TEST OF EXCESS IRRIGATION TO REDUCE SALINITY IN GROUND WATER AND SOIL, PALO VERDE IRRIGATION DISTRICT, RIVERSIDE COUNTY, CALIFORNIA

By Anthony Buono

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CONVERSION FACTORS

The inch-pound system is used in this report. For readers who prefer International System (SI) Units, the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain
acres	0.4047	hm^2 (square hectometers)
acre-ft (acre-feet)	1,233	m^3 (cubic meters)
acre-ft/yr (acre-feet per year)	0.001233	hm^3/a (cubic hectometers per annum)
feet	0.3048	m (meters)
inches	25.4	mm (millimeters)
miles	1.609	km (kilometers)
tons (short)	0.9072	Mg (megagrams)

Abbreviations used:
meq/L - milliequivalents per liter
mg/L - milligrams per liter

Degrees Fahrenheit (°F) is converted to degrees Celsius (°C) by using the formula: °C = (°F-32)/1.8.

ALTITUDE DATUM

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

DEFINITIONS

Water year: The water year starts October 1 and ends September 30; it is designated by the calendar year in which it ends.

TEST OF EXCESS IRRIGATION TO REDUCE SALINITY
IN GROUND WATER AND SOIL, PALO VERDE IRRIGATION DISTRICT,
RIVERSIDE COUNTY, CALIFORNIA

By Anthony Buono

ABSTRACT

A salinity-control method for reducing salt in soil and ground water by use of excess irrigation water was tested on a 311-acre tract of fallow farmland in the Palo Verde subarea of the Palo Verde Irrigation District, eastern Riverside County, California. Originally scheduled for 3 months of daily irrigation, the test was interrupted first by a loss of water supply to the fields and then by bank collapses in the irrigation return drain system. The bank collapses, resulting from the increase in ground-water discharges to the drain from the increased irrigation, indicated that within the irrigation district this salinity-control method is not feasible.

Although the test stoppages caused the test to be inconclusive regarding salinity reduction, mean dissolved-solids concentrations in ground-water samples collected prior to and immediately following the test suggested the movement of salts from the upper zones within the aquifer to the lowest zone beneath the fields most extensively irrigated during the test. A further sample comparison of irrigation water, soil extracts, ground water, and drain water indicated a similarity in chemical characteristics between salts in certain clayey sections of the soil and aquifer and in drain water. This similarity suggests that these clayey zones may be the primary source of salt contributions from the Palo Verde subarea to the drain system and the Colorado River.

INTRODUCTION

The Palo Verde Irrigation District is near Blythe in eastern Riverside County, Calif., about 40 miles from the United States-Mexico border (fig. 1). The climate features hot, dry summers and moderate to cool winters, typical of the deserts of the southwestern United States. Average monthly temperatures at Blythe range from about 53°F in January to about 92°F in July (National Oceanic and Atmospheric Administration, 1979), and precipitation averages about 4 inches per year, occurring mostly as summer thundershowers. The district has a year-round growing season and contains about 92,000 acres of irrigated land, most of which is on the flood plain of the Colorado River.

Ground-water levels in the district are generally within 15 feet of land surface. The levels are maintained by a 150-mile system of unlined drains that receive irrigation return flow as ground-water discharges to the drains. The drain system prevents mounding of ground water beneath irrigated fields and thus prevents the waterlogging and salt buildup in the soil caused by evaporation. The drain system delivers the irrigation return to the Colorado River at the Olive Lake drain, about 3 miles south of the Palo Verde diversion dam, and at the Palo Verde outfall, about 10 miles south of the district (fig. 1).

Water for irrigation in the district is diverted from the Palo Verde diversion dam at the northern apex of the district (fig. 1). The water is then distributed through a system of about 300 miles of canals, from which lateral canals divert water to individual fields. Excess diverted water is returned to the river unused at seven spillways along the river's course within the district. The dissolved-solids concentration of water diverted from the Colorado River at the Palo Verde diversion dam averaged about 735 mg/L in the 1979 water year. Average dissolved-solids concentrations of water discharged to the river from the Palo Verde Irrigation District in the 1979 water year were 735 mg/L in unused water in spillways to the river (Klein and Bradford, 1980, p. 16), 940 mg/L in Olive Lake drain, and about 1,620 mg/L in the Palo Verde outfall. Using these concentrations of dissolved solids and the conversion of milligrams per liter to tons of salt per acre-foot of water (735 mg/L is approximately equal to 1 ton per acre-foot of water), table 1 describes the mass balance of salts discharged to the Colorado River from the Palo Verde Irrigation District.

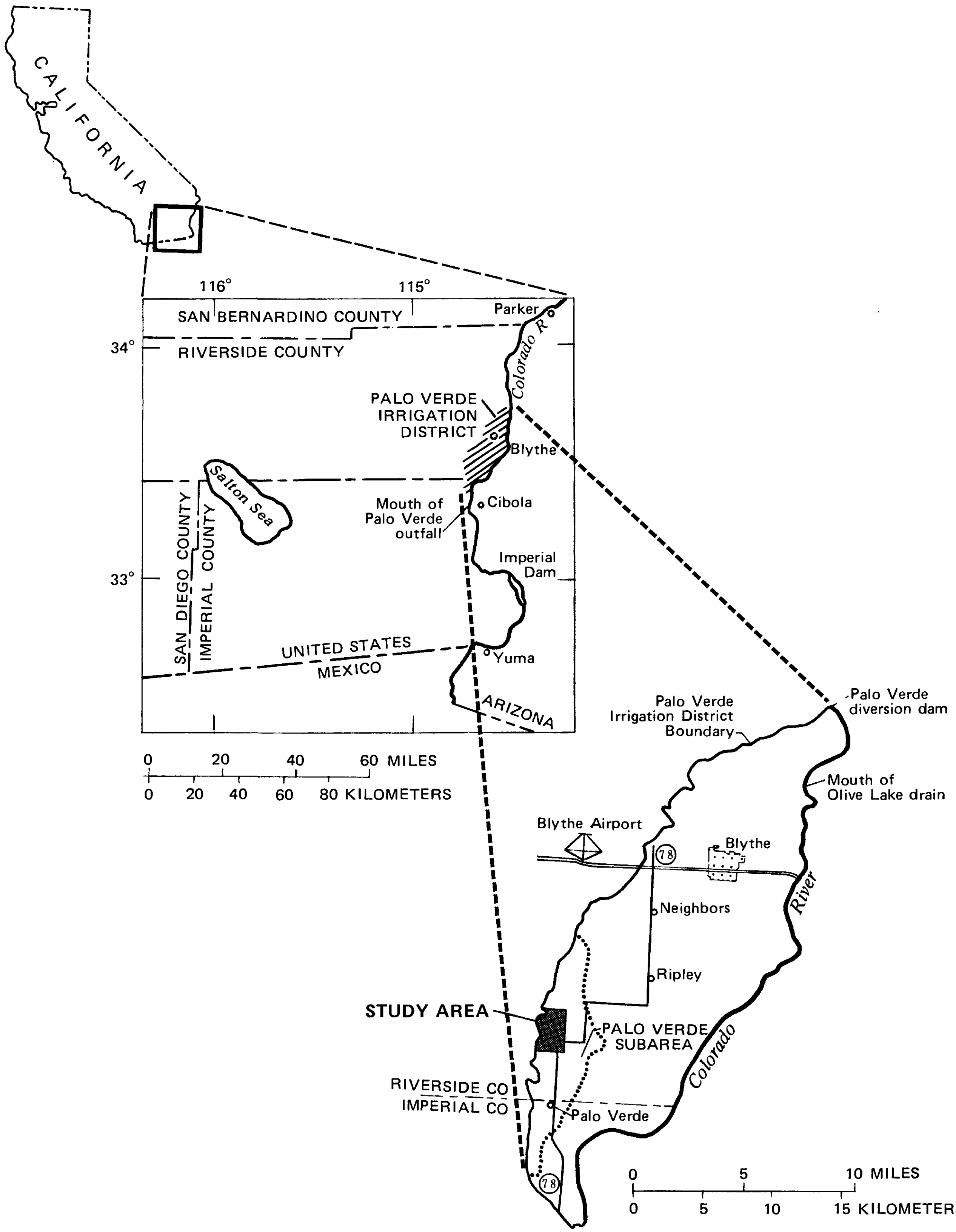

FIGURE 1. — Location of the Palo Verde study area.

Table 1.--Mass balance of salt diverted to and discharged from the Palo Verde Irrigation District for 1979 water year

	Discharge for 1979 water year (acre-ft/yr)	Average dissolved-solids concentration (mg/L)	Total salt diverted from or discharged to the river (ton)
Palo Verde diversion dam--------	928,850	735	- 928,850
Excess diverted water returned unused to the river---------	62,788	735	+ 62,788
Olive Lake drain-------	6,624	940	+ 8,472
Palo Verde outfall-----	419,200	1,620	+ 923,951
Total net salt contribution to the Colorado River from the Palo Verde Irrigation District in the 1979 water year----------------------------------			+ 66,000 (rounded)

In the 1979 water year, irrigation within the Palo Verde Irrigation District flushed about 66,000 tons of salt into the river from the soil and the upper section of the aquifer. According to the U.S. Water and Power Resources Service (1980, p. 3), under present irrigation practices the excess salt in the soil and aquifer is expected to continue to be flushed in gradually declining amounts until completely removed. This process is expected to take well over 100 years, although most of the excess salt may be removed within 60 years.

The salt-loaded water discharged from the Palo Verde outfall contributes to the increase in dissolved-solids concentrations in the Colorado River between Palo Verde and Imperial Dams. Imperial Dam is about 90 miles downstream from Palo Verde Dam and about 40 miles downstream from the Palo Verde outfall (fig. 1). In the 1979 water year the dissolved-solids concentration at Imperial Dam averaged 850 mg/L (U.S. Geological Survey, 1979), 115 mg/L more than the average at Palo Verde Dam for the same water year.

The Federal Water Pollution Control Act (Public Law 92-500) mandates control of salinity[1] along the Colorado River. According to the water-quality standards set by the Environmental Protection Agency, the dissolved-solids concentrations at Imperial Dam should not exceed 879 mg/L during periods of normal flow in the Colorado River. The standard is based on the recommendation of the Colorado River Basin Salinity Control Forum (U.S. Water and Power Resources Service, 1980, p. 2). Planned increases in river-water use for irrigation (U.S. Water and Power Resources Service, 1980, p. 2) are expected to significantly add to the concentrations of dissolved solids along the river. Projections indicate that without controls on salt discharges to the river, dissolved-solids concentrations at Imperial Dam could reach 1,140 mg/L by the year 2000 (U.S. Bureau of Reclamation, 1981, p. 6).

Purpose and Scope

The objective of the investigation was to determine if periodic flooding of fallow farmland would accelerate flushing of excess salts from soil and the upper section of the aquifer in the Palo Verde Irrigation District. Water diversion from the Colorado River to the Central Arizona Project scheduled to begin in 1985 would decrease river flow and reduce the river's diluting ability, posing a problem to water management, inasmuch as public law mandates a dissolved-solids concentration standard of 879 mg/L in the river at Imperial Dam. If the test flushing proves to be an effective means of reducing the total volume of salts within the soil zone and shallow aquifers, the method could be used within the Palo Verde Irrigation District until 1985 while the river flows are expected to be sufficient to dilute the increased salt load. In subsequent years when river flows are expected to be less, decreased residual salts in the soil zone and aquifer would be available to be flushed into the river.

The salt-flushing test was conducted on a 311-acre tract of farmland on the southwestern side of the Palo Verde subarea (fig. 1) abutting the Palo Verde Mesa (fig. 2). The Palo Verde subarea was selected for testing because of its ranking among the top three contributers of salts to the Palo Verde outfall (Bookman-Edmonston, 1976, p. 55; and Klein and Bradford, 1980, p. 16).

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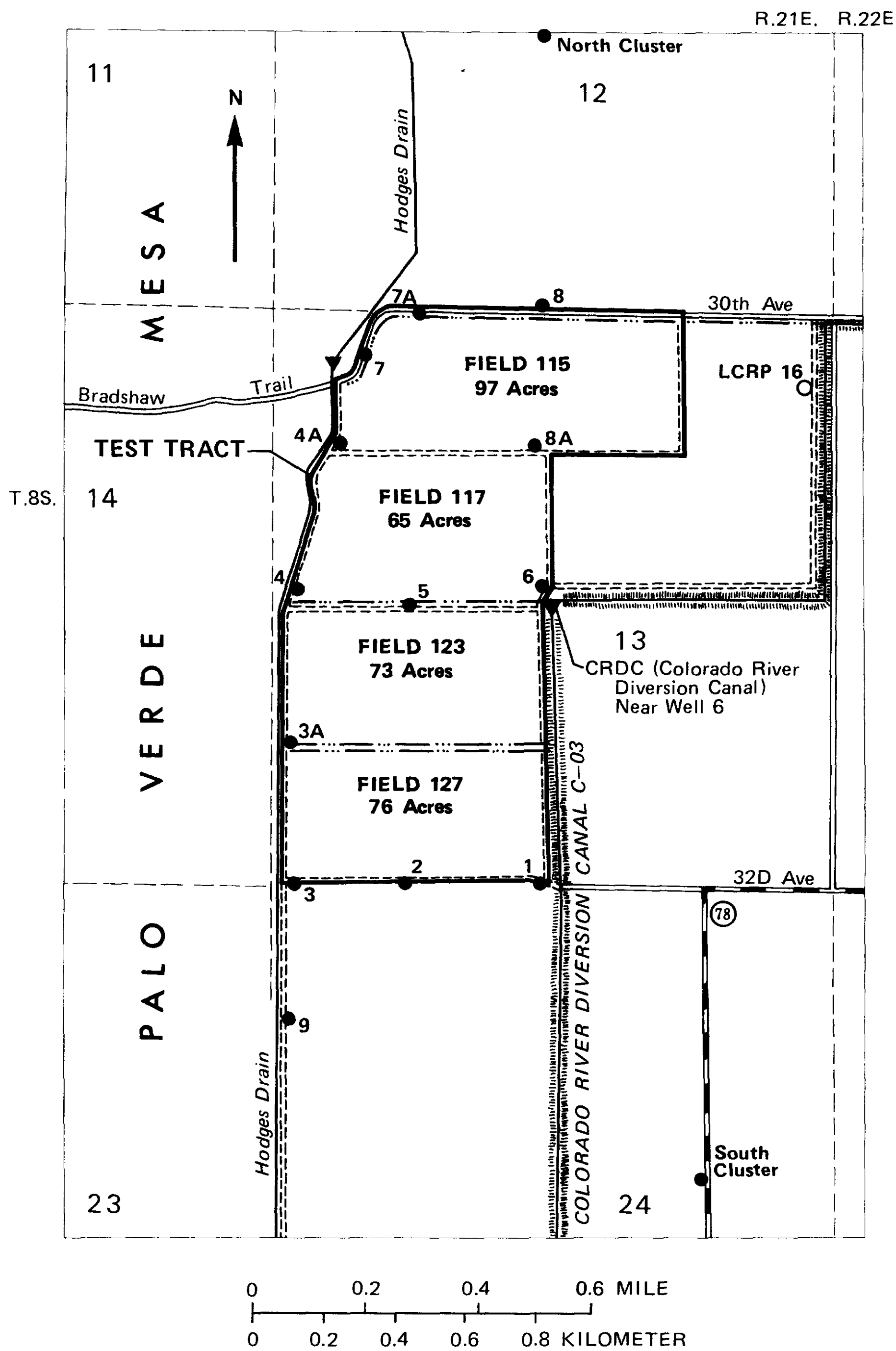
[1]Salinity is the term used in Public Law 92-500 to describe the weight of dissolved minerals per unit volume of water, reported in milligrams per liter.



EXPLANATION

6● WATER-LEVEL MONITOR WELL CLUSTER

LCRP 16○ WELL WITH GEOLOGIC LOG. Log published in Metzger, Loeltz, and Irelan, 1973, p.125

▼ SURFACE-WATER-QUALITY SITE

—··— FIELD IRRIGATION LATERAL CANALS

FIGURE 2. – Location of well clusters, surface-water-quality sites, field reference numbers and acreages, canals, and drains.

Planned Approach

The 311-acre tract was to be plowed and left fallow during the test. The four individual fields within the tract were to be simultaneously subjected to 3 months of daily irrigation of sufficient volume to ensure almost continual standing water on all fields.

Soil samples from land surface to the water table were to be collected from all fields prior to and following the 3 months of irrigation. Salts extracted from the samples were to be analyzed for dissolved-solids concentrations and major ions in the extracted solution. Soil extracts were to be compared for changes in chemical characteristics to determine the effect of the irrigation on the unsaturated zone.

An extensive network of well clusters was to be installed within and along the perimeter of the 311-acre tract as test monitors for water-level and water-quality changes. Clusters were to include wells to depths of 15, 25, and 40 feet below land surface. In addition, three clusters were to be located between 0.25 and 0.6 mile from the perimeter of the test tract. Each of these remote clusters was to have three wells drilled to the same depths monitored within the test tract, and at both the cluster farthest north and the cluster farthest south an additional well was to be drilled to 100 feet in depth.

Ground-water levels were to be measured and ground-water-quality samples collected periodically from all wells installed for the study. Measurements and samplings were to begin during normal irrigation prior to the test and continue through a period of nonirrigation, the irrigation test, another period of nonirrigation, and into the resumption of normal irrigation of the fields.

Ground-water levels were to be compared horizontally and vertically to determine the direction of ground-water movement, the hydraulic continuity within the aquifer, and the aquifer's response to the test irrigation. Changes in ground-water levels within the test tract were also to be compared with background changes monitored in the three remote clusters of wells.

Ground-water samples from the test tract were to be compared horizontally and vertically through time to determine changes and differences in dissolved-solids concentrations and chemical characteristics. Water samples from the test tract were also to be compared with background water quality from the three remote clusters of wells.

Water-quality samples from the diversion canal on the east side of the test tract and Hodges Drain on the west side (fig. 2) were to be collected periodically during the study. These samples were to be compared with samples from the test tract wells and the remote wells to determine the changes in water-quality characteristics that occur as irrigation water moves through the soil and ground-water system to the drainage system.

Previous Investigations

Information from previous studies of the area used by the author during this investigation included the general geology and hydrology of the Palo Verde Irrigation District from Metzger, Loeltz, and Irelan (1973); soil composition within the test tract from Elam (1974); general background and water-quality information from Bookman-Edmonston Engineering, Inc. (1976), and Klein and Bradford (1980); and background information from the Colorado River Basin Salinity Control Forum (1981), the U.S. Water and Power Resources Service (1980), and the U.S. Bureau of Reclamation (1981).

Cooperation and Acknowledgments

The investigation was made by the U.S. Geological Survey in cooperation with the U.S. Bureau of Reclamation.

The author wishes to express his appreciation for assistance in data collection provided by Gerald M. Davisson of the Palo Verde Irrigation District and Robert Michalezio of Norton Farms, Inc. A special thanks is also expressed to Martin P. Einert, Val H. Carter, and Arlo G. Hyde of the U.S. Bureau of Reclamation for the coordination of activities among agencies, soil sampling, and the analyses of soil and water samples for the investigation.

Well-Numbering System

Land Net System.--Wells are numbered according to their location in the rectangular system for the subdivision of public lands. For example, in the number 8S/21E-24D1, the part of the number preceding the slash indicates the township (T. 8 S.), the part between the slash and the hyphen indicates the range (R. 21 E.), the number between the hyphen and the letter indicates the section (sec. 24), and the letter indicates the 40-acre subdivision of the section, as shown in the diagram below. Within the 40-acre tract, wells are numbered serially as indicated by the final digit. All wells are south and east of the San Bernardino base line and meridian.

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

Latitude-Longitude System.--Data are filed in the computer using the grid system of latitude and longitude. The system provides the geographic location of the well site and a unique number for each site. The number consists of 15 digits. The first 6 digits denote the degrees, minutes, and seconds of latitude, the next 7 digits denote degrees, minutes, and seconds of longitude, and the last 2 digits (assigned sequentially) identify the wells within a 1-second grid.

GEOLOGY, SOILS, AND HYDROLOGY

The composition and salinity of the soils and aquifer to a depth of about 40 feet below land surface were of primary concern during this investigation. This zone is within the younger alluvium of the Colorado River (Holocene age) and is the zone from which salts were expected to be flushed during the test.

Geology and Soils

The younger alluvium of Holocene age was deposited by flooding and meandering of the Colorado River within the Palo Verde Valley. This formation unconformably overlies (erosional unconformity) the older alluvium (Pliocene and Pleistocene age) of the Colorado River (Metzger, Loeltz, and Irelan, 1973, p. G22, plates 1, 3). The younger alluvium decreases in thickness near the western boundary of the valley where it intersects and overlies the erosional escarpment created by the dissection of the older alluvium by the Colorado River, then it thins and pinches out at the surface exposure of the formation contact with the older alluvium. Here the scarp of the older alluvium becomes a surface feature forming the eastern part of the Palo Verde Mesa. Well LCRP 16 (fig. 2) is the only well in the study area that has a geologic log. The log indicates that the younger alluvium near the eastern side of the test tract is about 130 feet thick (table 2).

Figure 3 shows the areal distribution of silty-clayey and sandy soils within the test tract and vicinity (Elam, 1974, plate 13). Within the tract, sandy soils predominate, composing about 66 percent of the area. The sandy soils are categorized as fine sandy loams, fine sand, and gravelly sands. The clayey soils compose about 34 percent of the tract and are categorized as silty clay loams and silty clays.

Figure 3 also shows the locations of complete vertical soil samples collected from land surface to the water table with a hand auger during this investigation. Sandy soils composed about 83 percent of the samples, ranging from sands to fine sandy loams and 3 percent sand and gravel. Silty clays composed about 14 percent of the samples. The vertical samples (see table 4) showed a higher percent distribution of sandy soils than did the horizontal distribution in figure 3.

Table 2.--Lithologic log of well LCRP 16 (8S/21E-13A1)

[From Metzger, Loeltz, and Irelan, 1973, p. 125-126]

SE¼NE¼NE¼ sec. 13, T. 8 S., R. 21 E., San Bernardino base line and meridian

	Thickness (feet)	Depth (feet)
Younger alluvium:		
Silt, sandy, light-brown	5	5
Sand, medium, light-brown, fairly well sorted	10	15
Sand, medium, pale-yellowish-brown; few pebbles as much as 2 in. in diameter	21	36
Gravel as much as 4 in. in diameter, rounded to well-rounded; 20-40 percent medium to very coarse sand	19	55
Sand, fine to medium, pale-yellowish-brown, fairly well sorted; few pebbles and light-brown clayballs; wood fragments between depths of 65 and 70 ft	20	75
Sand, fine, silty, pale-yellowish-brown	5	80
Sand, fine to medium, pale-yellowish-brown, fairly well sorted	5	85
Gravel as much as 7 in. in diameter, subrounded to well-rounded; 40 percent sand	7	92
Sand, fine to coarse; 30 percent rounded to well-rounded gravel as much as 6 in. in diameter	13	105
Gravel, rounded to well-rounded; 50 percent sand	10	115
Sand, medium; 30 percent rounded to well-rounded gravel	9	124
Sand, medium, pale-yellowish-brown, fairly well sorted	3	127
Older alluvium:		
Caliche, yellowish-gray	3	130
Sand, fine to medium, pale-yellowish-brown, fairly well sorted; few pebbles and clayballs	22	152
Silt, sandy and clayey, pale-yellowish-brown	4	156
Sand, medium, pale-yellowish-brown; 15 percent well-rounded gravel	24	180
Sand, medium to coarse, pale-yellowish-brown; few small pebbles and some clayballs	20	200
Sand, medium to coarse, pale-yellowish-brown; 20 percent gravel as much as 1½ in. in diameter; few clayballs	10	210
Sand, medium to coarse, pale-yellowish-brown; cemented streaks	16	226
Sand, medium, pale-yellowish-brown; some clayballs	17	243
Clay, silty, pale-yellowish-brown	2	245
Sand, medium, pale-yellowish-brown, fairly well sorted	14	259
Sand, medium, pale-yellowish-brown, fairly well sorted; 10 percent gravel as much as 3 in. in diameter; some wood fragments and clayballs	19	278
Sand, medium, pale-yellowish-brown; few small pebbles	30	308
Siltstone, pale-yellowish-brown; clayballs	2	310
Sand, fine to coarse, poorly sorted; 10 percent small pebble gravel	17	327

Table 2.--Lithologic log of well LCRP 16 (8S/21E-13A1)--Continued

	Thickness (feet)	Depth (feet)
Older alluvium--Continued		
Sand, fine to medium, pale-yellowish-brown, poorly sorted; some clay and silt	12	339
Sand, fine to coarse, pale-yellowish-brown, fairly well sorted	14 [16?]	355
Sand, medium to coarse, pale-yellowish-brown; 30-40 percent small pebble gravel	35	390
Claystone, pale-brown and pale-yellowish-brown	2	392
Gravel, subrounded to well-rounded, pebble and cobble gravel; 40 percent sand	23	415
Sand, medium to coarse, pale-yellowish-brown; 10 percent gravel; few clayballs containing wood fragments	6	421
Gravel, subrounded to rounded, pebble and cobble; 30 percent sand	9	430
Sand, medium to coarse, pale-yellowish-brown; 35 percent gravel as much as 4 in. in diameter; few clayballs	15	445
Bouse Formation: [Upper Tertiary]		
Sand, medium, pale-yellowish-brown, fairly well sorted; few small pebbles	18	463
Clay, greenish-gray	2	465
Sand, fine, silty, pale-yellowish-brown	40	505
Sand, medium, pale-yellowish-brown; few pebbles and clayballs	10	515
Sand, medium to coarse, pale-yellowish-brown	10	525
Sand, fine to medium, pale-yellowish-brown; few clayballs and small pebbles	10	535
Sand, fine to medium, pale-yellowish-brown; large light-olive-gray clayballs and shell fragments	10	545
Sand, fine, pale-yellowish-brown; clayballs	5	550
Clay, light-olive-gray and light-gray	2	552
Sand, fine, pale-yellowish-brown, poorly sorted; shell fragments	8	560
Sand, fine, silty, pale-yellowish-brown, poorly sorted; light-olive-gray and light-gray clay; shell fragments	30	590
Clay, light-olive-gray and light-gray; some silt and fine sand	35	625
Clay, light-olive-gray; light-gray silt and fine sand	10	635
Clay, light-olive-gray; light-gray silt and fine sand; light-brown clay and fine sand	5	640
Clay, light-olive-gray; light-gray silt and fine sand; wood fragments in sand	5	645
Clay, light-olive-gray; light-gray silt and fine sand	30	675
Clay, light-olive-gray; light-gray silt and fine sand; light-brown clay and fine sand	10	685
Clay, light-olive-gray; light-gray silt and fine sand	55	740
Sand, fine, silty, light-gray; fossils	10	750
Clay, light-olive-gray; light-gray silt and fine sand	50	800

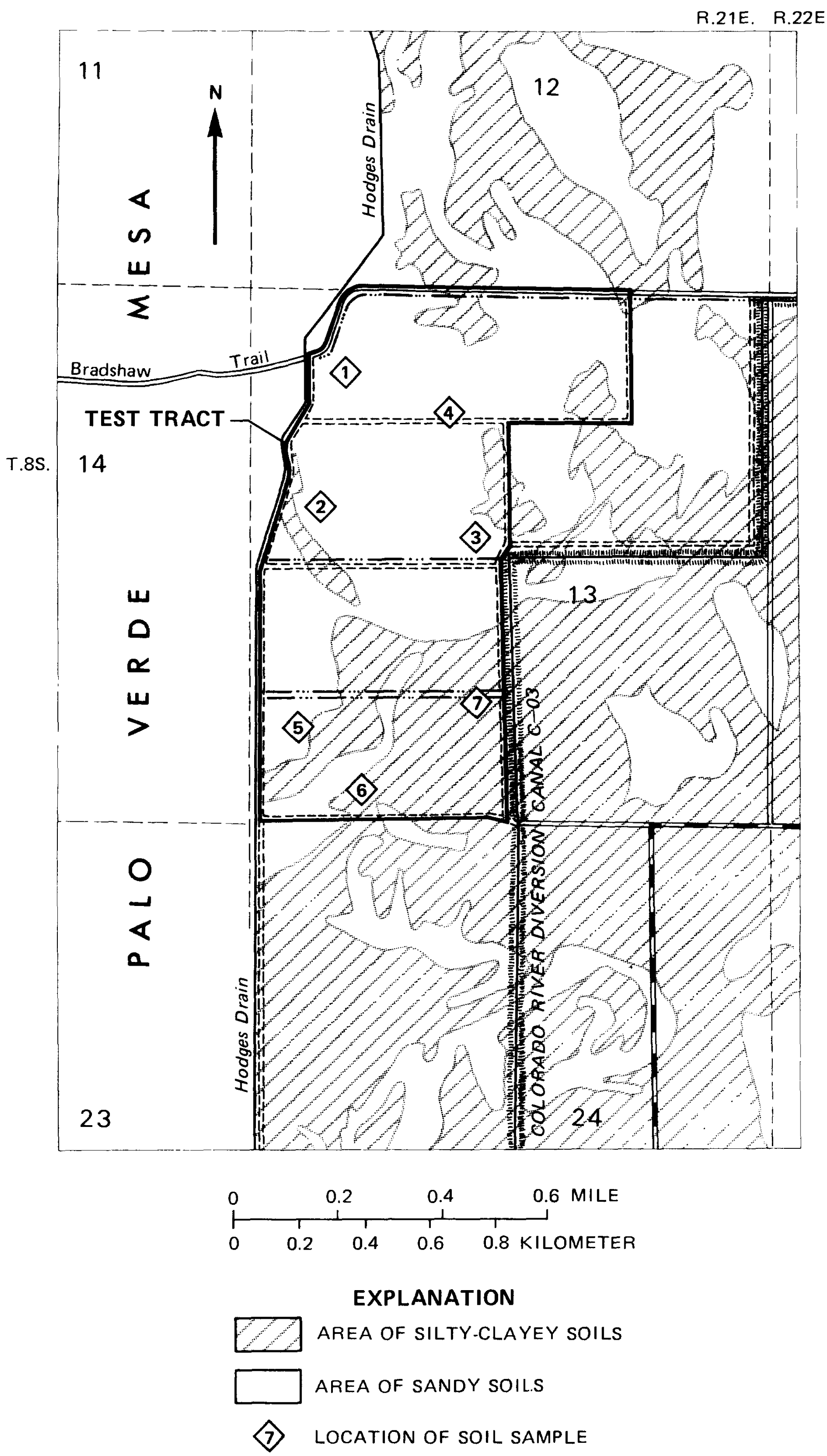


FIGURE 3. – Areal distribution of silty-clayey soils and sandy soils in the test tract and vicinity, east of Hodges Drain, showing locations of soil samples collected during the study. (Modified from Elam, 1974)

Ground-Water-Monitoring Network and Hydrology

Prior to the start of the irrigation test, 46 monitor wells were installed in the study area (fig. 2). Wells were distributed in clusters of two to four wells each and were constructed of 1½-inch galvanized iron casing with the bottom 18 inches finished with 0.01-inch slotted, corrosion-resistant well points. Within the test tract and on its perimeter, 35 wells were installed, including 11 clusters of wells penetrating 15, 25, and 40 feet below land surface and one cluster (cluster 3A) of wells penetrating 25 and 40 feet below land surface (table 3). These wells were installed to monitor ground-water-level and ground-water-quality responses to the test. The remainder of the 46 wells were installed in three clusters located from 0.25 to 0.6 mile from the test tract and included the north cluster, located 0.5 mile north of the test tract, and the south cluster, located 0.6 mile south-southeast of the test tract, each consisting of four wells penetrating to 15, 25, 40, and 100 feet below land surface, and cluster 9, located 0.25 mile south of the tract, consisting of three wells penetrating to 15, 25, and 40 feet below land surface (table 3). These wells were installed as background monitors for comparison with the test-tract wells. Monitoring of the wells consisted of the collection of ground-water-level measurements and ground-water-quality samples, beginning during normal irrigation 7 weeks prior to the test irrigation and continuing into the first period of normal irrigation following the test.

Table 3.--Locations and depths of monitor wells

Monitor well cluster	Land net well No.	Latitude-longitude well No.	Depth of well (feet below land surface)
1 Shallow	8S/21E-13P2	332841114440701	15
Medium	13P3	02	25
Deep	13P4	03	40
2 Shallow	8S/21E-13N1	332841114442201	15
Medium	13N2	02	25
Deep	13N3	03	40
3 Shallow	8S/21E-13N4	332841114443501	15
Medium	13N5	02	25
Deep	13N6	03	40
3A Medium	8S/21E-13N7	332854114443501	25
Deep	13N8	02	40
4 Shallow	8S/21E-13E1	332909114443401	15
Medium	13E2	02	25
Deep	13E3	03	40

Table 3.--Locations and depths of monitor wells--Continued

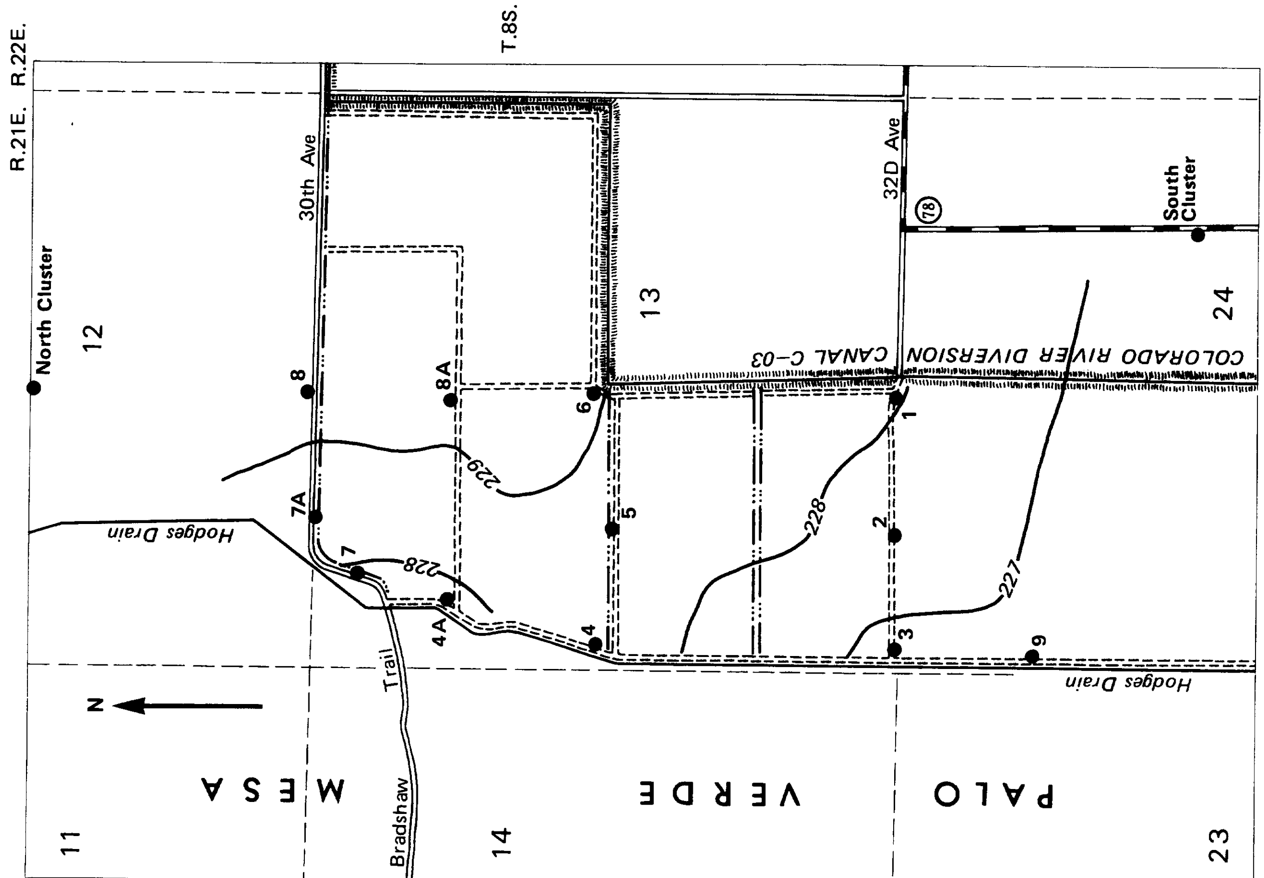
Monitor well cluster	Land net well No.	Latitude-longitude well No.	Depth of well (feet below land surface)
4A Shallow	8S/21E-13D1	332922114443001	15
Medium	13D2	02	25
Deep	13D3	03	40
5 Shallow	8S/21E-13M1	332907114442201	15
Medium	13M2	02	25
Deep	13M3	03	40
6 Shallow	8S/21E-13F1	332909114440701	15
Medium	13F2	02	25
Deep	13F3	03	40
7 Shallow	8S/21E-13D4	332931114442601	15
Medium	13D5	02	25
Deep	13D6	03	40
7A Shallow	8S/21E-13C2	332933114442101	15
Medium	13C3	02	25
Deep	13C4	03	40
8 Shallow	8S/21E-12P1	332935114440701	15
Medium	12P2	02	25
Deep	12P3	03	40
8A Shallow	8S/21E-13C5	332921114440801	15
Medium	13C6	02	25
Deep	13C7	03	40
9 Shallow	8S/21E-24D1	332828114443501	15
Medium	24D2	02	25
Deep	24D3	03	40
North			
Shallow	8S/21E-12E1	333000114440701	15
Medium	12E2	02	25
Deep	12E3	03	40
100 feet	12E4	04	100
South			
Shallow	8S/21E-24H1	332814114435001	15
Medium	24H2	02	25
Deep	24H3	03	40
100 feet	24H4	04	100

Figure 4 shows the configuration of the water table at the 15-, 25-, and 40-foot depths below land surface for the period November 24-25, 1980, during the nonirrigation period prior to the start of test irrigation. All zones show a nearly identical pattern of ground-water movement and gradient generally toward Hodges Drain on the western side of the test tract. This similarity among the water-table configurations indicates that good hydraulic connection occurs within the upper 40 feet of the younger alluvium. This is in agreement with Metzger, Loeltz, and Irelan (1973, p. 77) who state, "Water probably moves freely between the sands and gravels of the [younger and older] alluvial units, and from them into the sands of the uppermost part of the Bouse Formation, except where local impermeable clay layers are present. Consequently, all water-bearing rocks beneath the flood plain and terraces of the Colorado River above the less permeable part of the Bouse Formation constitute a single ground-water reservoir that is hydraulically connected to the Colorado River."

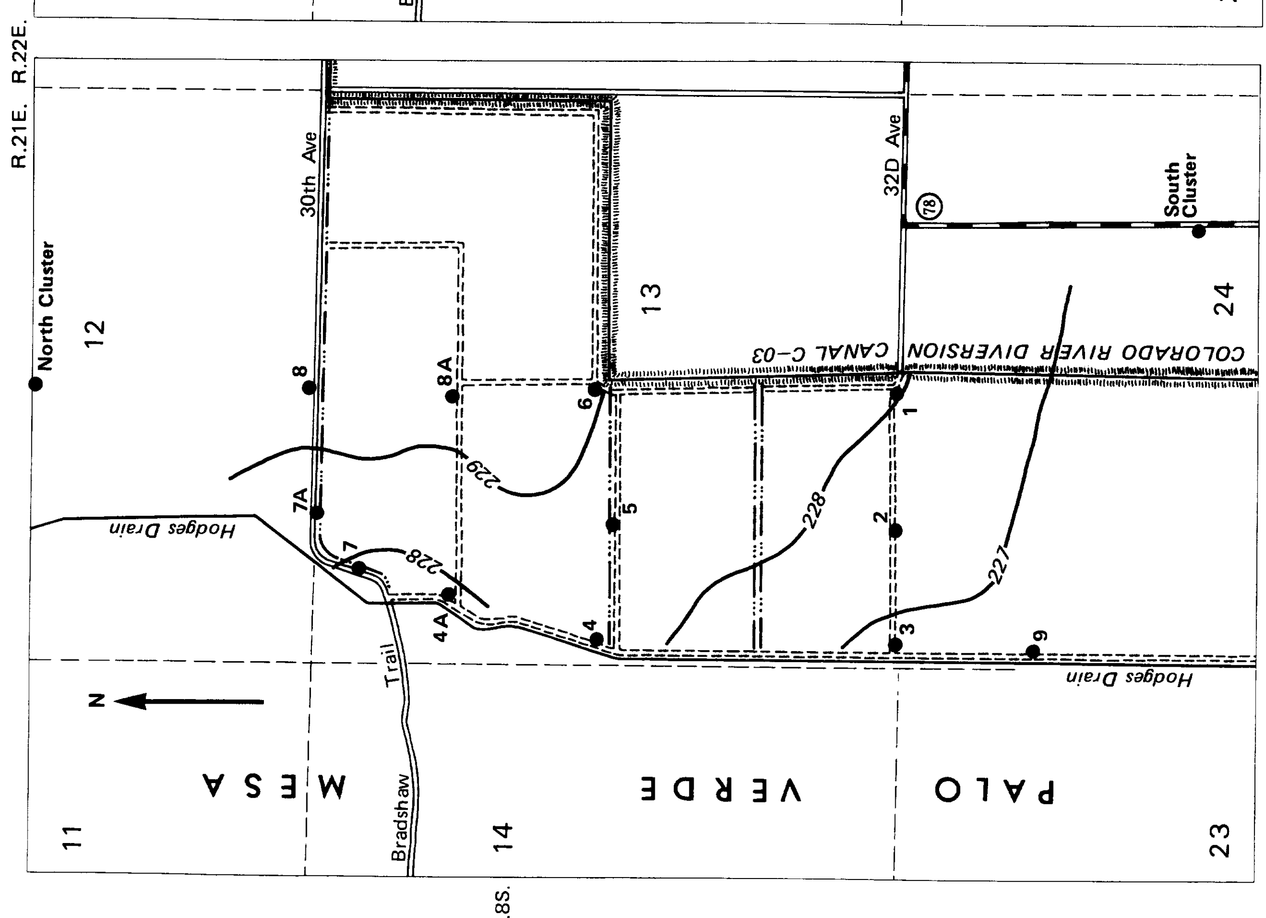
Analysis of Salts Extracted from Soils and Ground-Water Quality

Analyses of soils collected from land surface to the water table at seven sites within the test tract (fig. 3) consisted of soil classification and chemical analysis of the salt solutions extracted from soil samples for major ions and dissolved-solids concentrations. Extracts from the soil samples were obtained by adding deionized water to a sample and hand mixing until a pasty consistency was obtained. Part of the sample was removed after 2 hours to determine the percent moisture contained in the sample. The remainder of the sample was sealed in a jar for 24 hours, after which all moisture was evacuated from the sample through a filter. The filtrate was then chemically analyzed.

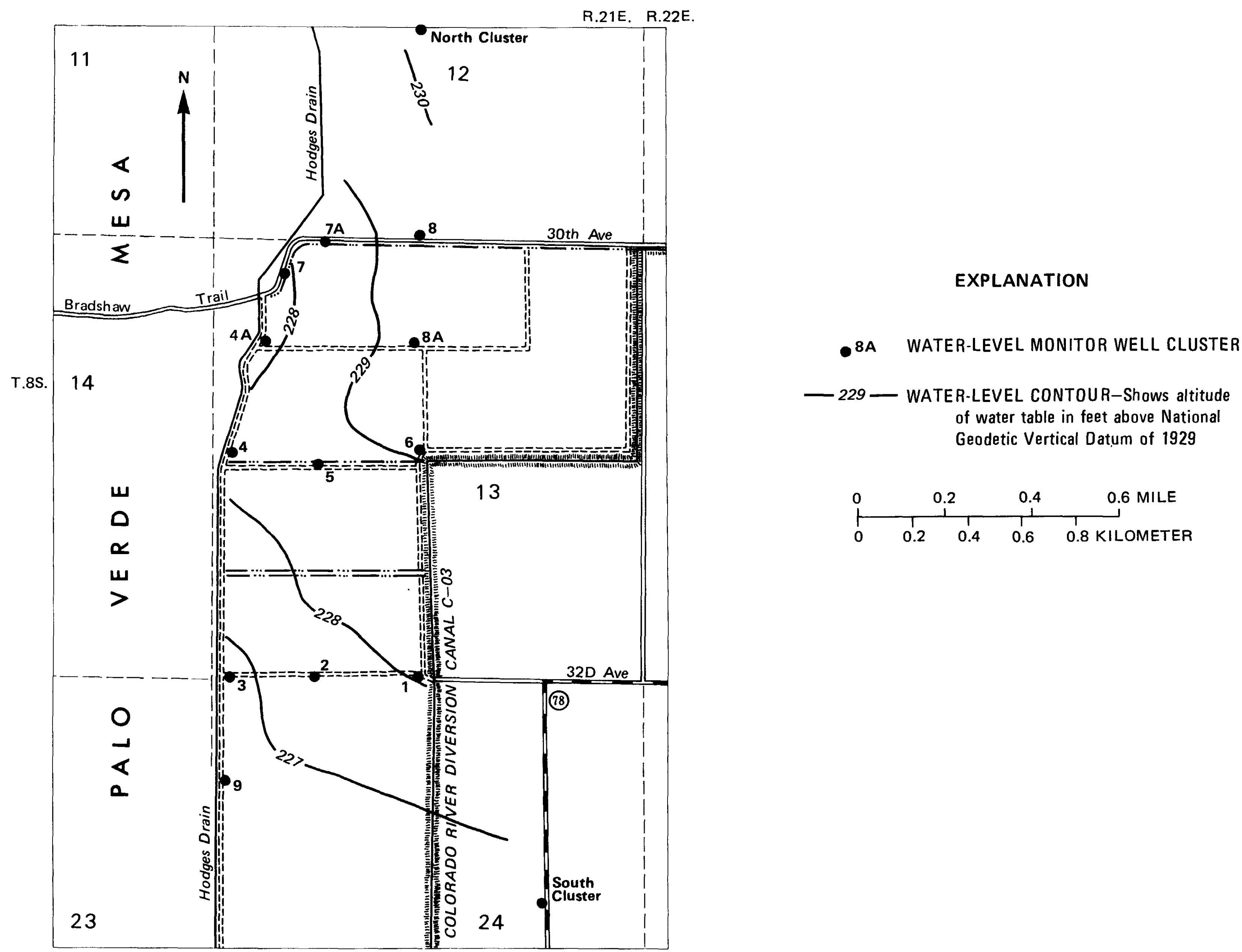
Sample analyses showed a wide variation in both soil type and salinity throughout the test tract (see table 4 under "Quality Changes in Solution Extracts from Soils"). The mean dissolved-solids concentration of all extracts from soils collected before test irrigation was 1,290 mg/L. The range was from a 189-mg/L sodium calcium magnesium bicarbonate type water in a fine sand taken from 36 to 60 inches below land surface at site 1 (fig. 3, table 4), to a 10,700-mg/L sodium sulfate chloride type water in a silty clay taken from 84 to 104 inches below land surface at site 2.



b. Medium wells (25 feet deep)



a. Shallow wells (15 feet deep).



c. Deep wells (40 feet deep).

FIGURE 4. — Configuration of the water table, November 24–25, 1980.

Ground-water samples collected during the nonirrigation period before the test (November 24-25, 1980) also showed much variation in water quality horizontally and vertically in and around the test tract. The mean values and ranges of dissolved solids and mean water types at the three depths monitored within the 311-acre test tract (well clusters 1-8A) were as follows:

	Mean dissolved solids (mg/L)	Range of dissolved solids (mg/L)	Water type
Shallow (15 feet)	995	784 (cluster 8)	Na SO_4
		to	
		1,600 (cluster 2)	Na Ca Mg SO_4
Medium (25 feet)	1,030	788 (cluster 7)	Na Ca Mg SO_4
		to	
		1,460 (cluster 2)	Na Ca Mg SO_4
Deep (40 feet)	1,080	761 (cluster 5)	Na Ca Mg SO_4
		to	
		1,990 (cluster 3)	Na SO_4 Cl HCO_3

The mean values and ranges of dissolved solids and mean water type of samples collected November 24-25, 1980, from wells outside the test tract (cluster 9, north cluster, and south cluster) were as follows:

	Mean dissolved solids (mg/L)	Range of dissolved solids (mg/L)	Water type
Shallow (15 feet)	2,668	860 (north cluster) to 6,050 (cluster 9)	Na Ca Mg SO_4 to Na Cl SO_4
Medium (25 feet)	2,010	749 (north cluster) to 4,180 (cluster 9)	Na Ca Mg SO_4 to Na SO_4 Cl
Deep (40 feet)	2,350	1,150 (north cluster) to 4,580 (cluster 9)	Na Ca SO_4 to Na Cl

Sources of Salts in Soil and Ground Water

According to Metzger, Loeltz, and Irelan (1973, p. 77), salts in ground water must have originated from the Colorado River or from local recharge because no beds containing appreciable quantities of soluble mineral salts have been found in local alluvial deposits. Prior to the completion of Hoover Dam in 1935 and subsequent regulation of the Colorado River, lands within the Palo Verde Valley were frequently flooded during spring months. This flooding created a high ground-water table that caused bogs and sloughs to develop. As phreatophytes such as salt brush, arrow weed, and tules used the water, salt concentration in the soil and ground water increased. In addition, salts were carried upward by capillary movement of water and deposited on the surface and in upper levels of the soil profile as the water evaporated (U.S. Water and Power Resources Service, 1980, p. 3).

THE IRRIGATION TEST AND TEST RESULTS

The irrigation test began on December 9, 1980, but did not proceed as originally scheduled (see the section, "Planned Approach"). All fields were not irrigated simultaneously throughout the test, and irrigation was not continuous for the scheduled 3 months. Figure 5 shows the distribution and volume of water applied to the tract during the study. Harvesting of the cotton crop on fields 123 and 127 (fig. 2) had not been completed by the start of the test, initially limiting irrigation to fields 115 and 117. Irrigation proceeded for 28 consecutive days (December 9-January 5) on fields 115 and 117 when the test was temporarily interrupted for the annual maintenance of the canal system. After 10 days, flow in the canal system was resumed, and irrigation resumed for 7 consecutive days (January 16-22) on all fields. However, this irrigation period was discontinued because of bank collapses in Hodges Drain. The collapses were presumed to have been caused by the increase in ground-water seepage to the drain and the resulting increased saturated bank area during the test. After 13 days, irrigation resumed for 7 days (February 5-12) with application limited to fields 117 and 123. This period of irrigation resulted in more extensive bank collapses in Hodges Drain and prompted final shutdown of the test.

Modification of the planned approach to data analysis was prompted by the discontinuity of irrigation as well as the variations in the number and locations of fields actually irrigated during the test. Figure 5 shows that fields 115 and 117 received the most extensive irrigation during the test, most closely resembling irrigation plans for the entire test tract in the original project approach. Soil-extract and ground-water-quality data from fields 115 and 117 were therefore compared with data from the other sites in the study area in an attempt to determine the effectiveness of the excess-irrigation method as a means of salinity reduction. Soil-extract and ground-water-quality data from fields 123 and 127, where relatively little test irrigation took place, were used in addition to data from cluster 9, north cluster, and south cluster as background control for the study.

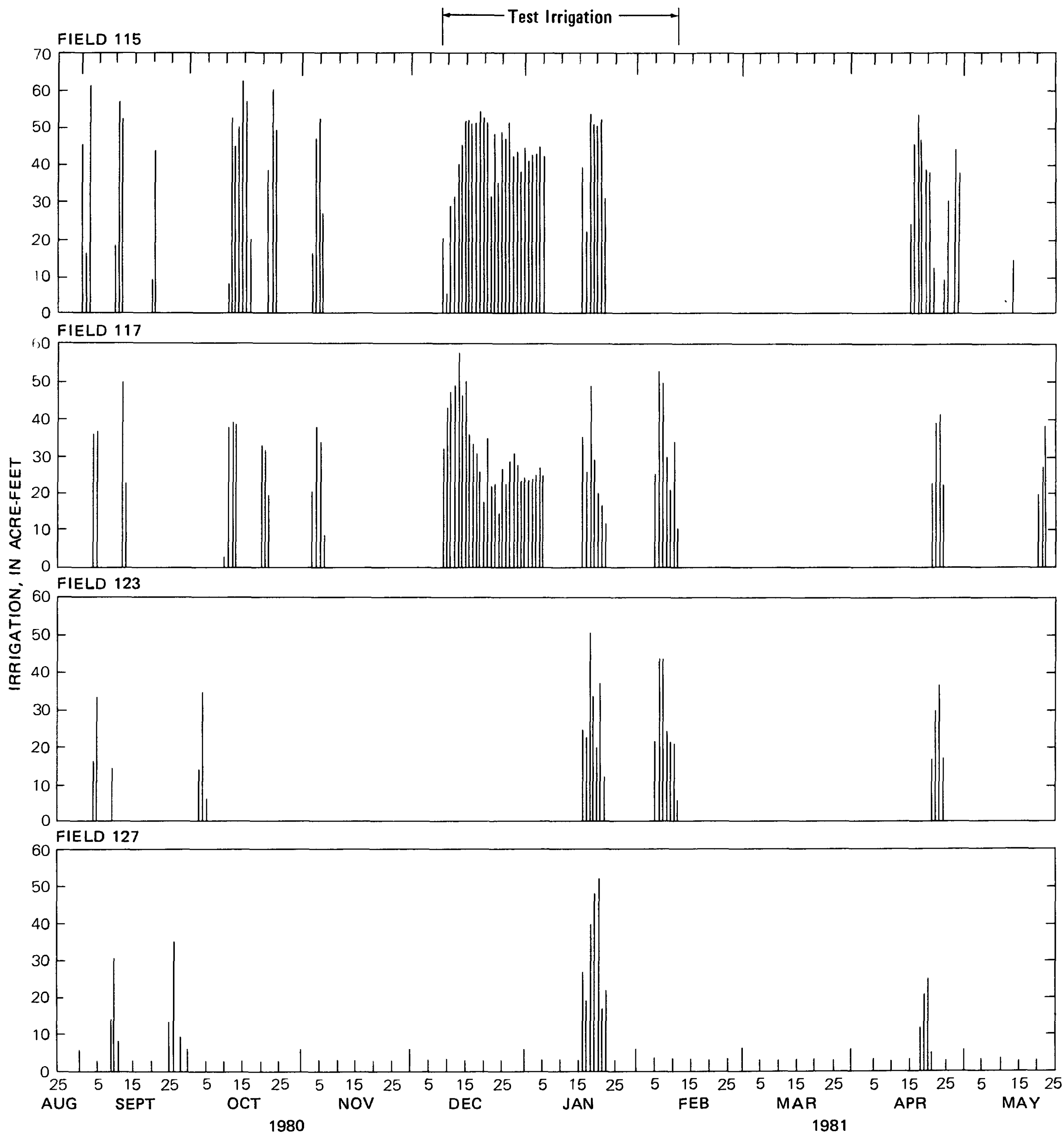


FIGURE 5. – Distribution and volume of irrigation on the test fields, September 1980 to May 1981.

Ground-Water-Level Changes

Figure 6 shows the altitude and configuration of the water table at 15, 25, and 40 feet below land surface on January 5, 1981, the final day of the most extensive period of irrigation during the test. The ground-water high that developed from the irrigation can be inferred by comparing this figure with figure 4, the configuration of the water table during the nonirrigation period prior to the test. The ground-water gradient increased from about 1.5 feet on November 24-25, 1980, to almost 5.5 feet on January 5, 1981, between cluster 8A on the east side of the tract and cluster 4A adjacent to Hodges Drain. The gradient to the south increased from about 1.4 feet to almost 9 feet between cluster 8A and cluster 1 at the southeast corner of the test tract.

The similarities in the water-table configurations at the 15, 25, and 40 foot depths for November 24-25, 1980, as well as for January 5, 1981, confirm the good hydraulic connection within the aquifer to a depth of 40 feet below land surface. This hydraulic connection indicates that the clays found in soil samples and suspected within the aquifer are discontinuous, creating no barrier to the vertical movement of ground water and the movement of ground water toward Hodges Drain.

Figure 7 shows fluctuations in the water table in clusters 4A, 5, and 8A on the perimeter of fields 115 and 117 from September 1980, during normal irrigation prior to the test, through May 1981, during normal irrigation following the test. This figure can be compared to figure 8, which shows the water-level fluctuations in clusters 1 and 9, north cluster, and south cluster, all between 0.5 and 1 mile away from fields 115 and 117, the fields most extensively irrigated during the test. The comparison shows that good response to irrigation was observed in the wells on the perimeter of fields 115 and 117.

Quality Changes in Solution Extracts from Soils

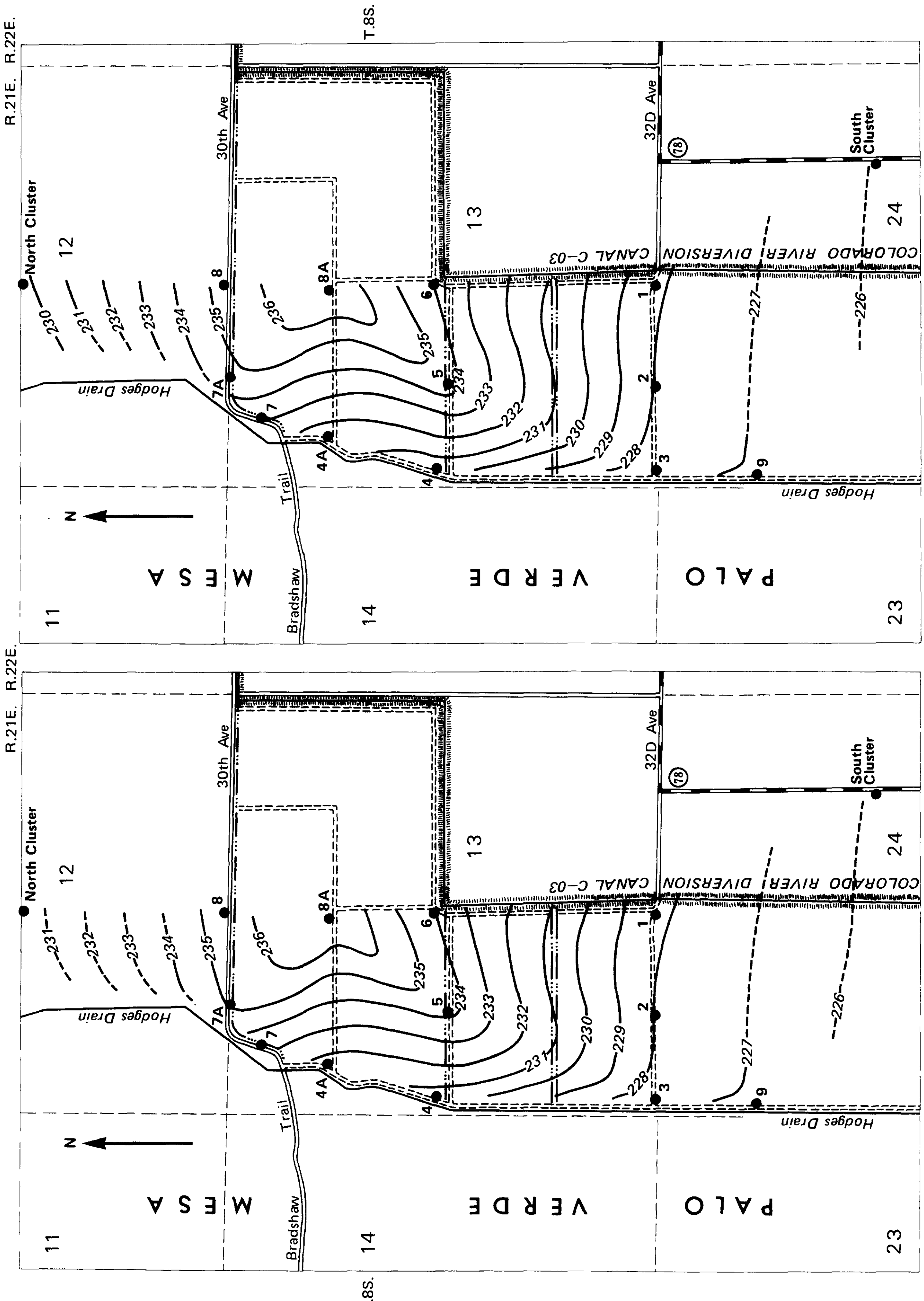
Soil-salinity data for samples collected from within the test tract prior to and following test irrigation are shown in tables 4 and 5, respectively. Soil sites 1 through 4 were located in fields 115 and 117, and sites 5 through 7 were located in field 127 (fig. 3).

Soil samples collected at sites 1 through 4 were expected to be the most promising for indicating the effectiveness of the test irrigation on soil-chemical quality because fields 115 and 117 were those most extensively irrigated during the test. In actuality, however, because the sampling sites could not be precisely replicated and because of the proximity of a large variety of soil textures within the tract, samples showed that different soil sequences had been penetrated (tables 4 and 5). A comparison of these samples for changes in dissolved-solids concentrations was therefore not possible. Figure 9 shows a graphic representation of the chemical characteristics of solutions extracted from the soils and the soil textures of the samples from sites 1 through 4, as well as the samples collected at soil sites 5 through 7.

Because field 127 did not receive much irrigation during the test, it was assumed that changes in the chemical quality of the soil would not be significant. Replication of sample sites 5 through 7 was easily accomplished, however, because the irrigation had not washed away the mounds of soil from the original sampling, and comparison of samples from before and after the test did show changes in the chemical quality of the soil.

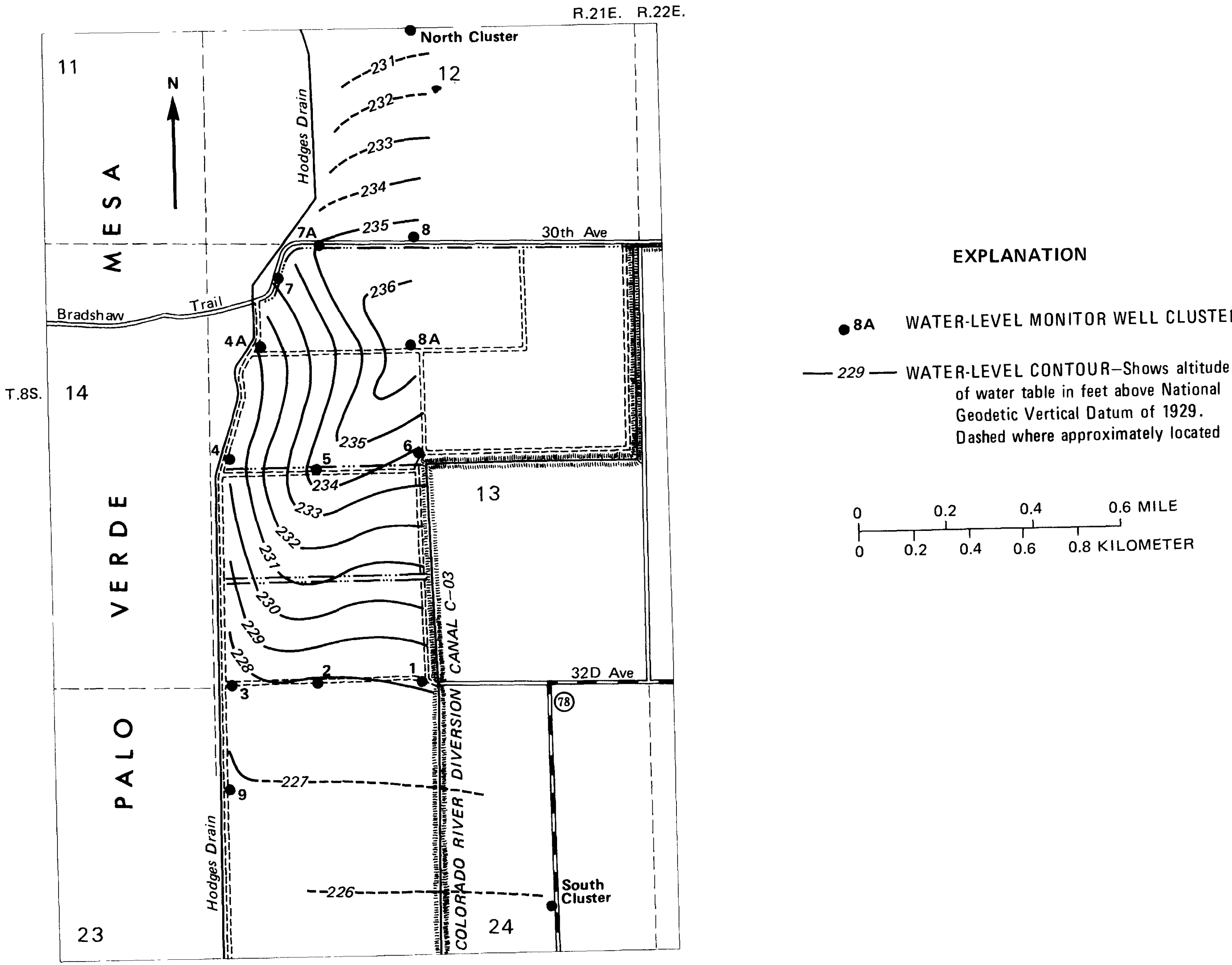
Analyses of solutions extracted from soils collected at site 5 showed a significant reduction in the dissolved-solids concentration within the upper 18 inches of soil and an increase in the dissolved-solids concentration in all soil samples below that level (table 4, 5, and fig. 9e). Site 6 also showed a reduction in salinity in the upper 18 inches and alternating increases and decreases below that level. Site 7 showed decreases at all depths to the water table. These samples suggest that even though irrigation of field 127 was not extensive (fig. 5), some downward movement of salts within the soil zone did occur.

After comparing the pre-irrigation test and post-irrigation test solution extracts from soil samples for chemical differences, it was noted that extracts from certain clayey soils were much different in dissolved-solids concentration and chemical character in extracted solutions from most of the soil samples collected (fig. 9). Extracts from the silty clays at site 2 prior to the test irrigation had the highest dissolved-solids concentrations within the test tract, ranging from 4,040 mg/L in the sample taken from 36 to 60 inches in depth, to 10,700 mg/L in the sample taken from 84 to 104 inches in depth (fig. 9b and table 4). The chemical character of the zone from 36 to 104 inches in depth was a sodium sulfate chloride type. Extracts from all samples collected before and after irrigation, excluding site 2, had a mean dissolved-solids concentration of 576 mg/L. On the average, these extracts had a sodium calcium sulfate bicarbonate water type.



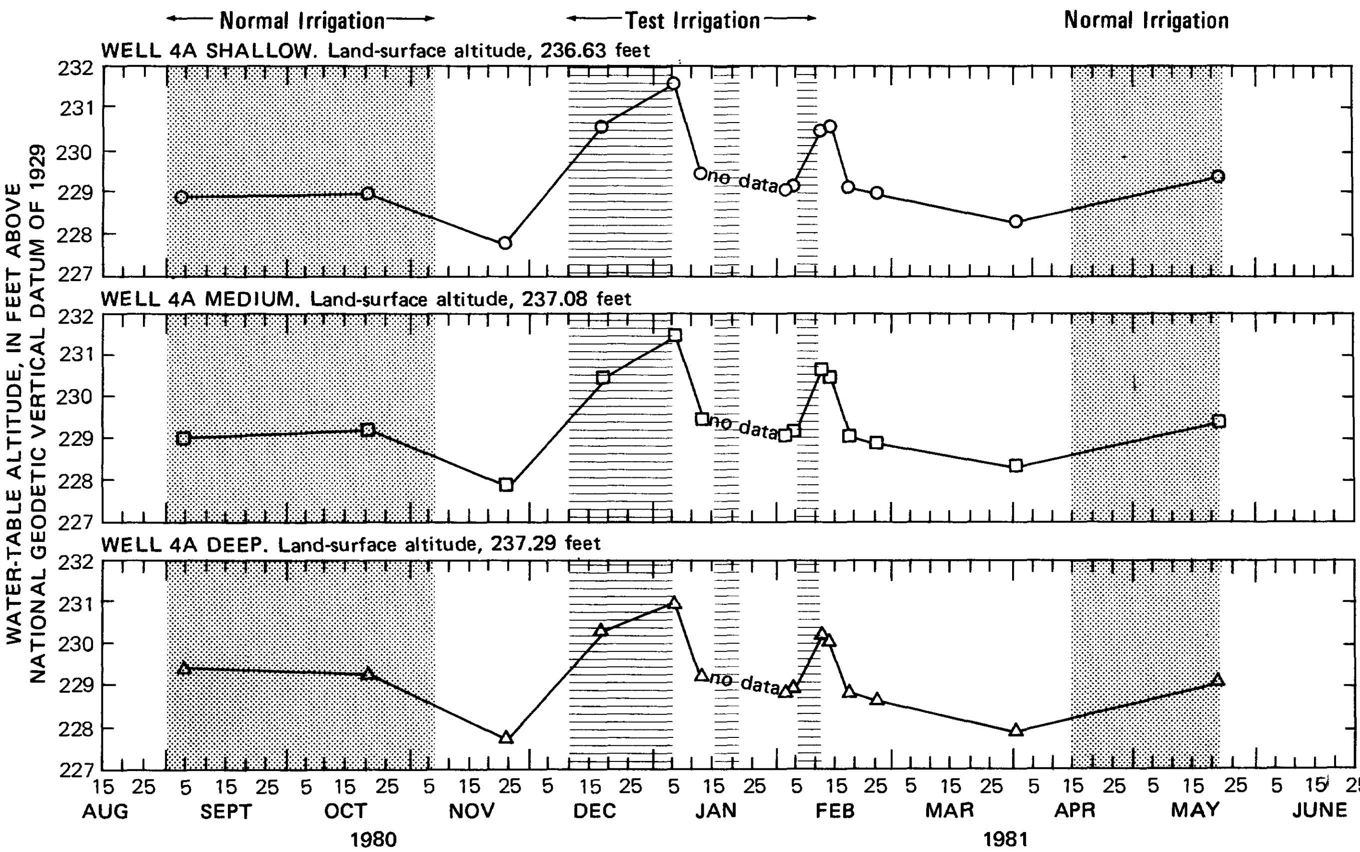
b. Medium wells (25 feet deep)

a. Shallow wells (15 feet deep)



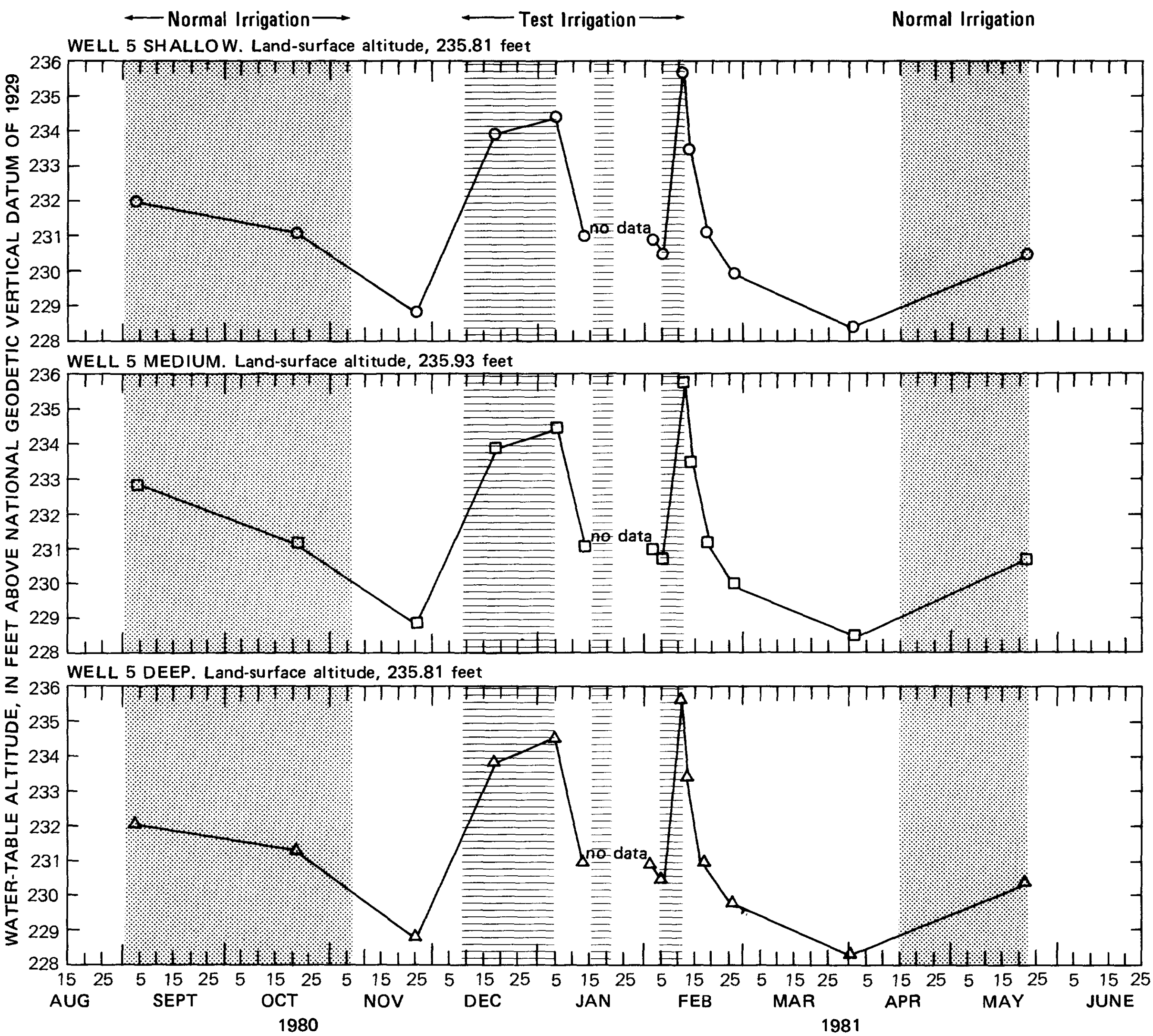
c. Deep wells (40 feet deep)

FIGURE 6. – Configuration of the water table, January 5, 1981.



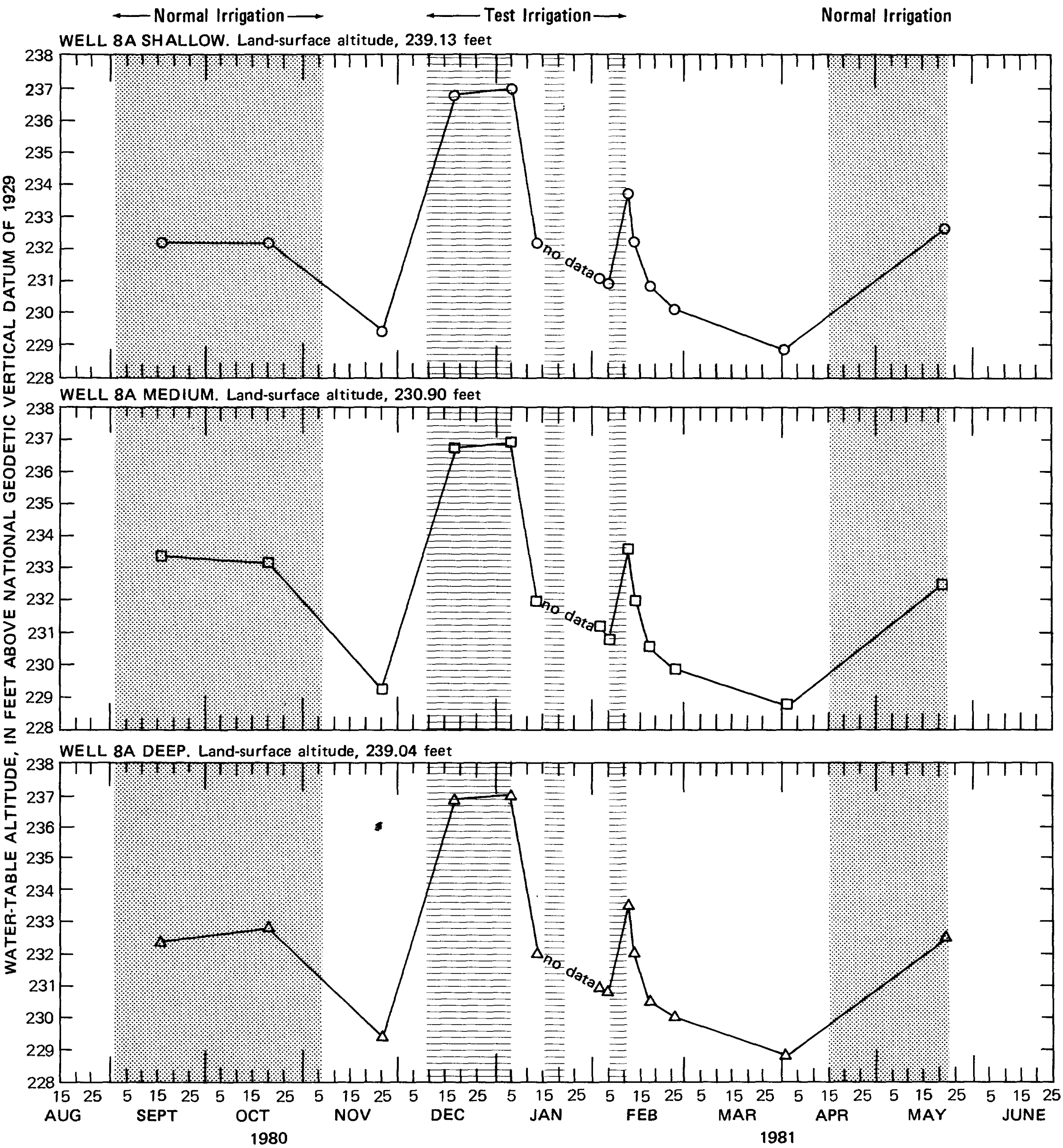
a. CLUSTER 4A

FIGURE 7. – Water-table fluctuations.



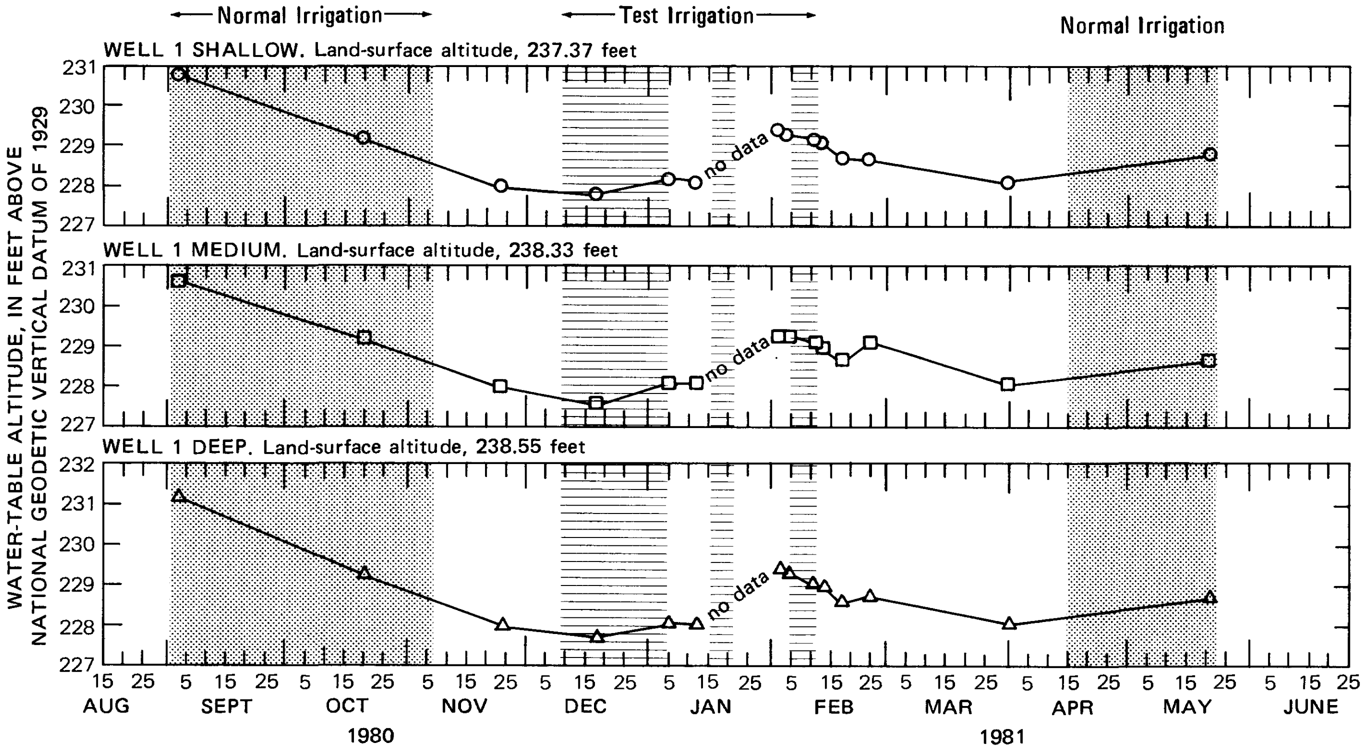
b. CLUSTER 5

FIGURE 7. – Continued.

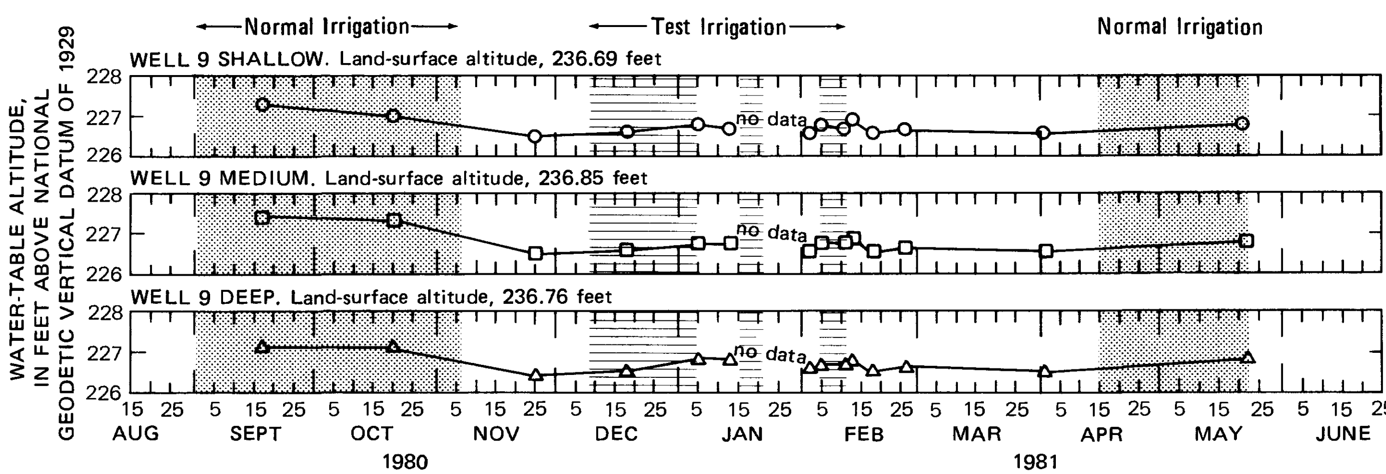


c. CLUSTER 8A

FIGURE 7. – Continued.

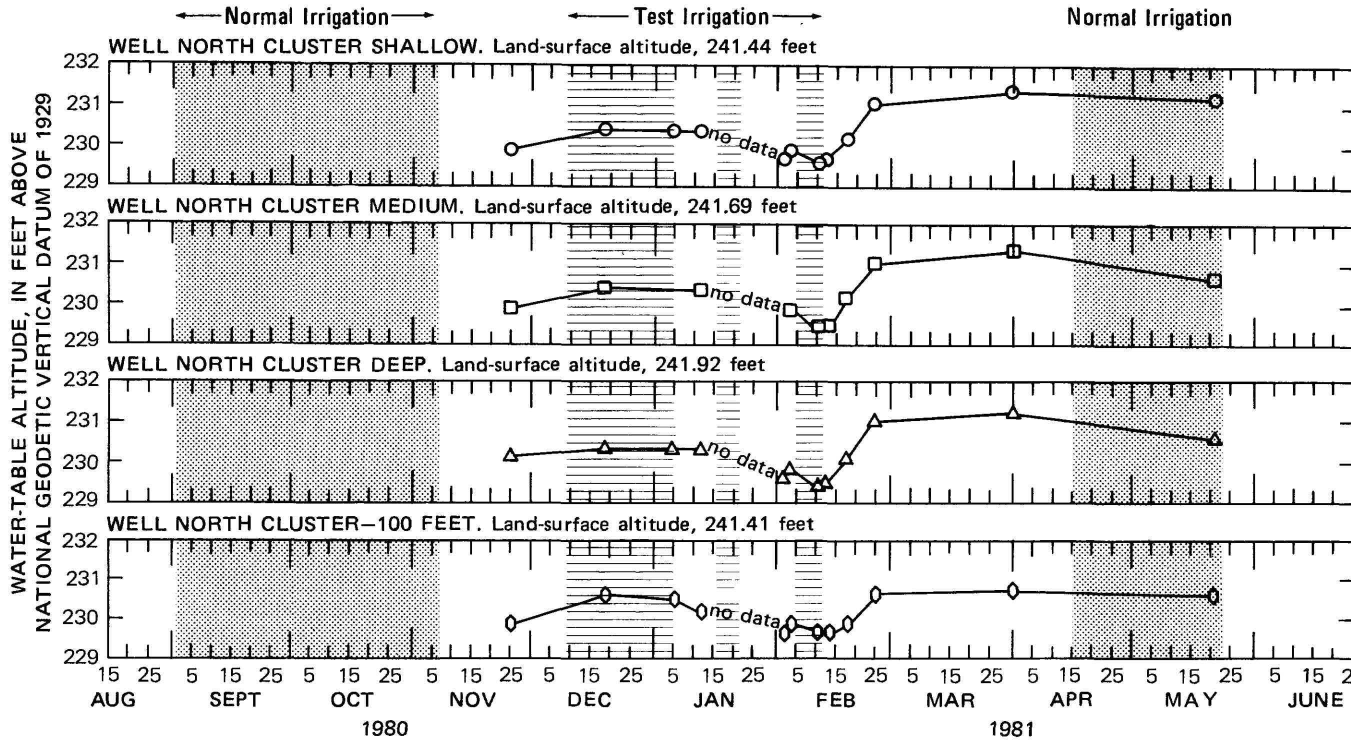


a. CLUSTER 1

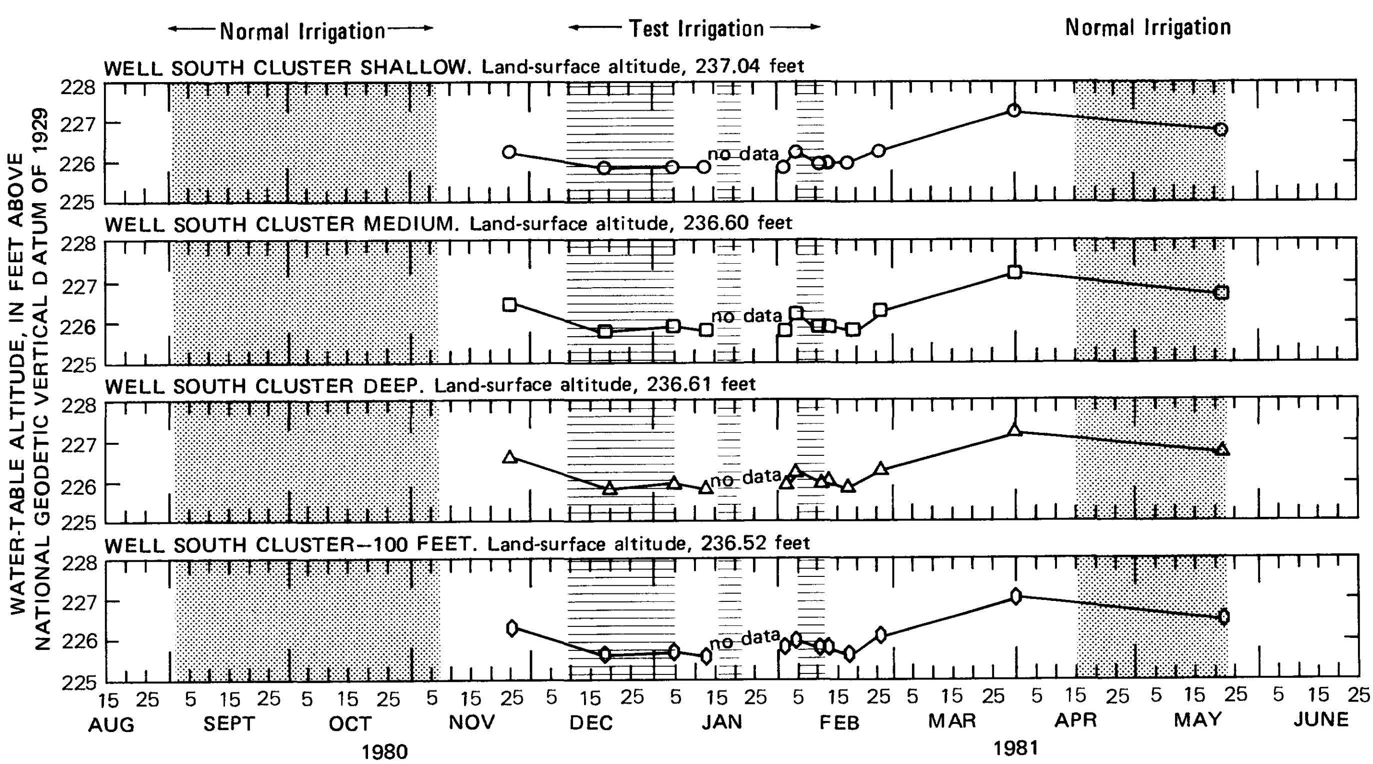


b. CLUSTER 9

FIGURE 8. – Water-table fluctuations.



c. NORTH CLUSTER



d. SOUTH CLUSTER

FIGURE 8. — Continued.

Table 4.--Analyses of solutions extracted from soils collected prior to test irrigation

SITE 1

Depth (inches)	0-12	12-36	36-60	60-84	84-108	108-132
Field texture	Loamy sand	Fine sand	Fine sand	Fine sand	Fine sand	Fine sand
Saturation[1] (percent)	22.8	22.1	26.3	24.9	25.6	23.5
pH	7.9	8.4	8.3	8.2	8.2	8.1
Dissolved solids (mg/L) (calculated sum)	464	455	189	207	261	493
Bicarbonate (meq/L)	3.52	4.32	1.78	1.90	2.08	1.60
Chloride (meq/L)	0.96	1.10	0.36	0.38	0.40	1.72
Sulfate (meq/L)	3.32	2.60	1.04	1.24	1.88	4.44
Calcium (meq/L)	2.80	2.92	1.20	1.16	1.36	2.44
Magnesium (meq/L)	1.56	1.92	0.64	0.62	0.76	1.20
Sodium (meq/L)	3.64	3.00	1.64	1.88	2.28	4.44
Potassium (meq/L)	0.16	0.28	0.08	0.08	0.12	0.12

SITE 2

Depth (inches)	0-18	18-36	36-60	60-84	84-104	104-120
Field texture	Fine sandy loam	Loamy fine sand	Silty clay	Silty clay	Silty clay	Very fine sand
Saturation[1] (percent)	26.2	27.4	61.5	109.2	94.0	28.8
pH	8.5	8.3	8.8	9.3	9.4	8.9
Dissolved solids (mg/L) (calculated sum)	6,330	2,850	4,040	4,390	10,700	1,730
Bicarbonate (meq/L)	6.50	2.70	8.00	13.50	26.00	4.20
Chloride (meq/L)	13.48	7.99	22.13	24.94	59.28	9.06
Sulfate (meq/L)	76.00	32.10	32.40	30.25	78.50	13.60
Calcium (meq/L)	30.25	9.30	1.40	0.75	3.00	1.00
Magnesium (meq/L)	24.00	7.30	2.00	0.50	1.00	0.40
Sodium (meq/L)	46.50	28.00	60.00	70.00	170.00	26.00
Potassium (meq/L)	0.50	0.60	0.60	0.25	0.50	0.20

See footnote at end of table.

Table 4.--Analyses of solutions extracted from soils collected prior to test irrigation--Continued

SITE 3

Depth (inches)	0-24	24-60	60-84	84-120
Field texture	Fine sandy loam	Loamy fine sand	Fine sand	Fine sand
Saturation[1] (percent)	30.3	28.3	29.0	28.6
pH	8.5	8.6	8.5	8.5
Dissolved solids (mg/L) calculated sum	542	435	342	465
Bicarbonate (meq/L)	4.64	3.28	2.20	2.12
Chloride (meq/L)	1.26	0.99	0.73	1.48
Sulfate (meq/L)	3.52	2.92	2.68	3.92
Calcium (meq/L)	3.08	2.20	1.80	2.32
Magnesium (meq/L)	1.96	1.12	0.96	1.16
Sodium (meq/L)	4.16	4.24	3.00	4.12
Potassium (meq/L)	0.20	0.16	0.12	0.12

SITE 4

Depth (inches)	0-21	21-60	60-84	84-120
Field texture	Silty clay	Fine sand	Fine sand	Fine sand
Saturation[1] (percent)	49.4	26.1	25.6	24.8
pH	8.3	8.2	8.1	8.0
Dissolved solids (mg/L) calculated sum	46	250	358	670
Bicarbonate (meq/L)	4.70	1.84	2.40	1.92
Chloride (meq/L)	2.51	0.45	0.77	2.12
Sulfate (meq/L)	8.15	1.94	2.76	6.44
Calcium (meq/L)	5.65	1.60	2.12	4.04
Magnesium (meq/L)	2.95	0.47	1.08	2.12
Sodium (meq/L)	7.30	1.90	2.80	4.96
Potassium (meq/L)	0.20	0.12	0.16	0.20

See footnote at end of table.

Table 4.--Analyses of solutions extracted from soils collected prior to test irrigation--Continued

SITE 5

Depth (inches)	0-18	18-30	30-48	48-68	68-104	104-120
Field texture	Very fine sandy loam	Fine sandy loam	Loamy fine sand	Fine sand	Sand and gravel	Sand
Saturation[1] (percent)	30.7	29.7	28.8	24.9	20.6	21.9
pH	8.0	8.3	8.3	8.2	8.2	8.1
Dissolved solids (mg/L) (calculated sum)	1,850	376	357	339	400	487
Bicarbonate (meq/L)	9.45	3.04	2.94	3.02	2.56	2.02
Chloride (meq/L)	7.47	0.73	0.80	0.68	0.98	1.59
Sulfate (meq/L)	14.00	2.52	2.40	2.08	3.08	4.04
Calcium (meq/L)	12.20	2.20	2.16	2.12	2.12	2.80
Magnesium (meq/L)	9.80	1.20	1.12	1.04	1.08	1.44
Sodium (meq/L)	10.50	3.24	2.76	2.72	3.48	4.16
Potassium (meq/L)	0.70	0.12	0.12	0.16	0.12	0.16

SITE 6

Depth (inches)	0-12	12-33	33-45	45-80	80-110	110-114	114-120
Field texture	Silty clay	Silty clay	Fine sandy loam	Loamy fine sand	Loamy fine sand	Silty loam	Fine sand
Saturation[1] (percent)	32.1	31.2	25.9	28.6	28.3	30.9	30.7
pH	8.5	8.5	8.3	8.4	8.3	8.0	8.1
Dissolved solids (mg/L) (calculated sum)	1,100	696	727	288	519	573	459
Bicarbonate (meq/L)	6.73	4.56	4.00	2.10	2.56	2.98	2.35
Chloride (meq/L)	3.87	2.21	2.30	0.67	1.77	2.00	1.36
Sulfate (meq/L)	7.80	4.80	5.52	1.92	3.92	4.30	3.70
Calcium (meq/L)	7.60	4.72	4.56	1.74	2.48	2.75	2.00
Magnesium (meq/L)	3.75	2.28	2.36	0.82	1.20	1.35	1.00
Sodium (meq/L)	7.50	5.16	5.60	2.54	5.12	5.45	4.45
Potassium (meq/L)	0.45	0.24	0.28	0.14	0.24	0.25	0.20

See footnote at end of table.

Table 4.--Analyses of solutions extracted from soils collected prior to test irrigation--Continued

SITE 7				
Depth (inches)-----------	0-21	21-69	69-80	80-96
Field texture------------	Fine sandy loam	Fine sand	Fine sand	Fine sand
Saturation[1] (percent)	23.4	23.2	24.4	24.7
pH	8.1	8.3	8.2	8.2
Dissolved solids (mg/L) (calculated sum)	1,600	487	944	602
Bicarbonate (meq/L)	5.85	3.08	2.90	2.50
Chloride (meq/L)	7.18	0.90	3.94	2.07
Sulfate (meq/L)	13.40	3.75	8.40	5.00
Calcium (meq/L)	8.30	3.30	6.30	2.95
Magnesium (meq/L)	5.90	1.60	3.10	1.45
Sodium (meq/L)	12.00	4.05	6.20	5.75
Potassium (meq/L)	0.20	0.10	0.20	0.10

[1]Saturation, in percent, is determined by taking the weight of the water extracted from the saturated sample divided by the dry weight of the sample, multiplied by 100.

Table 5.--Analyses of solutions extracted from soils collected after test irrigation

SITE 1					
Depth (inches)-----------	0-12	12-36	36-60	60-84	84-118
Field texture------------	Loamy sand	Sand	Sand	Sand	Sand
Saturation[1] (percent)	23.0	27.9	26.6	24.4	24.1
pH	8.3	8.0	8.2	8.2	8.1
Dissolved solids (mg/L) (calculated sum)	457	233	213	209	292
Bicarbonate (meq/L)	3.80	2.13	1.86	1.74	2.11
Chloride (meq/L)	0.79	0.35	0.33	0.38	0.79
Sulfate (meq/L)	3.20	1.52	1.54	1.52	2.02
Calcium (meq/L)	2.64	1.24	1.12	0.98	1.10
Magnesium (meq/L)	1.64	0.68	0.64	0.58	0.66
Sodium (meq/L)	3.56	2.02	1.68	1.81	3.08
Potassium (meq/L)	0.16	0.10	0.08	0.06	0.06

See footnote at end of table.

Table 5.--Analyses of solutions extracted from soils collected after test irrigation--Continued

SITE 2

Depth (inches)	0-18	18-36	36-60	60-84	84-104
Field texture	Very fine sandy loam	Loamy fine sand	Silty clay	Silty clay	Very fine sand
Saturation[1] (percent)	38.7	26.7	41.9	90.2	31.0
pH	8.6	8.2	8.9	8.9	8.9
Dissolved solids (mg/L) (calculated sum)	2,920	3,000	8,280	5,120	1,600
Bicarbonate (meq/L)	5.15	3.95	12.00	15.00	5.90
Chloride (meq/L)	9.01	9.26	1.11	13.46	4.92
Sulfate (meq/L)	30.20	31.80	102.20	52.00	14.00
Calcium (meq/L)	7.10	4.90	8.25	1.20	0.60
Magnesium (meq/L)	5.70	3.20	7.50	0.80	0.20
Sodium (meq/L)	33.20	37.60	115.00	71.60	24.00
Potassium (meq/L)	0.40	0.50	1.75	0.40	0.10

SITE 3

Depth (inches)	0-24	24-36	36-96	72	72-102
Field texture	Fine sandy loam	Loamy fine sand	Fine sand	Silty clay	Fine sand
Saturation[1] (percent)	48.4	29.6	33.3	66.1	30.7
pH	8.1	8.4	8.4	8.4	8.3
Dissolved solids (mg/L) (calculated sum)	638	821	457	504	406
Bicarbonate (meq/L)	3.28	2.88	2.94	2.42	2.76
Chloride (meq/L)	1.57	2.82	1.11	1.16	0.91
Sulfate (meq/L)	5.60	7.55	3.40	4.50	3.00
Calcium (meq/L)	3.55	4.85	2.20	2.80	1.92
Magnesium (meq/L)	1.65	2.20	1.08	1.45	0.88
Sodium (meq/L)	5.20	6.25	4.60	4.20	4.04
Potassium (meq/L)	0.10	0.10	0.08	0.10	0.12

See footnote at end of table.

Table 5.--Analyses of solutions extracted from soils collected after test irrigation--Continued

SITE 4

Depth (inches)	0-21	21-60	60-96
Field texture	Fine sandy loam	Fine sand	Fine sand
Saturation[1] (percent)	27.8	22.2	27.1
pH	8.2	8.0	7.9
Dissolved solids (mg/L) (calculated sum)	1,260	227	401
Bicarbonate (meq/L)	4.30	2.07	1.74
Chloride (meq/L)	3.98	0.39	1.22
Sulfate (meq/L)	12.10	1.42	3.52
Calcium (meq/L)	8.00	1.32	1.88
Magnesium (meq/L)	4.80	0.72	0.96
Sodium (meq/L)	7.80	1.88	3.56
Potassium (meq/L)	0.40	0.12	0.12

SITE 5

Depth (inches)	0-18	18-30	30-48	48-90	90-104	104-120
Field texture	Very fine sandy loam	Fine sandy loam	Loamy fine sand	Fine sand	Sand and gravel	Sand
Saturation[1] (percent)	34.5	27.1	26.7	23.9	21.8	22.3
pH	8.2	8.2	8.3	8.2	8.1	7.9
Dissolved solids (mg/L) (calculated sum)	690	762	568	997	544	1,080
Bicarbonate (meq/L)	3.05	3.02	2.04	2.75	1.85	1.90
Chloride (meq/L)	2.19	2.50	1.63	2.72	1.35	3.61
Sulfate (meq/L)	6.00	6.65	4.90	9.80	5.30	11.20
Calcium (meq/L)	4.10	4.00	2.55	4.20	2.60	5.00
Magnesium (meq/L)	2.05	2.05	1.35	2.20	1.30	2.20
Sodium (meq/L)	5.05	6.55	5.55	9.80	4.90	9.50
Potassium (meq/L)	0.25	0.20	0.20	0.30	0.15	0.20

See footnote at end of table.

Table 5.--Analyses of solutions extracted from soils collected after test irrigation--Continued

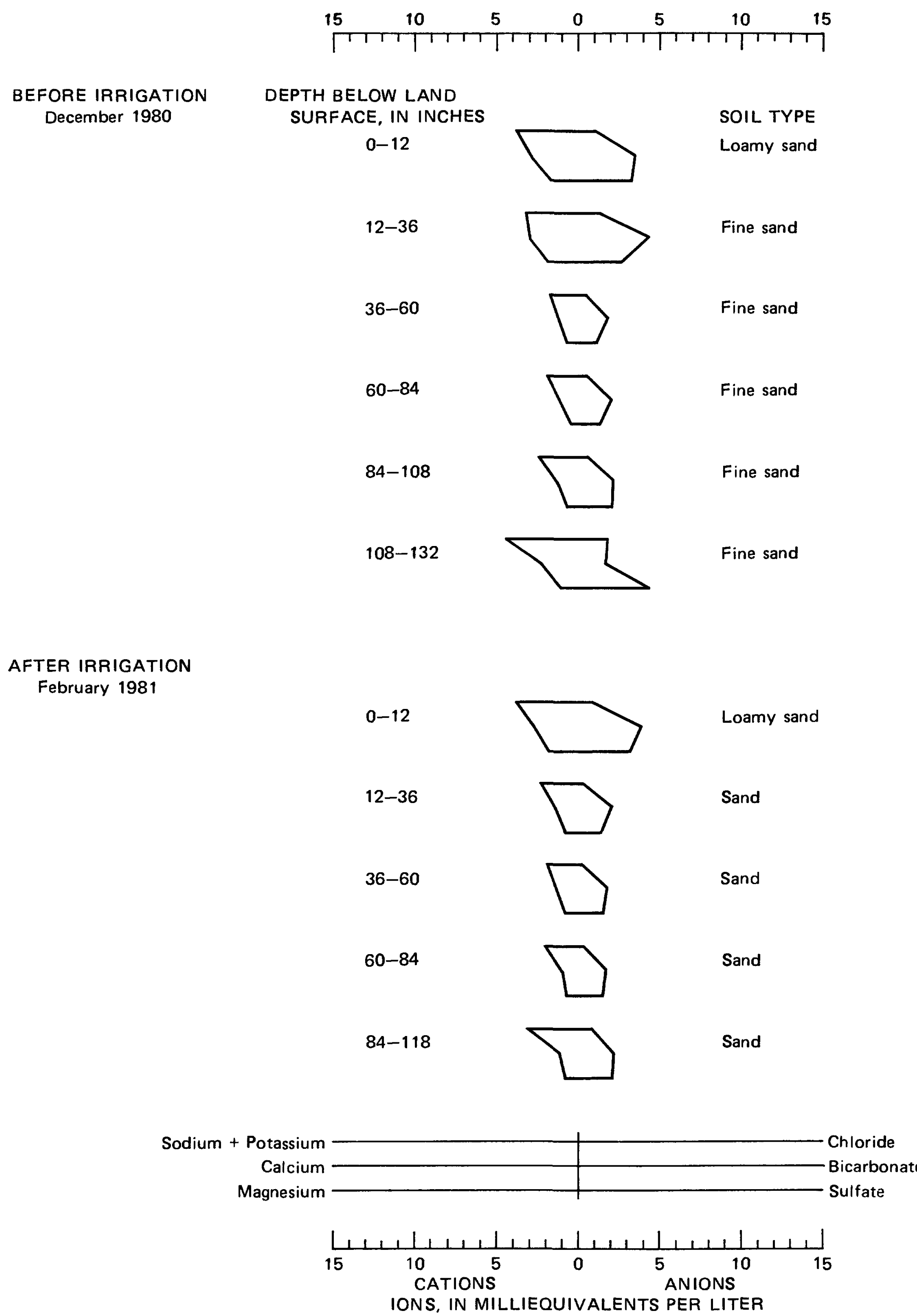
SITE 6

Depth (inches)	0-18	18-33	33-45	45-80	80-104	104-108
Field texture	Silty clay	Silty clay	Fine sandy loam	Loamy fine sand	Loamy fine sand	Silty loam
Saturation[1] (percent)	37.0	39.3	33.2	29.5	32.4	36.7
pH	8.0	8.0	8.4	8.3	8.5	8.2
Dissolved solids (mg/L) (calculated sum)	706	739	426	708	436	716
Bicarbonate (meq/L)	3.45	2.98	2.18	1.75	1.86	2.45
Chloride (meq/L)	1.36	1.90	1.15	2.64	1.56	2.45
Sulfate (meq/L)	6.90	7.00	3.52	6.50	3.40	6.50
Calcium (meq/L)	3.80	4.05	2.00	4.25	1.96	3.20
Magnesium (meq/L)	1.80	2.10	1.08	2.50	1.24	1.70
Sodium (meq/L)	4.90	5.45	3.88	5.40	4.32	6.40
Potassium (meq/L)	0.30	0.35	0.20	0.25	0.20	0.30

SITE 7

Depth (inches)	0-21	21-69	69-90
Field texture	Fine sandy loam	Fine sand	Fine sand
Saturation[1] (percent)	26.7	23.0	26.3
pH	8.1	8.2	8.0
Dissolved solids (mg/L) (calculated sum)	923	278	413
Bicarbonate (meq/L)	4.35	2.03	1.65
Chloride (meq/L)	3.07	0.54	1.35
Sulfate (meq/L)	8.10	2.12	3.65
Calcium (meq/L)	9.40	1.34	1.90
Magnesium (meq/L)	3.00	0.76	0.90
Sodium (meq/L)	6.00	2.46	3.90
Potassium (meq/L)	0.30	0.08	0.05

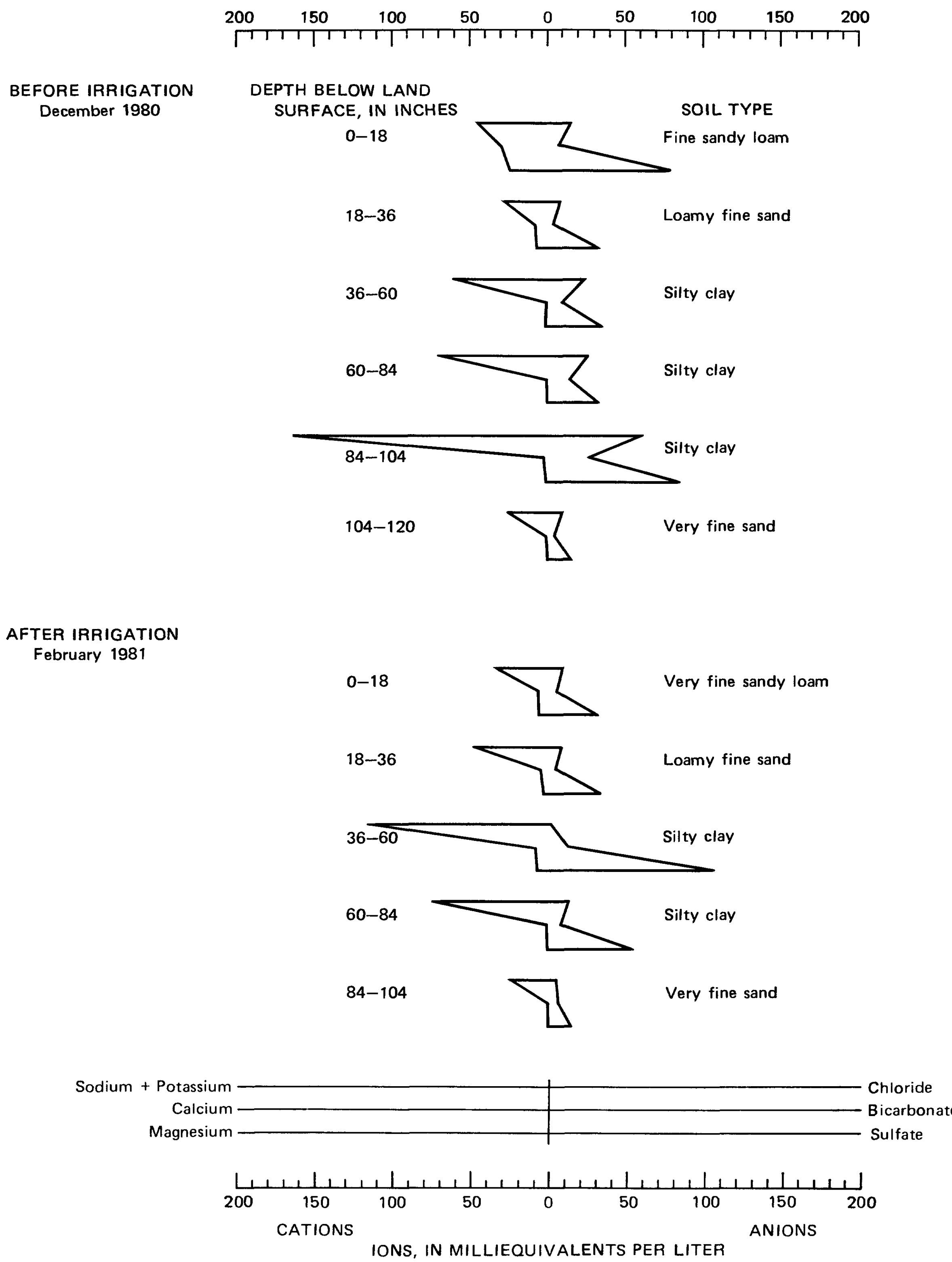
[1]Saturation, in percent, is determined by taking the weight of the water extracted from the saturated sample divided by the dry weight of the sample, multiplied by 100.



a . SOIL SITE 1

(Samples collected before and after test irrigation were not taken at precisely the same location)

FIGURE 9.– Stiff diagrams showing chemical characteristics of extracts of soil samples collected before and after test irrigation.

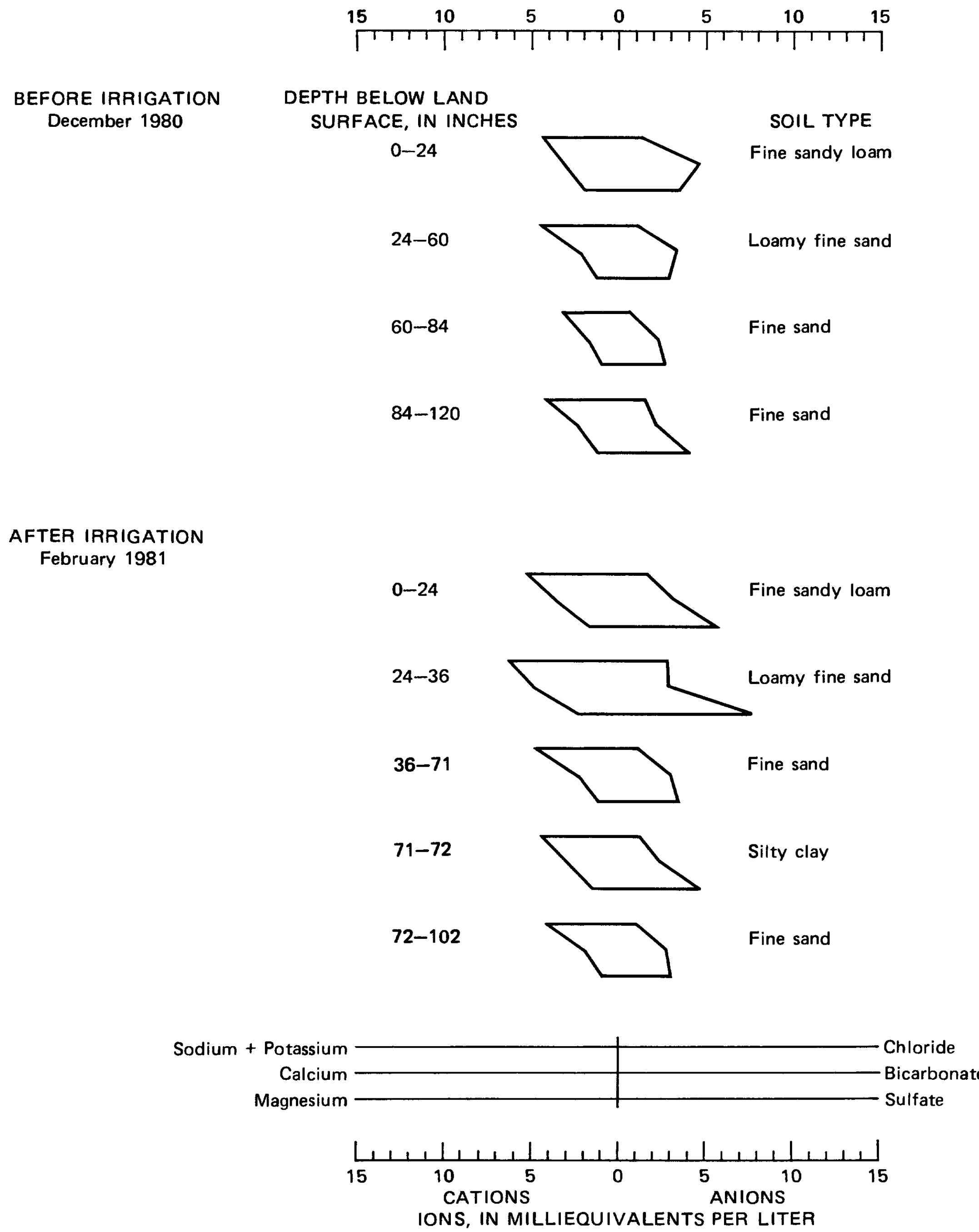


b . SOIL SITE 2

Note scale difference from other sites.

(Samples collected before and after test irrigation were not taken at precisely the same location)

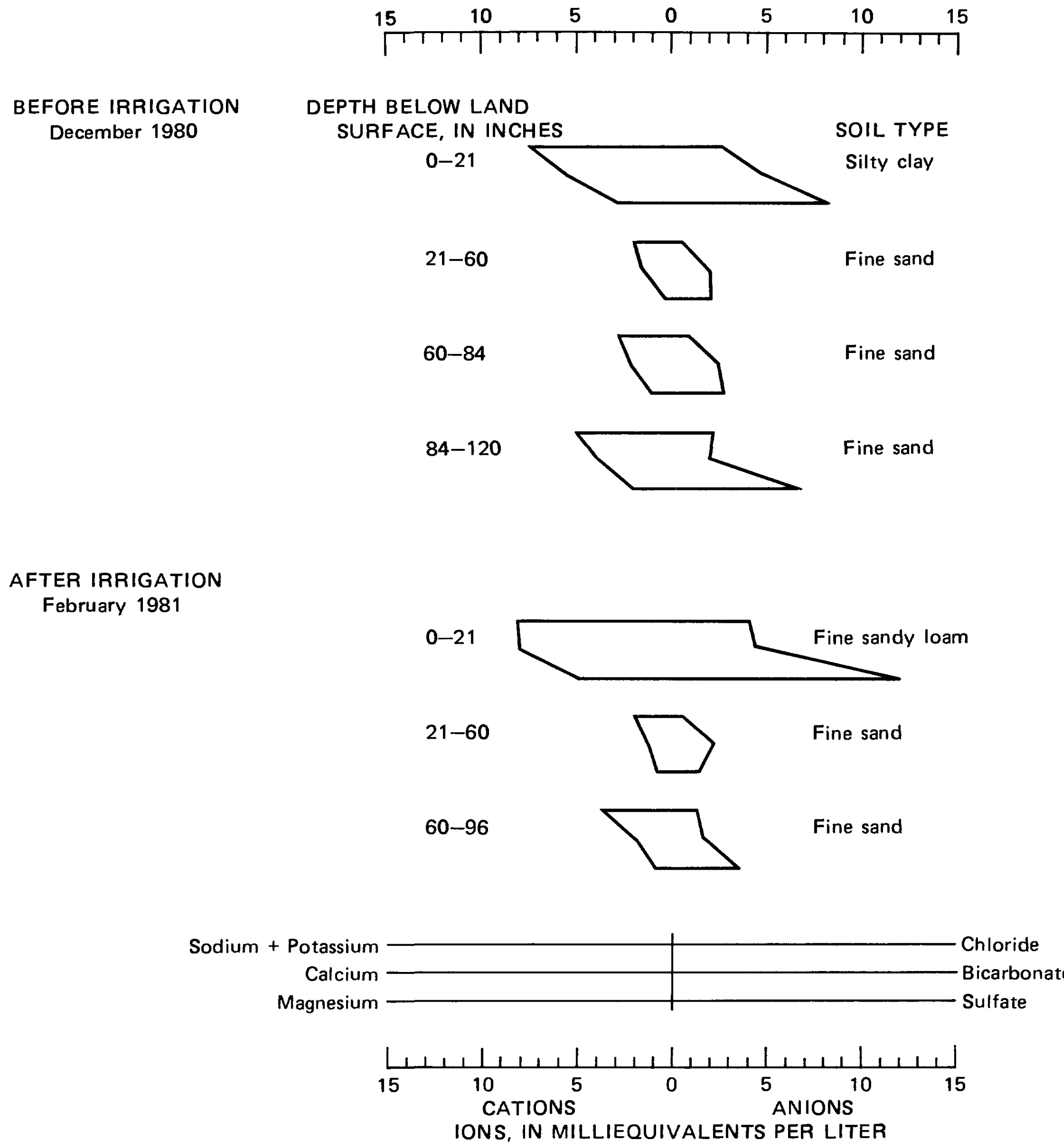
FIGURE 9. – Continued.



c. SOIL SITE 3

(Samples collected before and after test irrigation were not taken at precisely the same location)

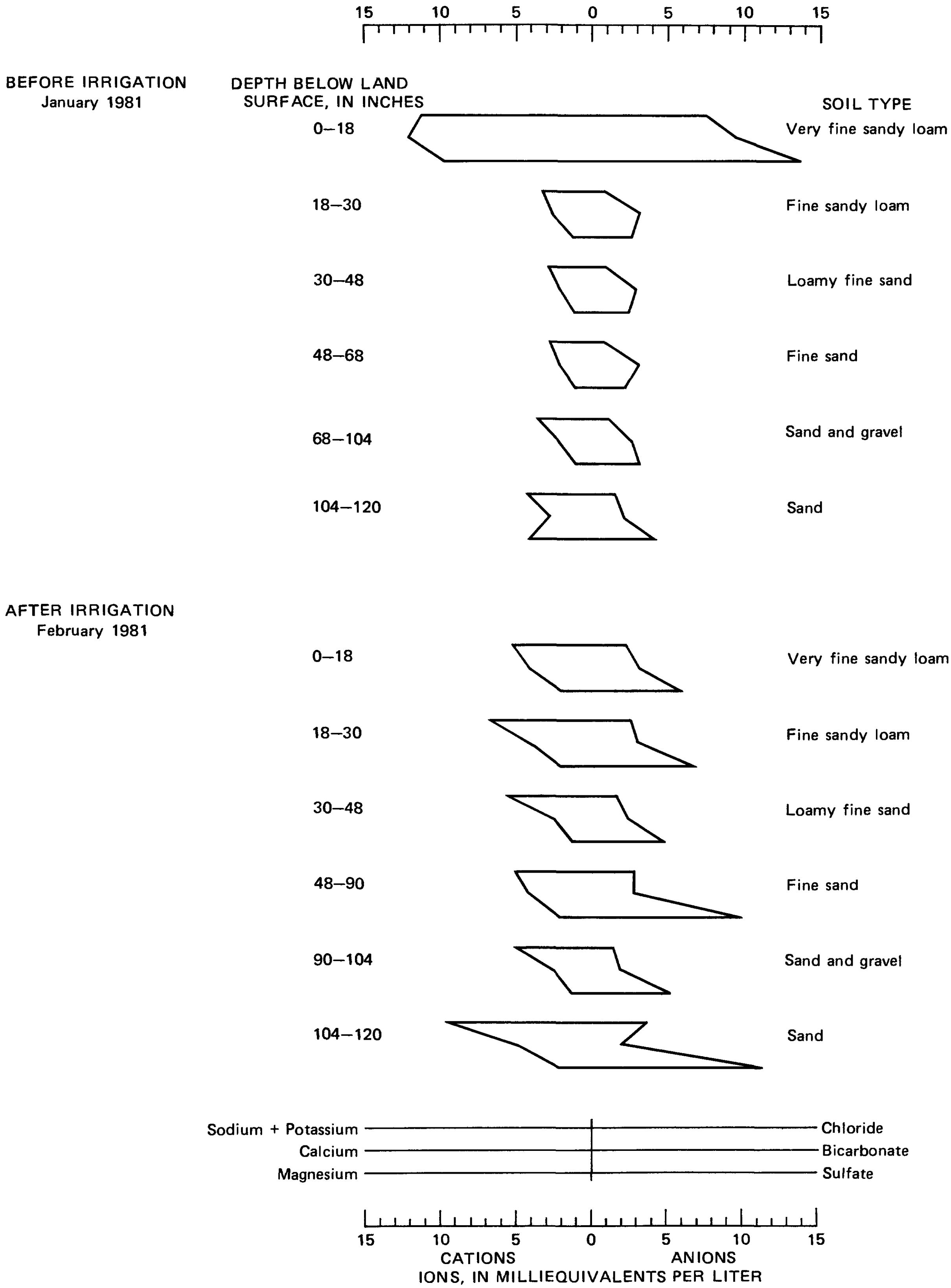
FIGURE 9. – Continued.



d . SOIL SITE 4

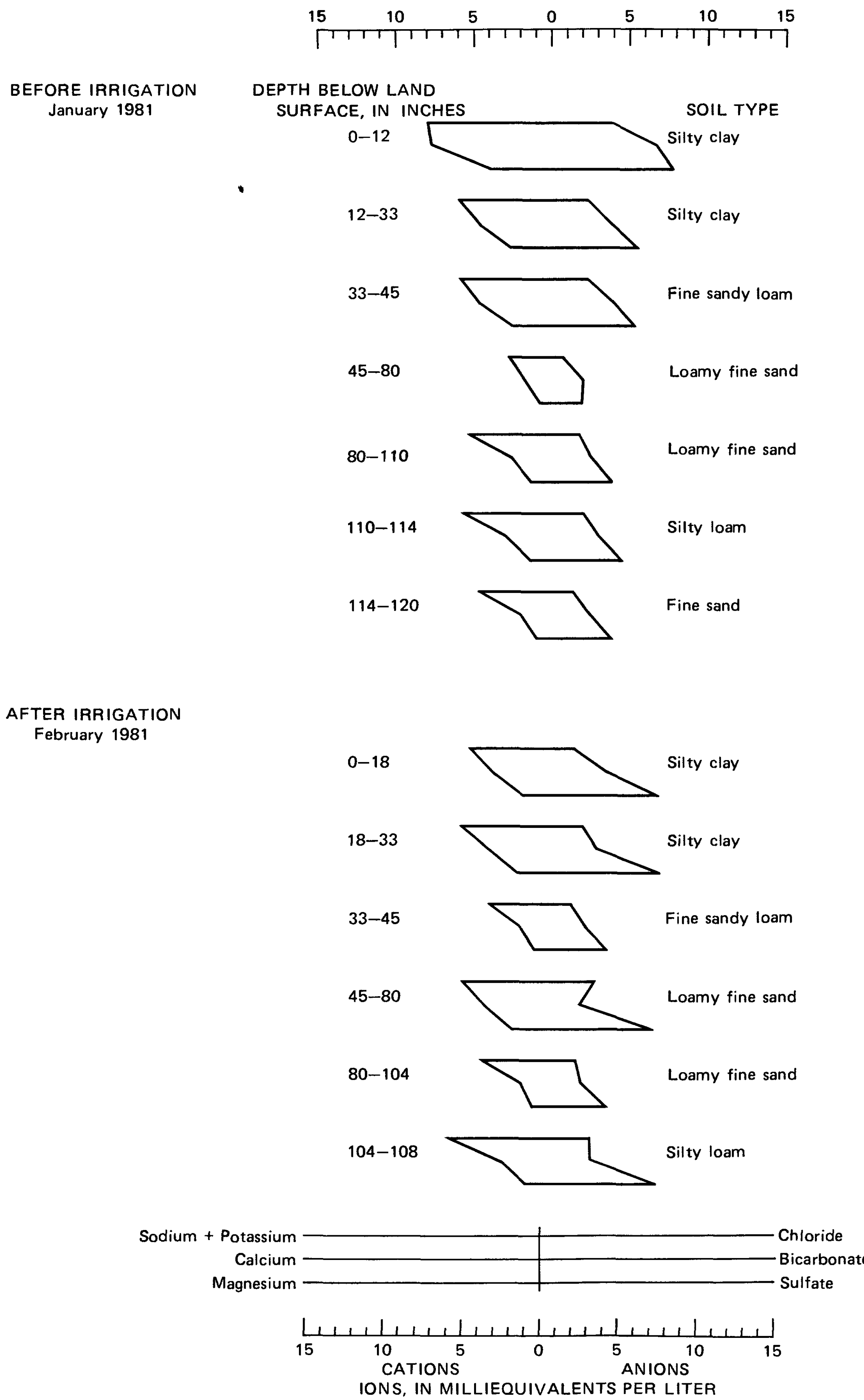
(Samples collected before and after test irrigation were not taken at precisely the same location)

FIGURE 9. – Continued.



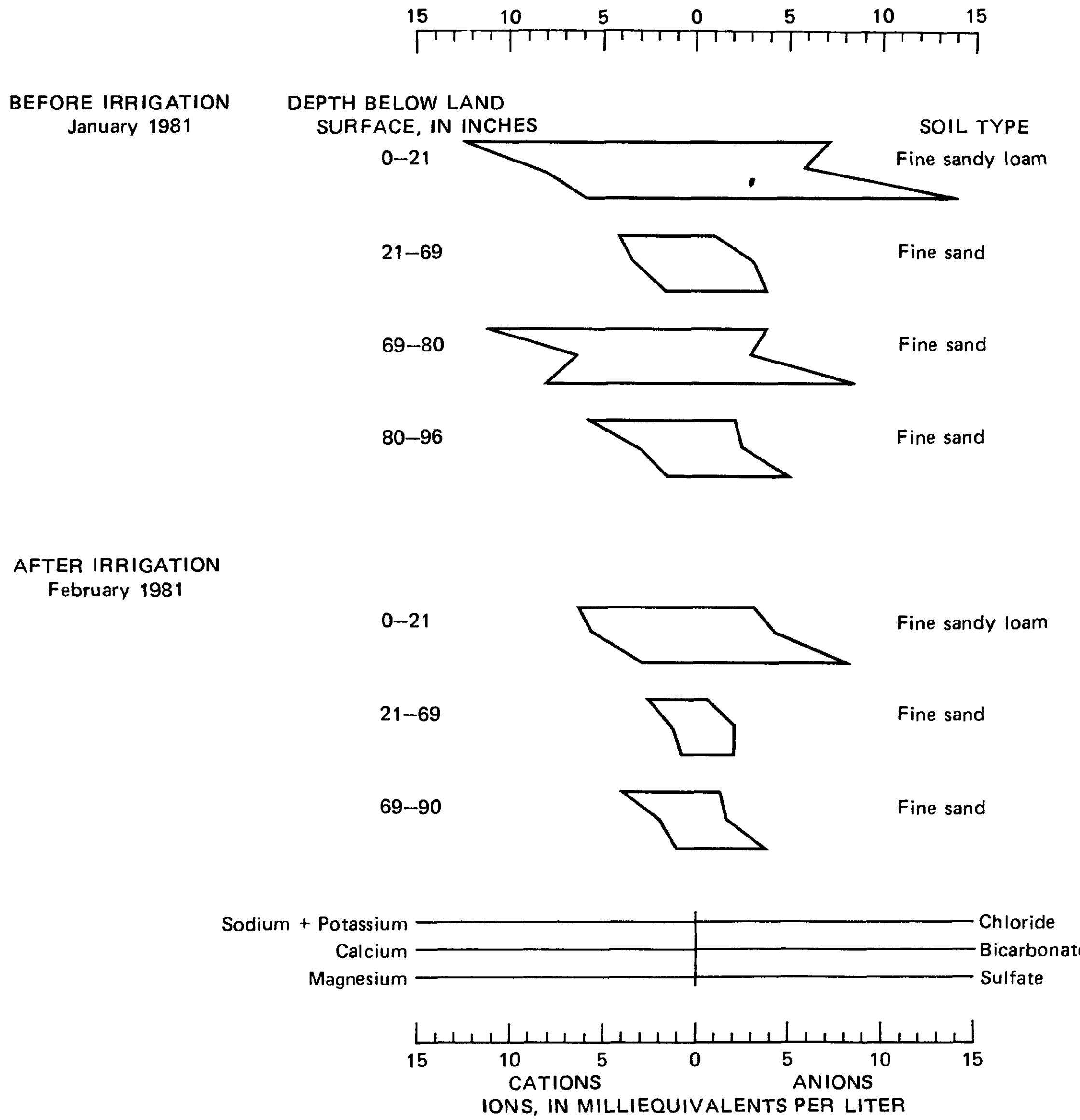
e . SOIL SITE 5

FIGURE 9. – Continued.



f. SOIL SITE 6

FIGURE 9. – Continued.



g. SOIL SITE 7

FIGURE 9. – Continued.

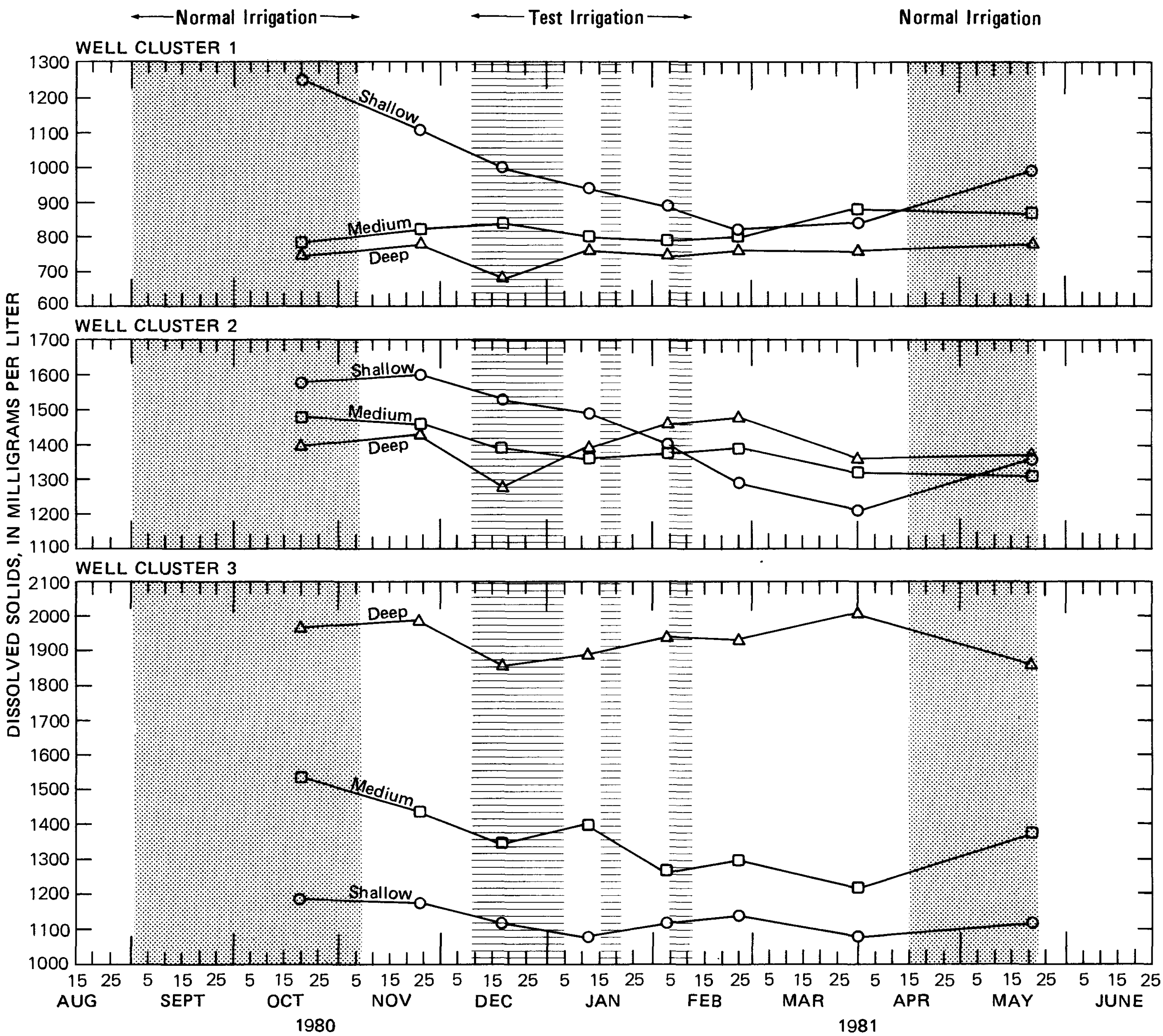
Ground-Water-Quality Changes

Changes in ground-water quality were monitored in the study area beginning in October 1980, during normal irrigation prior to the test, through May 1981, during normal irrigation following the test. Monitoring included eight periods of sampling, and analyses were performed by the U.S. Bureau of Reclamation laboratory at Boulder City, Nev. Figure 10 shows the changes in dissolved-solids concentrations for each well in the study area. The graphs show no consistent pattern of change among the data to indicate the effect that test irrigation had on the concentration of dissolved solids within the section of the aquifer studied. Other unsuccessful attempts to analyze ground-water-quality data included an evaluation of the areal variation and change with time of dissolved-solids concentrations, and an areal comparison of dissolved-solids concentrations with the soil distribution (fig. 3). Finally, changes in the mean values of dissolved-solids concentrations for all wells on the perimeter and within fields 115 and 117 (fig. 11a), where the most extensive irrigation took place, were compared with changes in mean dissolved-solids concentrations for all other wells monitored during the study (fig. 11b). Because of the limited amount of irrigation that took place on fields 123 and 127, and the distance of clusters 1, 2, 3, and 3A from fields 115 and 117, clusters 1, 2, 3, and 3A were included along with cluster 9, north cluster, and south cluster as controls for background data.

Figure 11a shows that the net change in mean dissolved-solids concentrations between the sampling prior to and immediately following the test was a slight decrease in the shallow wells, a significant decrease in the medium wells, and a significant increase in the deep wells. Figure 11b shows a significant decrease in the shallow, medium, and deep wells between the sampling periods. Comparison of the figures suggests that the test irrigation may have flushed salts from the soil and the upper part of the aquifer to the lowest part of the aquifer in the study area, indicating that the flushing method may be an effective means of salinity reduction in the uppermost zones. The data, however, are merely suggestive of salt flushing beneath fields 115 and 117. The interruptions in the test irrigation that occurred and the variations in the fields that were irrigated made any more definitive conclusions impossible.

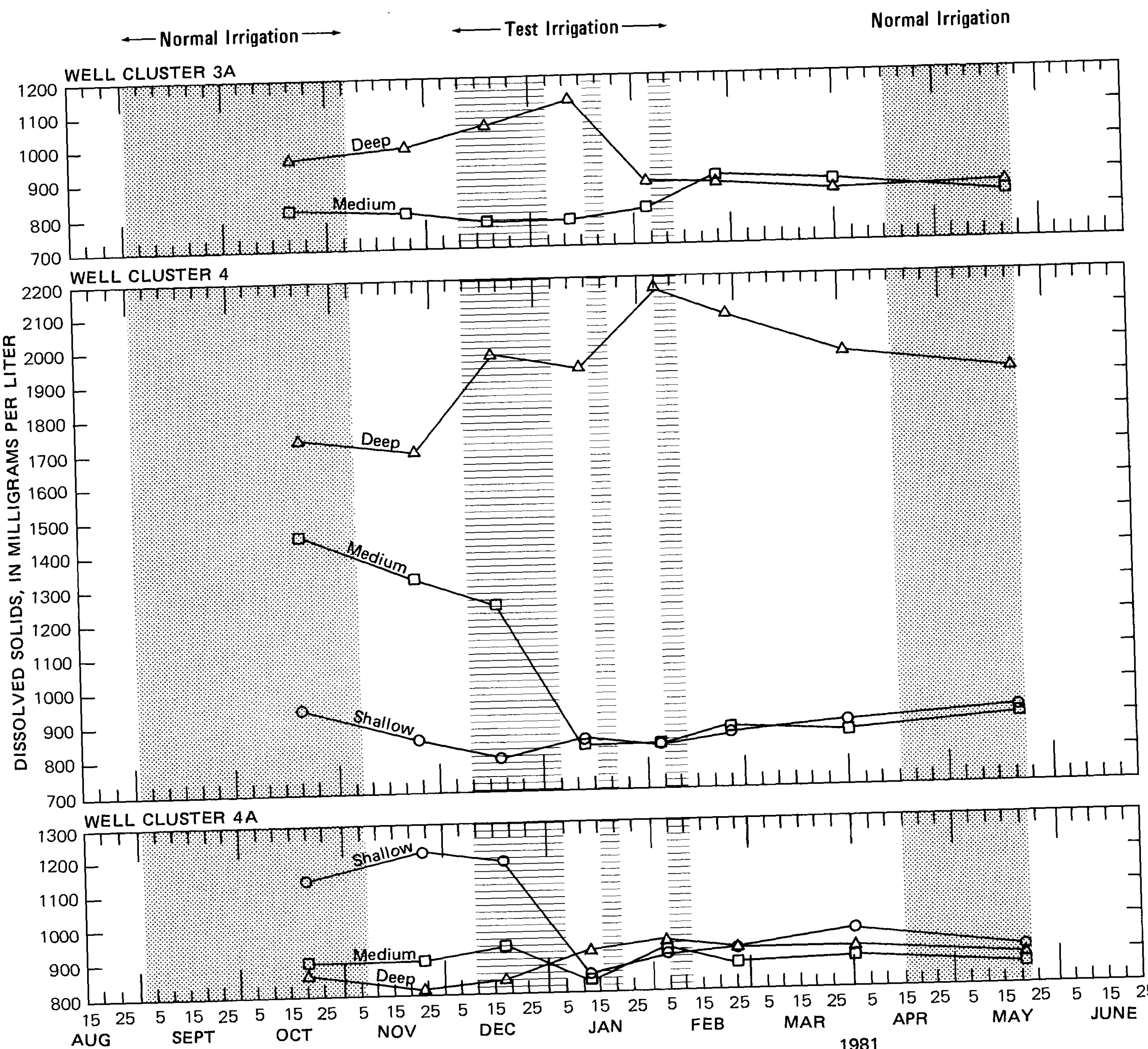
Source for the Quality Changes Between Irrigation and Drain Water

A comparison of stiff diagrams (fig. 12) shows that as irrigation water moves through the soil and ground-water system to the drain system in the Palo Verde subarea, it not only increases in dissolved solids, but its chemical characteristics also change. During the study, all irrigation-water samples collected from the Colorado River diversion canal near well cluster 6 (fig. 2) had a mean value of 761 mg/L of dissolved solids and were a sodium calcium magnesium sulfate type. For all water samples collected from the drain during the study, the mean dissolved-solids concentration was 2,050 mg/L, and the water type was sodium chloride sulfate. Sodium and chloride showed the largest increases in concentration when comparing irrigation water to drain water.



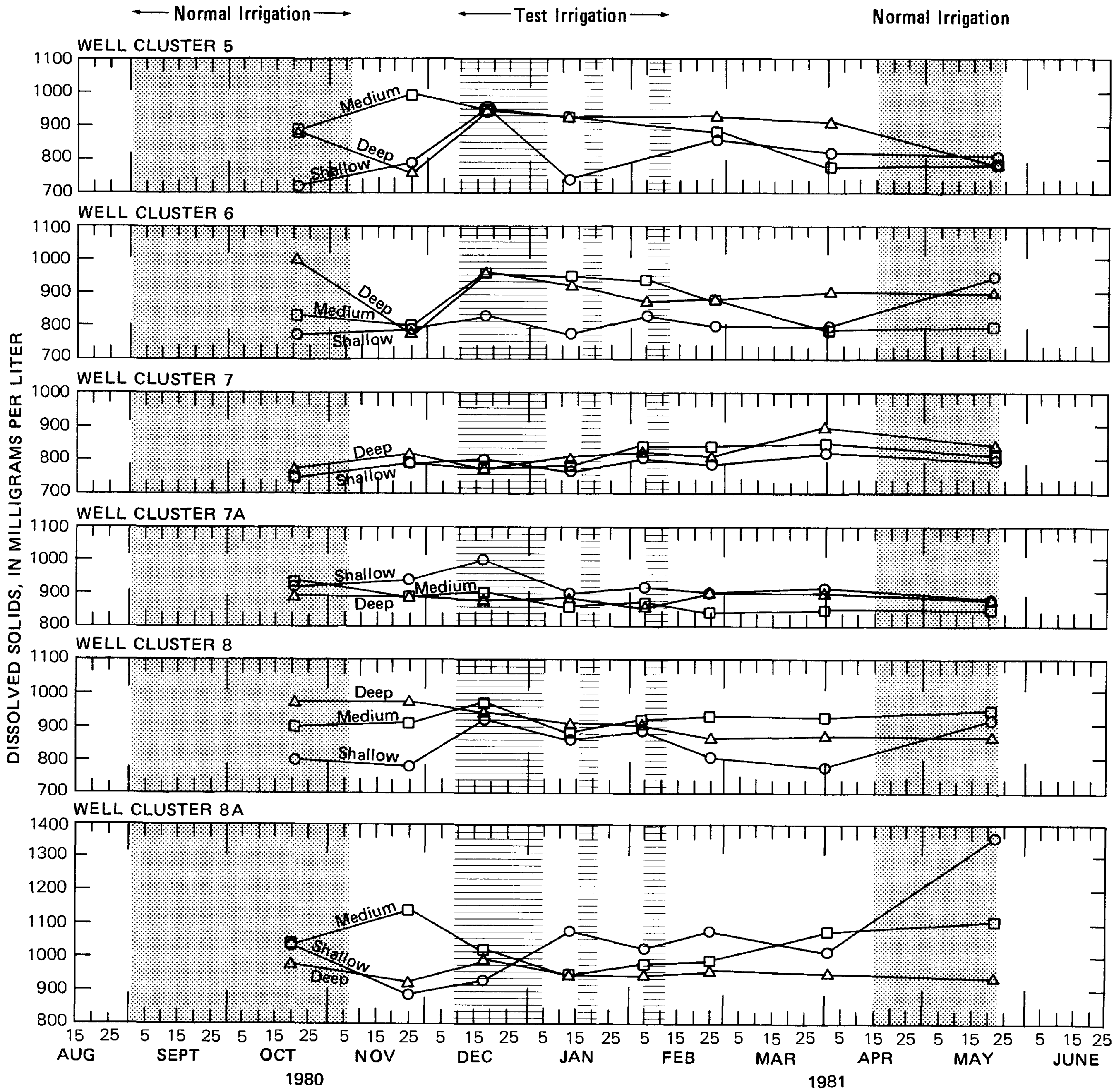
a. CLUSTERS 1–3

FIGURE 10. – Fluctuations in dissolved-solids concentrations (residue at 180° Celsius).



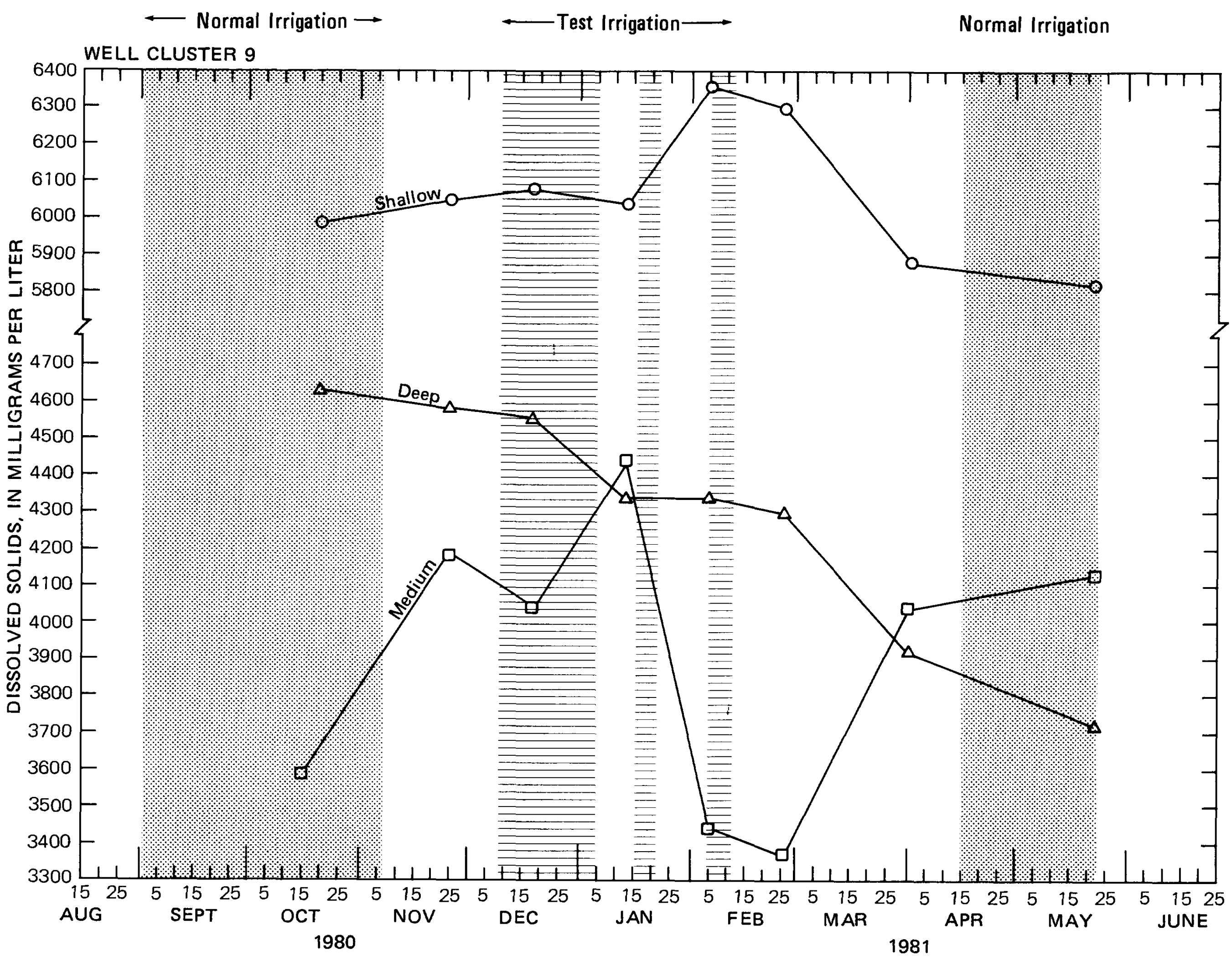
b. CLUSTERS 3A–4A

FIGURE 10. – Continued.



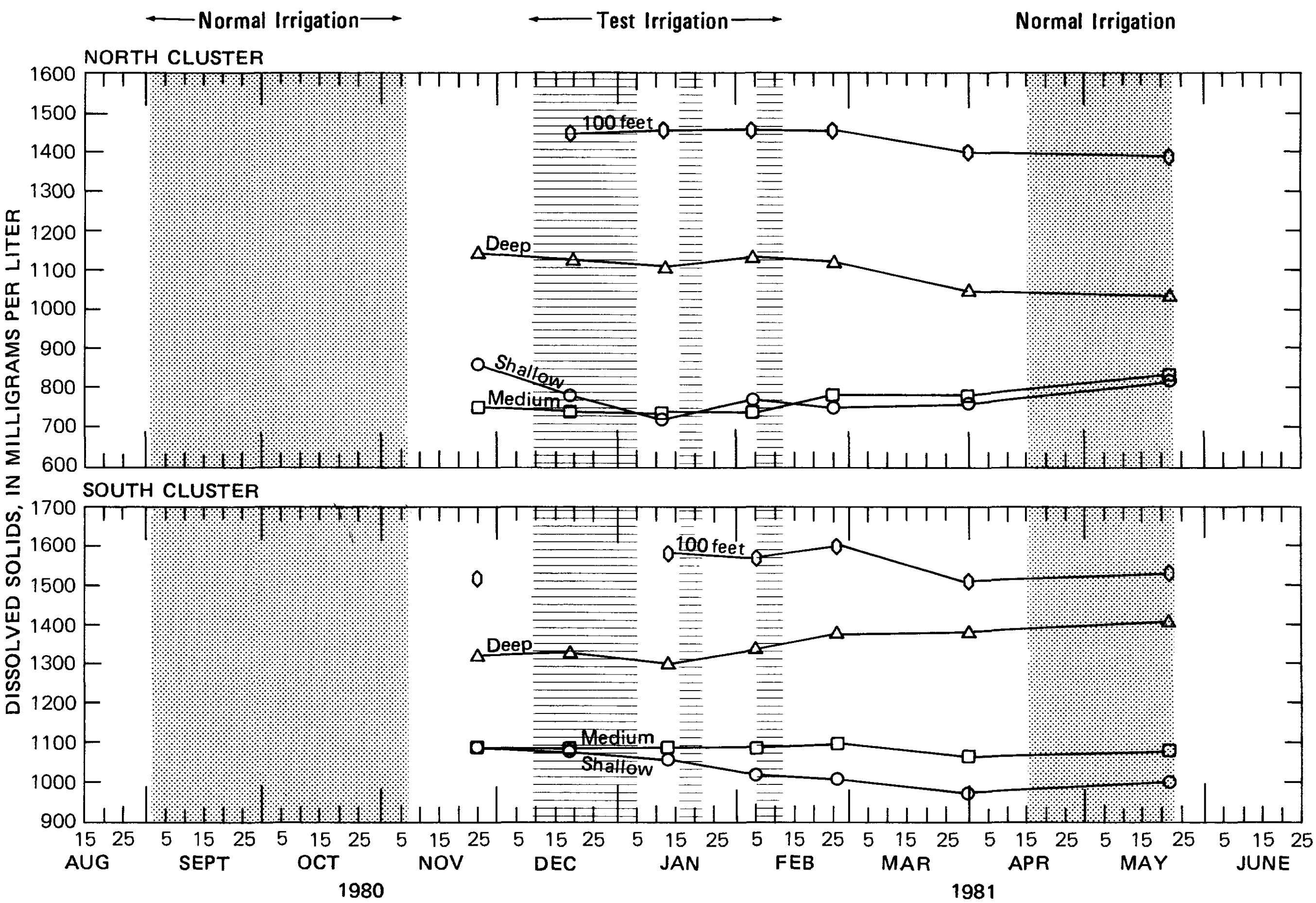
c. CLUSTERS 5–8A

FIGURE 10. – Continued.



d. CLUSTER 9

FIGURE 10. – Continued.



e. NORTH CLUSTER, SOUTH CLUSTER

FIGURE 10. – Continued.

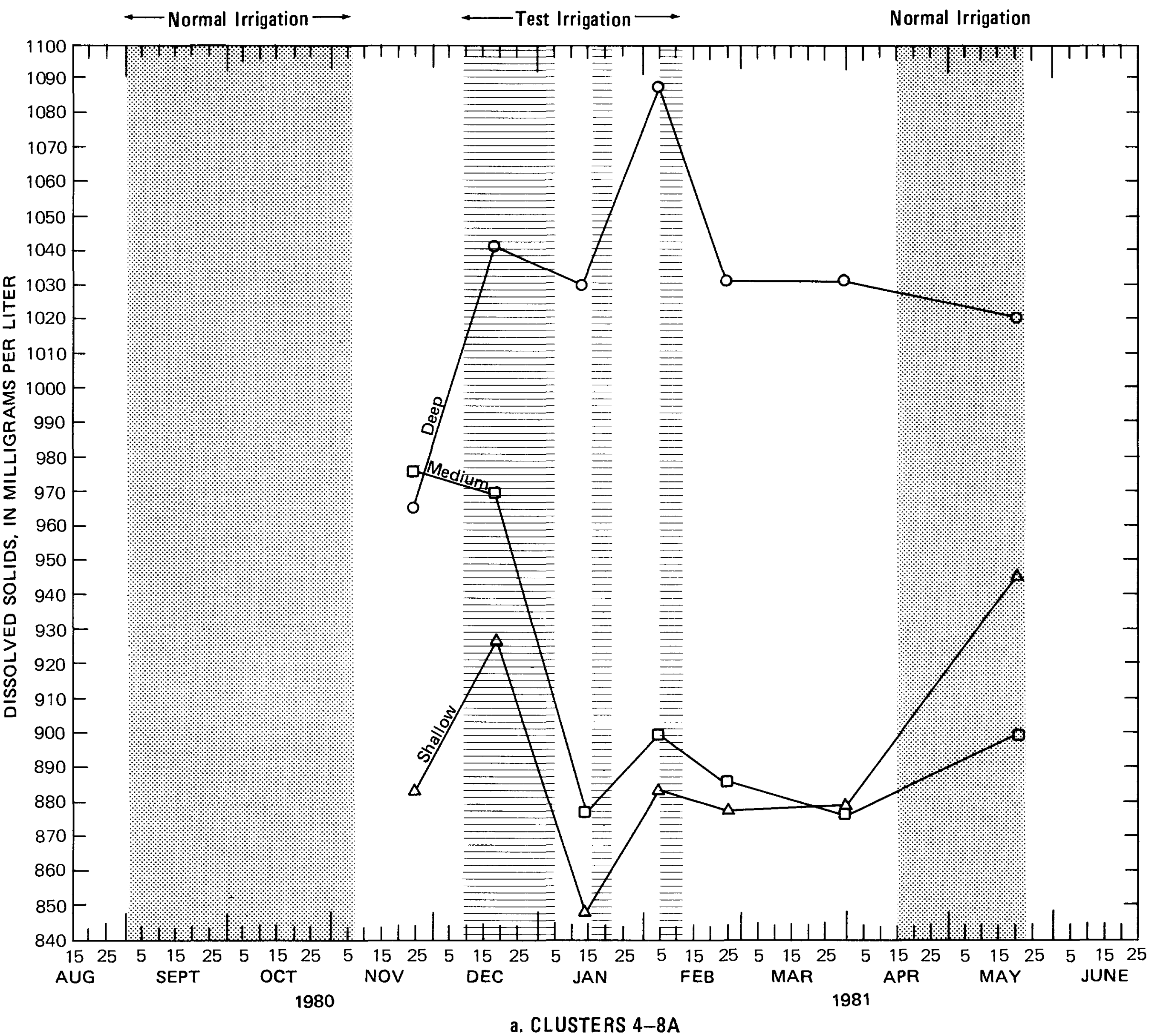
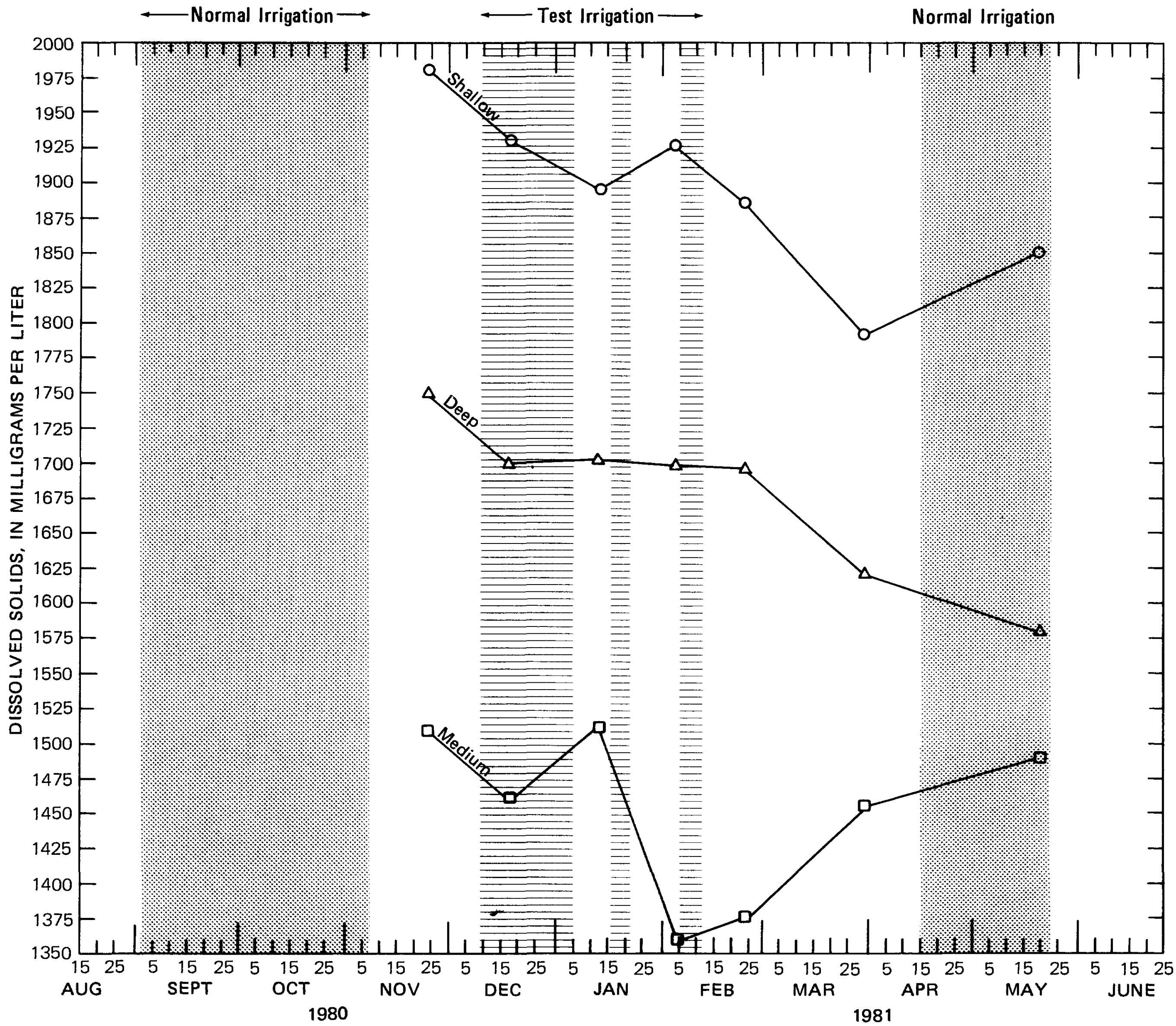


FIGURE 11. – Fluctuations in mean dissolved-solids concentrations, in the shallow, medium, and deep wells.



b. CLUSTERS 1–3A, 9, NORTH CLUSTER, SOUTH CLUSTER

FIGURE 11. – Continued.

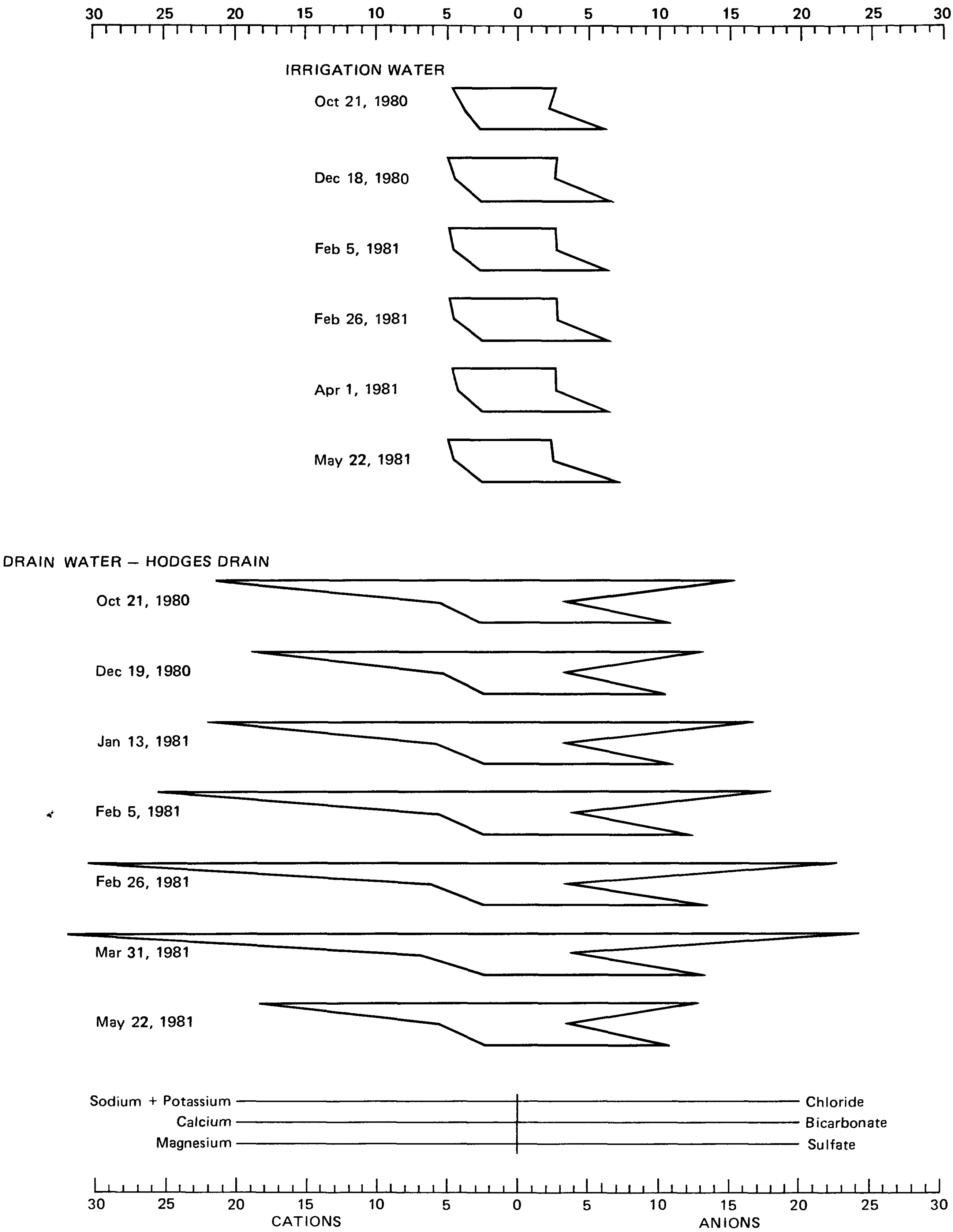


FIGURE 12. – Stiff diagrams showing chemical characteristics of irrigation-water and drain-water samples, October 1980 to May 1981.

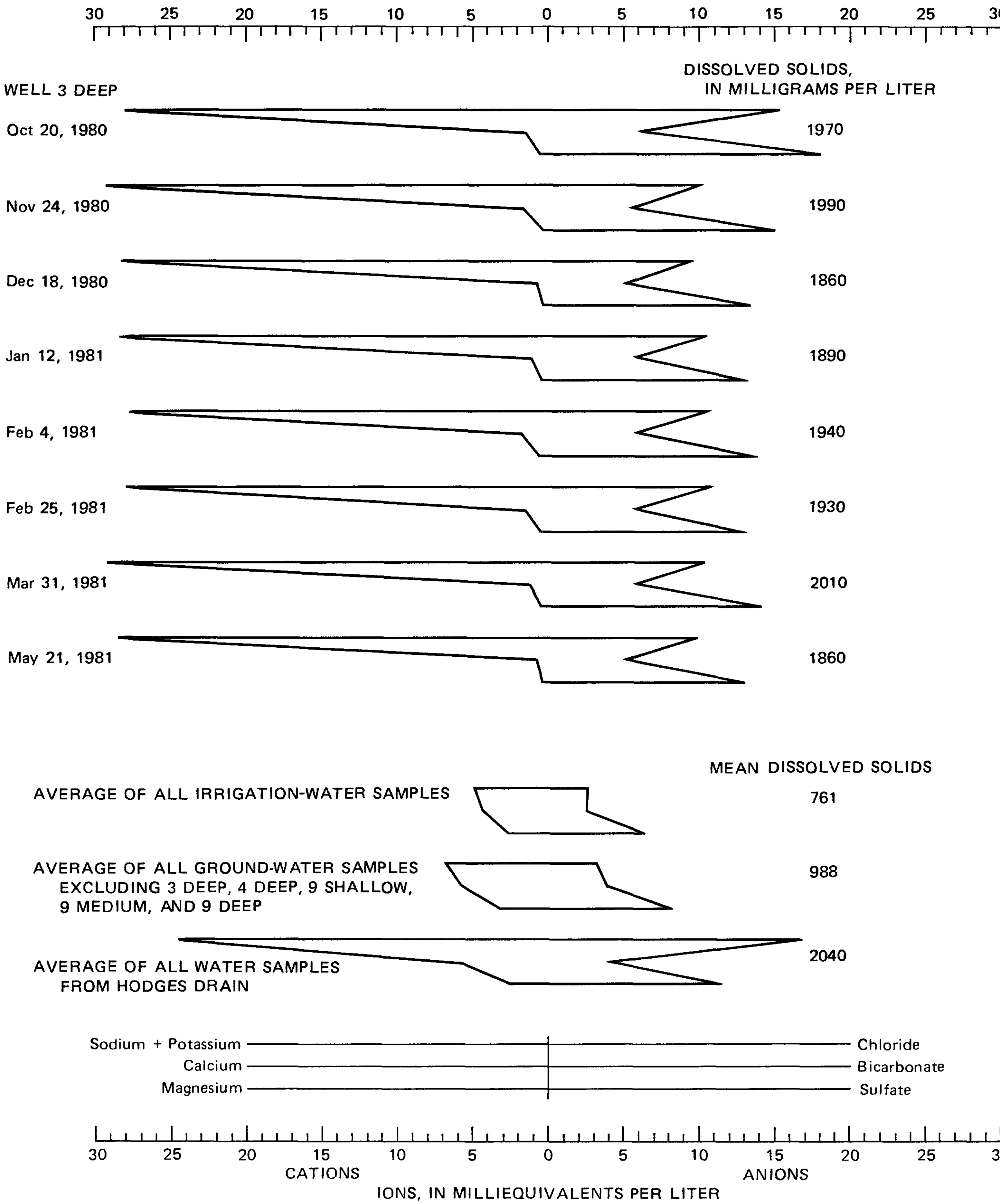
The chemical characteristics of irrigation and drain water were compared with those of solutions extracted from soil samples (fig. 9 and table 4 and 5) and ground-water samples (fig. 13) to determine if any sources of sodium and chloride were available to account for the increases observed between the irrigation and drain water. Certain clayey soils from site 2 (fig. 9b and tables 4 and 5) were considered possible sources of the increases. Dissolved-solids concentrations in extracts from this site were as high as 10,700 mg/L, and the water was a sodium sulfate chloride type, similar to the drain water.

The chemical characteristics of water from wells 3 deep, 4 deep, and 9 shallow, medium, and deep (fig. 13) were also similar to that of the sodium chloride sulfate type water from Hodges Drain. Water from these wells was higher in concentrations of dissolved solids than water from most of the monitor wells, ranging from 1,700 mg/L in well 4 deep to 6,360 mg/L in well 9 shallow (see average of all ground-water samples excluding wells 3 deep and 4 deep, and the wells in cluster 9 in fig. 13), and was a sodium sulfate chloride or sodium chloride sulfate type; generally, sodium calcium magnesium sulfate type water was found in the other wells. Wells 3 deep, 4 deep, and all the wells in cluster 9 were suspected of being screened in silty clay zones because of their similar water type to solutions extracted from the silty clay zones at soil site 2 and their low water production during sampling. In fact, recharge of well 4 deep was so slow that after water was cleared from the well a full sample could not be obtained until the following day after a sufficient volume of water had entered the well.

These data suggest that silty clay zones, rich in sodium, chloride, and sulfate, may contribute the largest amount of salts to the drain system in the Palo Verde subarea. Further testing for the salinity characteristics and the distribution of silty clay in the soil and aquifer would be necessary to confirm this hypothesis.

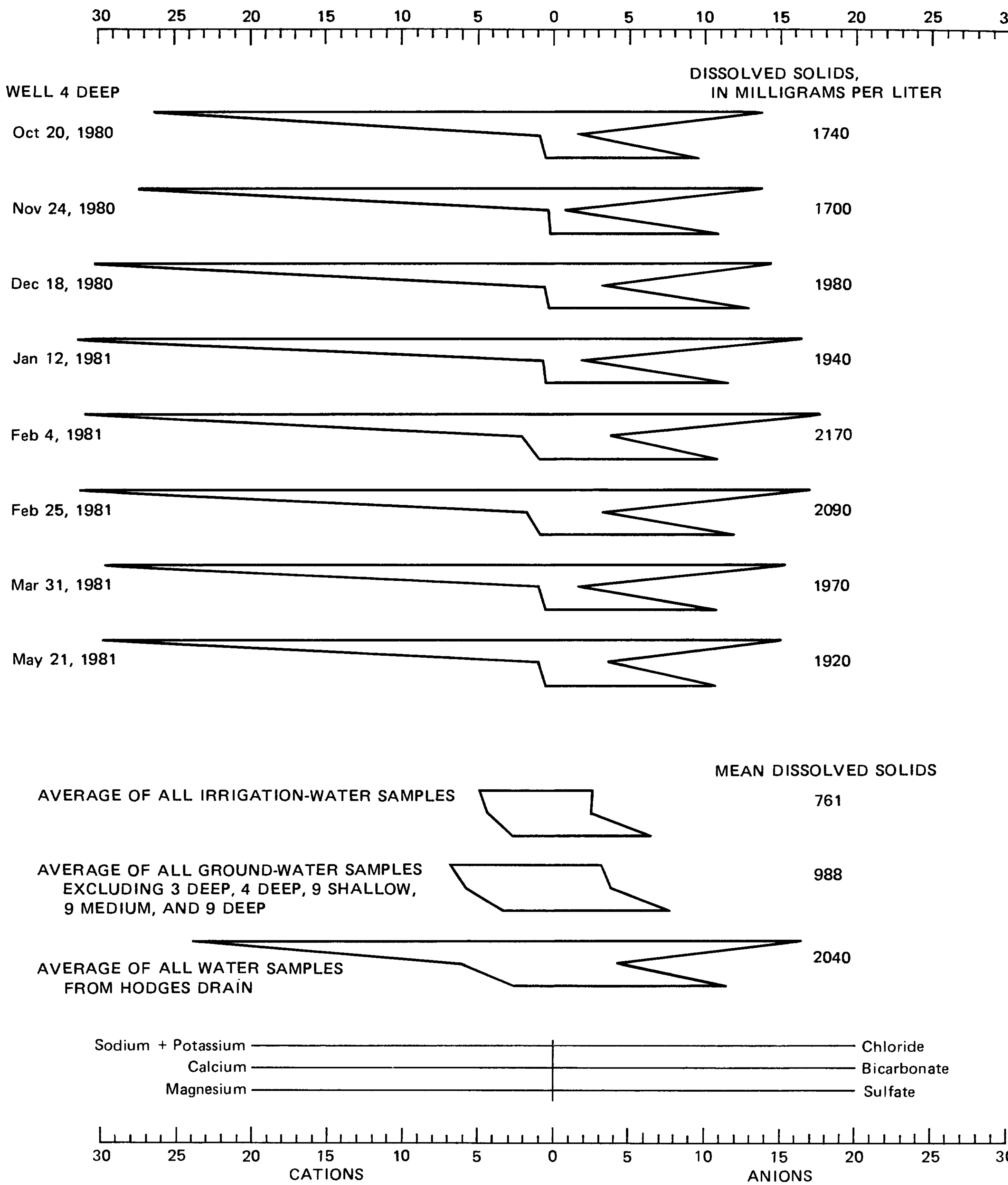
Feasibility of the Irrigation Method of Salinity Reduction

Although test data suggest that excessive irrigation may have increased the downward movement of salt within the soil and upper part of the aquifer, further testing of the method is not planned. The Palo Verde Irrigation District determined that the method is not practicable within the district because of the bank collapses that resulted from the increased ground-water discharge to the drain system. Similar occurrences of collapsing drain-system banks in the Palo Verde Irrigation District resulted in the ban of rice production in the district more than 25 years prior to this study (Gerald Davisson, Palo Verde Irrigation District, oral commun., 1981). The swampy environment maintained in rice paddies is similar to the soil environment created by the irrigation during this test.



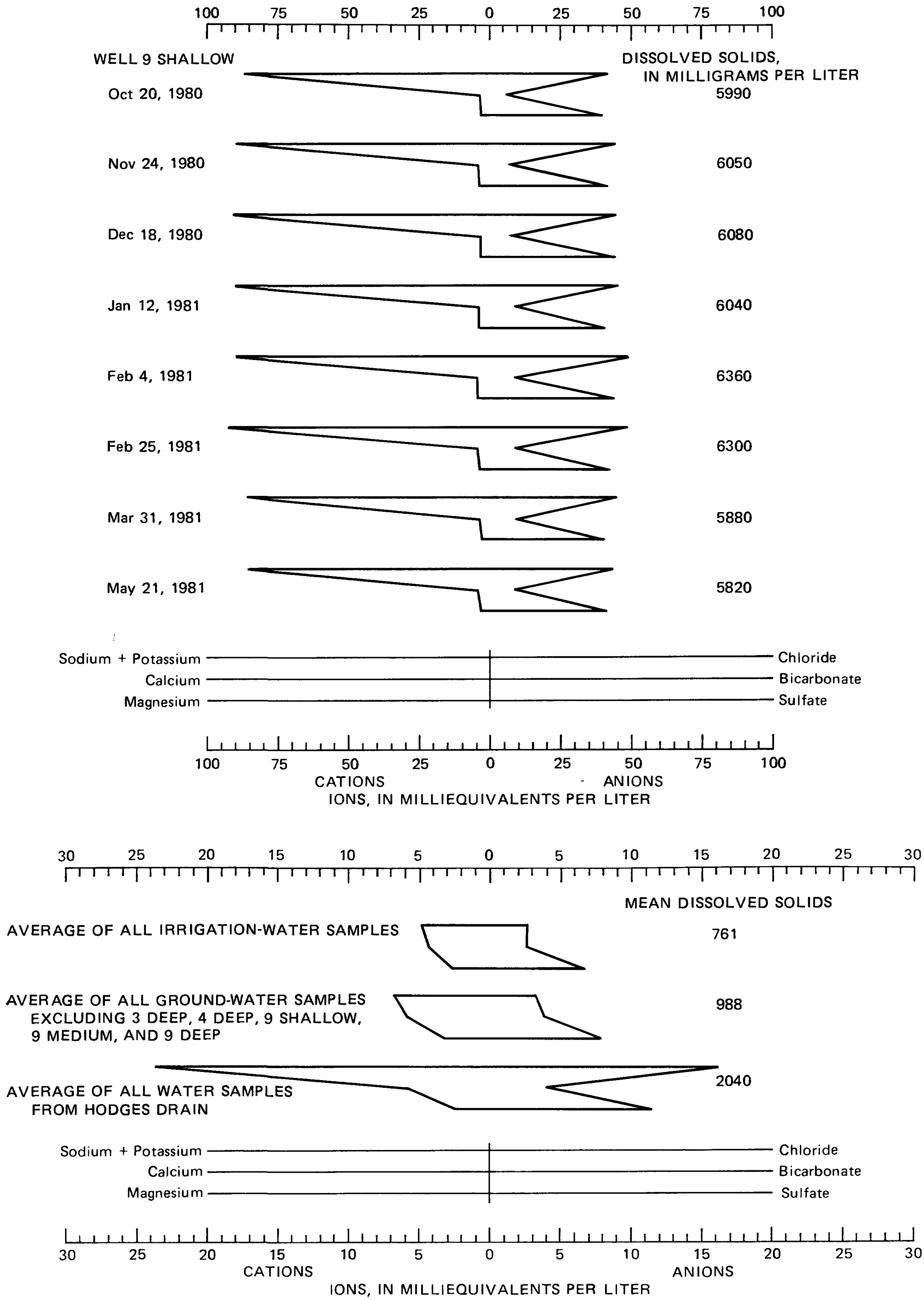
a. WELL 3 DEEP

FIGURE 13. – Stiff diagrams comparing chemical charateristics of water from selected wells with average chemical characteristics of irrigation-water samples; ground-water samples, excluding 3 deep, 4 deep, 9 shallow, medium, deep; and Hodges Drain water samples; October 1980 to May 1981.



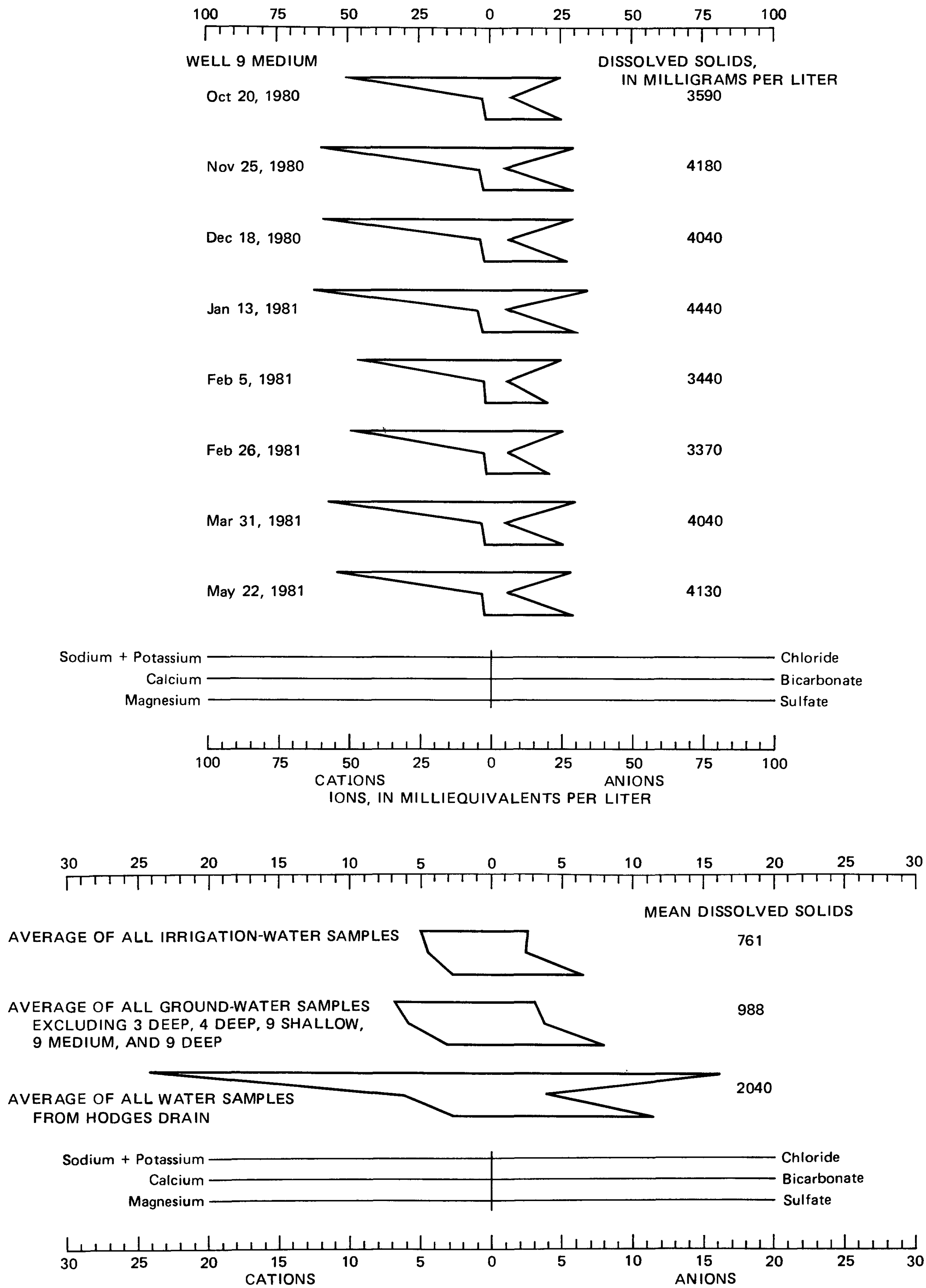
b. WELL 4 DEEP

FIGURE 13. – Continued.



c. WELL 9 SHALLOW
Note scale difference from other sites.

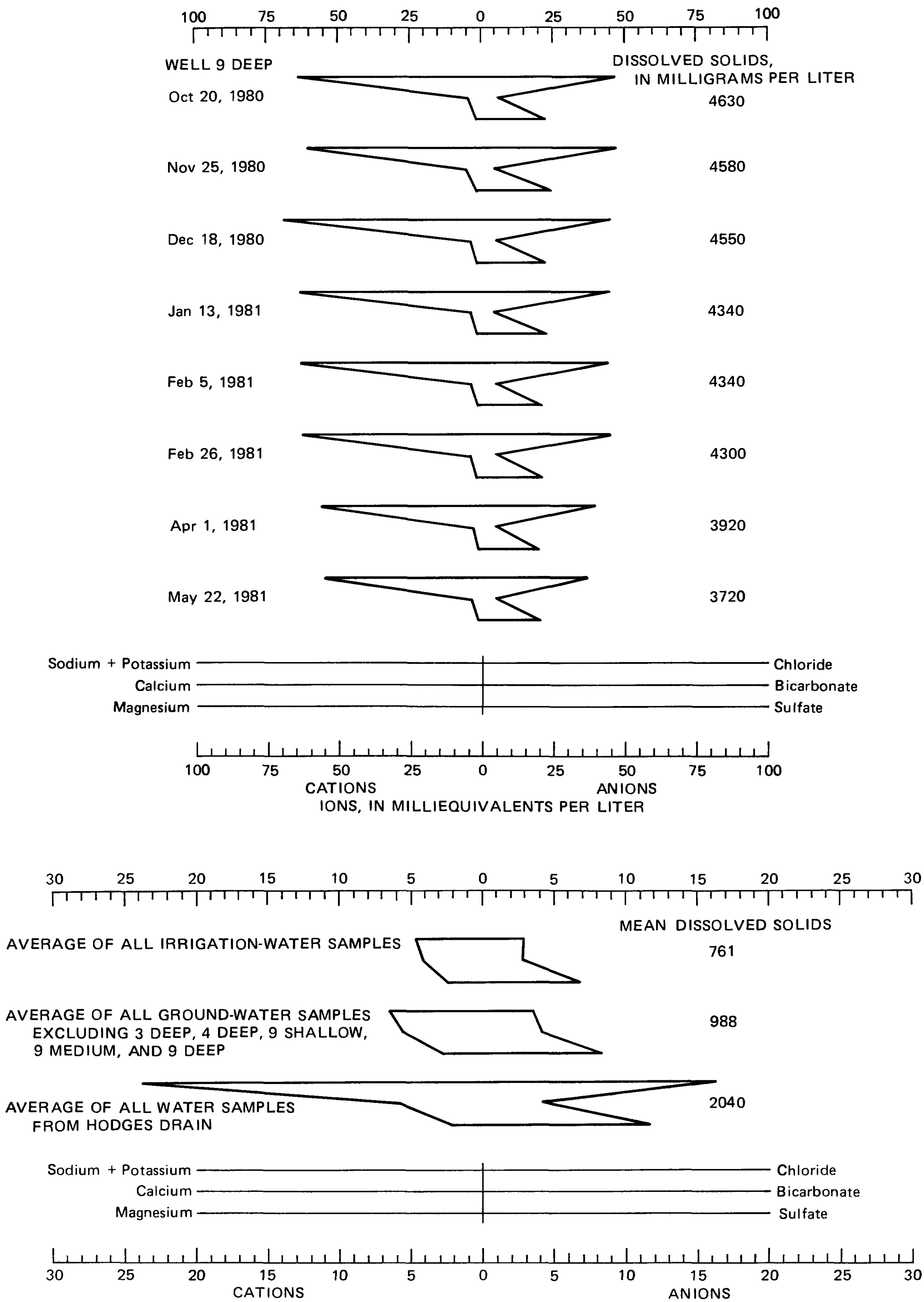
FIGURE 13. – Continued.



d. WELL 9 MEDIUM

Note scale difference from other sites.

FIGURE 13. – Continued.



e. WELL 9 DEEP
Note scale difference from other sites.

FIGURE 13. – Continued.

SUMMARY AND CONCLUSIONS

The Federal Water Pollution Control Act (Public Law 92-500) has mandated control of salinity along the Colorado River. At Imperial Dam the standard for concentrations of dissolved solids, as set by the U.S. Environmental Protection Agency, is 879 mg/L. Planned increases in river-water use for irrigation have created the concern that dissolved-solids concentrations at Imperial Dam could reach 1,140 mg/L by the year 2000 if controls on salt discharges to the river are not initiated. One method of control proposed in the Palo Verde Irrigation District was the accelerated flushing of salts from soil and the aquifer through periodic excessive irrigation of fallow farmland. If feasible, the method could be used until 1985, when diversions of Colorado River water to the Central Arizona Project are to begin. Decreasing ground-water and soil salinity before 1985 could reduce the amount of salts available for flushing in subsequent years. This salt reduction could mitigate the effects of the Central Arizona Project diversions on the river's diluting ability, thereby aiding the control of river salinity.

The test to determine the effectiveness of the excess irrigation method as a means for salinity reduction was conducted on a 311-acre tract on the western border of the Palo Verde subarea of the Palo Verde Irrigation District. The subarea was selected because it has been reported as one of the top three contributors of salts from the district to the Colorado River.

The irrigation test, although planned for 3 months of daily irrigation of all fields within the test tract, did not proceed according to schedule, and all fields were not simultaneously irrigated. The test actually proceeded for 28 consecutive days on about half of the tract (the northern two fields) when the test was interrupted for 10 days by a discontinuation of flow in the diversion canal for annual canal maintenance. Irrigation resumed on all of the tract, but after 7 days it was once again interrupted because of bank collapses in Hodges Drain. After a 13-day break, irrigation resumed once more, this time on the central half of the tract, and after 7 days was discontinued permanently because of more extensive bank collapses within Hodges Drain. The bank collapses were presumed to have been caused by the increased ground-water discharges to the drain system.

The discontinuous nature of the irrigation test resulted in a modification of the approach to data analyses so that an attempt could be made to determine the effectiveness of the excessive irrigation method for salinity control. The northern two fields of the tract, where 28 consecutive days of irrigation took place, were considered the new test area, and the other monitored areas were considered background or control areas. Data from the 24 wells surrounding the northern two fields were compared with data collected from the other parts of the study area.

Analyses of soil samples collected before and after test irrigation showed that soil textures and salinities varied greatly horizontally and vertically within the 311-acre tract. This variation made a comparison of samples collected before and after the test from the northern two fields impossible because resampling locations could not be precisely replicated, which resulted in different sequences of soils being encountered. Sampling sites in the southern two fields were identically located, and the samples did indicate some downward movement of salts within the soil zone.

Changes in concentrations of dissolved solids in the ground water did not show a consistent pattern of increase or decrease with time among wells in and around the northern two fields of the tract and in other wells within the study area. Therefore, changes in mean dissolved-solids concentrations in water from wells around the northern two fields were compared with water from the other wells monitored in the study area. A difference between the two sets of wells was noted. In water from the 15- and 25-foot deep wells surrounding the northern two fields, decreases in the means of dissolved-solids concentrations were noted between the last sampling prior to and the first sampling after test irrigation. The wells that were 40 feet deep showed an increase in mean dissolved-solids concentrations during the same period. The means of dissolved-solids concentrations for the other wells monitored in the study area showed decreases in the 15-, 25-, and 40-foot deep wells for the period. These data suggest that the irrigation on the northern two fields may have caused the movement of salts from within the soil and upper part of the aquifer into the lowest part of the aquifer that was monitored during the test.

In a comparison of water-quality characteristics of irrigation water, solution extracts from soil samples, ground water, and water from Hodges Drain, a similarity was noted among extracts from certain silty clays, ground water from several low-producing wells (screened in suspected clayey zones), and water from Hodges Drain. The study revealed that the dissolved-solids concentration of irrigation water averaged about 760 mg/L during the study and was a sodium calcium magnesium sulfate type, whereas Hodges Drain water averaged about 2,050 mg/L and was a sodium chloride sulfate type. Solution extracts from certain silty clays had a dissolved-solids concentration as high as 10,700 mg/L and were a sodium sulfate chloride type, similar to Hodges Drain water. Water from several low-producing wells was either a sodium chloride sulfate or sodium sulfate chloride type, also similar to the Hodges Drain water, and had a dissolved-solids concentration as high as 6,360 mg/L in well 9 shallow. These data may suggest that silty clay zones which are rich in sodium, chloride, and sulfate, may contribute the largest amount of salts to the drain system in the Palo Verde subarea. Further testing for the salinity characteristics and distribution of silty clay within the soil and aquifer would be necessary to confirm this hypothesis.

Because of bank collapses in Hodges Drain, which resulted from the increased ground-water discharges to the drain system, the Palo Verde Irrigation District determined that the irrigation method for salinity control is not practicable within the district. Therefore, no further testing of the method is planned.

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