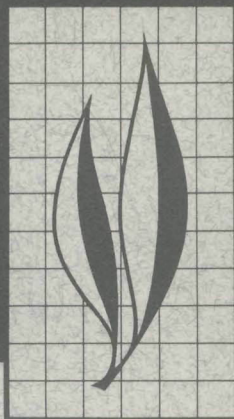


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Quality of Percolating Waters

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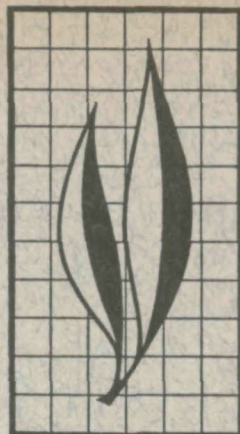
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K. K. Tanji, L. D. Doneen, and J. L. Paul



The San Luis Project, a major new unit in the Central Valley Project, is currently under construction. It will transport Feather River water to the west side of the San Joaquin Valley. The State of California Water Plan envisions a program of cyclic use of ground water during periods of deficiency, and storage of excess surface water when supplies are plentiful. Recharge of underground storage basins will involve the percolation of water through substrata, and the quality of the percolating water will be influenced by salts present in the substrata.

A series of papers in this issue present a method of predicting the quality of percolating waters in substrata (Part III), utilizing field data obtained from substrata profiles in the west side of the San Joaquin Valley (Part I). Theoretical considerations and approximations (Parts II and III) are formulated in the computer programs, for calculating simultaneously the major physicochemical reactions that occur during recharge.

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I. Properties of Deep Substrata Materials in the West Side of the San Joaquin Valley, California¹

INTRODUCTION

FOR MANY YEARS the west side and the southern part of the San Joaquin Valley have been areas of overdraft on ground water. Investigations by the U. S. Geological Survey (Davis *et al.*, 1957) and the California Department of Water Resources (1959) showed that about 10 million acre-feet of ground water were pumped from about 50,000 wells to supply the irrigation needs of more than 3 million acres of land in the San Joaquin Valley. In 1955 an estimated average annual overdraft of 500,000 acre-feet of ground water occurred for a portion of the west side of the San Joaquin Valley. Davis *et al.* (1957) reported the storage capacity of underground reservoirs in this valley to be about 93 million acre-feet at limited depths of 10 to 200 feet below the land surface.

To alleviate the problem of demand over water supply, a joint state-federal project has been initiated to transport water to the west side of the San Joaquin Valley. The proposed 104-mile San Luis Canal will deliver about one million acre-feet of water to this area for irrigation. It has been suggested that ground-water reservoirs be replenished during years of excessive surface water and that this reserve be used for irrigation during periods of insufficient surface supply. Replenishment may be accomplished by artificial recharge in selected locations, by overirrigation of

crop lands, or by other feasible means. The recharge will involve the percolation of water into the substrata profile.

Water percolating through the soil profile and into the deeper substratum will dissolve soluble salts and minerals and transport them to the ground-water aquifers. Salts of limited solubility will also be solubilized and/or precipitated. Ion exchange and adsorption processes will further modify the composition of the water. Thus the quality of percolating water will be constantly changing, under the influence of such materials and processes, as it moves deeper into the substrata. Consequently, information on substrata properties is essential for predicting ground-water quality.

The purpose of this investigation was to determine the amount and kinds of salts and slightly soluble minerals present in the substrata. Chemical and physical properties that may influence quality of percolating water were also determined. In addition, the sampling sites selected for these analyses may be used as reference points for changes that may occur in the profile with prolonged irrigation. From this initial appraisal, studies were made, with laboratory and computer models, to predict the quality of percolating waters that will be stored in aquifers (see third paper in this series).

¹ Submitted for publication May 6, 1966.

DESCRIPTION OF AREA

Location and general features

The San Joaquin Valley consists of a broad structural trough, 250 miles long and about 40 miles wide—the southern two-thirds of the Central Valley of California. The northern part drains into the San Joaquin River which flows northward to the Sacramento-San Joaquin Delta. Most of the southern area drains into an interior section of the Tulare Lake Basin and Buena Vista Lake. The valley floor is formed entirely by unconsolidated deposits covering an area of more than 10,000 square miles and ranging in thickness from a few feet, along the dissected uplands, to about 16,000 feet in the southern edge of the valley.

The area investigated (fig. 1) ranges from Dos Palos south to Kettleman City in what is known as the west side of the San Joaquin Valley, and from Stratford south to Shafter in the Tulare Lake Basin area. This survey covered an area about 100 miles long and about 10 miles wide. Nineteen sampling sites are reported, about half of which are along the proposed San Luis Canal. Most of the sites are located on alluvial fans; the rest are in the axial trough and basin areas.

In general, soils on the recent alluvial fans produce good crop yields, but are limited by the availability of water and its quality. The basin soils, especially around the rim, are saline and/or sodic. Drainage is poor to imperfect, with subsoils compacted to varying degrees. Harradine (1950), working in west Fresno County, reported that salt accumulation in these areas may be attributed to arid climate, high salt content in parent material, and high water table due to inadequate drainage.

Because of low precipitation (± 6 inches annually), rainfall contributes only a small fraction of the soil moisture required for crop production, and

stream flow is not important. Thus, ground water is used extensively for irrigation, and overdraft has been occurring for many years.

Geological features

Streams in the area surveyed are intermittent, and runoff to the valley floor is small, but subject to sudden floods. Consequently, the sediments deposited are chiefly ill-sorted materials. The parent material of alluvial fan soils is derived from the Diablo Range and consists of calcareous and gypsiferous sandstones, shales, and conglomerates. The axial trough of the valley consists of mixed sedimentary and igneous rock alluvium. Sediments derived from the Sierra Nevada to the east are predominantly granitic in origin.

A typical cross-section of the west side is shown in figure 2. The land surface to the top of the Corcoran layer may, however, range from 200 to 800 feet in depth, and includes the younger and older alluvium. In the upper unit, alluvial deposits from the Coast Ranges and Sierra Nevada interlace one another and grade into the lacustrine clay deposits.

The Corcoran clay, sometimes referred to as blue clay, is a well-sorted bed of diatomaceous lake clay. It underlies much of the San Joaquin Valley. Davis *et al.* (1957) reported that the lacustrine deposit extends southeastward from Tracy to west of Bakersfield—an area 200 miles long and about 25 miles wide. The clay bed is estimated 10 feet thick near the edges, extending to 160 feet thick beneath the present bed of Tulare Lake Basin. The Corcoran clay is the only lateral continuous stratification in the continental deposits of the valley. The hydrology of the valley is largely defined by this principal confining bed which generally

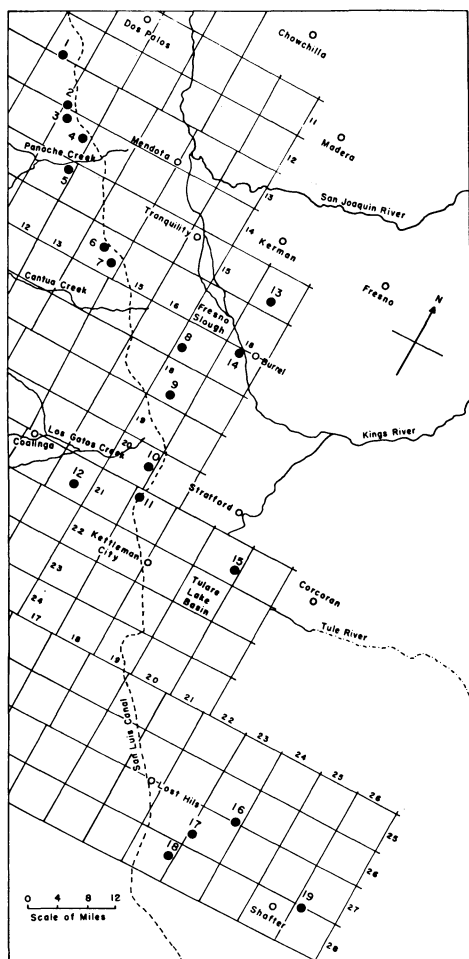


Fig. 1. Locations of sampling sites, west side of the San Joaquin Valley, California. Sites (solid dots) are denoted by numbers 1 through 19. See table 1 for township/range, section designation.

separates waters of different chemical character and concentration.

The lower unit, below the Corcoran clay, is about 600 to 1,000 feet thick, and contains sediments from both the east and west mountain ranges. The continental deposits lie above the consolidated to semiconsolidated marine sedimentary rocks of the coast ranges which extend eastward beneath the valley. Highly saline connate waters are present in the marine sedimentary rocks.

Ground-water conditions

Three distinct bodies of ground water occur throughout much of this portion of the valley. A body of unconfined to semiconfined fresh water is located in the alluvial deposits overlying the Corcoran clay (fig. 2); a second body of fresh water is confined beneath the clay bed in the lower water-bearing zone; and a body of saline connate waters is found in the marine sediments beneath the lower zone. Ground-water quality, both vertically and throughout the area, is characterized by marked chemical differences. Waters in deposits from the Coast Ranges contain predominantly SO_4^{--} , Ca^{++} , and Mg^{++} at relatively high concentrations. Waters found in deposits from the Sierra Nevada are low in concentration, with Na^+ and HCO_3^- ions predominating. A mixture of Coast Range-type waters with those of the Sierra Nevada is found in the ground waters of the lower fans and basins.

Vertical differences in ground-water quality have also been reported by Davis *et al.* (1954; 1957) and the California Department of Water Resources (1959). In the upper, unconfined water-bearing zone the total dissolved solids are $\pm 1,500$ ppm in the top 200 feet and $\pm 3,000$ ppm at lower depths. Sodium content of the waters is about 35 and 55 per cent, respectively, for the corresponding depths. However, immediately above the blue clay layer are ground waters of poorer quality, containing $\pm 5,000$ ppm of dissolved solids with SO_4^{--} and Na^+ the predominant ions. In the lower, confined water-bearing zone the dissolved solids are generally lower (± 800 ppm), but the sodium content is higher (± 75 per cent). Total dissolved solids of the waters in the marine sediments are greater than 6,000 ppm, with a predominance of Na^+ and Cl^- ions.

Ground water flows exceedingly slowly to lower elevations or to regions

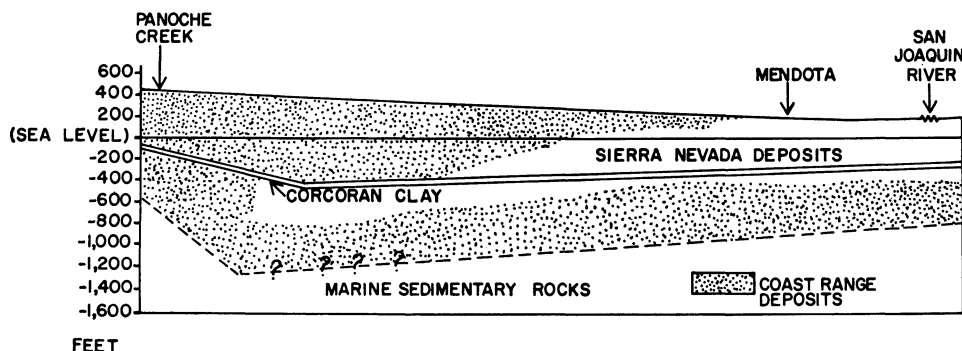


Fig. 2. Diagrammatic cross-section between Panoche Creek and San Joaquin River, California (after Davis *et al.*, 1954).

of lower pressure. In the case of the west side, the movement is from areas of recharge to areas of overdraft in the basin. In the upper water-bearing zone,

this results in a westward movement across the axis of the valley from the east side, and an eastward movement of percolating west-side streams.

METHODS OF INVESTIGATION

Profile sampling of substrata

The sites were sampled by a rotary-type drill equipped with a Hawthorne drag bit, by circulating air for the shallow depth, and by mud slurry for the deeper depths (fig. 3). Substrata core samples were obtained by inserting four brass liners into an open-tube sampler. Each liner was 6 inches long, with an inner diameter of 2.5 inches. The sampler was pushed into the substrata by hydraulic pressure up to 600 psi. When this method was impractical, a 175-pound hammer with a 30-inch stroke was used to advance the sampler.

Substrata samples in the brass liners were designated relatively undisturbed core samples. The liners were sealed at both ends and brought to the laboratory for analysis. In addition, samples representing about 6 inches in depth were obtained from the lower end of the sampling tube, and these were designated shoe or disturbed samples.

Methods of analyses

Substrata samples were characterized by several chemical and physical

determinations. Among the more important properties influencing quality of percolating water are the presence of soluble and slightly soluble salts and exchange properties of the substrata.

The term soluble salts, as used in this publication, refers to the soluble ions found in a 1:1 water extract. It is recognized that the total amount of dissolved salts in a 1:1 extract will be larger than that at a lower moisture content (such as field-moisture or pore-volume saturation) because of the dissolution of slightly soluble salts such as gypsum and, to some degree, lime. With the aid of the computer program, however, solutes and gypsum data from a 1:1 water extract may be readily converted to their respective equilibrium values at a lower moisture content (see second paper in this series).

Cations (Na^+ , K^+ , Ca^{++} , Mg^{++}) were determined by a Beckman DU flame photometer. Anions (Cl^- , HCO_3^-) were determined by titration with AgNO_3 and H_2SO_4 , respectively. Water-soluble SO_4^{--} in the 1:1 extract was estimated by taking the difference between total cations and $\text{HCO}_3^- + \text{Cl}^-$, assuming



Fig. 3. Drilling for substrata core samples.

NO_3^- and other anions to be present in negligible amounts. Boron was determined colorimetrically with carmine solution (Richards, 1954).

Adsorbed cations were extracted by neutral 1 N ammonium acetate. Exchangeable sodium corrected for soluble sodium, as found in the 1:1 extract, is the only exchangeable base reported. Exchangeable calcium and magnesium are not reported since the substrata samples contained appreciable amounts of gypsum and/or lime. Cation-exchange capacities were determined by the ammonium acetate method.

Gypsum was estimated by the increase in soluble sulfate with successive dilution. Upon complete dissolution of gypsum, SO_4^{2-} was quantita-

tively determined by precipitation as BaSO_4 before and after dilution. Lime was determined by gravimetric loss due to CO_2 evolution upon addition of acid.

Other measurements taken on relatively undisturbed substrata core samples were volume weight, field-moisture content, and moisture equivalent. For all practical purposes, volume weight refers to the bulk density of the sample. Field-moisture content is the moisture found in sealed core samples and is reported on an air dry-weight basis. Moisture-equivalent determinations are given on an oven-dry weight basis, and this value approximates field capacity for medium- and many fine-textured agricultural soils.

RESULTS AND DISCUSSION

This investigation resulted in an accumulation of extensive analytical data. Detailed results for the five sites used are described in the Appendix. Detailed analyses are available on samples from 14 other sites.² Consequently

many of the data reported in this section and in subsequent papers are summarized, and are subject to limitations and inherent errors when means or averages are utilized.

The location of each profile site by

² Water Science and Engineering Paper No. 4003. Department of Water Science and Engineering, University of California, Davis.

TABLE 1
DISTRIBUTION OF SOLUBLE SALTS IN SUBSTRATA PROFILES IN THE
WEST SIDE OF THE SAN JOAQUIN VALLEY, CALIFORNIA

Profile location (township/range, section)	Site no.	Month and year of sampling	Means of samples (50-ft. increments)						
			0-50	50-100	100-150	150-200	200-250	250-300	300-350
			m.e. per 100 gm						
Alluvial fan:									
12/11,33.....	1	1-60	2.9	2.2	1.2	0.7	0.7	1.0	...
13/12,31.....	2	5-56	4.9	5.7	...	...	...	...	...
14/12,8.....	3*	10-58	6.2	5.1	3.1	1.8	0.8	0.7	1.4
14/12,13.....	4	8-59	4.0	3.1	1.6	...	...	...	...
15/12,12.....	5	2-60	2.2	1.7	0.7	0.9	1.3	1.2	1.0
16/14,16.....	6*	1-59	7.5	7.2	7.0	6.9	7.1	6.9	5.8
16/14,25.....	7	6-56	8.0	9.1	8.0	4.2	3.9	3.9	...
17/17,20.....	8*	11-58	10.4	3.0	2.2	1.8	3.1	3.5	2.3
18/17,27.....	9*	3-60	9.0	1.8	1.1	0.8	0.6	0.7	...
20/17,13.....	10	8-59	0.8	3.0	...	...	...	...	...
21/18,7.....	11*	9-58	3.1	0.4	0.4	0.4	0.4	0.4	0.4
21/16,13.....	12	2-60	5.6	0.5	0.6	0.6	0.7	0.6	0.6
Axial trough and basin:									
15/18,21.....	13	3-60	1.3	0.3	...	...	...	...	...
17/18,4.....	14	3-60	0.3	0.4	0.4	0.3	...	...	...
21/20,24.....	15	2-60	5.2	0.9	3.1	1.7	1.9	2.3	...
26/23,36.....	16	2-60	2.2	0.4	0.4	0.3	0.2	...	...
27/23,19.....	17	2-60	2.5	1.0	1.6	...	...	...	...
28/22,12.....	18	2-60	2.1	1.0	0.7	...	...	...	...
28/26,5.....	19	2-60	0.3	0.2	0.2	0.2	0.2	0.3	...

* Detailed analyses in appendix.

township, range, and section is given in table 1. Site numbers are also listed, and will be referred to in the tables and figures that follow.

Soluble salts

Salts readily transported by percolating water are those represented in the solution of a 1:1 extract. Considerable variation in soluble-salt content occurs between locations and within the depth of the profile, as illustrated in Appendix tables A to E. A summary of soluble-salt distribution in the substrata profile is given in table 1 where 1 m.e. (milliequivalent) per 100 gm \approx 1.4 tons of salt per acre-foot of substrata. The constituents reported in this and other tables are the mean values of samples within arbitrarily chosen 50-foot depth increments. Thus in certain instances, only gross differences are apparent. Appreciable salinity was found throughout the profile in sites 6 (Appendix table B) and 7. In other locations, only the

surface depths had moderate salt content—for example, sites 3 and 9 (Appendix tables A and D, respectively). Some sites, such as 14 and 19, were found to be relatively free of soluble salts. At other locations the salts were stratified in the profile, as illustrated in sites 8 (Appendix table C) and 15.

Sites 1 through 12 are located on the alluvial fans, and 13 to 19 in the axial trough or basin of the valley (table 1). In general, the alluvial fans constitute the lighter soils with higher permeability than those in the basin, which are predominantly heavy, with low permeability. The substrata of the alluvial fans contain an appreciable amount of salt, indicating that these soils have not been extensively leached. Further evidence for this is the large amount of gypsum found at some of the sites (table 2). In contrast, the basin soils are subject to flooding, and the salinity in these profiles is relatively low. Salts

and gypsum occurring in appreciable amounts are usually limited to the surface 15 feet, where the soils are heavy clays with extremely low permeability. Logically, the replenishment of the ground water should be through the alluvial soils, but these are high in salinity (see third paper in this series). Recharge of the ground water through the basin soils is impractical because of their low permeability.

In addition to total soluble salts, the ionic composition of cations and anions in solution is important in determining the quality of percolating waters, particularly if those waters are to be used for irrigation. High concentrations of Na^+ and Cl^- degrade the quality of irrigation water more than do most of the other ions. Examples of profile distribution of the soluble salts and ionic composition are presented in figures 4 and 5 for sites 3 and 6, respectively. Site 3 has a weighted mean soluble sodium percentage of 56 for the 330-foot depth. The high concentration of salt occurs in the surface 100 feet, decreases in the next 100, and is relatively low below the 200-foot depth. The weighted mean sodium percentage of the total exchangeable bases for the 330-foot depth is 56. In the top 100 feet of the profile it is less than 50 per cent, and increases to more than 50 per cent in the lower depths (fig. 4). The weighted mean for Cl^- is 37 per cent—the highest in the profiles studied. Chloride occurs admixed with $\text{SO}_4^{=}$ throughout the profile. Sulfate ion predominates in the surface 100 feet, but at some lower depths it decreases to less than a third of the total anions. The bicarbonate ion is relatively low where concentration of the salts is high, particularly when Ca^{++} is involved. In the deeper depths, with lower salt concentrations and less soluble calcium, HCO_3^- increases in concentration and percentage of the anions. Bicarbonate ion is derived chiefly from lime with a limited solubility, which is influenced to a lim-

ited degree by the concentration of other ions.

In contrast, site 6 has a high soluble salt content for the entire depth of the profile, with a fairly uniform cation composition (fig. 5). The weighted mean sodium percentage of the total cations is 46. Sulfate is the major anion present, with small amounts of Cl^- in the top 200 feet and only traces of HCO_3^- throughout the profile.

Gypsum

Gypsum was found at certain depths for 15 of the 19 locations sampled (table 2). Gypsum usually occurs in beds or stratified deposits, and in only three sites (2, 6, and 7) was it present in all sampling depths (for example, site 6, Appendix table B). An example of stratification is site 8, where gypsum was found in every 50-foot depth increment (table 2), but only about half of the individual sampling depths contained gypsum (Appendix table C). At other locations, gypsum was found only in the surface depths except at site 3 where it occurs in the top half of the 300-foot profile. In general, sites adjacent to stream beds had less gypsum than did sites farther removed, and locations along the lower alluvial fans and axial trough of the valley had smaller amounts or none. The latter is the area subject to flooding.

Gypsum in the soil has two major influences on the quality of percolating water: (1) it will increase the salinity by solution; and (2) it will modify cationic composition by exchange processes and, in addition, will result in increased concentration of the water. The solubility of gypsum is about 30 m.e. per liter, or the equivalent of approximately 3.5 tons of salt per acre-foot of water. These concentrations will be influenced to some degree by other ions present in the water.

As gypsum is dissolved by percolating water, Ca^{++} will exchange for other ions on the exchange complex, chiefly

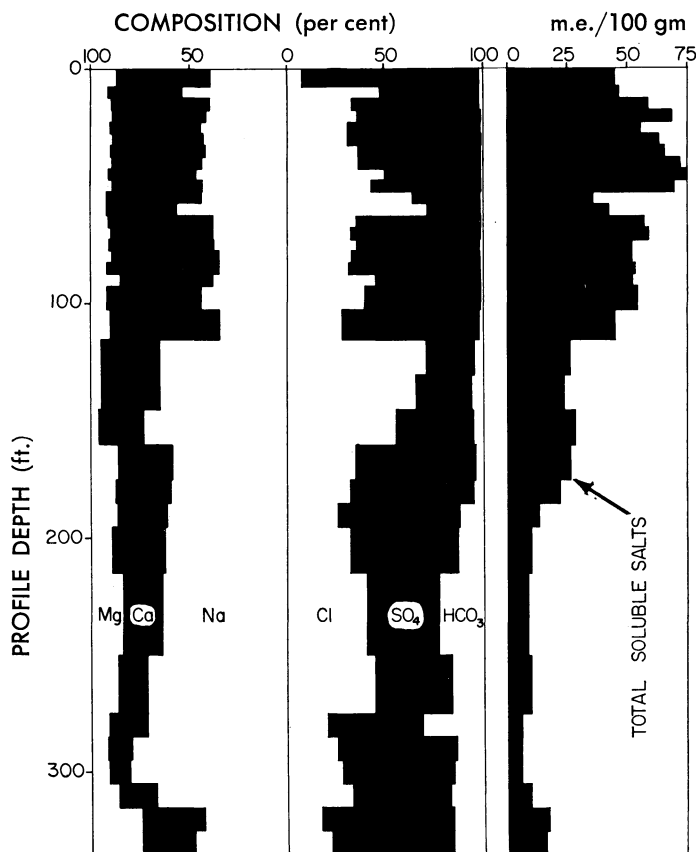


Fig. 4. Relative proportion of soluble ions and total concentration (black areas) by profile depth for site 3, west side, San Joaquin Valley, California.

Na⁺ and Mg⁺⁺. These two salts of SO₄⁼ are extremely soluble and, with the reduction of soluble Ca⁺⁺, will allow some additional dissolution of gypsum to occur, thus increasing the total concentration of the percolating water. Because of the higher replacement power of calcium for sodium in the exchange reaction, the percolating waters will be enriched with the latter. This condition will exist until all the gypsum has been dissolved or all the sodium removed from the exchange complex (see the third paper in this series).

A summation of soluble salts and gypsum in the substrata profile sites is given in table 3. Average tons of salts per acre-foot for the disturbed samples were calculated by assuming a

volume weight of 1.58 gm per cm³. This value represents the mean volume weight of 141 samples from relatively undisturbed core samples (table 7 and Appendix tables A to E). The magnitude of soluble salts and gypsum content in certain sites indicates that recharge at those particular locations may contribute considerable salinity to ground water.

Lime

Lime is found in all the profile samples (table 4). Lime contents at sites 6 and 9 on the alluvial fan are relatively low, while other sites, such as 5 and 12, have large accumulations. At sites 6 and 7 a considerable quantity of soluble salts and gypsum is present, but the

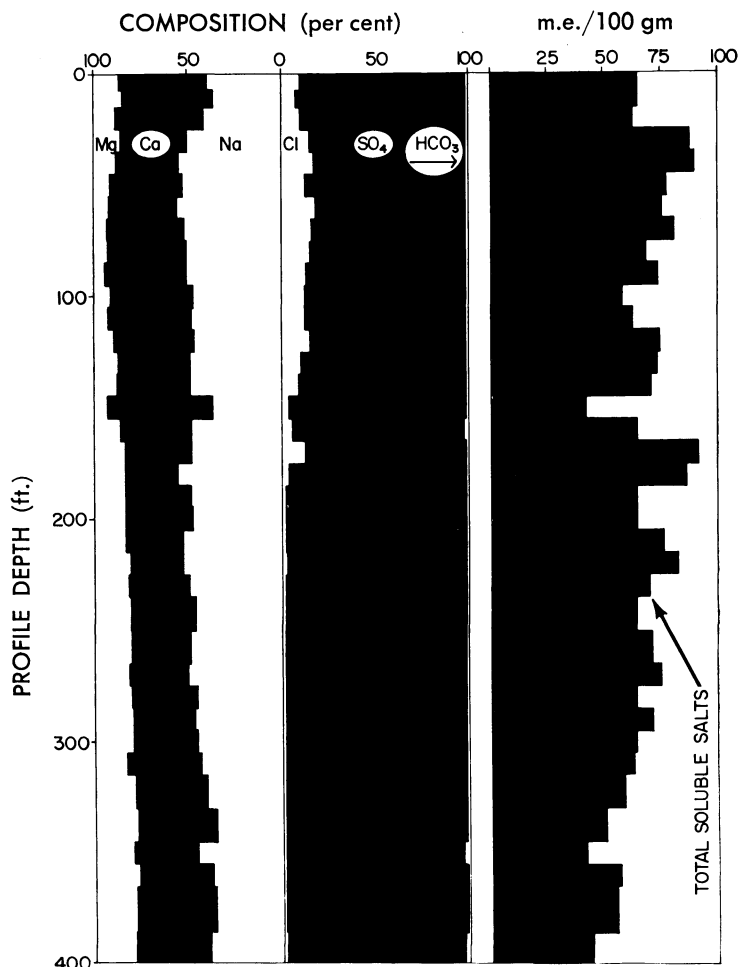


Fig. 5. Relative proportion of soluble ions and total concentration (black areas) by profile depth for site 6, west side, San Joaquin Valley, California.

lime content is relatively low. The greatest variation occurs between the basin locations, with only trace amounts at site 19 and a large accumulation of lime at 15. Lime is the least soluble of the salts influencing water quality, and has only a minor significance in the presence of high salinity or gypsum. Once the more soluble salts are removed by leaching, however, the concentration in the percolating water will decrease, and the character will change from a predominantly sulfate water to a bicarbonate type.

Examples of stratification of soluble

salts, gypsum, and lime are shown in figures 6 and 7. At site 3, gypsum and soluble salts are layered in the surface 100 feet, with lime throughout the profile. At site 6, large quantities of gypsum and soluble salts occur throughout the sampling depths, with lime accumulation considerably less than at site 3.

Boron

Boron at relatively low concentrations—2 ppm in irrigation waters (Eaton, 1935)—may be toxic to many crops. With 5 ppm boron in the saturation extract of the soil, Reeve, Pills-

TABLE 2
GYPSUM DISTRIBUTION IN SUBSTRATA PROFILES IN THE WEST SIDE
OF THE SAN JOAQUIN VALLEY, CALIFORNIA

Profile location and site no.	Means of samples (50-ft. increments)						
	0-50	50-100	100-150	150-200	200-250	250-300	300-350
	<i>m.e. per 100 gm</i>						
Alluvial fan:							
1.....	1.3	0	0	0	0	0	....
2.....	16.0	10.0	....	....	....	....	....
3*.....	25.3	30.9	3.2	0	0	0	....
4.....	†	0	0	....	....	....	....
5.....	2.6	1.0	0	0	0	0	0
6*.....	41.6	44.8	42.1	42.1	50.8	32.4	26.7
7.....	25.0	13.5	18.6	10.4	25.0	13.9	....
8*.....	27.9	5.6	21.6	1.7	8.8	15.5	....
9*.....	8.2	0	0	0	0	0	0
10.....	†	0	....	....	....	....	....
11*.....	0.6	0	0	0	0	0	0
12.....	†	0	0	0	0	0	0
Axial trough and basin:							
13.....	0	0	....	....	....	....	....
14.....	0	0	0	0	....	....	....
15.....	7.2	0	0	0	0	....	....
16.....	1.2	0	0	0	0	....	....
17.....	1.1	0	0	....	....	....	....
18.....	0	0	0	....	....	....	....
19.....	0	0	0	0	0	0	....

* Detailed analyses in appendix.

† Gypsum present, but not determined.

bury, and Wilcox (1955) reported a noticeable reduction in oat yields; with 15 ppm, the yield was reduced 50 per cent. It is not known to what extent this particular ion will be introduced to ground water by percolation. However, Reeve, Pillsbury, and Wilcox (1955) and Biggar and Fireman (1960) have reported that boron is leached at a slower rate than are the soluble salts. The boron content in the 1:1 extract (table 5) indicates that certain sites may contain critical concentration values. For example, site 8 (Appendix table C) has 8.0 and 11.5 ppm boron in the 10- to 20-foot depths, respectively. This concentration, based on the saturation extract, would be approximately twice as high.

Cation-exchange properties

As indicated above, ion exchange with the soluble salts and gypsum will modify the ionic constituents of perco-

lating water. The cation-exchange capacity of the substrata samples is similar to that of surface agricultural soils, and has about the same range (table 6). Textural stratifications consisting of sand and gravelly soils have low exchange capacities, ± 5 m.e. per 100 gm (Appendix tables C, D, and E). High exchange capacities of 35 to 40 m.e. per 100 gm in the clay strata were found in four of the five locations (Appendix tables A, B, C, and D). In general, the capacities were ± 25 m.e. per 100 gm, and comparable with soils containing predominantly montmorillonitic clay of medium to fine texture.

Exchangeable sodium is particularly harmful because it contributes to an increase in sodium percentage of the ground water. The mean exchangeable sodium, by 50-foot increments, is presented in table 6. The largest quantities are at sites 3 and 6, whereas site 9 has only a nominal amount. The sodium

TABLE 3
ELEVATION OF PROFILE LOCATIONS AND AVERAGE TONS PER ACRE-FOOT
DEPTH OF SOLUBLE SALTS AND GYPSUM IN SUBSTRATA IN THE
WEST SIDE OF THE SAN JOAQUIN VALLEY, CALIFORNIA

Profile location and site no.	Approx. elevation†	Sampling depth	Soluble salts	Gypsum
	<i>ft.</i>	<i>ft.</i>	<i>av. tons per acre-foot depth</i>	
Alluvial fan.				
1.....	370	370	2.4	0.6
2.....	500	66	7.7	20.8
3*.....	450	330	4.3	14.3
4.....	350	103	4.8	‡
5.....	470	330	1.9	0.8
6*.....	390	410	9.6	64.9
7.....	380	259	10.1	34.7
8*.....	225	330	6.0	24.0
9*.....	280	301	3.5	1.2
10.....	340	81	2.1	‡
11*.....	320	500	1.0	1.0
12.....	610	390	1.8	‡
Axial trough and basin:				
13.....	205	52	0.4	0
14.....	195	152	1.8	0
15.....	180	252	3.7	25.3
16.....	260	250	0.9	3.3
17.....	255	150	2.6	8.5
18.....	250	150	1.9	0
19.....	425	300	0.4	0

* Detailed analyses in appendix.

† Based on U. S. Geological Survey.

‡ Gypsum present, but analyses incomplete.

percentage of the cation-exchange capacity varies with depth in the profile—for example, site 8, figure 8. Near the surface it represents more than 50 per cent of the exchangeable ions, but in the deeper substrata the percentages are lower. Site 6 is fairly uniform throughout the profile, with an average sodium percentage of 17.3. At sites 8 and 11, most of the sodium occurs in a surface depth of less than 50 feet (Appendix tables C and E).

At four of the five locations, the large amount of gypsum present in the profile (table 2), is in excess of that required to replace all the sodium from the exchange complex. It can be assumed that the exchangeable sodium will be leached and the ground water will be enriched in sodium and sulfate ions. Hence, profiles at sites 3, 6, 8, and 9 contain 976, 2,037, 903, and 325 tons of sodium sulfate per acre, respectively. Recharge at these locations would leach

large quantities of sodium into the ground-water basin and cause a deterioration in water quality.

Volume weight and moisture status

For medium- to fine-textured soils, the volume weights are very high except for the surface layers (table 7). This is probably accounted for by the overburden on the deeper substrata. According to Doneen (1952) and Bodman (1935) volume weights above 1.5 denote very low percolation rates, except for sandy soils. All sites at some particular depths have volume weights above 1.7, and site 11 has 10 individual depths above that figure, while a few samples at several locations ranged as high as 1.8 (Appendix tables A to E). The slow movement of water through these high-density subsoils will allow the water to come into equilibrium with the soluble salts and the exchange complex.

TABLE 4
LIME CONTENT (CaCO₃ EQUIVALENT) IN SUBSTRATA PROFILES IN THE
WEST SIDE OF THE SAN JOAQUIN VALLEY, CALIFORNIA

Profile location and site no.	Means of samples (50-ft. increments)						
	0-50	50-100	100-150	150-200	200-250	250-300	300-350
	<i>m.e. per 100 gm</i>						
Alluvial fan:							
1.....	60	22	64	10	12	14	..
2.....	26	32	..	..	..	..	..
3.....	40	48	56	88	60	28	..
4.....	24	28	14	..	..	..	..
5.....	48	64	72	68	66	110	108
6.....	22	22	22	24	28	28	28
7.....	38	50	34	32	40	26	..
8.....	38	38	36	30	34	24	38
9.....	22	22	52	36	28	6	..
10.....	*	*	..	..	..	..	..
11.....	42	14	20	28	40	62	46
12.....	64	44	94	36	56	28	52
Axial trough and basin:							
13.....	36	6	..	..	..	..	..
14.....	32	8	8	4	..	..	..
15.....	284	8	202	102	304	..	..
16.....	74	52	8	2	4	..	..
17.....	10	4	2	..	..	..	..
18.....	50	16	24	..	..	..	..
19.....	†	†	†	†	†	†	..

* Not determined.

† Trace amounts.

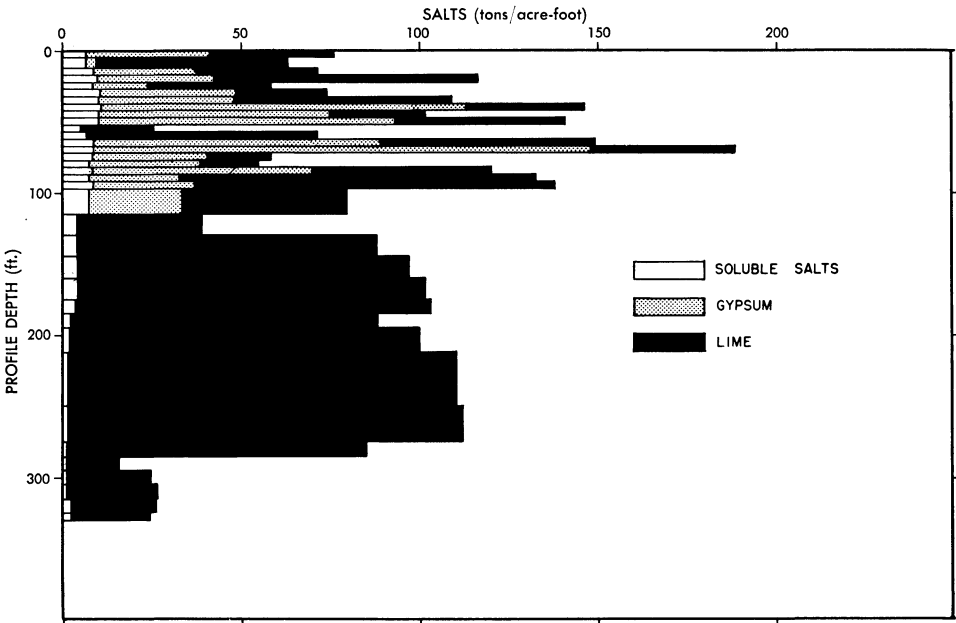


Fig. 6. Distribution of soluble salts, gypsum, and lime in the substrata profile at site 3, west side, San Joaquin Valley, California.

TABLE 5
BORON CONTENT IN SUBSTRATA PROFILES IN THE WEST SIDE
OF THE SAN JOAQUIN VALLEY, CALIFORNIA

Profile location and site no.	Means of samples (50-ft. increments)						
	0-50	50-100	100-150	150-200	200-250	250-300	300-350
	<i>p.p.m. 1 : 1 extract</i>						
Alluvial fan:							
1.....	3.0	2.3	0.3	0.4	0.3	0.2	...
2.....	5.0	6.2	...	...	...	...	...
3.....	3.3	2.5	1.6	1.5	0.9	0.9	0.5
4.....	1.5	1.5	0.6	...	...	...	...
5.....	0.7	0.5	0.2	0.3	0.3	0.4	0.3
6.....	0.5	0.4	0.5	0.6	0.8	0.7	0.5
7.....	1.7	1.8	1.3	1.3	1.2	0.9	...
8.....	4.9	1.7	1.1	1.1	1.5	3.2	2.0
9.....	2.3	1.0	0.5	0.5	0.5	0.3	...
10.....	0.9	1.8	...	...	...	...	...
11.....	1.0	0.3	0.2	0.3	0.3	0.3	0.2
12.....	2.9	0.3	0.3	0.2	0.4	0.3	0.2
Axial trough and basin:							
13.....	0.2	0	...	...	...	...	...
14.....	0.1	0	0	...	...	...	...
15.....	1.3	6.4	0.5	0.5	0.5	0.4	...
16.....	0.2	0	0	0	0	...	...
17.....	1.5	0.5	0.9	...	...	...	...
18.....	2.1	0.6	0.2	...	...	...	...
19.....	0.5	0.1	0.1	0.1	0	0.1	...

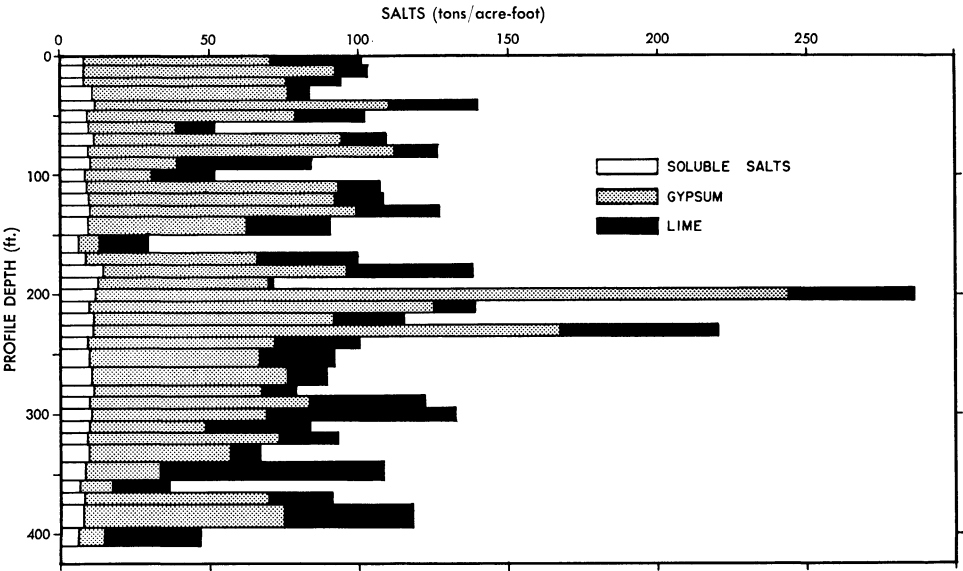


Fig. 7. Distribution of soluble salts, gypsum, and lime in the substrata profile at site 6, west side, San Joaquin Valley, California.

TABLE 6
CATION-EXCHANGE CAPACITIES AND EXCHANGEABLE SODIUM
OF THE SUBSTRATA SAMPLES

Site no.	Means of samples (50-ft. increments)						
	0-50	50-100	100-150	150-200	200-250	250-300	300-350
Exchange capacity (m.e. per 100 gm)							
3.....	23.5	18.4	25.0	28.1	29.3	27.2	28.3
6.....	27.2	22.7	24.0	22.3	24.9	30.7	24.9
8.....	18.3	12.7	19.5	22.1	26.4	27.1	40.6
9.....	20.9	12.4	24.5	20.5	28.5	28.9	....
11.....	18.9	14.6	18.8	16.7	21.4	17.8	20.8
Exchangeable sodium (m.e. per 100 gm)							
3.....	2.4	2.0	2.7	2.3	2.0	1.8	2.2
6.....	4.5	4.8	4.4	3.9	4.7	4.5	6.0
8.....	6.8	0.8	0.9	0.8	1.3	1.4	2.0
9.....	0.2	0.7	0.9	0.9	0.7	0.7	...
11.....	4.8	0.7	1.0	0.7	0.7	0.8	0.8

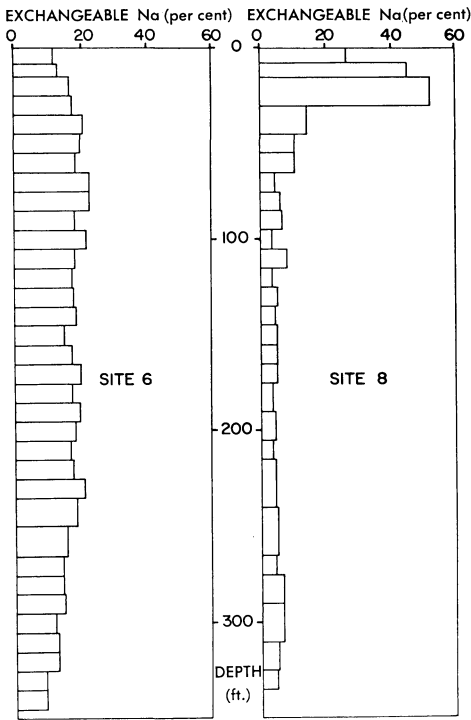


Fig. 8. Exchangeable sodium of the soil in two substrata profiles, sites 6 and 8, west side, San Joaquin Valley, California.

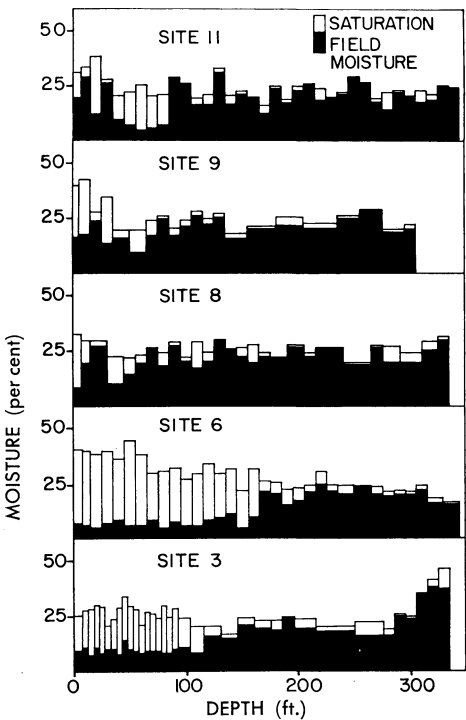


Fig. 9. Pore volume of undisturbed soil, and field-moisture content, based on dry weight, in substrata samples.

TABLE 7
VOLUME WEIGHT OF THE SUBSTRATA SAMPLES

Site no.	Means of samples (50-ft. increments)						
	0-50	50-100	100-150	150-200	200-250	250-300	300-350
	<i>gm per cm³</i>						
3.....	1.53	1.55	1.74	1.61	1.66	1.65	1.34
6.....	1.29	1.37	1.46	1.57	1.58	1.64	1.73
8.....	1.53	1.59	1.53	1.58	1.58	1.59	1.51
9.....	1.43	1.65	1.61	1.63	1.61	1.63	....
11.....	1.48	1.62	1.63	1.72	1.64	1.62	1.65

The field-moisture content of the sealed core samples shows that most of the substrata are saturated, or nearly so (fig. 9). Under field conditions, most of the substrata samples were undoubtedly saturated, as a small amount of moisture was probably lost by the sampling technique and in the process of sealing the containers. The moisture equivalent is a measure of the water-holding capacity of agricultural soils. This value often exceeds those of the field moisture and/or pore volume be-

cause of the high volume weights in the substrata, and the moisture equivalent is determined on fragmented samples. Soil moisture below field capacity (moisture equivalent) moves at a very slow rate, which again indicates that equilibrium will be established mainly between the percolating water, solutes, and exchangeable ions. The moisture equivalent, along with the exchange capacity, is closely related to the clay content, and indicates textural properties of the substrata.

SUMMARY

Properties of deep substrata in the west side of San Joaquin Valley were appraised from 19 drilling sites along the proposed San Luis Canal, on the upper alluvial fans, and in the vicinity of the axial trough of the valley. Depth of sampling ranged from about 50 to 500 feet below the ground surface.

Soluble-salt content, 1:1 extract basis, varies from 0.2 to 10.4 m.e. per 100 gm, between locations and with depth. Substrata in the axial trough were lower in salt content than were those in alluvial fans. Profiles in virgin or nonirrigated areas had more salts than did those of intensively irrigated land. Soluble sodium percentages were considerably higher in lower fans and the axial trough than in sites located in the upper fans.

Heavy deposits of 20 to 50 m.e. per

100 gm of gypsum were located in many sites. Gypsum was present in surface depths in certain sampling sites while in others it occurred throughout the sampled profile. Less accumulation of gypsum was found in areas adjacent to streams than at more distant sites. Gypsum was either absent or was present only in small amounts in lower alluvial fans and in the axial trough.

Lime was found in all profiles, either in trace amounts (less than 0.1 per cent) or in large accumulations (± 15 per cent).

Cation-exchange capacities of substrata materials were found to be similar to those of surface agricultural soils of medium to fine texture (± 25 m.e. per 100 gm). The degrees of sodium saturation of the exchange com-

plex in the substrata soils were in the order of 4 to 15 per cent of the exchange capacity.

High boron concentrations, 5 to 11 ppm in 1:1 extract, were found in certain locations.

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LITERATURE CITED

- BIGGAR, J. W., and M. FIREMAN
1960. Boron adsorption and release by soils. *Soil Sci. Soc. Amer. Proc.* **24**:115-20.
- BODMAN, G. B.
1935. Factors affecting downward movement of water in soils. Sixteenth Ann. Meeting Amer. Soil Survey Assoc., Committee of Forest Soil, Chicago, 33-38.
- CALIFORNIA DEPARTMENT OF WATER RESOURCES
1959. Ground water conditions in central and northern California 1957-58. Sacramento: Dept. of Water Resources Bul. **77-88**:1-90.
- DAVIS, G. H., J. F. POLAND, *et al.*
1954. Ground water conditions in Mendota-Huron area, Fresno and Kings counties, California. Sacramento: Open-file Rept. U. S. Geol. Survey, 1-102.
- DAVIS, G. H., J. H. GREEN, F. H. OLMSTED, AND D. W. BROWN
1957. Ground water conditions and storage capacity in the San Joaquin Valley, California. Sacramento: Open-file Rept. U. S. Geol. Survey, 1-559.
- DONEEN, L. D.
1952. Soil conditions affecting infiltration of water and root development of crop plants. *Amer. Soc. Sugar Beet Tech. Proc.*, 214-23.
- EATON, F. M.
1935. Boron in soils and irrigation waters and its effect on plants, with particular reference to the San Joaquin Valley of California. Washington, D.C.: U. S. Dept. Agr. Tech. Bul. **448**.
- HARRADINE, F. F.
1950. Soils of Western Fresno County. Soil Survey No. **7**. Dept. of Soils and Plant Nutrition, Univ. of California, Berkeley.
- REEVE, R. C., A. F. PILLSBURY, AND L. V. WILCOX
1955. Reclamation of a saline and high boron soil in the Coachella Valley of California. *Hilgardia* **24**(4):69-91.
- RICHARDS, L. A.
1954. Diagnosis and improvement of saline and alkali soils. Washington, D.C.: U. S. Dept. Agr. Handbook No. **60**:1-135.

APPENDIX TABLE A
ANALYSES OF SUBSTRATA PROFILE AT SITE NO. 3, LOCATION T14S, R12E, SEC. 8

Sampling depth	EC	Soluble ions						Exch. cap.	Exch. Na	Soluble salts	Gypsum	CaCO ₃	Vol. wt.	ME*	Field moist.
		HCO ₃	Cl	SO ₄	Na	Ca	Mg								
		m.e./l	m.e./l	m.e./l	m.e./l	m.e./l	m.e./l	m.e./100 gm	m.e./100 gm	m.e./100 gm	m.e./100 gm	m.e./100 g	gm/cm ³	per cent	per cent
feet															
4.5.....	3.6	1.0	3.7	41	17.5	22.0	6.1	25.9	2.0	4.6	18.3	32	1.57	26	9
10.5.....	4.4	1.0	22.8	23	25.2	17.5	4.2	22.5	2.1	4.7	1.5	52	1.52	26	11
16.0.....	4.7	0.6	19.6	38	23.0	29.0	6.5	17.2	1.7	5.8	16.8	32	1.51	21	7
20.5.....	5.7	0.9	24.7	44	28.1	33.0	8.0	25.0	3.1	6.9	19.1	74	1.48	28	11
25.5.....	4.7	0.9	17.2	38	24.3	26.0	5.8	19.2	2.3	5.6	9.3	34	1.48	21	8
30.5.....	5.2	0.6	21.1	42	26.5	30.0	7.0	21.6	2.6	6.4	19.7	22	1.69	24	10
35.5.....	5.4	0.9	23.5	41	27.3	32.0	6.5	21.1	2.8	6.6	20.4	56	1.61	26	10
40.5.....	3.7	0.8	26.3	45	31.3	33.5	7.7	22.9	2.0	7.2	59.2	32	1.50	23	8
45.5.....	6.4	0.9	36.5	38	35.0	33.0	7.5	32.7	3.9	7.6	40.5	28	1.38	34	14
50.5.....	5.8	0.9	29.6	40	26.5	36.0	7.5	27.4	1.9	7.0	48.0	48	1.48	27	10
55.5.....	3.5	0.6	22.4	13	19.7	13.0	3.0	13.2	2.3	3.6	.....	20	1.50	22	9
60.5.....	3.7	0.9	30.1	12	24.1	15.0	3.7	21.1	2.5	4.3	.....	56	1.68	23	8
65.5.....	4.9	0.9	20.3	36	21.0	31.0	5.3	16.4	1.7	5.7	44.9	58	1.53	22	9
70.3.....	4.7	0.6	19.0	39	21.7	31.0	5.8	20.1	2.1	5.9	76.7	38	1.55	21	9
75.5.....	4.4	0.9	18.5	33	19.1	28.0	5.0	19.2	1.6	5.2	17.3	16	1.60	20	9
80.5.....	4.4	0.9	17.2	34	17.7	29.0	5.3	16.1	1.2	5.2	18.5	16	1.46	20	8
85.5.....	4.3	0.9	16.6	36	18.2	30.0	4.7	17.1	1.9	5.3	33.3	46	1.59	21	8
90.5.....	3.2	0.7	23.4	29	19.7	26.8	6.0	20.4	2.5	5.2	14.2	98	1.50	25	10
95.5.....	4.6	0.9	21.3	33	23.8	26.0	4.7	22.1	2.0	5.4	11.5	92	1.62	25	11
110.5.....	3.8	0.9	12.7	32	15.6	25.0	4.2	14.5	1.2	4.5	12.8	16	1.70	16	8
120.5.....	2.6	1.1	17.9	7.0	16.6	7.5	1.5	30.5	3.2	2.6	.....	30	1.70	32	16
140.5.....	2.4	1.4	15.0	7.3	15.2	7.0	1.2	30.9	3.2	2.4	.....	64	1.81	34	15
150.2.....	2.7	1.4	15.1	12.0	20.1	6.5	1.2	24.2	3.4	2.8	.....	86	1.59	30	21
170.5.....	2.4	1.1	9.0	16.0	15.2	7.5	3.5	22.6	2.1	2.6	.....	88	1.63	30	19
180.5.....	2.1	1.1	8.0	12.0	12.7	6.0	2.7	30.2	2.8	2.2	.....	90	1.63	36	18
190.5.....	1.3	1.5	3.2	8.2	7.6	3.2	1.7	37.7	2.5	1.3	.....	80	1.58	38	24
200.5.....	1.1	1.4	3.6	6.2	6.9	3.0	1.2	21.9	1.7	1.1	.....	90	1.61	30	19
231.0.....	0.7	1.8	2.2	4.0	4.9	1.6	1.3	29.3	2.0	0.8	.....	94	1.71	34	18
270.8.....	1.0	1.5	4.1	3.7	6.5	1.4	1.3	15.2	1.4	1.0	.....	100	1.63	22	16
280.5.....	0.6	1.9	3.2	3.2	4.4	1.2	0.6	23.4	1.9	0.6	.....	70	1.76	30	16
290.5.....	0.6	0.8	1.5	3.6	4.6	0.7	0.5	32.5	2.2	0.6	.....	14	1.56	42	25
300.6.....	0.6	0.8	1.5	3.2	4.4	0.6	0.5	36.6	2.3	0.6	.....	22	1.53	46	24
310.3.....	1.0	1.4	2.8	4.6	5.6	1.7	1.2	32.2	2.3	0.8	.....	28	1.34	48	36
320.5.....	0.7	2.6	3.0	12.0	7.2	5.5	4.4	29.6	2.4	1.7	.....	28	1.25	51	38
330.5.....	1.6	2.5	3.6	11.0	7.8	4.5	4.2	23.2	1.8	1.6	.....	28	1.18	51	40

* Moisture equivalent, oven-dry weight basis.

APPENDIX TABLE B
ANALYSES OF SUBSTRATA PROFILE AT SITE NO. 6, LOCATION T16S, R14E, SEC. 16

Sampling depth	EC <i>mhos/cm</i>	Soluble ions							Exch. cap. <i>m.e./100 gm</i>	Exch. Na <i>m.e./100 gm</i>	Soluble salts <i>m.e./100 gm</i>	Gypsum <i>m.e./100 gm</i>	CaCO ₃ <i>m.e./100 gm</i>	Vol. wt. <i>gm/cm³</i>	ME* <i>per cent</i>	Field moist. <i>per cent</i>
		HCO ₃	Cl	SO ₄	Na	Ca	Mg	B								
		<i>m.e./l</i>	<i>m.e./l</i>	<i>m.e./l</i>	<i>m.e./l</i>	<i>m.e./l</i>	<i>m.e./l</i>	<i>ppm</i>								
5.5.....	5.3	0.8	6.7	58	25.4	30.9	9.0	0.3	30.1	3.6	6.5	42.2	36	1.26	27	7
11.0.....	5.3	0.6	5.2	60	22.2	21.9	9.7	0.3	22.7	3.0	6.5	56.2	12	1.28	22	6
20.5.....	5.2	0.8	5.8	56	25.4	29.9	7.2	0.5	27.7	3.6	6.5	43.6	18	1.31	16	5
31.0.....	7.2	0.6	13.1	75	31.9	31.9	12.5	0.7	29.1	5.9	8.8	43.8	8	1.38	22	7
40.3.....	7.6	1.1	15.8	75	49.7	31.9	10.3	0.6	34.6	7.3	9.2	63.5	32	1.33	25	8
50.3.....	6.7	0.6	12.3	66	41.6	29.9	7.2	0.8	25.0	5.0	7.9	49.4	28	1.21	22	6
60.5.....	6.7	0.8	14.2	69	41.6	27.8	6.3	0.8	24.9	4.6	7.6	18.0	14	1.32	21	6
70.5.....	6.7	0.8	13.3	67	41.6	22.0	6.3	0.5	24.6	4.9	8.1	48.5	14	1.37	22	8
80.5.....	6.0	0.8	10.3	58	34.8	28.8	5.2	0.6	22.5	5.1	6.9	60.3	14	1.45	22	7
90.5.....	6.4	0.6	9.3	64	37.0	31.9	4.5	0.5	23.4	4.3	7.4	17.8	46	1.42	21	7
100.5.....	5.2	0.6	7.1	50	27.0	25.8	5.2	0.3	21.8	4.7	5.8	12.7	20	1.53	20	6
110.5.....	5.2	0.6	7.8	54	29.6	27.8	5.2	0.4	20.5	3.8	6.2	48.2	14	1.49	20	6
120.5.....	6.2	0.6	6.7	65	33.9	31.9	8.2	0.5	26.5	4.6	7.5	47.5	22	1.39	23	8
130.3.....	6.2	0.6	7.6	65	34.8	28.8	9.7	0.6	24.5	4.3	7.3	51.4	28	1.37	23	9
140.7.....	6.2	0.6	6.8	64	33.9	27.8	9.0	0.4	24.7	4.6	7.1	31.9	23	1.43	24	11
160.5.....	2.4	0.4	1.5	40	15.6	23.8	2.7	0.2	10.7	1.6	4.2	3.6	14	1.68	13	4
170.5.....	5.3	1.1	3.5	40	30.4	25.0	9.0	0.3	14.8	2.6	6.4	34.4	32	1.63	21	9
180.5.....	7.4	0.8	11.5	78	42.6	31.9	15.3	0.5	22.4	4.4	8.0	51.0	36	1.55	22	21
190.3.....	6.9	1.1	3.1	82	47.2	23.8	14.7	1.4	40.5	7.1	8.6	31.3	0	1.57	25	20
200.4.....	5.2	0.8	1.6	62	30.4	22.8	10.8	0.6	23.1	4.6	6.4	100.4	32	1.55	21	15
210.2.....	5.2	0.8	1.7	62	29.6	23.8	10.8	0.7	22.9	4.3	6.4	60.0	12	1.64	22	17
220.3.....	6.1	1.1	1.9	73	39.1	23.8	12.5	1.0	26.4	4.5	7.5	40.1	29	1.60	25	21
230.3.....	6.4	1.1	2.5	79	42.6	23.8	15.3	1.1	29.9	5.2	8.2	90.0	52	1.48	25	24
240.3.....	5.4	0.8	1.5	67	33.9	22.5	12.5	0.8	23.2	4.9	6.9	33.4	26	1.39	24	22
250.5.....	5.0	0.6	1.5	62	29.6	22.0	11.7	0.8	21.9	4.1	6.3	30.4	22	1.61	23	19
270.5.....	5.8	1.1	1.7	68	34.8	22.0	13.8	0.7	29.8	4.7	7.1	34.4	16	1.62	26	23
280.8.....	5.9	0.8	1.4	72	37.0	23.8	13.2	0.9	37.9	5.5	7.4	29.7	10	1.62	29	20
290.7.....	5.2	0.7	1.0	63	28.7	22.8	12.5	0.6	25.0	3.7	6.4	37.4	34	1.67	24	19
300.7.....	5.3	1.0	1.0	66	31.1	22.0	13.2	0.5	30.1	4.5	6.6	30.1	56	1.66	27	20
310.9.....	5.1	1.1	1.0	62	28.7	22.0	12.5	0.6	27.2	3.4	6.3	19.9	30	1.68	25	20
320.5.....	5.1	0.8	0.8	61	27.0	25.8	9.7	0.6	29.2	3.8	6.2	33.8	18	1.61	25	22
330.7.....	4.6	0.7	0.7	57	23.6	22.5	12.2	0.6	22.1	2.8	5.8	22.9	8	1.77	21	16
340.5.....	4.0	0.7	0.6	49	17.9	21.5	10.8	0.4	21.0	2.0	5.0	11.6	60	1.83	20	16
360.5.....	3.6	1.1	0.7	40	18.5	14.4	8.2	0.6	25.5	2.4	4.1	5.6	16	1.73	22	18
370.2.....	4.4	0.8	0.5	56	21.3	22.5	12.7	0.5	22.6	2.2	5.6	33.9	20	1.55	24	24
380.2.....	4.2	0.7	0.5	54	19.6	23.6	11.7	0.4	25.6	2.7	5.5	37.9	42	1.51	22	20
410.2.....	3.6	1.2	0.5	43	17.0	17.5	9.3	0.4	36.9	2.4	4.4	4.7	32	1.53	28	24

* Moisture equivalent, oven-dry weight basis.

APPENDIX TABLE C

ANALYSES OF SUBSTRATA PROFILE AT SITE NO. 8, LOCATION T17S, R17E, SEC. 20

Sampling depth	EC	Soluble ions							Exch. cap.	Exch. Na	Soluble salts	Gypsum	CaCO ₃	Vol. wt.	ME*	Field moist.
		HCO ₃	Cl	SO ₄	Na	Ca	Mg	B								
		m.e./l	m.e./l	m.e./l	m.e./l	m.e./l	m.e./l	ppm	m.e./100 gm	m.e./100 gm	m.e./100 gm	m.e./100 gm	m.e./100 gm	gm/cm ³	per cent	per cent
feet	mmbhos/cm															
3.5.....	6.1	2.8	11.1	54	50.4	12.0	5.3	2.9	27.2	7.2	6.8	5.7	44	1.41	31	8
10.5.....	15.6	1.7	56.6	152	152.0	27.0	30.5	9.0	26.4	12.0	21.0	43.7	26	1.47	33	19
20.5.....	13.5	1.4	15.2	170	133.0	26.0	27.3	11.5	25.1	13.3	18.6	82.8	28	1.47	33	27
40.5.....	2.8	0.5	2.8	33	12.9	14.2	9.2	1.0	5.8	1.0	3.6	7.4	38	1.64	5	10
50.5.....	1.9	1.1	2.8	15	14.3	2.5	1.7	1.3	7.0	0.7	1.9	.....	54	1.66	8	
60.9.....	2.1	0.9	3.2	18	14.8	4.7	2.4	1.5	8.3	0.9	2.2	.....	40	1.63	10	19
70.5.....	3.5	1.1	1.9	44	13.3	22.5	11.2	2.2	18.1	0.8	4.7	21.4	46	1.55	25	27
80.6.....	1.5	1.9	1.3	13	7.2	6.0	2.6	1.3	9.5	0.6	1.6	.....	38	1.60	12	18
90.5.....	2.9	0.9	1.7	34	13.3	15.7	7.4	1.7	15.5	1.0	3.6	6.3	42	1.50	20	27
100.5.....	2.4	0.9	1.4	25	10.9	11.2	4.7	1.6	12.2	0.4	2.7	.....	24	1.65	15	20
110.5.....	3.1	0.9	1.0	46.0	16.1	23.4	7.7	2.0	16.4	1.4	4.7	58.6	36	1.49	26	17
120.5.....	2.9	0.9	0.7	33.0	8.7	21.5	4.0	1.3	26.9	0.9	3.4	49.5	32	1.59	33	20
130.5.....	1.2	1.0	1.4	9.4	5.7	4.7	1.2	0.9	21.5	1.2	1.2	.....	36	1.46	30	29
140.5.....	1.1	1.0	1.1	8.3	5.1	4.0	1.3	0.6	15.4	0.7	1.0	.....	38	1.56	22	25
150.5.....	0.7	1.0	0.8	4.3	3.4	2.0	0.6	0.6	17.5	0.9	0.6	.....	40	1.55	23	22
160.3.....	1.1	1.0	1.4	9.6	5.1	5.5	1.2	0.5	13.5	0.7	1.2	.....	44	1.52	18	19
170.5.....	0.8	0.7	0.8	6.0	3.9	3.1	0.5	0.9	16.1	0.8	0.8	.....	22	1.61	21	22
180.5.....	1.9	0.9	0.8	20.0	6.8	12.5	1.7	1.3	22.4	0.8	2.1	.....	26	1.66	27	22
200.6.....	2.7	0.7	0.7	23.0	8.3	18.0	2.7	1.6	36.5	1.5	2.9	6.7	26	1.52	38	27
210.5.....	2.0	1.1	0.7	27.0	7.6	18.3	3.0	0.9	25.1	1.0	2.9	5.3	30	1.61	30	22
220.5.....	2.9	0.9	0.9	31	8.5	18.5	5.8	2.0	27.8	1.3	3.3	12.4	38	1.55	32	26
260.5.....	2.4	0.9	0.4	22	7.0	15.0	1.5	2.4	25.4	1.3	2.3	.....	28	1.73	28	19
270.5.....	2.9	1.0	0.4	30	10.6	18.7	2.1	2.6	29.1	1.3	3.2	17.6	22	1.52	35	26
280.3.....	3.4	1.3	1.1	40	15.2	22.5	4.2	3.5	25.2	1.7	4.2	44.4	20	1.53	28	19
300.3.....	3.6	0.9	0.6	41	16.5	21.5	4.0	4.3	25.2	1.9	4.2	†	22	1.60	33	19
320.3.....	2.1	1.4	0.7	23	9.9	12.9	2.3	2.4	39.6	2.1	2.5	.....	38	1.50	39	25
330.5.....	2.1	1.1	0.8	20	9.0	10.5	1.9	1.5	41.7	2.1	2.1	.....	38	1.44	41	30

* Moisture equivalent, oven-dry weight basis.

† Present but not determined.

APPENDIX TABLE D
ANALYSES OF SUBSTRATA PROFILE AT SITE NO. 9, LOCATION T18S, R17E, SEC. 27

Sampling depth	EC mmhos/cm	Soluble ions							Exch. cap. m.e./100 gm	Exch. Na m.e./100 gm	Soluble salts m.e./100 gm	Gypsum m.e./100 gm	CaCO ₃ m.e./100 gm	Vol. wt. gm/cm ³	ME* per cent	Field moist. per cent
		HCO ₃	Cl	SO ₄	Na	Ca	Mg	B								
feet		m.e./l	m.e./l	m.e./l	m.e./l	m.e./l	m.e./l	ppm								
5.5.....	2.5	1.6	11.5	36.0	31.3	12.0	5.0	1.7	27.7	0.4	4.8	1.2	16	1.29	31	16
10.5.....	3.3	1.2	5.8	67.0	27.8	32.0	13.4	1.7	21.2	tr	7.3	3.0	10	1.24	34	17
21.5.....	6.8	1.3	5.2	168.0	84.4	45.0	44.2	3.3	29.1	tr	17.4	28.1	10	1.52	38	23
31.0.....	3.2	1.6	2.6	63.0	48.1	9.2	9.7	2.9	16.4	0.5	6.7	2.9	26	1.37	19	13
42.5.....	3.6	1.0	2.7	82.0	34.1	29.0	22.7	1.8	10.1	tr	8.6	5.7	54	1.75	14	16
61.5.....	1.5	1.0	2.7	11.0	9.5	2.3	2.7	1.3	5.2	0.3	1.5	....	26	1.73	6	9
71.5.....	1.9	1.4	3.5	14.0	12.0	2.5	4.2	1.3	13.2	1.3	1.9	....	46	1.61	18	17
81.5.....	1.8	1.3	2.7	16.0	9.3	3.5	6.7	0.7	16.0	0.9	2.0	....	8	1.56	25	24
91.5.....	1.6	1.2	2.3	13.0	7.4	3.2	5.5	0.7	15.3	0.5	1.6	....	8	1.71	18	17
101.5.....	1.2	1.5	1.5	9.0	5.8	2.5	3.6	0.5	21.5	0.9	1.2	....	126	1.62	29	21
111.5.....	1.3	1.8	1.2	10.0	6.0	2.8	4.6	0.4	28.0	1.0	1.3	....	22	1.51	35	26
121.5.....	1.2	1.9	1.0	9.0	5.6	2.3	3.8	0.6	27.3	0.9	1.2	....	30	1.59	32	22
131.2.....	1.1	1.5	1.0	8.0	5.2	2.1	3.2	0.5	27.0	1.0	1.0	....	18	1.54	33	25
141.5.....	0.9	1.8	0.6	6.2	4.3	1.6	2.6	0.5	18.8	0.8	0.9	....	68	1.79	26	16
171.5.....	0.8	1.5	0.6	6.1	4.3	1.4	2.4	0.4	19.7	0.8	0.8	....	44	1.69	25	20
191.4.....	0.9	1.4	0.8	6.6	4.6	1.5	2.6	0.4	21.3	0.7	0.9	....	30	1.57	25	21
221.0.....	0.7	1.5	0.6	4.4	4.0	1.2	1.2	0.6	25.5	1.0	0.6	....	28	1.65	30	20
250.8.....	0.7	1.6	0.6	4.5	4.4	1.2	1.0	0.6	31.5	1.3	0.7	....	30	1.56	35	25
262.5.....	0.9	1.6	0.7	6.2	5.0	1.8	1.6	0.6	40.8	1.8	0.8	....	6	1.50	43	28
290.4.....	0.7	1.5	0.6	4.4	3.7	1.2	1.5	0.4	17.2	0.6	0.6	....	14	1.73	31	18
301.1.....	0.8	1.6	0.6	5.7	4.8	1.4	1.5	0.3	28.6	0.6	0.8	....	0.0	1.67	22	20

* Moisture equivalent, oven-dry weight basis.

APPENDIX TABLE E

ANALYSES OF SUBSTRATA PROFILE AT SITE NO. 11, LOCATION T21S, R18E, SEC. 7

Sampling depth	feet	EC	Soluble ions						Exch. cap.	Exch. Na	Soluble salts	Gypsum	CaCO ₃	Vol. wt.	ME*	Field moist.
			HCO ₃	Cl	SO ₄	Na	Ca	Mg								
		mmhos/cm	m.e./l	m.e./l	m.e./l	m.e./l	m.e./l	m.e./l	m.e./100 gm	m.e./100 gm	m.e./100 gm	m.e./100 gm	m.e./100 gm	gm/cm ³	per cent	per cent
4.5	1.2	3.7	0.6	7.7	11.0	0.6	0.4	17.8	8.6	1.2	3.6	28	1.47	23	19
9.5	4.8	1.3	1.4	53.0	30.4	19.0	6.3	32.2	4.7	5.6	.....	24	1.40	38	28
20.5	5.1	1.6	1.4	55.0	42.4	11.0	4.2	.....	.....	8.8	.....	28	1.32	18	12
30.5	3.1	1.5	10.4	20.0	21.7	5.5	4.2	22.8	4.7	3.1	.....	64	1.52	30	26
41.0	1.8	1.1	10.6	9.4	10.0	4.0	7.1	10.6	1.3	2.1	.....	74	1.71	13	9
50.2	1.1	0.6	5.3	4.5	5.3	2.8	2.2	11.3	0.8	1.0	.....	8	1.67	12	7
60.5	0.4	0.5	0.3	1.7	2.0	0.4	0.2	7.6	0.4	0.3	.....	14	1.57	16	4
71.7	0.4	1.4	0.5	1.6	2.4	0.6	0.2	.....	0.4	0.3	.....	2	1.71	7	5
81.0	0.4	1.4	0.5	1.3	2.4	0.6	0.2	6.6	0.5	0.2	.....	8	1.69	7	7
90.5	0.7	2.3	1.1	3.9	3.9	2.1	1.2	29.1	1.6	0.7	.....	26	1.50	32	28
100.3	0.5	1.5	0.6	2.3	2.9	1.0	0.5	23.2	1.2	0.4	.....	18	1.56	26	26
111.0	0.4	1.4	0.4	1.7	2.1	0.9	0.5	20.6	0.9	0.4	.....	12	1.75	22	16
121.0	0.3	1.1	0.5	1.2	1.8	0.7	0.3	14.9	0.7	0.3	.....	4	1.69	18	16
130.2	0.6	1.4	0.7	2.8	3.2	1.0	0.6	25.1	1.3	0.5	.....	24	1.41	25	21
141.0	0.5	1.8	0.8	2.8	2.6	1.8	1.0	15.6	0.7	0.5	.....	34	1.72	21	16
150.5	0.4	1.5	0.5	1.7	2.3	0.9	0.5	17.7	0.9	0.4	.....	22	1.65	21	21
160.7	0.4	1.4	0.5	1.7	2.2	0.9	0.5	20.5	0.9	0.4	.....	68	1.73	23	20
170.6	0.3	0.6	0.8	1.4	1.8	0.7	0.4	10.7	0.4	0.3	.....	8	1.84	13	12
180.7	0.4	1.5	0.6	1.8	2.4	0.9	0.6	24.3	1.0	0.4	.....	38	1.90	27	23
190.4	0.3	1.4	0.4	1.1	1.8	0.7	0.4	10.2	0.4	0.3	.....	10	1.78	12	16
200.6	0.4	1.6	0.6	2.3	2.1	1.3	0.9	17.7	0.7	0.4	.....	16	1.62	21	22
211.0	0.4	1.5	0.5	2.0	2.4	0.9	0.7	27.2	1.1	0.4	.....	62	1.56	32	25
220.4	0.4	1.4	0.6	1.9	2.2	0.9	0.7	13.7	0.5	0.4	.....	16	1.62	18	18
230.7	0.5	1.6	0.6	2.0	2.4	1.0	0.8	15.7	0.6	0.4	.....	66	1.72	18	19
240.3	0.4	1.4	0.6	2.1	2.4	0.9	0.7	17.3	0.7	0.4	.....	22	1.66	20	21
250.2	0.5	1.8	0.7	2.5	2.8	1.1	0.4	33.3	1.2	0.5	.....	32	1.48	37	29
260.6	0.4	1.7	0.6	2.2	2.2	1.3	1.0	25.8	1.1	0.4	.....	72	1.56	32	25
270.2	0.4	1.4	0.4	1.5	1.9	0.8	0.5	15.6	0.7	0.3	.....	126	1.75	19	17
280.5	0.3	1.1	0.4	1.2	1.7	0.6	0.5	8.6	0.4	0.3	.....	34	1.68	8	13
290.5	0.4	1.3	0.4	1.8	2.0	0.8	0.6	17.9	0.7	0.4	.....	36	1.64	22	23
300.3	0.4	1.6	0.4	2.3	2.1	1.4	0.8	21.2	0.8	0.4	.....	40	1.71	23	20
310.2	0.3	1.1	0.4	1.2	1.7	0.6	0.4	15.0	0.7	0.3	.....	20	1.64	14	17
320.3	0.3	1.1	0.4	1.0	1.5	0.7	0.4	13.1	0.6	0.3	.....	28	1.68	16	18
330.5	0.4	1.6	0.4	1.6	2.0	0.8	0.7	34.0	1.2	0.4	.....	28	1.58	33	23
340.2	0.4	1.5	0.6	2.5	2.1	1.4	1.0	23.7	0.9	0.4	.....	112	1.62	28	24
390.2	0.4	1.3	0.4	1.6	1.8	0.9	0.6	18.3	0.7	0.3	.....	68	1.80	20	18
440.2	0.4	1.5	0.6	1.7	2.1	1.0	0.7	.....	.....	0.4	.....	.....	1.59	25	22
470.2	0.4	1.4	0.3	1.7	1.8	1.0	0.6	21.2	0.9	0.3	.....	120	1.73	17	17
480.2	0.4	1.4	0.3	1.3	1.9	0.8	0.3	21.4	0.9	0.3	.....	72	1.87	24	16
500.3	0.5	1.8	0.4	2.7	2.7	1.5	0.6	30.0	1.2	0.5	.....	60	1.55	35	28

* Moisture equivalent, oven-dry weight basis.

† Present but not determined.

APPENDIX TABLE F
 PROFILE DISTRIBUTION OF IONS AND SALTS IN SUBSTRATA AFTER 1 AND 3 PORE-VOLUME DISPLACEMENTS
 (Site 9)

Soil depth	Soluble ions						Undissoc. CaSO ₄	Exchangeable ions			Gypsum
	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	SO ₄ ⁻	Cl ⁻	HCO ₃ ⁻		Ca ⁺⁺	Mg ⁺⁺	Na ⁺	
	m.e. per liter						mM per l	m.e. per 100 gm			
meters											
After 1 pore-volume displacement											
0.0-6.1.....	4.5	2.1	0.9	6.5	0.03	1.4	0.6	18.7	6.0	0.11	0.0
6.1-13.2.....	18.9	15.5	4.9	38.4	0.03	1.4	4.9	10.7	6.2	0.20	6.7
13.2-21.8.....	17.5	19.2	12.5	48.3	0.05	1.1	4.9	6.1	4.7	0.33	1.9
21.8-29.7.....	9.8	23.3	22.5	54.5	0.11	1.3	2.9	5.2	8.7	0.87	0.0
29.7-37.2.....	8.3	22.5	27.7	57.7	0.26	1.7	2.5	8.1	15.6	1.9	0.0
37.2-45.3.....	8.0	26.5	27.1	60.6	0.56	1.7	2.4	6.2	14.7	1.6	0.0
45.3-54.0.....	7.2	33.6	25.1	63.9	1.1	1.7	2.2	4.4	14.2	1.2	0.0
54.0-61.7.....	9.3	35.5	23.4	65.6	1.8	1.4	2.7	5.5	14.7	1.2	0.0
61.7-69.6.....	13.7	33.1	22.2	65.5	2.6	1.5	4.0	8.6	14.5	1.2	0.0
69.6-77.2.....	17.2	30.6	21.8	65.3	3.6	1.6	4.9	11.7	14.6	1.3	0.3
77.2-84.8.....	17.5	28.6	21.2	62.1	4.5	1.6	4.9	12.3	14.1	1.3	0.1
84.8-91.1.....	17.7	28.4	20.9	60.9	5.4	1.6	4.9	12.4	14.0	1.3	<0.01
After 3 pore-volume displacements											
0.0-6.1.....	0.54	0.25	0.22	0.06	0.03	1.4	<0.1	18.7	6.0	0.07	0.0
6.1-13.2.....	0.57	0.27	0.18	0.06	0.03	1.4	<0.1	12.8	4.3	0.04	0.0
13.2-21.8.....	0.52	0.37	0.17	0.11	0.03	1.1	<0.1	7.4	3.7	0.02	0.0
21.8-29.7.....	0.35	0.55	0.38	0.33	0.03	1.3	<0.1	7.0	7.8	0.07	0.0
29.7-37.2.....	0.20	0.48	1.2	0.90	0.03	1.7	<0.1	9.3	15.9	0.45	0.0
37.2-45.3.....	0.16	0.51	2.3	2.0	0.03	1.7	<0.1	6.8	14.9	0.81	0.0
45.3-54.0.....	0.19	0.78	3.9	3.9	0.03	1.7	<0.1	4.8	14.1	1.0	0.0
54.0-61.7.....	0.34	1.4	5.7	6.5	0.03	1.4	<0.1	5.3	14.8	1.2	0.0
61.7-69.6.....	0.79	2.2	7.7	9.6	0.03	1.5	0.1	7.8	15.0	1.4	0.0
69.6-77.2.....	1.6	3.2	9.3	13.2	0.03	1.6	0.3	11.1	15.0	1.6	0.0
77.2-84.8.....	2.7	4.5	10.7	16.9	0.03	1.6	0.6	12.0	14.2	1.5	0.0
84.8-91.1.....	3.8	6.1	11.7	20.6	0.03	1.6	0.9	12.3	14.0	1.4	0.0

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