarea has a dissolved-solids contents ranging from about 700 to about 2,000 parts per million, of which sulfate and chloride are the predominant constituents. Suitability of the water for irrigation is variable and is dependent principally on "potential salinity" of the water, soil premeability, and type of crop.

Changes in water quality are not consistent throughout the subarea. No doubt the chloride concentration increases as a result of both recycling irrigation water and inflow of high-chloride low-sulfate connate water from the consolidated Tertiary rocks. The influence of recycled irrigation water is indicated by increase concentrations of chloride and sulfate in a ratio of 1:2. Inflow of high-chloride low-sulfate connate water is indicated by increased chloride concentration correlated with little or no change in sulfate concentration. Peak chloride concentrations in three local areas are probably the result of the inflow of connate water. Furthermore, ground-water gradients in each of the local areas are favorable for inflow from the consolidated rocks.

INTRODUCTION

The Lompoc subarea is the westernmost of five hydrologically separated subareas that compose the Santa Ynez River basin, as shown in figures 1 and 2. The subarea includes the drainage between Robinson Bridge and the Pacific Ocean and between the Purisima Hills and the Santa Ynez Mountains. Most of the flat valley floor, known as the Lompoc plain, is irrigated agricultural land and includes more than 8,000 acres of various truck and field crops and pastureland. Common crops grown include artichokes, asparagus, sugarbeets, flowers, broccoli, beans, carrots, alfalfa and clover.

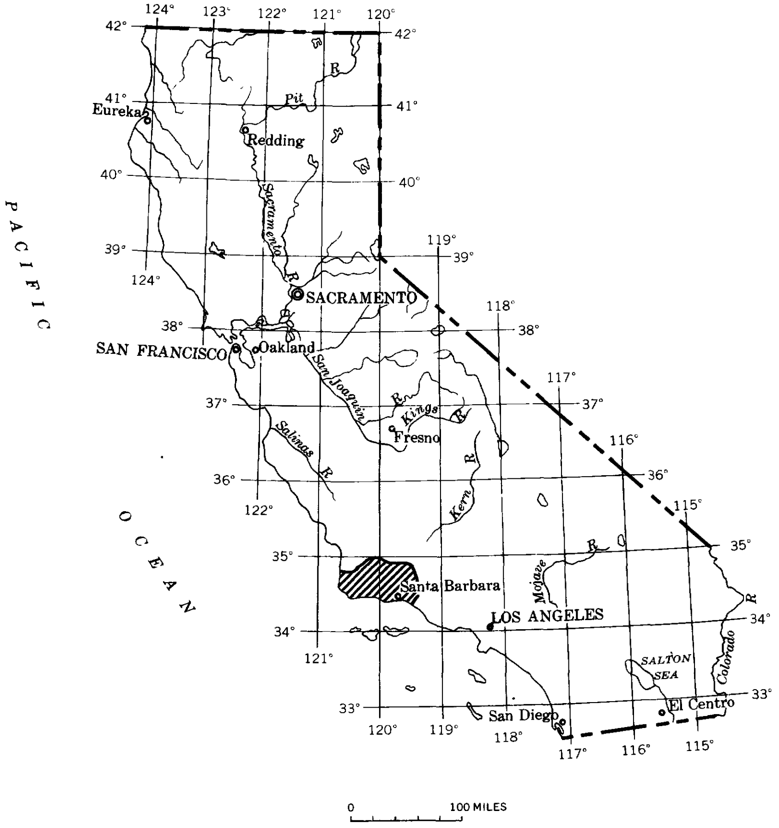

FIGURE 1.—Index map of Santa Barbara County, Calif.

Analyses of water samples collected since 1934 from some of the irrigation wells in the Lompoc plain have shown a gradual deterioration in the chemical quality of the water. The analyses have also shown that the concentration of the chloride ion in water from certain wells has doubled. At least two former irrigation wells are not being used because crops were damaged by water from them or because seeds irrigated with water from them failed to germinate.

PURPOSE AND SCOPE OF THE STUDY

The purpose of the study was to determine the causes, other than those related to waste discharge,[1] of changes in chemical quality of ground water in the Lompoc plain; determine the magnitude and rate of the changes; and develop a classification of the various types of

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[1] The State of California, Department of Water Resources, at the request of the Central Coastal Regional California Water Pollution Control Board, made a concurrent study to investigate the effect of waste discharge on the water quality in the Lompoc subarea.

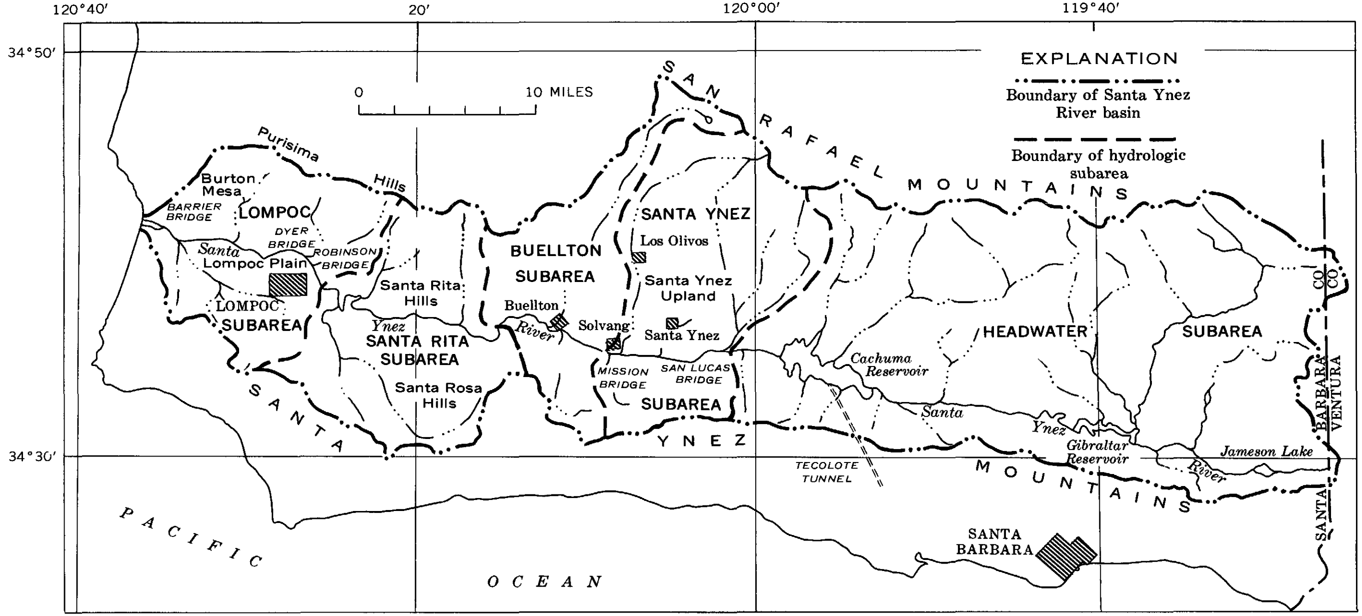

Figure 2.—Hydrologic subareas of the Santa Ynez River basin.

water related to their suitability for irrigation. This report presents (1) a summary of the geologic and hydrologic features that provide a basis for interpretation of the chemical data, (2) the basic data on the chemical quality of the water, (3) a discussion of the classification of the water as related to the water's suitability for irrigation, and (4) explanations for observed changes in the chemical quality of the water.

This work was done in cooperation with the Santa Barbara County Water Agency and the State of California, Department of Water Resources. It was done under the supervision of H. D. Wilson, Jr., and Fred Kunkel, successive district supervisors for the U.S. Geological Survey, Ground Water Branch, in California.

ACKNOWLEDGMENTS

Thanks and appreciation are expressed to the residents of the Lompoc subarea who permitted access to their lands and facilitated the collection of water samples from wells. Thanks also are given to Mr. Paul Nixon and his staff at the Agricultural Research headquarters in Lompoc for assistance in the collection of water samples.

Mr. David Willets and Mr. Allen Joy of the State of California, Department of Water Resources, reviewed the manuscript. Chemical analyses of water samples were made by the State of California, Department of Water Resources, and by the U.S. Geological Survey, Quality of Water Branch. Supplemental chemical data were obtained from the Santa Barbara office of the Farm Advisor and from the Santa Barbara office of the U.S. Department of Agriculture, Soil Conservation Service.

PREVIOUS WORK

Upson and Thomasson (1951) were the first to describe the geology and water resources of the Santa Ynez Valley, which includes the Lompoc subarea. They also analyzed hydrologic conditions and estimated perennial yield based on the period 1935–44. In their study the chloride concentration in water from wells ranged from 77 to 2,050 ppm (parts per million). The variation seemed to be governed in large part by the different formations that contained deep water in different parts of the area. Some local variation also may have resulted from downward percolation of shallow water of high-chloride concentration. Water from four shallow wells had chloride concentrations greater than 500 ppm and were thought to "reflect progressive contamination of shallow water by deep penetration of irrigation water that has leached salts from the soil zone" (Upson and Thomasson, 1951, p. 163).

Wilson (1959) appraised ground-water conditions in the basin and, for the period 1945–52, revised the previous estimate of perennial yield. He also made a more detailed study of the chemical quality of ground water. He classified ground water as to its suitability for irrigation and to its chemical composition, reviewed the status of possible contaminants, and determined if any change had taken place over the years owing to chemical reaction or to the mixing of fresh water with exterior contaminants. Wilson (1959, p. 110–116) also tabulated all available chemical analyses of well water in the Lompoc subarea through 1953. Wilson's study indicated that the chloride concentration in water from wells tapping the main water-bearing zone increased substantially from 1935 to 1953. He concluded that "because sea-water intrusion has not occurred (p. 102), the increase in chloride concentration must be due to the leaching and concentration of salts from irrigation water and (or) the mixing of the ground water with some exterior contaminant" (Wilson, 1959, p. 103).

Evenson and Miller (1963) described in detail the southwestern part of the Lompoc subarea and made revisions in geologic and hydrologic interpretations.

METHODS OF INVESTIGATION

A comprehensive water-sampling program was begun in the Lompoc subarea at the beginning of the irrigation season in the spring of 1961 and was continued through calendar year 1962. The purpose of this program was to study the occurrence of water of high-chloride concentration in greater detail than had been done previously. Samples were collected from most of the irrigation wells, springs, and streams. Later in the irrigation season, samples were again collected from key wells and analyzed to determine changes in chemical quality. The samples were screened by determining chloride concentration in the field, and selected samples were sent to laboratories for complete chemical analysis. The field measurements of chloride concentration were made by correlating at a constant temperature the electrical potential of standard solutions of known chloride concentration with the electrical potential of the water samples collected from wells. The electrical potential, measured in millivolts by a potentiometer with a silver-billet electrode, was then equated graphically to chloride concentration using the method described by Back (1960, p. 923–936).

WELL-NUMBERING SYSTEM

The well-numbering system used in this report conforms to that used in California for most ground-water investigations by the Geological Survey and the State of California, Department of Water

Resources. This system, as explained below, is based on the rectangular subdivision of public land and serves to locate the well within a 40-acre plot. Section lines have been projected into unsurveyed areas for reference only.

As an example, for well 7/35–24K2 the part of the number that precedes the hyphen indicates the township and range (T. 7 N., R. 35 W.). Most of Santa Barbara County is north and west of the San Bernardino base line and meridian; therefore, the north (N) and west (W) designations are omitted. The number following the hyphen indicates that the well is in section 24, and the letter K corresponds to the 40-acre plot as shown in figure 3. Within the 40-acre plot the wells are numbered serially, as indicated by the final digit.

A similar numbering system designates sites from which surface-water samples were collected. In numbering the localities of surface-water samples, however, the final digit was omitted. For example, the number 7/35–18J indicates the location of a sampling point at a seep or along a stream.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

FIGURE 3.—Division of a section for numbering wells.

SUMMARY OF GEOLOGY AND HYDROLOGY

The Lompoc subarea (fig. 2) is a structural basin (pl. 1) about 12 miles long and 10 miles wide adjacent to the Pacific Ocean. The northern flank of the basin is formed by consolidated rocks of Tertiary age that underlie Burton Mesa (fig. 2) and the Purisima Hills. The eastern and southern flanks of the basin are formed by similar rocks which underlie the Santa Rita Hills and Santa Ynez Mountains. Unconsolidated sediments ranging in age from Pliocene to Recent fill the basin. These sediments, which are as much as 1,000 feet thick, include marine and continental deposits of Pliocene and Pleistocene age and younger alluvium and river-channel deposits of Recent age.

The unconsolidated marine and continental deposits underlie an extensive upland area of low foothills north of the Lompoc plain and east of Santa Lucia Canyon. The sediments dip gently toward the Lompoc plain and fill a structural trough in the underlying consolidated rocks. (See geologic sections shown by Upson and Thomasson, 1951, pl. 4.) The younger alluvium and river-channel deposits underlie the flat valley floor of the Lompoc plain. Together, these deposits range in thickness from about 185 feet at The Narrows to about 200 feet at the coast.

Recent geologic studies by Evenson and Miller (1963, pl. 1) indicate that the east-west faults (pl. 1) that bound the Lompoc terrace ground-water basin on the north and south probably are continuous beneath the younger alluvium. Also, the south fault probably is continuous at least as far east as the Santa Rita area. The contacts between the consolidated rocks and the unconsolidated marine and continental deposits are steeply dipping planes along these two faults. The buried fault trace is probably on a gently undulating surface beneath the younger alluvium. Connate water in the consolidated rocks is contained in permeable zones, probably in fractured or broken Monterey Shale, and may be associated with faults that form permeable conduits either in the broken shale or between the shale and the unconsolidated sediments. A passage way or channel is formed at any point where permeable fractured zones in the shale intersect a low point along the fault trace so that connate water under hydrostatic pressure can discharge either at the surface or into the main water-bearing zone of the alluvium.

Connate water is known to occur as oil-field brine (fig. 6, plot 1) in the consolidated rocks that border and underlie the unconsolidated sediments. The high-chloride low-sulfate concentration of the brine is in agreement with White's (1957, p. 1666, table 3) tentative criteria for recognition of chloride-type connate water. Deep oil-test wells in the consolidated rocks beneath the Lompoc plain reportedly flowed salt water during production tests (State of California Div. Oil and Gas, written commun., 1960). Chemical analysis of this water shows high-chloride concentration typical of connate water. Thus, an origin as brine under hydrostatic pressure is indicated.

Connate or connate-fresh water mixtures are also recognized by the position on a trilinear plot (fig. 6, points 10 and 11) of chemical constituents in water from well 7/35–18J1 [2] and from a surface seep

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[2] Upson (Upson and Thomasson, 1951, p. 147) was of the opinion that well 7/35–18J1 taps the main water-bearing zone, but Wilson (1959, p. 98) thought that this well penetrates the shallow water-bearing zone. Recent test drilling indicates that this well actually does penetrate the shallow water body and bottom in broken shale in the consolidated rocks. Therefore the water is probably a mixture of connate water from the shale and fresh water from the shallow zone. The position of this analysis on the trilinear diagram supports this conclusion (fig. 6).

at the confluence of Pine and Santa Lucia Canyons near location 7/34–18F (point 2). Connate-fresh water mixtures probably also occur in other wells, springs, and seeps in the Lompoc subarea.

Fresh ground water occurs in both a shallow water body and a deep water body. The fresh-water aquifers constitute the major part of the unconsolidated sediments of the basin. The shallow water body, contained in a zone of permeable younger alluvium, locally is in hydraulic continuity with the deep water body. However, the shallow water body, though unconfined, generally is separated from the deep water body by a zone of fine-grained sand, silt, and clay.

The deep water body is contained in a main water-bearing zone that includes principally a highly permeable aquifer in the lower member of the younger alluvium and in a secondary water-bearing zone of less permeable interconnected aquifers in the underlying unconsolidated marine and continental deposits of Pliocene and Pleistocene age and locally in adjacent terrace deposits (Upson and Thomasson, 1951, pl. 5).

The main water-bearing zone, underlying almost the full length of the Lompoc plain, is overlain and semiconfined by predominantly impermeable deposits in the upper part of the younger alluvium throughout much of the area. Water in the unconsolidated sediments may be separated from the deep water body locally on the north and south sides of the Lompoc plain.

Water in the main water-bearing zone moves westward. Some is discharged by withdrawals from wells, and some is discharged through a natural submarine outlet offshore from the mouth of the Santa Ynez River. Near the west end of the Lompoc plain, water in the shallow water-bearing zone is discharged into a swamp and into two drainage ditches that are tributary to the Santa Ynez River. Evaporation and transpiration from swamps and areas where phreatophytes grow account for a significant quantity of the water discharged from the shallow zone.

The source of water in the various aquifers is rain that either falls on the outcrops of the water-bearing formations and percolates underground or reaches the area as runoff in the Santa Ynez River and the tributary streams. Three specific and more immediate sources of recharge to the main and secondary water-bearing zones were distinguished by Upson and Thomasson (1951, p. 152) as follows:

> In order of relative volume of contribution these are: the Orcutt, Paso Robles, and Careaga Formations by transmission underground from the margins of the plain, and from below; the shallow water-bearing zone, partly by continual transmission of water to the main and secondary zones from the streams and partly by seasonal unwatering as a result of pumping from the main and secondary zones; and the Santa Ynez River by seepage loss in the first 3,000

ft below Robinson Bridge and in small part in secs. 23 and 24, T. 7 N., R. 35 W., and by movement of underflow through the tongue of the main zone that extends upstream through The Narrows.

WATER QUALITY

CHEMICAL CHARACTERISTICS

All water for domestic, industrial, and agricultural uses in the Lompoc subarea is obtained from wells; and although the suitability of the water for a specific use is determined by the chemical, physical, and biological characteristics, this report is concerned only with the chemical characteristics. Chemical characteristics of water are dependent on the mineral constituents in solution, most of which are ionized to form positive ions (cations) and negative ions (anions). Wilson (1959, figs. 19, 20, p. 100, 101) showed the wide range of distribution of cations and anions in water from wells in the Lompoc subarea. The principal cations are calcium, magnesium, sodium, and potassium; the principal anions are bicarbonate, chloride, sulfate, and nitrate.

DISSOLVED SOLIDS AND SPECIFIC CONDUCTANCE

The total concentration of dissolved mineral matter is referred to as dissolved solids and is commonly measured by the specific conductance of the water, the sum of concentrations separately determined for all the anions and cations in the water, and the residue on evaporation of a filtered sample. The first measurement can be done readily in the field, but the second and third require rather complex laboratory procedures.

In most water an approximate relation exists between the specific conductance and the quantity of dissolved solids, or constituents measured in a complete analysis. This relation for water of the Lompoc subarea is shown in figure 4. The mean curve in figure 4 can be expressed approximately by the relationship $DS=0.71\ (K\times10^6)$ where DS represents dissolved solids, in parts per million, and K is specific conductance, in micromhos at 25° C.

Dissolved solids or specific conductance, as well as other parameters, are common factors in determining the suitability of a water for domestic, industrial, or agricultural supply.

Plate 1 shows, in general, an increase in dissolved solids indicated by specific-conductance measurements from east to west across the Lompoc plain. Water from aquifers northeast and southwest of the plain generally has a specific conductance of less than 1,000 micromhos, whereas water from the main water-bearing zone ranges from less than 1,000 micromhos in the northeastern part to about 3,000 micromhos in the

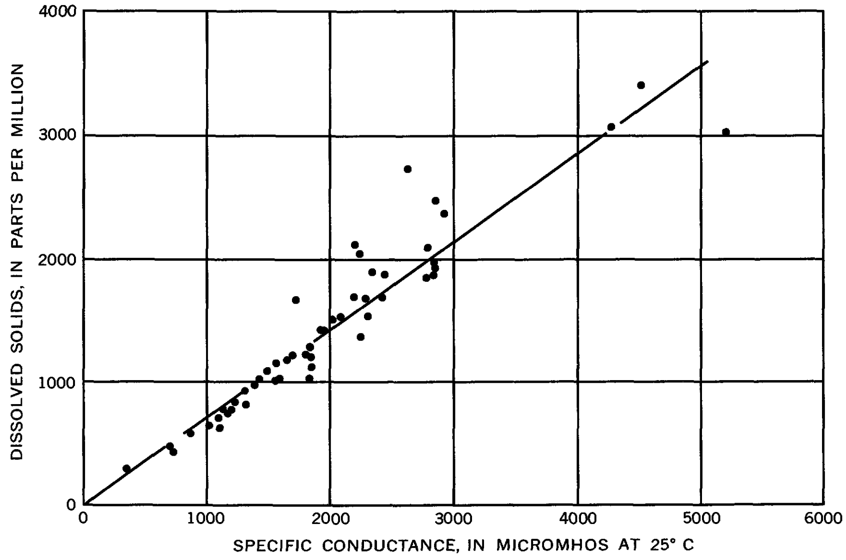


Figure 4.—Relation of specific conductance to dissolved solids in the Lompoc subarea.

west-central part. However, one water sample having a specific conductance of 3,940 micromhos was obtained from surface-water flow just downstream from the junction of Pine and Santa Lucia Canyons.

SUITABILITY OF THE WATER FOR IRRIGATION

A variety of criteria has been suggested for the evaluation of the suitability of water for irrigation based on chemical quality; some of these have been summarized in reports by the Geological Survey (1954, p. 9–14), Doneen (1954, p. 943–944), and Hem (1959, p. 242–250). Most of the suggested criteria include either dissolved solids or specific conductance as one parameter and toxic constituents such as boron as another. The interrelationship between dissolved solids and the relative proportion of sodium to other cations, either as percent sodium or as the sodium-adsorption-ratio, has frequently been used in reports. (For example, see Wilson, 1959, p. 97.)

Doneen (1954, p. 945) pointed out that the suitability of water for irrigation is not dependent on the concentration of dissolved solids (or total salts) but, rather, is dependent on the concentration of soluble salts. Doneen (1962, p. 2) listed the more common salts found in irrigation water on the basis of solubility, as shown in the following table; the most soluble are the chloride salts and some of the sulfate salts.

Low-solubility salt	*High-solubility salt*
$CaCO_3$	$CaCl_2$
$Ca(HCO_3)_2$	$MgSO_4$
$CaSO_4$	$MgCl_2$
$MgHCO_3$	$NaHCO_3$
$MgCO_3$	$NaSO_4$
	$NaCl$

Recycling irrigation water results in the accumulation and concentration of salts in the soil as the water evaporates or is used by the plants, and, with each irrigation, chloride and other soluble salts are redissolved and returned to the water body. Doneen (1962, p. 2) pointed out that low-solubility salts precipitate in the soil and accumulate with each successive irrigation, whereas high-solubility salts concentrate and increase the salinity of the soil solution. Subsequent deep percolation of water moves this soil solution to the water body; thus, the continued recycling of irrigation water may result in the concentration of the highly soluble salts in the ground water—namely, all the chloride salts and approximately half the sulfate salts. Thus, chloride, sulfate, and dissolved solids are reliable indexes of chemical changes in natural water of the Lompoc subarea.

In recent work, Doneen (1962, p. 3) proposed a tentative classification of irrigation water that considers the factor of soil permeability related to "potential salinity" of the water. Potential salinity is defined as the chloride concentration plus half the sulfate concentration. Therefore, it is an index of the concentration of the more soluble salts. As indicated by the extreme variations in characteristics of both water and soil in the Lompoc subarea, any classification of irrigation water for this area and other areas of California should include a consideration of both soil permeability and potential salinity.

A tentative classification of irrigation water from the Lompoc subarea derived for this report is given in table 1 and is based on soil conditions and related potential salinity, as expressed by specific conductance. This classification, originally proposed by Doneen (1962, p. 3), was modified by the author for use in the Lompoc subarea by relating specific conductance to potential salinity. Figure 5 shows that, for water in the Lompoc subarea, the potential salinity, in equivalents per million (epm) is approximately equal to the specific conductance multiplied by 0.006. Thus, table 1, used in conjunction with plate 1, offers a convenient guide for the classification of irrigation water in the Lompoc subarea.

The method used by Wilson (1959, p. 96–98) for interpreting the suitability of water for irrigation is useful with respect to the permissible limits of boron and the relation of specific conductance to percent sodium. Table 1 of this report relates specific conductance to soil conditions.

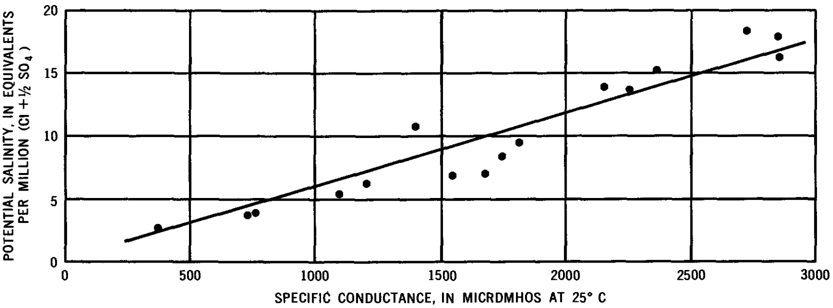


FIGURE 5.—Relation of specific conductance to potential salinity of irrigation water.

CHANGES IN WATER QUALITY

Changes in water quality because of modification of the chemical character of the water may result from a variety of natural conditions and related chemical reactions. These conditions include ion exchange, sulfate reduction, recycling irrigation water, and mixing with contaminants or with water of different types. The chemical character of different water types, or of mixtures, can be shown graphically by means of the trilinear diagram in figure 6 of this report or figure 19 of a report by Wilson (1959, p. 100). Figure 6 compares some of the analyses used by Wilson with selected analyses of connate water and ocean water and with a chronologic listing of water analyses from certain key wells. The changes in quality with time are especially significant to an understanding of the reasons for the increases in chloride concentration that have been observed in water from some wells.

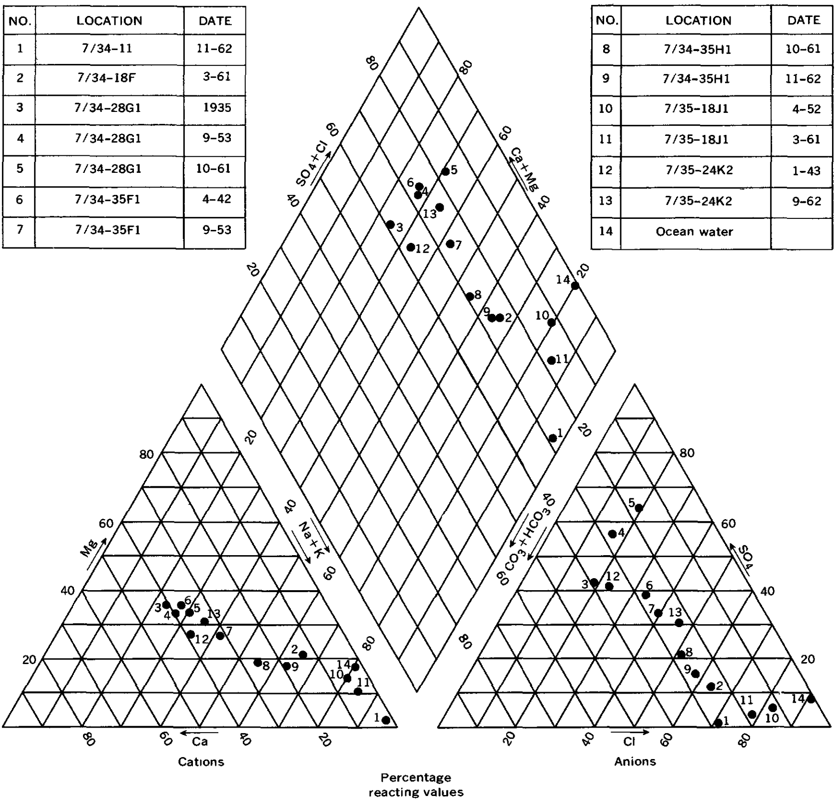
The points plotted on the trilinear diagram show the chemical character of water according to the relative concentration of its constituents. Each numbered point shows the percentage reacting value of the cations and the anions on the triangular fields. A composite location is shown on the diamond-shaped field.

The direction of chronologic progression of the plotted points on the diamond-shaped field in figure 6 summarizes both cation and anion changes and illustrates the effects of mixing of water types. In particular, points plotted for water from well 7/34–35F1 (points 6 and 7), 35H1 (points 8 and 9), and 7/35–18J1 (points 10 and 11) show

TABLE 1.—*Tentative classification of water to be used for irrigation in the Lompoc subarea*

[After Doneen (1962, p. 3)]

Effect on soil	Class 1 Excellent to good		Class 2 Good to injurious		Class 3 Injurious to unsuitable	
	Potential salinity (epm)	Specific conductance (micromhos at 25°C)	Potential salinity (epm)	Specific conductance (micromhos at 25°C)	Potential salinity (epm)	Specific conductance (micromhos at 25°C)
Minimal leaching; slow percolation rates	3.00	500	3.00- 5.00	500-800	>5.00	>800
Some restricted leaching; deep percolation slow	5.00	800	5.00-10.00	800-1,700	>10.00	>1,700
Maximum leaching; deep percolation rapid	7.00	1,200	7.00-15.00	1,200-2,500	>15.00	>2,500



NO.	LOCATION	DATE
1	7/34-11	11-62
2	7/34-18F	3-61
3	7/34-28G1	1935
4	7/34-28G1	9-53
5	7/34-28G1	10-61
6	7/34-35F1	4-42
7	7/34-35F1	9-53
8	7/34-35H1	10-61
9	7/34-35H1	11-62
10	7/35-18J1	4-52
11	7/35-18J1	3-61
12	7/35-24K2	1-43
13	7/35-24K2	9-62
14	Ocean water	

FIGURE 6.—Chemical character of water.

chronologic progression on the diamond field toward the area indicative of connate water (point 1). Points plotted for well 7/35–24K2 (points 12 and 13) also show a progressive trend toward connate water on the anion field, but complex chemical changes due to ion exchange (affecting the cations) and fresh water dilutions are also indicated. Well 7/34–28G1 (points 3, 4, and 5) shows slight changes on the cation field and an increase of sulfate that could be due to the effects of sulfate-type fertilizers in use.

CHANGES IN CHLORIDE CONCENTRATION

The geographic distribution of water quality changes in the Lompoc plain is shown by chloride concentrations recorded in selected wells that produce water from the main water body.

Of the various ions present in the water in the Lompoc subarea, the chloride ion has been the one most frequently determined by chemical analysis. It is a reliable indicator of chemical changes in water quality because the chloride ion does not enter into chemical reactions related to base exchange or to sulfate reduction. Because of high solubility of its salts, the chloride ion does not precipitate from solution in its passage through the soil.

No standards have been established for chloride concentration in irrigation water; however, chloride concentrations in drinking water should not exceed 250 ppm (U.S. Public Health Service, 1962, p. 7).

An increase of more than 100 percent in chloride concentration in water from wells just south of Pine Canyon was first noted by Wilson (1959, p. 103). However, as shown on plate 2, the concentration of chloride in water has varied widely in the Lompoc plain over a period of several years. Chloride concentration in water from some wells has shown a slight decrease, whereas that in water from other wells, as in the Pine Canyon area, has shown an increase of approximately 300 ppm (nearly 125 percent).

Shown on plate 2 for comparative purposes are the changes in sulfate concentrations plotted at twice the chloride concentration scale. Because water from the main water body everywhere has high-sulfate concentrations that show little evidence of reduction, water-quality changes caused by sulfate reduction are concluded to be negligible.

Changes in the quality of water from wells, as shown on plate 2, are the result of mixing with recycled irrigation water and connate water. Long-term records of water quality are not available for the wells (7/34–35H1 and 6/35–1A1, pl. 3) in the eastern and south-central parts of the area that have peak chloride concentrations. Therefore, the magnitude of changes in chloride concentration in these local areas are not known. Analyses of water samples collected at more frequent intervals were not available to specifically define the times at which the changes occurred.

Little or no change in chloride concentration, as shown on plate 2, for wells 7/34–30A1, 7/34–33P1, and 7/35–23E2 indicates a chemical equilibrium, probably the result of uniform and consistent localized recharge that forms small hydrologically stable areas between areas of recharge and discharge.

Recycled irrigation water.—Recycled irrigation water is indicated on plate 2 by wells 7/34–28G1, 7/34–31A2, 7/35–36P1, 7/35–25D1, and probably 7/35–22J1, all of which show an increase of both chloride and sulfate concentrations. The continued recycling of irrigation water results in an accumulation of highly soluble salts in the ground water. These salts include the chloride salts plus approximately half the sulfate salts (Doneen, 1962, p. 2), so sulfate concentrations are plotted at a scale twice that of the chloride concentrations.

Water from well 7/35–36P1 is perhaps typical of recycled irrigation water. This well showed proportional increases in chloride and sulfate concentrations at a 1:2 ratio from 1935 to 1958 which reached a maximum of about 260 ppm chloride and 380 ppm sulfate. From 1958 to 1962, chloride and sulfate concentration decreased, also in the 1:2 ratio. The reversal of the trend is probably the result of delayed effects of improvement in quality due to dilution that has occurred during a period of above average recharge. This dilution may have been caused by the extremely wet spring of 1952. The delay of several years was necessary for water to move from the recharge area along the southern part of the Lompoc plain.

A similar increase and subsequent decrease of chloride and sulfate concentrations were recorded for water from wells 7/35–25D1 and 7/34–31A2, which also are near the southwest-central area. The period of record, however, is not sufficiently continuous to allow determination of the specific year the trend reversed.

Although water from wells 7/34–28G1, 31A2, and 7/35–25D1 shows an increase of both chloride and sulfate concentrations, the sulfate concentration increased at a greater proportional rate to the chloride concentration than would be expected from recycling only. Sulfate fertilizers would be expected to cause an increase in the rate of accumulation of soluble sulfate salts greater than the normal accretion that results from recycled irrigation water. Water from wells near the edge of the basin (7/35–36P1) in areas where fertilizers do not contain sulfate would not be expected to reflect the increased rate of sulfate accumulation.

Connate water.—The effect of high-chloride low-sulfate connate water mixing with water from wells 7/34–35F1 and 7/35–24K2 are shown in figure 7 by an increase of chloride concentrations and either a decrease or only small change in sulfate concentration. Changes in chloride concentration are greatest for water from well 7/35–24K2 near the junction of the Santa Ynez River and Pine Canyon. The chloride concentration in water from this well increased from about 200 ppm in 1935 to slightly less than 500 ppm in 1962 but was as low as 180 ppm in 1943. Some fluctuations in concentration occurred from the spring of 1961 to the fall of 1962.

The period of record for wells 35F1 and 24K2 is not sufficiently continuous to allow positive determination of the specific year the change occurred. However, the data for well 7/35–24K2, which are generally substantiated by those from 35F1, show increases of chloride concentration sometime between 1943 and 1953. (See also Wilson, 1959, table 9, p. 115.)

Only wells 7/34–35F1 (fig. 6) and 7/35–24K2 show the effect of high-chloride low-sulfate connate water. Because none of the adjacent wells are similarly affected, the connate-water inflow presumably is from a localized source—possibly a point source. Hydrogeologic conditions favorable for inflow of the high-chloride low-sulfate water are explained as follows: Connate water, contained under hydrostatic pressure in permeable zones in the consolidated rocks, migrates through subsurface conduits formed by faults and discharges at any point along the fault trace, either at the surface (7/34–18F) or into the main water-bearing zone of the alluvium (7/34–35F1, 18H1, and 7/35–24K2). During periods when water levels are high, the hydrostatic pressure of the water in the main water-bearing zone is sufficient to prevent the connate water from discharging; but when water levels are lowered for prolonged periods, such as the 1946–51 dry period, connate water locally wells up and mixes with the fresh water. Data are lacking to demonstrate if this mechanism is, in fact, responsible for the observed changes, but the author considers the possibility a likely one.

There was no immediate improvement of quality as a result of dilution during the above-average precipitation in the spring of 1962; however, figure 6 indicates an improvement in water quality for some wells as a result of dilution by recharge water after a time lag of probably several years.

DISTRIBUTION OF CHLORIDE CONCENTRATION

Concentration of chloride ions in water from wells ranges from about 100 ppm in water from aquifers of the unconsolidated marine and continental deposits in the northeastern part of the Lompoc subarea to more than 1,500 ppm in water from the shallow water-bearing zone of the Lompoc plain near the ocean, as shown on plate 3. In some parts of the plain, chloride concentration is the same in both the shallow and deep zones; in other parts, chloride concentration is greater in the shallow zone than in the deep zone. Where there is a difference in chloride concentration between the shallow and deep zones, water in the shallow zone has the greater concentration. From the few complete analyses available, it seems probable that the greater chloride concentration in the shallow water is due to recycling of irrigation water that becomes, at least temporarily, perched in the shallow water body.

Chloride concentration in water from the aquifers northeast and southwest of the Lompoc plain is somewhat less than that in the hydrologically confluent aquifers of the main water-bearing zone. Because the general direction of water movement is from east to west across the area (Wilson, 1959, pl. 7) in both the shallow and main water-bearing zones, chloride concentration would generally be expected to increase progressively from the central part to the western part of the main water-bearing zone (pl. 3), in part owing to recycling of irrigation water. Plate 3 shows the areal distribution of chloride concentration in the main water-bearing zone, and the surface water in 1961.

In general, chloride concentration is less than 100 ppm in most of the springs and streams except downstream from the junction of Pine and Santa Lucia Canyons, where, in February 1961, the chloride concentration was 917 ppm, and in the Santa Ynez River downstream from its confluence with the surface flow from Pine Canyon, where at the same time the chloride concentration was 508 ppm. The chloride concentration in the water in ditches draining the shallow water-bearing zone near the west end of the Lompoc plain is more than 400 ppm.

In three widely separated areas of the Lompoc plain, the chloride concentration of water in the main water-bearing zone is greater than 300 ppm. As shown on plate 3, peak chloride concentrations were recorded for water from wells 6/35–1A1 in the south-central area, 7/34–35H1 in the extreme east-central area, and 7/35–24K2 in the north-central area. In each of these three areas, the direction of ground-water movement is away from the peak chloride concentration (see pl. 2). Water-levels contours drawn by Wilson (1959, pl. 7) show that the ground-water movement has consistently been away from these three areas of peak concentration during periods of both low (Oct.–Nov. 1951) and high (Mar.–Apr. 1952) water levels. The three wells with peak chloride concentrations have two features in common: they (1) produce irrigation water from aquifers confluent with the main water-bearing zone, and (2) are near the edge of the Lompoc plain and are perforated very close to the approximate subsurface geologic contact (probably a fault contact buried beneath the younger alluvium) between the consolidated rocks and the unconsolidated marine and continental deposits (see pl. 2). Therefore, in each of these three separate areas, peak chloride concentration probably is the result of high-chloride connate water migrating upward into the deep water body in the younger alluvium, presumably from the underlying Tertiary rocks.

An association of high-chloride well water with proximity to geologic contacts is an indication that connate water may be percolating into the basin along permeable zones related to the geologic structure.

Continued monitoring of the water quality is necessary to determine, if possible, future rates of change in quality, stabilization of change in quality in certain areas, and extent of areal distribution of the high-chloride concentration. Further studies will demonstrate if the relations suggested in this report are valid.

SUMMARY AND CONCLUSIONS

In the Lompoc subarea specific conductance is a good index of the suitability of water for irrigation. It correlates very well with two commonly used parameters—percent sodium and soil conditions.

Significant changes in water quality have occurred during the period of record in some of the wells but not in others. These changes may be the results of mixing with recycled irrigation water and (or) high-chloride low-sulfate connate water. Where analyses show a change in both chloride and sulfate contents, recycling is indicated; where the change in sulfate content is small compared to that in chloride content, mixing with connate water is indicated.

Local peak chloride concentrations in water from irrigation wells occur in three widely separated areas of the Lompoc plain. One peak occurs in the east end of the plain in the vicinity of Robinson Bridge; another peak occurs in the south-central part of the plain; and the third peak occurs in the central part of the plain, near the mouth of Pine Canyon. The three areas of peak chloride concentration have in common a sequence of geologic formations in which the Recent alluvial deposits overlie the geologic contact between the consolidated rocks and the unconsolidated marine and continental deposits. The peak concentration in each of these three areas may be the result of connate water discharging from a buried orifice into the main water-bearing zone. Geologic and hydrologic conditions are favorable for the upward migration of high-chloride connate water from the Tertiary rocks into the deep water body in the younger alluvium. The migration of high-chloride water from the consolidated rocks would no doubt be accelerated during periods when water levels and artesian pressures are low owing to overdraft of the water supply as a result of extended drought and excessive pumping; conversely, migration might cease during periods when water levels are high.

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