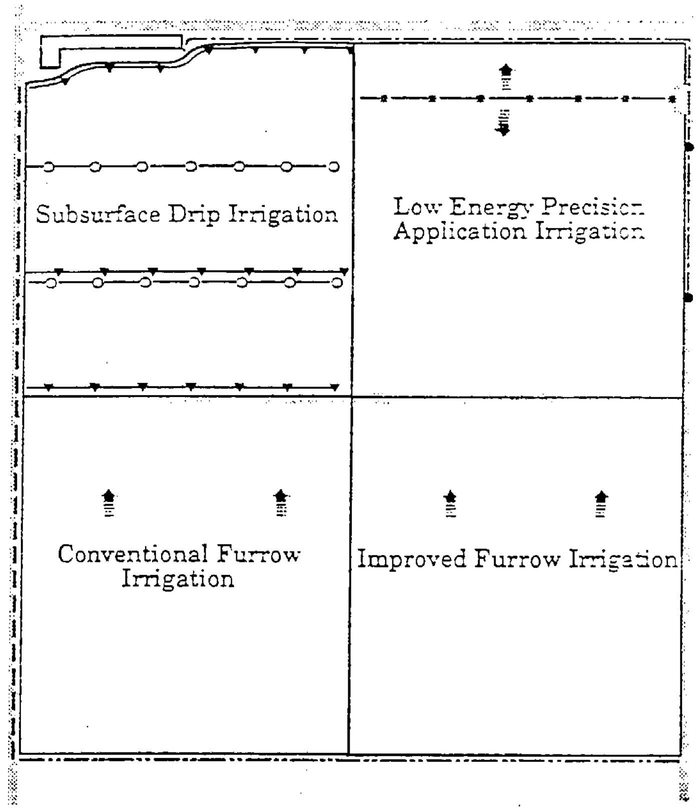

DEMONSTRATION OF EMERGING IRRIGATION TECHNOLOGIES

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JULY 1992

STATE WATER RESOURCES CONTROL BOARD
CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

FINAL REPORT

TO THE

STATE WATER RESOURCES CONTROL BOARD

ON THE

EMERGING IRRIGATION TECHNOLOGIES PROJECT

JULY 1991

Prepared by
Water Conservation Office
Department of Water Resources
Sacramento, California

for

Division of Water Quality

State Water Resources Control Board
State of California

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EMERGING IRRIGATION TECHNOLOGIES PROJECT
JULY 1991

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EXECUTIVE SUMMARY

1. PURPOSE

Shallow ground water accretions because of deep percolation resulting from irrigation may cause the water table to rise and impact a crop's root zone. Subsurface drains have been installed in many agricultural fields on the west side of the San Joaquin Valley to lower the shallow ground water table, while at the same time providing a means for leaching the crop root zone. The objective of this demonstration project was to evaluate subsurface drip, low-energy precision application (LEPA), improved furrow and conventional furrow irrigation technologies in reducing deep percolation and the feasibility of these technologies.

2. BACKGROUND INFORMATION

A 160 acre demonstration site in western Fresno County was subdivided into four 40-acre plots. There was one plot for each of four irrigation technologies: subsurface drip, low-energy precision application, improved furrow and conventional furrow irrigation. Cotton was planted both years in all four plots.

A demonstration project was conducted to evaluate the amount of irrigation water applied, the volume of deep percolation produced and study the feasibility of the four irrigation systems. This report was written after the second year of the project to present to the State Water Resources Control Board (State Board). The project will continue for a total of five years.

3. FINDINGS

Some findings of this study are:

a. The majority of the deep percolation occurred during the pre-irrigation and the first irrigation of each growing season according to the individual irrigation system evaluations. Pre-irrigation was performed with hand-move sprinkler and furrow irrigation systems both years. Seasonal irrigations were performed with the respective irrigation technology. Approximately half of the deep percolation for the subsurface drip, improved furrow and conventional furrow systems occurred during the first two irrigations for both years. The volume of deep percolation was the greatest for the conventional furrow system during both years. Reduction in the amount of the water applied during the pre-irrigation and the first season irrigation has the greatest potential to reduce the amount of agricultural drainage.

b. Deep percolation from each irrigation system was estimated three different ways in this study. Deep percolation was not measured in this study. Boyle Engineering estimated deep percolation during each irrigation event by irrigation system evaluation, given in Tables 7 - 14 of this report. Boyle Engineering also estimated the deep percolation by seasonal water balance calculations, given in Tables 19 and 20 of this report. The Department of Water Resources estimated deep percolation by more refined seasonal water balance calculations, also given in Tables 19 and 20 of this report. The three methods estimated different volumes of deep percolation from each irrigation system.

c. In 1989, zero deep percolation was estimated for the LEPA system, while at least 0.16 acre-feet per acre of deep percolation was estimated by the Department of Water Resources for the other three irrigation systems. In 1990, 0.14 acre-feet per acre of deep percolation was estimated for the improved furrow system, while at least 0.35 acre-feet per acre of deep percolation was estimated by the Department of Water Resources for the other three irrigation systems.

d. Cotton irrigated with the subsurface drip system used the least applied water during 1989. (The LEPA system had mechanical problems and unintentionllay applied less water than the subsurface drip system.) Cotton irrigated with the improved furrow system used the least applied water during 1990.

e. Irrigation scheduling alone appears to be insufficient to reduce the volume of applied water or deep percolation from furrow irrigation. Irrigation scheduling alone on the improved furrow irrigation plot in 1989 did not result in significant water conservation or reduced agricultural drainage compared to conventional furrow irrigation. Irrigation scheduling, shorter furrow lengths (630 feet), tailwater return, furrow torpedoes and modified set times and flow rates on the improved furrow irrigation plot in 1990 did result in significant water conservation and reduced agricultural drainage compared to conventional furrow irrigation. Irrigation scheduling should be promoted in combination with the others methods, such as those mentioned above, to reduce the volume of applied water and agricultural drainage water with furrow irrigation.

f. The shallow ground water depth tended to start the season in April at approximately 2.5 - 3.3 feet below the soil surface and subside over the course of the growing season to approximately 5.8 - 7.5 feet in October. The depth to the shallow ground water fluctuated during the course of the season. Over-irrigation for the furrow systems during the first and second irrigation caused the shallow ground water table to rise early in the season. The shallow ground water table decreased later in the season mostly because of consumptive use by the crop. The decrease of the shallow ground water table was also affected by deep percolation below the confining layer and net subsurface lateral flow from the field.

g. Two of the four irrigation plots showed seasonal changes in soil salinity. The average soil salinity in the subsurface drip and LEPA plots increased between the spring and the fall during both years of the project. The average soil salinity in the improved furrow irrigation and the conventional furrow irrigation plots showed no clear change between spring and fall samplings.

h. Three of the four irrigation plots showed annual changes in soil salinity. The average soil salinity in the subsurface drip and LEPA plots increased between the first and the second year of the project. The average soil salinity in the improved furrow irrigation plot decreased between the first and the second year of the project. The average soil salinity in the conventional furrow irrigation plots was uniform between the two years of the project.

i. The average ground water salinity generally varied during the irrigation season. The reductions in the average ground water salinity appeared to be the result of dilution by better quality irrigation water. However, the magnitude of the salinity reductions did not correspond with the deep percolation estimated by Boyle Engineering individual irrigation system evaluation.

j. The average ground water boron concentration appeared to be influenced by deep percolation. Changes in the average ground water boron concentration may be the result of dilution by better quality irrigation water, soil variability and reaction of boron from the soil exchange complex. However, the magnitude of the boron concentration reductions did not correspond with the deep percolation estimated by Boyle Engineering individual irrigation system evaluation.

k. The average ground water selenium concentration beneath the west side of the field increased over the first two years of study. The two plots on this side of the field were the subsurface drip and conventional furrow plots. The increase in selenium concentration appeared to be the result of subsurface ground water inflow from adjacent areas containing higher concentration of selenium to the west of the field. The average ground water selenium concentration beneath the two plots on the east side of the field was generally uniform during each growing season and from year to year. These two plots were not affected by the lateral flow during the period of study because of the small magnitude of the lateral flow.

l. Boyle Engineering estimated the greatest net economic return to the grower from the subsurface drip irrigation system in 1989 ($268.58 per acre) and from the conventional furrow irrigation system in 1990 ($235.98 per acre). These values do not include costs of a subsurface drainage system, or costs of disposal or treatment of agricultural drainage water. The subsurface drip, improved furrow and conventional furrow systems had a positive net economic return both years of the project. The LEPA system was estimated to have a negative net economic return during both years.

m. The results from the first two years of study indicate that there is potential for changing irrigation technologies to reduce the volume of applied water and the volume of agricultural drainage water. For example, the subsurface drip system had least applied water, the least estimated volume of drainage water and the largest net economic return to the grower the first year of the project. The subsurface drip system had a lower crop yield during the second year of the project and therefore did not perform as well economically as during the first year. The change of irrigation technology requires large initial capital expenses and will probably be resisted by growers on these grounds. However, these changes appear to provide the grower with less water applied, less agricultural drainage water and a positive net economic return in the long term.

n. The results also indicate that there is potential for better management of conventional furrow irrigation systems to reduce the volume of applied water and drainage water. The improved furrow irrigation system had the least applied water, the least estimated volume of agricultural drainage water and a positive net economic return to the grower the second year of the project. The management changes are also expensive because they require capital investment, monitoring of field conditions and possibly more intensive labor for irrigation. However, like potential technological changes, management changes appear to provide the grower with less applied water, less agricultural drainage water and a positive net economic return in the long term.

4. Report Organization

A brief introduction and the project facilities are described in Chapter 1. The sampling procedures and data collected are described in Chapter 2. An analysis of the data and a discussion of the results are presented in Chapter 3. A conclusion is presented in Chapter 4.

CHAPTER 1. PROJECT DESCRIPTION

I. INTRODUCTION

Irrigation on the west side of the San Joaquin Valley results in shallow ground water accretions. The accretions occur directly from irrigation because of leaching and deep percolation and indirectly from irrigation because of seepage from conveyance facilities. In some areas on the west side of the San Joaquin Valley the geology causes a perched shallow ground water table. Ground water accretions to the shallow ground water may cause the shallow ground water table to rise and impact a crop's root zone. In 1986 approximately 405,000 acres of agricultural land had a shallow ground water table less than five feet from the soil surface (Boyle, 1990). This land will be referred to as the drainage problem area.

Subsurface drains have been installed in many agricultural fields in the drainage problem area to lower the shallow ground water table, while at the same time providing a means for leaching the crop root zone. Treatment and disposal options for the agricultural drainage are expensive. Because treatment and disposal costs are directly related to the volume of subsurface drainage water, a reduction in the volume of agricultural drainage produced will lower the treatment and disposal costs. The University of California Committee of Consultants on Drainage Water Reduction states that there are opportunities to reduce drainage volumes by changing irrigation technologies and improved management of existing systems.

The objective of this demonstration project was to evaluate subsurface drip, LEPA, improved furrow and conventional furrow irrigation technologies in reducing deep percolation, the associated drainage volume produced and the feasibility of these technologies.

II. PROJECT FACILITIES

The demonstration project was located on Harris Farms in western Fresno County. Figure 1 is a project location map. Figure 2 is a project vicinity map, reprinted from the Boyle Engineering Fourth Semiannual Report. The 160-acre field was subdivided into four 40-acre plots. The field layout is presented in Figure 3. There was one plot for each of four irrigation technologies:

A. The southwest plot demonstrated conventional furrow irrigation technology. Harris farms used existing management practices to irrigate this plot.

B. The southeast plot demonstrated improved furrow irrigation technology. Management of this plot included the use of irrigation scheduling in 1989, irrigation scheduling, monitoring of plant-water status, furrow torpedoes, shorter furrows and associated modified sets times and flow rates and the use of a tailwater return system in 1990.

C. The northeast plot demonstrated LEPA irrigation technology.

D. The northwest plot demonstrated subsurface drip irrigation technology.

The field received water from Westlands Water District, which could be turned into a reservoir at the northwest corner of the field. The reservoir also collected tailwater from this field and other fields for reuse. The subsurface drip and LEPA irrigation plots could be independently irrigated with water from this reservoir. The improved furrow and conventional furrow plots could be irrigated with water from either Westlands Water District or from the reservoir.

The field soil is classified as a Ciervo series by the United States Department of Agriculture Soil Conservation Service. The soil is mapped as a clay, silty-clay or clay-loam with zero to two percent slopes.

The field had a shallow ground water table near the soil surface that fluctuated during the growing season. The shallow ground water began each growing season at a depth between 2.5 - 3.3 feet and ended each growing season at a depth between 5.8 - 7.5 feet. There was no subsurface drainage system for this field during the first two years of the project.

Figure 1
Project Location Map

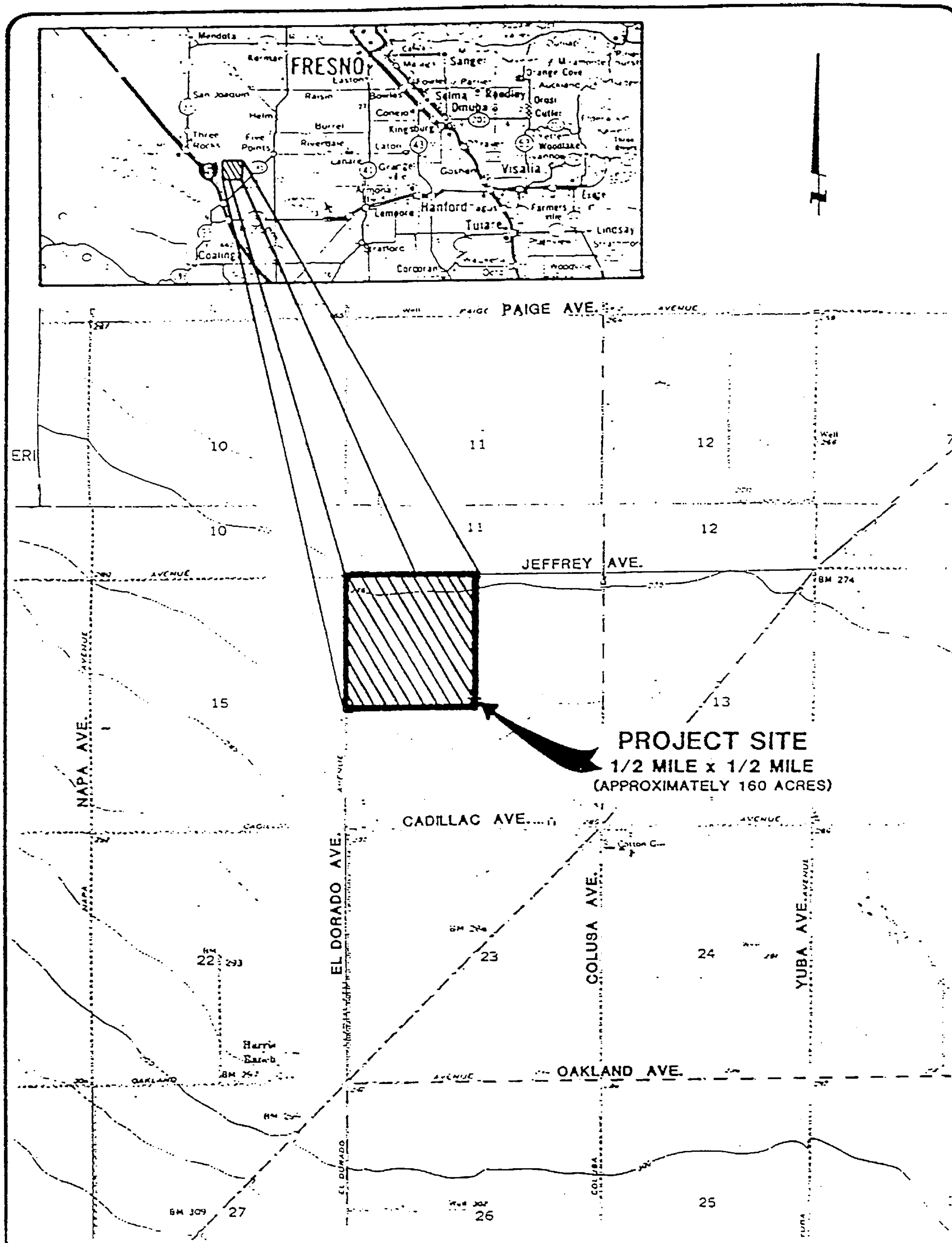


Figure 2 Project Vicinity Map

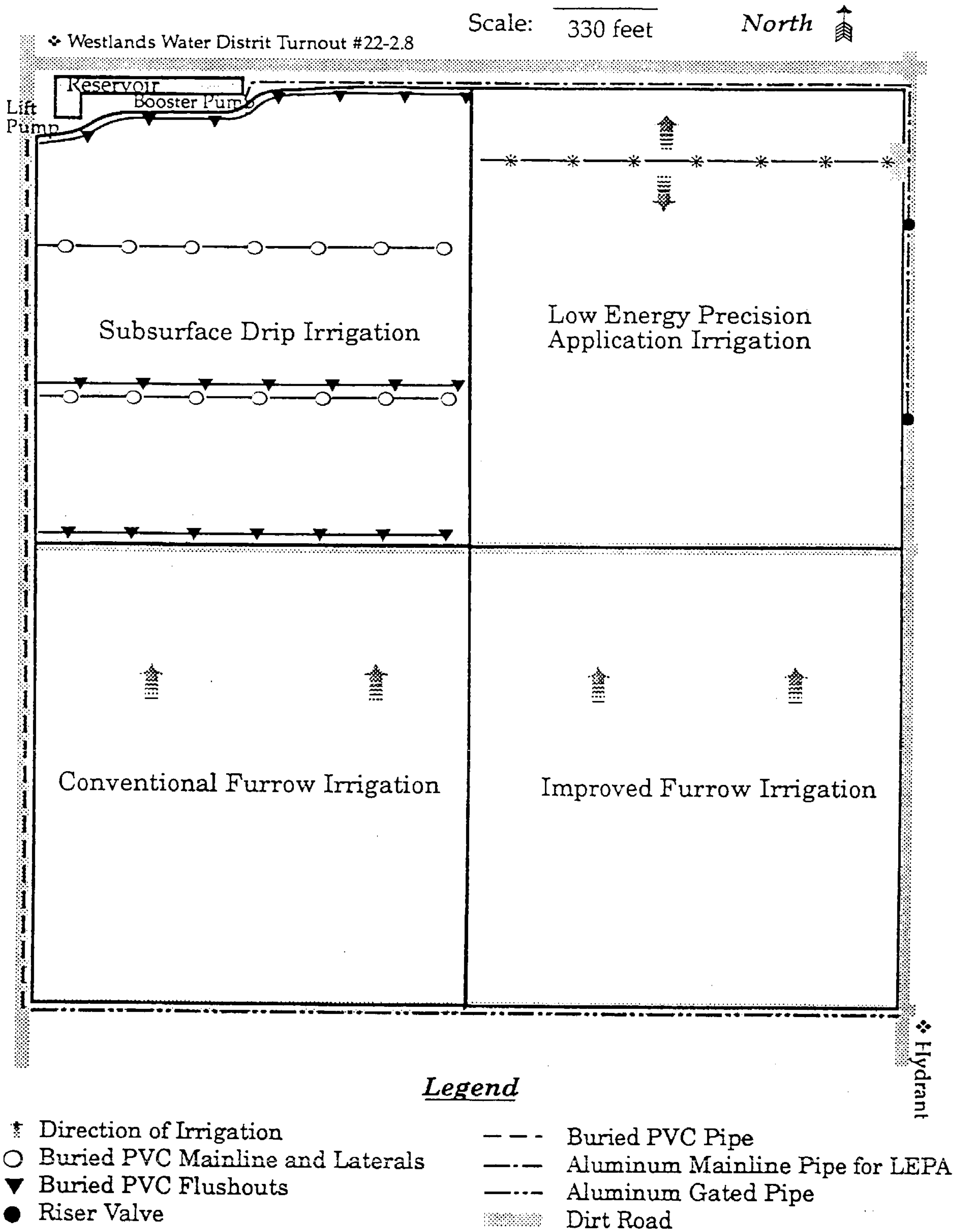


Figure 3
Project Facility Map

CHAPTER 2. MATERIALS AND METHODS

I. IRRIGATION SYSTEMS

A. Subsurface Drip

The subsurface drip system used the Netafilm 0.4 gallon per hour (nominal) emitter. The depth of the emitters and tubing was approximately 18 inches below the soil surface. The spacing of emitters was 40 inches apart along each hose and 80 inches between hoses. The average application rate was 0.04 inches per hour and was based on 0.56 gallons per hour discharge per emitter. The calculated emission uniformity was 93 percent. This was a one-set system and was designed to run approximately 8.5 hours per day to meet the average peak cotton evapotranspiration demand of 0.32 inches per day.

The subsurface drip plot was generally operated twice per day. The start and stop times were automated with a field clock.

Manifold (sub-main) pressures were controlled with pressure regulators, but individual hose pressures were not regulated. The calculated emission uniformity was 87 percent in 1989 and 81 percent in 1990 during individual seasonal irrigations.

The volume of water applied was measured with a flow meter on the main pump. Applied water was supplied from reservoir in the northwest corner of the field. Soil moisture content was monitored every week with the neutron probe. The irrigation schedule was predicted based on the soil moisture content, predicted weather and predicted plant evapotranspiration. Plant evapotranspiration was based on California Irrigation Management Information System (CIMIS) data collected at the University of California West Side Field Station and a crop coefficient developed by the Department of Agriculture, Agriculture Research Service in Fresno. A computer program divided the weekly predicted evapotranspiration into daily averages and calculated hours of system operation. Water balances from the previous week were used to check the accuracy of irrigation scheduling.

The media filters were back-flushed when the pressure difference across the filter reached 5.0 psi. This occurred approximately every two to three hours, depending on the quality of water in the reservoir.

Sulfuric and phosphoric acids were injected into the system to prevent root intrusion into the emitters and biological growth inside the system.

The plot was pre-irrigated both years with hand-move sprinklers. Enough water was applied to leach salts below the depth of the subsurface drip hose.

B. Low-Energy Precision Application (LEPA)

The LEPA system was manufactured by Lindsay Manufacturing. Nozzles were spaced approximately 40 inches apart. The discharge rate of each nozzle was approximately 1.6 gallon per minute. The LEPA system was designed to operate between 10.5 and 11 hours per day to meet the average peak cotton evapotranspiration demand of 0.32 inches per day.

The LEPA system was operated as a two-set system, with each set covering approximately 20 acres.

The volume of water applied was measured with a flow meter on the main pump. Applied water was supplied from the reservoir in the northwest corner of the field. The frequency of irrigation and volume of water applied were based on crop water requirements, soil water content, and system performance. Plant evapotranspiration was based on CIMIS data collected at the University of California West Side Field Station and a crop coefficient developed by the Department of Agriculture, Agriculture Research Service in Fresno. Set times were determined by soil water depletion and predicted crop evapotranspiration. A water balance was used to check the irrigation schedule accuracy of the previous week.

This plot was pre-irrigated with hand-move sprinklers in 1989 and with the LEPA system itself in 1990.

C. Improved Furrow

Furrows in this plot were spaced 40 inches apart and were 1,190 feet long (approximately 0.23 miles). Furrows were irrigated with a ten inch gated pipe and energy dissipation socks. A ten inch flow meter was placed at the entrance to the gated pipe to measure the volume of applied water. A flume and Stevens water level recorder were placed at the northeast corner of the plot (the low corner) to measure tailwater flows.

Applied water was supplied directly from Westlands Water District. The frequency of irrigation and volume of water applied were based on crop water requirements, soil water content and system performance. Plant evapotranspiration was based on CIMIS data collected at the University of California West Side Field Station and a crop coefficient developed by the Department of Agriculture, Agriculture Research Service in Fresno. Set times were determined by soil water depletion and estimated soil intake rates. Alternative furrows were used during regular season irrigations. A water balance was used to check the irrigation schedule accuracy of the previous week.

This plot was pre-irrigated using furrow irrigation in 1989 and hand-move sprinklers in 1990.

Irrigation scheduling was the only improvement used during the 1989 growing season. In 1990, a tailwater return system was installed and serviced more than just this field. Irrigation scheduling, shorter furrows (630 feet) modified set times and flow rates, furrow torpedoes, a pressure chamber to measure plant-water status and the tailwater return system were used during the 1990 growing season.

D. Conventional Furrow

Furrows in this plot were spaced 40 inches apart and were 1,190 feet long (approximately 0.23 miles). Furrows were irrigated with a ten inch gated pipe and energy dissipation socks. A ten inch flow meter was placed at the entrance to the gated pipe to measure the volume of applied water.

Applied water was supplied directly from Westlands Water District. The frequency of irrigations and volume of applied water were estimated based on timing and plant status as determined by the grower. The furrows were irrigated with blocked ends.

Pre-irrigation was performed using furrow irrigation on all furrows both years.

II. SAMPLING AND ANALYSIS

A. Soil Physical and Chemical Characteristics

The 160-acre field was divided into 16 ten-acre subplots. Two ten-acre subplots were chosen from each plot for testing. Soil boring were made from near the middle of the two ten-acre subplots. Soil samples were collected from each boring in one foot increments, to a depth of seven feet, or until the shallow ground water table was encountered, whichever was shallower. The soil samples were analyzed for percent saturation, soil salinity, pH, sodium (Na), calcium (Ca), magnesium (Mg), bicarbonate (HCO3), carbonate (CO3), chloride (Cl), boron (B), molybdenum (Mo) and selenium (Se).

B. Soil Matric Potential and Data Loggers

Soil matric potential monitoring equipment was located at two sites in each 40-acre plot. Each site consisted of five sensors, buried in 0.98 foot increments (30 cm) to a depth of 4.9 feet (150 cm). Two sensors were buried at a depth of 4.9 feet, for a total of six sensors per profile. Information from the sensors was stored in data loggers every four hours. Data from the data loggers were retrieved once every two weeks.

C. Neutron Probe Access Tubes

Neutron probe access tubes were installed at three sites in each 40-acre plot. Two tubes were installed at each site to a depth of approximately seven feet below the soil surface. Soil water content was monitored weekly with the neutron probe.

D. Observation Wells

Observation wells were installed at six locations in each 40-acre plot. Perforation in the well casing began at two feet below the soil surface. Sixteen additional observation wells were installed around the perimeter of the 160-acre field in 1989. Before the 1990 growing season, the peripheral observation wells were moved and the number was increased to 24 to provide more coverage.

Ground water levels were recorded in the observation wells at the beginning of the pre-irrigation and once between each irrigation. Boyle Engineering tried to make observations on the same day every two weeks. Depth to ground water maps and ground water elevation maps were prepared from data collected.

E. Piezometers

Piezometers were installed at two sites in each 40-acre plot. Three piezometers were installed at each site at depths of 4.5, 7.5, and 10.5 feet. Piezometers were monitored weekly during the irrigation season. This data was used to help determine the direction of ground water movement.

F. Irrigation Water Quality

Irrigation water samples were collected at the beginning, middle and end of each irrigation season. The samples were submitted for analysis of pH, salinity, Na, Ca, Mg, B, Mo, and Se.

G. Shallow Ground Water Quality

Shallow ground water samples were collected each week from observation wells. There were three observation wells for each 40-acre plot. The samples were analyzed for salinity, B, Mo, and Se.

H. Plant Tissue Analysis

Petiole samples were collected to monitor plant nutrient status during the growing season. Samples were collected at first bloom, peak bloom and late bloom from each 40-acre plot. The plant tissue samples were analyzed for nitrogen, phosphorous, potassium and zinc.

I. Crop Production

Crop production data was provided by Harris Farms. Crop operations, total and unit equipment costs were provided to Boyle Engineering. Plots were harvested individually and labelled for ginning and data summary. Crop production data was then used to economically evaluate each system.

CHAPTER 3. RESULTS AND DISCUSSION

This section analyzes the data from the various sampling and monitoring activities discussed above, and describes the results of the four projects. The monitoring activities are discussed in the previous chapter. This chapter is organized so that information presented at the beginning is used to support conclusions later in the chapter.

I. CROP INFORMATION

Cotton was planted on April 9, 1989 in all four plots. The cotton cultivar was 'SJ-2'. The first pick of cotton was done during the first week of October 1989. The second year cotton was planted on April 4, 1990 in all four plots. The cotton cultivar was 'GC-510'. The first pick of cotton was done during the second week of October 1990 (personal communication with Boyle Engineering).

The crop was fertilized with approximately 120 pounds per acre of nitrogen and approximately 50 pounds per acre of P_2O_5. The fertilization rates were the same for each plot both years of the project (personal communication with Boyle Engineering).

II. IRRIGATION WATER QUALITY

Tables 1 and 2 present summaries of irrigation water quality for 1989 and 1990 respectively. The irrigation water quality varied from irrigation to irrigation because various volumes of tailwater was blended with water from Westlands Water District. The salinity of the irrigation water varied between 0.40 and 1.63 dS m^{-1} during the first two years of the project. The boron concentration varied between less than or equal to 0.01 to 0.11 ppm. The selenium concentration varied between less than or equal to 0.02 to 0.71 ppb.

III. IRRIGATION WATER QUANTITY

Tables 3 to 6 present summaries of the amount of water applied for pre-irrigation, seasonal, and total applied water. In most cases the cotton received an adequate supply of water according to Boyle Engineering's crop evapotranspiration estimates. The two exceptions to this were the subsurface drip plot and LEPA plots in 1989, as discussed below.

Table 1
Summary of 1989 Irrigation Water Quality

Date	EC ($dS\ m^{-1}$)	pH	Sodium ($mmol\ L^{-1}$)	Calcium ($mmol\ L^{-1}$)	Magnesium ($mmol\ L^{-1}$)	SAR $\sqrt{mmol\ L^{-1}}$	Boron (ppm)	Molybdenum (ppm)	Selenium (ppb)
Subsurface Drip									
June 7, 1989	0.97	7.45	6.56	0.850	0.485	5.68	0.67	0.11	0.71
July 19, 1989	0.58	8.24	3.06	0.580	0.580	2.84	2.2	0.04	≤ 0.20
August 5, 1989	0.40	7.45	2.04	0.400	0.415	2.26	0.15	0.05	0.66
LEPA									
June 7, 1989	0.97	7.45	6.56	0.850	0.485	5.68	0.67	0.11	0.71
July 19, 1989	0.58	8.15	3.04	0.580	0.580	2.82	1.4	0.03	≤ 0.20
August 5, 1989	0.43	7.83	1.98	0.410	0.415	2.19	0.13	≤ 0.03	0.22
Improved Furrow									
June 7, 1989	0.40	7.69	1.98	0.460	0.455	2.08	0.16	0.02	0.47
July 19, 1989	0.64	8.18	3.20	0.570	0.615	2.95	1.5	≤ 0.03	≤ 0.20
August 5, 1989	0.45	7.36	2.13	0.440	0.435	2.28	0.14	≤ 0.03	0.22
Conventional Furrow									
June 7, 1989	0.39	7.89	1.96	0.460	0.455	2.05	0.12	0.04	0.24
July 19, 1989	0.65	8.08	3.22	0.570	0.610	2.97	0.19	≤ 0.03	≤ 0.20
August 5, 1989	0.46	7.16	2.11	0.410	0.435	2.30	0.14	0.04	0.22

EC = Electrical Conductivity, reported at 25°C. SAR = Sodium Adsorption Ratio

Table 2
Summary of 1990 Irrigation Water Quality

Date	EC ($dS\ m^{-1}$)	pH	Sodium	Calcium ($mmol\ L^{-1}$)	Magnesium	SAR $\sqrt{mmol\ L^{-1}}$	Boron (ppm)	Molybdenum (ppm)	Selenium (ppb)
Subsurface Drip									
February 5, 1990	0.59	7.90	2.78	0.555	0.618	2.57	0.20	≤ 0.03	≤ 0.02
July 25, 1990	0.57	8.29	3.00	0.580	0.590	2.77	0.20	≤ 0.01	≤ 0.02
August 21, 1990	1.6	7.62	11.9	1.18	0.295	9.82	1.1	0.07	0.98
LEPA									
February 5, 1990	0.59	7.90	2.78	0.550	0.615	2.58	0.20	≤ 0.03	≤ 0.02
July 25, 1990	0.59	8.30	3.19	0.650	0.560	2.90	0.30	0.05	≤ 0.02
August 21, 1990	1.63	7.62	11.9	1.18	0.295	9.82	1.4	0.07	0.98
Improved Furrow									
February 5, 1990	0.59	7.90	2.78	0.550	0.600	2.59	0.20	≤ 0.03	≤ 0.02
July 25, 1990	0.54	8.23	2.85	0.500	0.600	2.72	0.33	≤ 0.01	≤ 0.02
August 21, 1990	0.59	7.92	2.91	0.470	0.580	2.84	0.10	0.04	≤ 0.02
Conventional Furrow									
February 5, 1990	0.59	7.90	2.78	0.550	0.615	2.58	0.20	≤ 0.03	≤ 0.02
July 25, 1990	0.54	8.23	2.85	0.500	0.600	2.72	0.33	≤ 0.01	≤ 0.02
August 21, 1990	0.60	7.92	2.91	0.470	0.580	2.84	0.10	0.04	≤ 0.02

EC = Electrical Conductivity, reported at 25°C. SAR = Sodium Adsorption Ratio

Table 3
Summary of Applied Water by Subsurface Drip
(data taken from the Semiannual Reports, Boyle Engineering)

Year	Pre-Irrigation (AF/Ac)	Seasonal (AF/Ac)	Total (AF/Ac)
1989	0.48	1.44	1.92
1990	0.40	1.60	2.00

The subsurface drip plot was pre-irrigated with hand-move sprinklers both years of the project. This plot received less than 0.5 acre-feet per acre during pre-irrigation. The seasonal irrigations applied 1.44 and 1.60 acre-feet of water per acre in 1989 and 1990, respectively. The subsurface drip system was shut down in 1989 for approximately seven days to cultivate. This caused the applied water for the subsurface drip plot in 1989 to lag slightly behind the estimated crop transpiration. The total amount of water applied was approximately two acre-feet per acre both years of the project.

Table 4
Summary of Applied Water by LEPA
(data taken from the Semiannual Reports, Boyle Engineering)

Year	Pre-Irrigation (AF/Ac)	Seasonal (AF/Ac)	Total (AF/Ac)
1989	0.48	1.20	1.68
1990	0.28	1.93	2.21

The LEPA plot was pre-irrigated with hand-move sprinklers in 1989 and with the LEPA system in 1990. This plot received less than 0.5 acre-feet per acre during both pre-irrigations. The seasonal irrigations applied 1.20 and 1.93 acre-feet of water per acre in 1989 and 1990, respectively. The total amount of water applied was 1.68 and 2.21 acre-feet per acre in 1989 and 1990, respectively.

The LEPA system was shut down because of mechanical failure for ten days in June 1989 and again for ten days in August 1989. This caused the LEPA plot to be under-irrigated in 1989.

Inconsistent bed subbing during the 1990 pre-irrigation caused a stand reduction and lint yield loss. The LEPA plot was over-irrigated when the LEPA system was operated continuously for approximately 12 days in July 1990. This resulted in an over-application of approximately 0.44 acre-feet per acre according to the Fourth Semiannual Boyle Report.

Table 5
Summary of Applied Water by Improved Furrow
(data taken from the Semiannual Reports, Boyle Engineering)

Year	Pre-Irrigation (AF/Ac)	Seasonal (AF/Ac)	Total (AF/Ac)
1989	0.73	1.73	2.46
1990	0.32	1.32	1.64

The improved furrow plot was pre-irrigated with furrow irrigation in 1989 and with hand-move sprinklers in 1990. Irrigation with hand-move sprinklers reduced the amount of water applied during pre-irrigation by approximately 0.5 acre-feet per acre. The seasonal irrigations applied 1.73 and 1.32 acre-feet of water per acre in 1989 and 1990, respectively. Less water was applied during the second year of the project because of shorter furrow lengths, modified set times and flow rates, and the use of a tailwater return system. The total amount of water applied was 2.46 and 1.64 acre-feet per acre in 1989 and 1990, respectively. Changes to the improved furrow system the second year of the project resulted in approximately 0.8 acre-feet of less water applied than during the first year of the project.

Table 6
Summary of Applied Water by Conventional Furrow
(data taken from the Semiannual Reports, Boyle Engineering)

Year	Pre-Irrigation (AF/Ac)	Seasonal (AF/Ac)	Total (AF/Ac)
1989	0.78	1.76	2.54
1990	0.73	1.67	2.40

The conventional furrow plot was pre-irrigated with furrow irrigation both years of the project. Pre-irrigation received approximately 0.75 acre-feet per acre each year. The seasonal irrigations applied 1.77 and 1.67 acre-feet of water per acre in 1989 and 1990, respectively. The total amount of water applied was approximately 2.5 acre-feet per acre in both years of the project.

Pre-irrigation with hand-move sprinklers on subsurface drip and the LEPA plot in 1989, and the improved furrow in 1990 resulted in approximately 0.5 feet of less water applied than pre-irrigation by furrows on the conventional furrow plot.

A. Irrigation Parameters

Distribution uniformity and irrigation efficiency are as important as the amount of water applied. Tables 7 - 14 present selected data from individual irrigation system evaluations performed by Boyle Engineering during the season. Westside Resources Conservation District guidelines were used to conduct these evaluations.

Table 7
Summary of 1989 Irrigation Parameters for Subsurface Drip Irrigation Technology
(data taken from the Second Semiannual Report Appendix, Boyle Engineering, 1989)

Date	Technology	Applied Water (in/Ac)	Distribution Uniformity (%)	Irrigation Efficiency (%)	Deep Percolation (in/Ac)
3/15	HMS	5.72	55	54	2.2
5/29	SSD	0.25	87	100	0.0
6/05	SSD	0.32	87	100	0.0
6/12	SSD	0.32	87	100	0.0
6/19	SSD	0.08	87	100	0.0
6/26	SSD	0.53	87	100	0.0
7/03	SSD	1.16	87	100	0.01
7/10	SSD	1.75	87	100	0.0
7/17	SSD	1.79	87	100	0.0
7/24	SSD	2.16	87	100	0.0
7/31	SSD	2.23	87	100	0.0
8/07	SSD	2.58	87	92	0.2
8/14	SSD	2.14	87	100	0.01
8/21	SSD	1.82	87	100	0.01
8/28	SSD	0.69	87	100	0.0
Seasonal		23.54	79	86	2.43

HMS = Hand-move sprinkler, SSD = Subsurface Drip

The total amount of deep percolation was 2.43 inches per acre according to the irrigation system evaluation performed by Boyle Engineering (Appendix A, Second Semiannual Report, 1989). This deep percolation amounted to 10.3% of applied water.

Table 8
Summary of 1990 Irrigation Parameters
for Subsurface Drip Irrigation Technology
(data taken from the Fourth Semiannual Report Appendix, Boyle Engineering, 1990)

Date	Technology	Applied Water (in/Ac)	Distribution Uniformity (%)	Irrigation Efficiency (%)	Deep Percolation (in/Ac)
3/01	HMS	4.80	55	60	1.77
5/19	SSD	0.88	81	79	0.16
6/02	SSD	1.58	81	41	0.89
6/16	SSD	2.02	81	62	0.71
6/30	SSD	1.87	81	97	0.0
7/14	SSD	2.29	81	97	0.0
7/28	SSD	4.47	81	87	0.44
8/18	SSD	4.79	81	97	0.0
8/25	SSD	1.34	81	96	0.01
Seasonal		24.04	76	81	3.98

HMS = Hand-move sprinkler, SSD = Subsurface Drip

The amount of deep percolation was 3.98 inches per acre according to the irrigation system evaluation performed by Boyle Engineering (Appendix A, Fourth Semiannual Report, 1990). This deep percolation amounted to 16.6% of applied water.

Table 9
Summary of 1989 Irrigation Parameters for LEPA Irrigation Technology
(data taken from the Second Semiannual Report Appendix, Boyle Engineering, 1989)

Date	Technology	Applied Water (in/Ac)	Distribution Uniformity (%)	Irrigation Efficiency (%)	Deep Percolation (in/Ac)
3/21	HMS	5.68	50	46	2.65
5/29	LEPA	0.87	92	97	0.0
6/05	LEPA	1.51	92	97	0.0
6/12	LEPA	0.65	92	97	0.0
6/26	LEPA	1.06	92	97	0.0
7/03	LEPA	0.48	92	97	0.01
7/10	LEPA	1.11	92	97	0.0
7/24	LEPA	1.94	92	97	0.0
7/31	LEPA	1.35	92	97	0.0
8/07	LEPA	0.60	92	97	0.2
8/14	LEPA	3.07	92	97	0.01
8/21	LEPA	1.02	92	97	0.01
8/28	LEPA	0.55	92	97	0.0
Seasonal		19.89	80	82	2.88

HMS = Hand-move sprinkler

The amount of deep percolation was 2.88 inches per acre according to the irrigation system evaluation performed by Boyle Engineering (Appendix A, Second Semiannual Report, 1989). This deep percolation amounted to 14.5% of applied water.

Table 10
Summary of 1990 Irrigation Parameters for LEPA Irrigation Technology
(data taken from the Fourth Semiannual Report Appendix, Boyle Engineering, 1990)

Date	Technology	Applied Water (in/Ac)	Distribution Uniformity (%)	Irrigation Efficiency (%)	Deep Percolation (in/Ac)
3/01	LEPA	3.36	92	89	0.26
6/01	LEPA	3.71	92	61	1.35
6/16	LEPA	2.56	92	74	0.59
6/30	LEPA	1.43	92	97	0.0
7/14	LEPA	4.19	92	73	1.02
7/28	LEPA	6.87	92	59	2.62
8/11	LEPA	0.93	92	97	0.0
8/25	LEPA	3.50	92	89	0.29
Seasonal		26.55	92	74	6.13

The amount of deep percolation was 6.13 inches per acre according to the irrigation system evaluation performed by Boyle Engineering (Appendix A, Fourth Semiannual Report, 1990). This deep percolation amounted to 23.1% of applied water.

Table 11
Summary of 1989 Irrigation Parameters for Improved Furrow Irrigation Technology
(data taken from the Second Semiannual Report Appendix, Boyle Engineering, 1989)

Date	Technology	Applied Water (in/Ac)	Distribution Uniformity (%)	Irrigation Efficiency (%)	Deep Percolation (in/Ac)
2/17	Furrow	8.88	65	32	5.99
5/24	Furrow	4.60	58	37	2.81
6/28	Furrow	5.35	58	32	3.49
7/18	Furrow	5.90	57	29	4.02
8/10	Furrow	5.04	57	46	2.59
Seasonal		29.77	60	35	18.90

The amount of deep percolation was 18.90 inches per acre according to the irrigation system evaluation performed by Boyle Engineering (Appendix A, Second Semiannual Report, 1989). This deep percolation amounted to 63.5% of applied water.

Table 12
Summary of 1990 Irrigation Parameters
for Improved Furrow Irrigation Technology
(data taken from the Fourth Semiannual Report Appendix, Boyle Engineering, 1990)

Date	Technology	Applied Water (in/Ac)	Distribution Uniformity (%)	Irrigation Efficiency (%)	Deep Percolation (in/Ac)
3/01	HMS	3.84	62	73	0.90
6/02	Furrow	5.95	89	11	5.13
7/07	Furrow	4.99	89	97	0.09
7/21	Furrow	3.21	84	96	0.03
8/11	Furrow	2.20	84	97	0.0
Seasonal		20.19	82	66	6.06

HMS = Hand-move sprinkler

The amount of deep percolation was 6.06 inches per acre according to the irrigation system evaluation performed by Boyle Engineering (Appendix A, Fourth Semiannual Report, 1990). This deep percolation amounted to 30.0% of applied water.

Table 13
Summary of 1989 Irrigation Parameters
for Conventional Furrow Irrigation Technology
(data taken from the Second Semiannual Report Appendix, Boyle Engineering, 1989)

Date	Technology	Applied Water (in/Ac)	Distribution Uniformity (%)	Irrigation Efficiency (%)	Deep Percolation (in/Ac)
2/21	Furrow	9.49	66	32	6.40
5/27	Furrow	4.39	57	36	2.71
6/25	Furrow	5.44	57	26	3.88
7/15	Furrow	5.54	60	36	3.38
8/07	Furrow	5.89	63	46	3.02
Seasonal		30.75	61	35	19.39

The amount of deep percolation was 19.39 inches per acre according to the irrigation system evaluation performed by Boyle Engineering (Appendix A, Second Semiannual Report, 1989). This deep percolation amounted to 63.9% of applied water.

Table 14
Summary of 1990 Irrigation Parameters
for Conventional Furrow Irrigation Technology
(data taken from the Fourth Semiannual Report Appendix, Boyle Engineering, 1990)

Date	Technology	Applied Water (in/Ac)	Distribution Uniformity (%)	Irrigation Efficiency (%)	Deep Percolation (in/Ac)
3/01	HMS	8.76	71	34	5.50
6/07	Furrow	4.80	73	25	3.44
7/12	Furrow	5.63	73	93	0.21
7/27	Furrow	4.65	73	82	0.67
8/17	Furrow	4.92	73	96	0.03
Seasonal		28.76	72	62	9.85

HMS = Hand-move sprinkler

The amount of deep percolation was 9.85 inches per acre according to the irrigation system evaluation performed by Boyle Engineering (Appendix A, Fourth Semiannual Report, 1990). This deep percolation amounted to 9.85% of applied water.

Tables 7 - 14 indicate that the majority of the deep percolation occurred during the pre-irrigation and the first irrigation of each growing season. Pre-irrigations during the two years were performed with either hand-move sprinkler or furrow irrigation. The first seasonal irrigation was performed with the respective irrigation system. Reduction in the amount of water applied during these irrigations has the greatest potential to reduce the amount of agricultural drainage produced.

IV. Soil Chemistry

The soil salinity, soil boron, and soil selenium were sampled during each year of the project. The sample locations are shown in Figure 4. The locations changed for the subsurface drip and improved furrow irrigation plots, and remained the same for the other two plots. Samples were collected from locations 1 and 4 both years within the conventional furrow plot. Samples were collected from locations 5 and 8 during 1989, and from 6 and 7 during 1990 within the subsurface drip plot. Samples were collected from locations 9 and 12 during 1989, and from 10 and 11 during 1990 within the improved furrow plot. Samples were collected from locations 13 and 16 both years within the LEPA plot.

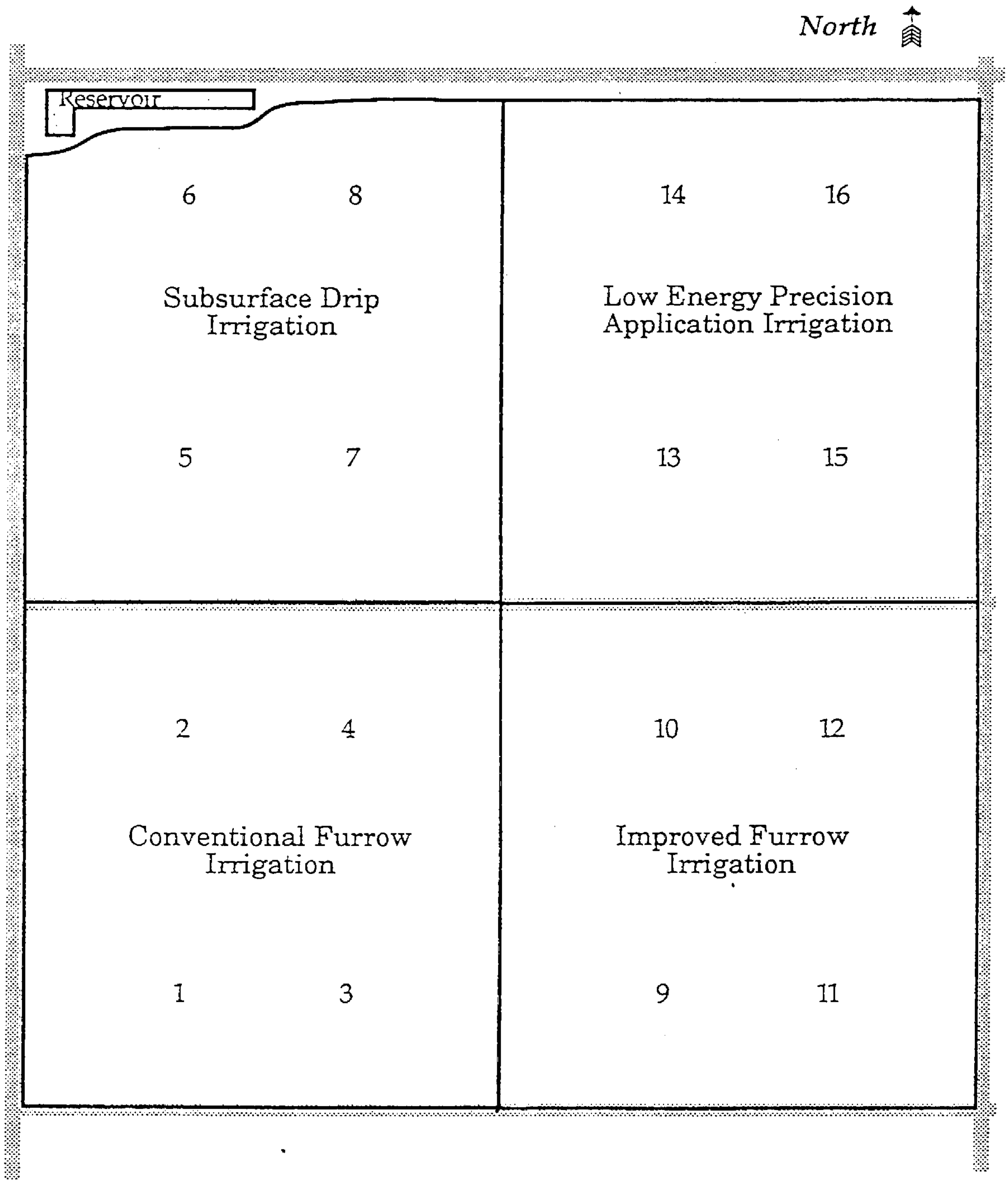


Figure 4
Soil Sample Location and Identification Number

A. Soil Salinity

The average soil salinity within the field during the first two years of the project was 3.00 ± 1.92 dS m^{-1}. The greatest soil salinities were observed at location 6 during 1990 (7.05 ± 1.66 dS m^{-1}), at location 5 during 1989 (5.91 ± 2.21 dS m^{-1}), and at location 8 during 1989 (4.33 ± 1.76 dS m^{-1}). These locations were within the subsurface drip and improved furrow irrigation plots.

1) Changes in Soil Salinity over Time

If the sol salinity increases above a crop specific threshold level, the crop yield can be reduced. Soil salinity was measured in the spring and fall of each growing season to examine changes in soil salinity over time.

Figure 5 presents the measured soil salinity for the subsurface drip plot in 1989 and 1990. The soil salinity of the subsurface drip plot varied between 3 and 6 dS m^{-1} in 1989. The greatest salinity occurring at a depth between 1 and 2.5 feet. This was approximately the depth at which the subsurface drip tubing was placed (1.5 feet). The average soil salinity was 4.32 dS m^{-1} in the spring and increased to 4.84 dS m^{-1} in the fall of 1989. The soil salinity of the subsurface drip plot varied between 3 and 8 dS m^{-1} in 1990. The salinity distribution of the soil profile generally tended to increase with depth during both samplings, with the greatest salinity occurring at a depth of 6.5 feet. The average soil salinity was 4.46 dS m^{-1} in the spring and increased to 5.77 dS m^{-1} in the fall of 1990. The soil salinity during the fall was greater than the soil salinity in the spring, with the difference being less than 2 dS m^{-1}. The average soil salinity increased during the second year of the project.

Figure 6 presents the measured soil salinity for the LEPA plot in 1989 and 1990. The soil salinity of the LEPA plot varied between 1 and 2.5 dS m^{-1} in 1989. The salinity distribution of the soil profile was generally uniform. The average soil salinity was 1.55 dS m^{-1} in the spring and increased to 2.05 dS m^{-1} in the fall of 1989. The soil salinity of the LEPA plot varied between 1 and 4 dS m^{-1} in 1990. The salinity distribution of the soil profile generally tended to increase with depth. The average soil salinity was 3.02 dS m^{-1} in both the spring and the fall of 1990. The soil salinity during the fall was greater than the soil salinity in the spring, with the difference being less than 2 dS m^{-1}. The average soil salinity increased during the second year of the project.

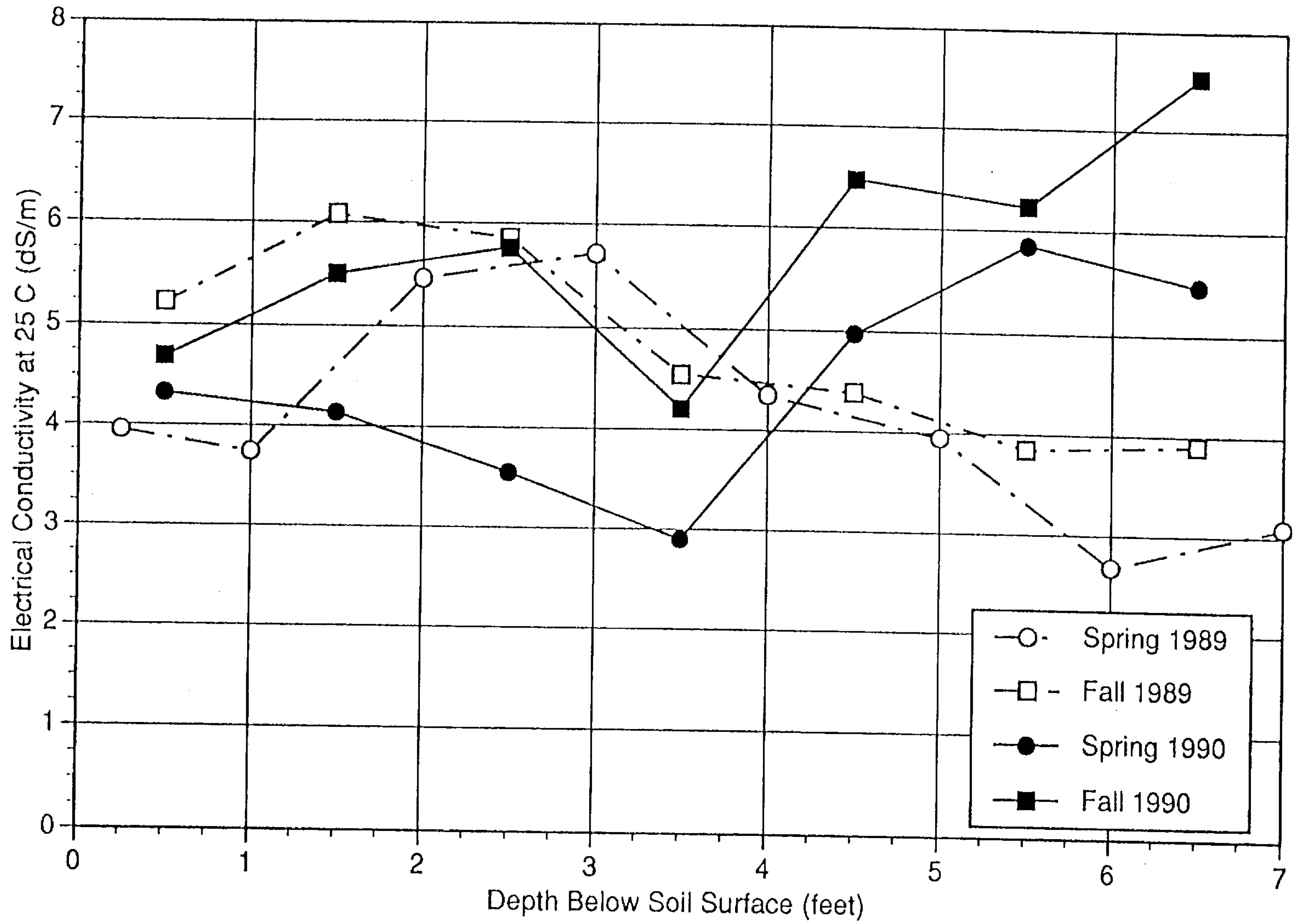


Figure 5

Soil Salinity Measurements during Spring and Fall for Subsurface Drip Plot

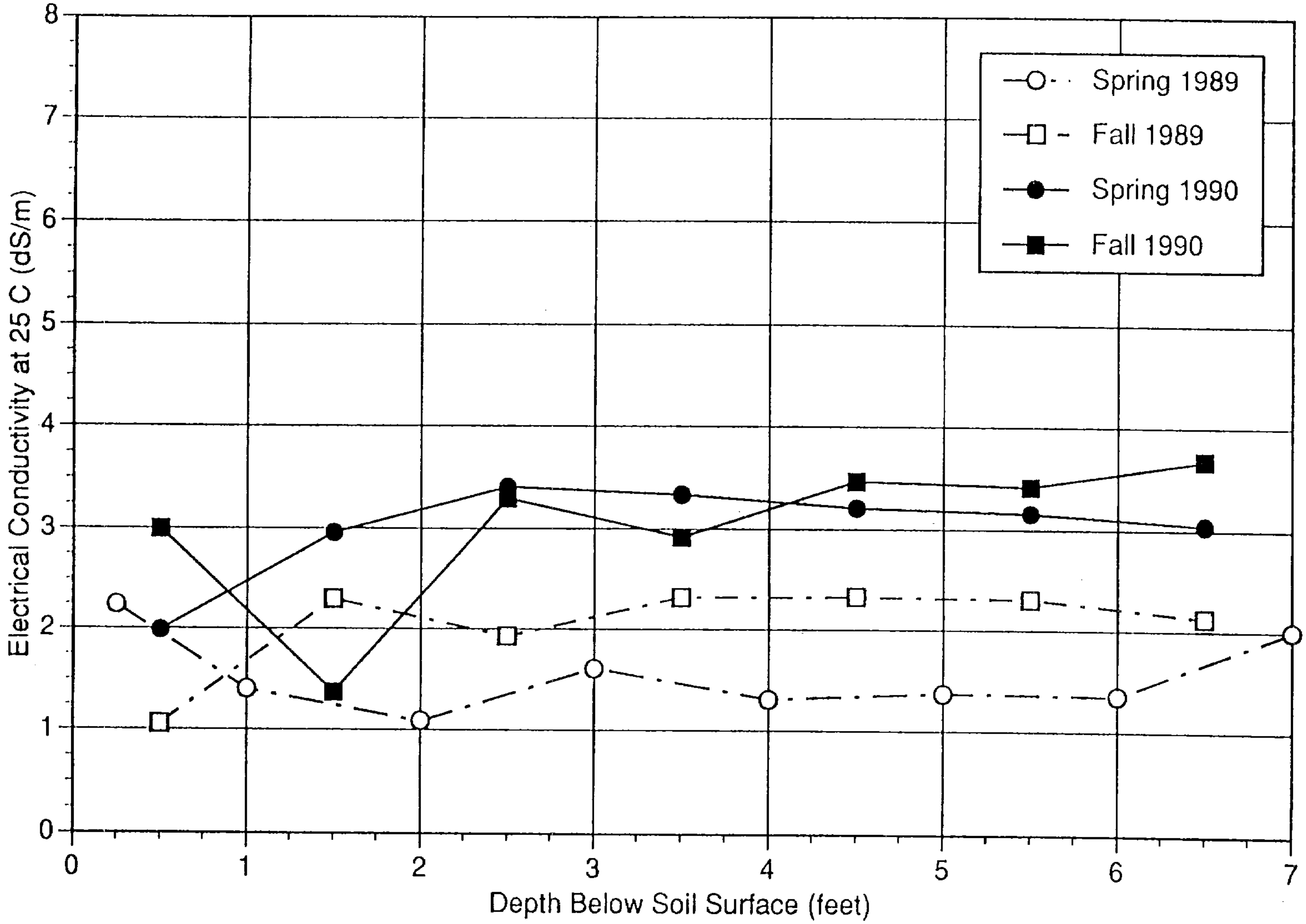


Figure 6
Soil Salinity Measurements during Spring and Fall for LEPA Plot

Figure 7 presents the measured soil salinity for the improved furrow irrigation plot in 1989 and 1990. The soil salinity of the improved furrow irrigation plot varied between 3 and 5 dS m^{-1} in 1989. The salinity distribution of the soil profile tended to decrease with depth. The average soil salinity was 3.72 dS m^{-1} in the spring and increased to 3.91 dS m^{-1} in the fall of 1989. The soil salinity of the improved furrow irrigation plot varied between 1.5 and 3.5 dS m^{-1} in 1990. The salinity distribution of the soil profile generally tended to decrease with depth. The average soil salinity was 2.29 dS m^{-1} in the spring and decreased to 1.92 dS m^{-1} in the fall of 1990. The soil salinity during the spring was greater than the soil salinity in the fall, with the difference being less than 2 dS m^{-1}. There was no clear trend how the soil salinity changed during the growing season. The average soil salinity decreased during the second year of the project.

Figure 8 presents the measured soil salinity for the conventional furrow irrigation plot in 1989 and 1990. The soil salinity of the conventional furrow irrigation plot varied between 1 and 3 dS m^{-1} in 1989. The salinity distribution of the soil profile was generally uniform with depth, with the greatest salinity occurring between 1 and 2.5 feet. The average soil salinity was 1.88 dS m^{-1} in the spring and the fall of 1989. The soil salinity of the conventional furrow irrigation plot varied between 1 and 2.5 dS m^{-1} in 1990. The salinity distribution of the soil profile was generally uniform with depth. The average soil salinity was 2.07 dS m^{-1} in the spring and decreased to 1.53 dS m^{-1} in the fall of 1990. There was no clear trend how the soil salinity changed during the growing season, or from year to year. The average soil salinity may have changed, but were within the range of errors of the observations. Because of the errors for the observations, a clear trend for the average soil salinity cannot be distinguished.

Changes in soil salinity are difficult to interpret. Differences in irrigation water quality, spatial variability and possible shallow ground water used late in the growing season effect individual observations. Trends from year to year reflect the variables mentioned above, and also from practices from previous years. In the improved furrow irrigation plot and the conventional furrow irrigation plot the average soil salinity changed slightly over the growing season, and decreased slightly between 1989 and 1990. The observed decreases in soil salinity were less than 1.0 dS m^{-1} yr^{-1}. In the subsurface drip and LEPA plots the range of soil salinity increased over each growing season, and increased from 1989 to 1990. The observed increases in soil salinity were less than 1.5 dS m^{-1} yr^{-1}.

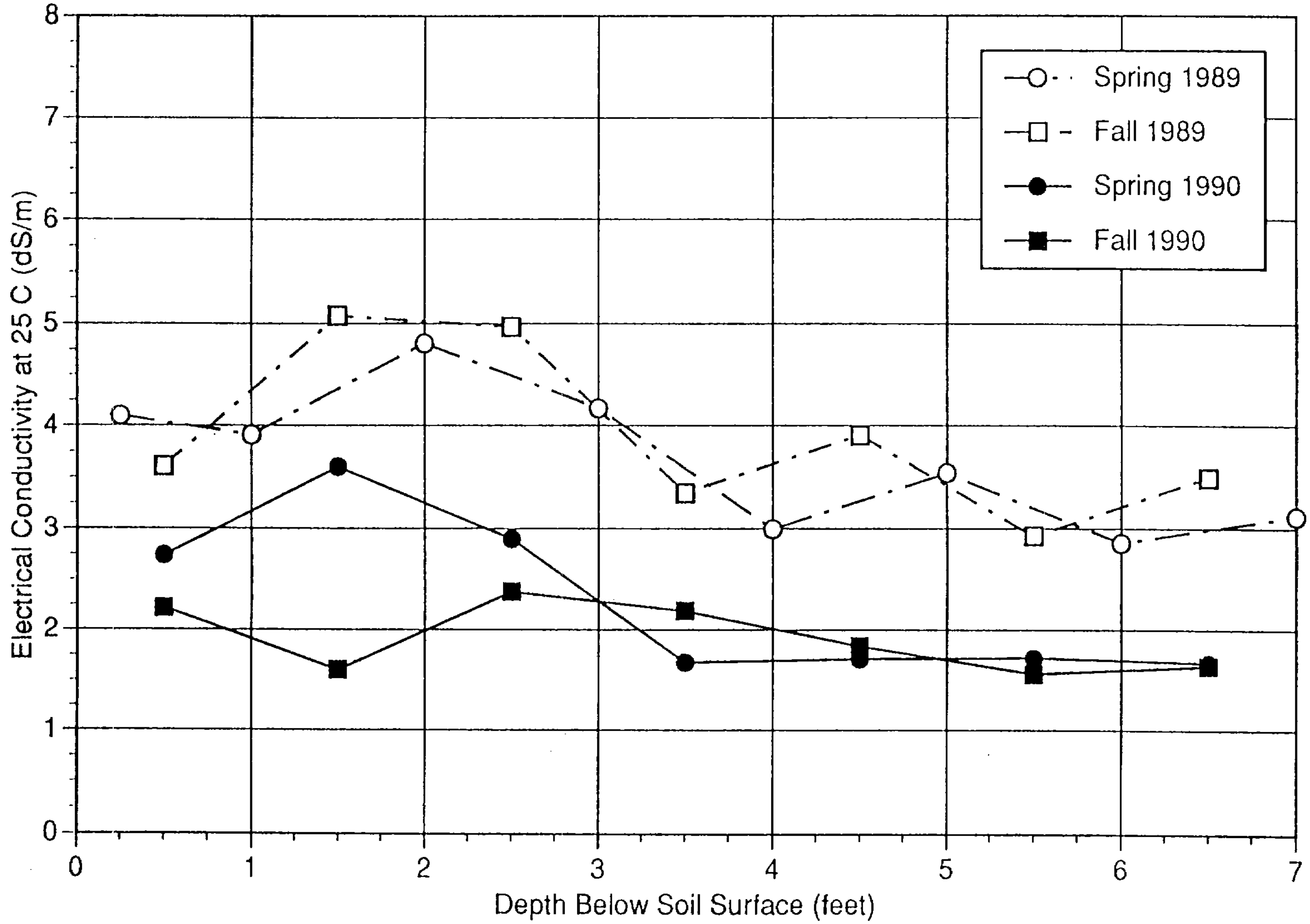


Figure 7

Soil Salinity Measurements during Spring and Fall for Improved Furrow Plot

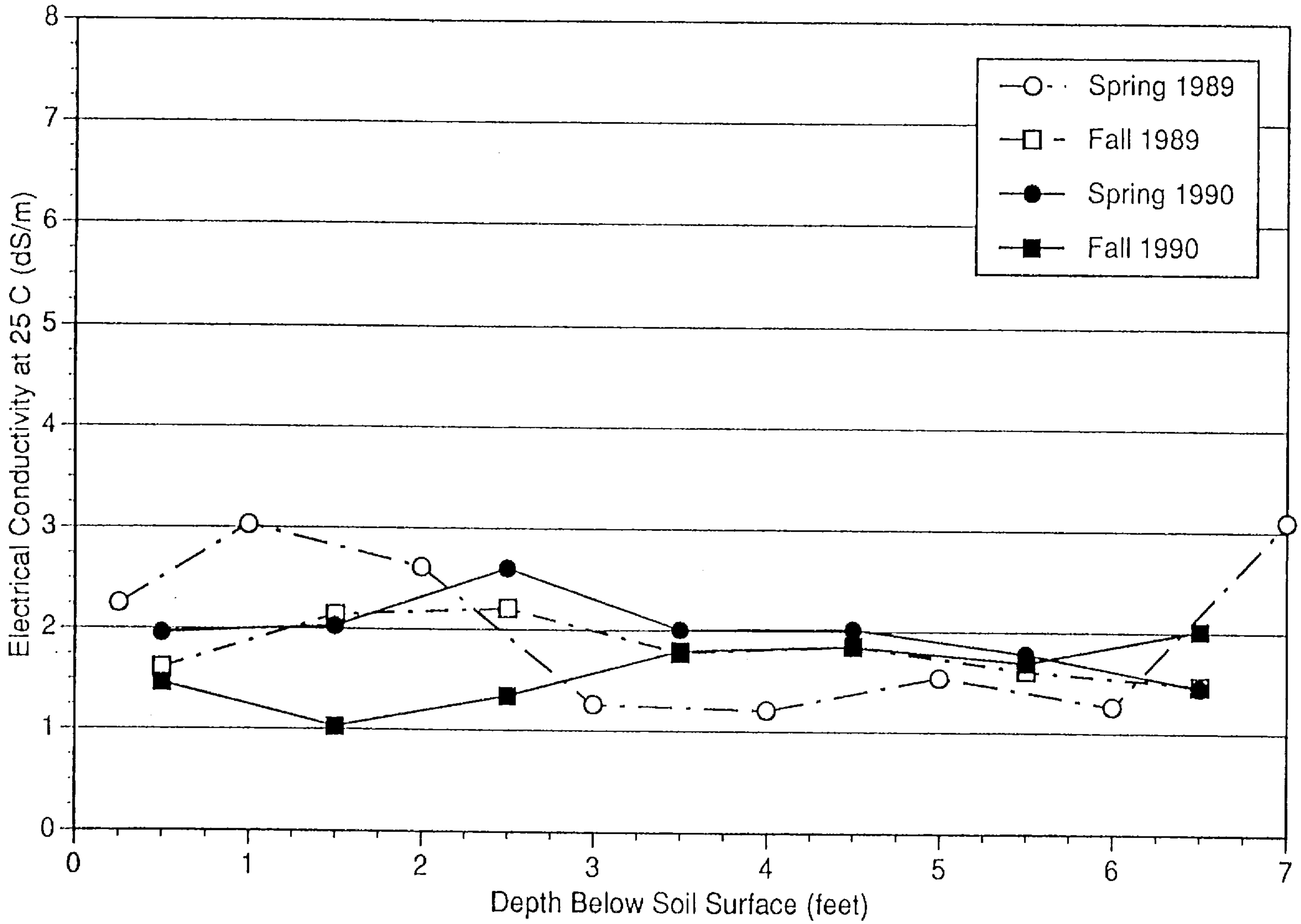


Figure 8

Soil Salinity Measurements during Spring and Fall for Conventional Furrow Plot

B. Soil Boron Concentration

The average soil born concentration within the field during the first two years of the project was 1.53 ± 1.31 ppm. The greatest soil boron concentrations were observed at location 5 during 1989 (4.05 ± 1.99 ppm), at location 6 during 1990 (3.24 ± 1.15 ppm), at location 11 during 1990 (2.39 ± 1.26 ppm), at location 8 during 1989 (2.29 ± 1.09 ppm). These locations were within the subsurface drip and improved furrow irrigation plots.

C. Soil Selenium Concentration

The average soil selenium concentration within the field during the first two years of the project was 2.30 ± 4.02 ppb. The greatest soil selenium concentrations were observed at location 6 during 1990 (8.76 ± 9.58 ppb), at location 10 during 1990 (5.54± 6.96 ppb), at location 9 during 1989 (3.41± 3.24 ppb) and at location 11 during 1990 (2.73 ± 5.79 ppb). These locations were within the subsurface drip and improved furrow irrigation plots.

V. Soil Moisture Content

The trends in the soil moisture content were consistent from plot to plot in 1989. The soil moisture content of the soil profile varied from 3 to 6 inches per foot. The soil moisture content showed a slight decrease at each depth between the beginning of the growing season and the end of the growing season. The top of the soil profile showed a lower average water content and a greater variation than the bottom of the profile. There was less variation in average soil moisture content with depth.

The trends in the soil moisture content in 1990 were similar to those in 1989. The soil moisture content of the soil profile varied from 3 to 7 inches per foot. The soil moisture content was approximately the same at the beginning and the end of the growing season. The top of the soil profile showed a lower average water content and a greater variation than the bottom of the profile. There was less variation in average soil moisture content with depth. There was more variation of soil moisture content at each depth during 1990 than was observed in 1989.

Neutron probes were changed in July 1990 (personal communication with Boyle Engineering). This change may account for some of the observed variation, but should not effect calculations using differences between two points within the soil profile.

The variation in soil moisture content corresponded well with the timing of irrigations, especially at the top of the soil profile.

VI. Soil Matric Potential

Two sets of six soil matric potential sensors were installed in each plot at 0.98 foot (30 cm) increments to a depth of 4.9 feet (150 cm). Data for one set of sensors was reported in the Boyle Engineering Reports. Soil matric potentials were reported as negative numbers.

The soil matric potential measurements for 1989 were generally uniform, except for the shallowest depths. This is consistent with the soil moisture data discussed above.

The sensors for the subsurface drip system showed the smallest potential at the 2.95 feet (90 cm) depth throughout the 1989 growing season. This potential tended to decrease slightly over the season. Soil matric potentials for the other depths in the subsurface drip plot were similar, except for a large drop at 0.98 feet (30 cm) for one measurement in June 1988.

The sensors for the LEPA showed the smallest potential at the 0.98 feet (30 cm) depth throughout the 1989 growing season. This potential tended to decrease slightly over the season. Other soil matric potentials for the LEPA plot tended to increase with depth and varied little until the end of the season.

The sensors for the improved furrow system showed the smallest potential at the 1.97 feet (60 cm) depth until August 1989, when the potential at 0.98 feet (30 cm) became less. Potentials at 0.98 feet (30 cm) and 1.97 feet (60 cm) tended to decrease slightly over the season, and showed some response to an irrigation in August 1989. Other soil matric potentials for the improved furrow plot tended to increase with depth, and varied little over the growing season.

The sensors for the conventional furrow system showed the smallest potential at the 0.98 feet (30 cm) depth throughout the 1989 growing season. The soil matric potential was the only one to show a response to irrigations in July and August 1989. Other soil matric potentials for the conventional furrow plot varied little over the growing season.

The data for the soil matric potential during 1990 was very difficult to interpret because indistinguishable lines were used on several black and white graphs. The data will not be discussed in this report.

VII. Piezometers

Two sets of three piezometer (at depths of 4.5, 7.5 and 10.5 feet) were installed in each plot. Piezometer data reported by Boyle Engineering was corrected for elevation differences between the three piezometers. This data included both pressure and gravitational potentials.

Both piezometers for the subsurface drip system indicated there was little hydraulic gradient between the three depths throughout the 1989 growing season. Both piezometers for the subsurface drip system indicated there was little or no hydraulic gradient between the three depths throughout the 1990 growing season.

One piezometer for the LEPA system indicated there was little or no hydraulic gradient between the three depths throughout the 1989 growing season, while the other indicated an upward hydraulic gradient in September 1989. Both piezometers for the LEPA system indicated there was little or no hydraulic gradient between the three depths throughout the 1990 growing season.

One piezometer for the improved furrow system indicated there was an upward hydraulic gradient between the 7.5- and 10.5-foot depths during the later part of July and August 1989, while the other indicated a downward hydraulic gradient during this period. Both piezometers for the improved furrow system indicated there was an upward hydraulic gradient between the 7.5 and 10.5 foot depths during June and July 1990, and a downward hydraulic gradient during September 1990.

One piezometer for the conventional furrow system indicated there was a downward hydraulic gradient between the 7.5- and 10.5-foot depths during May, June and July 1989, while the other indicated little or no hydraulic gradient during this period. One piezometer for the conventional furrow system indicated there was a downward pressure gradient between the 7.5- and 10.5-foot depths during the May, June and July and an upward hydraulic gradient in September 1990, while the other indicated little or no hydraulic gradient during this period.

The piezometer data indicated there is generally no uniform direction of hydraulic gradient over the entire growing season for a given plot. When the data showed some hydraulic gradient, such as with the conventional furrow plot in 1990, the data was inconsistent between the two sets of piezometers within a plot. One set of piezometers would indicate an downward hydraulic gradient, while the other would indicate a little hydraulic gradient in either direction. The piezometer data was only consistent for the improved furrow plot during 1990. For this case, the hydraulic gradient changed during the growing season.

The piezometer data was difficult to interpret, except in three cases that there were negligible pressure gradients. Changes in the direction of the pressure gradients during the year and inconsistencies between piezometers in the same plot make estimate of the direction of vertical flow during the season and the amount of vertical flow very difficult. In cases where the pressure gradients were negligible, flow in one direction or the other was probably small.

VIII. Shallow Ground Water Elevation

The direction of shallow ground water flow was generally to the northeast in 1989 and 1990.

The depth to the shallow ground water showed the same trends in both years of the project. At the beginning of the growing season, the depth to the shallow ground water was approximately 2.5 - 3.3 feet in each of the four plots. The depth to shallow ground water gradually increased each year until the later part of August. The depth to shallow ground increased rapidly from this time until the end of September. At the beginning of October the shallow ground water was approximately at a depth of 5.8 - 7.5 feet. The decline of the shallow ground water was the result of a combination of consumptive use, deep percolation through the confining layer, and subsurface lateral flow.

The different irrigation technologies temporarily influenced the depth to the shallow ground water. The effect can be seen in the variations in depth to ground water measurements in Figures 9 to 12.

Operation of the subsurface drip irrigation technology had little effect on the depth to the shallow ground water in 1989, and somewhat of an effect in 1990, Figure 9. The effect can be seen in Figure 9 as the variation in the observed depths. The depth of the shallow ground water was between 3 and 4 feet during the first half of the 1989 growing season. The depth increased to 7 feet in October 1989. The depth to the shallow ground water was between 2 and 3 feet for the first half of the 1990 growing season. The depth increased to 6 feet in October 1990. Shutdown of the subsurface drip system in July 1989 may have reduced the influence of this technology on the depth to the shallow ground water.

The depth to the shallow ground water was the largest of the four irrigation technologies with the operation of the LEPA system in 1989, Figure 10. This was because, in part, the LEPA system had been shut down for several days. During 1990, there was a large effect of operation of the LEPA system. In late July 1990 operation of the LEPA system caused a relatively large, temporary ground water mound. This ground water mound corresponded to the operation of the LEPA system for 24 hours over approximately 12 days, when there was some miscommunication as to how the system should have been operated.

The depth to the shallow ground water beneath the improved furrow system is presented in Figure 11. Temporary shallow ground water mounds were created soon after this plot was irrigated in 1989. These mounds persisted approximately one observation period. Similar observations were made in 1990.

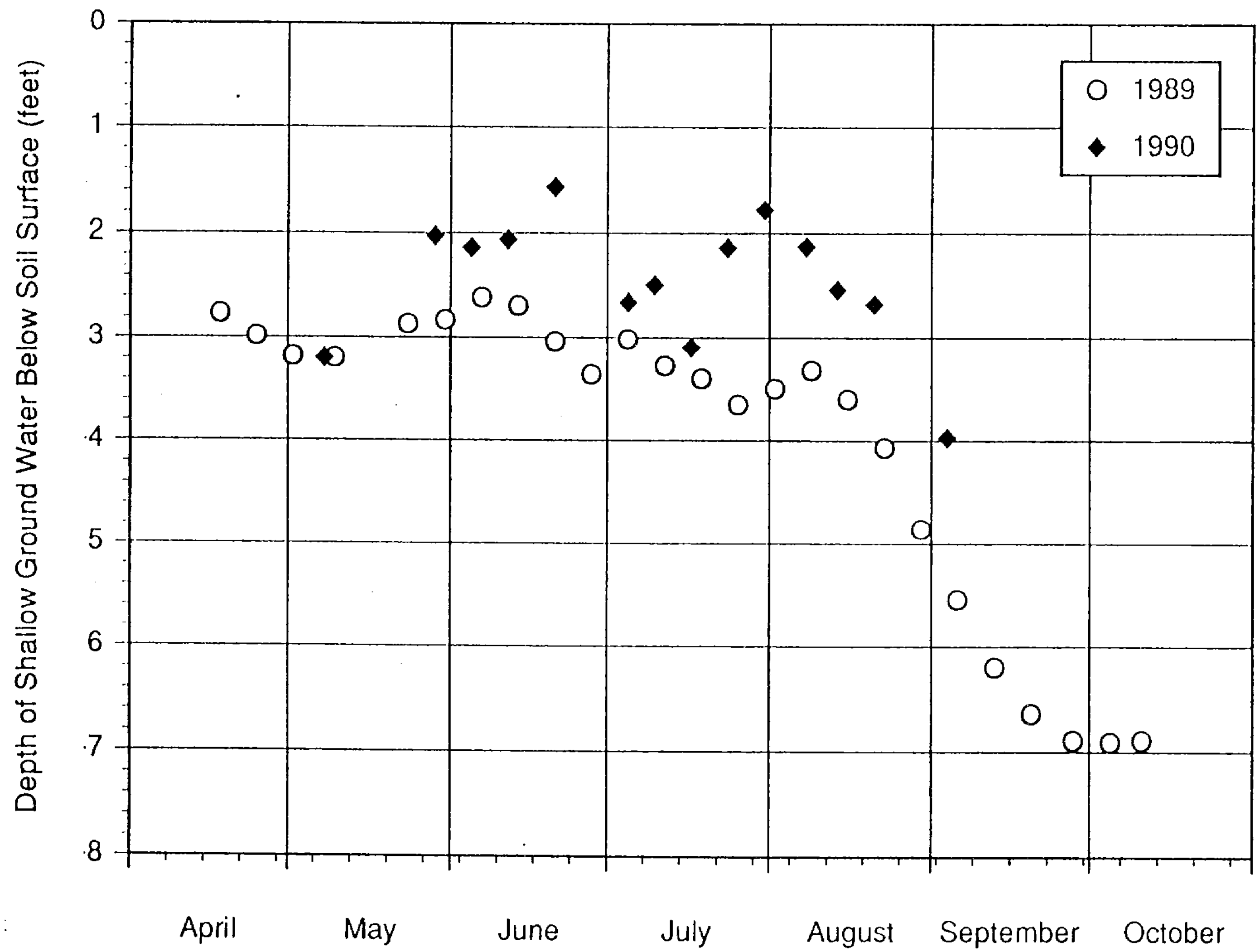


Figure 9

Mean Depth to Shallow Ground Water beneath Subsurface Drip Plot

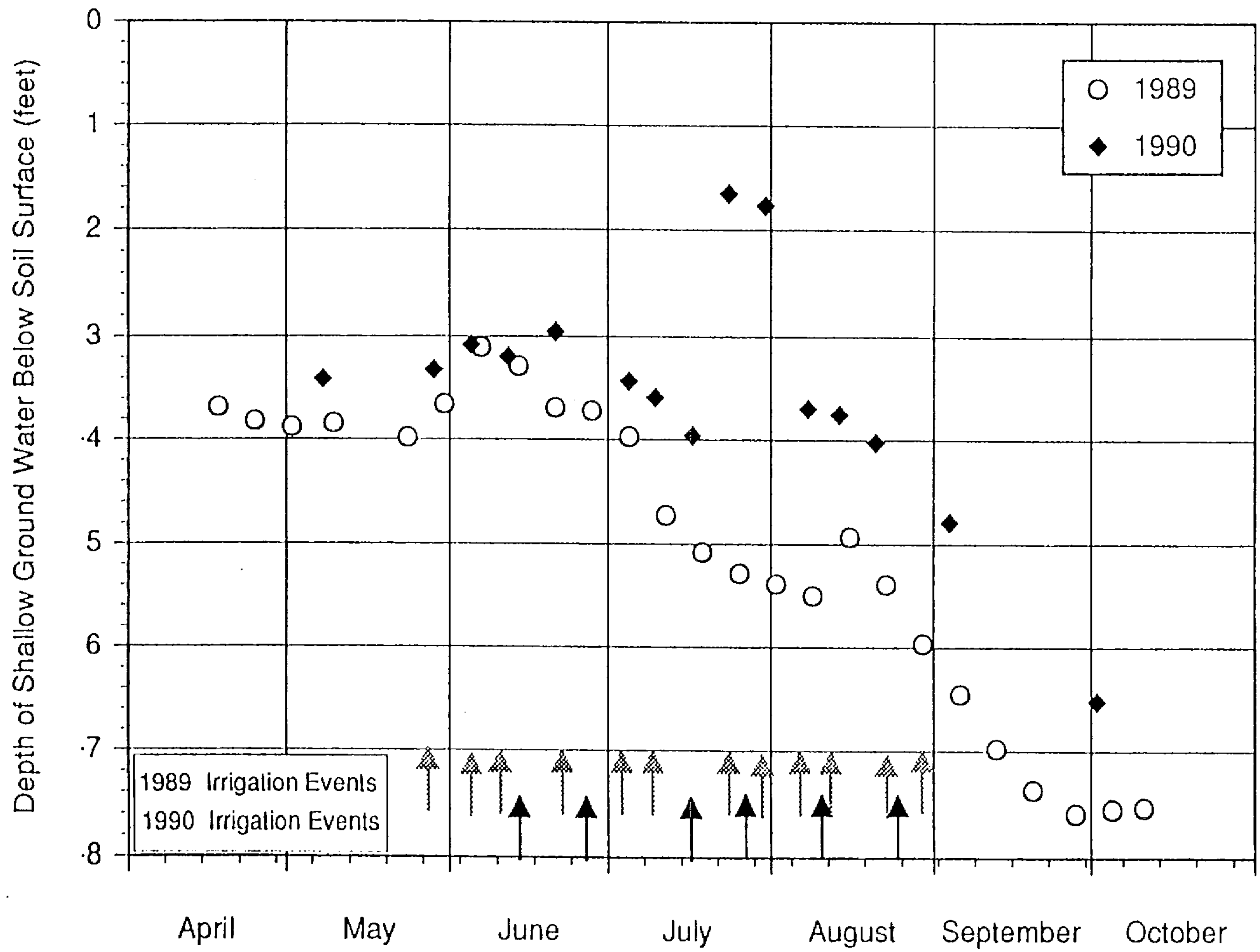


Figure 10

Mean Depth to Shallow Ground Water beneath LEPA Plot

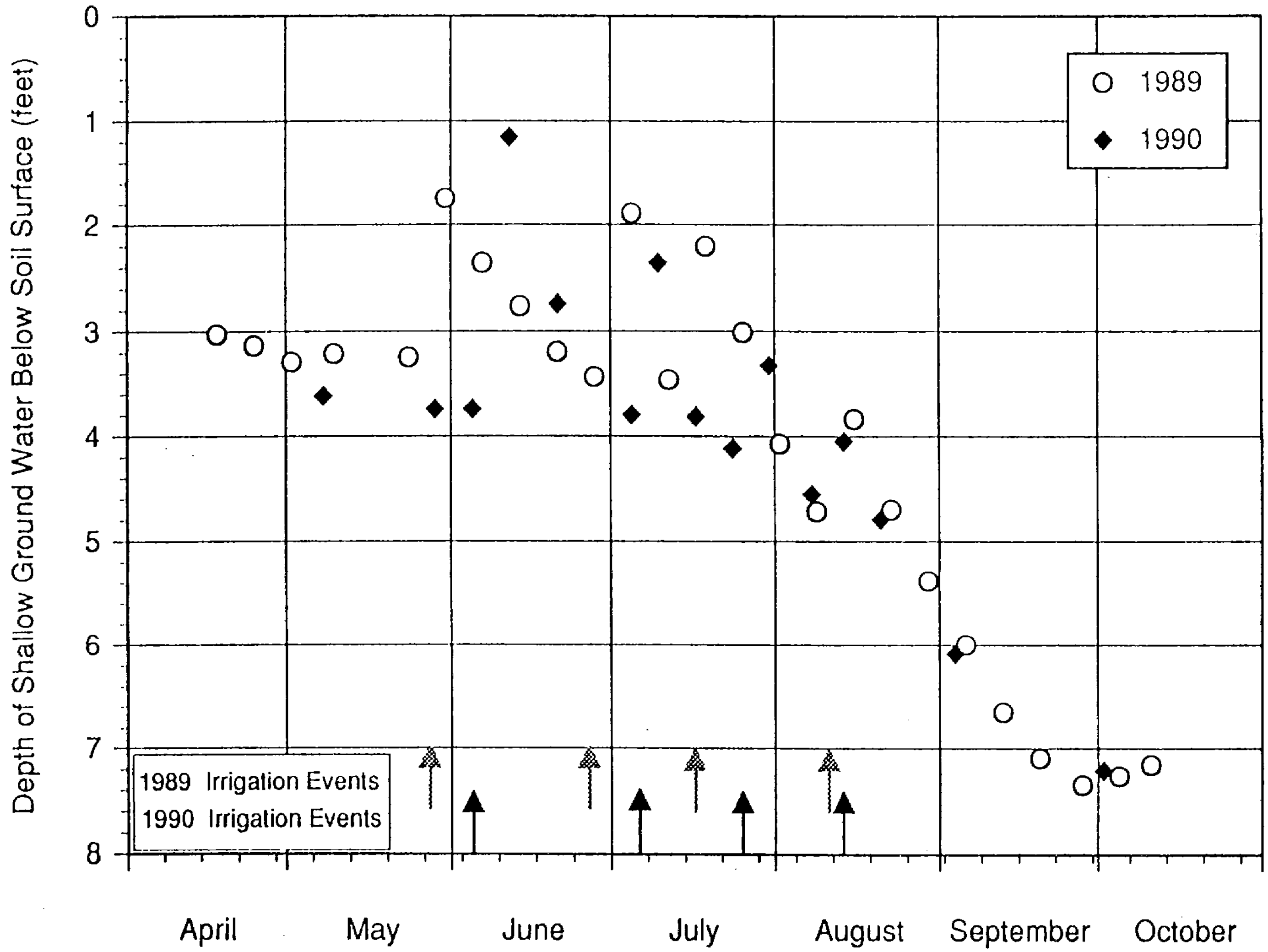


Figure 11

Mean Depth to Shallow Ground Water beneath Improved Furrow Plot

The depth to the shallow ground water beneath the conventional furrow system in 1989 was similar to the other irrigation technologies, Figure 12. Temporary shallow ground water mounds were created soon after this plot was irrigated. These mounds persisted approximately one observation period. Similar observations were made in 1990. The first irrigation in 1989 and the irrigation on July 27, 1990 created the largest shallow ground water mounds during those seasons.

The creation of a ground water mound below a plot closely followed the timing of an irrigation. The creation of ground water mounds was rapid, occurring between one observation and the next (a period of between one and two weeks). The well casings were sealed with bentonite in 1990 to minimize potential seepage down the well casing by irrigation water. The ground water mounds generally did not last more than two weeks. The depletion of the shallow ground water was the result of a combination of consumptive use, deep percolation through the confining layer and subsurface lateral flow. The depth to the shallow ground water table was stable at the beginning and end of the growing season during both years. At these times, there was little consumptive use by the crop, and there was no irrigation. If deep percolation through the confining layer were a similar magnitude as daily crop evapotranspiration, its effect could be detected at these times. Because the depth to the shallow ground water was stable, it can be inferred that deep percolation through the confining layer was small when compared with consumptive use.

If depletion of the ground water mounds during the growing seasons were a result of subsurface lateral flow, then the shallow ground water in neighboring plots should rise as lateral spreading occurs. The general ground water flow pattern was to the northeast. A depletion of the shallow ground water mound below the conventional furrow irrigation plot (in the southwest corner of the field) should have resulted in some rise of the shallow ground water table in the other three plots. The shallow ground water gradients can be estimated from ground water elevation maps of the Boyle Engineering reports for 1989 and 1990.

One of the steepest shallow ground water gradients during either year was at the end of July 1990, Figure 11. The shallow ground water table rose substantially beneath the conventional furrow, producing a large gradient between observation wells OH4 and OI1. From Figure 13 (Reproduced from Figure 90-10 of the Boyle Engineering report for 1990) the shallow ground water gradient between observation well OH4 and observation well OI1 was approximately -0.40 percent.

$$\text{Slope} = \left(\frac{\text{rise}}{\text{run}}\right) = \left(\frac{-3.71\text{ ft}}{932\text{ ft}}\right) = -0.40\ \%$$

The two observation wells are marked with bold "•'s" on Figure 13.

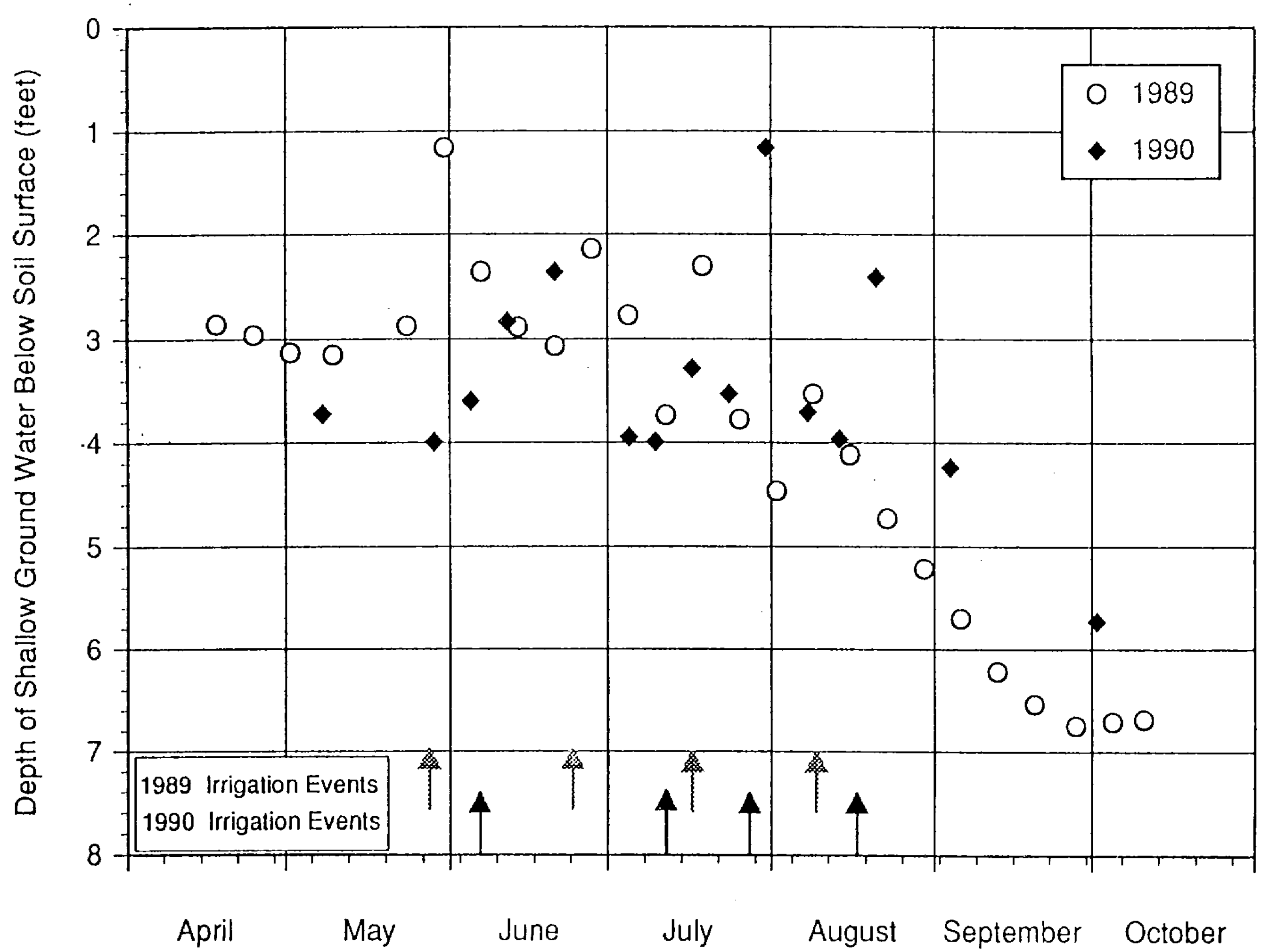
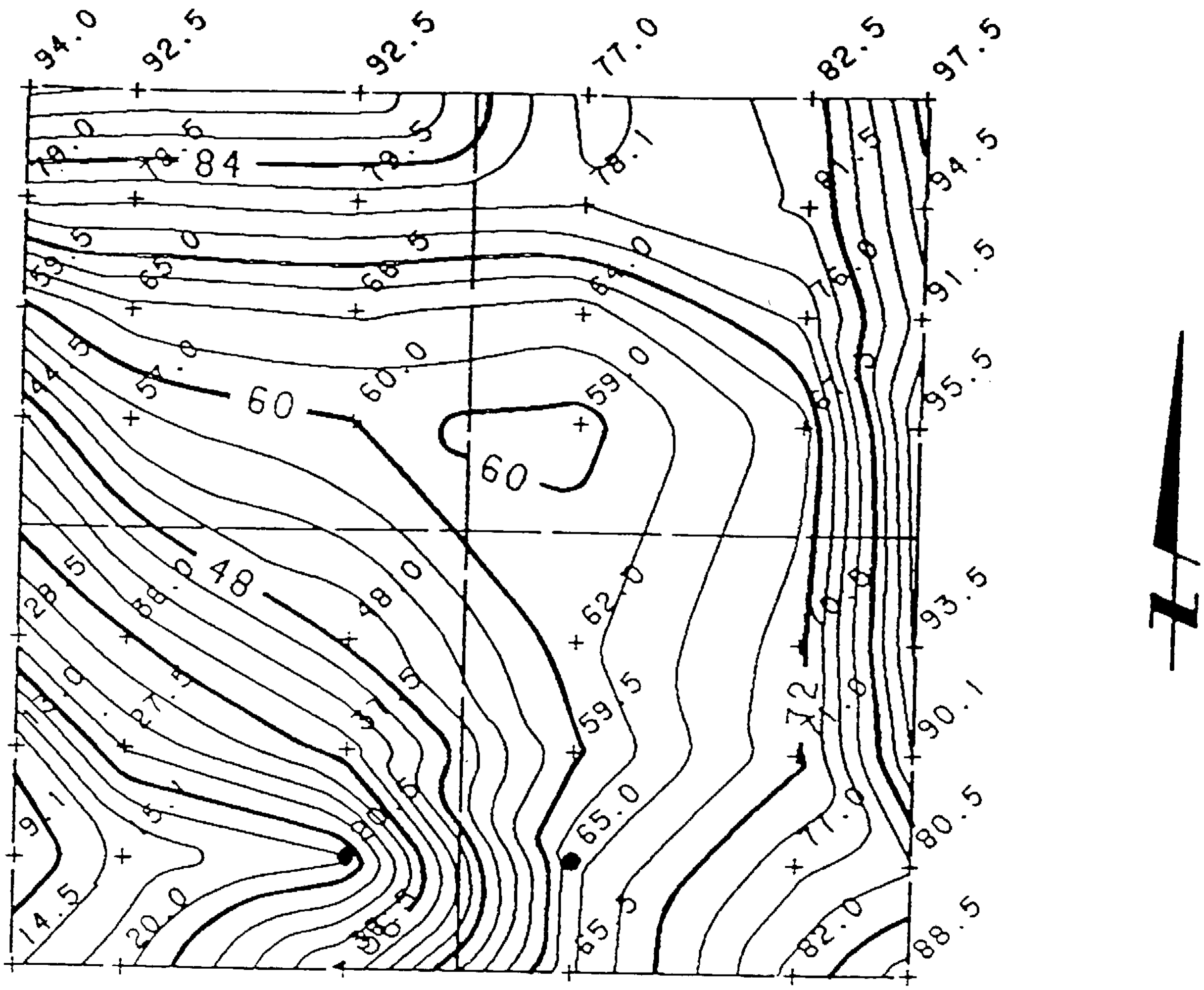


Figure 12

Mean Depth to Shallow Ground Water beneath Conventional Furrow Plot

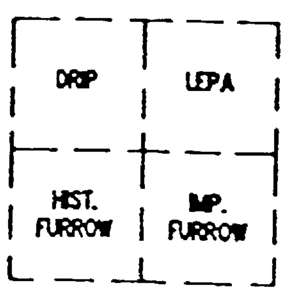


LEGEND

+97.0 — OBSERVATION WELL LOCATION AND DEPTH TO GROUNDWATER FROM GROUND SURFACE

— 96 — GROUNDWATER CONTOUR (3 inch CONTOUR INTERVAL)

— — — TEST PLOT BOUNDARY



TEST PLOT LAYOUT

Figure 13
Shallow Ground Water Contour Map
for July 31, 1990

DEPTH TO GROUNDWATER (inches)
FROM REFERENCE PLANE

Sample Date 7/31/90

At the next measurement on August 8, the depth to the shallow ground water had dropped more than 0.825 feet in both observation wells. If subsurface lateral flow were important, then there should have been some evidence of rise in the shallow ground water, or at least not a 0.825 feet decrease in its depth.

This was one of the steepest gradients during the two years of the project and yet it did not persist more than two weeks. Shallow ground water gradients were generally -1 percent or less. Such shallow ground water gradients would not provide a substantial driving force for moving the shallow ground water from one plot to another.

The data is rough, but it appears that most of the rise of the shallow ground water can be explained by irrigation and the resulting deep percolation, rather than by subsurface lateral spreading. The depletion of the shallow ground water mounds was mainly the result of consumptive use of the water by the crop. Subsurface lateral flow and deep percolation through the confining layer were also occurring, but were not as significant in reducing the shallow ground water during the growing season.

IX. Shallow Ground Water Quality

The shallow ground water salinity, boron and selenium were sampled during each year of the project. Observation well locations from which the samples were collected are shown in Figure 14.

A. Average Shallow Ground Water Salinity

The average ground water salinity varied during the growing season and from irrigation technology to technology. This information was presented in appendices of the Boyle Engineering semiannual reports and is summarized here.

The average ground water salinity beneath the subsurface drip plot varied between 7.5 and 10.5 dS m^{-1} during the 1989 growing season. The average ground water salinity was approximately 6 dS m^{-1} during 1990 with generally smaller variations than observed during the previous season. The average ground water salinity observed both years are presented in Figure 15.

The average ground water salinity beneath the LEPA plot began at approximately 9 dS m^{-1}, and decreased to approximately 5 dS m^{-1} in July, and remained at this level for the remainder of the growing season. The average ground water salinity began the 1990 growing season at approximately 7 dS m^{-1}, and ended the season at approximately 5 dS m^{-1}. Each year there was one large decrease in the observed average ground water salinity. The average ground water salinity observed both years are presented in Figure 16.

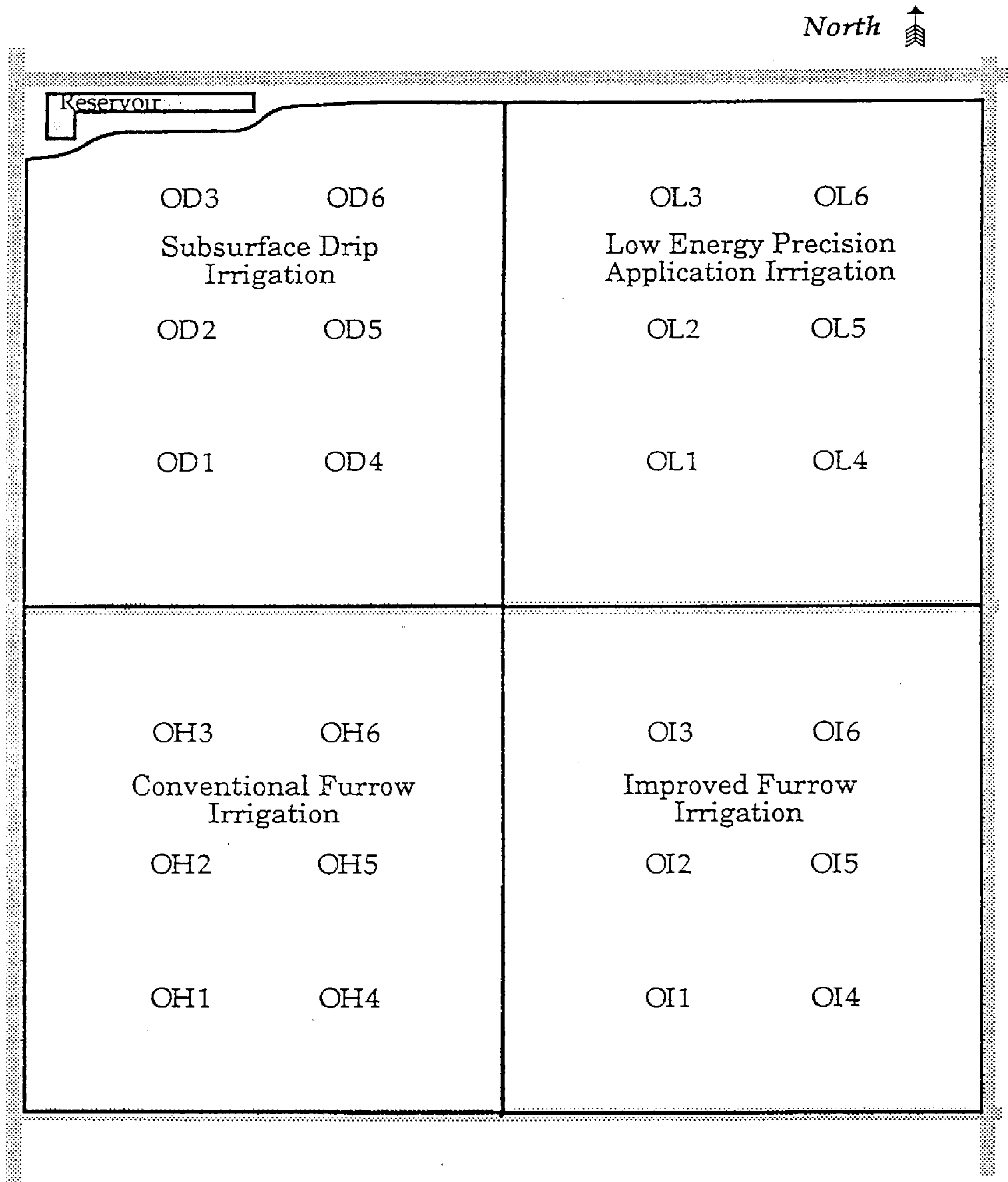


Figure 14
Observation Well Location and Identification Number
(Perimeter observation wells not shown.)

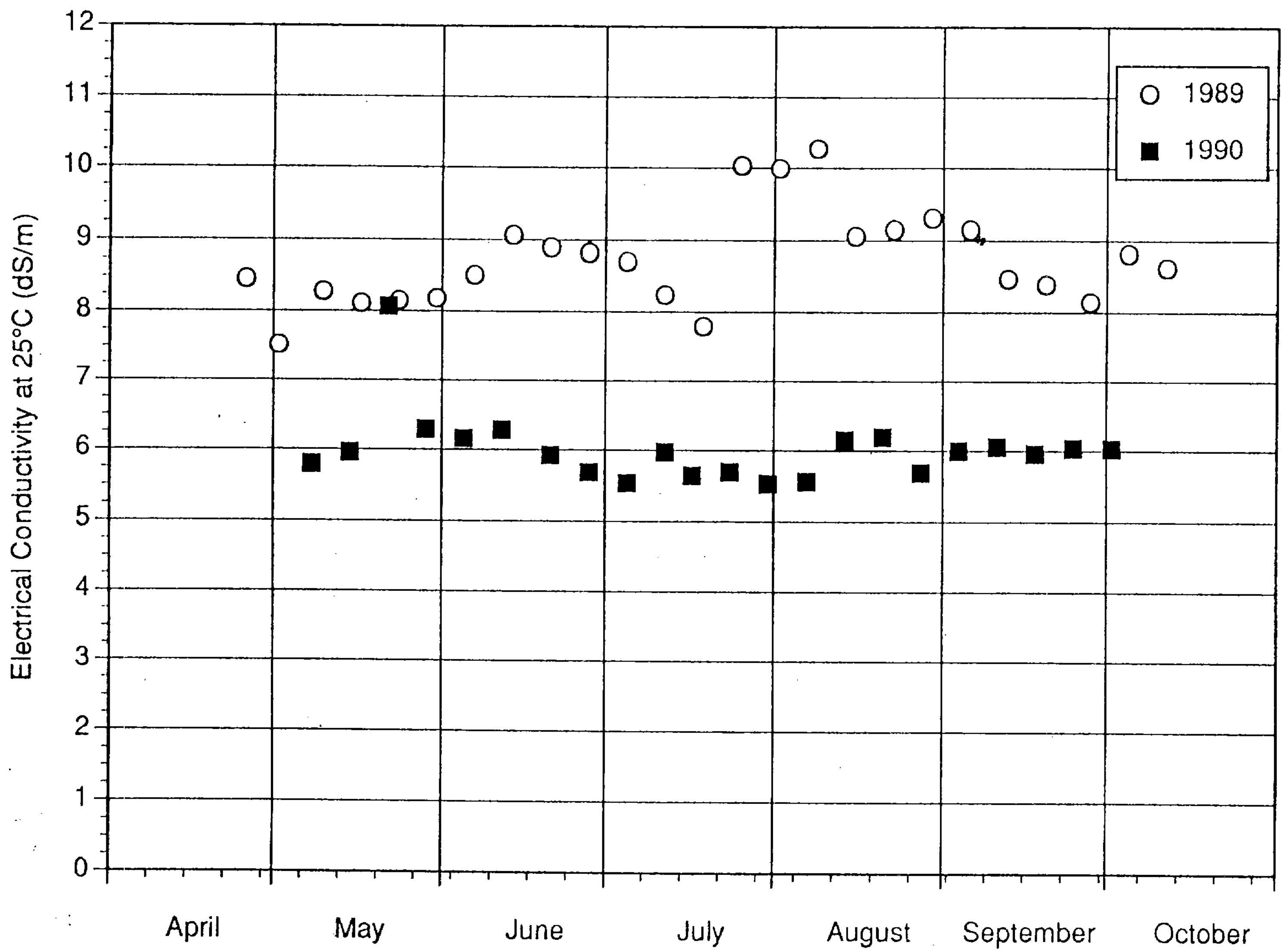


Figure 15
Average Shallow Ground Water Salinity beneath Subsurface Drip Plot

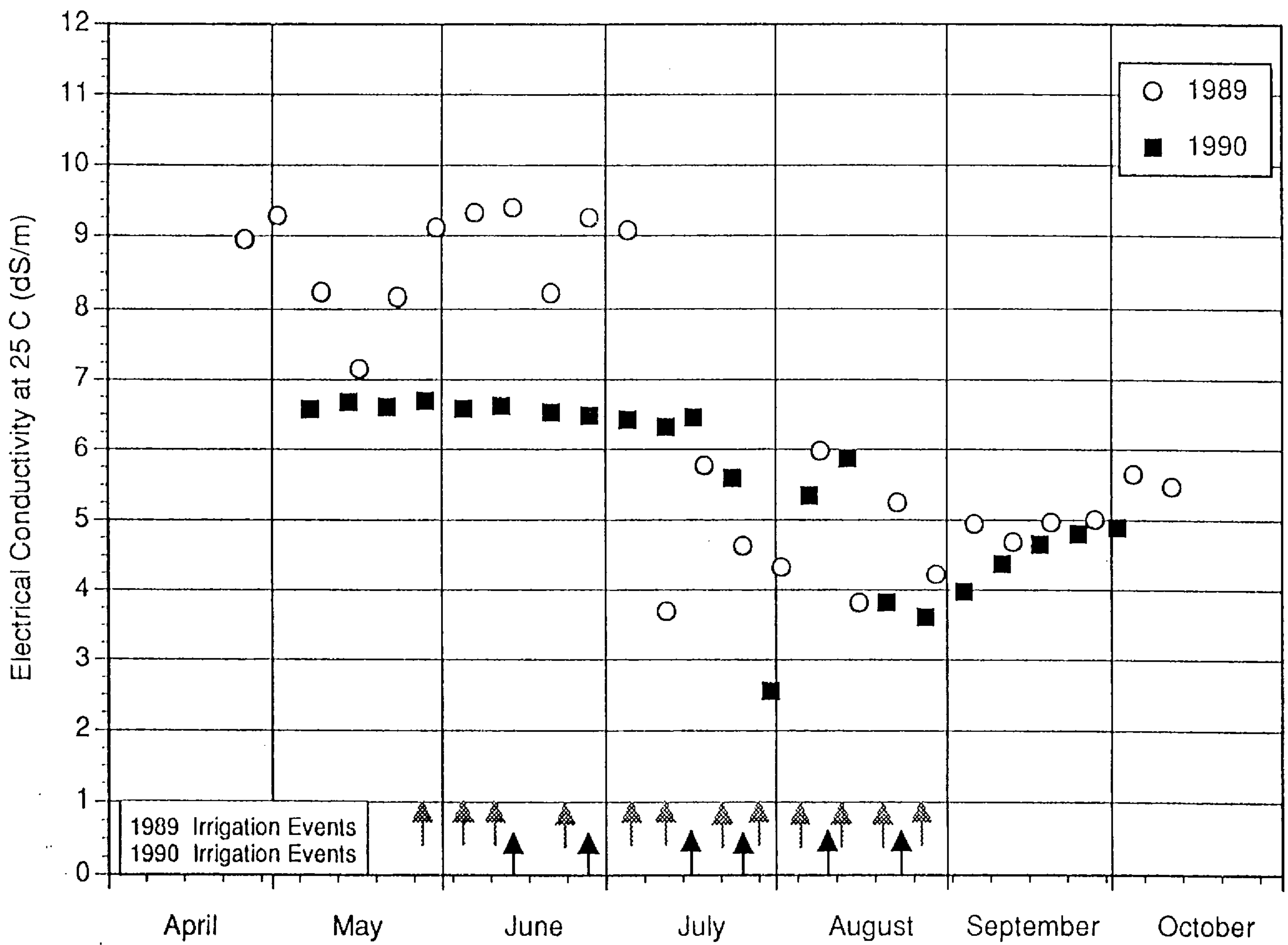


Figure 16
Average Shallow Ground Water Salinity beneath LEPA Plot

The average ground water salinity beneath the improved furrow varied between approximately 3 and 4.5 dS m^{-1} during the 1989 growing season. The average ground water salinity beneath the improved furrow varied between approximately 3 and 5.5 dS m^{-1} during the 1990 growing season. The average ground water salinity observed both years are presented in Figure 17.

At the beginning of 1989, the average ground water salinity beneath the conventional furrow plot was greater than 10 dS m^{-1}. This was the greatest average ground water salinity of the four plots. The average ground water salinity decreased over the growing season to a minimum of approximately 2 dS m^{-1}. There were three very large decreases, at roughly the time of the last three seasonal irrigations. The average ground water salinity was 6 dS m^{-1} at the end of the 1989 growing season. The average ground water salinity was greater than 8 dS m^{-1} at the beginning, and approximately 7 dS m^{-1} at the end of the 1990 growing season. There were three temporary decreases in average ground water salinity roughly corresponding with the timing of three seasonal irrigations. Variations of the average shallow ground water salinity were smaller in 1990 than in 1989. The average ground water salinity observed both years are presented in Figure 18.

These fluctuations in average ground water salinity during either 1989 or 1990 did not correspond well with the amount of over- and under-irrigation of the particular plots. For example, during 1990, the average ground water salinity beneath the conventional furrow irrigation plot decreased from approximately 7.5 to 2 dS m^{-1} in a two-week period between July 24 and July 31, 1990 (Figure 18). There was an irrigation of this plot on July 27, immediately before the decrease, as seen in Table 14 with 0.67 inches of deep percolation during this irrigation. On June 7, 1990 there were 3.44 inches of deep percolation (Table 14), approximately five times as much. On June 12, the average ground water salinity increased slightly from the previous week. On June 21, the average ground water salinity decreased 2 dS m^{-1} (Figure 18). The timing of the salinity fluctuations may have corresponded with the timing of irrigations, but the magnitude of the salinity changes would be hard to predict from the volume of deep percolation reported by Boyle Engineering's irrigation system evaluations.

The average shallow ground water salinity was generally greater than the average soil salinity. Soil salinities may have been diluted when preparing the soil pastes for measurement.

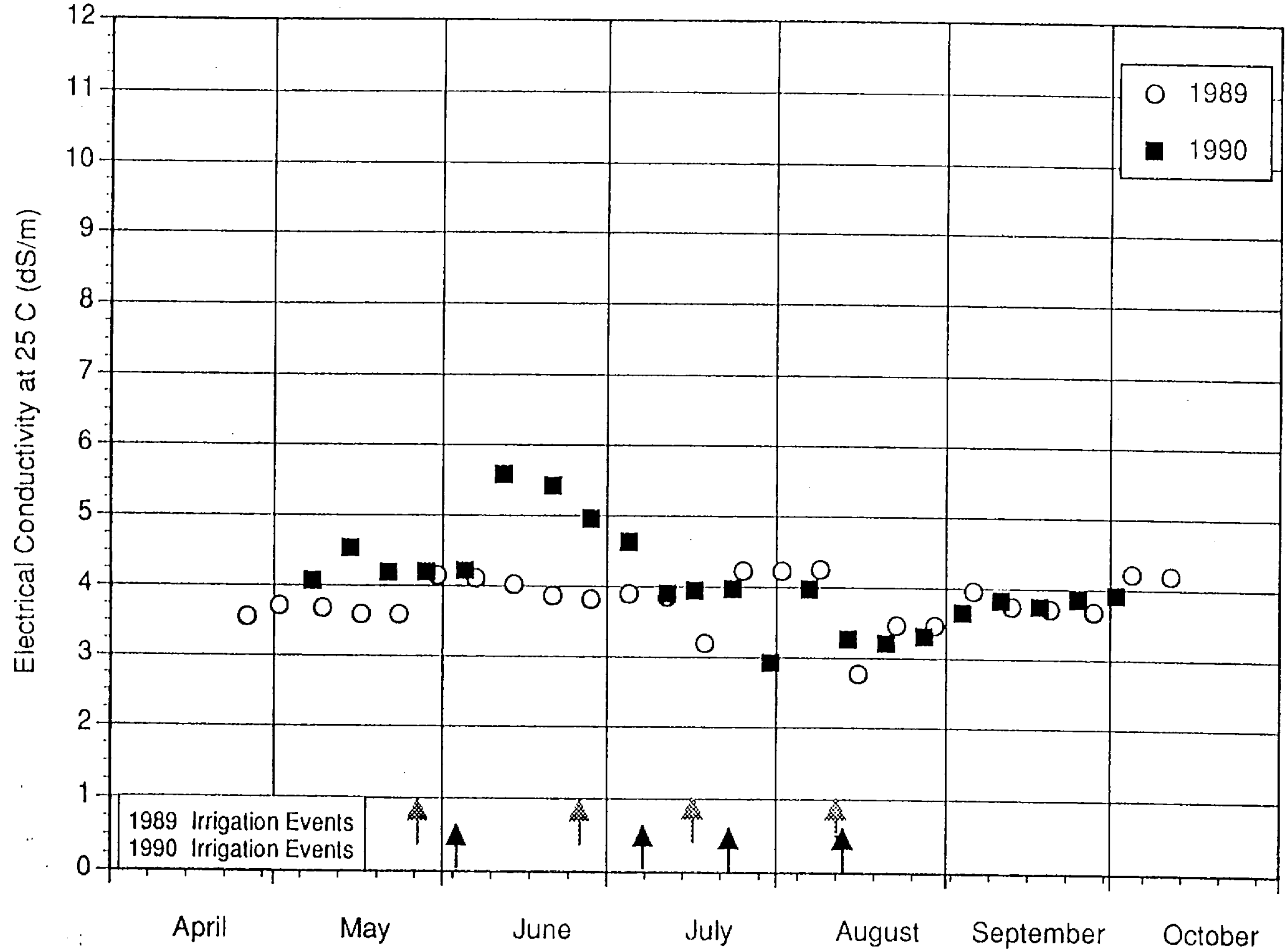


Figure 17
Average Shallow Ground Water Salinity beneath Improved Furrow Plot

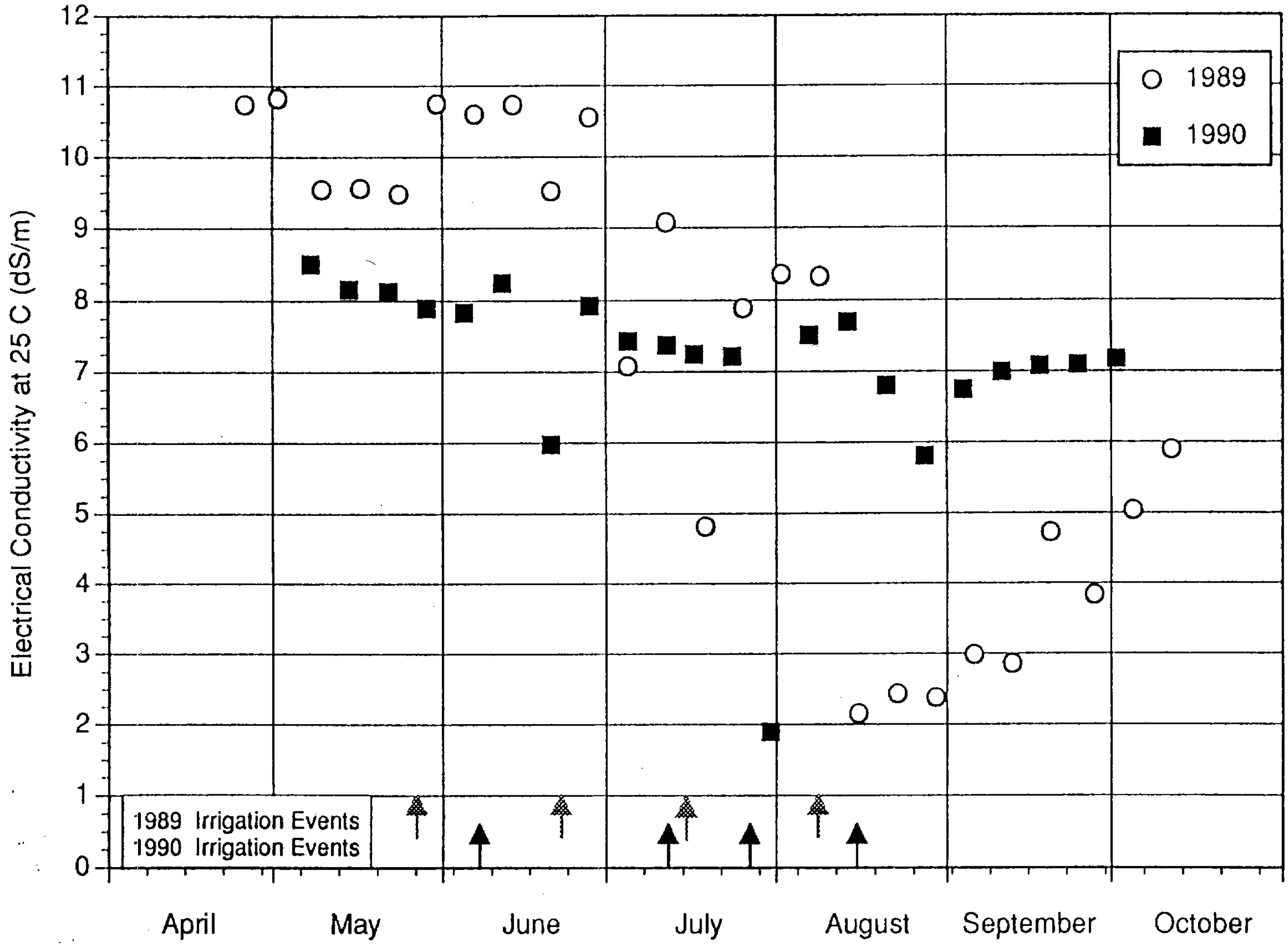


Figure 18

Average Shallow Ground Water Salinity beneath Conventional Furrow Plot

B. Average Shallow Ground Water Boron Concentration

The average shallow ground water boron concentration varied during each growing season and from irrigation technology to technology, Figures 19 to 22. The average shallow ground water boron concentration was greatest with the subsurface drip plot in 1989 and LEPA plot in 1990. In general, the average shallow ground water boron concentration decreased slightly during the 1989 growing season, and increased slightly during the 1990 growing season. Changes were generally less than 2 ppm.

Fluctuations in average shallow ground water boron concentration during either 1989 or 1990 did not correspond well with amount of over- and under-irrigaiton of the particular plots. As with the average ground water salinity, the timing of the fluctuations may have corresponded with the timing of irrigations, but the magnitude of the changes did not correspond with the volume of deep percolation reported by Boyle Engineering's irrigation system evaluations.

Increases in the average shallow ground water boron concentration for the subsurface drip plot in 1989 and the LEPA plot in 1990 are particularly puzzling. With these trials, the boron concentration rose above the measured values at the beginning and the end of the season. Assuming the boron concentrations at these times were indicative of the natural level of boron in the shallow ground water, then the ground water had to be supplied with boron. The irrigation water had boron concentrations less than the shallow ground water, so applied water was not the direct source of the boron. One possibility was that boron in the soil solution was concentrated by evapotranspiration before influencing the shallow ground water. Another possibility was that boron dissolved from the soil exchange complex, thereby increasing the boron concentration. However, these do not explain why there was an increase in boron in only one of the four plots each growing season, why the increase occurred with different trails in different years, or why the increases in shallow ground water boron concentrations were not observed in the same plots with higher than average soil boron concentrations (subsurface drip and improved furrow plots).

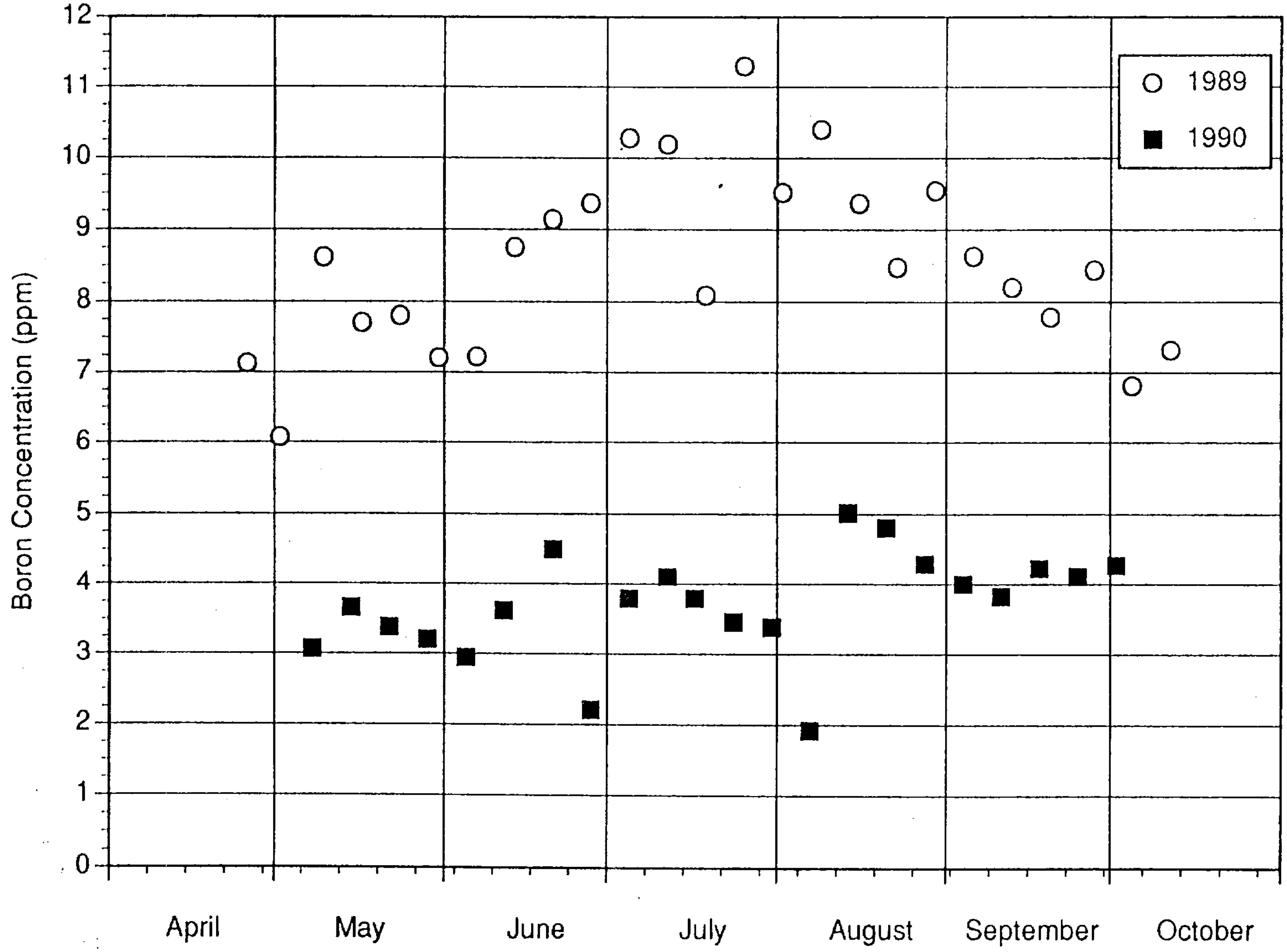


Figure 19

Average Shallow Ground Water Boron Concentration beneath Subsurface Drip Plot

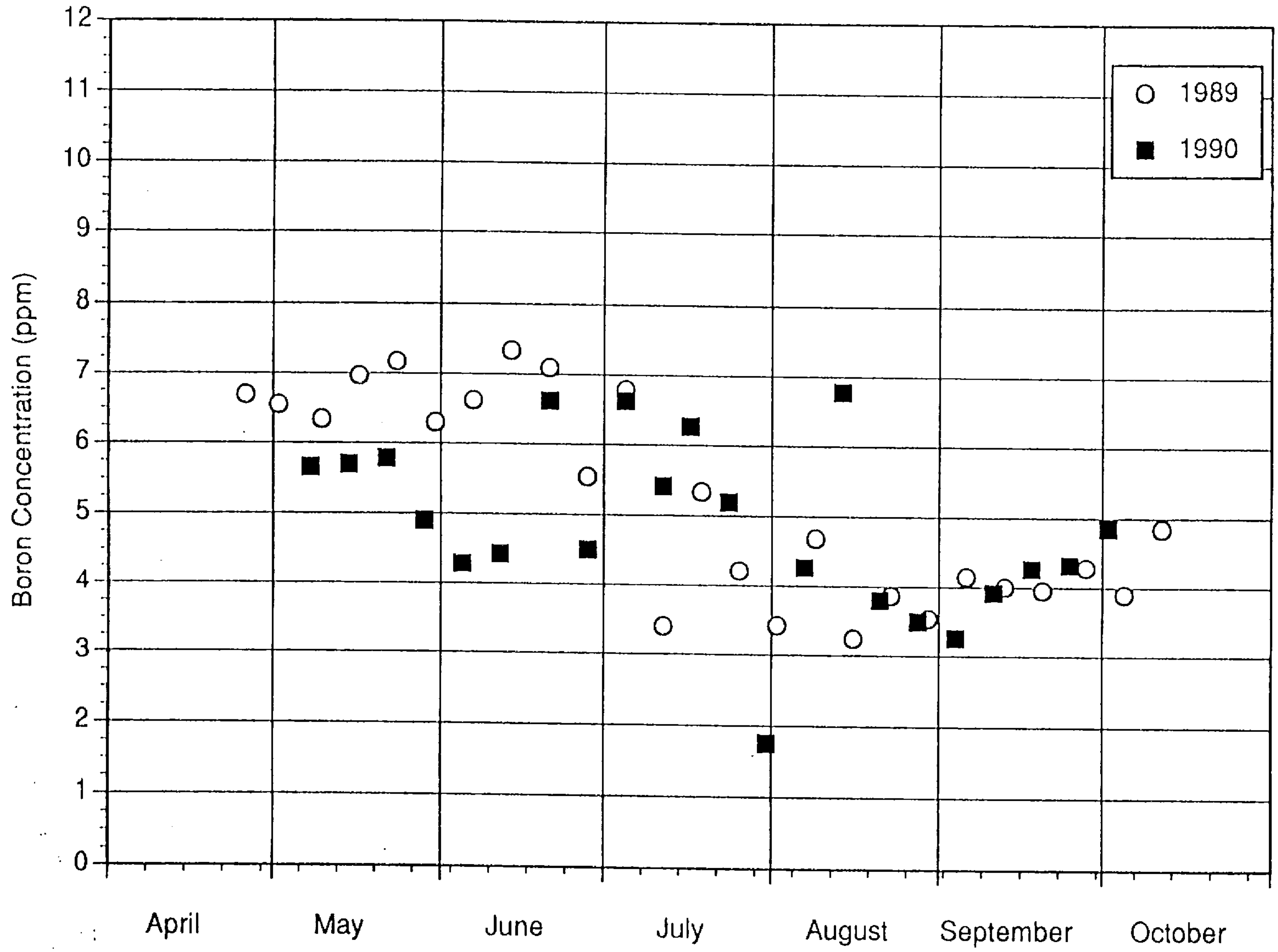


Figure 20
Average Shallow Ground Water Boron Concentration beneath LEPA Plot

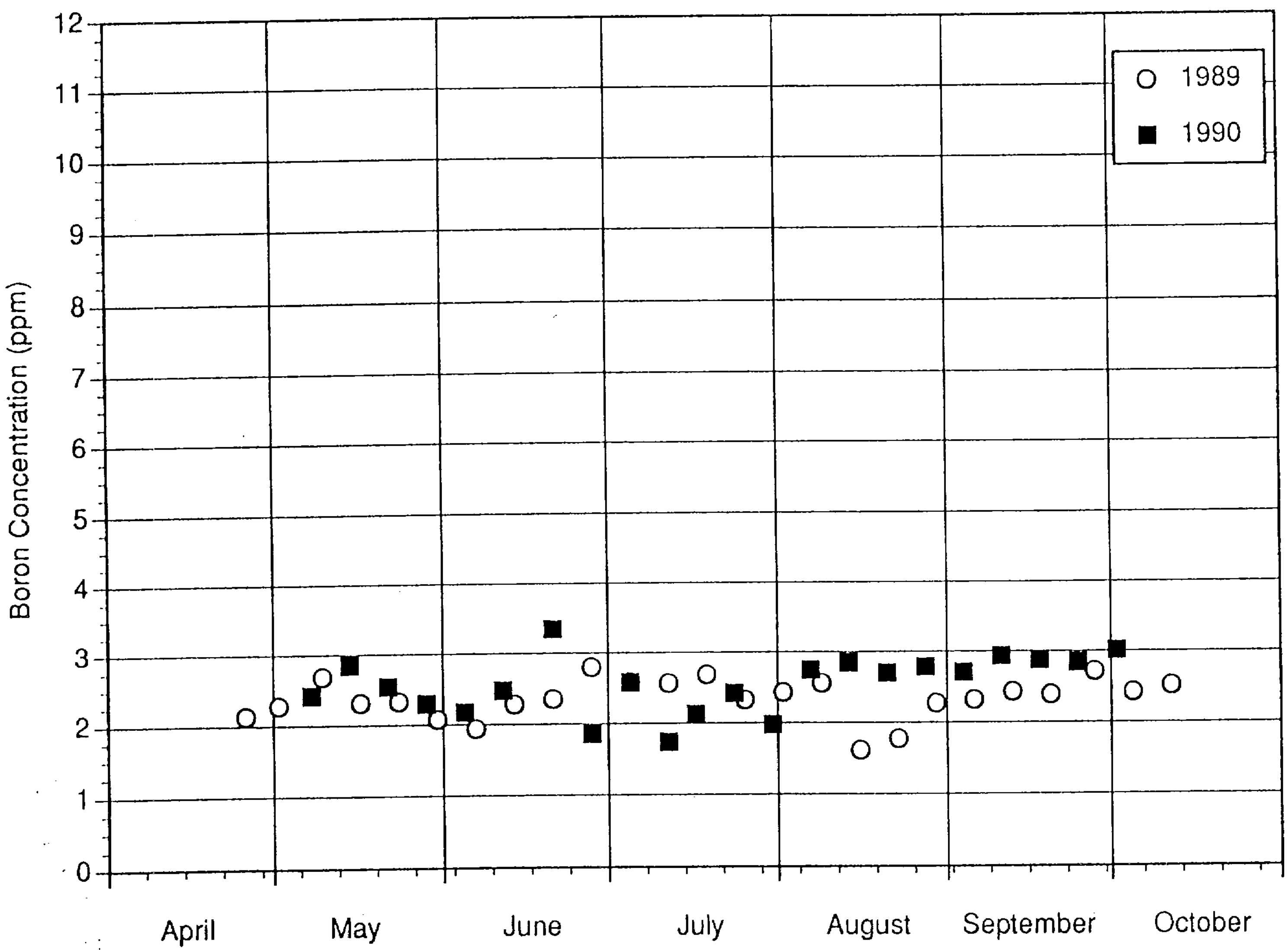


Figure 21
Average Shallow Ground Water Boron Concentration beneath Improved Furrow Plot

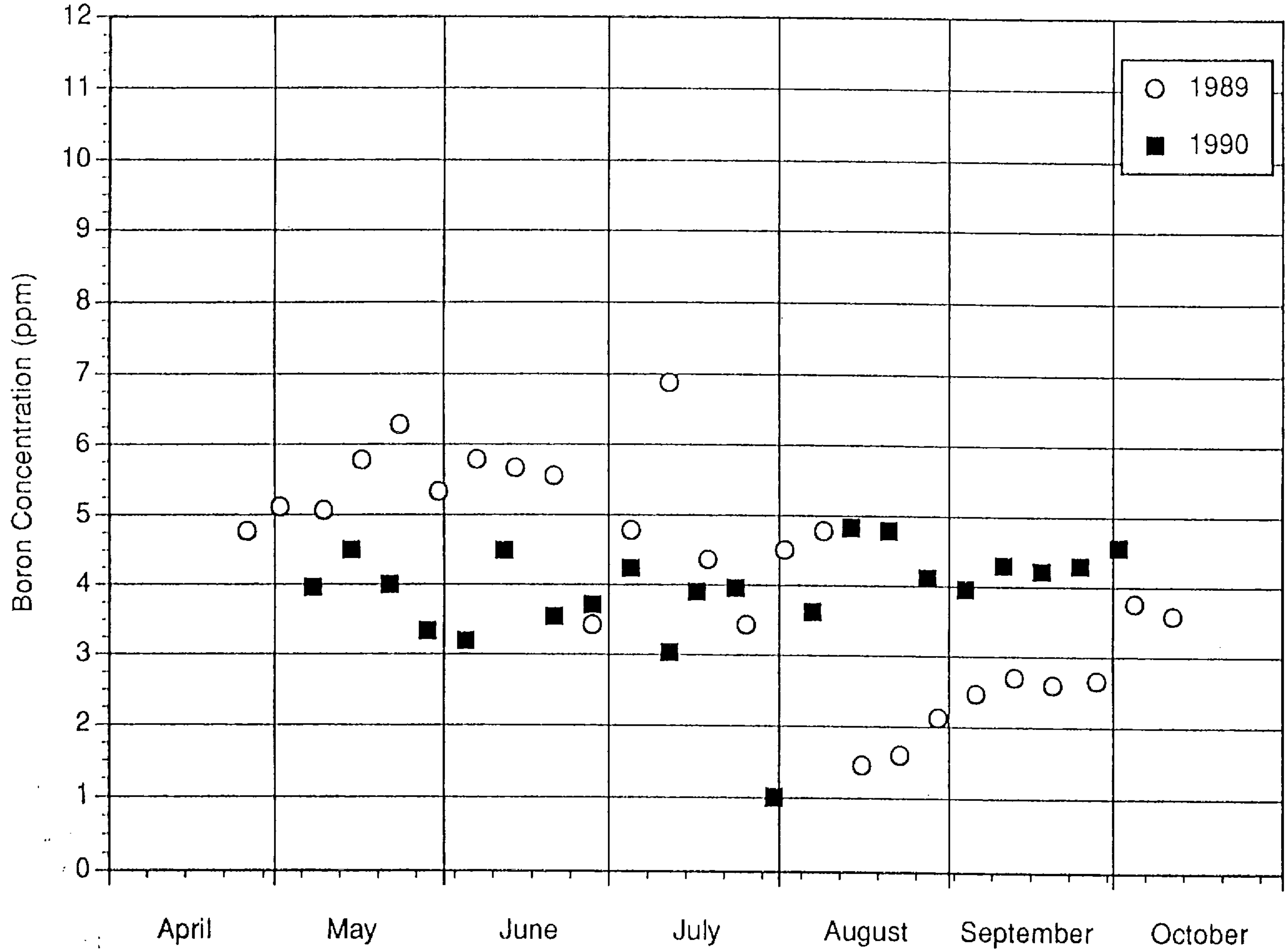


Figure 22
Average Shallow Ground Water Boron Concentration beneath Conventional Furrow Plot

C. Average Shallow Ground Water Selenium Concentration

The average shallow ground water selenium concentration varied during each growing season and from irrigation technology to technology, Figures 23 to 26. There are trends in the shallow ground water selenium concentrations that did not appear with the measurements of shallow ground water salinity and boron concentrations. The average shallow ground water selenium concentration was greatest beneath the subsurface drip and conventional furrow plots during both years of the project. The average selenium concentrations beneath these two plots began the 1990 season slightly greater than the ending 1989 concentrations and generally increased during the 1990 growing season.

The average shallow ground water selenium concentration was generally less than 6 ppb and exhibited little variation beneath the LEPA and improved furrow plots during both years of the project.

The selenium concentrations was the largest for the subsurface drip and conventional furrow plots. The average shallow ground water selenium concentration did not appear to be related to the volume of deep percolation. Both Boyle Engineering and DWR estimated that the volume of deep percolation produced from the subsurface drip plot was at least 0.4 acre-feet per acre less than that produced by the conventional furrow plot. As with the average ground water salinity and average boron concentrations, the timing of the fluctuations may have corresponded with the timing of irrigations, but the magnitude of the changes did not correspond with the volume of deep percolation reported by Boyle Engineering's irrigation system evaluations.

Variation of the average selenium concentration did not appear to be related to the chemistry and transport soil selenium of individual sites. Transport of soil selenium would have been done by over-irrigation during individual irrigations. Over-irrigation increased the depth of the shallow ground water table. Linear regressions of the the depth to the shallow ground water and the observed selenium concentrations in observation wells OD2 and OH3 were computed for the two year period. In both cases the correlation was very poor ($r^2 = 0.004$ both years).

Variations of the shallow ground water selenium concentrations may have been the result of complex selenium chemistry and soil variability. However, the observed shallow ground water selenium concentrations in the subsurface drip and conventional furrow plots were greater than the observed soil selenium in these plots and the field as a whole. The measured soil selenium concentrations were the greatest in the subsurface drip and improved furrow irrigation plots, while the observed shallow ground water selenium concentrations were the greatest in the subsurface drip and conventional furrow plots. And observed average shallow ground water selenium concentrations increased during the second year of the project.

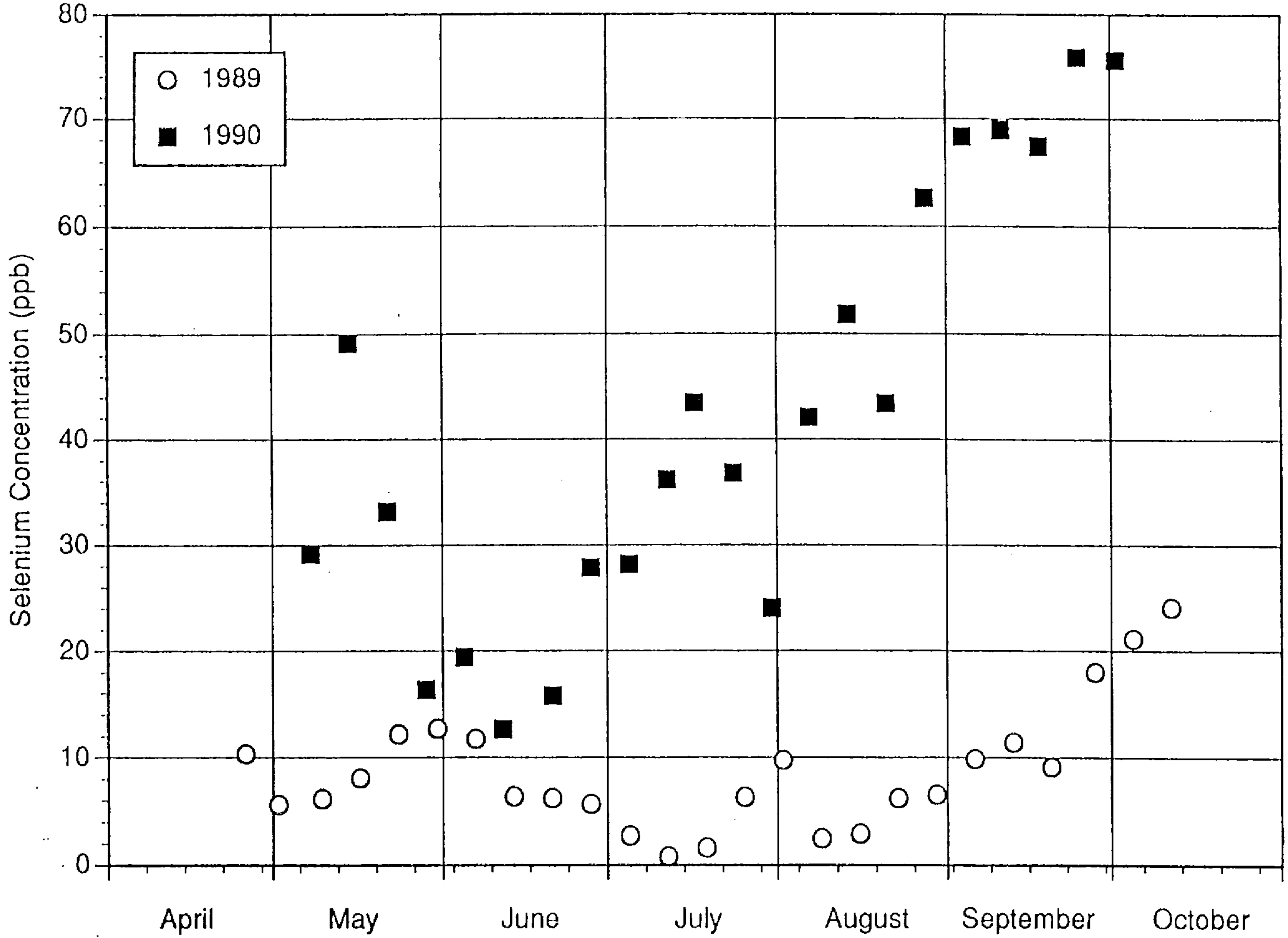


Figure 23
Average Shallow Ground Water Selenium Concentration beneath Subusrface Drip Plot

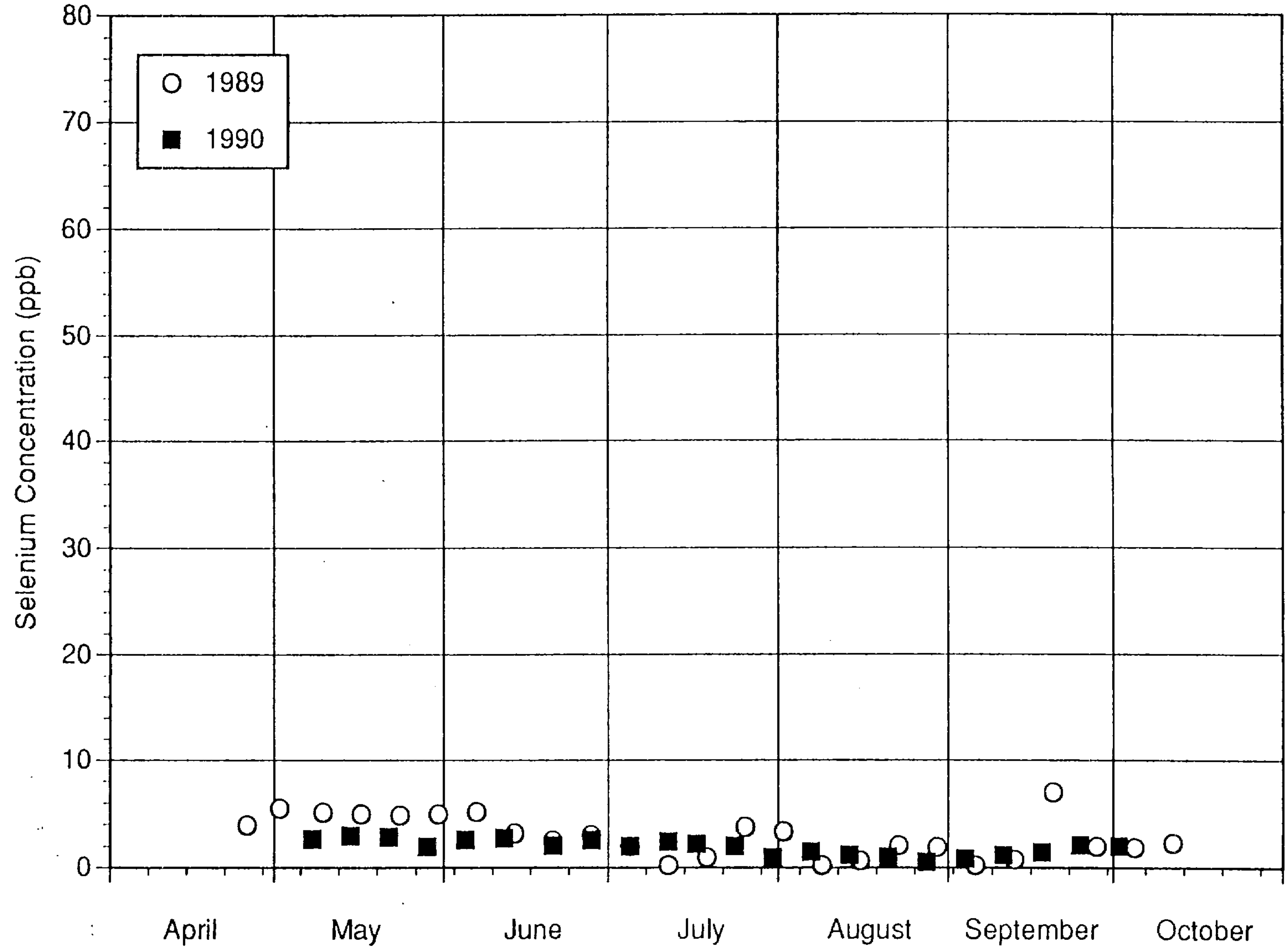


Figure 24
Average Shallow Ground Water Selenium Concentration beneath LEPA Plot

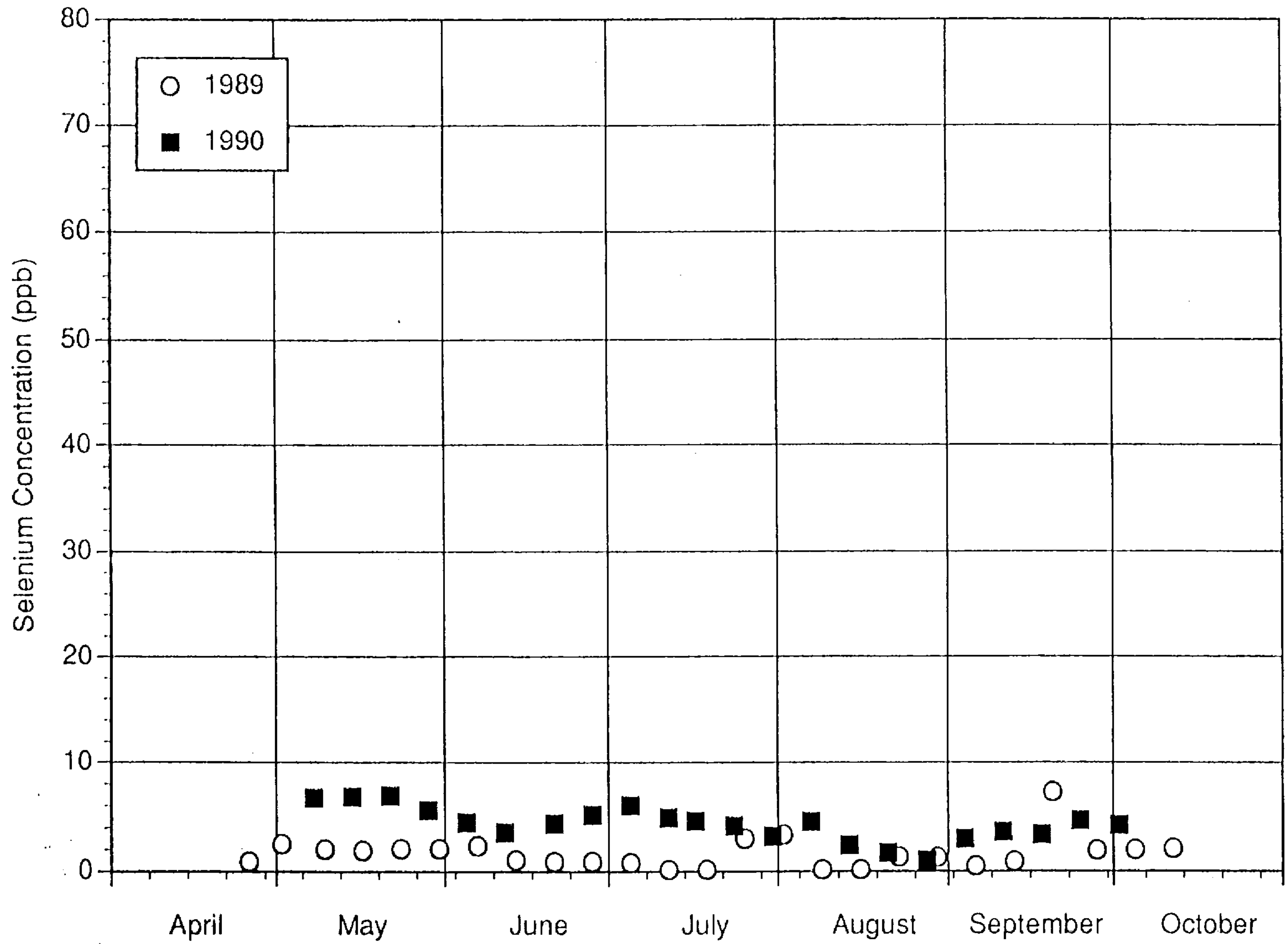


Figure 25
Average Shallow Ground Water Selenium Concentration beneath Improved Furrow Plot

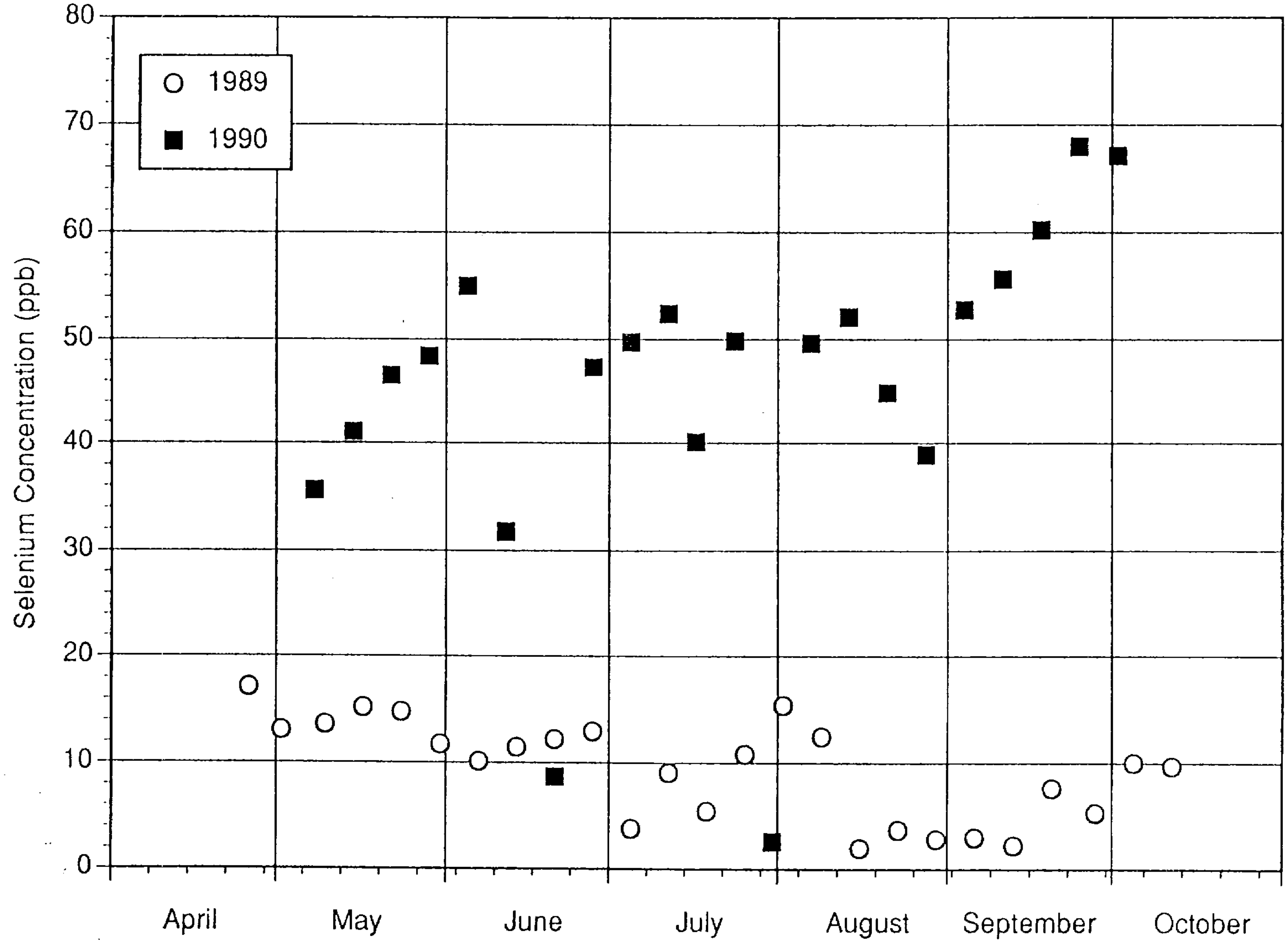


Figure 26
Average Shallow Ground Water Selenium Concentration beneath Conventional Furrow Plot

Attributing the results to soil variability does not explain the trends observed with shallow ground water selenium concentrations: why two of the four plots had consistently higher measured selenium concentrations, why the measured selenium concentrations in the spring of 1990 were slightly higher than in the fall of 1989, or why the measured selenium concentrations of these plots increased during the second year of the project?

There were six observation wells on the far west side of the field: OD1, OD2, and OD3 in the subsurface drip plot, and OH1, OH2, and OH3 in the conventional furrow plot. Boyle Engineering monitored three observation wells within each plot. Data for observation wells OD2, OH1, and OH3 were given in the Boyle Engineering Reports. Measurements from OD2 and OH3 were consistently much greater than measurements reported by Boyle Engineering from the other observation wells both years of the project. Data from OH1 was consistently greater than measurements reported by Boyle Engineering from other observation wells in 1990.

It appeared the measured shallow ground water selenium concentrations were influenced by ground water containing higher selenium concentrations to the west of field. The two plots in which the measured shallow ground water selenium concentrations were the greatest were on the west side of the field. During the second year of the project, this source continued to influence the western edge of the field, and continued to increase the measured shallow ground water selenium concentrations in these observation wells.

The subsurface lateral flow was probably small, as stated above. This is consistent with the analysis for shallow ground water selenium. During the two years of the project, the apparent western subsurface flow did not influence observation wells on the eastern side of the subsurface drip or conventional furrow plots, less than a quarter of a mile away. A large subsurface lateral flow would have had a greater effect on the entire field. However, it appears that the subsurface lateral flow has had only a local effect on the west side of the field at this time.

X. Water Balance

A water balance was presented in the Boyle Engineering reports. The results of the water balance calculations predicted that there was no deep percolation for the subsurface drip system or the LEPA system in 1989, or for the improved furrow system in 1990. The largest volume of deep percolation was predicted to be produced from the conventional furrow system in both years.

The water balance calculations have been re-calculated in this report. The Boyle Engineering reports used only the applied water and the estimated crop evapotranspiration to compute the predicted deep percolation. This analysis has been refined to include changes in the soil moisture content over the growing season, rainfall, and changes of the elevation of the shallow ground water. This method results in increasing the water available to the crop during the growing season. The next several pages explain the alternative method used, and compare the results with those of Boyle Engineering.

A conceptual, seasonal water balance equation for a field consumptively using the shallow ground water table is:

Diverted Water + Precipitation
+ Consumptively Used Shallow Ground Water
+ Subsurface Lateral Flow to the Field
= Crop Evapotranspiration + Change in Soil Moisture
+ Runoff + Change in Ground Water Elevation
+ Deep Percolation
+ Subsurface Lateral Flow from the Field (1)

There are many components to this equation, most of which are difficult to monitor and quantify.

The Boyle Engineering reports provide data for diverted water, precipitation, and runoff (respective appendices for irrigation system evaluation in the Second and Fourth Semiannual Reports). There was approximately 1.24 inches of rain in April and May 1990. Boyle Engineering estimated that only 0.53 inches of this precipitation was effective. The following analysis assumes that all of this precipitation was effective. The difference of 0.71 inches per acre, or approximately 0.06 acre-feet per acre is minimal.

Neutron probe data for soil moisture content was used to estimate the change in soil moisture during the growing season, including changes in the depth of the shallow ground water. The neutron probe readings have been assumed to be representative and the soil relatively homogeneous in order to make this calculation.

The ground water elevation maps illustrate that some lateral flow did occur. However, there was a lack of data to be able to quantify this volume. Net subsurface lateral flow was probably minimal. An assumption of no net lateral flow is reasonable.

There are two remaining unknown terms in the water balance equation above: the volume of deep percolation and the amount of crop evapotranspiration.

A. Crop Evapotranspiration

Crop evapotranspiration is the second largest term in the water budget equation. Boyle Engineering used three different methods to evaluate crop evapotranspiration during the two years.

1) ET_{Crop} Estimate

A crop coefficient was multiplied by daily reference ET (ET_0) to predict crop evapotranspiration. This method is referred to the ET_{crop} method below. Daily reference evapotranspiration was obtained from the University of California West Side Field Station. Boyle Engineering used an equation developed by Dr. C. Phene, USDA/ARS at Fresno, to calculate the crop coefficient:

$$\begin{aligned} K_{crop} = {} & 6.67 * 10^{-4} \text{ (Cumulative Growing Degree Days)} \\ & - 9.05 * 10^{-7} \text{ (Cumulative Growing Degree Days)}^2 \\ & + 2.40 * 10^{-9} \text{ (Cumulative Growing Degree Days)}^3 \\ & - 1.25 * 10^{-12} \text{ (Cumulative Growing Degree Days)}^4 \end{aligned} \qquad (2)$$

$$\text{Cumulative Growing Degrees Days} = 0.5 \sum_{\text{days}} \left(\text{Temp.}_{\text{maximum}} - \text{Temp.}_{\text{minimum}} \right)$$
$$\text{when the Temperature}_{\text{minimum}} \text{ is} \geq 13 \text{ C (55°F)} \qquad (3)$$

K_{crop} does not include the entire season. This coefficient covers the growing season until defoliation of the cotton. Estimates by this method under-predict crop evapotranspiration.

2) Dry Mass Estimate

Crop evapotranspiration was estimated from plant samples that were collected, dried and weighed. This method is referred to as the Dry Mass method below.

3) Lint Yield Estimate

Crop evapotranspiration was estimated by an expression relating lint yield to crop evapotranspiration. This method is referred to as the Lint Yield method below. Boyle Engineering used an equation developed by Dr. C. Phene, USDA/ARS at Fresno, relating the lint yield to the crop evapotranspiration:

$$\text{Lint Yield} = -970.06 + 6.70\,(\text{Crop Evapotranspiration}) + 0.0044\,(\text{Crop Evapotranspiration})^2 \qquad (4)$$

where crop evapotranspiration has dimensions of mm and lint yield has units of kg ha^{-1}. Equation (4) was solved for Crop Evapotranspiration as a function of Lint Yield. Measured yields each year were then used to estimate crop evapotranspiration each year.

4) Crop Evapotranspiration Estimates

The three estimates of crop evapotranspiration for the two years are presented in Tables 15 and 16, respectively.

Table 15
Summary of Estimated Crop Evapotranspiration in 1989
(data taken from the Second Semiannual Report, Boyle Engineering, 1989)

	ET_{crop} (AF/Ac)	Dry Mass (AF/Ac)	Lint Yield (AF/Ac)
Subsurface Drip	1.99	1.38	2.50
LEPA	1.99	1.36	1.48
Improved Furrow	1.99	1.31	1.57
Conventional Furrow	1.99	1.31	1.58
Average	1.99	1.34	1.78
Standard Deviation	0.00	0.04	0.48

Table 16
Summary of Estimated Crop Evapotranspiration in 1990
(data taken from the Fourth Semiannual Report, Boyle Engineering, 1990)

	ET_{crop} (AF/Ac)	Dry Mass (AF/Ac)	Lint Yield (AF/Ac)
Subsurface Drip	1.85	1.43	1.94
LEPA	1.85	1.38	1.13
Improved Furrow	1.85	1.48	1.79
Conventional Furrow	1.85	1.57	1.90
Average	1.85	1.47	1.69
Standard Deviation	0.00	0.08	0.38

There are substantial differences between the three predictions of crop evapotranspiration. Difference between the three predictions of crop evapotranspiration varied by approximately half an acre-foot of water per acre during each year. In addition, during 1989 the estimated crop evapotranspiration from lint yield varies by more than 1 acre-foot per acre for the four plots. Crops were grown on contiguous 40-acre fields, so the weather and soil conditions were similar. There were differences in stand establishments because of the volume and timing of irrigation, salinity of the soil, and other factors. It is unlikely that these factors contributed to such large differences in crop evapotranspiration, as indicated by the standard deviation of the lint yield prediction of crop evapotranspiration.

Differences in crop evapotranspiration between plots should be expected. There was variation in stand establishment among the four plots. For example, in 1990 the LEPA plot was not well pre-irrigated, which resulted in a poor stand of cotton (approximately 70 - 80% percent of maximum plant cover). This should have resulted in a lower volume of water transpired by the crop that year. There was also differences in soil salinity, which can influence the evapotranspiration of the crop.

Errors in the predicted crop evapotranspiration propagate when trying to calculate a water balance for an individual field. The errors in other terms are likely to be large because of the magnitude of this term relative to other terms in the equation above. Therefore, it is important to obtain a defensible estimate of crop evapotranspiration before continuing with water balance calculations.

Estimates of cotton evapotranspiration in Tables 13 and 14 differ from the predictions annual evapotranspiration value of approximately 2.5 acre-feet per acre per year from CIMIS data. Preliminary estimates from Westlands Water District cotton evapotranspiration were 2.17 and 2.25 acre-feet per acre in 1989 and 1990, respectively (personal communication with Westlands Water District). The value will vary depending on the yearly weather conditions, the date of planting and factors affecting the growth of the crop.

Boyle Engineering decided to use the ET_{crop} estimate of crop evapotranspiration while this report was being written. They are working with Dr. Phene to extend the crop coefficient to the entire growing season. Once this has been done, Boyle Engineering will revise the estimates presented in the second and fourth semiannual reports.

XI. Salt and Water Balance

Another way to estimate crop evapotranspiration is by calculating a salt balance and a water balance simultaneously (Aragües 1990). A salt balance equation, similar to the water balance equation above, can be used. Each term in the water balance equation can be multiplied by the respective term for representative salt concentration to produce an equation for the mass of salt. A necessary assumption of this method is that some amount of salts from the soil profile dissolve during the growing season. This mass of salt has to be accounted for if the mass balance equation is to be used properly.

A salt and water balance method was used because of the different approaches used by Boyle Engineering. This alternative method used both salt and water data in the Boyle Engineering reports to obtain a consistent estimate of both the salt and water within the crop root zone for the growing season. Computing a salt balance provides a check on the terms used in the water balance equation. One assumption of this method is that the electrical conductivity of the deep percolation was similar to or less than the electrical conductivity of the shallow ground water. Because irrigations appeared to dilute the average ground water salinity as discussed above, this assumption is reasonable.

Tables 17 and 18 present the estimated electrical conductivity of deep percolation and the average measured electrical conductivity of the shallow ground water for 1989 and 1990, respectively. The electrical conductivity of the ground water has been averaged over the entire growing season.

Table 17
Comparison of Measured and Estimated EC's in 1989

	Measured EC of Shallow Ground Water (Boyle Engineering, 1990) (dS/m)	Estimated EC of Deep Percolation (calculated by DWR, 1991) (dS/m)
Subsurface Drip	8.73	9.23
LEPA	6.59	0.00
Improved Furrow	3.81	2.57
Conventional Furrow	7.25	2.21

The estimated electrical conductivity of deep percolation calculated by DWR agrees well with the average measured electrical conductivity of the shallow ground water in two of the four cases in 1989. No deep percolation was estimated by DWR for the LEPA system (Table 19), so the electrical conductivity was set to zero. For the conventional furrow, the estimated electrical conductivity was less than the measured conductivity of the shallow ground water.

Table 18
Comparison of Measured and Estimated EC's in 1990

	Measured EC of Shallow Ground Water (Boyle Engineering, 1990) (dS/m)	Estimated EC of Deep Percolation (calculated by DWR, 1991) (dS/m)
Subsurface Drip	6.01	6.05
LEPA	5.53	7.23
Improved Furrow	4.07	7.92
Conventional Furrow	6.86	2.15

The estimated electrical conductivity of deep percolation calculated by DWR generally agrees with the average measured electrical conductivity of the shallow ground water in two of the four cases in 1990. The electrical conductivity was over-estimated for the LEPA system and under-estimated for the conventional furrow.

Salt and water balances were calculated for 1989 and 1990. The estimated electrical conductivity of the deep percolation was compared with the average electrical conductivity of the shallow ground water each year. The crop evapotranspiration was varied until the estimated and measured electrical conductivities were similar. The resulting value of crop evapotranspiration in 1989 was 1.95 acre-feet per acre. The resulting value of crop evapotranspiration in 1990 was 1.92 acre-feet per acre. The estimated values of crop evapotranspiration for 1989 and 1990 by the salt and water balance were similar to the ET_{crop} estimates given by Boyle Engineering, even though the two numbers were computed by different methods.

Electrical conductivity of the deep percolation is very sensitive to changes in the water balance. Sensitivity of the electrical conductivity of the deep percolation was exploited to arrive at the estimated crop evapotranspiration values above. For example, the average electrical conductivity of the deep percolation for the four irrigation systems in 1990 was 5.75 dS m^{-1} when the crop evapotranspiration was set to 1.92 acre-feet per acre. If the crop evapotranspiration was increased about half an inch per acre to 1.975 acre-feet per acre, the average electrical conductivity of the deep percolation for the four irrigation systems in 1990 was estimated to be 9.07 dS m^{-1}. If the crop evapotranspiration was increased about another half an inch per acre to 2.02 acre-feet per acre, the average electrical conductivity of the deep percolation for the four irrigation systems in 1990 was estimated to be 11.27 dS m^{-1}.

If the electrical conductivity of the deep percolation was much greater than that of the shallow ground water, then some seasonal increase of the soil or shallow ground water salinity should have been observed. The soil salinity for the subsurface drip and LEPA plots showed small tendencies to increase during the 1990 growing season, while the other two plots did not. The electrical conductivity of the shallow ground water for the four plots did not show tendencies to increase during the 1990 growing season. Therefore, the maximum crop evapotranspiration for 1990 consistent with both water and salt data would have been approximately 2.0 acre-feet per acre.

Once the crop evapotranspiration was estimated, the volume of deep percolation during the growing season was computed by the water balance equation. Tables 19 and 20 present the estimates of net deep percolation based on crop evapotranspiration values estimated by DWR. These estimates use the assumptions discussed above in the Salt and Water Balance Section of this Report. A positive value represents an net accretion to the shallow ground water, while a negative value represents a net contribution from the shallow ground water to crop evapotranspiration.

Table 19
Comparison of Estimated Net Deep Percolation in 1989

	Estimated Net Deep Percolation by Boyle Eng. (Boyle Engineering, 1989) (AF/Ac)	Estimated Net Deep Percolation by DWR (calculated by DWR, 1991) (AF/Ac)
Subsurface Drip	-0.07	0.16
LEPA	-0.31	-0.16
Improved Furrow	0.47	0.61
Conventional Furrow	0.55	0.74

Net deep percolation estimated by the method above compares well with net deep percolation estimated by Boyle Engineering for the 1989 water balance data. Estimated net deep percolation indicates net contributions to the shallow ground water for the three of the four irrigation technologies. Boyle Engineering estimated a net contribution from the shallow ground water, rather than an accretion to the shallow ground water, for the subsurface drip and LEPA systems in 1989. Differences between the estimated and estimated net deep percolation values are both small, and within the range of error for the values.

There were slight increases in the soil salinity of the subsurface drip and LEPA plots over the 1989 growing season. These increases were consistent with small volumes of net deep percolation produced, such as that estimated by DWR, or no net deep percolation at all, such as those estimated by Boyle Engineering and DWR.

Table 20
Comparison of Estimated Net Deep Percolation in 1990

	Estimated Net Deep Percolation by Boyle Eng. (Boyle Engineering, 1989) (AF/Ac)	Estimated Net Deep Percolation by DWR (calculated by DWR, 1991) (AF/Ac)
Subsurface Drip	0.15	0.37
LEPA	0.36	0.35
Improved Furrow	-0.21	0.14
Conventional Furrow	0.55	0.77

DWR predictions of net deep percolation indicate that Boyle Engineering may have under-estimated net deep percolation by as much as 0.35 acre-feet per acre for the 1990 water balance data. Estimated net deep percolation by DWR indicates an accretion to the shallow ground water for all four irrigation technologies during 1990. Boyle Engineering estimates a net contribution from the shallow ground water, rather than an accretion to the shallow ground water, for the improved furrow system in 1989.

There were increases in the soil salinity of the subsurface drip and LEPA plots over the 1990 growing season, but not the other two plots. These increases were consistent with small volumes of deep percolation produced, such as those estimated by Boyle Engineering and DWR. There was no indication that soil salinity of the improved furrow plot increased during 1990. This event would have been estimated if no net deep percolation were produced during the growing season.

Estimated net deep percolation by DWR was greater than estimated net deep percolation by Boyle Engineering for both 1989 and 1990. These differences arise because of the additional terms included the DWR water balance equation: changes in the soil moisture content over the growing season, effective rainfall, and changes of the elevation of the shallow ground water. Inclusion of these terms in the volume of water increased the amount of the water available to the crop. Boyle Engineering and DWR estimated of the amount of water used by the crop were similar during 1989 and 1990. Because the volume of available water estimated by DWR was greater than that estimated by Boyle Engineering, the resulting deep percolation estimated by DWR was greater than that estimated by Boyle Engineering.

Net deep percolation for the four irrigation systems estimated by the two methods above do not compare well with the calculated deep percolation from the individual irrigation system evaluations (Tables 7 - 14). The discrepancy is due to the definition of "deep percolation" used in each case. Irrigation system evaluations, such as those conducted by Boyle Engineering in 1989 and 1990, consider deep percolation as water that passes beyond the root zone during a single irrigation event. In well drained areas, this water cannot be reused by the plant. The only affect one irrigation would have on a subsequent irrigation is a change in the soil moisture between the two events. The field at Harris Ranch was not in a well drained area. There was a shallow ground water table close to the bottom of the root zone, so this definition has some difficulty. The irrigation system evaluations do not generally account for changing water table elevations, and use of water later in the season. The rise in the shallow ground water table may be the result of over-irrigation early in the season. The crop can then use the shallow ground water later in the season. This water was classified as deep percolation when it was originally applied as irrigation water. Deep percolation in the water balance equation is defined as water that is lost and becomes an unused part of the ground water over the entire growing season.

XII. SEASONAL IRRIGATION PARAMETERS

Tables 21 and 22 present a re-evaluation of seasonal irrigation parameters. Applied water and seasonal distribution uniformity reported by Boyle Engineering in Tables 7 through 14 are repeated here. The crop water requirement and drainage volume values are calculated from the salt and water balance method by DWR.

Table 21
Re-evaluation of 1989 Seasonal Irrigation Parameters

System	Applied Water [a] (AF/Ac)	Crop Water Requirement [b] (AF/Ac)	Estimated Drainage Volume [c] (AF/Ac)	Seasonal Distribution Uniformity (%)	Seasonal Irrigation Efficiency [d] (%)
Subsurface Drip	1.92	1.88	0.16	79	98
LEPA	1.68	1.80	-0.16	80	107
Improved Furrow	2.46	2.01	0.61	60	82
Conventional Furrow	2.54	1.96	0.74	61	77

a. Applied Water values taken from the Second Semiannual Report, Boyle Engineering, 1989.

b. Crop Water Requirement = Crop Evapotranspiration + Leaching Requirement + Shallow Ground Water Contribution - Effective Precipitation - Change in Soil Moisture Contributing to Crop Evapotranspiration. This value was estimated by DWR using the salt and water balance method.

$$\text{Leaching Requirement} = 5\% * \left(\frac{\text{Applied Water used for Evapotranspiration}}{\text{Distribution Uniformity}} \right)$$

c. Estimated Drainage Volume = Leaching Requirement + Deep Percolation. This value was estimated by DWR using the salt and water balance method.

d. $\text{Seasonal Irrigation Efficiency} = \left(\frac{\text{Crop Water Requirment}}{\text{Applied Water}} \right) * 100\%$. This value was calculated for this report.

Applied water varied between 1.68 and 2.54 acre-feet per acre during 1989 according to Boyle Engineering. Seasonal distribution uniformities varied between 60 percent and 80 percent during 1989. These irrigation management practices produced seasonal irrigation efficiencies between 82 and 107 percent, and estimated drainage yields between -0.16 and 0.74 acre-feet per acre. A seasonal irrigation efficiency greater than 100 percent indicates that the crop was under-irrigated. This is confirmed by a negative, estimated drainage yield. The largest estimated drainage volume, 0.74 acre-feet per acre, was produced by the conventional furrow irrigation system.

Table 22
Re-evaluation of 1990 Seasonal Irrigation Parameters

System	Applied Water [a] (AF/Ac)	Crop Water Requirement [b] (AF/Ac)	Estimated Drainage Volume [c] (AF/Ac)	Seasonal Distribution Uniformity (%)	Seasonal Irrigation Efficiency [d] (%)
Subsurface Drip	2.00	1.76	0.37	76	88
LEPA	2.21	1.96	0.35	92	103
Improved Furrow	1.64	1.61	0.14	82	98
Conventional Furrow	2.40	1.77	0.77	72	74

a. Applied Water values taken from the Fourth Semiannual Report, Boyle Engineering, 1990.
b. Crop Water Requirement = Crop Evapotranspiration + Leaching Requirement + Shallow Ground Water Contribution- Effective Precipitation - Change in Soil Moisture Contributing to Crop Evapotranspiration. This value was estimated by DWR using the salt and water balance method.

$$\text{Leaching Requirement} = 5\% * \left(\frac{\text{Applied Water used for Evapotranspiration}}{\text{Distribution Uniformity}} \right)$$

c. Estimated Drainage Volume = Leaching Requirement + Deep Percolation. This value was estimated by DWR using the salt and water balance method.

d. $\text{Seasonal Irrigation Efficiency} = \left(\frac{\text{Crop Water Requirment}}{\text{Applied Water}} \right) * 100\%$. This value was calculated for this report.

Applied water varied between 1.64 and 2.40 acre-feet per acre during 1990 according to Boyle Engineering. Seasonal distribution uniformities varied between 72 and 92 percent during 1990. The distribution uniformities are generally greater than in 1989. These irrigation management practices produced seasonal irrigation efficiencies between 74 percent and 103 percent, and estimated drainage yields between 0.14 and 0.77 acre-feet per acre. The largest estimated drainage volume, 0.77 acre-feet per acre, was produced by the conventional furrow irrigation system.

The calculated seasonal irrigation efficiencies in Tables 21 and 22 are greater than the seasonal irrigation efficiencies in Tables 7 - 14. The irrigation efficiencies in Tables 7 - 14 evaluated pre-irrigations and seasonal irrigations. The individual efficiencies were then averaged over the season to compute a seasonal irrigation efficiency. This method did not account for re-use of water later in the season in areas with a shallow ground water table. Over-irrigation early in the season could result in a rise in the shallow ground water that was available for crop use later in the season. The use of the water later in the season increased the calculated seasonal irrigation efficiencies in Tables 21 and 22.

XIII. Yields

Yields and crop values are presented in Tables 23 and 24 for 1989 and 1990, respectively. The price of lint was assumed to be $0.75 per pound and the price of seed was assumed to be $170 per ton for the the calculation of crop value.

Table 23
Summary of Crop Yield in 1989
(data taken from the Second Semiannual Report, Boyle Engineering, 1989)

	Lint (lb/Ac)	Seed (ton/Ac)	Value ($/Ac)
Subsurface Drip	1,527	2,864	1,388.69
LEPA	1,016	1,841	918.49
Improved Furrow	1,064	2,158	981.43
Conventional Furrow	1,081	1,975	978.63

Table 24
Summary of Crop Yield in 1990
(data taken from the Fourth Semiannual Report, Boyle Engineering, 1990)

	Lint (lb/Ac)	Seed (ton/Ac)	Value ($/Ac)
Subsurface Drip	1,291	2,783	1,204.81
LEPA	728	1,816	700.53
Improved Furrow	1,224	2,494	1,129.99
Conventional Furrow	1,275	2,537	1,171.90

The yield and crop value of the subsurface drip plot were substantially greater than the other plots in 1989. During 1990, the difference between the three of the four plots was less dramatic. The low yield and crop value of the LEPA plot was the result of problems with pre-irrigation and equipment in 1989, and problems with pre-irrigation and management in 1990.

XIV. Costs and Benefits

A. Financial Results Estimated by Boyle Engineering

Tables 25 to 28 present summaries of the net revenues report by Boyle Engineering for each irrigation system for 1989 and 1990, respectively. Revenues were taken from Tables 23 and 24 above. Costs include both fixed and variable costs. The costs vary between the two years because of changes in variable costs, such as the cost of energy and the volume of water applied. The costs do not include costs of treatment or disposal of potential agricultural drainage, impacts to third parties or degradation of ground water quality, and some capital costs. Irrigation system costs were calculated assuming a life of ten years and a ten percent interest rate.

Costs for the subsurface drip system were the greatest of the four irrigation technologies, while costs for the conventional furrow system were the lowest of the four irrigation technologies in each of the two years. Costs for the improved furrow system in 1990 include costs for shorter run length and the tailwater return system.

Table 25
Summary of Estimated Net Revenues by Subsurface Drip
(data taken from the Semiannual Reports, Boyle Engineering)

Year	Revenue ($/Ac)	Costs ($/Ac)	Net Revenue ($/Ac)
1989	1,388.69	1,120.11	268.58
1990	1,204.81	1,158.77	46.04
Average	1296.75	1139.44	157.31
Standard Deviation	130.03	27.44	157.36

The subsurface drip system had the largest net return of the four irrigation technologies in 1989 reported by Boyle Engineering. This was directly attributable to the higher yields from this plot in 1989. The revenues were able to overcome the higher system costs because of the large yield. The yield from the subsurface drip plot was less in 1990 than 1989. The net revenue reported by Boyle Engineering in 1990 was, therefore, not as great as in 1989.

Table 26
Summary of Estimated Net Revenues by LEPA
(data taken from the Semiannual Reports, Boyle Engineering)

Year	Revenue ($/Ac)	Costs ($/Ac)	Net Revenue ($/Ac)
1989	918.49	1,000.12	(81.63)
1990	700.53	1,061.83	(361.30)
Average	809.51	1030.98	(221.47)
Standard Deviation	154.12	43.64	197.76

'( )' = a loss

The LEPA system was not able to overcome relatively high system costs in either year of operation. This was attributed to malfunctioning equipment in the first year, and miscommunication and mismanagement during the second year. Because of these problems, the LEPA system was not tested to its full potential during either 1989 or 1990.

Table 27
Summary of Estimated Net Revenues by Improved Furrow
(data taken from the Semiannual Reports, Boyle Engineering)

Year	Revenue ($/Ac)	Costs ($/Ac)	Net Revenue ($/Ac)
1989	981.43	853.78	127.65
1990	1,129.99	964.40	165.59
Average	1,055.71	909.09	146.62
Standard Deviation	105.55	78.22	26.83

The improved furrow system had slightly greater net revenues reported by Boyle Engineering in 1990 than in 1989, despite the increased costs. Higher yield during the second year of operation offset the increased costs of improvements.

Table 28
Summary of Estimated Net Revenues by Conventional Furrow
(data taken from the Semiannual Reports, Boyle Engineering)

Year	Revenue ($/Ac)	Costs ($/Ac)	Net Revenue ($/Ac)
1989	978.63	848.60	130.03
1990	1,171.90	935.92	235.98
Average	1,075.27	892.26	183.01
Standard Deviation	136.66	61.74	74.92

The conventional furrow system had greater net revenues the second year than the first year of operation. The yield increased by about 200 pounds of lint per acre during 1990. This system had the highest net returns of the four irrigation technologies during 1990 reported by Boyle Engineering.

Individual irrigation systems will have variable financial performance over several years. The financial analysis for the first two years of the project suggests an interesting result: there was no statistical difference between the average net revenue of the conventional furrow, subsurface drip and improved furrow systems after the first two years of the project. This result will probably change at the end of the fifth year of the project.

B. Future Evaluation of Economic Results

The financial results of Boyle Engineering are not complete analyses of the irrigation systems because after two years of the project, the different irrigation systems cannot be fully evaluated. The discussion below presents a framework for the analysis at the end of five years. Assumptions that would have to be made after two years because of lack of data are identified.

Evaluation of the irrigation technology should be performed over many years. Total costs and revenues should be used, along with the individual lives of the capital components. Costs and benefits should be extended over a 50-year period with a six-percent annual discount rate. This is a typical project life with a real interest rate. Costs of a drainwater collection system, treatment and initial land leveling costs should be included in the analysis. Such an evaluation would be a more complete comparison between irrigation technologies.

Capital costs of land leveling in both furrow irrigation systems should be included in the total costs of the systems. Land had to be leveled by growers, even if it was done very infrequently. Farmers and Boyle Engineering consider the cost of initial land leveling as sunken costs, and therefore they were not included in the cost of operation by Boyle Engineering. Neither Boyle Engineering nor Harris Farms leveled any of the four plots before conducting the demonstration project, so there was some defense for not including initial land leveling costs in the capital costs of the project. A small amount of land leveling was included in the cost of yearly operations by Boyle Engineering for maintenance of the furrow irrigation plots.

Costs of individual capital components should be discounted by the respective life of the component. Boyle Engineering reported the economics by the individual costs of the irrigation technology, and by the net benefit to the grower. When reporting the net benefit of the grower, the total capital costs of the irrigation technology were generalized, and discounted over a life of ten years at a rate of ten percent (Tables 25 - 28). This analysis should use the lives reported by Boyle Engineering on the economics of the individual irrigation technologies. For example, the pump and filtration system for the subsurface drip technology in 1990 was assumed to have a life of 15 years, not ten years.

One of the purposes of this project was to evaluate the amount of agricultural drainage produced by the different irrigation technologies. Part of this purpose includes making the irrigation system financially responsible for the agricultural drainage produced over its reasonable life. In order to do this, the evaluation of each irrigation system must include a cost for the agricultural drainage it was predicted to produce each year of the life of the project.

The field did not have a subsurface drainage system during the first two years of the project. When a financial analysis was performed for individual years, the cost of a subsurface drainage system did not have to be included. However, it is unlikely that this land would remain in production for 50 years without installation of a subsurface drainage system.

A subsurface drainage system could be installed to reduce the depth to the shallow ground water and/or to be able to remove salts from the soil profile. An estimate has to be made as to when during the life of the project a subsurface drainage system would be installed in each field. After two years of the project, there is no clear trend as to the change in soil salinity or change in the elevation of the shallow ground water. Estimates of when a subsurface drainage system would be installed beneath a plot are very difficult without trends in these parameters.

The irrigation system would be managed differently once a subsurface drainage system was installed beneath a plot. Applied water and drainage volume would change. These changes would effect the yield of the crop. It is beyond the scope of this report to evaluate the relationships between deep percolation, changing shallow ground water elevations, soil salinity and yield of the crop. Estimates of how an individual irrigation system would be managed after installation of a subsurface drainage system are also very difficult with only two years of data.

The estimates of when a subsurface drainage system will be installed and how the irrigation system would be managed will not be easy after five years. However, these estimates will be necessary in order to financially account for volume of drainage volume produced by each irrigation system.

Finally, a cost for treatment or disposal of the drainage produced by the individual plot will have to be estimated. Once the subsurface drainage system has been installed , this cost can then be included in the total costs of the system over the remainder of the life of the project.

When the treatment cost of drainage can be included in the economic analysis of the irrigation systems, each system can be fully evaluated. Until then there will be two different ways to evaluate each system. There will be an economic analysis of the individual system, such as given in Tables 25 to 28. There will be the volume of drainage produced, such as those given in Tables 21 and 22. There is no present method to combine the two rankings into one without assumptions about the installation of subsurface drainage systems and the changes in operation of irrigation systems after the drainage systems are installed.

CHAPTER 4. CONCLUSIONS

Two years is not a very long time to conduct a field demonstration project. The conclusions of this report are based on a short study. The study will continue for another three years, at the end of which some of the initial conclusions may change.

The majority of the deep percolation occurred during the pre-irrigation and the first irrigation of each growing season according to the individual irrigation system evaluations. Pre-irrigation was performed with hand-move sprinkler and furrow irrigation systems both years. Seasonal irrigations were performed with the respective irrigation technology. Approximately half of the deep percolation for the subsurface drip, improved furrow and conventional furrow systems occurred during the first two irrigations for both years. The volume of deep percolation was the greatest for the conventional furrow system during both years. Reduction in the amount of the water applied during the pre-irrigation and the first season irrigation has the greatest potential to reduce the amount of agricultural drainage.

Cotton irrigated with the subsurface drip system used the least applied water during 1989. (The LEPA system had mechanic problems and unintentionally applied less water than the subsurface drip system.) Cotton irrigated with the improved furrow system used the least applied water during 1990.

Irrigation scheduling alone appears to be insufficient to reduce the volume of applied water or deep percolation from furrow irrigation. Irrigation scheduling alone on the improved furrow irrigation plot in 1989 did not result in significant water conservation or reduced agricultural drainage compared to conventional furrow irrigation. Irrigation scheduling, shorter furrow lengths (630 feet), tailwater return, furrow torpedoes and modified set times and flow rates on the improved furrow irrigation plot in 1990 did result in significant water conservation and reduced agricultural drainage compared to conventional furrow irrigation. Irrigation scheduling should be promoted in combination with the others methods, such as those mentioned above, to reduce the volume of applied water and agricultural drainage water with furrow irrigation.

The shallow ground water depth tended to start the season in April at approximately 2.5 - 3.3 feet below the soil surface and subside over the course of the growing season to approximately 5.8 - 7.5 feet in October. The depth to the shallow ground water fluctuated during the course of the season. Over-irrigation for the furrow systems during the first and second irrigation caused the shallow ground water table to rise early in the season. The shallow ground water table decreased later in the season mostly because of consumptive use by the crop. The decrease of the shallow ground water table was also affected by deep percolation below the confining layer and net subsurface lateral flow from the field.

Two of the four irrigation plots showed seasonal changes in soil salinity. The average soil salinity in the subsurface drip and LEPA plots increased between the spring and the fall during both years of the project. The average soil salinity in the improved furrow irrigation and the conventional furrow irrigation plots showed no clear change between spring and fall samplings.

Three of the four irrigation plots showed annual changes in soil salinity. The average soil salinity in the subsurface drip and LEPA plots increased between the first and the second year of the project. The average soil salinity in the improved furrow irrigation plot decreased between the first and the second year of the project. The average soil salinity in the conventional furrow irrigation plots showed no clear between the two years of the project.

The average ground water salinity generally varied during the irrigation season. The reductions in the average ground water salinity appeared to be the result of dilution by better quality irrigation water. However, the magnitude of the salinity reductions did not correspond with the deep percolation estimated by Boyle Engineering individual irrigation system evaluation.

The average ground water boron concentration appeared to be influenced by deep percolation. Changes in the average ground water boron concentration may be the result of dilution by better quality irrigation water, soil variability and reaction of boron from the soil exchange complex. However, the magnitude of the boron concentration reductions did not correspond with the deep percolation estimated by Boyle Engineering individual irrigation system evaluation.

The average ground water selenium concentration beneath the west side of the field increased over the first two years of study. The two plots on this side of the field were the subsurface drip and conventional furrow plots. The increase in selenium concentration appeared to be the result of subsurface ground water inflow from adjacent areas containing higher concentration of selenium to the west of the field. The average ground water selenium concentration beneath the two plots on the east side of the field was generally uniform during each growing season and from year to year. These two plots were not affected by the lateral flow during the period of study because of the small magnitude of the lateral flow.

There are a variety of ways to evaluate the four irrigation systems. The ranking of the four irrigation systems varies according to the measure used, and varies from year to year. For example, the systems can be evaluated by the return to the grower, the net benefits to the grower over some period of time, or the amount of deep percolation produced by the system. The results do not indicate that one irrigation technology was clearly better than another in all circumstances.

In the fifth year of a drought, one measure of success is to compare the amount of water used for each system. When this is done, the LEPA system applied the least amount of water in 1989 (1.66 acre-feet per acre), and the improved furrow system applied the least amount of water in 1990 (1.64 are-feet per acre). (The LEPA system had mechanical problems and unintentionllay applied this amount of water.) The subsurface drip system consistently applied less than or equal to 2.0 acre-feet of water per year to the cotton. These values were less than the crop requirement computed by CIMIS for a normal year. The improved furrow system applied 2.46 acre-feet per acre in 1989 and 1.64 acre-feet per acre in 1990. The conventional furrow system consistently applied 2.5 acre-feet of water per acre. By this measure of success, the subsurface drip system during both years, and the improved furrow system during 1990, were better than the other systems.

Another measure of success is the volume of agricultural drainage produced by the irrigation system. Deep percolation from each irrigation system was estimated three different ways in this study. Deep percolation was not measured in this study. Boyle Engineering estimated deep percolation during each irrigation event by irrigation system evaluations, given in Tables 7 - 14 of this report. Boyle Engineering also estimated the deep percolation by seasonal water balance calculations, given in Tables 19 and 20 of this report. The Department of Water Resources estimated deep percolation by more refined seasonal water balance calculations, also given in Tables 19 and 20 of this report. The three methods estimated different volumes of deep percolation from each irrigation system.

The estimates of deep percolation by Boyle Engineering for the four irrigations systems over the two years were lower than those predicted by DWR. When Boyle Engineering's deep percolation estimates were used, the ranking of the irrigation systems during the two years was similar to the above ranking. The LEPA and the subsurface drip system did the best during 1989, and the improved furrow system did the best during 1990.

Zero deep percolation was estimated from the LEPA system by DWR in 1989. This was primarily the result of mechanical failure of the LEPA system for ten days during the growing season. In the same year, deep percolation from the other systems was estimated to be at least 0.16 acre-feet per acre by DWR. In 1990 the deep percolation from the improved furrow system was estimated to be 0.14 acre-feet per acre by DWR. In the same year, deep percolation from the other systems was estimated to be at least 0.35 acre-feet per acre by DWR. By this measure of success, the improved furrow system was better than other systems in 1990, and the subsurface drip system was a close second.

Salt and water balances should be combined if the data is available. Such combinations are more justifiable because they are based on a larger data set than just a water balance, and because salt concentrations are sensitive to changes in the estimated volume of deep percolation. In an area where salinity and drainage problems are common, salt balance may be just as important as the water balance.

A final measure of success is the feasibility of the system. Boyle Engineering estimated the greatest net economic return to the grower from the subsurface drip irrigation system in 1989 ($268.58 per acre) and from the conventional furrow irrigation system in 1990 ($235.98 per acre). These values do not include costs of a subsurface drainage system, or costs of disposal or treatment of agricultural drainage water. The subsurface drip, improved furrow and conventional furrow systems had a positive net economic return both years of the project. The LEPA system was estimated to have a negative net economic return during both years.

The results from the first two years of study indicate that there is potential for changing irrigation technologies to reduce the volume of applied water and the volume of agricultural drainage water. For example, the subsurface drip system had least applied water, the least estimated volume of drainage water and the largest net economic return to the grower the first year of the project. The subsurface drip system had a lower crop yield during the second year of the project and therefore did not perform as well economically as during the first year. The change of irrigation technology requires large initial capital expenses and will probably be resisted by growers on these grounds. However, these changes appear to provide the grower with less water applied, less agricultural drainage water and a positive net economic return in the long term.

The results also indicate that there is potential for better management of conventional furrow irrigation systems to reduce the volume of applied water and drainage water. The improved furrow irrigation system had the least applied water, the least estimated volume of agricultural drainage water and a positive net economic return to the grower the second year of the project. The management changes are also expensive because they require capital investment, monitoring of field conditions and possibly more intensive labor for irrigation. However, like potential technological changes, management changes appear to provide the grower with less applied water, less agricultural drainage water and a positive net economic return in the long term.

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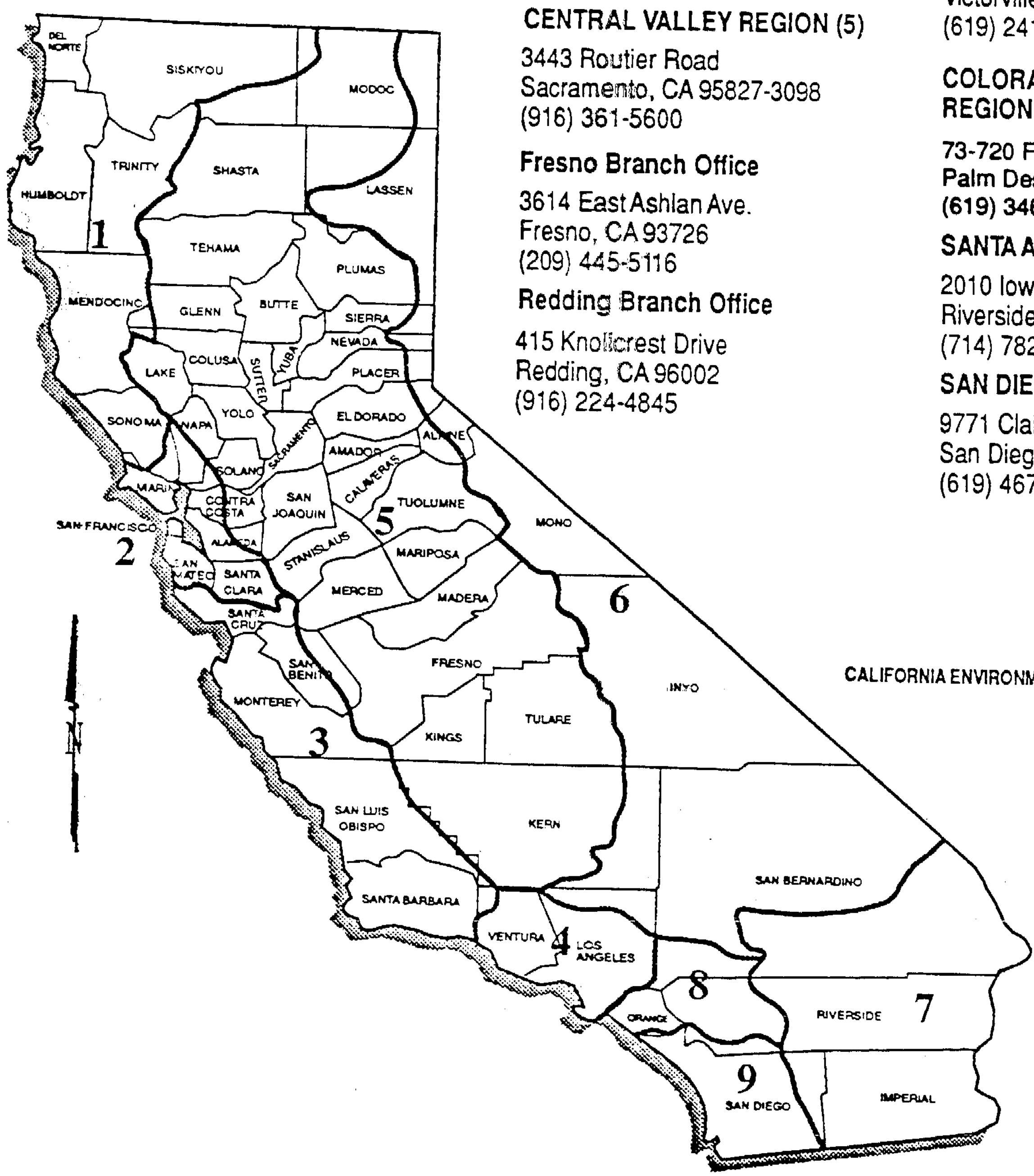

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