DETERMINATION OF AGRICULTURAL CHEMICAL IMPACTS ON SHALLOW GROUNDWATER QUALITY IN THE RIO GRANDE VALLEY: LAS NUTRIAS GROUNDWATER PROJECT

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DISCLAIMER

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None of this work could have been accomplished without the support and cooperation of the landowner. He alerted us to irrigations and chemical applications, and allowed us to drill, trench, and stumble all over his fields for almost five years. We hope the information in this report is some compensation for the inconvenience we have caused.

To the individuals listed above, plus others too numerous to cite individually, thanks for all your effort and support.

ABSTRACT

A comprehensive assessment was made of water and chemical relationships at a commercial farm in the central Rio Grande valley during 1994, 1995, and 1996. A highly instrumented 15-acre tile-drained field (Las Nutrias Groundwater Project) was used to collect areally averaged data on recharge rates and nitrate and pesticide leaching to shallow groundwater.

Because its outlet to a surface drain was submerged, the tile-drainage system did not perform to design specifications. The resultant high water table below the field served as a source of water for crops during the summer, but also resulted in salinization of the field. Due to its submerged condition the tile drain collected primarily ambient groundwater rather than recharge water from the overlying field. The amount of recharge water captured by the drain was less than 5%.

In the spring of 1994, nitrate-nitrogen concentrations in recharge water periodically exceeded the drinking water standard of 10 mg/l nitrate-nitrogen; in subsequent years, nitrate never exceeded the standard. The greater leaching of nitrate in 1994 resulted from anomalously high residual nitrogen levels in the topsoil at the beginning of that year's growing season, which allowed significant levels of nitrate (up to 38% of the fertilizer nitrogen applied that season) to be transported to groundwater by preferential flow processes. Due to rapid dilution of the recharge by ambient groundwater, however, groundwater flowing offsite had nitrate-nitrogen concentrations of only a few mg/l, well below the drinking water standard.

No pesticides were detected in tile drain water beneath the project field. Pesticides applied by the landowner included chlorpyrifos (Lorsban), dimethoate (Dimate 4E), and cyfluthrin (Baythroid 2). Groundwater samples were analyzed for these chemicals as well as other pesticides applied in the area. A few monitoring well samples showed chlorpyrifos at levels of less than 1 μg/l. Similarly, no pesticides applied off-site were detected in groundwater beneath the field.

The flow rate and chemical signature in the tile changed rapidly in response to an irrigation event. These responses suggest rapid transmission of water and surface-applied chemicals via preferential flow. The preferential flow hypothesis was supported by measurements of soil hydrologic properties and by visual observations of soil cracks and animal burrows.

This study provides the first detailed information on agricultural leaching below a commercially managed New Mexico farm. The results suggest that current management practices do not present a threat to shallow groundwater quality in the Rio Grande basin.

Keywords: pesticides, nitrate, recharge, salinity, irrigation, preferential flow, leaching, pollution

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Pesticides and fertilizers have contributed significantly for the past 50 years to the sustained growth in U.S. agricultural productivity. Today, about 600 million pounds of pesticides are applied annually, in addition to a much greater amount of fertilizer. One cost of widespread pesticides and fertilizer use is the occurrence of residues (often at trace levels) in groundwater. Since the health effects of chronic exposure to such residues in drinking water are still largely unknown, the prudent course is to minimize groundwater contamination. Unfortunately, there is a lack of data at the local, regional, and national levels on impacts of typical agricultural practices on the quality of shallow groundwater. While agricultural chemicals have been detected in groundwater at numerous locations throughout the U.S., it is often not clear whether such occurrences are due to recommended agricultural practices or to spills, dumping, or over-application. In the absence of data, the current trend is to restrict or ban the use of chemicals once they are detected in groundwater, even if the source of the contamination is not certain. Therefore, regulatory agencies (such as the New Mexico Environment Department) may choose to err on the side of safety and limit chemical use over broad areas. Such decisions can have serious short- and long-term economic impacts on local agricultural producers.

The deep fresh groundwater supplies in the Rio Grande Valley are diminishing while the urban populations of Albuquerque, Las Cruces, El Paso, and Ciudad Juárez are growing and demands for high quality drinking and industrial water are increasing. The lack of water resources in the El Paso-Ciudad de Juárez area is critical (U.S. Environmental Protection Agency [EPA] 1996). The Hueco Bolson, which has been a major source of drinking water for the region, may be depleted during the first half of the next century. Therefore, there is an increasing reliance on the surface waters of the Rio Grande for sustainable future water supplies.

The use of Rio Grande surface waters as a source for drinking water requires adherence to water quality standards. Of special concern is the potential hazard of agricultural chemicals to both surface water and shallow groundwater. The leaching of applied fertilizers and pesticides may degrade groundwater quality. Surface water quality be affected by direct runoff or by return flow from contaminated shallow groundwater. Nevertheless, to date relatively little effort has been expended in characterizing the impact of agricultural chemicals on shallow groundwater in the southwestern United States. Most previous studies have been conducted at experimental test sites where the investigators had essentially complete control over all aspects of the investigation. Additionally, many of these investigations have concentrated their efforts in areas where soil conditions, climate, and farming practices differ substantially from those experienced in New Mexico (Baker and Johnson 1981; Kladivko et al. 1991; Owens et al. 1994; Vinten et al. 1994; EPA 1996). Prior to the Las Nutrias Groundwater Project described herein, no comprehensive studies concerning the impacts of agriculture on shallow groundwater quality under commercial agricultural conditions have been completed in New Mexico.

In agricultural fields, nitrogen fertilizers are used to enhance crop production. Most crops need a rather large nitrogen supplement for optimal growth, but nitrogen can undergo several conversions to other forms which may or may not be used by most crops. Oxidation of nitrogen to nitrate is of particular interest in terms of groundwater contamination, since nitrate is a very mobile anion. Concentrations of nitrate in excess of the state and federal regulations (10 mg/l nitrate as nitrogen, nitrate-N) can cause methemoglobinemia in infants, a disease which depletes the oxygen content in the blood supply. Nitrate can also degrade surface water quality by enhancing excessive growth of algae.

As of late 1989, only 0.4% of New Mexico's public water supply systems exceeded the state and federal regulations for nitrate concentration (Anderholm et al. 1995). Livestock waste and/or sewage disposal systems are suspected of causing this problem. Although these are considered to be non-point sources of pollution, they are much more localized and isolated than agricultural areas, where hundreds of thousands of pounds of nitrogen fertilizers are applied annually to broad regions. Yet, in 1990, the New Mexico Water Quality Control Commission stated that "available data are inadequate to determine whether or not agricultural chemicals and practices are also causing a problem." The Commission (1990) also states that "a comprehensive survey of the State's groundwater quality has not been done so no quantitative statement concerning groundwater quality can be made." In 1986, the National Water Quality Assessment (NAWQA) program began when Congress appropriated funds to the U.S. Geological Survey (USGS) to address a wide range of water quality issues. By 1991, when several pilot studies were near completion, the USGS implemented a full-scale NAWQA program in the Rio Grande Valley Study Unit, of which 83% is located in New Mexico. The investigations have revealed that there is a relatively small contribution to groundwater contamination from agricultural chemicals (Anderholm et al. 1995; Healy 1996). However, the collected data are based on only two sampling events — once during the irrigation season where groundwater flow is at a maximum, and once during the lower flow non-irrigated season. Such random sampling most certainly obscures variations in nitrate concentrations that may exist. Since New Mexico still lacks a more detailed database of information pertaining to the assessment of agricultural impacts to groundwater, significant data are needed to determine if a problem with agricultural nutrients and chemicals does, in fact, exist. Such data may provide protection to New Mexican farmers if and when regulatory agencies propose banning the use of fertilizers and pesticides that significantly enhance crop productivity, but may not necessarily exist at dangerous levels in underlying groundwaters.

In 1991, Las Nutrias Groundwater project was initiated with the objective of providing a detailed quantitative and mechanistic description of the impacts of irrigation return flows on shallow groundwater quality. Being the first study of its kind in New Mexico, the main focus of this project was to investigate effects of nitrogen fertilizer and pesticides on shallow groundwater quality and to study the mechanisms by which agricultural chemicals are transported to shallow groundwater. Our observations and findings are considered representative for agriculture in the Rio Grande Valley as a whole because the local and regional hydrogeology along the valley is similar, the soil types are similar, and many New Mexico farmers use similar cropping, nutrient, pesticide, and water management practices.

FIELD CHARACTERISTICS AND SETTING

Location of Las Nutrias Groundwater Project

Las Nutrias Groundwater Project field site is located on a 60-ac commercial farm approximately 35 mi north of Socorro, New Mexico, near the village of Las Nutrias at the southern end of the Albuquerque Basin (Figure 1). The site is reached by taking Interstate 25 Exit 175 at Bernardo, east 3.5 mi on US Highway 60, then north 3.3 mi on NM Highway 304 to the village of Las Nutrias (Figure 2). The project site is approximately 0.9 mi west of the village along a dirt road. The western edge of the site is about 0.25 mi east of the Rio Grande. An aerial photo of the site, showing the division of the field into three benches, is presented in Figure 3. The three benches lie at progressively lower elevations to the west and are hereafter referred to as the east, center, and west benches. The center bench, described in more detail later, is the most heavily instrumented and most intensely studied portion of the site. Other irrigated farms lie adjacent to the north, east, and south of the site, with bosque (riparian) lands to the west between the west bench and the Rio Grande.

Soils

A detailed soil survey conducted by the Natural Resource Conservation Service (NRCS) in April and July, 1993, described soil profiles at 196 locations on the center bench to a depth of 5 ft. Four main soil series were identified: Anthony, Glendale, Saneli, and Harkey (Figure 4). These soil series are described in the Soil Survey of Socorro County (USDA 1988).

The Anthony series is classified as a coarse-loamy, mixed (calcareous), thermic Typic Torrifluvent that is well drained and has a moderately rapid permeability. The Ap horizon ranges from fine sand to sandy loam in texture. The C horizon above about 100 cm is fine sand, loamy very fine sand, or very fine sandy loam.

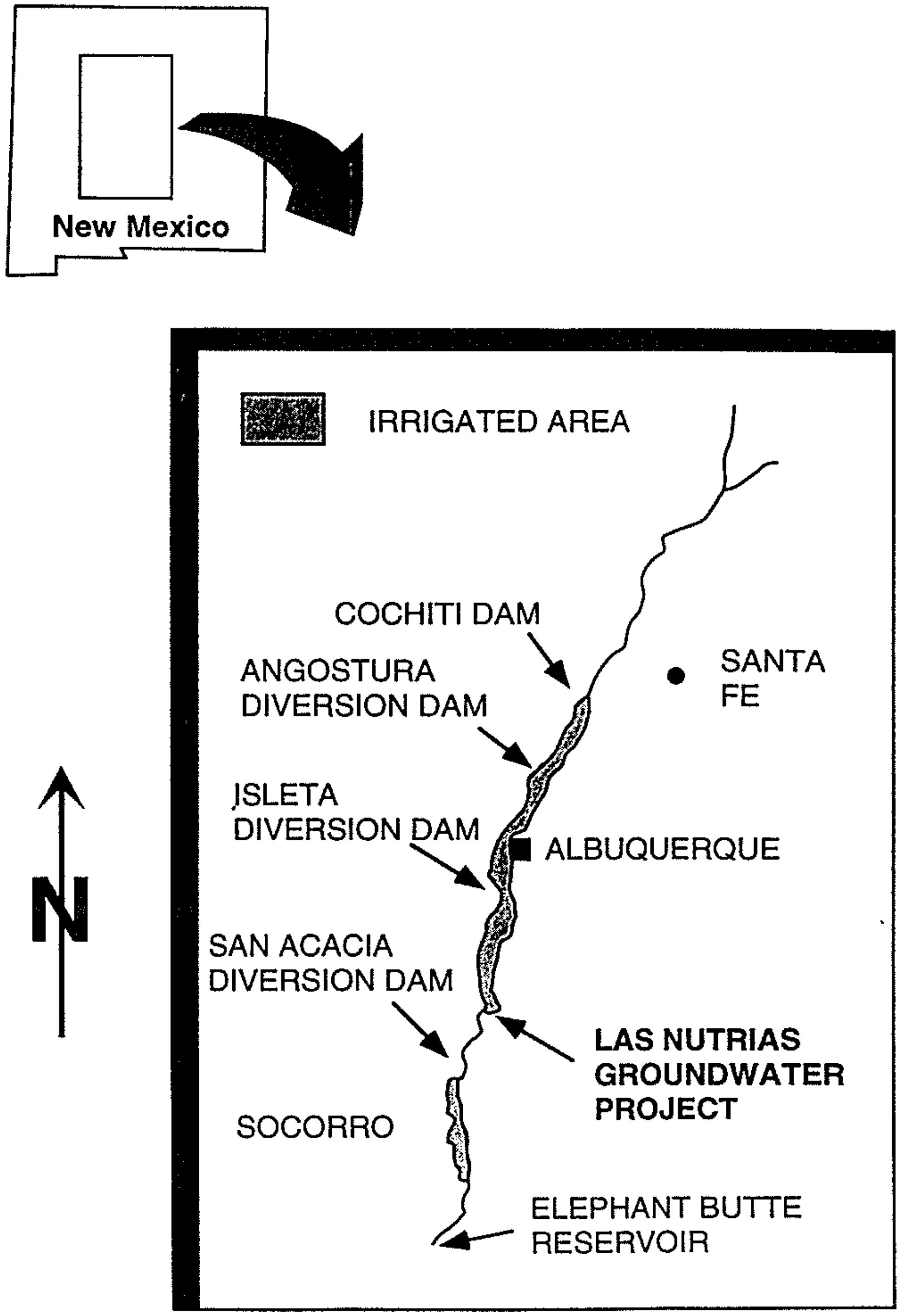


Figure 1. Location of Las Nutrias Groundwater Project in New Mexico.

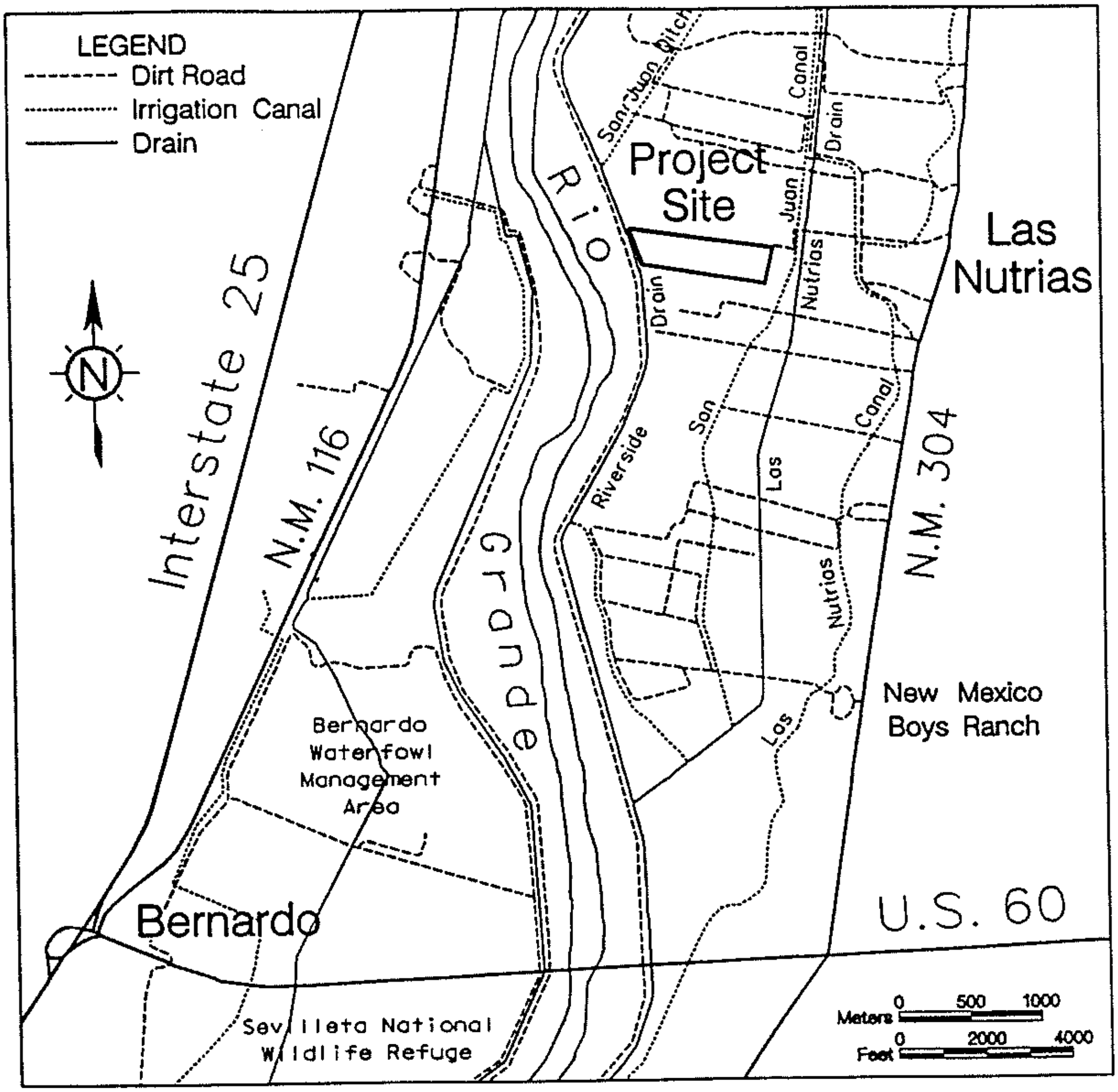


Figure 2. Location of Las Nutrias Groundwater Project in the Las Nutrias area.

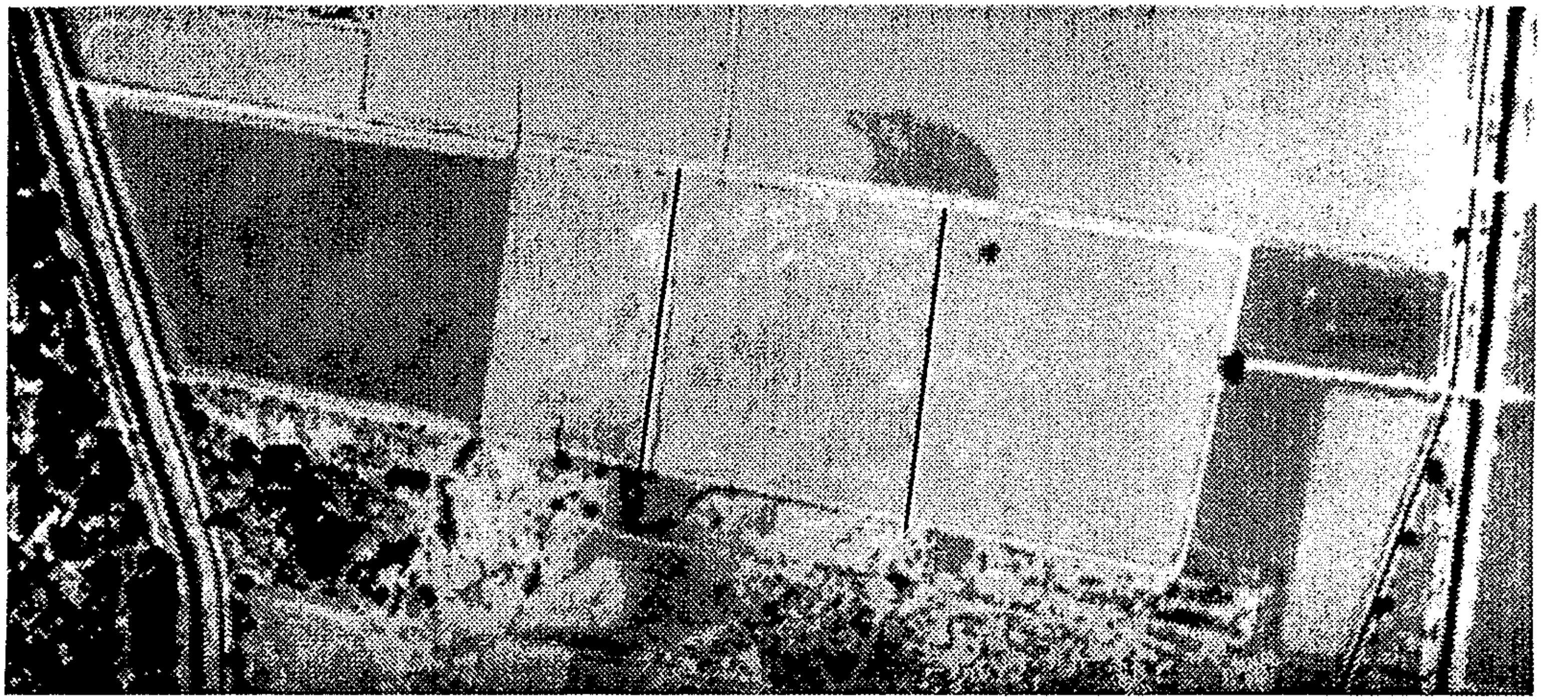


Figure 3. Aerial photo (1984) of the Las Nutrias Groundwater Project site. Heavy lines indicate the berms between the east, center, and west benches.

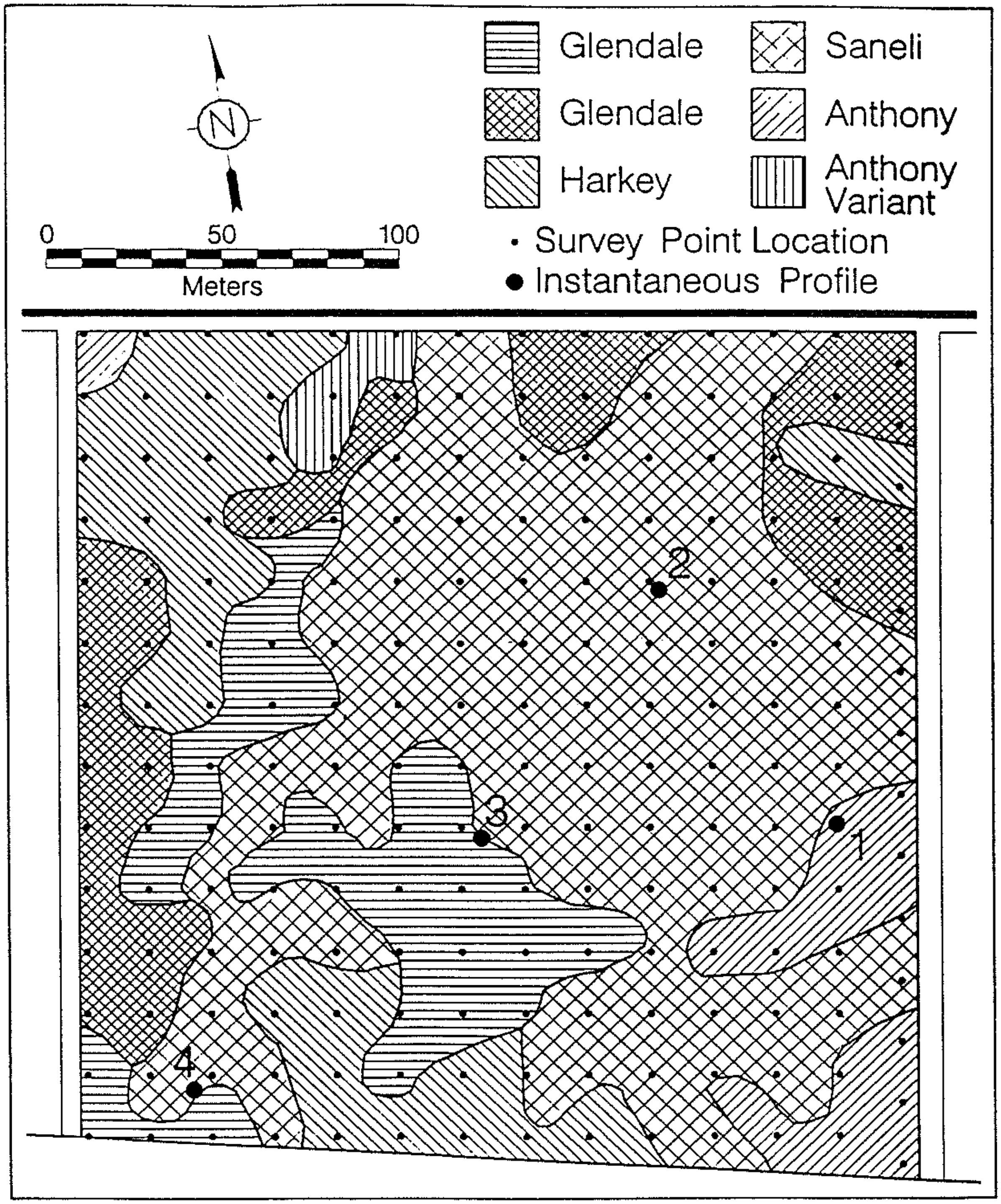


Figure 4. Soil series map of the center bench. Soil physical characteristics were measured at the instantaneous profile locations.

Below 100 cm, the C horizon is fine to very fine sand or silt loam. Clay contents are generally less than 18%, with some thin clayey strata possible. Pore structure is described as very fine interstitial grading downward to very fine tabular. The Anthony Variant series is classified as a coarse-loamy over clayey, mixed (calcareous), thermic Typic Ustifluvent that is well drained and has a slow permeability. It is similar to the Anthony series but with a 20 to 40 cm thick clay layer at a depth of 60 to 95 cm.

The Glendale series is classified as a fine-silty, mixed (calcareous), thermic Typic Torrifluvent that is well drained and has a moderately slow permeability. The Ap horizon ranges from sandy loam to clay loam, while the C horizon is stratified clay loam, silty clay loam, sandy loam or silt loam. Pore structure is described as commonly medium tabular grading downward to very fine tabular.

The Saneli series is classified as a clayey over sandy or sandy-skeletal, montmorillonitic (calcareous), thermic Vertic Torrifluvent that is well drained and has a very slow permeability. The Ap horizon is clay or silty clay. The upper C horizon is clay or silty clay while the lower C horizon is sand, fine sand, loamy sand, or loamy fine sand. The clay layer is 40 to 80 cm thick at depths from 20 to 75 cm. Cracks up to 2 cm in width are noted to extend from the surface through the clay layer.

The Harkey series is classified as coarse-silty, mixed (calcareous), thermic Typic Torrifluvent that is well drained and has moderate permeability. The Ap horizon is silt loam with a weak medium subangular blocky structure. The C horizon is statified sand and silt loam with a massive stucture. The soil is friable and nonplastic throughout the profile.

The soils are quite variable even over short distances and exhibit a full range of textures from clay through sand, with the clay areas developing well defined shrinkage cracks at the surface as they dry. The Saneli series dominates much of the center bench. With the noted macropore structure of this series and, to a lesser extent, of the other mapped series, there is a high potential for preferential flow pathways through the clayey upper soil layers to the sands below. The system of macropores is further enhanced by both floral and faunal activity in the form of root channels, earthworm burrows, and gopher tunnel networks. The latter have been observed to be extensive near the berms, especially during the early part of the irrigation season. Irrigation water applied to a higher-elevation bench is transmitted through the tunnels to the adjacent lower bench at substantial rates. Gopher tunnel networks were also noted in the more sandy regions within the central regions of the fields.

Climate

The climate at Las Nutrias is arid to semi-arid, with an average annual air temperature of 59 °F. Winter daily temperatures range from 18 to 50 °F, while summer daily temperatures range from 60 to 92 °F. Relative humidity averages about 45% for the year, with daily ranges of 10-60% in the summer and 30-100% in the winter. Daily maximum and minimum relative humidity values generally coincide with the daily minimum and maximum temperature. Mean annual precipitation is about 210 mm and mean annual potential evapotranspiration is approximately 2000 mm.

Daily precipitation events at the site during 1995 are presented in Figure 5. Using weather data from the Agricultural Science Center at Los Lunas and crop observations, we estimated the daily actual evapotranspiration rates for the alfalfa growing on the center bench during 1995 (Figure 6). The calculations were based on the modified Penman equation (Penman 1963) using methods described by Doorenbos and Pruitt (1977). The total actual evapotranspiration during 1995 was calculated to be 1484 mm, which is approximately 25% less than the calculated potential evapotranspiration of 1984 mm.

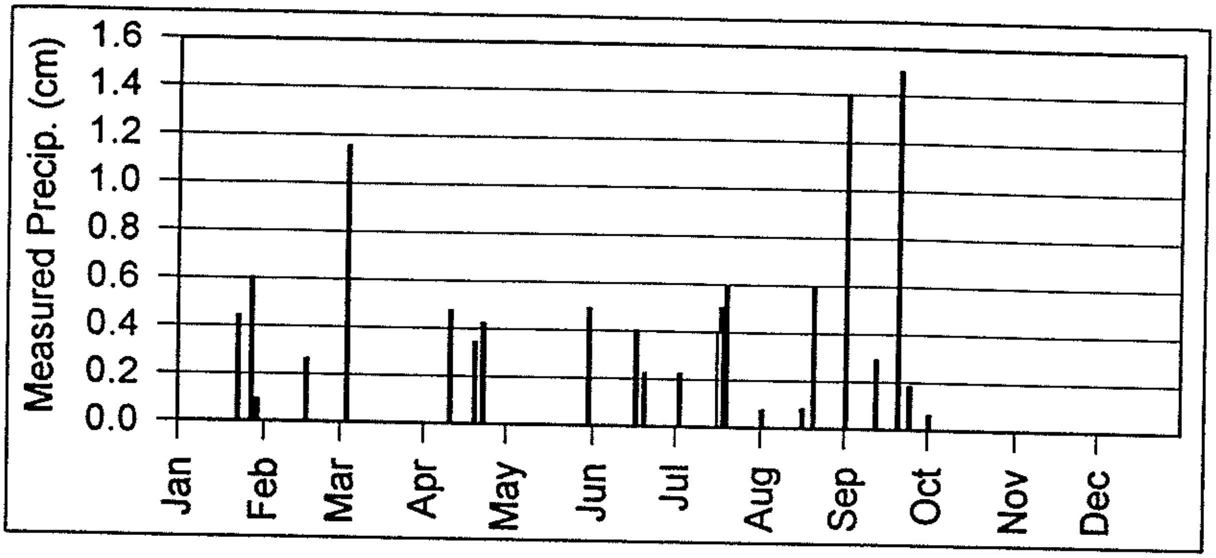


Figure 5. Daily precipitation rates in 1995.

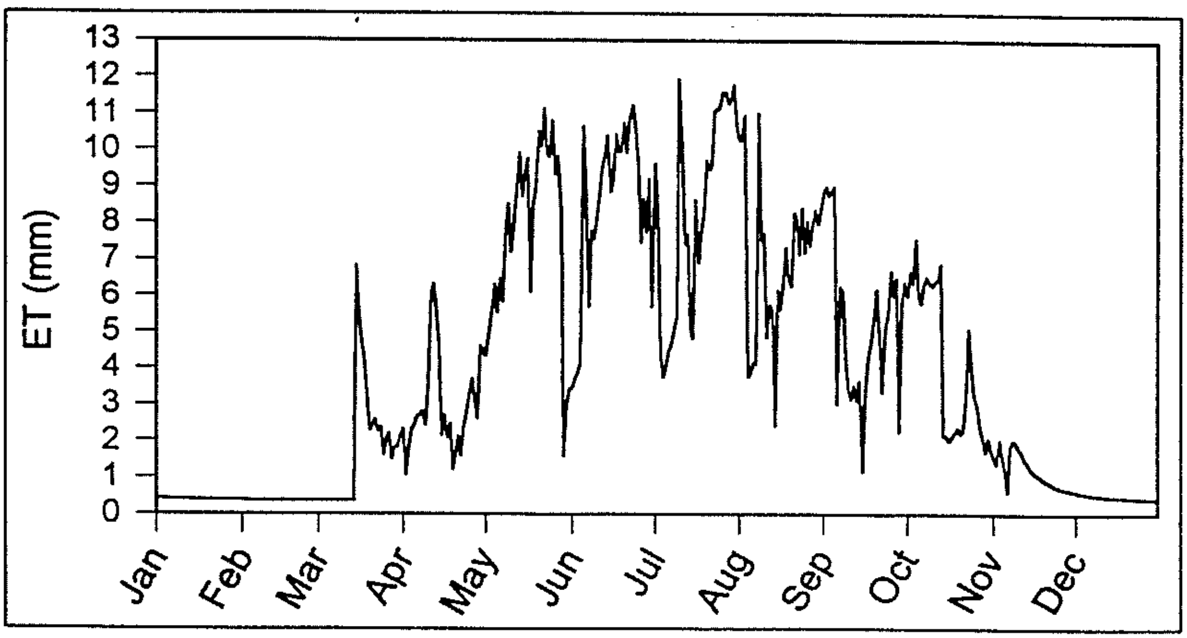


Figure 6. Daily estimated evapotranspiration rates in the center bench in 1995.

Agricultural Practices

Common crops grown in the area of the site are alfalfa, corn, sorghum-sudan, oats, and chile. The average growing season, defined as frost-free days, is from late-April or early-May to about mid-October, a period of approximately 165 days. The land is flood irrigated. Irrigation water is available from March 1 through October 31 and is conveyed through a system of diversion dams, ditches, and drains administered by the Middle Rio Grande Conservation District. The amount of fertilizer administered depends upon crop requirements, soil conditions, and type of fertilizer. Commonly used fertilizers include ammonium sulfate, ammonium nitrate, urea, and nitrogen-phosphorous-potassium-sulfur formulations. Alfalfa, which is a nitrogen-fixing plant and therefore requires little or no nitrogen fertilization, generally demands fewer supplemental nutrients. There are literally thousands of pesticide formulations approved for use in New Mexico. Application of pesticides varies in both amount and timing. Often, pesticides are applied as a preventive measure, while at other times they are applied on an as-needed basis to combat pests.

METHODS AND RESULTS

Experimental Design and Instrumentation

A schematic diagram of the dimensions and instrumentation of the east, center, and west benches is shown in Figure 7. A detail of the center bench is shown in Figure 8. To monitor the water table and local hydraulic gradients, a total of 34 groundwater monitoring wells (2-in inner-diameter [ID] PVC pipe installed to a depth of 2 m, screened over the entire length) and 23 piezometers (solid 1-in ID PVC pipe installed to depths of 3, 5, and 7 m, screened at the bottom 20 cm) were located at the site around the perimeter of the cultivated areas during February-March, 1993 (Figures 7 and 8). The monitoring wells allowed measurement of groundwater levels while the piezometers allowed measurement of water pressures below the water table.

The main selection criterion for the experimental site was its subsurface tile-drainage system, which provided a means for measuring both the average quantity and quality of groundwater flowing beneath the field. The tile-drainage system was installed by the landowner in 1979 in an effort to abate soil salinization by lowering the groundwater table (Figure 9). Since that time, the disturbance of the soil profile due to installation has been mitigated by cultivation.

The tile-drainage system at the site consists of four lateral pipes, numbered 1 through 4 from north to south (see Figures 7 and 8). The tile-drains are perforated plastic pipe wrapped with nylon filter sock and buried approximately 4 to 6 ft below ground surface. The pipes are 4-in ID under the east bench while under the center bench they are 5-in ID. Under the west bench, the ID of some of the tile lines increases to 6 in. The laterals are spaced at approximate 215-ft intervals trending east-west with a design gradient of 0.1% under the east bench and 0.05% under the center and west benches. However, a survey of the tile-drain pipe elevations revealed that the actual gradient below the center bench is closer to 0.025%. The lateral spacing

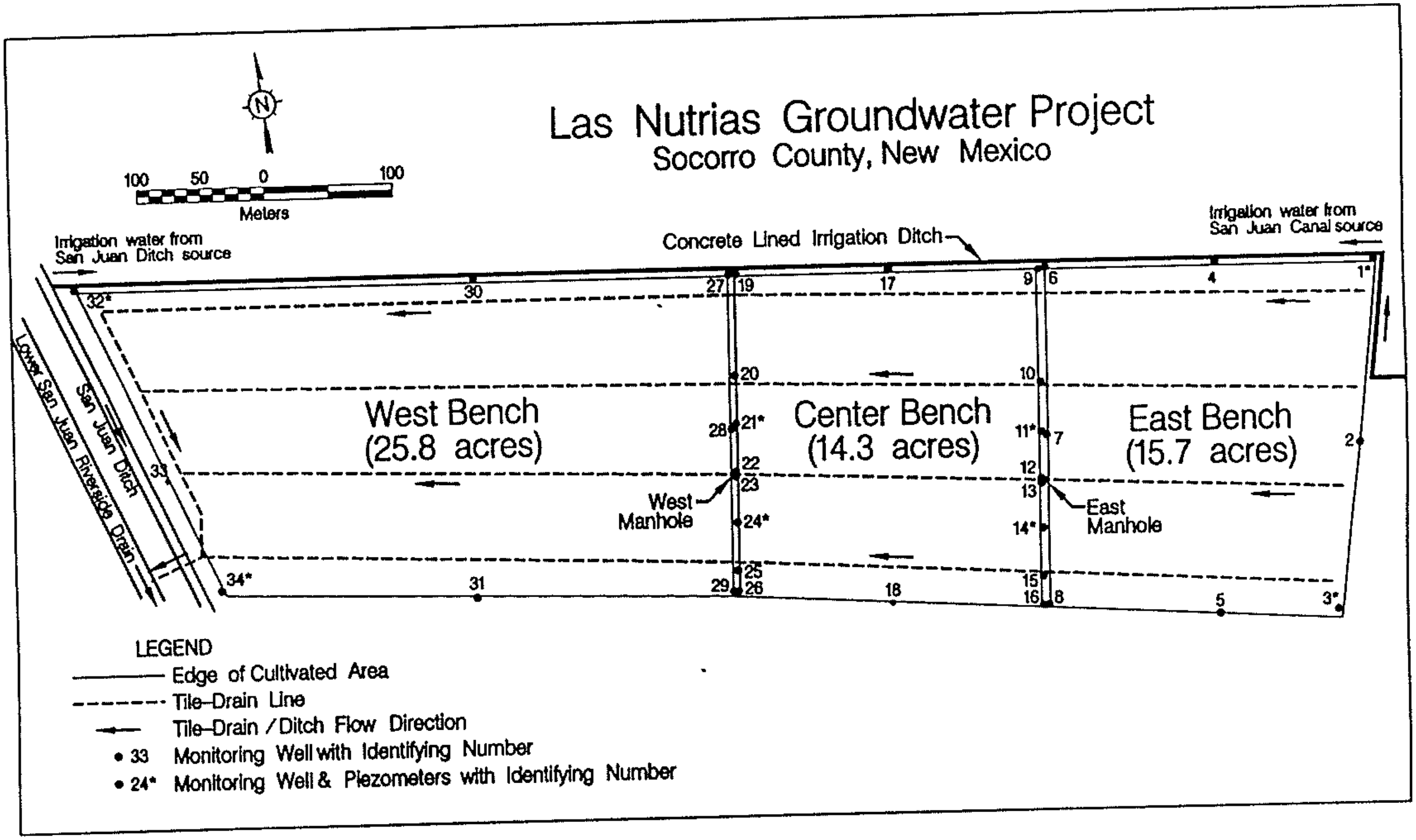


Figure 7. Experimental lay-out of the Las Nutrias Groundwater Project.

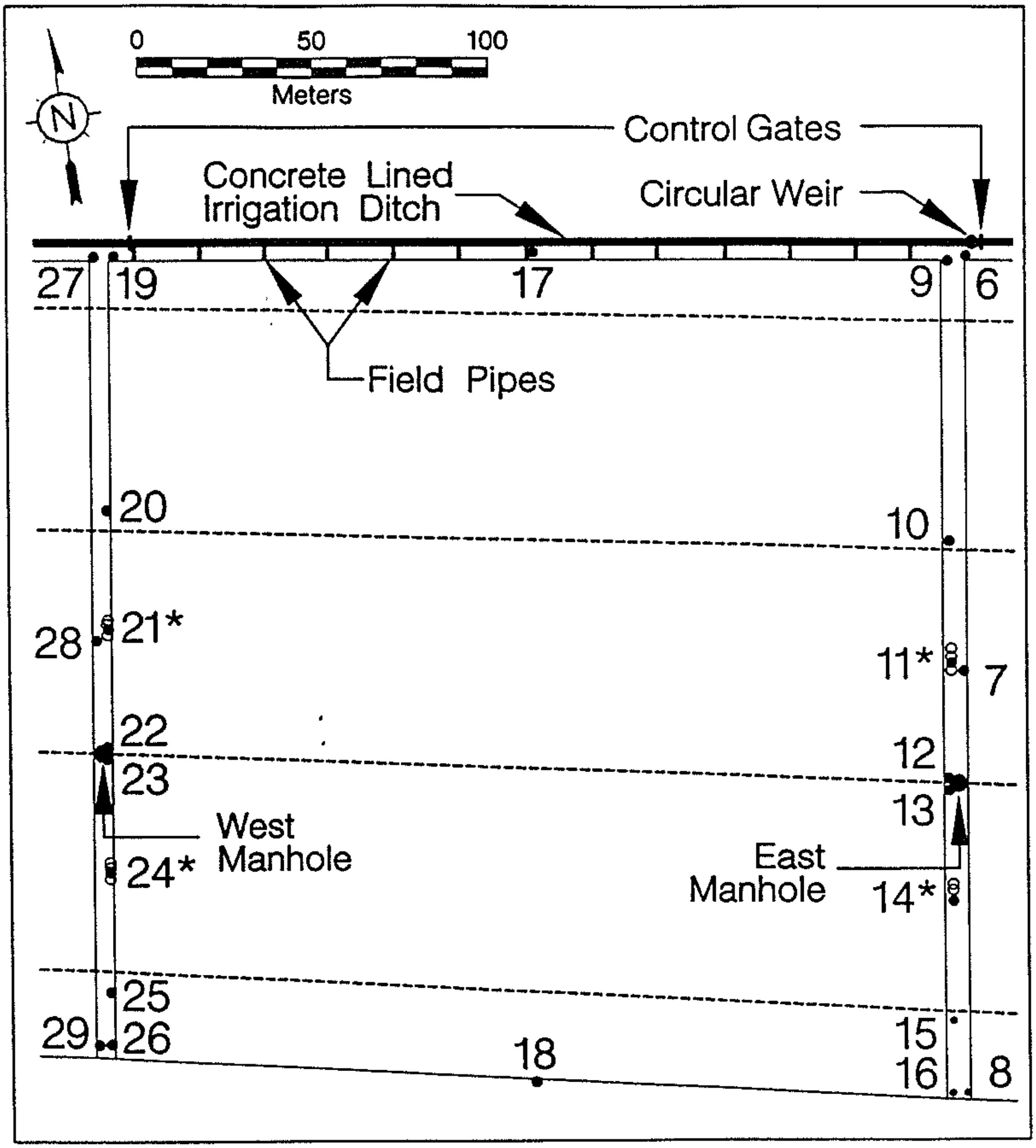


Figure 8. Experimental detail of the center bench. Numbers refer to wells — see legend in Figure 7.

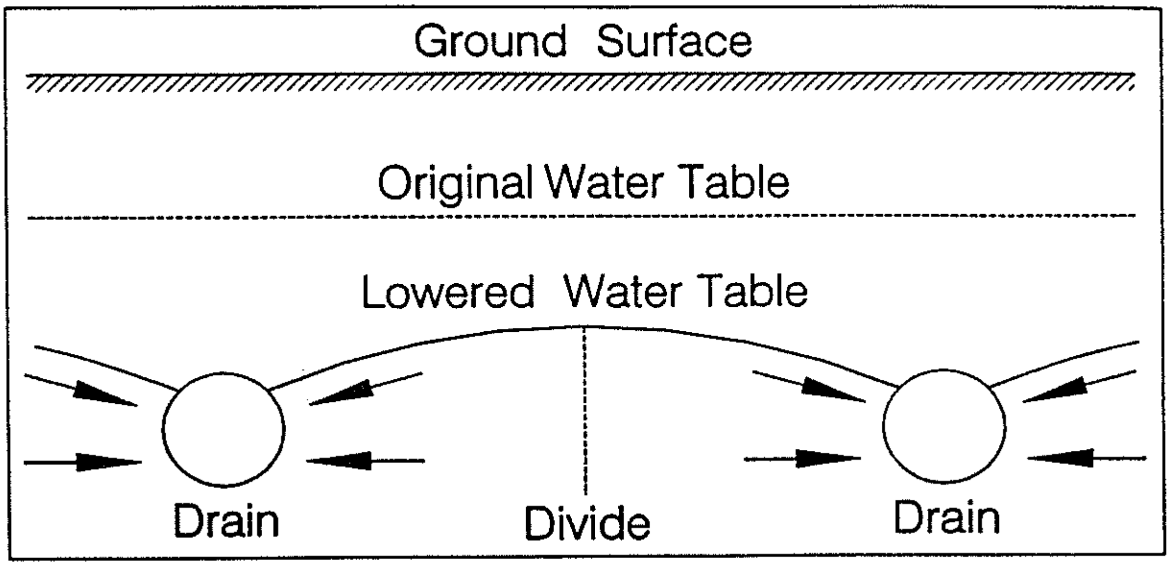


Figure 9. Principle of a subsurface tile-drainage system. The arrows indicate the direction of groundwater flow.

gradually increases from west to east. All four laterals join at their western ends to a southerly flowing 6-in ID collection pipe that enlarges to 8-in ID at the junction with lateral #3. At the junction with lateral #4, the collection pipe turns southwest for 145 ft to the system effluence into the Lower San Juan Riverside Drain, the last 20 ft of pipe enlarging to 10-in ID. The discharge pipe passes under the San Juan Ditch, a water supply canal (Figure 7). Due to silting of the Riverside Drain, the tile-drainage system discharge pipe is submerged throughout the irrigation season and for much of the winter. This inhibits drainage of the tile drains and results in a decrease in the efficiency of the entire system.

To isolate a tile-drain section for drain flow measurement and water quality sampling, two manholes were installed intersecting tile-drain #3 in the center bench (see Figures 7 and 8). The manholes were approximately 5-ft diameter corrugated galvanized steel with a welded bottom plate installed to a depth of approximately one foot below the bottom of the tile-drain pipe. The tile drain line was cut and attached to flanges mounted inside the manholes at both the inflow and outflow sides.

Figure 10 is a schematic diagram of the manholes and their instrumentation. Since the manholes were located almost a mile from the nearest electrical transmission line, power was provided with a photovoltaic/battery storage system. Measurement of tile-drain flow rates was accomplished with a paddle-wheel type Signet 2530 Low Flow Sensor (Signet Scientific Co., El Monte, CA) capable of measuring fluid velocities of 0.1 to 3 m/sec.

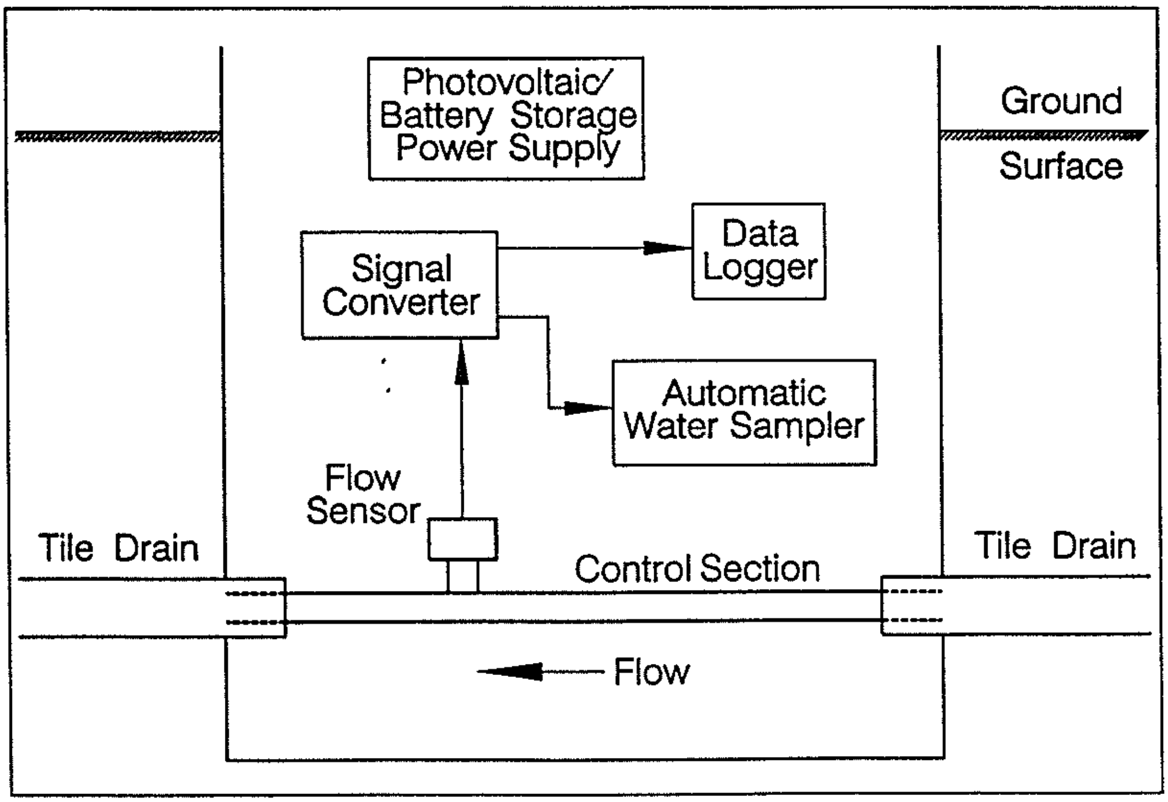


Figure 10. Schematic diagram of the manhole instrumentation.

Water quality samples were collected in each manhole with ISCO® (Lincoln, NE) Model 2900 automated water samplers having a 12-sample capacity, each with 350 ml volume. Water samples were pumped directly from the tile drain line down gradient of the flow sensor (Figure 10). Sampling intervals ranged from 2 hours during and immediately following irrigation events to 3.5 days or longer between irrigations and during the winter.

The amounts of applied irrigation water were measured using a circular weir (Samani and Magallanez 1993) located in the irrigation ditch at the northeast corner of the center bench (Figure 7). Figure 11 presents a schematic diagram of the circular weir. Flow was measured during an irrigation by noting the depth of water on a gauge attached to the upstream side of the weir. Readings were typically obtained every 15 min throughout the irrigation event, with more frequent readings gathered during the initial and final stages or when relatively rapid fluctuations were noted.

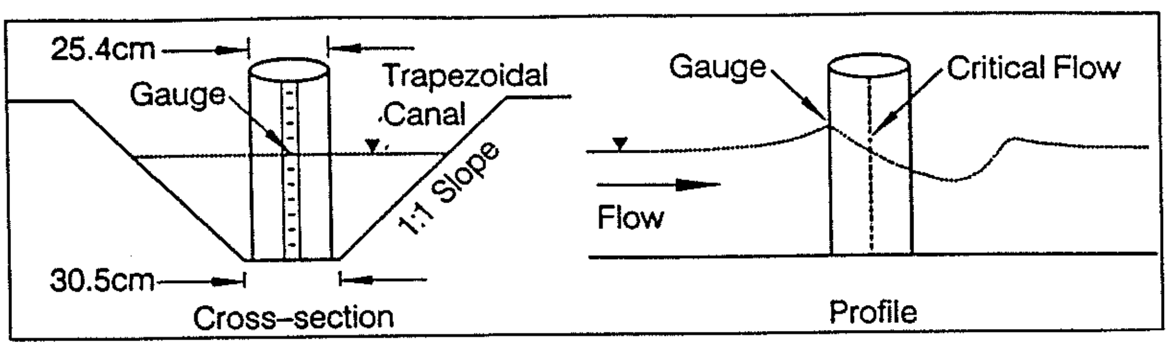


Figure 11. Schematic diagram of the circular weir.

Cropping History

The cropping calendar as well as fertilizer and pesticide applications at the three benches are summarized in Table 1. Crops planted included alfalfa, corn, sorghum-sudan grass hybrid, and winter wheat. The winter wheat planted on the center bench in October, 1993, did not grow, most likely due to the sensitivity of winter wheat to the saline soil conditions in the center bench. Therefore, the nitrogen fertilizer applied to stimulate

Table 1: Site crop rotation, harvest, and chemical application schedule.

			Bench		
Year	Date	Event	West	Center	East
pre-1993	---	(Crop)	Corn	Corn	Alfalfa
1993	6/25	Fert. (400 lb/ac $(NH_4)_2SO_4$)	X[1]	X	---[2]
	10/5	Harvest	X	X	---
	10/10	Plant	WW[3]	WW	---
	10/15	Fert. (200 lb/ac Urea)	X	---	---
	10/25	Fert. (200 lb/ac Urea)	---	X	---
1994	3/7	Fert. (400 lb/ac $(NH_4)_2SO_4$)	X	---	---
	4/19	Pesticide (Lorsban)	---	---	X
	5/13	Harvest	X	nc[4]	---
	5/13	Plant	SS[5]	SS	---
	5/13	Fert. (200 lb/ac Urea)	X	---	---
	5/30	Harvest	---	---	X
	7/19	Harvest	X	X	---
	7/23	Pesticide (Lorsban, 1 pt/ac)	---	---	X
	9/14	Harvest	X	X	---
	9/25	Plant	Alfalfa	Alfalfa	---
1995	4/3	Fert. (250 lb/ac 8-36-4-4 N-P-K-S)	X	X	X
	4/20	Pesticide (Lorsban, 1.5 pt/ac)	---	---	X
	5/29	Harvest	X	X	X
	7/3	Harvest	X	X	X
	8/4	Harvest	X	X	X
	9/5	Harvest	X	X	X
	10/14	Harvest	X	X	X
1996	3/21	Fert. (250 lb/ac 8-36-4-4 N-P-K-S)	X	X	X
	4/18	Pesticide (Dimate 4E 0.75 pt/ac)	X	X	X
	4/18	Pesticide (Baythroid 2 3.2 oz/ac)	X	X	X
	5/15	Harvest	X	X	X

[1]event occurred [2]event did not occur [3]winter wheat [4]no crop [5]sorghum-sudan

the wheat growth was not utilized. This resulted in a high concentration of nitrate near the soil surface, thought to be the source of an observed increase of nitrate levels in the tile-drain water through the 1994 growing season. These nitrogen dynamics are discussed in detail later in this report.

Water Management and Impacts

Groundwater level surveys were conducted at varying time intervals. For example, Figure 12 shows the groundwater level contours on August 18, 1995, and Figure 13 the average groundwater table depth in the center bench during 1995.

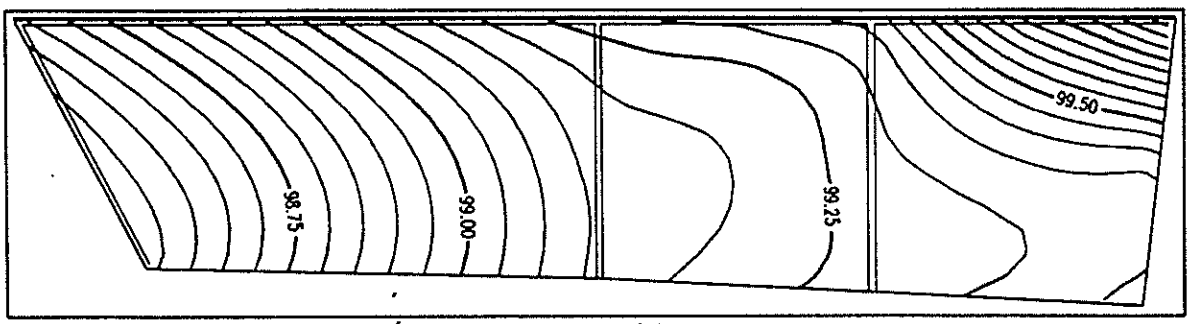


Figure 12. Groundwater level contours on August 18, 1995. Elevations are meters above an arbitrary datum.

In general, vertical hydraulic gradients measured in the piezometers were close to zero, which indicates the absence of upward or downward flow below the water table. Exceptions occurred following irrigation events, when transient gradients were encountered. The greatest upward vertical gradients were found during the months May and June between the groundwater table and a depth below it of about 2 m. This coincided with the rise of the groundwater table after the initiation of irrigation (see Figure 13).

Measurement of tile-drain flow rates began in 1995. During March and April, 1995, flow rates were recorded every 3 minutes. During May through November, 1995, flow rates were recorded every 5 minutes. From

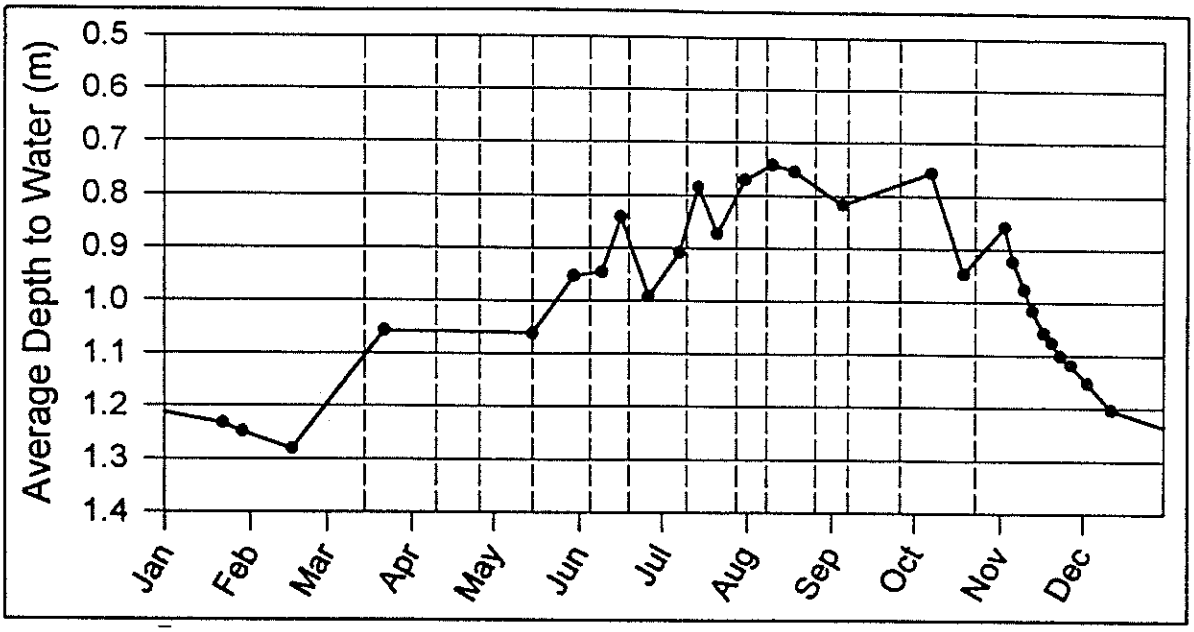


Figure 13. Average groundwater table depths below land surface in the center bench during 1995. Dashed vertical lines indicate irrigations.

November onward, flow rates were recorded every 10 minutes. For example, Figure 14 presents drainage flow rates measured in the west and east manholes from October 2, 1995, through October 9, 1995. Subtracting the two flow rates yields the net drainage flow rate from the center bench. The two peaks in the net rate on October 4 and 6 were caused by irrigations on fields adjacent to the site and indicate the sensitivity of the drainage flow rate of the center bench to hydrological events in the surroundings. At no time was a response in drainage flow rate noted following a precipitation event.

During the 1995 irrigation season, 52.7 inches of water were applied to the center bench using 13 irrigations in the period from March 15 to October 23, 1995. The average irrigation amount was 4.1 inches with a range from 5.3 inches on October 23 to 2.8 inches on September 7. The large volume during the last irrigation of the season was made in anticipation of the dry winter season.

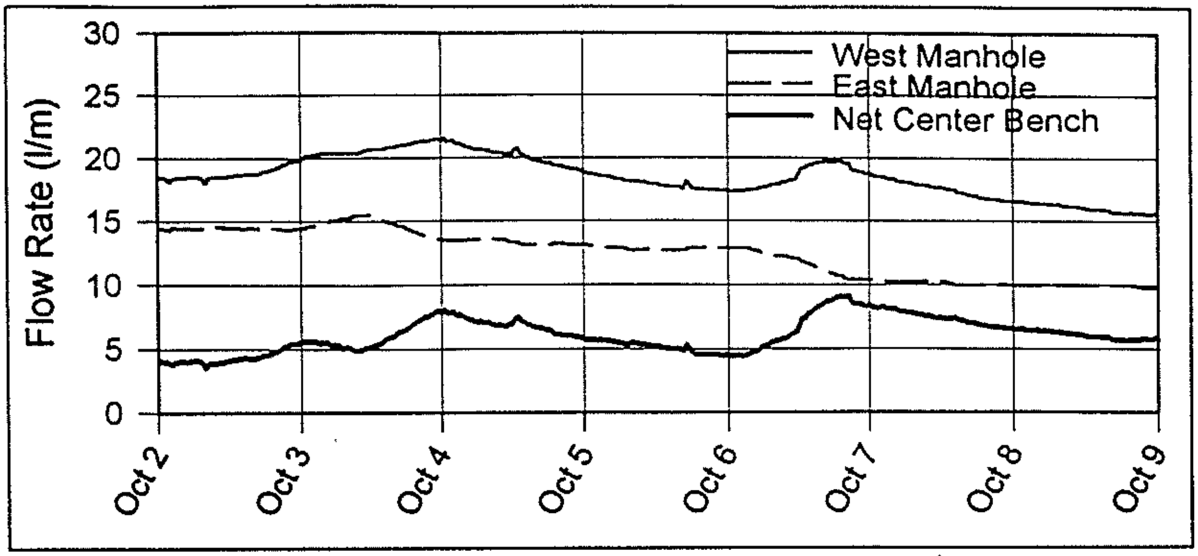


Figure 14. Tile-drain flow rates measured in the west and east manholes from October 2 through October 9, 1995. The difference between the west and east flow rates yields the net drainage flow rate of the center bench.

Figure 15 displays (for two irrigation events) the rate of advance of the irrigation water across the surface from the source at the north end of the center bench. For these two irrigations as well as the other irrigations, 3 to 4 hours was required for water to traverse the 150 m to a position above the drain. This contrasts with the much shorter time (on the order of one hour) for the flow rates in the monitored drain to respond to the commencement of an irrigation (Figure 16). This rapid drain flow response suggests the presence of preferential pathways through the soils and a highly dynamic saturated flow system.

Using the information collected on irrigation water application volumes and chemistry, along with tile drain flow response and drain water chemistry, the fraction of recharge water collected by the tile drainage system was estimated (Reedy 1996). The estimates indicate that the drainage system collected only about 1.3% to 3.3% of the water draining from the soil profile to the shallow water table and that the bulk of the water collected by the drainage system was ambient groundwater. The low efficiency of the drainage system was

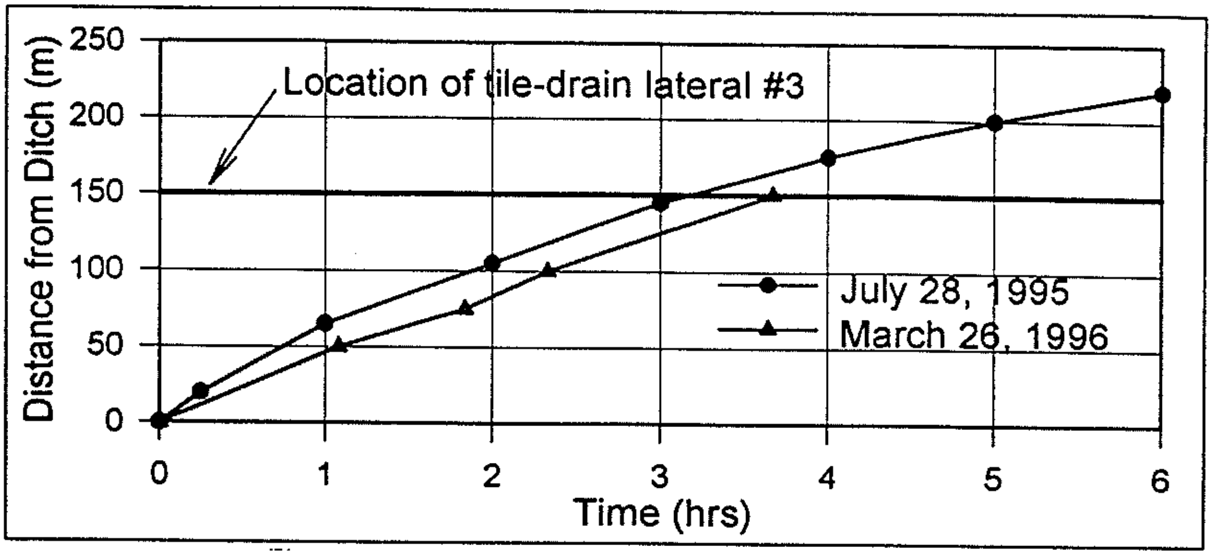


Figure 15. Rate of advance of irrigation water across the field from the ditch.

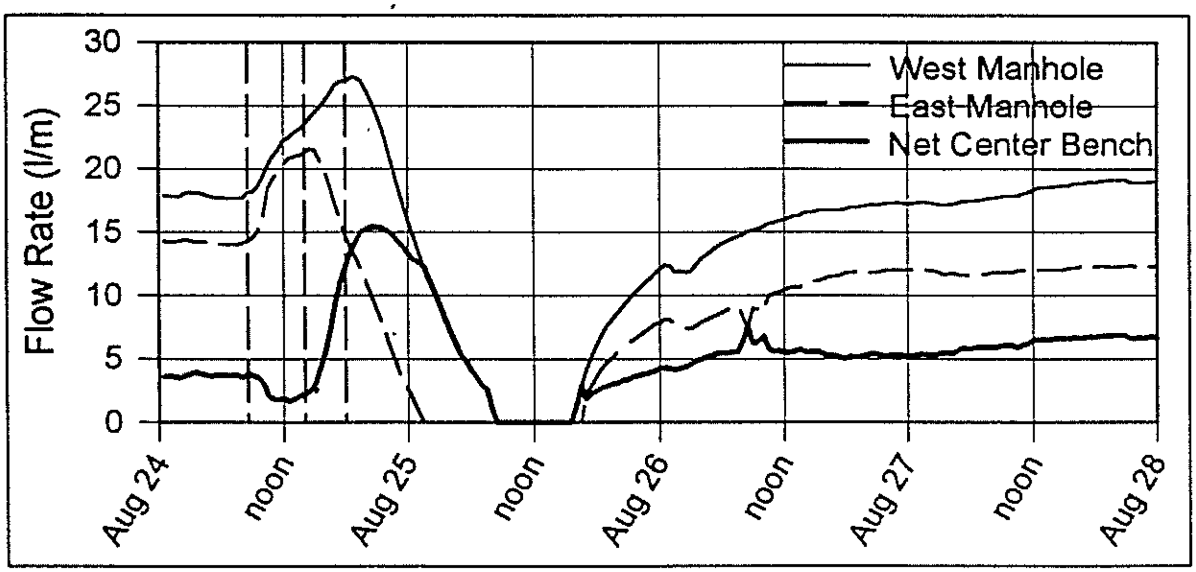


Figure 16. Tile drain flow response to an east-center-west irrigation sequence. Dashed vertical lines indicate irrigation start times for each bench.

due largely to the continuously submerged discharge outlet in the Riverside Drain (Figure 7). During most of the irrigation season, the water level in the Riverside Drain was 6-10 inches above the tile drain discharge pipe. This submerged condition severely reduced the hydraulic gradient in the tile drain system, causing the water table below the field to remain high, in contrast to the ideal situation shown in Figure 9.

The transport of agricultural chemicals and salts through a soil is controlled largely by its hydraulic properties, particularly the soil water retention and hydraulic conductivity. The hydraulic conductivity of the topsoil on the center bench was determined at 103 locations with a tension infiltrometer (White and Perroux 1989; Hendrickx 1990), a compact field instrument used for the in situ measurement of soil hydraulic properties. The saturated hydraulic conductivity varied over three orders of magnitude from 0.1 to 16 m/day with a mean value of 1.8 m/day. The unsaturated hydraulic conductivity at a soil water pressure of -6 cm varied much less, from 0.1 to 0.7 m/day with a mean of 0.2 m/day (Chaves 1995). The large changes in range as well as mean values between the saturated hydraulic conductivity and the hydraulic conductivity at pressure -6 cm indicate that much of the saturated flow takes place preferentially through macropores and cracks (Mohanty et al. 1997). Thus, the hydraulic conductivity measurements quantitatively confirm the soil structure observations made during the soil survey.

In addition to the infiltrometer measurements, four representative locations (Figure 4) were chosen on the center bench to conduct an "instantaneous profile experiment" (Watson 1966) for the determination of the unsaturated hydraulic conductivity and water retention to a depth of approximately 1 m. The method consists of measuring simultaneously and at successive times the volumetric water content and soil water pressures at different depths within a soil profile as the initially saturated profile drains. The data yielded estimates of the hydraulic properties of the major soil horizons, which were used to simulate water flow and chemical transport at the site (Mohanty et al. 1998).

The high water table in the center bench (Figure 13) causes a capillary upward flow from the groundwater table toward the root zone of the crop and the soil surface. This capillary rise provides supplemental water to the crop but the increases soil salinity which ultimately decreases yield. Knowledge of the capillary flux is important for the evaluating the movement of chemicals in the soil profile. Using the measured hydraulic properties, the area-averaged capillary flux for the center bench was determined as a function of groundwater table depth (Figure 17). During winter when no irrigation takes place the average groundwater table is at 120 cm (4 feet). Assuming a near-surface soil water tension of 1000 cm, capillary rise is approximately 0.05 cm/day or 0.02 in/day. During the five months without irrigation, a total upward flux of approximately 7.5 cm or 3 in takes place. Since the groundwater has a total dissolved solids content of about 650 mg/l, approximately 450 pounds per acre of salt is deposited by capillary rise in the top layer of the soil during the winter. This explains the observed saline conditions on the center and west benches. During the irrigation season, the water table rises to about 75 cm (30 in) below the land surface and a higher capillary rise of about 0.25 cm/day (0.1 in/day) results. This provides a considerable supplemental water supply to the crop. Salinity problems are less severe in summer because the regular irrigation applications leach most of the salts deeper into the soil. Nevertheless, at some locations of the center and west benches the salinity is so high that no crop growth is possible during any season.

Soil salinity can have a substantial indirect impact on the leaching of agricultural chemicals. For example, the increase of nitrate levels in the tile-drain water during 1994 (discussed below) was associated with the poor growth of winter wheat due to soil salinity. The stunted wheat crop could not take up the applied fertilizer and, as a result, nitrates leached toward the groundwater. Since soil salinity typically occurs as patches in agricultural fields with otherwise acceptable crop performance, excess chemical leaching as a result of soil salinity may be quite common.

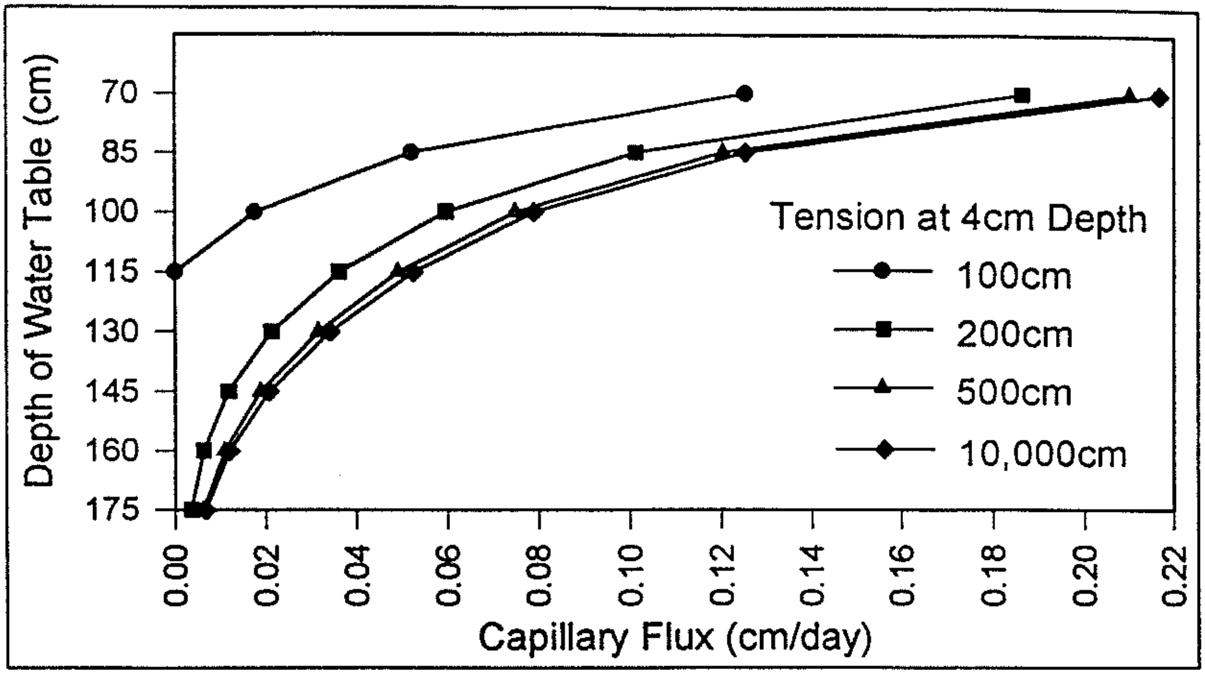


Figure 17. Average maximum capillary flux in the center bench as a function of the groundwater table depth.

Soil salinity on the center bench was measured with the EM38 ground conductivity meter. This instrument measures the apparent electrical conductivity of the soil, which is related to the salinity of the soil solution. This instrument is used for mapping soil salinity on agricultural fields worldwide (Rhoades and Oster 1986; Hendrickx et al 1992; Sheets et al. 1994). Figure 18 presents the soil salinity in the top 0.75 m of the center bench on May 30, 1994. Since irrigation probably already leached out some of the salts that accumulated during the winter, soil salinity during the winter wheat crop in the winter of 1993-94 was likely higher, especially in the top soil layer. Figure 19 presents the effect of salinity on the growth of forage corn as measured in September 1993 (Chaves 1995). If average soil salinity remained below 50 mS/m, the corn produced well, with heights above 2 m;. salinities from 50 to 100 mS/m decreased corn heights to 1-2 m; while mean soil salinities exceeding 130 mS/m greatly reduced corn growth, resulting in stalk heights less than 1 m. These observations of salinity effects on growth agree with data reported in the literature for forage corn (Bresler et al. 1982).

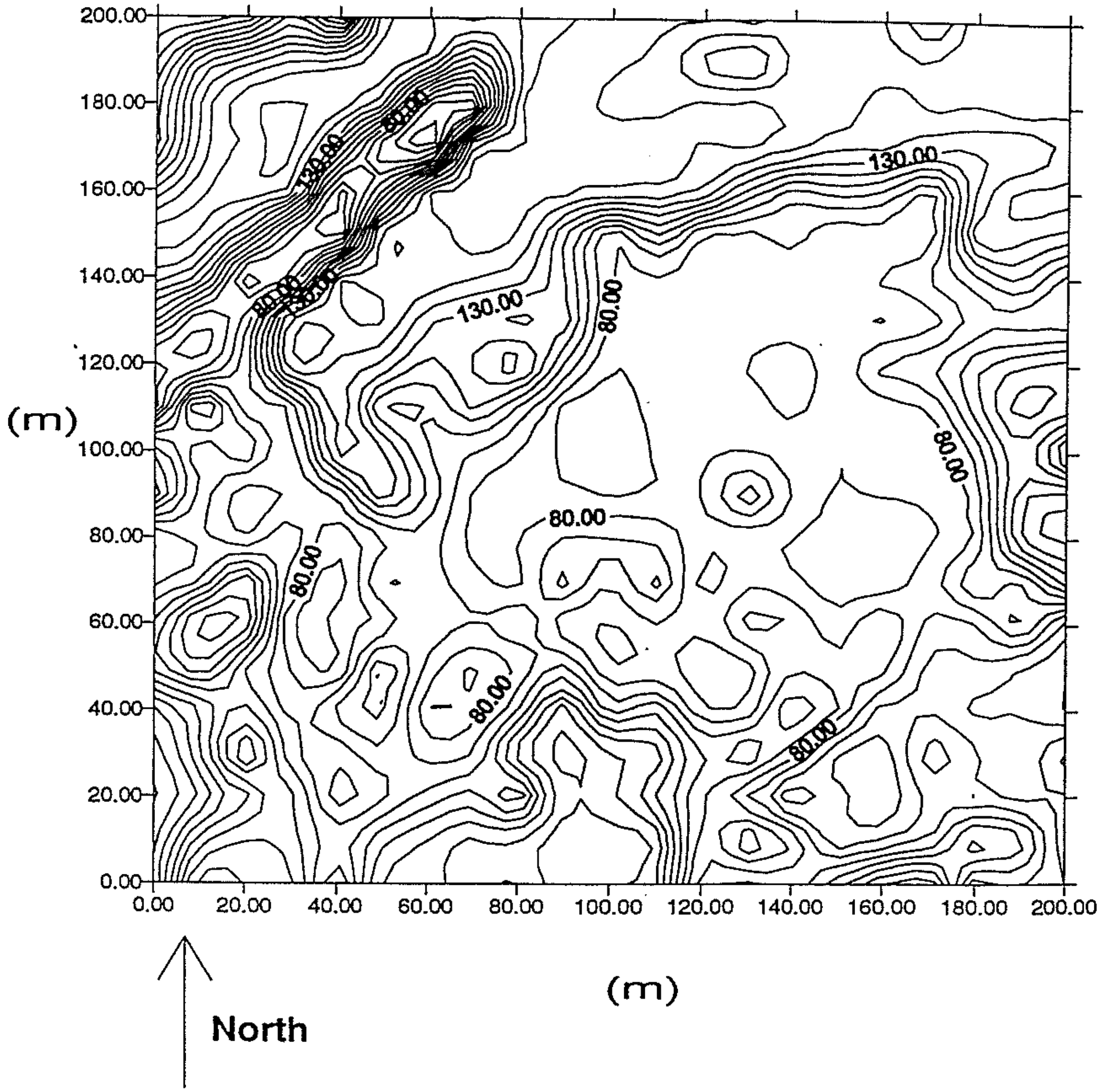


Figure 18. Salinity contour map based on May 30, 1994, EM38 measurements for the 0.75-m depth. The units are relative salinity values which can be correlated to actual soil salinities using methods described by Chaves (1995).

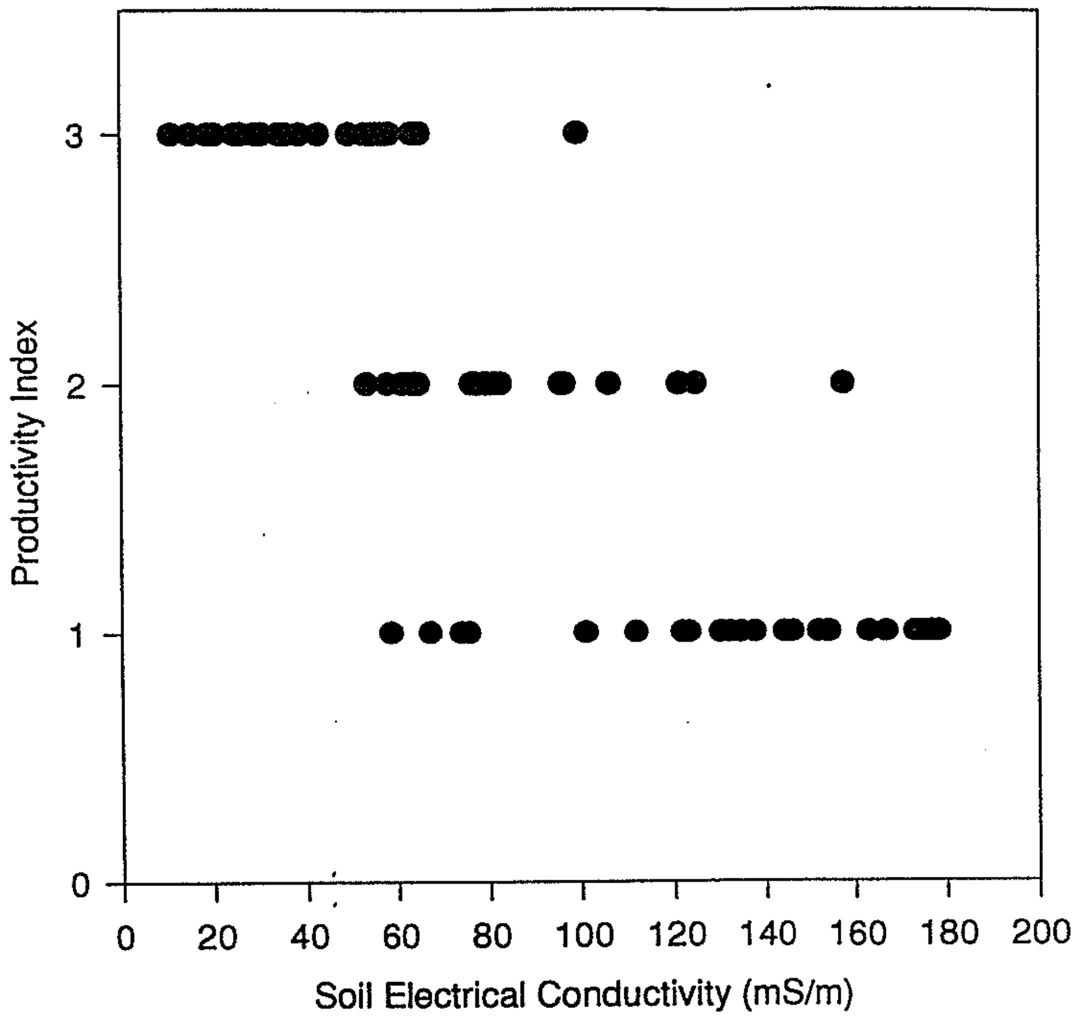


Figure 19. Relation between soil salinity (mS/m)and the productivity of forage maize on the center bench in September 1993. Productivity index 3 indicates a corn height > 2 m; 2 corn height 1-2 m; 1, corn height <1m.

Nitrogen Management and Impacts

The monitoring wells and piezemeters were also used to sample groundwater quality. Monthly samples were taken for determination of nitrate concentration and electrical conductivity. Nitrate analysis was performed by high performance liquid chromatography. Figures 20 and 21 show the nitrate-N concentrations and the electrical conductivity in the shallow groundwater under the three benches on May 25, 1994. The east bench had the highest nitrate-N concentrations but none exceeded the EPA's 10 mg/l drinking water standard. The

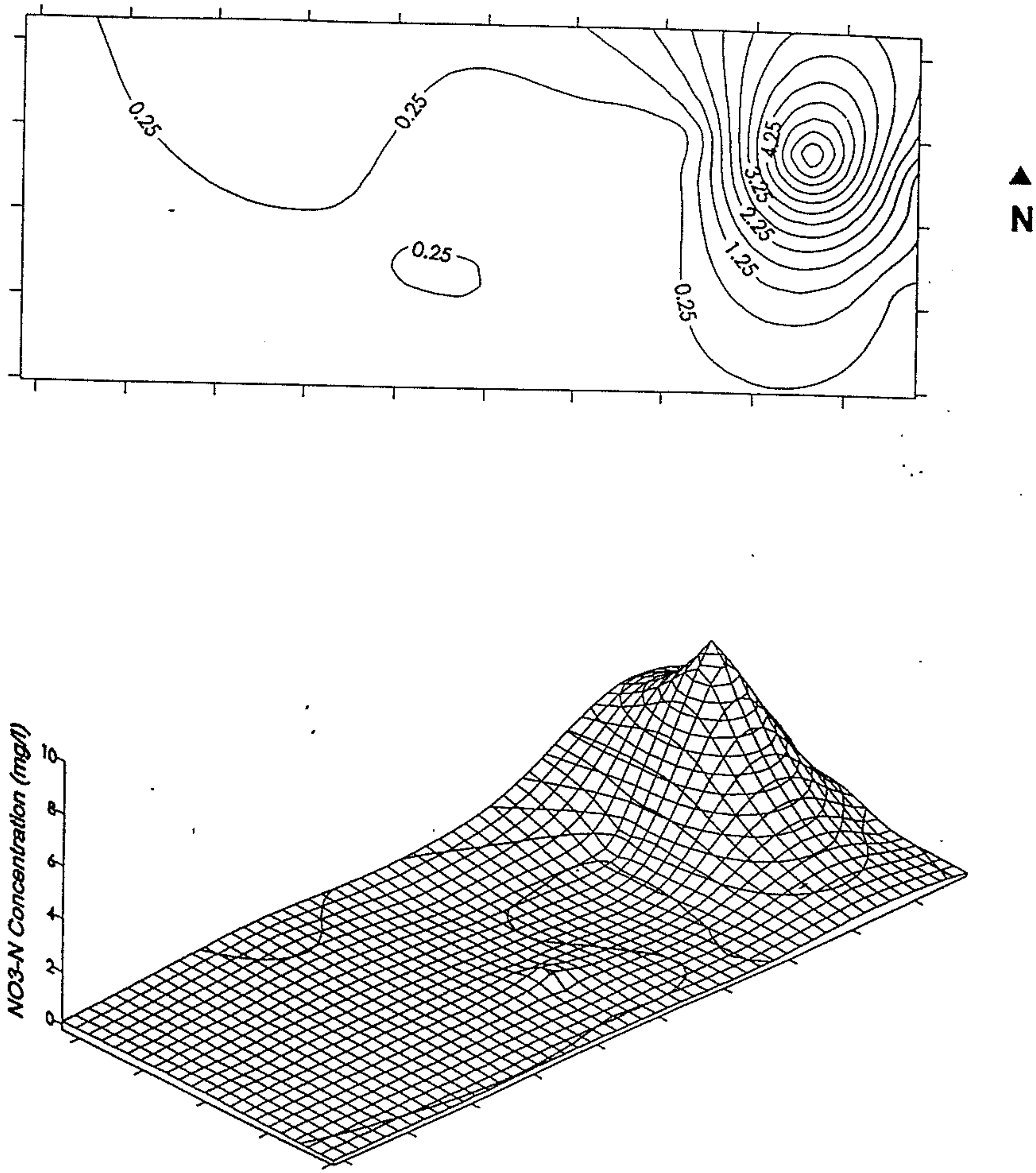
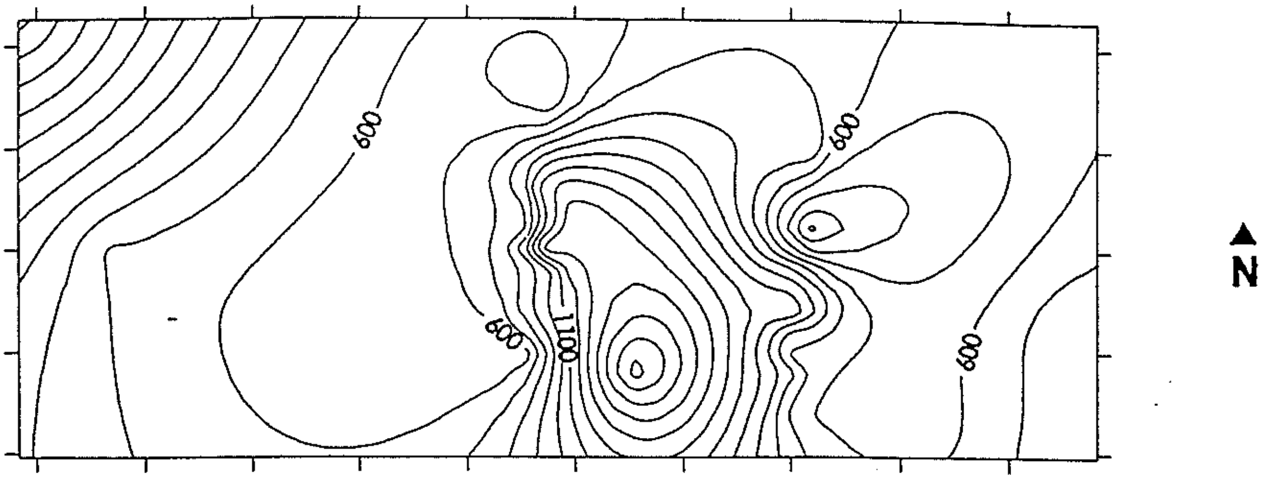


Figure 20. Nitrate concentrations in the shallow groundwater under the three benches on May 25, 1994. Field boundaries (horizontal axes on lower figure) not to scale.



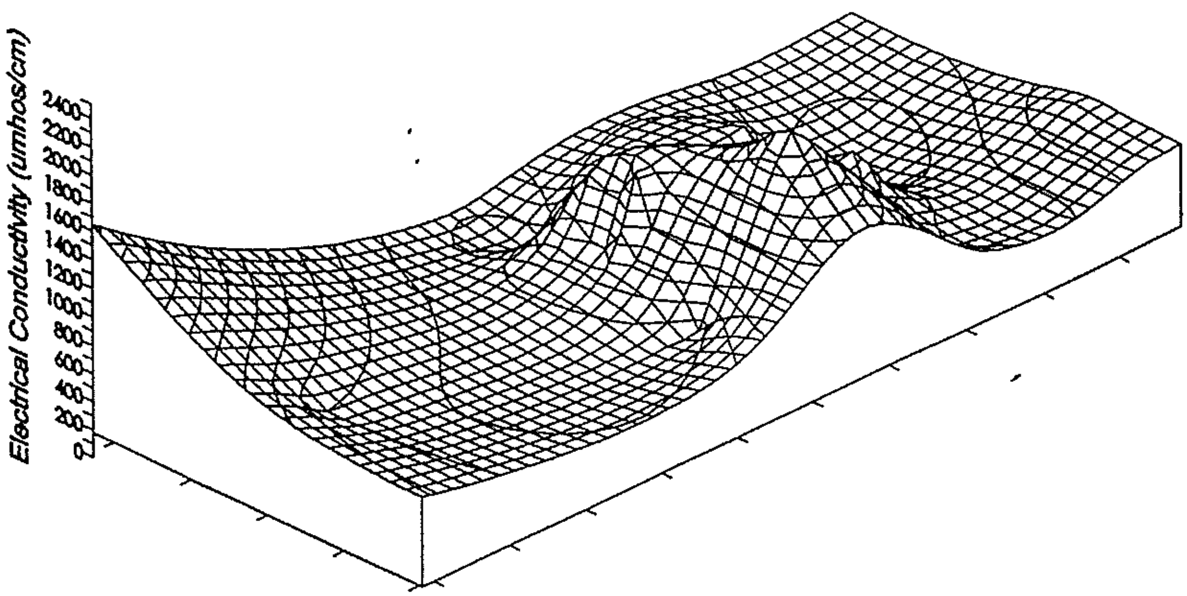


Figure 21. Electrical conductivities in the shallow groundwater under the three benches on May 25, 1994. Field boundaries (horizontal axes on lower figure) not to scale.

electrical conductivity exhibited a pattern completely different from the nitrate, since it is a function of all of the ions present in the water.

The nitrate samples collected from the piezometers showed a decreasing concentration with depth (Figure 22). This indicates that the regional groundwater does not contribute any significant amount of nitrate to the local groundwater below the Las Nutrias site.

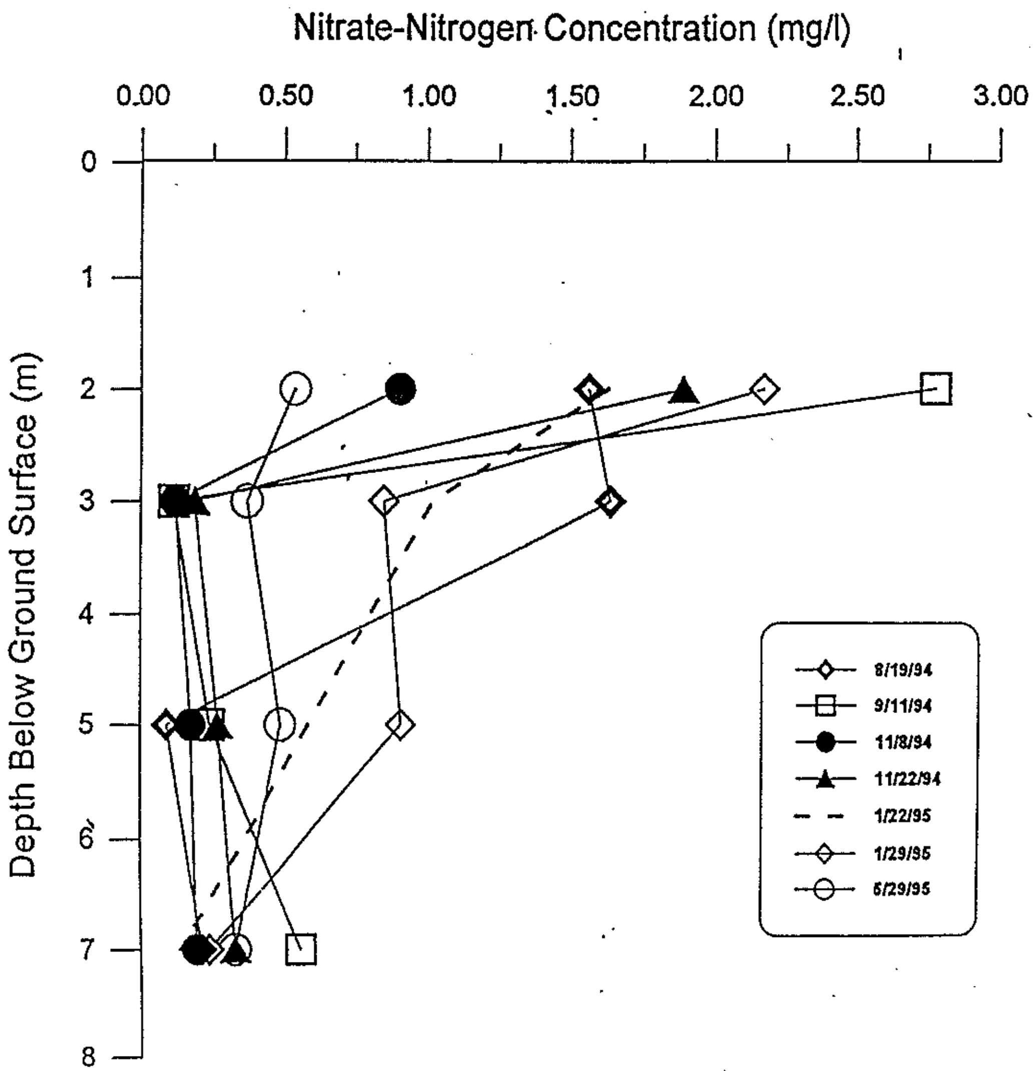


Figure 22. Nitrate-nitrogen concentrations (mg/l) in piezometer nest 1 (northeast corner of the east bench) from August 1994 through May 1995.

Intermittent sampling of the tile drains for nitrate began in the 1992 growing season. None of the 1992 or 1993 samples showed nitrate-N levels exceeding a few mg/l. Intensive sampling for nitrate was performed during the 1994 and early 1995 growing seasons. Samples were collected every few hours following an irrigation, with a decreasing sampling frequency after several days. Figure 23 shows the fluctuations in the concentrations of nitrate-N in the west (down gradient) manhole during the 1994 growing season. From the beginning of the irrigation season through the late summer, the nitrate-N concentration peaked approximately one day after the irrigation and then returned to its background concentration of less than 1 mg/l after one to two weeks. Although occasionally nitrate-N concentrations peaked slightly above the drinking water standard of 10 mg/l, the average drainage water concentration over time remained well below this level in 1994. The nitrate-N levels in the east (up gradient) manhole showed a similar pattern, but with fewer, lower concentration peaks. Samples collected from the tile-drain system effluence in the Riverside Drain never exceeded the drinking water standard of 10 mg/l, even during the periods when concentrations in the monitored drain water were high. By the end of the 1994 irrigation season, nitrate-N in the tile drain had decreased to a background level of less than 0.5 mg/l in both the east and west manholes. During the 1995 and early 1996 growing seasons, nitrate-N concentrations averaged 0.30 and 0.25 mg/l (about the same as ambient groundwater concentrations in the monitoring wells) and showed none of the sharp peaks noted in 1994 (Figure 23). The relatively large amounts of nitrate-N leached in 1994 thus appear to be anomalous.

The reasons for the high nitrate leaching in 1994 can be understood by looking at the nitrate-N in the soil profile at the beginning of the 1994 and 1995 growing seasons. Figure 24 shows average soil nitrate-N concentrations versus depth for samples collected at 54 locations in the center bench. In 1994, there was a large reservoir of soil nitrate near the surface, presumably due to the late nitrogen fertilization in 1993 combined with the poor growth and nutrient uptake of the winter wheat planted that fall (Table 1). A portion of this nitrate was rapidly leached to the tile drain line by preferential flow following each of the early 1994

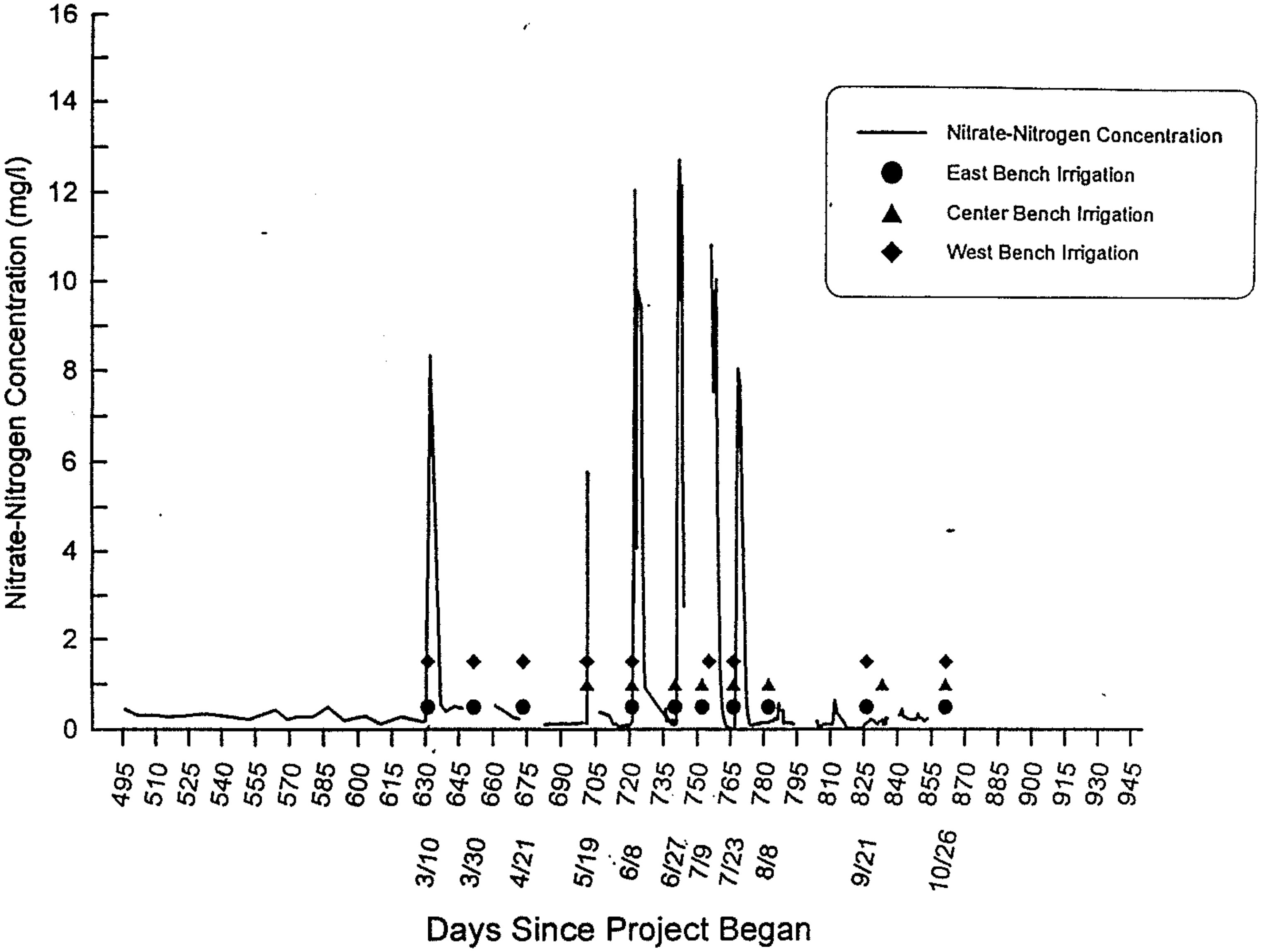


Figure 23. Nitrate-nitrogen concentration (mg/l) with time measured in the west manhole during the 1994 growing season. Day zero corresponds to June 17, 1992.

irrigations, resulting in the sharp peaks noted in the tile drain water concentrations (Figure 23). By late in the 1994 growing season, this reservoir of soil nitrogen had been depleted (Figure 24) and nitrate-N in the drain water decreased to background levels. Mohanty et al. (1998) discuss the nitrogen dynamics at the Las Nutrias site in more detail.

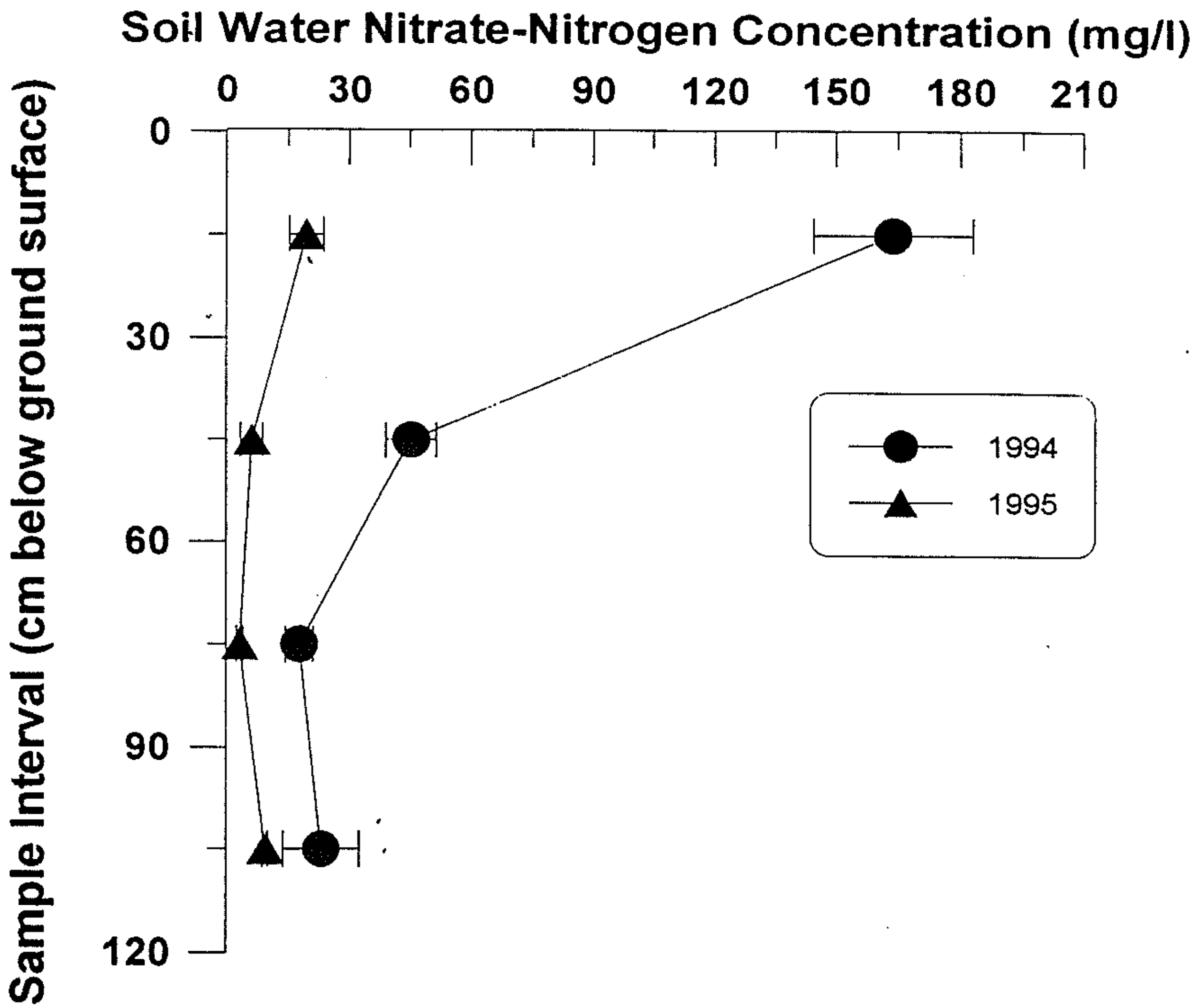


Figure 24. Mean soil water concentrations of nitrate-nitrogen in the center bench at the beginning of the 1994 and 1995 growing seasons.

Using estimates of the amount of recharge collected by the tile drains, the total amount of nitrate-N leached to the groundwater in 1994 was estimated. Since the excess nitrogen was presumably due to residual fertilizer in the center bench, monitoring data for nitrate and tile drain flow collected in the west manhole was used for these calculations. From 14% to 38% (120 to 316 kg, or 265 to 700 lb) of the 840 kg (1850 lbs) of nitrate-N lost from the center bench by all mechanisms (i.e., crop uptake, bacterial denitrification, and leaching to shallow groundwater) was leached to the shallow groundwater during the 1994 irrigation season, equating to

21 to 55 kg/ha (19 to 49 lb/acre) (Reedy 1996). Again, the relatively high losses in 1994 were anomalous due to the winter wheat crop's failure to grow and the resultant failure to utilize the applied nitrogen fertilizer. Nitrogen losses to groundwater were negligible in 1995 and 1996 when all benches at the project site were planted to alfalfa.

Pesticide Management and Impacts

Pesticide analysis was performed both as broad screening of common agricultural and synthetic chemicals and as targeted analyses for pesticides applied by the farmer. During the 1995 growing season, two rounds of sampling (27 April and 15 June) were performed in cooperation with the New Mexico Environment Department. A total of 84 samples were collected from both manholes, the Riverside Drain outfall, and selected monitoring wells. The samples were analyzed at the New Mexico Scientific Laboratory Division in Albuquerque. Samples were analyzed by standard EPA methods for 1, 2-dibromoethane (EDB) and 1,2-dibromo-3-chloropropane (DBCP) (Method 504), acid herbicides (Method 515.15), synthetic organics (Method 525.1), carbamate pesticides (Method 531.1) and/or aromatic and halogenated purgeables (Method 601/602). No pesticides were detected in any of these samples. Several samples contained detectable amounts of plasticizers and glue components probably associated with the plastic monitoring wells and tile drains.

Lorsban

Targeted analyses were performed in 1995 for chloripyrifos (Lorsban) applied to control alfalfa pests. The landowner applied the Lorsban (40.7 % chlorpyrifos by weight) at the rate of 1.5 pints per acre to the east bench only on 20 April 1995. Tile drain samples were collected regularly from both manholes over the next six months and periodically from the Riverside Drain outfall and selected monitoring wells. The samples were analyzed for chloripyrifos by an Enzyme Linked Immunosorbent Assay (ELISA) method, with a detection limit of 0.1 μg/l

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The results of the ELISA analyses are plotted versus time in Figure 25 No chloripyrifos was detected at any sampling time in the tile drain (manhole) samples. On a few occasions, chloripyrifos was detected in the Riverside Drain or monitoring well samples, but the concentration never exceeded 1 μg/l. These detections may indicate greater leaching of chloripyrifos from portions of the east bench not captured by our instrumented drain and/or migration of chloripyrifos in groundwater from off site. In any case, the levels of measured chlorpyrifos were very low, not much above the detection limit of 0.1μg/l.

The low chloripyrifos levels measured at Las Nutrias are consistent with other results for this chemical using tile drain systems (Kladivko et al. 1991; Spencer et al. 1985). These earlier studies indicate strong sorption (K_{oc} 1-30 * 10^3 l/kg) and rapid dissipation (half life 60-120 days) of chlorpyrifos in agricultural soils.

Dimate 4E

Targeted analyses were performed in 1996 for dimethoate (Dimate 4E) applied to control alfalfa pests. The landowner applied the Dimate 4E (4 lbs dimethoate per gallon) at the rate of 0.75 pints per acre to all three benches on 16 April 1996. The field was irrigated soon after pesticide application. Tile drain samples were collected intensively beginning with the onset of irrigation and over the next four days, since experience with nitrate leaching indicated that chemical detection was most likely during this period. Water from discrete sampling times was composited and five samples were sent to a commercial laboratory for analysis by EPA method 8141 (GC/MS). The method detection limit was 0.1 μg/L. No dimethoate was detectable in any of the samples.

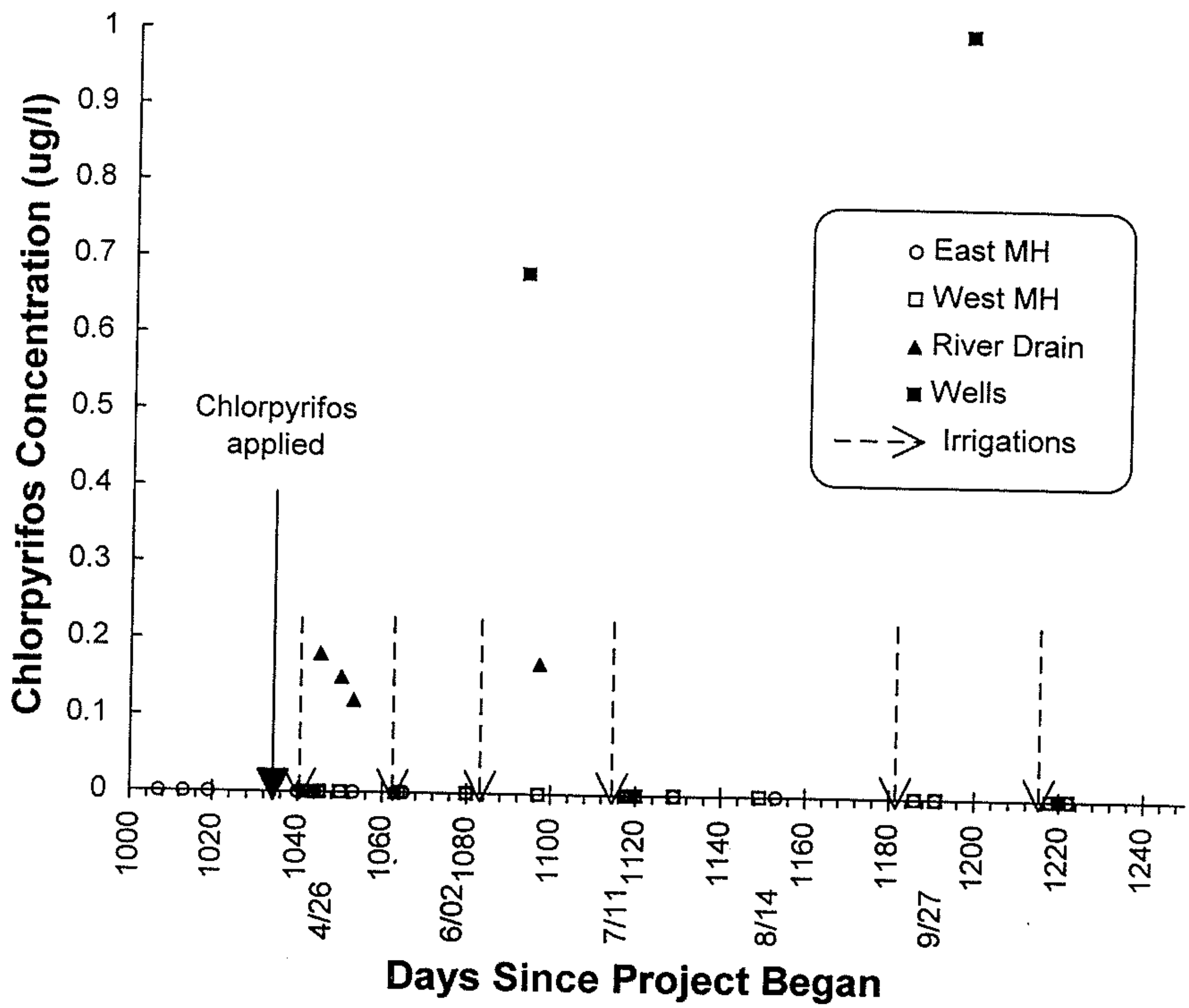

Figure 25. Chlorpyrifos concentrations in the east and west manholes, the Riverside Drain, and in selected monitoring wells during the 1995 season. Day zero corresponds to June 17, 1992.

Baythroid 2

Simultaneously with dimethoate application, the insecticide cyfluthrin (Baythroid 2) was applied to all three benches. Baythroid 2 (2 lbs cyfulthrin per gallon) was applied to all three benches at the rate of 3.2 fluid ounce of per acre. We did not have the available equipment to analyze for cyfluthrin, nor were we able to identify a commercial laboratory to perform the analysis; therefore no analyses were conducted for this chemical. Given the lack of detection of dimehtoate and the 75% lower application rate for cyfluthrin, we expect that no detectable cyfluthrin was present in the tile drain water samples. However, this assumption cannot be proven.

MAJOR FINDINGS AND CONCLUSIONS

Field Water Balance

Evapotranspiration from the center bench at Las Nutrias Groundwater Project site exceeded the sum of irrigation and precipitation. The net upward flow of water in 1995 was 5 cm (2 in) for the calendar year; during the growing season, it was at least 33.5 cm (13 in). This negative water balance explains the persistent saline soil conditions observed in the center and west benches.

Tile Drain Efficiency and Impacts

The efficiency of the tile-drain system was very low, due to the submerged conditions of the system outlet at the Riverside Drain. Silting of the drain pipe filter-socks and/or sediment buildup in the drains did not appear to be limiting factors for tile drain flow.

The low efficiency of the drain resulted in a high water table during most of the year and promoted salinization of the topsoil due to capillary rise. This capillary rise also provided additional water for crop growth during the summer, however.

Due to the poor tile drain efficiency and the resultant submerged condition of the drain, the fraction of soil recharge captured by the drain during irrigation response periods was very low, averaging only 1.25% to 3.3% of the total recharge volume. Most of the water collected in the tile drain was regional groundwater, and not water from the overlying field.

Implications for Drainage System Design

Agricultural operators considering the installation of tile-drain systems should take note of the inefficiency of Las Nutrias Groundwater Project tile-drain system. Elevations of surface drain water must be kept below the tile-drain discharge points through proper ditch maintenance. Also, in areas with highly conductive subsoils, the tile-drain system design should account for potentially high inputs of regional groundwater.

Nitrate Leaching to Shallow Groundwater

Nitrate leaching at Las Nutrias Groundwater Project site does not appear to create a major or persistent problem with regard to shallow groundwater quality. During the 1994 irrigation season, nitrate-N concentrations in excess of 10 mg/l in the monitored tile-drain lasted for only a short period of time immediately following a flood irrigation event. Samples collected from the tile-drain system effluence in the Riverside Drain never exceeded the drinking water standard of 10 mg/l, despite the (temporarily) elevated nitrate-N concentrations under the center bench. The relatively high spikes in nitrate-N concentration during the 1994 season were due to unusually high nitrate-N levels in the soil profile at the beginning of that season (due to fertilization) and to low crop uptake of N due to a poor stand of winter wheat.

From 14% to 38% (120 to 316 kg, or 265 to 700 lb) of the 840 kg (1850 lbs) of nitrate-N lost from the center bench by all mechanisms (i.e., crop uptake, bacterial denitrification, and leaching to shallow groundwater) was leached to the shallow groundwater during the 1994 irrigation season, equating to 21 to 55 kg/ha (19 to 49 lb/acre). Again, the relatively high losses in 1994 were anomalous due to the winter wheat crop's failure to grow and the resultant failure to utilize the applied nitrogen fertilizer. Nitrogen losses to groundwater were negligible in 1995 and 1996 when all benches at the project site were planted to alfalfa.

Pesticide Leaching to Shallow Groundwater

No pesticides were detected in the in the tile drain water at any time during 1995 or 1996. Organics targeted in 1995 included 1, 2-dibromoethane (EDB); 1,2-dibromo-3-chloropropane (DBCP); acid herbicides; synthetic organics; carbamate pesticides; and aromatic and halogenated purgeables. Intensive groundwater and tile drain sampling was conducted for chloripyrifos (Lorsban) in 1995, and dimethoate (Dimate 4E) in 1996. A few groundwater samples, but no tile drain samples, contained chlorpyrifos at concentrations between 0.1 and 1 µg/l; no dimethoate was detected in any sample.

Preferential Flow of Surface-Applied Water and Chemicals

There is a strong preferential flow component (channeling of water through cracks, root channels, and animal burrows) in Las Nutrias Groundwater Project soils. A significant fraction of applied irrigation water bypasses the bulk of the soil matrix and quickly flows to the water table. This conclusion was supported by the rapid head, flow, and chemical response in the tile-drain to both on- and off-site flood irrigation events. The preferential flow can cause chemicals near the soil surface to bypass the bulk of the soil and appear in groundwater shortly after an irrigation. Preferential flow was the mechanism responsible for the sharp peaks in nitrate-N concentration noted in the tile drains in 1994.

Overall Agricultural Chemical Impacts on Shallow Groundwater

Based on the information collected during Las Nutrias Groundwater Project, typical agricultural cropping, water, nutrient, and pesticide management practices do not appear to pose a broad threat to shallow groundwater in the Rio Grande Valley. Due to large dilution by ambient groundwater (whose source includes mountain-front recharge, infiltration losses from the Rio Grande, and recharge from other agricultural fields) temporary spikes in field drainage chemical concentrations are rapidly diluted below regulatory levels.

FURTHER INFORMATION

This report provides only an overview of the data and results generated by Las Nutrias Groundwater Project. For more detailed information, the reader should refer to the Hydrology Open File Reports upon which this summary is based. In particular, soil hydrologic characterization and salinity mapping are described by Chaves (1995); nitrate and other water chemistry data are described by Roth (1996); and the system design, water balance calculations, and nitrate leaching estimates are described by Reedy (1996). Copies of these reports are available from the Hydrology Program at New Mexico Tech. In addition, the papers by Mohanty et al. (1997, 1998) describe mechanistic models of water flow and nitrate transport at Las Nutrias.

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