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THE LUBBOCK LAND TREATMENT SYSTEM RESEARCH AND DEMONSTRATION PROJECT. VOLUME V: EXECUTIVE SUMMARY

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The Lubbock Land Treatment System Research and Demonstration Project:

Volume V. Executive Summary

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16. ABSTRACT

The Lubbock Land Treatment System Research and Demonstration Project, funded by Congress in 1978 (H.R. 9375), was designed to address the various issues concerning the use of slow rate land application of municipal wastewater. The project involved the 1) physical expansion of overloaded 40 year old Lubbock slow rate land treatment system; 2) characterization of the chemical, biological and physical conditions of the ground water, soils and crops prior to and during irrigation with secondary treated municipal wastewater; 3) evaluation of the health effects associated with the slow rate land application of secondary effluent and 4) assessment of the effects of hydraulic, nutrient and salt mass loadings on crops, soil and percolate.

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VOLUME V

Executive Summary

by

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DISCLAIMER

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FOREWORD

The U.S. Evironmental Protection Agency was established to coordinate the administration of major Federal programs designed to protect the quality of our environment.

An important part of the Agency's effort involves the search for information about environmental problems, management techniques, and new technologies through which optimum use of the Nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

The U.S. Environmental Protection Agency's Office of Research and Development conducts this search through a nationwide network of research facilities. As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs including the development and demonstration of soil and other natural systems for the treatment and management of municipal wastewaters.

The slow rate land treatment process of municipal wastewaters uses the unsaturated soil profile and agricultural crops managed as the treatment media. The Lubbock Land Treatment System Research and Demonstration Program, funded by Congress in 1978 (H.R. 9375) was designed to address the various issues limiting the use of slow rate land application of municipal wastewater. The project involved expansion of the Lubbock Land Treatment System to 2,967 hectares; characterization of the chemical, biological and physical condition of the ground water, soils and crops prior to and during irrigation with secondary treated municipal wastewater; and evaluation of the U.S. Environmental Protection Agency's design criteria for slow rate land application. Results demonstrate that, where such systems are correctly designed and operated, they can be cost effective alternatives for municipal sewage treatment at sites where conditions are favorable for low hydraulic loading combined with cropping practices.

This report contributes to the knowledge which is essential for the U.S. Environmental Protection Agency to meet requirements of environmental laws and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American public.

Clinton W. Hall

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Robert S. Kerr Environmental Research Laboratory

ABSTRACT

The Lubbock Land Treatment System consists of two privately owned farms. The Gray farm comprises 1,489 ha and has been reusing treated wastewater for crop irrigation for more than 40 years. In 1981 the land application system was enlarged to include the Hancock farm which had 1,153 ha under cultivation. The primary irrigation mode employed by both farms was spray irrigation using center pivot irrigation machines. The Lubbock Land Treatment system Research and Demonstration Project involved the 1) physical expansion of the Lubbock Land Treatment System; 2) characterization of the chemical, biological and physical conditions of the ground water, soils, and crops prior to and during irrigation with secondary treatment municipal wastewater; 3) evaluation of health effects of slow rate land application of secondary effluent; and 4) assessment of the effects of hydraulic, nutrient and salt mass loadings on crops, soil and percolate.

During the period when a portion of the treated wastewater was diverted to the Hancock farm, a decrease in the ground-water level beneath the Gray farm was measured. In conjunction with the lowering of the groundwater table was an increase in water quality beneath most of the farm (primarily the ground water underlying the spray irrigated areas). The cultivation of alfalfa in the spray irrigated areas was probably the primary factor affecting the quantity and quality of percolate.

Chemical and nutrient constituents in the treated wastewater applied to the Hancock farm were removed by the soil-crop matrix. An increase in ground water beneath the Hancock farm resulted from deep percolation of surface runoff collected in moats surrounding the reservoirs and excavations constructed to reduce flooding of crop land. Deep percolation of surface runoff leached existing nitrate and salt deposits within the soil profile to the ground water; thereby, causing increased ground-water nitrate and total dissolved solids concentrations.

The epidemiological study conducted on the populace in and surrounding the Hancock farm indicated that wastewater spray irrigation produced no

obvious disease during the project period. However, the rate of viral infections was slightly higher among participants who had a high degree of aerosol exposure. The polio virus 1 infections during spring 1982 were probably related to this exposure.

Agricultural studies showed that cotton and grain sorghum produced greater yields with increasing annual hydraulic loading rates up to 3m.ha/ha.yr. The highest alfalfa yields were obtained in test plots irrigated with 365 and 434 cm.ha/ha.yr. The alfalfa test plots appeared to remove all nutrients applied in the wastewater stream. Salts were leached beyond 91 cm of soil in all plots receiving 60 cm.ha/ha.yr or greater.

The Lubbock Land Treatment System Research and Demonstration Project was conducted by Lubbock Christian College Institute of Water Research (LCCIWR), Southwest Research Institute (SwRI), University of Illinois (UI) University of Texas at San Antonio (UTSA), University of Texas at Austin (UT), and Texas Tech University (TTU). This report was submitted in fulfillment of CR807501 and CS806204 by LCCIWR under primary sponsorship of the U.S. Environmental Protection Agency. This report covers a summary of research activities performed from May 1, 1980 through December 31, 1983. This work was completed on June 30, 1985.

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SECTION 1

INTRODUCTION

Agriculture is the major user of freshwater in the United States with approximately 99 percent of the agricultural water demand used for irrigation (Williams, 1982). Increasing water demands by agriculture, industry and municipalities have created severe water shortages in various regions of the United States and the world. Application of municipal wastewater to agricultural lands is a viable alternative to reduce the withdrawal of freshwater from surface water and ground-water sources. In addition, land application of wastewater is a cost-effective treatment alternative. Slow rate wastewater application, usually in the form of spray irrigation, is the most widely used form of land application.

The Lubbock Land Treatment System Research and Demonstration Program, funded by Congress in 1978 (H.R. 9375), was designed to address the various issues concerning the use of slow rate land application of municipal wastewater. The project involved the 1) physical expansion of the Lubbock Land Treatment System; 2) characterization of the chemical, biological and physical conditions of the ground water, soils and crops prior to and during irrigation with secondary treated municipal wastewater; 3) evaluation of the health effects associated with the slow rate land application of secondary effluent; and 4) assessment of the effects of hydraulic, nutrient and salt mass loadings on crops, soil and percolate. Results from the Lubbock Land Treatment Research and Demonstration Project are published in four volumes:

1. Volume I: Demonstration/Hydrogeologic Study (George et al 1985);
2. Volume II: Percolate Investigation in the Root Zone (Ramsey and Sweazy 1985);
3. Volume III: Agricultural Research Study (George et al 1985); and
4. Volume IV: Lubbock Infection Surveillance Study (LISS) (Camann et al 1985).

BACKGROUND

During the 1930s the City of Lubbock entered into a contractual agreement with Dr. Fred Standefer to pump all the sewage effluent to his farm, later to be known as the Gray farm. As Lubbock grew, the Gray farm was able to expand to encompass 1,489 ha. Nonetheless, the Gray farm could not adequately manage the hydraulic flow pumped from the City of Lubbock. Consequently, the farm was over-irrigated and ground water accumulation occurred beneath the farm with associated water quality problems.

In November 1980 construction commenced to expand the Lubbock Land Treatment System to include the Hancock farm located 25 km southeast of Lubbock and directly north of the City of Wilson, Texas. The expansion was designed to reduce the hydraulic and nutrient overloaded condition of the Gray farm. The combined area of the Lubbock Land Treatment system was 2,967 ha (7,330 acres).

DESCRIPTION OF LAND APPLICATION SYSTEM EXPANSION

Lubbock's Southeast Water Reclamation Plant (SeWRP) consists of two trickling filter systems and an activated sludge system (Figure 1). Unchlorinated effluent from the two trickling filter plants was pumped to the Gray and Hancock farms.

A total wastewater discharge of approximately 5.5 x $10^4 m^3/d$ (15 mgd) was to be divided equally between the Gray and Hancock land application sites. Effluent from SeWRP was conveyed to the Hancock land from a three-pump, pumping station through 25 km of 0.69 m force main.

The diurnal flow variation within the wastewater treatment system due to the management of water between the trickling filter plants and the activated sludge plant reduced flow through the trickling filters from 2:00 a.m. to 10:00 a.m. each day to 315 m^3/hr (2.0 mgd). The pump capacity and sump were not designed to absorb the variations in flow from the trickling filter plant. Consequently, the dynamic nature of the effluent hydrograph made it impossible to operate two pumps for more than 16 hours each day.

At the northern boundary of the Hancock farm, the effluent was routed

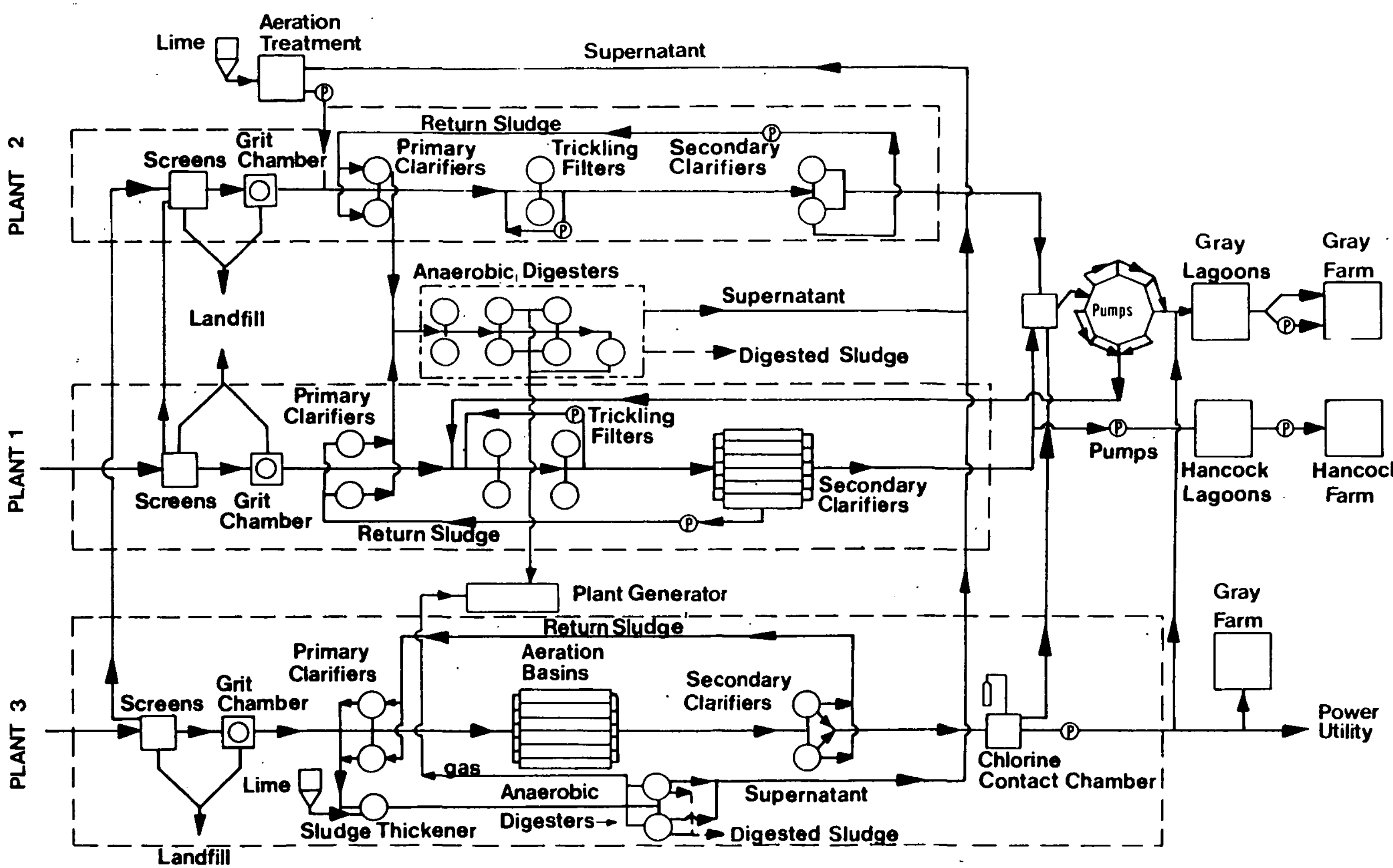

Figure 1. Southeast Water Reclamation Plant Flow Diagram

through three 0.38 m plastic irrigation pipelines to three separate reservoirs (Figure 2). The reservoirs were constructed on natural playa lakes. The reservoir capacity was adequate to provide emergency storage during rainfall events, and to prevent the necessity of irrigating during periods of cultivation, seeding, and harvesting of crops. Approximately 3.5 months of storage were provided by the three reservoirs. Irrigation pump stations were provided at each reservoir. Constant pressures were maintained throughout the system by a variable speed (lead) pump and a constant speed (lag) pump located on Reservoir 1. Both pumps were controlled by system pressure and discharge flow rate.

The hydraulic distribution system was designed to irrigate 1,153 ha with 1,082 ha irrigated by electric drive center pivot irrigation machines. Each center pivot was designed to irrigate up to 15 cm in 20 days after allowing for 20 percent loss due to evaporation. Without the use of the reservoirs, five to six center pivots could be operated at the same time, utilizing the flow pumped directly from Lubbock's wastewater treatment plant. Each center pivot had a centrifugal booster pump. The booster pumps increased the line pressures to an operating level of 3.1×10^6 pascals (45 psi).

In-line screens were placed between the centrifuge booster pumps and the center pivots to reduce clogging of the spray nozzles. On each irrigation machine Nelson® spray nozzles were installed on drops located 3.2 m apart. The size of the nozzles varied from 2.4 mm (3/32 in) to 7.1 mm (9/32 in). Nozzles were positioned a distance of 1.2 m to 1.8 m above the ground which allowed easy maintenance of the nozzles. Each nozzle provided a 360° umbrella pattern with an effective wetted diameter of 8.5 to 9.1 m (28 to 30 ft) to allow for the greatest application intensity. The energy dissipating deflector incorporated into the nozzle assembly was a concave plastic plate. Water discharged through the orifice was deflected upward once it struck the deflector which enhanced the creation of aerosols during the period of study and increased drift and evaporation of water. Convex deflectors were installed on most nozzles after the LISS monitoring period ended (i.e., after October 1983) to direct the water downward. This change reduced aerosol formation and drift. In addition, end guns were provided

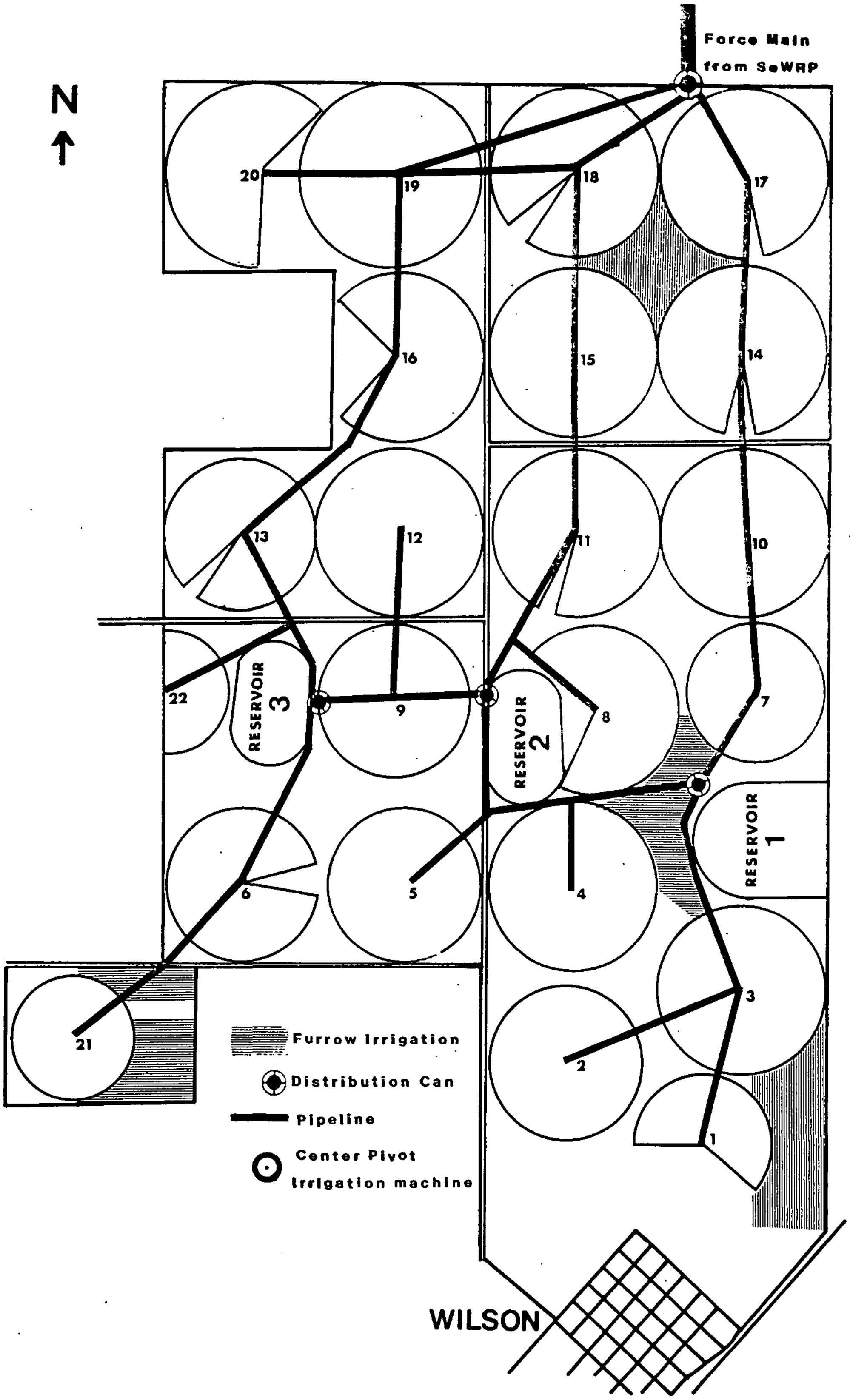

Figure 2. Hancock Farm Hydraulic Distribution System

on each pivot to irrigate the corners.

EFFLUENT QUALITY

During 1980 and 1981, Lubbock's SeWRP was producing an effluent from the trickling filter system which had a composition equivalent to a typical medium untreated domestic wastewater (Table 1). The City of Lubbock's wastewater discharge permit for SeWRP required the plant to produce an effluent with a 30-day-average 5-day biochemnical oxygen demand (BOD_5) not greater than 45 mg/l. During the project monitoring period the effluent BOD_5 quality from SeWRP ranged from a monthly high of 260 mg/l to a monthly low of 27 mg/l:

Month	Average Monthly Effluent BOD_5 Produced by Lubbock SeWRP 1982 mg/l	1983 mg/l
January	143	71
February	260	120
March	198	105
April	139	65
May	108	30
June	128	39
July	130	49
August	76	27
September	69	43
October	171	31
November	63	63
December	86	49

This poor quality effluent was mainly attributable to the malfunctioning of the anaerobic digestion process. From June 1980 to February 1982, the average effluent total organic carbon (TOC) produced from trickling filter Plant 2 was 118.7 mg/l. Total Kjeldahl Nitrogen (TKN) concentration averaged 38.59 mg-N/l of which 67 percent was ammonia-nitrogen (25.95 mg N/l) and 33 percent was organic nitrogen. Approximately 57 percent of the total

TABLE 1. CHARACTERIZATION OF EFFLUENT PRODUCED BY SOUTHEAST WATER RECLAMATION PLANT IN 1980 AND 1981

Parameter	Concentration	
	Average	Standard Deviation
Alkalinity (mg $CaCO_3$/l)	337	34
Specific Conductance (μmhos/cm)	2216	290
Total Dissolved Solids (mg/l)	1695	537
pH	7.54	0.21
Chloride Ion (mg/l)	468	55
Sulfate Ion (mg/l)	315	43
Total Kjeldahl Nitrogen (mg N/l)	38.59	15.23
Nitrite plus Nitrate Nitrogen (mg N/l)	0.29	0.30
Ammonia Nitrogen (mg N/l)	25.95	6.69
Total Phosphorus (mg P/l)	14.43	4.27
Orthophosphate Phosphorus (mg P/l)	8.36	2.03
Organic Phosphorus (mg P/l)	5.15	4.20
Chemical Oxygen Demand (mg/l)	302	136
Total Organic Carbon (mg/l)	118	45

phosphorus (14.43 mg/l) present in the effluent from the trickling filter plant was orthophosphate phosphorus (PO_4). During the spring of 1982, SeWRP placed on-line additional anaerobic digesters and rehabilitated the primary clarifiers and rotary distributors of the trickling filter plants. A much higher quality waste stream was pumped to the Hancock and Gray farms in 1982 through 1983. TOC levels at the terminus of the forced main were 46 percent less than the average concentrations measured in trickling filter plant effluent samples obtained the previous sampling periods. No statistically significant differences ($\alpha = 0.05$) were observed in TKN levels measured in the waste streams from Plant #2 (38.59 mg N/l) and at the terminus of the force main (41.70 mg N/l). As SeWRP's effluent reached the Hancock farm, 62 percent of the TKN was ammonia-nitrogen (25.80 mg N/l). The data indicate no nitrogen transformations through the force main. Average total phosphorus (TP) and organic phosphorus (Org P) levels (11.82 mg/l and 1.6 mg/l) contained in water samples obtained from the terminus of the force main did decrease significantly from baseline effluent concentrations. The decrease in TP appeared to be a result of a decrease in organic phosphorus mass loading from the trickling filter plant. As anticipated, the bulk (71 percent) of the nitrogen contained in the water entering the Hancock farm (41.77 mg-N/l) was lost within the reservoirs. The reservoir effluent average TKN concentration was 11.74 mg-N/l. The median nitrite plus nitrate (NO_2+NO_3 level in the reservoir discharge stream was 0.27 mg N/l.

Approximately 85 percent of the total phosphorus contained in the effluent (11.82 mg/l) pumped to the Hancock farm was orthophosphate. Average orthophosphate levels decreased from 8.43 to 4.85 mg/l and as the wastewater flowed through the reservoirs total phosphorus concentrations were reduced by 47 percent from 11.82 mg/l to 6.31 mg/l. Orthophosphate removal in the reservoir accounted for about 65 percent of the decrease in TP.

The wastewater effluent pumped to the Gray farm was significantly affected by the activated sludge plant. The nitrate-nitrogen concentration averaged 3.45 mg/l. Furthermore, the higher treatment efficiency of the activated sludge plant decreased the TOC levels to an average of 52.6 mg/l.

Uptake of phosphorus by suspended biomass, also, significantly reduced the average TP concentration (9.18 mg/l) in the waste stream pumped to the Gray farm.

The sewage treated by SeWRP was primarily derived from domestic sources with less than 30 percent contributed from industrial sources. Trace metal levels contained in SeWRP effluent reflected this low industrial wastewater flow and presented no potential phytotoxicity problems. Table 2 summarizes the concentration ranges of specific trace metals measured in treated wastewaters. No significant differences ($\alpha = 0.05$) in trace metal and mineral levels were determined between any irrigation water source from February 1982 to October 1983.

TABLE 2. CONCENTRATION OF TRACE ELEMENTS IN TREATED WASTEWATER

Element	Wastewater Effluent Range* (mg/l)	Wastewater Effluent Median* (mg/l)	Median Concentration (mg/l) SeWRP	Median Concentration (mg/l) Hancock Reservoir
As	<0.005-0.023	<0.005	<0.005	<0.005
B	0.3-2.5	0.7	0.027	0.038
Cd	<0.005-0.22	<0.005	<0.0005	<0.0005
Cr	<0.001-0.1	0.001	0.060	0.006
Cu	0.006-0.053	0.018	0.047	0.033
Hg	<0.0002-0.001	0.0002	<0.0004	<0.0004
Mo	0.001-0.018	0.007	<0.003	<0.003
Ni	0.003-0.60	0.004	0.065	0.007
Pb	0.003-0.35	0.008	0.032	<0.005
Se	---	---	<0.005	<0.005
Zn	0.004-.35	0.04	0.133	0.066

* Chang and Page, Land Treatment of Wastewater, Vol. 1, pp.47

The data indicate that minerals may create salinity and sodic problems within the upper soil profile. The effluent produced by SeWRP was slightly saline (dissolved solids from 1,000 to 3,000 mg/l). The low hydraulic loading to the Gray and Hancock farm (20 to 60 cm) could contribute to the accumulation of salts within the upper soil profile. Without proper salt management, salts could pose future phytotoxicity problems to farmers. The adjusted sodium adsorption ratio (SAR) of the effluent stream from the trickling plant averaged 21.6. Irrigation water with an adjusted SAR above 10 may create severe water penetration problems and development of alkali soils (Stromberg and Tisdale 1979, EPA 1981, Loehr et al 1979). Proper management of salts contained in the irrigation water was viewed as the most important task which would govern the long term success of the land application system.

Since agriculture is the major industry in the Lubbock area, herbicides (e.g., atrazine and propazine) and by-products produced from the decomposition of herbicides (e.g., 2,3-dichloroaniline and 3,4-dichloroaniline) existed in the SeWRP's effluent. Carbon tetrachloride, chlorobenzene, and diethylphthalate levels exceeded the respective organic concentration range in municipal wastewater treatment plants cited by Majeti and Clark (1981) and Pettygrove and Asano (1984). A mean anthracene concentration of 6.1 μg/l, 4.0 μg/l and 8.4 μg/l was contained in the effluent from the trickling filter plant; wastewater pumped to the Gray farm; and effluent at the terminus of the force main, respectively.

The average fecal coliform concentration in the waste stream pumped to the center pivot irrigation machine exceeded EPA guidelines throughout the study period. The guidelines state:

> "Biological treatment by ponds or inplant processes plus control of fecal coliform count to less than 1,000 MPN/100 ml - acceptable for controlled agricultural irrgation except for human food crops to be eaten raw." (USEPA, 1981)

The actual flow-weighted average fecal coliform concentrations of the applied wastewater during the four major irrigation periods were:

	Fecal coliform concentration colony forming units (cfu)/100 ml
Spring 1982	4,300,000
Summer 1982	840,000
Spring 1983	5,200
Summer 1983	120,000

During the first two years of the study (June 1980 to February 1982), total enterovirus levels as measured on HeLa cell monolayers ranged from 0.045 pfu/ml to over 1.0 plaque forming unit (pfu/ml) in the summer of 1980. The first effluent sample from the terminus of the force main was obtained at the Hancock farm in February 1982 and represented a highly atypical microbiological sample. Once a daily wastewater flow to the Hancock site was established, the initial microbial and physical profile of the wastewater delivered to the irrigation site was not dissimilar from the wastewater previously characterized at the treatment plant. In 24-hour composite samples, maximal viral levels of about 0.1 pfu/ml were detected during the summer 1982 irrigation season. A similar pattern of enteric viruses enumerated on HeLa cell monolayers was observed during 1983. While viral levels in effluent at the pipeline terminus did not reach the highest levels seen in June 1982, the number of viruses recovered remained relatively constant from late June through August 1983 at over 0.25 pfu/ml.

A comparison of both indicator bacteria and virus levels showed that, in general, organism concentrations in reservoir water were two to three orders of magnitude lower than comparable wastewater at pipeline terminus (Table 3). Of the 19 samples of reservoir water concentrate which were assayed in two cell lines, enteroviruses were detected in only 12 samples with a maximum level of about 0.06 pfu/ml. In most of the reservoir samples, viral levels were at or below the detection sensitivity of the recovery procedures employed.

The most prevalent Enterobacteriaceae species encountered in wastewater from Lubbock included Citrobacter, Enterobacter, Escherichia and Klebsiella. Aeromonas hydrophila was the most abundant non-Enterobacteriaceae member recovered, followed by Pseudomonas species. The effectiveness

TABLE 3. MICROORGANISM CONCENTRATIONS IN WASTEWATER APPLIED BY SPRINKLER IRRIGATION

Measurement by irrigation period	Wastewater Source: Pipeline effluent[a]	Wastewater Source: Reservoir effluent[b]
FECAL COLIFORMS (colony forming units/ml)		
Feb-Apr 1982	43,000	--
Jul-Sep 1982	13,000	130
Feb-Apr 1983	20,000	50
Jul-Sep 1983	90,000	30
ENTEROVIRUSES (plaque forming units/ml)		
Feb-Apr 1982	0.04	--
Jul-Sep 1982	0.05	0.003
Feb-Apr 1983	0.07	<0.004
Jul-Sep 1983	0.17	<0.004

[a] Geometric mean of four to eight 24-hour composite samples.

[b] Geometric mean of four to five grab samples.

TABLE 4. BACTERIAL SCREEN[a]-- HANCOCK RESERVOIR

Organisms (10^3 cfu/ml)	Sampling date: Jul 26-27, 1982
ENTEROBACTERIACEAE	
Enterobacter cloacae	0.4
Klebsiella oxytoca	0.1
Klebsiella ozaenae	0.1
NON-ENTEROBACTERIACEA	
Achromabacter xylosoxidans	0.9
Acinetobacter calcoaceticus var. Lwoffi	0.2
Aeromonas hydrophila	4.3
Alcaligenes sp.	0.5
CDC Group V E-2	0.1
Pseudomonas sp.	0.5
Psuedomonas cepacia	0.1
Pseudomonas maltophilia	0.3

a. Highest levels observed on either MacConkey agar of brilliant green agar and identified by API 20E bio-chemical tests.

of ponding for the reduction of microbial numbers was evident both by the lower levels and the reduced diversity of organisms seen in a single bacterial screen completed on a sample from the Hancock reservoir (Table 4). Since microorganism densities were much higher in the wastewater from the pipeline than from the reservoirs, the exposure which most of the study population received to most microorganisms via the wastewater aerosol was greater in 1982 than in 1983.

During system operation, the fecal coliform concentration of the waste stream from SeWRP and the discharge from the storage reservoirs greatly exceeded EPA guidelines, especially in 1982. The effluent BOD_5 concentration produced by SeWRP did not satisfy Texas permit requirements until May 1983. The system, however, was operated below hydraulic design capacity in 1982 and 1983.

SYSTEM OPERATION

Hancock Farm

The Hancock slow rate system had the following alternative operational modes:

1. Direct irrigation with effluent from SeWRP;
2. Irrigation with water only from reservoir; and
3. Combined direct irrigation with SeWRP effluent and reservoir water.

During 1982 the Hancock farm was irrigated primarily with secondary effluent produced by SeWRP. Odorous compounds stripped from the effluent stream as it was emitted from the spray nozzles created public nuisance conditions. Consequently, the reservoirs were used to oxidize the odor compounds prior to irrigation. In 1983 practically all of the water applied to land was pumped from the storage reservoirs. Since the same pipeline distribution network was used to provide water to the center pivot irrigation machines and transport water to the reservoirs, main pipelines had to be dedicated to either irrigation from the reservoirs or transporting water to the reservoirs. Increased head losses resulting from closing of valves to accomplish irrigation solely from the reservoirs, in conjunction with the wastewater management condition at SeWRP, reduced the flow pumped to the Hancock farm. Consequently, the Hancock farm received only 28 percent (4,128,219 m^3) of the total effluent produced from February through December 1982. In 1983, 19 percent (3,744,395 m^3) of the total effluent was pumped to the Hancock farm from January 1 through October. The hydraulic loading pumped through each center pivot irrigation machine in 1982 and 1983 is presented in Table 5. These hydraulic loadings are very low for a slow rate land application system.

Due to the necessity to divert all SeWRP effluent to the reservoirs, water management at the farm was a problem. A maximum of nine of 22 center pivot machines were operated simultaneously. Consequently, system hydraulics was the major factor which governed irrigation practices and not crop requirements. Cotton was the primary crop grown at the Hancock farm prior to 1982. Rainfall and associated hail during the months of May and June 1982 which were the 24th and 25th months of the study monitoring period (Figure 3) destroyed over 8.09 x 10^5 ha (2 x 10^6 acres) of the cotton crop in the South Plains of Texas. Only 16.2 ha (40 ac) of cotton remained on the Hancock farm. The majority of the farmers planted grains to partially recuperate financial losses. Tenant farmers at the Hancock farm planted approximately 552 ha (1365 ac) of grain sorghum, 162 ha (400 ac) of sunflowers, and 257 ha (635 ac) of soybeans (Figure A.1).

During the summer of 1983, less than 2.5 cm (1 inch) of rain was recorded from the end of June through mid-October. Figure A.2 shows the crops grown in 1983 at the Hancock farm.

Gray Farm

Secondary treated effluent from SeWRP was delivered to the Gray farm through three pipelines to three storage reservoirs (Figure 4). The estimated hydraulic retention time of the ponds was 10 days.

Prior to 1982, with 75 to 80 percent of the farm planted in cotton, water was applied to the cotton areas in early spring, February through April (prewater); and in the summer from June through August. An estimated 70 cm of water was applied to the land designated for cotton planting (Table 6). Any other irrigation (the remaining six months), with no stor-

TABLE 5. TOTAL WATER APPLIED TO HANCOCK FARM IN 1983

Pivot No.	Total 1982 (cm)	Total 1982 (in)	Total 1983 (cm)	Total 1983 (in)
1	13.23	5.21	20.0	7.9
2	20.50	8.07	34.0	13.4
3	18.16	7.15	27.0	10.6
4	23.16	9.12	48.0	18.9
5	11.79	4.64	40.9	16.1
6	20.47	8.06	50.0	19.7
7	19.69	7.75	31.8	12.5
8	14.58	5.74	26.9	10.6
9	14.38	5.66	38.4	15.1
10	13.13	5.17	29.0	11.4
11	23.80	9.37	29.2	11.5
12	20.50	8.07	31.0	12.2
13	16.26	6.40	33.3	13.1
14	10.72	4.22	22.9	9.0
15	26.06	10.26	43.9	17.3
16	14.68	5.78	35.3	13.9
17	17.15	6.75	29.2	11.5
18	18.49	7.28	29.0	11.4
19	15.72	6.19	30.2	11.9
20	15.52	6.11	17.5	6.9
21	16.94	6.67	20.6	8.1
22	14.78	5.82	27.4	10.8

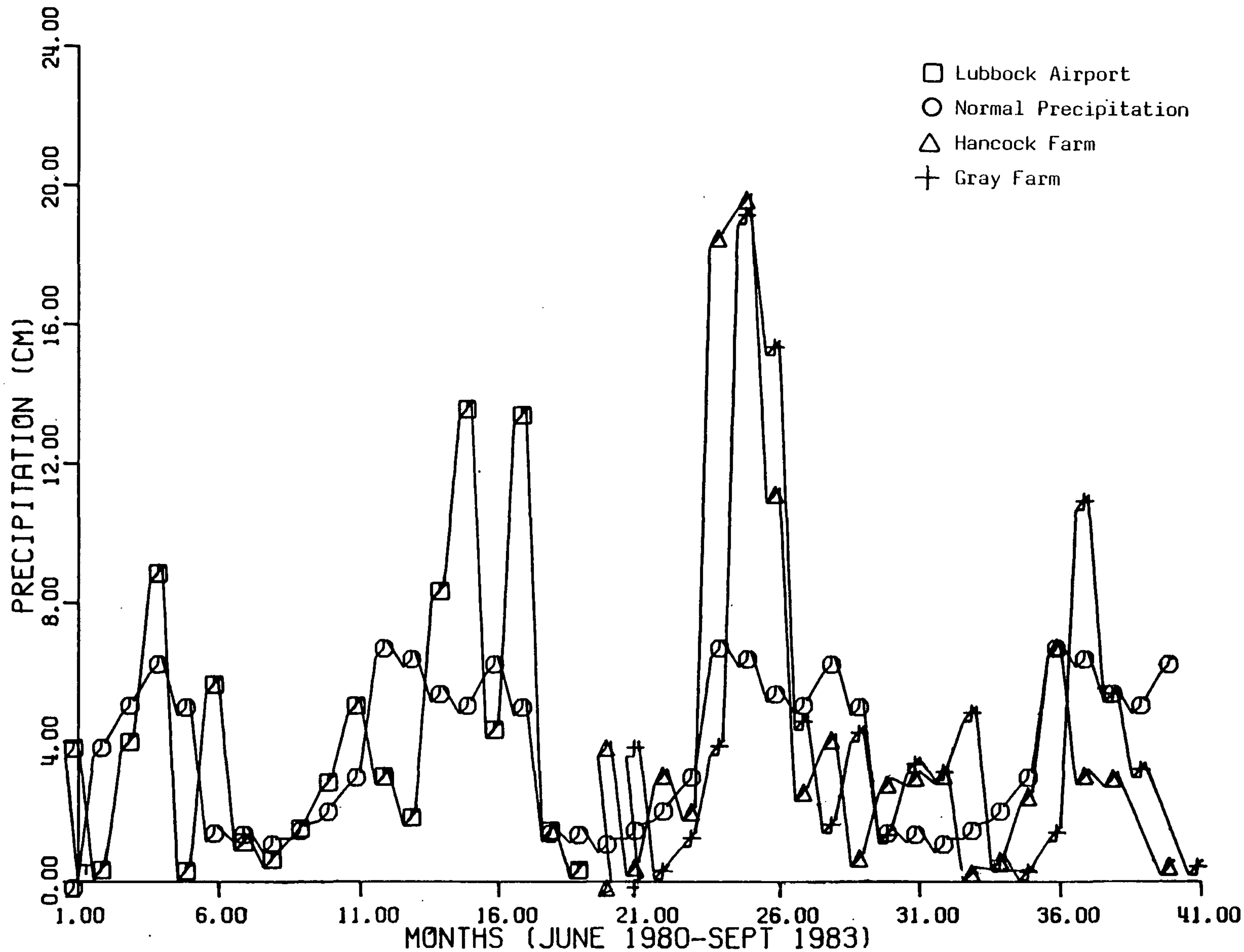

Figure 3. Precipitation During Project Period

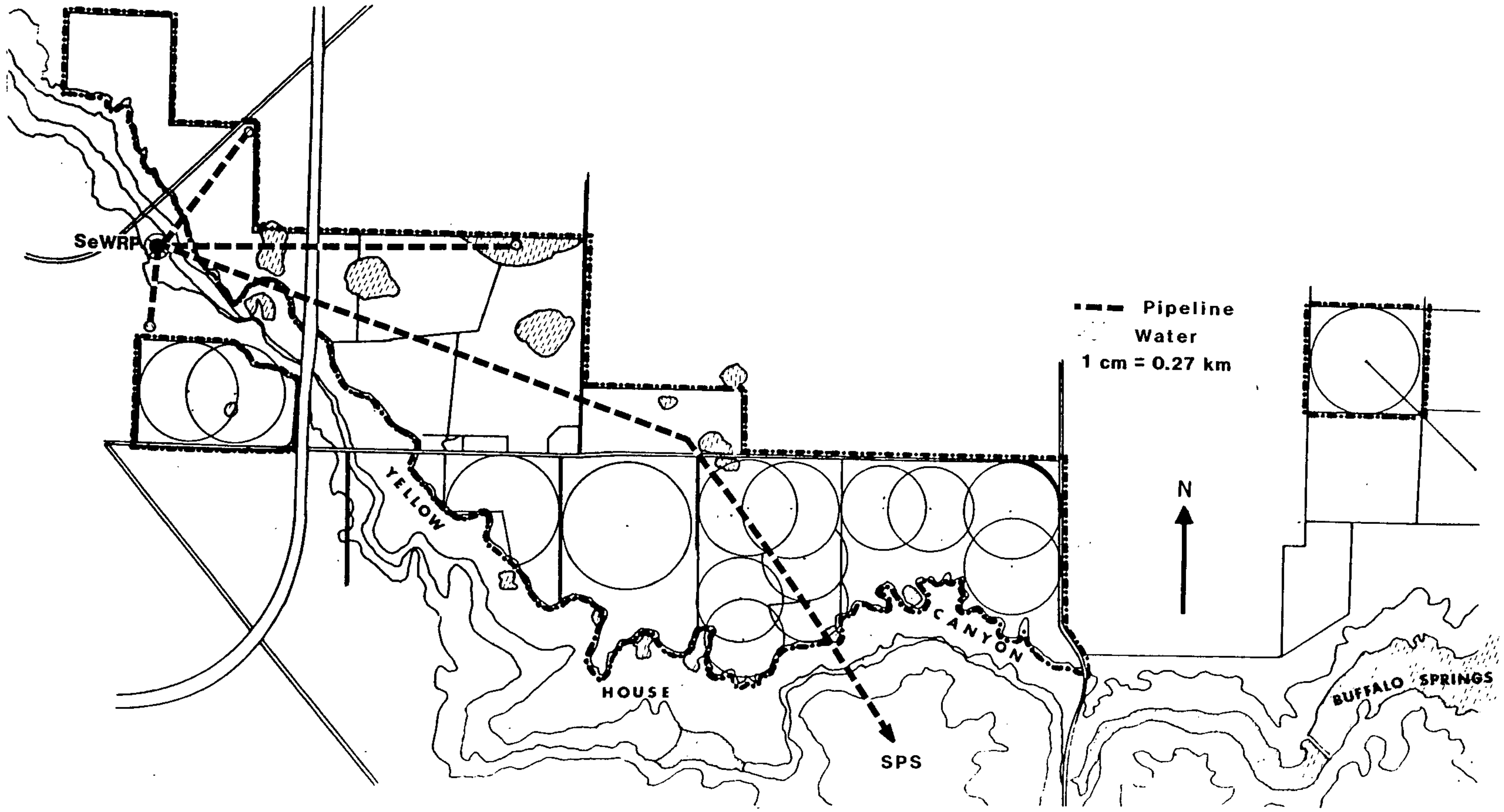

Figure 4. Gray Farm Land Application Site

age, had to be put on winter crop or grazing area (Figure A.3). From two to 4.5 m/yr was applied to these areas in order to keep the main economic crop (cotton) at maximum production. In the spring of 1982 over 506 ha (1,250 ac) of alfalfa (Figure A.4), 304 ha (750 ac) of wheat, and 121 ha (300 ac) of soy beans were planted on the Gray farm.

TABLE 6. GRAY FARM HYDRAULIC LOADINGS/CROP*

Season	Flow MGD	Cotton 1	Cotton 2	Milo 1	Wheat 1	Soybeans 1	Alfalfa 1	Alfalfa 2
Prior to 1982	14	70 cm	65 cm	--	465 cm	--	--	--
1982	10	--	--	70 cm	230 cm	70 cm	70 cm	55 cm
1983	10	--	--	70 cm	207 cm	--	70 cm	55 cm

* Approximate loadings applied based on maximum output pivot and number of days of potential operation during the growing season.

1 Row or flood irrigation areas. Row water crops are based on one pre-water application and six summer time applications.

2 Center pivot irrigation -- Pivots are nozzled to deliver 15 cm/21 days, over six months application time (7 on alfalfa). This yields hydraulic loadings of 90 cm (105 cm on alfalfa). Because only enough pivots are on hand to irrigate one-half of the acreage at any one time, these loadings must be halfed to 45 cm/yr and 52 cm/yr, respectively.

SECTION 2

SUMMARY OF CONCLUSIONS

The Lubbock Land Treatment System consists of two privately owned farms. In the past years, the Gray farm suffered from inadequate storage and distribution piping network to properly manage effluent produced by Lubbock's SeWRP. Consequently, an increase in ground-water elevation and degradation of ground-water quality occurred beneath the farm. The system was expanded in 1981 to include the 1,478 ha Hancock farm which is located 25 km southeast of Lubbock, Texas. The expanded slow rate land application system encompassed approximately 2,967 ha. From June 1980 to October 1983, both farms were monitored to assess the impacts on ground water, soils and crops of: 1) reducing the hydraulic, chemical, and biological mass loading for the Gray farm; and 2) spray irrigation of effluent to the Hancock farm which was primarily a dry land farm for ten years prior to 1982. Furthermore, an epidemiologic study at the Hancock farm was conducted to assess the association between human exposure to the wastewater used for irrigation and the development of new infections.

The findings of the project indicated that the major recharge of ground water beneath the Gray farm was from flood irrigated wheat areas. Deep percolation of irrigation water and precipitation continued in 1982 and 1983 in the flood irrigated areas. Physical limits of irrigation equipment, hydraulic distribution system, water storage, and crop cultivation eliminated the capabilities for proper water management. With adequate winter storage and the hydraulic capability to distribute more water on the alfalfa in 1982 and 1983, minimal deep percolation would have occurred through the soil throughout the farm. Comparison of 1981 and 1983 ground-water elevation data indicated that the ground-water levels beneath the Gray farm decreased.

During the period from February 1982 to October 1983, an increase in the ground-water quality also occurred beneath most of the Gray farm. Mass balances conducted on nutrient and minerals indicated continued leaching of constituents through a soil depth of 183 cm beneath the flood irrigated area; whereas, most of the chemical constituents applied by sprinkler irrigation were retained and/or removed through crop uptake beneath the spray irrigated areas.

Statistically significant decrease in NO_3-N levels were measured in five of 27 monitoring wells from February 1982 to October 1983. In general, 17 of 27 wells experienced a decrease in ground-water NO_3-N levels. A comparison of baseline data (June 1980 to February 1982) and data collected after February 1982 indicated a decrease in the frequency of ground-water NO_3-N concentrations equaling or exceeding drinking water standards in nine of 27 wells monitored.

Wastewater treated by SeWRP was primarily derived from domestic sources with less than 30 percent contributed by industrial sources. Consequently, trace metals posed no potential toxicity problems to humans or plants.

Total irrigation at the Hancock farm varied from 16 cm to 20 cm in 1982 and 36 to 49 cm in 1983. An overall increase in ground-water elevation occurred beneath the Hancock farm. A maximum rise of three to five meters was experienced in ground-water wells in close proximity to surface runoff collection areas. Increases in ground-water elevation beneath the Hancock farm were primarily due to percolation of surface runoff through coarse material contained in moats surrounding the reservoirs and excavations constructed to reduce flooding of cropland and migration of percolate through material surrounding poorly sealed well casings. Increases in ground-water elevation commenced approximately two months after heavy precipitation events.

Chemical constituents contained in the treated wastewater applied to the Hancock farm were removed by the soil-crop matrix from percolate water. Increases in ground-water chemical parameters appeared to be associated with deep percolation of surface runoff contained in moats and excavation pits constructed to contain surface runoff. Existing salt and nitrate deposits within the soil profile were leached with percolate to the ground water; thereby causing increases in nitrate and total dissolved solids (TDS) levels in several wells.

In general, no significant changes in trace metals or priority organic pollutants occurred in the ground water during the monitoring period. Based on values cited in literature, trace elements posed no public health problems.

Salt accumulation occurred in the upper 183 cm of the soil profile. As expected, salt accumulations were directly proportional to mass loadings from irrigation. Insufficient water was applied (less than 21 cm in 1982 and less than 50 cm in 1983) to leach salts below the root zone. Exchangeable sodium percentage increased from two to six percent in the top 30 cm of soil during the period from February 1982 to October 1983.

Cotton and grain sorghum (milo) were the primary crops grown on the Hancock farm in 1980, 1981 and 1983. Due to severe weather in 1982, sunflowers, soybeans and grain sorghum were planted as alternative crops to cotton. While milo yields were low due to late planting and trifluralin damage, sunflower and soybean yields were average for the High Plains area of Texas. An improvement in cotton crop production occurred in 1983. With irrigation with effluent, the cotton yields for the farm were 48 percent greater than the Lubbock County average. 1983 cotton yields may have been limited by possible nutrient shortages, boll worm infestation, and cool weather during late growing season. Cotton production in 1983 ranged from 353 to 740 kg/ha.

Amortized system construction cost over a 20 year period at ten percent annual interest rate would be $167/1,000 m^3 per year ($0.63/1,000 gal). With 85 percent federal cost sharing amortized construction cost would have been reduced to $25/1,000 m^3/yr ($0.10/1,000 gal). Inclusion of land cost would have increased annual capital cost by 24 percent. Total operation and maintenance (O & M) costs associated with the Lubbock Land Treatment System Expansion were $156/1,000 m^3 ($0.59/1,000 gal) in 1982 and $139/1,000 m^3 ($0.53/1,000 gal) in 1983. The City of Lubbock bore $71/1,000 m^3 of the total O & M cost in 1982 and $58/1,000 m^3 in 1983. The farmer's portion of the O & M was $85/1,000 m^3 ($0.32/1,000 gal) and $81/1,000 m^3 ($0.31/1,000 gal) in 1982 and 1983, respectively. The economic balance of cost expended and revenues received showed a net negative balance each year during the project period (1980 through 1983) ranging from

\$701,661.81 (1981) to \$1,103,687.57 (1982). Net costs were \$267.35/1,000 m^3 (\$1.00/1,000 gal) in 1982 and \$161.28/1,000 m^3 (\$0.61/1,000 gal) in 1983. Crop revenues offset costs by 18 and 47 percent of total costs in 1982 and 1983, respectively.

Spray irrigation of unchlorinated wastewater piped from the treatment plant was a more substantial source of aerosolized microorganisms than spray irrigation of wastewater stored in reservoirs. Enteroviruses were regularly recovered in the aerosol at 44 to 60 m downwind of irrigation with piped treatment plant wastewater. The geometric mean enterovirus density in the downwind air was 0.05 pfu/m^3, although a much higher density (17 pfu/m^3) was sampled in August 1982. In addition, fecal streptococci levels were detected at least 300 m downwind, and levels of fecal coliforms, mycobacteria and coliphage were isolated at least 200 m downwind. Organism levels downwind were also significantly higher than background levels in ambient air outside of participants' homes: fecal coliform levels were higher beyond 400 m downwind, mycobacteria and coliphage levels to at least 300 m and fecal streptococci levels to at least 200 m.

The results indicate that a general association between exposure to irrigation wastewater and new infections existed, especially for 1982 when there was exposure to higher levels of micro-organisms via wastewater aerosol. Poliovirus 1 seroconversions were probably related to wastewater aerosol exposure during the spring of 1982, even when the effects of polio immunizations were controlled. However, even during 1982, the strength of association remained weak and frequently was not stable. Wastewater of poor quality from the pipeline, comprised much of the irrigation water in 1982. Of the many infection episodes observed in the study population, few appear to have been associated with wastewater aerosol exposure, and none resulted in serious illness.

The lack of a strong, stable association of clinical illness episodes with the level of exposure to irrigation wastewater indicates that wastewater spray irrigation produced no obvious disease during the study period. However, when more sensitive indicators of infection were used, the evidence indicates an association existed, especially for 1982. A particular concern from a public health standpoint is the evidence that the poliovirus

1 seroconversions were related to wastewater aerosol exposure during the spring of 1982, even when the effects of polio immunizations were controlled. Because of the low prevalence of poliovirus antibody observed during the baseline period, the study population was immunized, and thus was probably better protected against polio than other rural populations. High concentrations of both bacteria and enteric viruses were observed in the 1982 poor quality wastewater applied as received via pipeline directly from the Lubbock sewage treatment plant. Exposure would have been reduced by using wastewater from the reservoirs for irrigation rather than irrigating directly from the pipeline.

Annual hydraulic loading rates up 3 m.ha/ha.yr did not adversely affect cotton, grain sorghum, and alfalfa crop production. Highest alfalfa yields were obtained in test plots irrigated with 365 and 434 cm.ha/ha.yr. Total dissolved solids and associated sodium salts were leached beyond 91 cm soil depth within plots irrigated with 61 cm of treated sewage per year or greater. Bermuda yields were limited by transport of macro and micro nutrients past the root zone.

Soybeans with a relatively shallow root system, produced highest yields with more frequent irrigation (i.e., one irrigation per week). Soybeans were unable to develop a deep root system to utilize deeper soil moisture during periods of water stress (one irrigation every four weeks or one irrigation every eight weeks); consequently, crop yields were reduced.

During long periods between irrigation events, the deep root system developed by grain sorghum enabled the plant to utilize available soil moisture and inorganic nitrogen at greater depths. Highest grain sorghum production was achieved in plots irrigated 61 and 122 cm/yr at application frequencies of once every four weeks and once every eight weeks.

Increasing the quantity of water applied to a crop transports sodium salts deeper into the soil profile. Soybean seed and stalk analysis indicated leaching of sodium from the root zone commenced almost immediately at the 122 cm/yr hydraulic loading. At the 61 cm/yr loading, irrigation events must occur at intervals of two weeks or longer to promote leaching of sodium. Practically no leaching occurred even at the one application per eight weeks frequency at the effluent loading of 31 cm/yr. With the shorter growing season experienced in 1982, soybeans may have had a higher water consumption rate than the grain sorghum due to the crop's maturity. Higher water requirement of soybeans in conjunction with its shallow root system may have caused higher sodium accumulations in the upper 61 cm than observed in grain sorghum test plots.

SECTION 3

PROJECT DESIGN

The human and environmental monitoring portions of the Lubbock Land Treatment Research and Demonstration Project was divided into two periods, each monitoring period having a time span of approximately two years. The baseline monitoring period extended from June 1980 to February 1982. During this time frame no effluent from SeWRP was pumped to the Hancock farm. In February 1982 treated sewage from the City of Lubbock's wastewater treatment facility was pumped to the Hancock farm. The second phase of the project monitoring period encompassed the land application of wastewater at the Hancock farm which began in February 1982 and continued through December 1983. The design of each project investigation is presented in the following text.

DEMONSTRATION/HYDROGEOLOGIC STUDY

The objective of the environmental monitoring program of the Demonstration/Hydrogeologic Study was to establish a data base characterizing conditions at the Gray and Hancock farms that would allow the detection of any changes which might occur in the ground water, soils, and crops due to reduction of sewage effluent loading at the Gray farm and use of sewage effluent at the Hancock farm.

Ground water beneath the Gray and Hancock farms was monitored each year after spring pre-irrigation (April), at the end of summer irrigation (September) and in winter (December). Ground water samples were taken from newly constructed monitoring wells, pre-existing irrigation wells, seeps and springs at the Gray farms, and drinking water wells of residents on or near the Hancock farm. Table 7 gives the number and types of ground-water monitoring wells at each site. Sampling locations were selected using hydrogeologic data in order to best monitor the movement and quality of water on the farms. Figures B.1 and B.2 show the ground-water monitoring location for each site.

TABLE 7. TYPE AND NUMBER OF UNDERGROUND WATER SAMPLING POINTS BY SITE

Number of Wells	Type of Well
	HANCOCK FARM
1	Organic Non-contaminated well 30 cm (8 in)
5	Continuous water level recording wells 20 cm (12in)
3	Non-continuous recording observation wells 10 cm (4 in)
15	Pre-existing irrigation wells (currently in use)
23	Home drinking water wells
	GRAY FARM
1	Organic non-contaminated well 20 cm (8 in)
5	Continuous water level recording wells 20 cm (8 in)
11	Non-continuous recording observation wells 10 cm (4 in)
10	Pre-existing irrigation wells (currently in use)
1	Multiple depth well [includes four, 12.5 cm (5 in) wells]
11	Seeps, springs and retention pond overflows

During each sampling period depth to water measurements were made just prior to taking water samples. Wells without pumps were sampled using a 7.6 cm (3 in) diameter, 122 cm (4 ft) long polyvinylchloride (PVC) bailer with a neoprene check valve connected to a 0.6 cm (1/4-in) diameter cotton rope. The bailer was cleaned between use in each well by immersion in ethanol followed by a distilled water rinse. The bailer removed approximately 4 l (1 gal) of water each time it was withdrawn from the well. Five to 15 bails of water, depending on depth of water in the well's saturated zone, were wasted before samples were obtained. The waste volume was approximately 60 to 80 percent of the water in the well.

Twenty-four hour composite water samples were obtained from 1) the Hancock and Gray effluent pump stations at the SeWRP; 2) the flow distribution can at the terminus of the force main prior to the Hancock water distribution system; and 3) flow distribution cans which divided the effluent from the reservoirs to various locations on the farm.

Water samples from the Lubbock Land Treatment System Research and Demonstration Project were analyzed for physical parameters, priority organic pollutants, other organics, metals, other inorganics, and indicator bacteria. During the project monitoring period, water samples were analyzed for 104 parameters listed in Table B.1.

Soil Samples

Soil sampling locations in the demonstration area were determined by first dividing each farm into 65 ha areas (one quarter-section). On the Hancock farm, each pivot encompassed approximately 65 ha (one quarter-section). Each field on the Gray farm was approximately 65 ha (one quarter-section). Sampling locations were randomly selected within the 65 ha area. Soil cores were pulled from each location and composited at 0.3 m (1 ft) increments to make one sample for each depth. Soil samples were cored just after harvest for cotton (November) and twice a year for double cropped areas (April and November).

During the first sampling period (March 1981) and final sampling period (November 1983), 1.8 m cores were obtained using a 10.2 cm diameter, 1.2 m long coring tube. Cores were taken to only 0.91 m depth during the intermediate sampling periods.

Soil samples were analyzed for the parameters shown in Table B.2. Soil samples from the baseline years and final sampling period (winter of 1983) were analyzed for the complete list of parameters. The 1982 soil samples had only the top three, 30 cm sections analyzed for pH, conductivity, potassium, total Kjeldahl nitrogen, total phosphorus and priority organics.

Crop Sampling

The purpose of crop sampling was to obtain plant samples which represented each farm, crop and type of irrigation. Sampling locations for crop samples were determined in a manner similar to that for soil samples. The two farms were divided into approximately 65 ha (quarter-sections) sampling areas, from which crop samples were randomly collected. Crop samples were collected at harvest time when the crops had developed maximum maturity. Normally, harvest occurred from mid-October through January. Some portions of the farms had two crops grown per year. These "double cropped" areas were harvested and sampled twice a year; mid-October through January and April through mid-May.

Crop samples were obtained for laboratory and yield tests. For laboratory analysis, all the plants within a square meter area in each sampling location were removed and composited into sterile, plastic bags to obtain one plant sample per 65 ha area (field or pivot). Crop samples were divided into specific plant parts (i.e., seed, stem, leaves, etc.) at the laboratory.

The analyses performed on crop samples were determined by the type of plant and plant part (Table B.3). Those parameters such as metals and nutrients, which could be translocated from the soil to all parts of the plant, were analyzed on all plant tissue samples. Bacteria, yeast and fungi, which could contaminate exposed surfaces of crops, were analyzed on all samples.

Irrigation Records

Documentation of the quantity of treated sewage applied to a specific area of the farm was necessary for the interpretation of soil and crop data. Furthermore, the records were used in assessing the economics of domestic wastewater reuse through farming. Finally, the irrigation records were used in assessing the exposure of participants in the Lubbock Infection Surveillance Study (LISS) to pathogens contained in aerosols generated from the spray irrigation center pivot machines. Each farmer recorded the daily amount of effluent pumped through a center pivot machine and the starting and final position of the machine in the field.

Economics

The economics of land treatment were monitored through operation and maintenance cost records provided by the City of Lubbock and the farmers utilizing the land treatment system. The city supplied yearly summaries of the cost of treating the water supplied to each farm and the cost of operating and maintaining the pump station delivering water to the Hancock farm. Most of these costs were divided into monthly subtotals. Yearly, the farmers turned in their financial statements including operation and maintenance costs of the center pivots, electrical costs of their share of the reservoir pumps, farming costs, and monetary returns.

THE LUBBOCK INFECTION SURVEILLANCE STUDY (LISS)

The LISS involved a four-year health watch of people residing on or near the Hancock farm and individuals farming the Hancock sites. Furthermore, organism levels of the wastewater and aerosols generated through spray irrigation were monitored.

The City of Wilson was the nearest community to the Hancock farm. It was situated at the southern boundary of the farm. The population of 576 (1980 census) occupied 181 residences ranging from small two bedroom stucco or frame bungalows to large all-brick homes. Local commerce was based primarily on agriculture.

The municipal water supply for city residents was obtained from six wells which tapped the Ogallala aquifer. A water tower and underground tank provided storage facilities where the water was intermittently chlorinated manually prior to distribution. Continuous chlorination of the City of Wilson water supply system commenced in March 1983.

All but ten of the household within the city limits were serviced by a municipal wastewater collection and treatment system. The treatment plant consisted of an Imhoff tank preceded by a bar screen. Plant effluent was allowed to evaporate from a series of lagoons while the settleable solids were removed from the tank on a monthly basis and placed in an adjacent drying bed. Those households not connected to the municipal system had septic tanks.

The rural portion of the study area lay primarily in Lynn County (1980 census population, 8,605), with a small portion above the northern boundary in Lubbock County. Approximately 130 households were located in this area in 1980 with an estimated population of 450.

Almost every rural household obtained its drinking water from a nearby private well which tapped the Ogallala aquifer. Treatment of domestic wastewater was accomplished by septic tank systems in half of the rural houses while the other half, typically the older homes, utilized cesspools.

The Hancock site was unique in that a typical rural community with no prior wastewater exposure was challenged by the enteric agents active in a much larger urban community (Lubbock). Persons residing around the Hancock site may have been exposed to infectious agents indigenous in the Lubbock population but not circulating in the study area. Thus, many in the study population may have been relatively susceptible to the pathogens in the wastewater. A health watch of the rural community was maintained before, during, and after periods of wastewater spray irrigation. The health watch focused on infections detected serologically and through isolates recovered from routine fecal specimens. To enhance the likelihood of interpreting observed episodes of infection, the likely routes of introduction and transmission were monitored.

Disease surveillance was maintained to protect the population from any obvious untoward effects. However, the study focused on infections and the infecting agents rather than illness in order to obtain greater objectivity, sensitivity, specificity, and etiologic evidence.

All participants were asked to provide blood samples semiannually, usually in June and December (Figure 5). Sera were assayed for antibody titers to specific enteroviruses and other microorganisms known or suspected to be present in the sprayed wastewater. A seroconversion, defined as the fourfold or greater increase in agent-specific antibody titer in simultaneously tested successive sera from one individual, was considered serologic evidence that the individual had been infected by the agent during the time interval between the blood collections. Since mycobacteria were present in the wastewater, tuberculin skin tests were administered annually to give suggestive evidence of a non-tuberculosis mycobacterial infection.

An adult from each household and any children under 13 years of age were designated as fecal donors. Each donor, whether well or ill, was asked to submit routine stool specimens for microbiological testing during scheduled weeks which spanned each major irrigation period in 1982 and

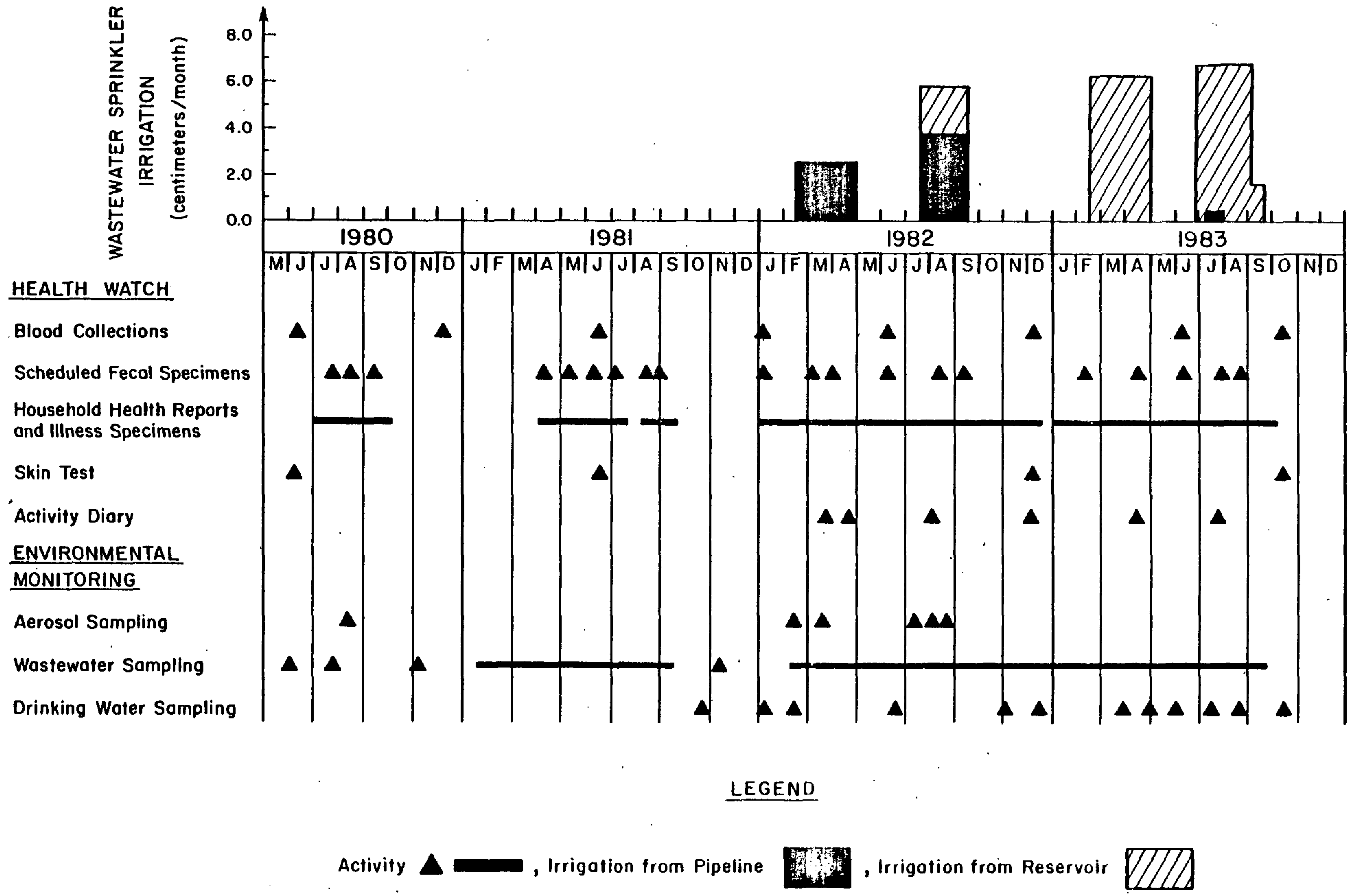

Figure 5. LISS Study Design: Time frame of monitoring in relation to major periods of irrigation

1983. A series of three 1-week fecal collection sessions were scheduled before, during, and near the end of each irrigation period to detect infection events occurring in the interim. Clinical bacteriological analyses were performed to isolate overt and opportunistic pathogens. Clinical virological analyses were performed to isolate enteric viruses in the fecal specimens by tissue culture techniques. Electron microscopic examination was performed on about one-fourth of the routine fecal specimens to detect a variety of virus-like particles, many of which are not recoverable by tissue culture techniques. Detection of a specific virus by laboratory cultivation or by electron microscopic examination was considered evidence of a viral infection. Each non-adenovirus viral infection was regarded to be new, unless the same agent had been recovered from the individual in the prior six weeks.

Each household was contacted weekly by telephone for a report of any illnesses during the prior week. When a sufficiently recent respiratory or gastrointestinal illness was reported, the ill participant was requested to submit a throat swab or stool specimen to identify the causative agent. Weekly self-reports of illness and appropriate illness specimens were obtained over the entire period of irrigation from January 1982 until October 1983 and over baseline periods corresponding to seasons of heavy irrigation.

The types and densities of potentially pathogenic bacteria and viruses were monitored in the wastewater, wastewater aerosol, and other environmental routes of introduction and transmission. An effort was made to determine the fluctuations in levels of every measurable infectious agent utilized in the health watch. However, the low densities of many agents in environmental samples necessitated reliance on indicator organisms to establish environmental patterns. Wastewater samples of the effluent from the pipeline and reservoirs to be utilized for spray irrigation, and of the Wilson effluent, were obtained and analyzed for indicator bacteria and enteroviruses biweekly to span the major irrigation periods. Identical analyses were conducted on the Wilson sewage to ascertain if any significant differences existed between Lubbock and Wilson wastewaters. Baseline wastewater samples had been obtained with the same frequency in 1981 and at lesser frequency in 1980 to characterize the effluents. Microbiological screens of indigenous enteric bacteria were conducted on one sample each from the pipeline and the reservoir per irrigation season. The purpose of the routine wastewater samples was to document the presence, prevalence, longitudinal pattern, and passage through the study community of viral and bacterial pathogens possibly introduced by the wastewater. Extensive aerosol sampling was conducted to characterize the aerosol density of indicator microorganisms produced by the spray irrigation of both pipeline and reservoir wastewater. Virus runs were also conducted to measure the density and diversity of enteroviruses in aerosols emanating from the sprinkler rigs. Drinking water, houseflies, and dust storms also were evaluated as other means of introducing microorganisms into the study population.

An aerosol exposure index (AEI) was devised to measure the degree of a participant's cumulative exposure to microorganisms in the wastewater aerosol, relative to all other study participants during a given irrigation period. When a number of similar infection events were observed either serologically or microbiologically in the study population within a time interval corresponding to an irrigation period, this infection episode was statistically analyzed for association with wastewater aerosol exposure using AEI. Infection incidence rates were compared among exposure subgroups and with baseline rates to determine the relative risk of infection.

PERCOLATE INVESTIGATION IN THE ROOT ZONE (PIRZ)

The PIRZ study investigated the impacts resulting from physical, chemical, and biological activities in the soil root zone on percolate flow and quality. To monitor percolate flow and possible quality changes with depth, a lysimeter system was installed at the Hancock and Gray farms so that percolate could be obtained at three different levels within the root zone. Measurements were made of the precipitation and of the irrigation waters applied to three cropping systems that were of economic importance to the region and which exhibited a range of water and nutrient requirements during growth. The crops grown on each test facility site were cotton, grain sorghum, and bermuda grass.

Tray and tube non-weighing lysimeters were employed in the percolate collection system (Figure 6). Vacuum devices were used to obtain percolate from the lysimeters. The vacuum level maintained in the percolate collection system of these units was adjusted to levels measured by a tensiometer located in adjacent undisturbed soil.

Replicates of the two lysimeter technique for collecting soil percolate were utilized on each test plot. Tubes containing undisturbed soil cores and trays containing disturbed soils placed in contact with undisturbed soils were installed on each plot. Three trays, located in cavities 108 degrees apart, were placed at depths of 61, 122, and 183 cm. Pairs of tube lysimeters were emplaced with the upper surfaces 30 cm underground so that normal tillage operations could be conducted. Percolate was collected from one pair of tube lysimeters at a depth of 122 cm and from the other pair at 183 cm. One plot on each farm area had an additional pair of tube lysimeters which collected percolate at the 244 cm depth.

An underground chamber was installed at the center of each test plot. These chambers contained the necessary support equipment for the installed vacuum extractors. The lysimeters were placed in the soil at varying depths radially around the chamber and at distances far enough from it so as not to be influenced by the chamber's interference with soil percolate flow.

A traveling-gun irrigation system was employed to apply treated sewage to approximately 2.5 ha of land. The amount of precipitation was monitored with both recording and non-recording rain gauges.

<u>Water Collection and Analyses</u>

The quantity of treated wastewater applied during the irrigation event was determined by the catch-can procedure. Lysimeters were inspected daily. The percolate volume collected in the 20 liter glass bottle which functioned as the specific percolate storage unit for the lysimeter was drained and measured in a graduated cylinder. Water quality analysis was limited by the volume of percolate collected. Grab samples were collected when a lysimeter first began percolate production; started percolate col-

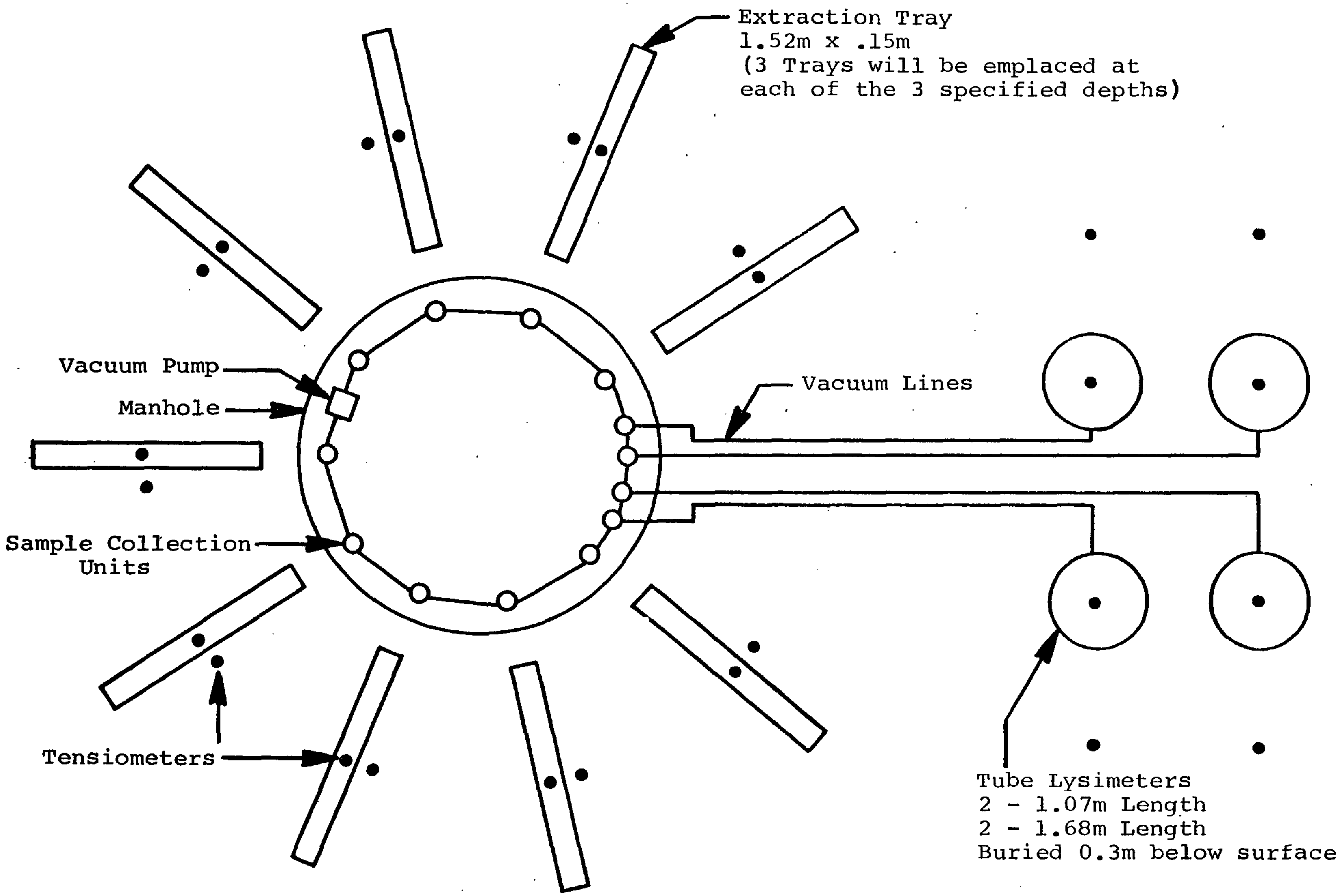

Figure 6. Plan of Test Facility

lection again after a period of operation with no percolate collection activity; and, by protocol, for a sample collection event.

Weekly composite samples were prepared by taking a portion of the daily collection volume from the lysimeter and compositing it with the water composited from the previous days. The compositing of percolate samples was accomplished by taking a constant volume sample from each daily percolate collection event prior to April 1983. After April, percolate samples were composited on a volume weighted basis by taking 10 percent of the daily percolate volume for the composite sample.

The original water quality analysis is presented in Table B.4. The parameters that were measured were reduced to a priority listing based primarily on the limited sample volume collected. In April, 1983 a sampling schedule was developed to obtain more quality data from the collected percolate. Based on the amount of sample present, the analyses to be performed on each type of composite sample were prioritized as follows. For the samples not acid-fixed, the analyses were: 1) pH; 2) COD; 3) TDS; 4) SO_4; and 5) alkalinity. For the acid-fixed samples they were: 1) NO_2+NO_3; 2) NH_3; 3) TKN; 4) COD; 5) minerals (i.e., Na, K, Ca, Mg); 6) Cl; and 7) TOC.

Grab samples were taken once a week from each lysimeter that had collected percolate over the previous 24-hour period. The sample analysis priorities to be followed under the grab sample collection schedule were: 1) conductivity; 2) NO_2+NO_3; 3) orthophosphate; 4) bromide; 5) total phosphorus; and 6) organic phosphorus. Also, irrigation water applied to the test plots were to be analyzed for 1) nutrients (TKN, NO_2/NO_3, NH_3, Total P, PO_4, Organic P); 2) minerals (i.e., Na, K, Ca, Mg); 3) COD; 4) TDS.

Soil Collection and Analysis

Soil cores extraction and analysis followed the same protocol as previously described in the Demonstration/Hydrogeologic Study. Three 1.8 m soil cores were collected from each test plot. Cores were taken only to a depth of 90 to 107 cm on the plots at the Gray site because of the hard caliche layer below those depths. A 7.6 cm x 120 cm flight auger was used to obtain soil samples from the bottom of the core hole to a 183 cm depth.

The cores were taken within 6.0 m of the ends of the lysimeter trays. Each core was divided into 30 cm sections. Sections from the same depth at each test plot were composited to make a sample. Soil samples obtained with the auger were not subdivided.

Crop Collection and Analysis

The procedure used to determine the yield and quality of crops grown on each test plot was the same as the protocol established for crop monitoring in the Demonstration/Hydrogeologic Study. Yield data on each plot were calculated from crop samples taken from three subplot areas that had been laid out parallel with the path of the traveling-gun irrigation unit and in line with the lysimeter battery.

AGRICULTURAL RESEARCH STUDIES

Agricultural research activities conducted at the Hancock farm focused on crop management to minimize problems associated with high hydraulic, nutrient, and salt loading rates.

Experimental plots were established to evaluate the effect of hydraulic loading rates on various crops, soil, and percolate water. Similarly, research plots were designed and planted to determine the effect of hydraulic loading rates and frequency of application on salt accumulation in soils and the ultimate impact on crops.

Hydraulic Loading Rate Studies

Cotton was planted in 4.1 m x 13.7 m test plots. Four replicates were tested for each treatment. Treatments consisted of annual treated wastewater hydraulic loading rates ranging from zero cm.ha/ha.yr to 297 cm.ha/ha.yr. A total of 13 hydraulic treatments were tested. Similarly, grain sorghum test plots were irrigated with 0, 122, 183, 229 and 297 cm of treated sewage/yr. Two replicate plots were established for each treatment.

The investigation not only considered the production of cotton and grain sorghum but also certain high nitrogen and water consuming crops such as alfalfa and bermuda. Certain alfalfa test plots were irrigated with 434 cm.ha/ha.yr in 1983 while specific common bermuda test plots had 396 cm ha/ha.yr applied in 1983. Three fresh water control alfalfa plots were established to differentiate the affects of increasing hydraulic loadings on crop yield and quality from the growth response of crops and associated quality resulting from certain constituents in the wastewater effluent. Irrigation of test plots was minimal until a crop stand was established. Once a stand was established, hydraulic loadings were increased to test water tolerance of crops and nutrient utilization. The alfalfa was initially watered with fresh water and sprinklers to get the best stand possible. Irrigation of seedlings with slightly brackish water (average TDS 1,227 mg/l) may have presented germination problems.

Alfalfa was harvested every 28 to 30 days. All test plots were flood irrigated. Each month from 12.7 to 58.8 cm of water had to be applied to the corresponding test plot per irrigation period.

Hydraulic Application Frequency Study

The average total dissolved solids (TDS) level in the wastewater applied to the Hancock farm was approximately 1200 mg/l. The major cation present in the waste stream was sodium. Sodium adsorption ratio of the effluent was about 10. Accounting for alkalinity (average concentration 344 mg/l as $CaCO_3$), the adjusted SAR was approximately 22. Management of salt and water in wastewater reuse systems can be greatly affected by the crop grown, hydraulic loading and the frequency of wastewater applications. Two operational parameters which potentially will aid in the management of salts are the hydraulic loading rate and the frequency of application.

A solid set sprinkler irrigation system was employed which reflected the method of irrigation used at the Hancock farm and is the most widely used throughout the United States. Three nozzles spaced 6.1 m (20 ft) apart on 3.8 cm (1.5 in) PVC was moved through the field to attain the necessary irrigation. Crop samples, yield and soil samples were obtained from within the circular irrigated areas. A four frequency by three hydraulic loading rate matrix was established with two crops, soybeans and grain sorghum (Table 8). Annual hydraulic loadings of 30, 61, and 122 cm were scheduled with applications made at one, two, four and eight week

TABLE 8. TREATMENT MATRIX HYDRAULIC LOADING RATE FOR TRIAL 17000

Application Frequency	Treatment Code	30 cm/yr (12") Rate	Treatment Code	61 cm/yr (24") Rate	Treatment Code	122 cm/yr (48") Rate
1 application per week	01	1.02 cm (0.4 in)	05	2.03 cm (0.8 in)	09	4.06 cm (1.6 in)
1 application per 2 weeks	02	2.03 cm (0.8 in)	06	4.06 cm (1.6 in)	10	8.13 cm (3.2 in)
1 application per 4 weeks	03	4.6 cm (1.6 in)	07	8.13 cm (3.2 in)	11	16.26 cm) (6.4 in)
1 application per 8 weeks	04	8.13 cm (3.2 in)	08	16.26 cm (6.4 in)	12	32.51 cm (12.8 in)

intervals. As the time intervals between applications increased, the amounts of water per application increased to maintain the scheduled yearly loadings.

Sample Collection and Analysis

Irrigation water was derived from three sources: 1) from the distribution pipeline as the effluent was pumped to the Hancock farm from the City of Lubbock; 2) from the reservoir wastewater discharge; and 3) from a well used to provide ground water for the alfalfa fresh water control plots.

In 1982 approximately 95 percent of the effluent applied to test plots was derived directly from the pipeline, prior to the reservoirs, and 15 percent of the effluent came from the reservoirs. The following year 80 percent of the effluent was obtained from the storage reservoirs and the remaining 20 percent from pipelines prior to reservoir storage. A well located adjacent to research plots was used for the fresh water source. The fresh water source was sampled in April, August, and December of each year. The effluent water from the City of Lubbock as the waste stream arrived at the Hancock farm, and from the reservoirs was sampled monthly during the irrigation seasons. The exact position of the effluent monitoring location was usually the effluent box at the northern end of the farm where the effluent force main from the City sewage treatment plant entered the farm. Except for trace organic compounds, water samples were analyzed for the same constituents monitored in the Demonstration/Hydrologic Study (Table B.1).

Soil and crop samples were collected from each trial. The soil and crop sampling locations within replications (reps) of a treatment were randomly selected. Soil and crop samples were composited across reps to obtain a representative sample of each treatment.

Each year prior to pre-irrigation and after harvest, soil samples were obtained representing each treatment and crop within a trial. Depending upon the particular number of treatments and replicates per trial, one to three soil cores were taken per plot, composited within a plot, and composited across reps. Sample collection and constituent analysis were similar to procedures stated previously.

SECTION 4

SUMMARY OF FINDINGS

DEMONSTRATION-HYDROGEOLOGIC INVESTIGATION

Gray Farm

Ground-water Levels--

An objective of expanding the Lubbock land treatment system was to relieve the hydraulic and nutrient mass overloading experienced at the Gray land application site. Prior to diverting treated wastewater to the Hancock farm, the Gray farm received up to 57,000 m^3/day of SeWRP effluent which was used to irrigate approximately 1,200 ha (Wells et al 1979). This was an average annual hydraulic loading of 1.7 m. Water percolation to the ground water created a ground-water mound beneath the Gray farm. Depth to water ranged from 4.6 m (15 ft) to 22.8 m (75 ft). Ground-water quality beneath the Gray farm was degraded due to water management problems and inappropriate cropping patterns. Figure C.1 presents ground-water level contours beneath the Gray farm in December 1981. Flow occurs from the Gray site toward the north, east, and south. During 1983, the water levels in most of the observation wells dropped (Table 9). In 1982 only 25 percent of SeWRP's total effluent (16,650,613 m^3) to be used for irrigation was transported to the Hancock farm. From January 1, 1983 to October 31, 1983, the Gray farm received 11,406,287 m^3 which was 69 percent of the total effluent applied to land. During 1982 and 1983 ground water withdrawal from beneath the Gray farm by the City of Lubbock to provide recreational water for its citizens remained relatively constant with withdrawal rates in 1980 and 1981. Consequently, the decline in ground-water beneath the Gray farm probably was only slightly affected by the transfer of water to the Hancock farm. The change in cropping pattern to alfalfa may have been the major contributing factor to the decrease in ground water level.

Ground-water Quality--

Prior to 1982 hydraulic and nutrient overloading applied to the farm

TABLE 9. STATISTICS OF DEPTH TO WATER IN OBSERVATION WELLS AT GRAY SITE DURING PROJECT

Well No.	Initial		Depth to Water m (ft) Minimum		Maximum		Final	
6880	19.9	(65.3)	10.61	(34.9)	19.9	(65.3)	17.7	(58.1)
6881	21.5	(70.6)	21.3	(34.9)	22.1	(72.5)	21.5	(70.5)
6882	22.9	(75.0)	22.3	(73.0)	25.6	(84.1)	22.2	(73.0)
6883	18.9	(62.0)	18.6	(61.1)	21.0	(68.8)	18.9	(62.0)
6884	8.5	(28.0)	5.3	(17.3)	10.7	(35.1)	9.2	(30.2)
6885	8.2	(26.8)	5.0	(16.4)	10.1	(33.0)	8.4	(27.6)
6886	15.2	(50.0)	15.2	(50.0)	16.7	(54.7)	16.5	(54.1)
6887	10.7	(35.0)	10.7	(35.0)	13.2	(43.2)	12.8	(42.0)
6888	19.8	(65.0)	19.8	(65.0)	21.3	(70.0)	21.2	(69.5)
6889	13.7	(45.0)	13.2	(43.3)	14.4	(47.4)	14.3	(46.9)
6890	4.6	(15.0)	3.4	(11.3)	5.8	(19.1)	4.3	(14.0)
6891	5.1	(16.7)	4.1	(13.4)	6.1	(20.0)	5.6	(18.5)
6892	8.5	(28.0)	3.4	(11.0)	12.2	(40.0)	8.9	(29.2)
6893	12.1	(39.6)	10.1	(33.0)	12.1	(39.8)	11.3	(37.0)
6896	12.6	(41.3)	3.6	(11.9)	15.0	(49.1	12.8	(42.0)
6895A	13.8	(45.3)	9.7	(31.7)	13.8	(45.3)	9.8	(32.0)
6895B	7.9	(25.8)	5.9	(19.4)	8.3	(27.2)	8.0	(26.2)
6895C	7.7	(25.4)	5.9	(19.5)	8.3	(27.2)	8.0	(26.2)
6895D	7.7	(25.3)	6.1	(19.9)	8.7	(28.4)	8.2	(26.8)
7000	6.9	(22.8)	5.9	(19.3)	8.3	(27.2)	7.9	(26.0)

had increased the quantity of ground water at the expense of ground-water quality. Table 10 presents the percent of well water samples collected from the Gray wells which contained constitutents equaling or exceeding drinking water standards. Due to improper nitrogen management on the farm, sufficient nitrate-nitrogen was leached to the ground water to create water quality problems (>10 mg N/l) throughout the entire aquifer beneath the farm. Several water samples contain Se concentrations greater than the drinking water maximum constituent level (MCl) (0.01 mg/l). Iron and manganese levels consistently equaled or exceeded recommended secondary constitutent levels of 0.3 mg/l and 0.05 mg/l, respectively. During the baseline period hydraulic overloading leached salt from and through the soil profile thereby increasing TDS, SO_4 and Cl levels in the ground water above recommended secondary constituent levels with regard to drinking water sources.

The range of the average concentration of specific water quality constituents contained in the ground water beneath the Gray farm during the baseline monitoring period (June 1980 to February 1982) and the irrigation monitoring period (February 1982 to October 1983) is presented in Appendix C. (Table C.1).

Nitrogen--Prior to pumping water to the Hancock farm, the average NO_2+NO_3-N levels in the ground water beneath the Gray farm ranged from 5.05 mg/l to 35.89 mg/l. Figure 7 illustrates that the higher ground-water NO_2+NO_3 were experienced in areas which were row watered or flood irrigated and wells down gradient from these areas. Once SeWRP's effluent was pumped to the Hancock farm, ground-water NO_2+NO_3-N concentrations beneath the Gray farm ranged from 0.77 mg/l to 33.43 mg/l. Comparison of the average baseline and irrigation monitoring period nitrate data showed a nitrate decrease in 17 of 27 monitoring wells while five wells (6852, 6855, 6885, 6864, and 6883) had an increase in average nitrate levels. Excessive precipitation (approximately 35 cm) in May and June 1982 caused surface runoff which inundated a few poorly sealed well casings producing a pulse increase in total Kjeldahl nitrogen (TKN). During the baseline period, TKN concentrations varied from 0.28 mg/l to 6.97 mg/l. Once water was diverted from

TABLE 10. PERCENT OF GRAY FARM WELL WATER SAMPLES WHICH EXCEED OR EQUAL DRINKING WATER STANDARDS FOR THE FOLLOWING PARAMETERS

Total Number of Wells = 25

Maximum Constituent Level

Date	No. of Wells	AS	BA	CD	CR	PB	HG	NO_3*	SE	AG
06/25/80	11	0	0	9	0	0	27	73	0	0
08/19/80	9	0	0	0	11	11	11	100	0	0
09/25/80	24	0	0	0	0	0	0	79	0	0
01/08/81	25	0	0	0	0	0	0	84	0	0
03/27/81	1	0	0	0	0	0	0	100	0	0
06/02/81	24	0	0	4	0	0	0	83	4	0
10/28/81	19	0	0	0	0	0	0	74	5	0
11/02/81	3	0	0	0	0	0	0	33	33	0
01/27/82	25	0	0	0	0	0	0	84	0	0
05/27/82	23	0	0	0	0	0	0	74	0	0
10/11/82	20	0	0	0	0	0	0	55	5	0
11/01/82	5	0	0	0	0	0	0	60	0	0
05/19/83	25	4	0	0	0	0	0	60	4	0
10/10/83	25	0	0	0	0	0	0	52	0	0

*Values reported as nitrogen

Recommended Secondary Constituent Levels

Date	No. of Wells	CL	CU	FE	MN	SO_4	TDS	ZN
06/25/80	11	55	0	18	82	64	100	0
08/19/80	9	89	0	0	0	7	100	0
09/25/80	24	63	0	0	0	4	92	0
01/08/81	25	84	0	12	8	56	96	0
03/27/81	1	100	0	100	100	0	100	0
06/02/81	24	83	0	13	13	63	96	0
10/28/81	19	68	0	26	26	53	79	0
11/02/81	3	33	0	33	33	0	67	0
01/27/82	25	80	0	12	16	60	92	0
05/27/82	23	78	0	43	17	48	91	0
10/11/82	20	65	0	35	15	45	80	0
11/01/82	5	80	0	100	20	60	100	0
05/19/83	25	76	0	4	16	64	88	0
10/10/83	25	76	0	72	12	36	88	0

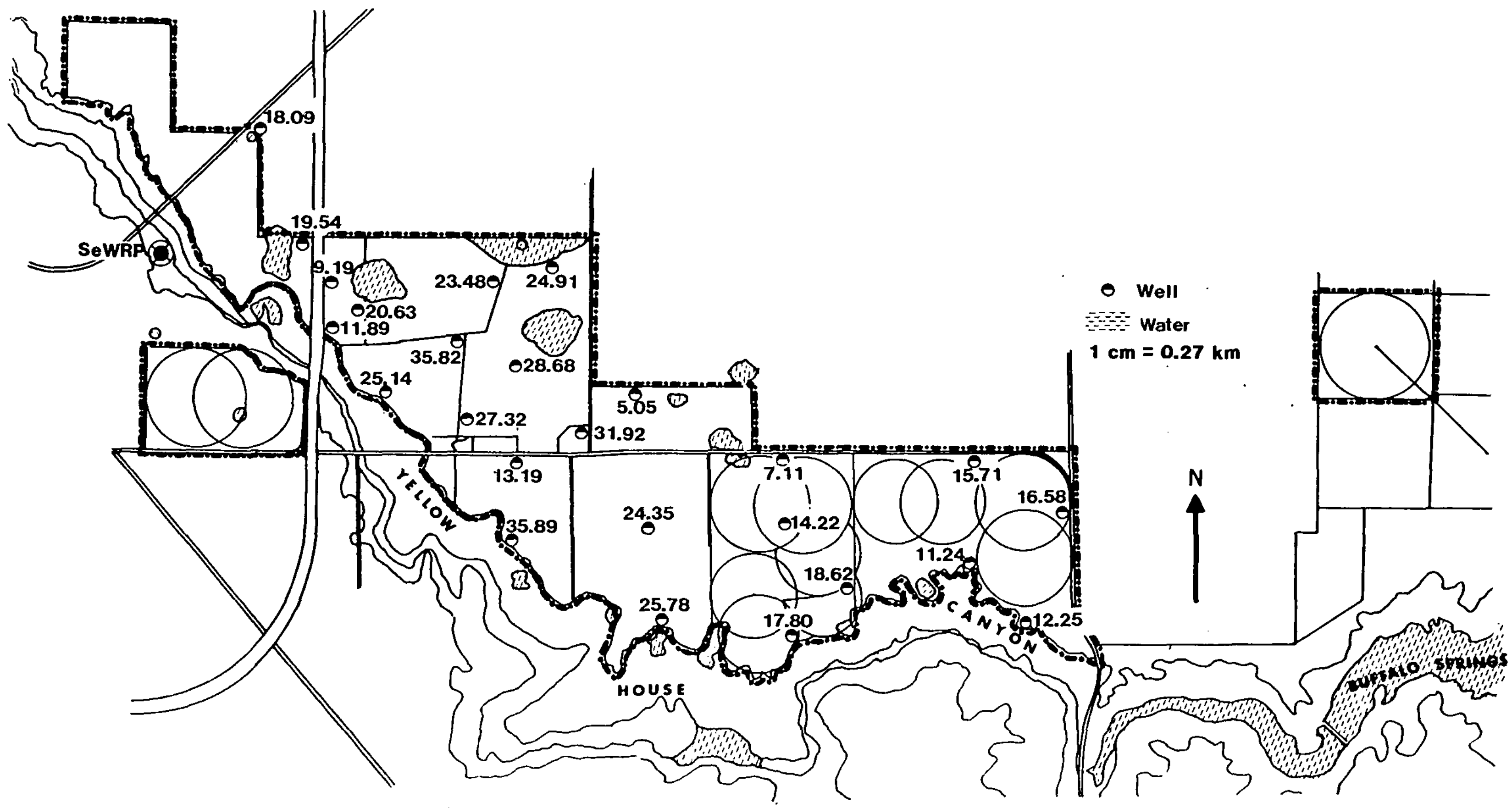

Figure 7. Nitrate Concentration (mg/l) in Well Water under Gray Farm, Baseline Period, 1981-1982

the Gray farm to the Hancock farm, average TKN levels ranged from 0.20 mg/l to 7.65 mg/l.

Phosphorus--Average total phosphorus (TP) levels in the ground water beneath the Gray farm ranged from 0.10 to 3.49 mg/l during the baseline period (Table C.1). During the irrigation period, from February 1982 to October 1983, ground water TP levels generally remained relatively stable with average concentrations ranging from <0.07 to 1.94 mg/l. Eighteen wells contained water which dropped in TP levels during the irrigation period.

Organic Carbon--Ground water COD measurements were quite variable from June 1980 through October 1982 and appeared to stabilize during 1983. During the baseline and irrigation periods, average COD values ranged from 27.2 mg/l to 125.4 mg/l and 11.4 mg/l to 100.3 mg/l, respectively. Median COD values were from 12.1 mg/l to 159.1 mg/l from June 1980 to February 1982 and 10.3 mg/l to 46.9 mg/l during the irrigation period. Approximately 80 percent of the Gray wells contained less than average COD in their respective ground water during the irrigation period compared to the baseline COD concentrations. Similarly, ground water TOC concentrations decreased from baseline period through the irrigation period.

Minerals--The salt management procedure employed at the Gray farm prior to transporting water to the Hancock farm was leaching. The average concentration of total dissolved solids (TDS) in the ground water beneath the Gray farm varied from 1,010 mg/l to 2,271 mg/l.

Calcium, magnesium, potassium, and sodium salts were the primary contributors to the ground-water dissolved solids beneath the Gray farm. The average ground-water calcium levels ranged from 47.7 mg/l to 161.7 mg/l during the baseline period. No significant ($\alpha = 0.05$) differences in ground-water calcium concentrations were determined when comparing the data obtained prior to February 1982 and the data from February 1982 to October 1983. A comparison of average ground-water calcium levels computed for the baseline and irrigation periods, however, does indicate a slight increase in calcium levels in 72 percent of the wells. Furthermore, magnesium concentrations increased slightly in 19 of 25 wells. Average magnesium concentrations were from 21.8 mg/l to 137.6 mg/l from June 1980 to February 1982 and from 38.5 mg/l to 148.7 mg/l during the irrigation period.

Associated with the increase in Ca and Mg in the ground water was a decrease in Na levels in 15 of 25 wells. The combined reduction in Na and increases in Mg and Ca produced a decrease in SAR_{adj} in 17 wells. During the baseline period the average SAR_{adj} of ground water from 25 wells exceeded 9 with well 6893 exhibiting the highest SAR_{adj} value of 23.9. Severe sodic problems would develop in the soils of adjacent farms which utilized this ground-water source for irrigation. As expected, ground water beneath the farm areas which were historically irrigated by flood or ridge and furrow method (row water) contained the higher sodium levels. In 1982 the cropping pattern was changed and alfalfa became the primary crop grown. A more even and reduced hydraulic distribution of water over the entire farm associated with higher evapotranspiration reduced leaching of sodium from the upper soil profile.

During the irrigation period, significant increases in ground-water iron concentration were measured in several wells. Saturated soil conditions in May and June 1982 caused reduction of iron to soluble ferrous iron and subsequent percolate water transported increasing quantities of ferrous iron to the ground water. Percolation resulting from heavy precipitation events in May and August/September 1981 leached sufficient quantities of iron to the ground water to exceed or equal drinking water standards.

Major anions associated with the salts were chlorides and sulfates. Average chloride concentrations ranged from 208 mg/l to 535 mg/l during the baseline monitoring period and 154 mg/l to 686 mg/l during the irrigation period. Before effluent was pumped to the Hancock farm, average ground-water sulfate concentrations varied from 149 mg/l to 795 mg/l. Once the hydraulic loading was reduced, 148 mg/l to 399 mg/l was the range of average ground-water sulfate (SO_4) concentrations measured in the ground water beneath the Gray farm. Use of the ground water located beneath the flood or row water irrigated areas for sprinkler irrigation of alfalfa and grain sorghum may cause foliar injury.

Trace Metals--The majority of trace metals analyzed in each water sample were at low concentrations. This was anticipated since the irrigation stream contained low levels of trace metals and the soil matrix had the ability to remove most metals. Nonetheless, certain metals did increase significantly in the ground-water samples obtained from certain wells and/or equaled or exceeded drinking water MCls. The data show that trace metals present in the ground water posed no potential public health risk. With the alkaline soils which existed at the Gray farm, anionic heavy metals such as As and Se were more soluble and consequently an apparent association was observed with rainfall events and slight As and Se increase in the ground water. Colloidal particulates entering the well casing during construction or after heavy rainfall events may have caused slight pulse increases in Pb, Cr, Cd, and Co concentration in ground water obtained from a few wells.

Priority Organic Pollutants--The ground water beneath the Gray farm contained very low levels of specific priority organic pollutants (POP) assayed. Contamination of ground water by priority organic pollutants was not a problem during the study period. The soil matrix was very efficient in removing and biologically degrading these organics.

Statistical analysis of propazine levels obtained from wells 6884 and 6892 showed an increase in propazine concentration during the irrigation period. Propazine was a common herbicide used to control weeds in grain sorghum crop production. Consequently, the small increase in propazine could have been attributable to leaching of the herbicide during the May precipitation or transport of a small quantity of particulates containing propazine directly into the well or through the gravel packing surrounding the well casing.

Bacteriological data--Bacterial indicator organisms, total coliform, and fecal streptococci were assayed in each water sample to determine the potential presence of pathogenic organisms. Salmonella was isolated in four wells during the baseline period. Three of five Salmonella isolations were measured during the fall 1981. Contamination of these wells by Salmonella and the indicator organisms was associated with heavy rainfall events. Similarly, heavy precipitation in May and June 1982 caused flooding of well 6884 which introduced Salmonella to water contained in the poorly sealed well. The presence of Salmonella in this water sample was the only isolation measured from February 1982 to October 1983.

Soils--

The Gray soils contained a higher percentage of coarse material throughout the upper 122 cm of the profile than measured in the soil profile at the Hancock farm. The predominate soil texture within the upper 30 cm of the profile was sandy loam. Sandy clay loams existed from a depth of 30 cm to 91 cm. Soil texture at depths greater than 122 cm varied primarily from clay to clay loams. An indurated caliche soil was observed at depths from 40 to 183 cm.

Nitrogen--The Gray farm crops were predominantly cotton in 1981 and alfalfa in 1982 and 1983. Nitrate nitrogen concentrations were fairly uniform throughout the entire 183 cm soil depth in 1981. Analysis of soils in 1983, however, indicated a decrease in nitrate levels in the upper 91 cm which resulted from greater nitrogen uptake by alfalfa. Ammonia nitrogen existed primarily in the top 30 cm of soil. No appreciable change in ammonia concentrations was observed between soil samples collected in 1981 and 1983. The bulk of the soil nitrogen was incorporated in organic matter. A reduction of organic nitrogen from the 1981 levels was measured in 1983. A nitrogen balance on the soil indicated that nitrogen uptake by crops grown beneath the center pivot irrigation machine was the major mechanism governing nitrogen losses. Deep percolation of inorganic nitrogen beneath the center pivot machines was not a major mechanism of nitrogen loss in 1982 or 1983. The results of the nitrogen mass balance for the flood irrigated area showed deep percolation of nitrates to the ground water remained a significant process for the loss of nitrogen from the soil profile in the flood or row water areas. The ground-water quality data also substantiate this conclusion.

Phosphorus--Phosphate-calcite reactions were probably an important mechanism for the removal of phosphorus from the soil solution. A total phosphorus mass balance showed annual phosphorus removal by crops in 1981, 1982 and 1983 was less than the mass applied through irrigation. Only 33 percent of the applied TP was consumed by crops. The remainder was probably fixed into the soil matrix.

The phosphorus uptake by wheat (flood irrigated) was only 12 percent of the estimated 1,072 kg/ha applied from 1981 through 1983. Fixation of phosphorus may have been the major mechanism which governed phosphorus removal from the soil solution.

Minerals--Total dissolved solids in the soil matrix beneath the center pivot machines increased gradually with depth in 1981; whereas, frequent leaching of salts in the wheat areas produced a more uniform TDS concentration throughout the entire soil profile. A TDS mass balance indicated flood and row irrigation and precipitation leached salts below a depth of 183 cm during the period from spring 1981 through 1983. Chloride and sulfate mass balances further substantiated the deep percolation of anions past 183 cm depth in the flood irrigated areas. The salts applied to cotton and alfalfa areas, however, were somewhat retained in the soil profile.

Increases in TDS levels measured in 1983 did not appear to be associated with increases in sodium ion. A slight increase in the average sodium concentration was measured at depths of 61 and 91 cm in 1981. Sodium levels were fairly uniform throughout the soil profile in 1983. Based on a cation exchange capacity (CEC) in the upper 30 cm of 22 meq/100g an exchangeable sodium percentage (ESP) of approximately seven was computed for sodium in the top 30 cm beneath the spray irrigated area. Therefore, sodium levels were maintained sufficiently low by leaching to prevent sodic conditions (ESP <15) in the soil. Similarly, the ESP value for 1981 and 1983 in the upper 30 cm of the flood or row water areas was seven.

Trace Metals--Table 11 presents the total average mass of specific trace metals applied by flood and row irrigation. Over a three year period from 1981 through 1983, input of trace metals through irrigation to the soil was low. Compared to the concentration of metals in the soils, the concentration of metals in the crop tissue was negligible. Anionic metals such as arsenic and chromium (VI) probably were transported by percolate to depths greater than 91 cm within the alkaline soils. In addition, barium, copper and nickel possibly leached beyond the 91 cm soil depth. Possible accumulation of cadmium, cobalt and lead occurred in the upper 91 cm of soil in the flood irrigated areas. Special variability had the most impact on deficiencies in trace metal levels measured in 1981 and 1983.

Priority Organics Pollutants--The majority of soil samples analyzed for specific priority organic compounds, contained levels below their respective detection limits. In both the spray and flood irrigated areas, solvents such as benzene and chloroform existed throughout the 183 cm soil profile in 1981.

TABLE 11. TRACE METALS MASS BALANCE ON SOILS COLLECTED FROM FLOOD IRRIGATED AREA

Trace Metal	Mass Applied (kg/ha)	Mass in Soil Profile (kg/ha) 1981	Mass in Soil Profile (kg/ha) 1983	Change in Soil Profile (kg/ha)	Unaccounted Mass (kg/ha)
As	1.887	85.0	26.9	-58.1	-60.0
Ba	26.96	2351	1267	-1084	-1111
Cd	0.276	2.56	4.40	+1.84	+1.56
Co	0.358	36.8	90.1	+53.3	+52.9
Cr	4.820	593.7	189.4	-404.3	-409.1
Cu	5.167	202.2	83.3	-118.9	-124.1
Pb	2.962	34.4	101.4	+67.0	+64.3
Ni	4.235	175.0	118.6	-56.4	-60.6

Benzene levels decreased to levels barely exceeding detection limits in 1983. In 1983, however, chloroform levels appeared to have increased above baseline levels. Furthermore, chloroform concentration increased with depth.

Carbon tetrachloride and tetrachloroethylene were not measured at concentrations above detection limits in 1981, but were detected at levels exceeding analytical limits in practically all samples collected from flood and spray irrigated areas in 1983.

Chlorinated aniline compounds such as 2,3-dichloroaniline and 3,4-dichloroaniline may have been derivatives of herbicides or fungicides. In general, 2,3-dichloroaniline was more prevalent at soil depths from 91 cm to 183 cm beneath the center pivot machines in 1983 than in 1981. Furthermore, less amounts of chlorinatedanilines were detected in the flood irrigated soils.

Acenaphthylene and the various dichlorobenzene forms in the soils may have been derived from application of insecticides. These organic compounds existed primarily in the upper 61 cm of the soil profile.

The presence of trace organics in the soil profile in 1981 and 1983 may have been directly related to the mass loadings of specific organics through flood irrigation of wheat. Decreased organic mass loadings by spray irrigation, however, reduced the potential of residual levels of priority organic compounds in 1983 being derived solely from irrigation.

Bacteriological Data--Total coliform, (TC) fecal coliform (FC) and fecal streptococcus (FS) were primarily retained in the top 30 cm of soil. Furthermore, FS was detected at greater concentrations in the spray irrigated areas in 1983 than in 1981. Certain soil samples obtained from the flood irrigated areas contained concentrations of TC and FS exceeding detection limits at depths of 183 cm.

Fungi and actinomycetes concentrations within the soil profile were relatively constant throughout the farm and the monitoring period. Changes in hydraulic loading or cropping patterns did not appear to affect the number of actinomycetes or fungi present throughout the entire 183 cm soil core.

Crops--

Cotton yields prior to 1982 equaled or exceeded irrigated Lubbock County yield averages of 434 to 457 kg/ha in 1980 and 1981, respectively. Alfalfa yields in 1982 (crop establishment year) ranged from 1.8 to 2.7 metric tons/ha which was relatively low compared to a normal range of 5.4 to 7.0 metric tons/ha. The yield reduction was partially due to 1) delays in watering, thereby delaying regrowth; 2) poor stand establishment; and 3) weed competition. Weed competition also affected the quality of the hay harvested; thus lowering the crop's marketability. The 1983 alfalfa yields on the Gray farm were again reduced by delays in watering which reduced the number of cuttings. Normally, five to seven cuttings of alfalfa are expected in the Lubbock area (Texas A & M Extension Service). The Gray farm produced three to four cuttings. Alfalfa yields were slightly improved over 1982 values. Soybean yields averaged 2,494 kg/ha (37 bu/ac). Wheat yields from the Gray farm were difficult to determine since no grain harvest was planned and forage harvest was accomplished by grazing. Analysis of crop tissue indicated macro and micro nutrients were within normal ranges. Potential toxic trace metals did not appear to accumulate in the crop tissue.

Hancock Farm

Ground-water Levels--

The saturated thickness of the aquifer beneath the Hancock farm was less than 6.1 m (20 ft). Depth to water varied from 24.4 to 36.6 m (80 to 120 ft). In 1981 ground-water flow occurred toward both the north and the south from a ridge through the center of the property (Figure C.2).

Ground-water levels increased beneath the Hancock site during the period from January 1982 to October 1983 (Table 12). Ground-water recharge from surface runoff contained in the moat areas surrounding the reservoirs and through coarse material along the fringes of the playa lakes most likely caused the water level rises beneath the farm. Irrigation amounts during the study period were far less than crop evapotranspiration rates; consequently irrigation does not appear to be a source of ground-water recharge.

Ground-water Quality--

Prior to land application of treated wastewater at the Hancock farm, the range of average concentration of constituents measured in the ground water beneath the Hancock farm is presented in Table C.2. Several well water samples contained levels of contaminants which exceeded or equaled drinking water maximum constituent levels (Table 13).

Nitrogen--Associated with the deep percolation of rainfall surface

TABLE 12. STATISTICS OF DEPTH TO WATER IN OBSERVATION WELLS AT HANCOCK SITE DURING PROJECT

Well No.	Depth to Water m (ft)							
	Initial		Minimum		Maximum		Final	
10112	34.0	(111.4)	27.9	(91.6)	34.4	(113.0)	32.6	(106.8)
10211	37.0	(121.5)	36.5	(119.9)	40.3	(132.1)	36.6	(120.0)
10521	24.2	(79.3)	22.9	(75.0)	25.8	(84.8)	22.9	(75.0)
10721	25.9	(85.0)	19.1	(62.6)	28.1	(92.2)	19.1	(62.6)
10731	24.7	(81.0)	19.0	(62.4)	25.2	(82.8)	19.0	(62.4)
10821	21.9	(72.0)	18.9	(67.7)	27.3	(72.0)	18.9	(62.0)
10842	26.9	(88.1)	20.6	(62.0)	27.3	(89.7)	24.9	(81.8)
10931	21.5	(70.4)	17.4	(57.0)	21.5	(70.5)	18.3	(59.9)
10932	20.6	(67.7)	13.4	(43.9)	20.7	(67.9)	15.5	(51.0)
11032	28.4	(93.1)	27.2	(89.3)	28.7	(94.3)	27.4	(90.0)
20112	35.7	(117.0)	33.7	(110.7)	36.1	(118.3)	34.2	(112.2)
20243	41.5	(136.0)	41.5	(136.0)	44.6	(146.3)	41.6	(136.4)
20711	31.4	(103.0)	31.1	(102.0)	32.4	(106.3)	31.2	(102.2)
20721	27.4	(90.0)	24.8	(81.3)	29.5	(96.7)	24.8	(81.3)
20842	30.5	(100.1)	25.3	(83.0)	30.7	(100.8)	28.0	(92.0)
21141	27.4	(90.0)	25.0	(81.9)	27.7	(91.0)	25.0	(82.0)
21152	26.3	(86.2)	22.0	(72.1)	26.3	(86.4)	22.4	(73.5)
21234	26.3	(86.3)	22.7	(74.4)	26.6	(87.3)	22.7	(74.4)
21323	29.6	(97.1)	29.0	(95.0)	30.2	(99.1)	29.0	(95.1)
30312	32.0	(105.0)	31.4	(103.1)	32.4	(106.3)	31.5	(103.4)
40231	30.2	(99.0)	29.6	(97.0)	30.8	(101.0)	29.8	(97.7)
40331	29.6	(97.0)	28.2	(92.7)	29.6	(97.0)	28.9	(94.8)

TABLE 13. PERCENT OF HANCOCK FARM WELL WATER SAMPLES WHICH EXCEED OR EQUAL DRINKING WATER STANDARDS FOR THE FOLLOWING PARAMETERS

Total Number of Wells = 27
Maximum Constituent Level

Date	No. of Wells	AS	BA	CD	CR	PB	HG	NO_3	SE	AG
07/22/80	12	0	0	17	0	8	0	8	0	0
10/30/80	7	0	0	0	0	0	0	0	29	0
11/11/80	16	0	0	0	0	0	0	25	0	0
01/26/81	23	0	0	0	0	0	0	0	0	0
03/27/81	2	0	0	0	0	0	0	0	0	0
06/11/81	24	0	0	0	0	0	0	13	4	0
10/29/81	2	0	0	0	0	0	0	0	50	0
11/18/81	22	5	0	0	0	0	0	27	18	0
01/18/82	27	0	0	0	0	0	0	4	19	0
06/14/82	27	0	0	0	0	4	0	11	15	0
09/22/82	25	0	0	0	0	0	0	12	0	0
11/10/82	2	0	0	0	0	0	0	0	0	0
02/15/83	7	0	0	0	0	0	0	57	0	0
03/14/83	12	0	0	0	0	0	0	8	0	0
05/09/83	27	0	0	0	0	0	0	15	15	0
07/20/83	1	0	0	0	0	0	0	0	0	0
09/15/83	27	0	0	0	0	0	0	7	11	0

(continued)

Table 13, continued

Recommended Secondary Constituent Levels

Date	No. of Wells	CL	CU	FE	MN	SO_4	TDS	ZN
07/22/80	12	0	0	25	67	0	8	0
10/30/80	7	0	0	14	71	0	0	0
11/11/80	16	0	0	0	25	0	0	0
01/26/81	23	0	0	22	30	0	0	0
03/27/81	2	0	0	0	100	0	0	0
06/11/81	24	0	0	4	42	4	4	4
10/29/81	2	0	0	100	50	0	0	0
11/18/81	22	9	0	73	45	0	0	0
01/18/82	27	0	0	85	52	0	4	0
06/14/82	27	4	0	96	52	4	7	0
09/22/82	25	0	0	92	44	8	0	0
11/01/82	2	0	0	100	100	0	0	0
02/15/83	7	0	0	0	0	14	29	0
03/14/83	12	0	0	0	0	0	0	0
05/09/83	27	4	0	59	30	4	7	0
07/20/83	1	0	0	0	0	0	0	0
09/15/83	27	7	0	89	48	4	11	0

runoff captured in playa lakes or moat areas surrounding the storage reservoirs was the leaching of nitrate nitrogen to the ground water. Nitrate levels in water obtained from seven wells, which were adjacent to surface runoff collection areas, increased after heavy precipitation events. The rapid increase in ground-water nitrate concentrations may have resulted from migration of percolate around poorly sealed well casings to the ground water. Most of the ground-water samples collected during the monitoring period contained less than one ppm TKN.

Phosphorus--During the baseline monitoring period, average TP levels measured in the ground water ranged from 0.19 mg/l to 0.58 mg/l. The average ground-water TP concentration from February 1982 through October 1983 ranged from 0.02 mg/l to 0.41 mg/l. The data indicate a decreasing trend in TP from baseline through irrigation. This decrease was primarily due to a decrease in organic phosphorus in the ground water.

There appeared to be an increase in TP and PO_4 in most wells in June 1982. During the baseline period ground-water PO_4 levels ranged from <0.01 to 0.22 mg/l. From February 1982 to October 1983, the majority of water samples analyzed contained less than 0.10 mg/l orthophosphate phosphorus.

Organic Carbon--Median COD concentrations during the baseline and irrigation periods ranged from 4.1 mg/l to 94 mg/l and 3.8 mg/l to 88 mg/l, respectively. High COD levels were primarily the result of soil entering the well during construction. Ground-water organic carbon levels decreased during the period from June 1980 to October 1983.

Minerals--Prior to transporting SeWRP's effluent to the Hancock farm, the average TDS in the ground water beneath the farm ranged from 363 mg/l to 989 mg/l. As was observed with increases in ground-water nitrate levels, increases in TDS in water obtained from a few wells appeared to be associated with heavy precipitation events.

Comparison of baseline and irrigation period average sodium adsorption ratio (SAR) for the water extracted from each well indicate a general change in composition of salts. From June 1980 to February 1982, the average adjusted SARs (SAR_{adj}) of the ground water ranged from 3.0 to 8.4. To prevent the creation of sodic soils, irrigation water should have an SAR_{adj}

below six (Stromberg and Tisdale 1971). Eleven wells contain water with average SAR_{adj} less than six. Increasing problems, however, may occur with SAR_{adj} from six to nine. Computed SAR_{adj} values for ground water obtained from 24 wells were between six and nine. Therefore, no severe problems with water penetration were indicated by the data. During the irrigation monitoring period, SAR_{adj} values ranged from 2.1 to 11.0. Approximately 60 percent of the wells demonstrated an increase in Ca and Mg, and Na was reduced in 79 percent of the wells during the irrigation period. Therefore, in 18 wells the SAR_{adj} was lowered during the irrigation period.

In general, no significant changes in ground-water chloride ion concentrations was detected throughout the monitoring period. A significant increase in Cl ion levels was observed in the monitoring wells adjacent to the moat area surrounding reservoir 2. During the baseline period, chloride levels ranged from 22 mg/l (0.6 meq/l) to 246 mg/l (6.9 meq/l) and from 17 mg/l (0.4 meq/l) to 345 mg/l (9.7 meq/l) from February 1982 to October 1983. Chlorides present in the ground water would not cause foliar injury to crops grown on the Hancock farm which were primarily cotton, grain sorghum, and alfalfa.

Trace Metals--As previously stated, trace metals were not a major concern due to the limited industrial waste water contribution to SeWRP's sewerage load and the ability of the alkaline calcareous soil profile to adequately remove and render relatively insoluble most trace metals. Trace metals posed no potential agricultural or public health problems during the project monitoring period.

Priority Organic Pollutants--In general, slow rate land application of organic compounds contained in municipal waste water should pose no hazard to ground water, soil microbial community and vegetation (Overcash 1983, Davidson et al 1980). The ground-water data confirms this statement. Major priority organic compounds measured in the ground-water samples were phthalates (i.e., dibutylphthalate, diethylphthalate, diisooctylphthalate). Phthalates are used as plasticizers in polymers and migrate quite readily to the surrounding environment. Consequently, phthalate contamination may have been an artifact of well construction, sample collection, and presence of plastics within the laboratory.

Ground water in well 10521, 10931, 10721, 30312, and 10721 experienced a pulse increase in atrazine in 1983. Average atrazine concentrations in wells 10521, 10931, 10721, 30312, and 10731 were all less than 2.0 ppb during the baseline period and 13.9 ppb, 2.5 ppb, 11.9 ppb, 10.8 ppb, and 12.6 ppb, respectively, from February 1982 to October 1983. Atrazine was used to kill weeds and grasses in borrow ditches, and around each center pivot irrigation machine. In addition, patches of weeds surrounding playa lakes or extending into fields were treated with atrazine.

Bacteriological data--During the baseline period, indicator organisms were isolated in water from more than 85 percent of the wells. A small biochemical study identified the fecal streptococci organisms to have been possibly S. faecalis subspecies liquefaciens and not of human source. A potential source of Salmonella, fecal coliform and fecal streptococci was most likely rodents which burrowed beneath concrete pads surrounding well casings. Detection of Salmonella in water samples decreased during the irrigation period. In general, very little difference was observed between bacteriological data obtained during the baseline and irrigation monitoring periods.

Soils--

At the Hancock farm, the soil texture within the upper 30 cm (1 ft) of the soil profile was generally sandy clay loam. Clay to clay loams dominated the soils from a depth of 30 cm to 122 cm (4 ft) within the profile. The majority of soils from 122 cm to 183 cm (6 ft) were clays. An indurate layer of calcium carbonate (caliche) existed within the soil profile at a depth of 61 cm to 183 cm throughout the farm.

Soils at the Hancock farm were alkaline and calcareous with pH values, within the upper 183 cm, of seven to eight. Cation exchange capacities (CEC) were greater than 20 meq/100 g (average 22.4 meq/100 g $\pm$ 3.7) which were characteristic of the clay/clay loam soils.

Nitrogen--The bulk of the nitrogen in the soil profile was in the organic form, which appeared to decrease linearly through the upper 152 cm of the profile. Carbon to nitrogen (C/N) ratios of the organic matter ranged from three to 47 with only three percent of 235 cores having a C/N ratio greater than 20. C/N ratios less than 22 are associated with net mineralization and ratios higher than 22 indicate net immobilization. The average C/N ratios of the effluent pumped to the farm and from the reservoirs were 4.0 and 5.9, respectively. Therefore, net mineralization of organic nitrogen predominated within the soil profile. Nitrate-nitrogen was the major inorganic nitrogen form within the soil profile. Nitrate lenses were detected within the lower 91 cm of several soil cores (Figure 8). Low moisture conditions due to the semiarid climate of the South Plains may have inhibited decomposition of organic matter and denitrification of nitrate-nitrogen.

Nitrogen mass balances were conducted on the soil-crop matrix. The spacial variability of the data in conjunction with the error associated with the assumptions imposed on the model produced highly variable results. At the lowest annual hydraulic loading (42.2 cm) the processes included in the nitrogen model described most of the nitrogen transformation within the soils (Figure 9). Increased nitrogen losses due to denitrification, volatilization, or possible leaching were not accounted for in the mass balance at the 52.2 cm/yr irrigation loading.

The nitrogen mass balance model when applied to the area of the farm irrigated with an average hydraulic loading of 68.9 cm/yr, predicted inorganic nitrogen mass in the profile of 302 kg/ha compared to a measured average of 277 kg N/ha. In general, the assumption that inorganic nitrogen was not leached from the upper 183 cm of the profile appeared to be substantiated by the nitrogen mass balance.

Phosphorus--Phosphate-calcite reactions were believed to be a major factor in the removal of phosphorus from the soil solution. The soil profiles throughout the farm denote a general decrease in TP from 1981 levels to 1983 levels.

A phosphorus mass balance on the soils at each hydraulic loading showed that the crops utilized more phosphorus than was applied in 1982. In 1983, the mass of phosphorus removed by crops was less than applied. Furthermore, the amount of phosphorus removed by the cotton was less than the

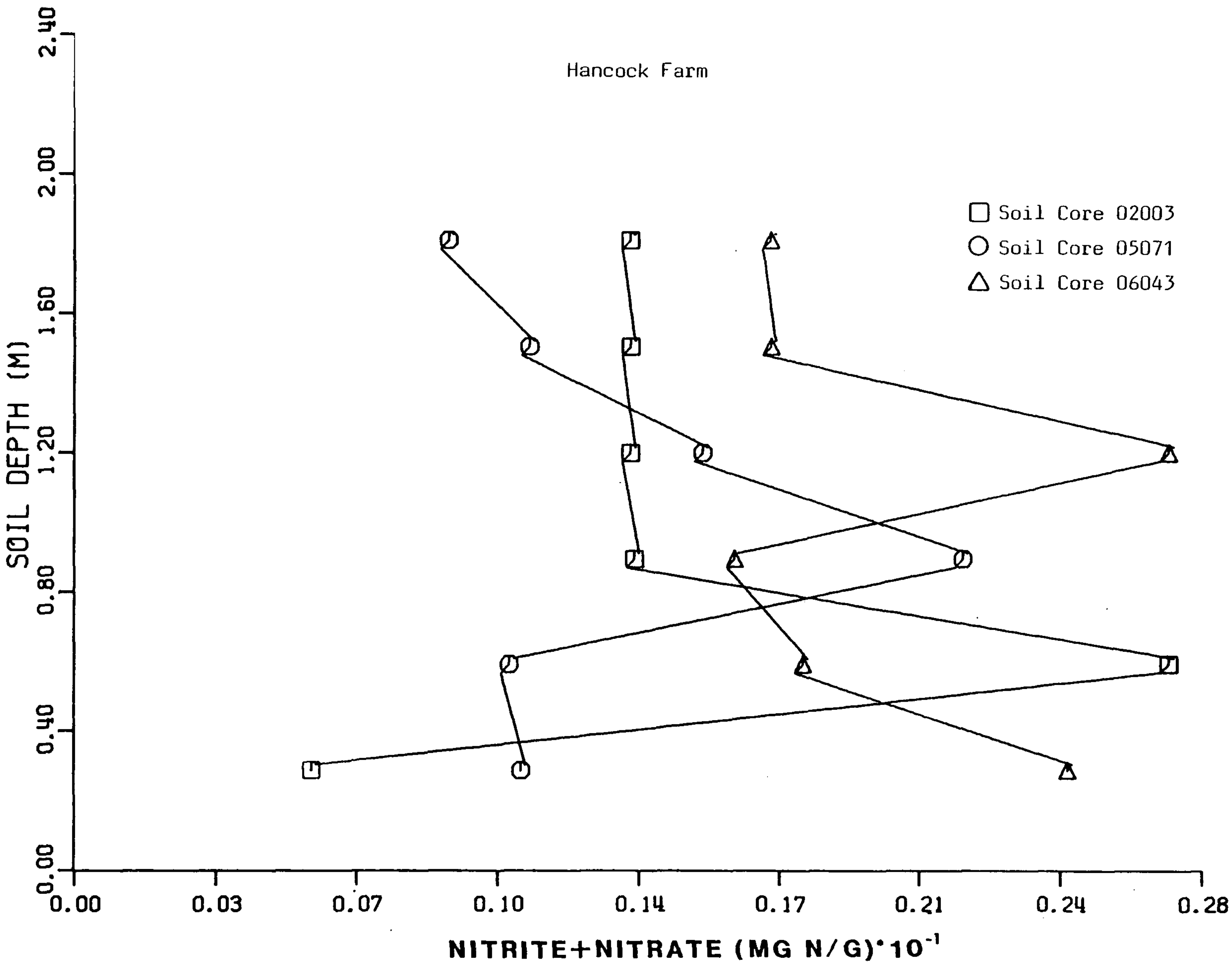

Figure 8. Illustration of Nitrite+Nitrate Lenses in Hancock Soil, 1981

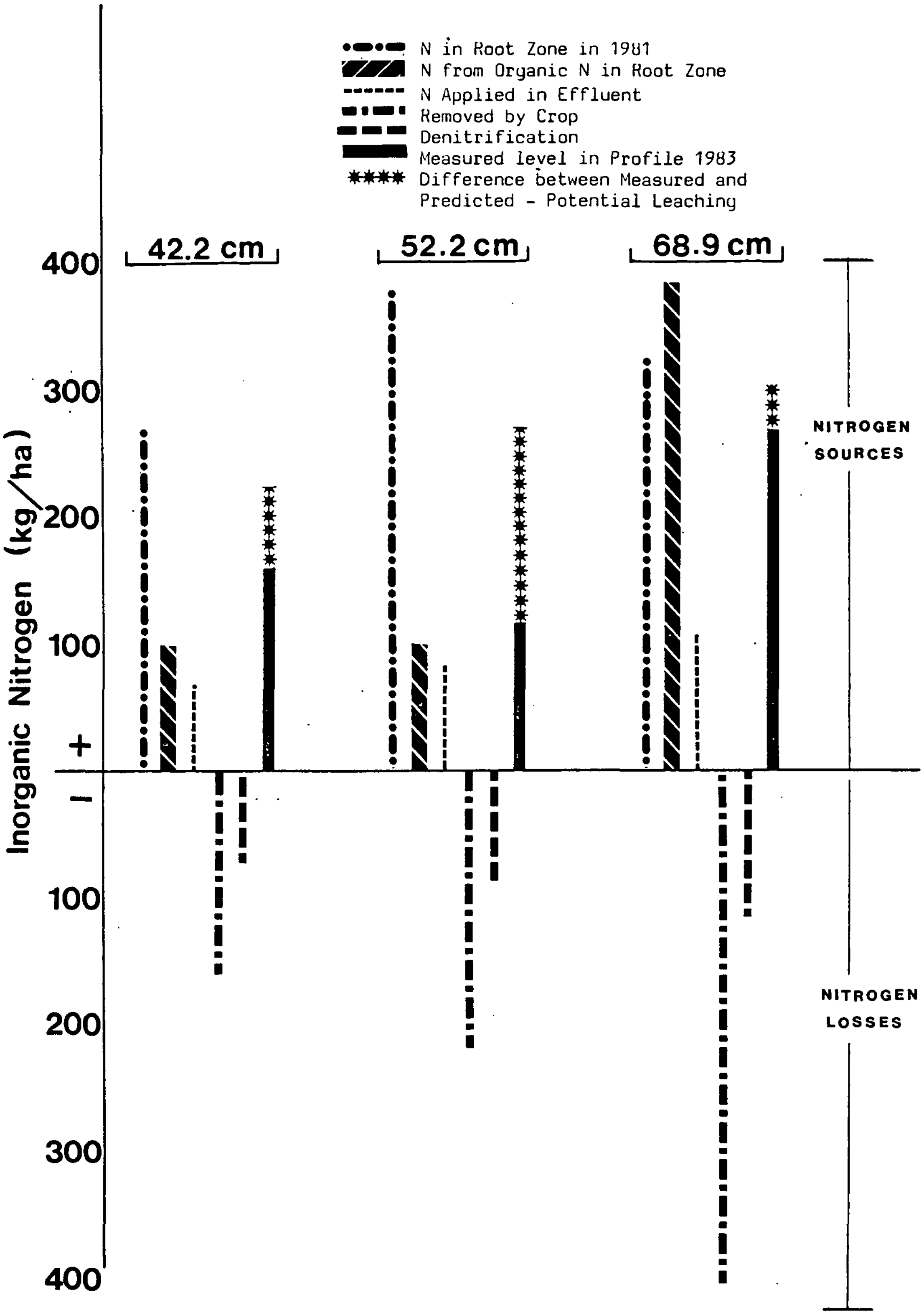

Figure 9. Inorganic Nitrogen in 183 cm Profile at the Hancock Farm

normal crop requirement of the 15 kg/ha.yr to 34 kg/ha.yr.

Minerals--In general, salts accumulated in the upper 122 cm of the profile. In the double cropped areas (68.9 cm hydraulic loading) TDS levels increased at the 152 cm and 183 cm depths, where no increase at these depths was detected in soils irrigated with less amounts of water. Assuming negligible crop uptake of salts, a mass balance of the TDS in the soil profile, indicated the majority of applied salts were retained within the 183 cm soil zone.

Sodium salts composed most of the salt load to the Hancock farm. A Na mass balance indicated that sodium was retained in the soil profile. The exchangeable sodium percentage (ESP) was approximately two in the upper 30 cm in 1981 and was increased to a maximum of six in the double cropped areas. Future use of SeWRP's effluent without proper management of sodium in the soil profile may produce sodic soil (ESP > 15) in the upper 30 cm.

Both Cl and SO_4 ions accumulated within the upper 122 cm of the soil profile. Average Cl levels ranged from 12 to 70 mg/l in soil samples collected in 1981 and 38 to 162 mg/l in soils obtained in the fall of 1983 and winter of 1984. The Cl concentration increased throughout the entire 183 cm soil profile beneath areas where the highest Cl mass loading was applied. The majority of soils analyzed contained Cl levels at the lower end of the normal range of 50 to 500 mg/l.

Trace Metals--Due to the low levels of metals in the wastewater, trace metals were not considered to pose a problem to crops or public health. A mass balance computed on the trace metals (Table 14) indicated the change in metals levels from 1981 to 1983 was not attributable to irrigation.

Priority Organics--The majority of samples analyzed for priority organics in 1981 and 1983 contained organic compounds at levels below detection levels of the analytical procedure. Atrazine, common in herbicides used on the farms, was measured in some soil samples in 1981 but was less than detection levels in 1983. Both 2,3-dichloroaniline and 3,4-dichloroaniline were detected in a few samples in the upper 30 cm of soil. These organic compounds were probably degradation products of the trifluralin herbicide which was commonly used on the farm. Benzene and chloroform

TABLE 14. METALS MASS BALANCE FOR HANCOCK FARM

	Total Mass Applied (kg/ha)	Soil Profile Mass (kg/ha) 1981	Soil Profile Mass (kg/ha) 1983	Δ in Profile (kg/ha)	Unaccounted Mass (kg/ha)	Percent Error
	a	b	c	d = c - b	e = d - a	e / (b + a)
42.2 cm						
As	0.026	108.0	170.4	+62.4	+58.8	54
Ba	0.165					
Cd	0.009	1.79	2.13	+0.34	+0.331	18
Co	0.138	56.32	91.87	+35.55	+35.41	63
Cr	0.032	317.9	206.3	-111.6	-111.6	35
Cu	0.055	147.1	93.9	-53.2	-53.3	36
Tl	0.021	24.7	22.6	-2.1	-2.1	8
Pb	0.091	64.1	81.3	+17.2	+17.1	27
Ni	0.06	288.89	172.82	-110.07	-110.13	38
Se	0.021	4.694	6.4	+1.706	+1.685	36
Zn	0.474					
52.2 cm						
As	0.32	152.55	124.30	-28.25	-28.57	19
Ba	0.203	6815	1284	-5531	-5531	81
Cd	0.012	1.750	2.688	+0.938	+0.926	53
Co	0.026	62.26	93.84	+31.58	31.55	51
Cr	0.045	377.65	158.14	-219.51	-219.55	58
Cu	0.068	140.95	75.53	-65.42	-65.49	86
Tl	0.026	22.62	12.80	-9.82	-9.84	43
Pb	0.111	71.77	72.41	+0.64	+0.53	0.7
Ni	0.073	184.8	137.8	-47.0	-47.	25
Se	0.026					
Zn	0.585	1181.0	957.9	-223.1	-224	19
68.9						
As	0.041	122.30	337.83	+215.53	+215.49	176
Ba	0.257	9532.9	1566.1	-7966.8	-7967.1	84
Cd	0.012	1.37	2.65	+1.28	+1,27	92
Co	0.034	56.37	118.37	+62	+62	110
Cr	0.054	218.35	200.00	-18.35	-18.40	8
Cu	0.087	143.08	81.29	-61.79	-61.88	43
Tl	0.034					
Pb	0.117	48.09	124.43	+76.34	+76.22	158
Ni	0.073	184.8	137.8	-47.0	-47.	25
Se	0.026					
Zn	0.585	1181.0	957.9	-223.1	-224	19

Mass Balance Computed on 91 cm of Soil

within the profile in 1981 and 1983 was most likely used as a solvent for herbicides sprayed on the land. Another solvent, tetrachloroethylene and carbon tetrachloride, was measured above detection limits in 1983. Organic compounds used as insecticides (i.e., acenaphthylene, m-dichlorobenzene, p-dichlorobenzene, and p-dichlorobenzene) were also isolated in the upper 30 cm of soil in 1981. The mass of each organic in the irrigation stream contributed very little to the mass detected in the soil profile.

Bacteriological Data--Irrigation with effluent apparently did increase the concentration of coliform bacteria in the upper 30 to 61 cm of the soil profile. Similarly, fecal streptococcus was detected in the upper 91 cm at levels greater than analytical limits in 1983 in soils collected from areas receiving 52.2 cm and 68.9 cm of treated sewage per year. Due to the frequency of isolation of fecal coliform above detection limits in samples from the irrigation wastewater and soil, fecal coliform appears to have a higher die-off rate than fecal streptococcus.

Average actinomycetes levels within the soil profile ranged from 10^9 to 10^{12} counts per gram of soil. During the irrigation period, actinomycetes within the upper 91 cm experienced a one-to-two log increase in concentration. Since an increase in actinomycetes normally follows increased bacterial and mold growth, the rise in actinomycetes indicated a general increase in biological activity in the upper 91 cm.

Crops--

In 1982 the Hancock farm was planted in three crops: sunflowers, soybeans, and grain sorghum. For late planted crops, sunflower yields were in the normal range recorded for the High Plains, 1,124 to 2,247 kg/ha (1,000 to 2,000 lbs/ac). Soybean production ranged from 2,036 kg/ha (30.2 bu/ac) under Pivot 19 up to 2,697 kg/ha (40 bu/ac) on Pivot 2 which was within the High Plains soybean range of 1,685 to 2,697 kg/ha (25 to 40 bu/ac) cited by Texas A & M Extension Service. Grain sorghum yields were less than expected and ranged from 3,307 kg/ha (2,943 lb/ac) beneath Pivot 9 to 6,691 kg/ha (5,944 lb/ac) under Pivot 19.

The 1980, 1981 and 1983 cotton yields obtained from the Hancock farm are presented in Table 15. A definite improvement in crop production was experienced in 1983. Regardless of irrigation, an increase in production was anticipated since 1983 was the only year during the study when a natural disaster did not affect crop planting and establishment. In general, cotton production in 1983 exceeded average yields obtained from irrigated land in Lubbock County.

The overall decrease of nitrogen and phosphorus in tissues from 1981 to 1983 was partially due to the failure of the irrigation stream to meet crop nutrient requirements. Originally, irrigation was expected to provide sufficient nitrogen and phosphorus to satisfy crop needs; however, due to odor problems the effluent was transported through the reservoirs before application to the soil. Nitrogen concentrations in the irrigation water were reduced from 42 mg/l to approximately 12 mg/l by passing the effluent through the reservoirs. The nitrogen reduction, in conjunction with a 50 percent reduction in the total hydraulic loading resulted in a nitrogen deficiency in many of the fields. In addition, no accumulation of trace metals appeared to have resulted from land application of the City of Lubbock's wastewater (Table 16).

Economics--

In the Lubbock land treatment situation, the Hancock farm was privately owned utilizing tenant farmers. The farm owner could not make land payment by $41,265 in 1980, $16,959 in 1981, and $45,063 in 1982; but gained $84,171 in 1983. Therefore, the landowner has experienced a four year net loss of $19,116. In addition, the tenant farmers as a group netted $30,584 in 1980, $65,564 in 1981, and $202,364 in 1983; but lost $15,584 in 1982. The farmer's operational cost did not include living expenses for the farmers. The average farmers net income during 1980 through 1983 was $70,715/yr. If each of nine tenants received an equal share of the profit then each tenant would have received an average net income of $7,857/yr for their families to live on.

A comparison of the shift in tenant farmers income between pre- and post- irrigation periods is given in Table 17. The table shows in general that the years the farmers had irrigation water (1982 and 1983) they made

TABLE 15. COTTON YIELDS, HANCOCK FARM

	1980*				1981*				1983*			
Tenant	Ha.	Ac.	kg/ha	lb/ac	Ha.	Ac.	kg/ha	lb/ac	Ha.	Ac.	kg/ha	lb/ac
Farmer A	56.7	140	70	62	56.7	140	222	198	56.7	140	615	547
Farmer B	87.8	217	137	122	143.3	354	118	105	142.5	352	579	515
Farmer C	120.2	297	234	208	172.0	425	178	158	65.6	162	676	602
Farmer E	171.2	423	100	89	213.7	528	131	117	207.2	512	560	498
Farmer F	100.8	249	85	76	100.8	249	274	244	50.6	125	740	659
Farmer G	82.2	203	417	371	82.2	203	316	281	82.2	203	572	509
Farmer H	116.1	287	393	350	116.1	287	196	174	116.1	287	353	314
Farmer I	87.4	216	109	97	87.4	216	246	219	29.9	74	597	531
Lubbock County***			156*				373*				(312)*	
Lubbock County***											395**	

* Dryland
** Irrigated Land
*** Texas A & M Extension Service, Lubbock, Texas

TABLE 16. ELEMENTAL SHIFTS IN COTTON TISSUES OBTAINED FROM HANCOCK FARM 1981 vs. 1983

Concentration 1981 > 1982	Concentration 1981 1983	Concentrations 1981 < 1983
TKN Stalk	TKN Seed	
TP Stalk	TP Seed	
Ca Stalk	K Seed	
Ca Seed	Fe Stalk	
K Stalk	Fe Seed	
Na Stalk	Ba Seed	
Na Seed	Cr Stalk	
Cd Stalk	Cu Seed*	
Cd Seed	Cu Seed**	
Cu Stalk		
Cu Stalk		
Pb Stalk		
Pb Seed		

* Overall the same but one or two sharp rises or drops show inconsistency in trend

** Pivots 3 and 11 show substantial drops but overall trend is same or a little increase

TABLE 17. COMPARISONS OF SHIFT IN FARMERS' INCOME PRE-EFFLUENT TO POST-EFFLUENT

	1980 + 1981 Net Average $Income/acre	1982 + 1983 Net Average $Income/acre*	Pre to Post Irrigation $Net acre/yr*
Farmer A	-5.22	+66.58	+71.37
Farmer B	+2.82	+56.57	+59.39
Farmer C	-0.59	+ 0.32	+ 1.22
Farmer D	-9.83	---	---
Farmer E	-0.96	+21.40	+22.36
Farmer F	-9.01	+105.20	+114.21
Farmer G	+15.72	+15.34	+ 9.63
Farmer H	+42.30	-44.79	+ 2.49
Farmer I	+25.58	+89.05	+63.48

*$/acre x 2.17 = $/hectare

more net income per hectare than the baseline period (1980 and 1981) when there was no effluent water applied. All of the farmers had a positive four year average net income primarily due to the income received in 1983.

The City of Lubbock paid for all costs associated with the treatment of the municipal wastewater and transporting the treated sewage to the Hancock farm. Assuming Lubbock paid 15 percent of the construction costs, the City's cost per 1000 m^3 would have been $98 ($0.37/1000 gal) and $83 ($0.31/1000 gal) for 1982 and 1983, respectively.

LUBBOCK INFECTION SURVEILLANCE STUDY (LISS)

The rectangular area within 4.8 kilometers (3 miles) to the north, 4.0 km (2.5 mi) to the south, and 3.2 km (2 mi) to the east and west of the perimeter of the spray irrigation rigs on the Hancock farm was designated as the study area. This area, which includes the small city of Wilson, Texas and the rural areas north, northwest, and northeast of Wilson, was divided into six sampling zones (Figure 10). The rectangular Zone 1 included all rural households located on the Hancock farm and within 0.5 miles of its perimeter. Zone 2 contained the households located within 0.5 miles of the Hancock site boundary within Wilson. Included in Zone 3 were all rural residences located from 0.5 to 1.0 (E and W) or 1.5 (N or S) miles from the Hancock farm. Zone 4 consisted of the Wilson households which were located 0.5 to 1.0 miles from the site. Zone 5 contained the rural households which were located from 1.0 or 1.5 to 2 miles (E and W), 2.5 miles (S) and 3 miles (N) of the Hancock farm boundary. Zone 5 was extended to approximately 3 miles north of the farm due to the prevailing southerly winds. The households of the small number of Hancock farm workers who resided outside the study area were placed in Zone 6.

The LISS monitored four major periods of wastewater irrigation at the Hancock farm. These periods were termed spring 1982 (February 16-April 30,1982), summer 1982 (July 21-September 17, 1982), spring 1983 (February 15-April 30, 1983) and summer 1983 (June 29-September 20, 1983). The quality of the wastewater used for irrigation varied substantially by irrigation period. All of the irrigation wastewater was obtained via pipeline

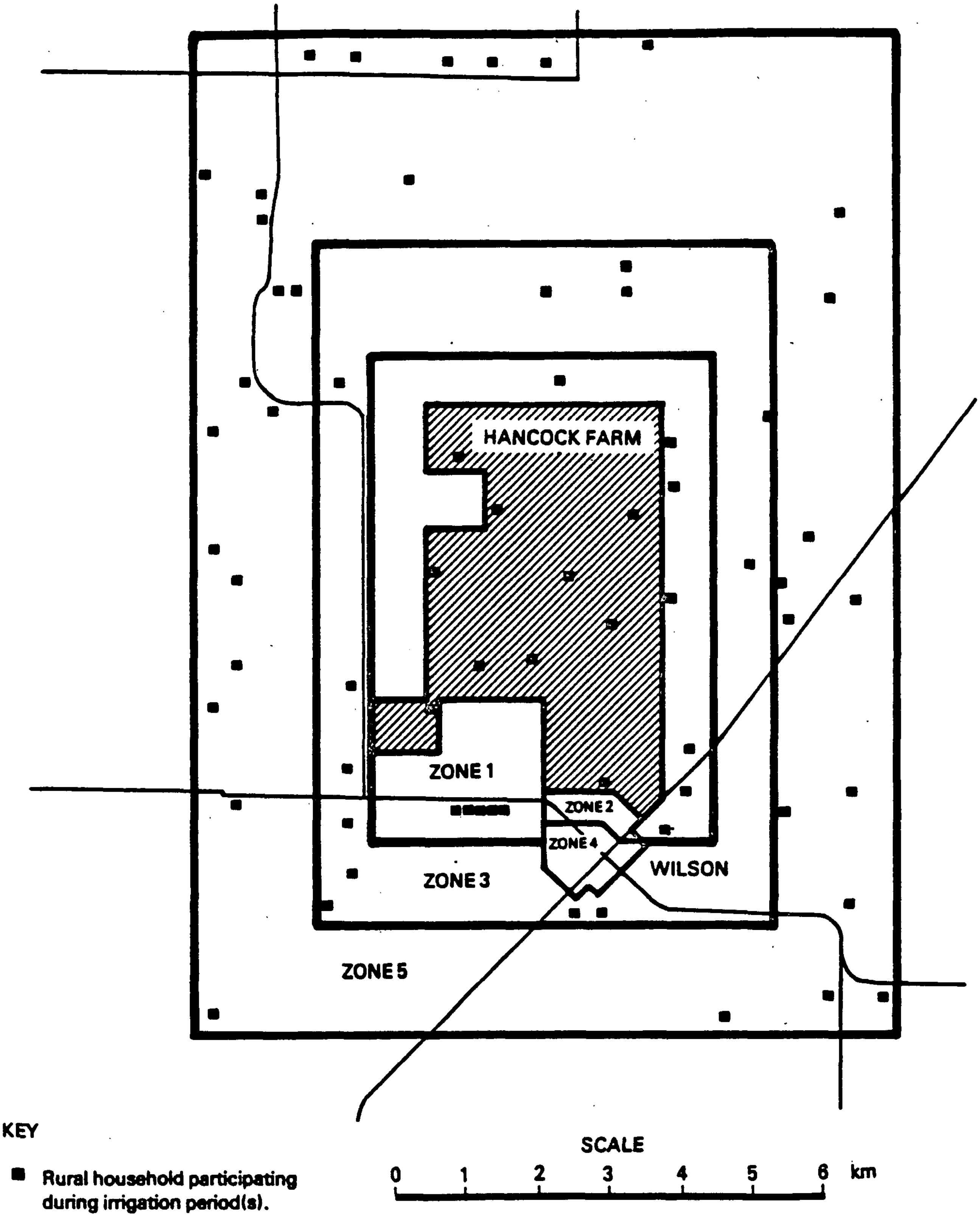

Figure 10. Sampling Zones Comprising the Study Area

directly from the Lubbock SeWRP in the spring 1982 irrigation period, since operation of the reservoirs had not been approved at that time. The quality of this pipeline effluent was similar to that of a low quality primary effluent. Pipeline wastewater comprised 64%, 0% and 1%, respectively, of the total applied by spray irrigation in the summer of 1982, spring of 1983, and summer of 1983 irrigation periods. There was some improvement in the pipeline wastewater quality during summer 1982 and spring 1983, but it did not reach the quality expected of secondary effluent until summer 1982. Reservoir wastewater was more consistently of secondary effluent quality in all three of these periods. This observation is important, since the majority of irrigation wastewater used during 1982 came via pipeline directly from the SeWRP, while essentially all the wastewater applied during 1983 was from the irrigation reservoirs.

The wastewater utilized at the Hancock farm contained a broad spectrum of enteric bacteria and viruses. Spray irrigation of wastewater received via pipeline directly from the Lubbock SeWRP was found to be a substantial aerosol source of each group of microorganisms monitored in the aerosol sampling (i.e., fecal coliforms, fecal streptococci, mycobacteria, Clostridium perfringens, coliphage, and enteroviruses). Microorganism levels in air downwind of spray rigs using pipeline wastewater were found to be significantly higher than upwind levels: fecal streptococci levels to at least 300m downwind, and levels of fecal coliforms, mycobacteria and coliphage levels to at least 200 m downwind. The downwind levels were also significantly higher than the background levels in ambient air outside the home of participants. Fecal coliform levels were higher than background levels to beyond 400 m downwind, mycobacteria and coliphage levels to at least 300 m downwind, and fecal streptococci levels to at least 200 m downwind. Operation at night and at high wind speeds appeared to elevate microorganism levels to greater downwind distances. Enteroviruses were recovered in the aerosol at 44 to 60 m downwind of irrigation with pipeline wastewater on each of four virus runs. The geometric mean enterovirus density in air was 0.05 pfu/m^3, although a much higher density (17 pfu/m^3) was sampled on one run in August 1982. Spray irrigation of reservoir wastewater was also found to be a source of aerosolized fecal coliforms, fecal streptococci and coliphage, sometimes to downwind distances of at least 125 m.

Since microorganisms densities were much higher in the wastewater from the pipeline than from the reservoirs, the exposure which most of the study population received to most microorganisms via the wastewater aerosol was greater in 1982 than in 1983. The irrigation period in which aerosol exposure at a given distance downwind was estimated to be highest was: summer 1982 for enteroviruses, summer 1982 for fecal coliforms, and spring 1982 for fecal streptococci. For each of the microorganism groups with adequate aerosol and wastewater monitoring data, summer 1982 was the irrigation period when most of the more highly exposed study population received either their largest or their second largest cumulative dose from the wastewater aerosol.

Findings from Self-reported Illness Data

Disease surveillance did not disclose any obvious connection between illness and degree of wastewater exposure. Self-reports of illness are always subject to respondent bias. Nevertheless, the participants in the high exposure level (AEI>5) reported the highest rate of illness shortly after the onset of wastewater irrigation, both in spring 1982 and in summer 1982. The excess total acute illness among high exposure level participants over the spring 1982 irrigation period occurred primarily during February 14-27, 1982, in the initial two weeks of wastewater irrigation. The high exposure level participants also reported a significant excess of total acute illness in August 1982, primarily during August 15-28 (after more than three weeks of wastewater irrigation had elapsed). The high exposure level participants did not report a comparable excess of acute illnesses during either irrigation period in 1983. This pattern of excess illness during both irrigation periods in 1982 is consistent with the hypothesis of an association of illness with exposure to wastewater irrigation: the pattern appeared both upon initial wastewater exposure and in the summer 1982 irrigation period which produced highest exposure to microorganisms in the wastewater aerosol. However, the patterns did not persist throughout either irrigation period in 1982. In addition, the effects of known risk factors such as age and social economic status have not been taken into account. A small excess rate of illnesses might have been associated with the initial and heaviest periods of microorganism emission from wastewater irrigation. Since the agents which the LISS monitored clinically and serologically show a very high proportion of asymptomatic infection, it is difficult to correlate the findings for self-reported illness with those for the clinically and serologically detected infections.

Findings from Seroconversion Incidence Densities

An overview of the association of serologically detected infections with exposure to wastewater aerosols was obtained by comparison of the seroconversion incidence densities for serum donors in the three levels (or two groups) of aerosol exposure, for both the entire baseline (June 1980-January 1982) and the entire irrigation (January 1982-October 1983) periods of observations. The high exposure level participants had a higher incidence density of coxsackievirus B4 infections versus intermediate level participants during the entire irrigation period. In contrast, participants in the high exposure level had no elevated infection incidence density to specific agents in the baseline period. Based on test-based 95% confidence intervals for the crude incidence density ratios, the high exposure group (AEI$\geq$3) had a significantly greater incidence of infections to coxsackievirus B2 and echovirus 11 over the irrigation period, but a significantly greater infection incidence only to one agent, echovirus 9, during the baseline period.

During the baseline period, individuals in the high exposure level had the lowest infection incidence densities of the three exposure levels to all of the adenoviruses tested, to all coxsackie B viruses tested, and to all echoviruses tested. In the irrigation period, individuals in the high exposure level had the highest incidence densities of infection by all coxsackie B viruses tested and by all echoviruses tested. Moreover, in the irrigation period the high exposure level also had the highest incidence density of infections to all of the tested viruses which had been recovered from the irrigation wastewater. These crude incidence densities suggest a probable association between seroconversions (especially to viruses recovered from the wastewater) and wastewater aerosol exposure. The crude incidence density ratios of the high exposure level to the intermediate and low exposure levels during the irrigation period were 1.8 and 1.5, respectively, for the viruses recovered from the wastewater, indicating some excess risk of viral infection from wastewater aerosol exposure.

Evidence of Association of Specific Infection Episodes with Wastewater Aerosol Exposure

Specific infection episodes which displayed good or marginal evidence of association with wastewater aerosol exposure were identified by comparison of results from four methods of investigation; i.e., confirmatory statistical analysis, exploratory logistic regression (ELR) analysis, confidence intervals of incidence density ratios, and risk ratio scoring.

Some excess risk of viral infection was associated with wastewater aerosol exposure, based on comparison of crude seroconversion incidence densities by aerosol exposure level and by irrigation vs. baseline period. A symmetric risk ratio score approach provided evidence of a stable and dose-related association between infection events and wastewater aerosol exposure in the infection episodes observed by the LISS. Furthermore, some infection episodes appear to have been related to wastewater aerosol exposure, because more statistically significant associations than expected were found in the confirmatory analysis of independent infection episodes using a one-sided Fisher's exact test. An exploratory logistic regression analysis found significant ($p<0.05$) associations between presence of infection and degree of aerosol exposure while controlling for the effects of extraneous variables in four infection episodes.

Additional evidence was considered regarding recovery of the infectious agent from the irrigation wastewater, seasonal correspondence of the infection response to aerosol dose, association with contaminated drinking water, alternative risk factors identified by ELR, and within-household transmission of infections. The eight infection episodes with good or marginal evidence of wastewater aerosol exposure association were placed in three categories based on the likelihood of causal association of the infection events with wastewater aerosol exposure:

1) More plausible alternative explanation identified:

- o Episode of Klebsiella infections in summer 1983

  --alternative: eating food prepared at local restaurant A
- o Spurious control episode of echovirus 9 seroconversions in the baseline period

  --alternative: within-household spread

2) Both aerosol exposure and identified alternative explanation(s) are plausible risk factors (evidence inconclusive):

- o Episode of clinical viral isolates excluding adenoviruses and immunization-associated polioviruses in summer 1982

  --alternative: eating food prepared at local restaurant A
- o Episode of echovirus 11 seroconversions in 1982

  --alternatives: o contaminated drinking water

  o caucasian, large household
- o Episode of seroconversions to viruses isolated from wastewater in summer 1982

  --alternatives: o contaminated drinking water

  o low income, caucasian
- o Episode of seroconversions to viruses isolated from wastewater in 1982

  --alternative: farmer, history of pneumonia
- o Episode of seroconversions in summer 1982 to all serum neutralization-tested viruses

  --alternative: contaminated drinking water

3) Strong evidence of aerosol exposure association and no alternative explanation identified:

- o Episode of poliovirus 1 seroconversions in spring 1982

All five of the infection episodes in Category 2 relate primarily to echo or coxsackie B viral infections observed in summer 1982 and to agents recovered from the wastewater at that time. Hence, it is reasonable to consider these to be five manifestations of a single nonpolio enterovirus episode centered on the summer 1982 irrigation season. With the heavy rainfall, widespread drinking water contamination and other unusual circumstances which occurred during this summer, it is not surprising that fragmentary evidence of various alternative explanations surfaced for this nonpolio enterovirus episode.

All the evidence, however, supports the finding that the episode of poliovirus 1 seroconversions in spring 1982 was associated with wastewater aerosol exposure. The results indicate that a general association between exposure to irrigation wastewater and new infections existed for 1982. However, even during 1982, the strength of association remained weak and frequently was not stable. Wastewater, directly from the pipeline, comprised much of the irrigation water in 1982. The isolation of enteroviruses from pipeline wastewater was greater than that observed with the wastewater that had been retained in reservoirs. The methods employed resulted in the observation of a large number of infection episodes, none of which resulted in serious illness. The voluntary nature of participation and the unrepresentative circumstances of the study area make generalization of the results unwise. A larger sample size with greater comparability of the exposure groups on the basis of drinking water sources and frequency of visiting the same eating establishments would have reduced their confounding effects.

From the public health standpoint, the lack of a strong, stable association of clinical illness episodes with the level of exposure to irrigation wastewater indicates that wastewater spray irrigation produced no obvious disease during the study period. However, when more sensitive indicators of infection were used, a general association was found to exist, especially for 1982. A particular concern is that statistical interpretation of the data indicates that the poliovirus 1 seroconversions were probably related to wastewater aerosol exposure during the spring of 1982, even when the effects of polio immunization were controlled. Because of the low prevalence of poliovirus antibody observed during the baseline period, the study population was immunized, and thus was probably better protected against polio than other rural populations.

PERCOLATE INVESTIGATION IN THE ROOT ZONE (PIRZ)

Percolate Quantity

During the PIRZ study several problems such as flooding of service manholes, improper vacuum system performance, inflexibility in irrigation schedule, etc., limited the amount of percolate quantity and quality data obtained from the root zone investigation. Therefore the objectives of the PIRZ study were not achieved. The percentages of the design irrigation application rates that were actually applied in 1982 to bermuda, cotton and grain sorghum were 27 percent (99 cm), 114.6 percent (57 cm) and 98.2 percent (99 cm), respectively, at the Hancock site; and 26.1 percent (97 cm), 83.5 percent (38 cm) and 60.7 percent (48 cm) at the Gray site. Only 25 of the 41 lysimeters on the Gray site contributed percolate during the five months of the 1982 growing season. At the Hancock site, 26 of the 46 units had contributed percolate by the end of September.

With increased amounts of irrigation in August and September and with decreased evapotranspiration requirements due to crop maturity during the latter part of the growth period, percolate flow increased in lysimeters on the crop plots. The increase of moisture in the soil profile during the fall of 1982 led to decreased air leakage in the vacuum systems at all manholes and reduced daily vacuum pump operations. In late November and during December, the number of lysimeters contributing percolate began to increase at both sites. Fall irrigation, fall precipitation, and decreased evapotranspiration improved soil moisture conditions in the profile and subsequently led to percolate generation. During the 1983 growing season, the percentages of the design application rates actually applied to the plots for the bermuda, cotton and grain sorghum at the Hancock site were 44.8 (164 cm), 17.5 (9 cm) and 18.4 (19 cm) percent, respectively. At the Gray site, the respective rates were 15.7 (55 cm), 46.6 (21 cm) and 24.4 (19 cm) percent of design loadings for bermuda, cotton and grain sorghum. Failure to apply the design hydraulic loading had a major impact on percolate collection amounts during the 1983 season. The amounts of percolate captured by the lysimeters at the Hancock and Gray sites during the study period are presented in Tables C.3 and C.4. In September 1983 the bermuda and cotton test plots were flood irrigated with approximately 40 cm of water. The tray lysimeters on the bermuda plot at the Hancock site were kept operative until November 16, 1983. Percolate was collected from the three trays at the 61 cm depth and two trays at the 183 cm depth. The depths of percolate collected by these trays in November were:

Tray	Depth in mm
108	<1
102	4.6
103	5.3
108	4.2
109	19.4

Tray 109 had contributed percolate in only one previous event over the project period. If the water had been in the profile, there was a possibility that more lysimeters would have contributed during the study period.

Percolate Quality

Many of the water quality samples were of such small volume that only a few parameters could be measured. Comparison of the geometric means of parameter concentrations generally revealed a decrease in nutrient levels in the percolate samples. Levels of total Kjeldahl nitrogen, ammonia nitrogen, total phosphorus, orthophosphate phosphorus, and organic phosphorus decreased by a factor of 10 or greater. The levels of nitrite plus nitrate-nitrogen (NO_2+NO_3) increased in the percolate. Most of this nitrogen was assumed to be in the form of nitrates. The increase in concentration of nitrate resulted from the oxidation of the other nitrogen compounds present in the applied wastewater as well as from the mobilization by the percolate of nitrates stored in the profile.

Examination of sample data sequentially taken over the project period showed a general decrease in the concentrations of the chemical constituents recorded as the total volume of percolate collected by the unit increased. This was easily noticeable in sample values obtained over time for TDS, NO_3 (Figure 11), NH_3, TP, and PO_4. Decreases in conductivity, Cl, and

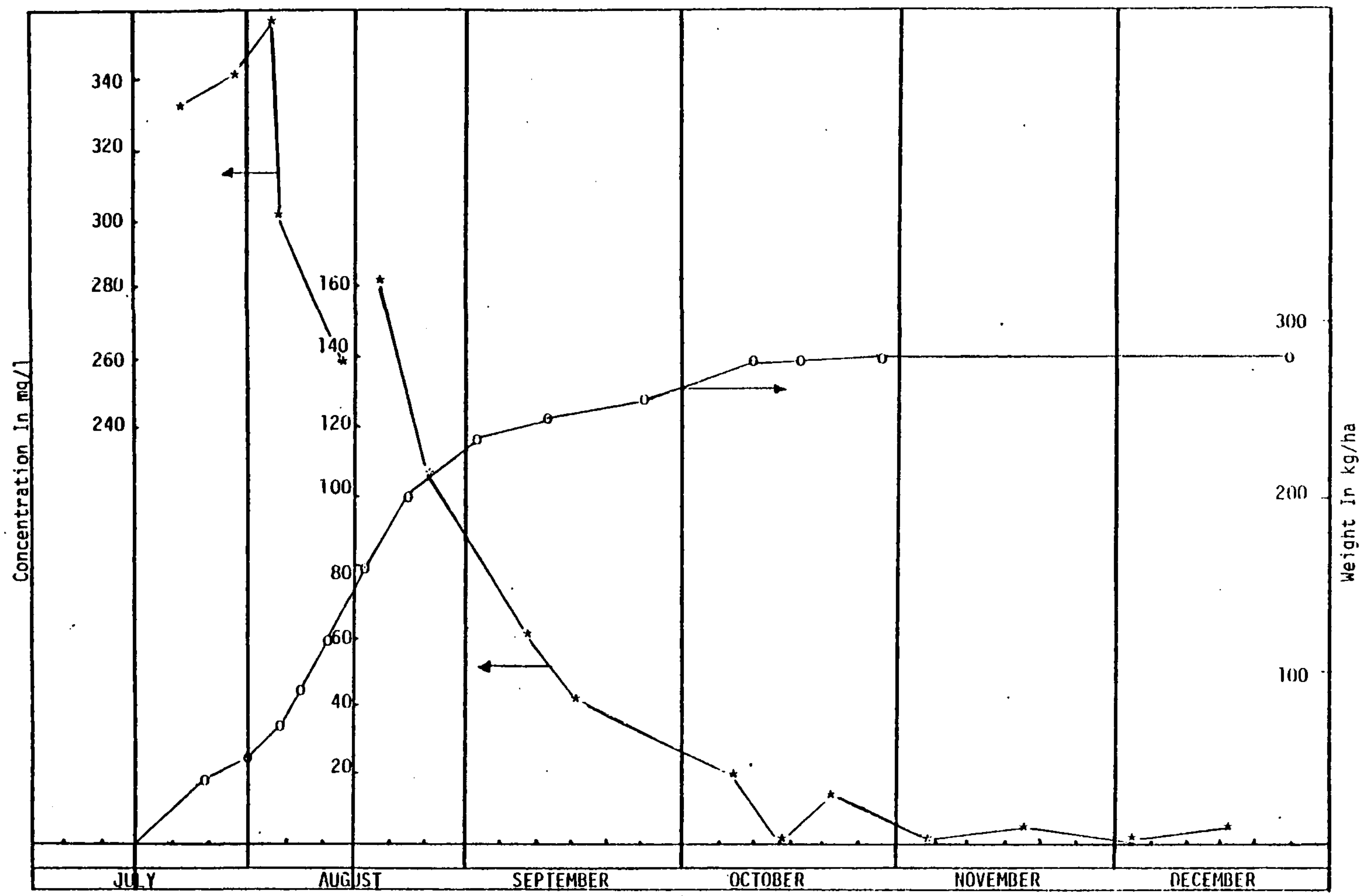

Figure 11. Variation of Nitrate Concentration in Percolate and Accumulated Weight of Leached Nitrate in kg/ha with Time for Tube 123 from July through December 1982

SO_4 also occurred during the monitoring period.

Soils

Nitrogen and Phosphorus--

As observed in the Demonstration/Hydrogeologic Study, organic nitrogen was the primary nitrogen form in the soil profile. The increase in soil moisture at the Hancock test site resulting from irrigation created favorable conditions for the mineralization of organic nitrogen and consequently a decrease in organic nitrogen. At the Gray site, the average TKN of the three plots at the 90 cm depth for each sampling period showed little change.

Nitrate-nitrogen was the major inorganic nitrogen form present in the soils at both test sites. The nitrate content in the soil profiles at the Hancock site were generally higher at both the start and end of the project than the levels measured at the Gray test site. The higher initial nitrate levels at the Hancock test site probably resulted from the drier soil conditions which historically have been experienced at this site. The drier soils will retain water-soluble nitrogen forms until excess soil water is available to leach them from the profile. The average profile nitrate content for the three sampling periods in the top 90 cm showed a general decrease over time. High concentrations of nitrates were found in the initial percolate volumes intercepted by many lysimeter units.

Average orthophosphate phosphorus values in the profile decreased over the project period in the upper 90 cm depth at both sites. The addition of this nutrient in the irrigation water would have offset some of the losses caused by vegetative growth. The total phosphorus consumed by the crops was less than the amount applied in the irrigation water; therefore, a portion of the orthophosphate was transformed to more insoluble compounds.

Priority Organics Pollutants--

The composition of the project soils at the beginning and end of the project period showed reductions in most of the priority organics measured at both sites. Increases had occurred in the concentration of nine compounds: carbon tetrachloride, dibutylphthalate, hexadecane, methylheptadecanoate, methylhexadeconate, octadecane, phenol, propazine, and tetrachlorethylene. The greatest increase in the soil profile occurred in the levels of carbon tetrachloride, hexadecane, and dibutylphthalate. The two former compounds are solvents. The wastewaters pumped to the Hancock site during the project period contained an average concentration of 4.7 μg/l for carbon tetrachloride (0.145 kg/ha); <2.0 μg/l for hexadecane (0.05 kg/ha); and 104 μg/l for dibutylphthalate (2.6 kg/ha). In water going to the Gray site the values were 3.2 μg/l for carbon tetrachloride (0.066 kg/ha) and 140 μg/l for dibutylphthalate (1.98 kg/ha).

Bromide--

Sodium bromide was applied to the surface of the sub-plots annually in order to trace the movement of percolate through the soil profile. In 1982, the bromide moved about 1.5 cm down through the profile for each centimeter of water applied at this site. Variability in movement was much greater at the Gray site. The bermuda sub-plot, with a much larger hydraulic loading, showed a bromide ion accumulation in the 60 and 90 cm level which corresponded to the depth of the indurated caliche layer. The movement of bromide on the other two plots was approximately 1.95 cm per centimeter of applied water.

In the fall of 1983, the cotton and grain sorghum sub-plots still had bromide present in the surface layer. Some translocations were evident in the bermuda plots because of the heavier hydraulic loading on these plots. At the Gray test site, the effect of the caliche layer on the bromide was evidenced by build-up of bromide in the 45 to 60 cm layer on the bermuda plots.

AGRICULTURAL RESEARCH STUDIES

Hydraulic Loading Study

Crops--

Crop yield data indicated grain sorghum yields increased as treated wastewater hydraulic loading increased to approximately 3 m.ha/ha.yr. Average cotton lint yields obtained from test plots irrigated with 122 cm.ha/ha.yr to 297 cm.ha/ha.yr ranged from 1,300 to 1,538 kg/ha. Cotton test plots having less than 122 cm.ha/ha.yr of treated sewage applied produced an average lint yield of 100 to 925 kg/ha. In general alfalfa irrigated with 365 and 434 cm.ha/ha.yr of treated sewage generated the highest yields during each cropping period. Furthermore, the alfalfa production was greatest during the month of June. Common bermuda grass production in test plots receiving treated sewage was greater than dryland plots. During June and September 1983, the highest bermuda yield (9368. $\pm$ 2327. kg/ha) was harvested from the lowest annual effluent hydraulic loading of 152 cm.

Chemical analysis of the bermuda plant tissue indicated that the crop had several macro and micro nutrient deficiencies. With the shallow root system of bermuda increased irrigation may have leached nitrogen past the root zone; thereby, limiting nitrogen availability to the crop. Other nutrients such as phosphorus, zinc, potassium and iron appeared to be deficient in the bermuda tissue.

Grain sorghum and cotton tissue experienced less nitrogen content in 1983 compared to 1982. Protein content in alfalfa ranged from 24 to 28 percent. Alfalfa irrigated with 137 cm.ha/ha.yr or greater contained more than 26 percent protein. Phosphorus and potassium, however, may have been deficient in the alfalfa tissue.

Soils --

Soil texture within the upper 30 cm (1 ft) of the soil profile were generally sandy clay loam. Clay to clay loams dominated the soils from a depth of 30 cm to 122 cm (4 ft) within the profile. The majority of soils from 122 cm to 183 cm (6 ft) were clays. Cation exchange capacities (CEC) within the test plots were greater than 20 meq/100 g (average 23.6 meq/100 g $\pm$3.3) which were characteristic of the clay/clay loam soils.

Nitrogen--As observed throughout the Hancock farm, organic nitrogen was the primary nitrogen from within the soil profile. In general, nitrate nitrogen was the major form of inorganic nitrogen. Leaching of inorganic nitrogen past a soil depth of 91 cm appeared to have occurred as annual hydraulic loadings of 61 cm or greater within the cotton test plots (Figure 12). Nitrogen mass balances indicated that nitrates were leached beyond 183 cm of soil in cotton, grain sorghum and bermuda test plots irrigated with 122 cm.ha/ha.yr or greater.

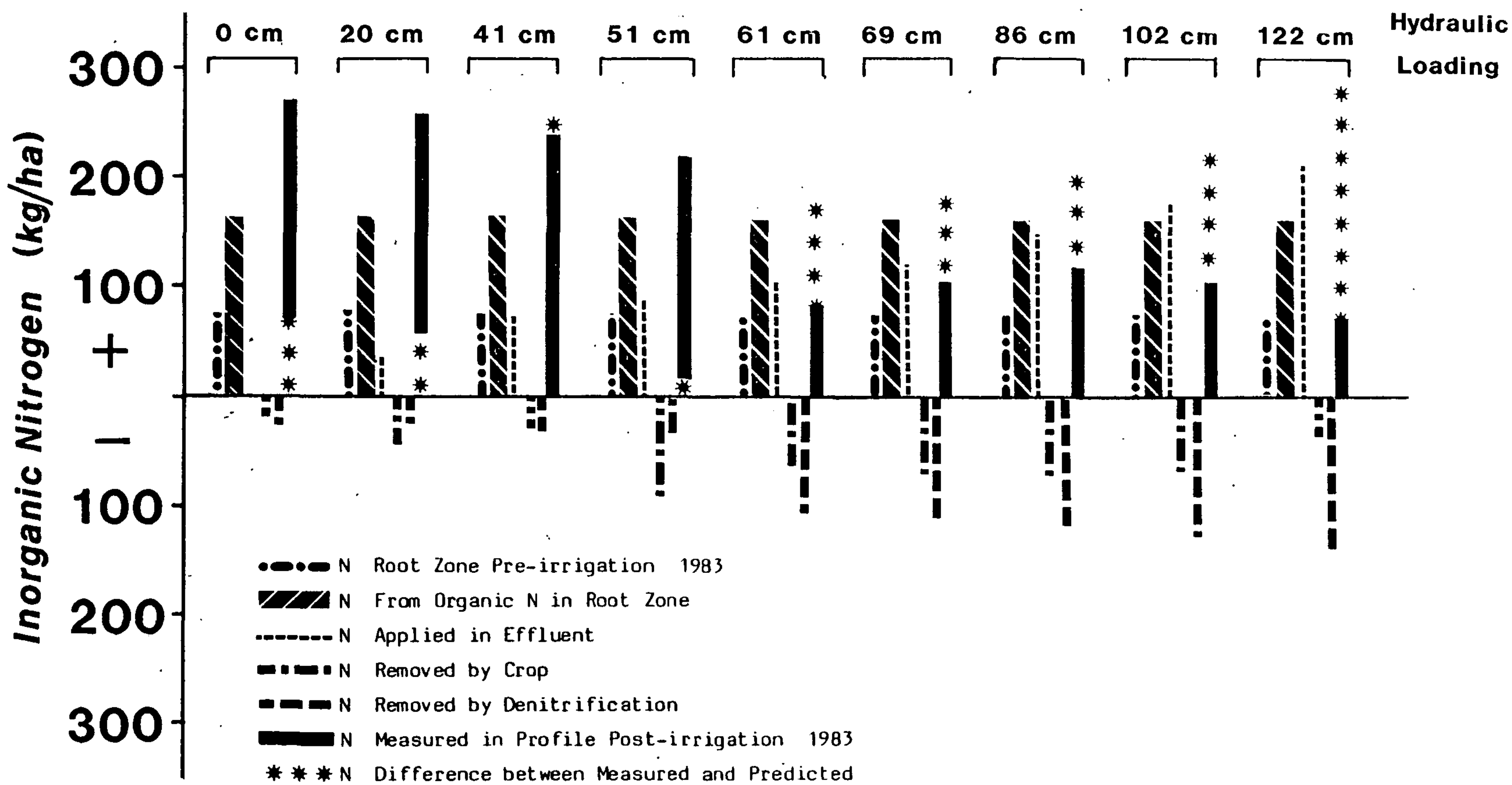

Figure 12. Nitrogen Mass Balance for Trial 14000 Cotton Plots

All nitrogen mass applied to the alfalfa plots, however, was consumed and nitrogen fixation was a source of inorganic nitrogen for the crop (Figure 13). Nitrite plus nitrate-nitrogen (NO_2+NO_3) lenses were measured beneath the entire research area. NO_2+NO_3 levels decreased with depth as hydraulic loadings increased. Inorganic nitrogen apparently was not leached beyond depth of 183 cm.

Minerals--Accumulations of total dissolved solids (TDS) were limited through leaching of TDS through the soil profile in test plots irrigated with 122 cm.ha/ha.yr or more. In the grain sorghum plots the exchangeable sodium percentage (ESP) was less than seven in the top 30 cm of soil. As the annual hydraulic and salt mass loading increased in the cotton plots (122 cm.ha/ha.yr to 297 cm.ha/ha.yr) and alfalfa test plots (137 cm.ha/ha.yr to 434 cm.ha/ha.yr) the ESP values within the top 30 cm of soil increased. In the fall of 1983, the ESP values within the top 30 cm of soil collected from cotton test plots irrigated with 183 cm and 297 cm/yr were 9.2 and 8.1, respectively. ESP levels were less than 10 within the upper 61 cm of soil. Sodic conditions may have existed within the upper 30 cm of the plots irrigated with 434 cm/yr. High water consumption of alfalfa caused accumulations of sodium within 1.8 m of the soil profile at scheduled hydraulic loadings of 137, 198, and 259 cm/yr.

Hydraulic Application Frequency Study

Crops--

Yield data (Figure 14) indicated soybean production was highest with more frequent wastewater application (i.e., one irrigation/week and one irrigation/2 weeks); whereas, grain sorghum yields were significantly higher with longer periods between irrigation (1 irrigation/4 weeks and 1 irrigation/8 weeks)(Figure 15). Soil moisture within the profile corresponded to the type of root system. Less soil moisture was measured beneath the grain sorghum at soil depths of 122, 152, and 183 cm. These soil moisture differences possibly were due to: (1) the more extensive grain sorghum root system and (2) the fact that growing season for soybeans ends with a complete shutdown of the plant while the milo plants stay green and continue to extract moisture from the soil until frost kills the crop.

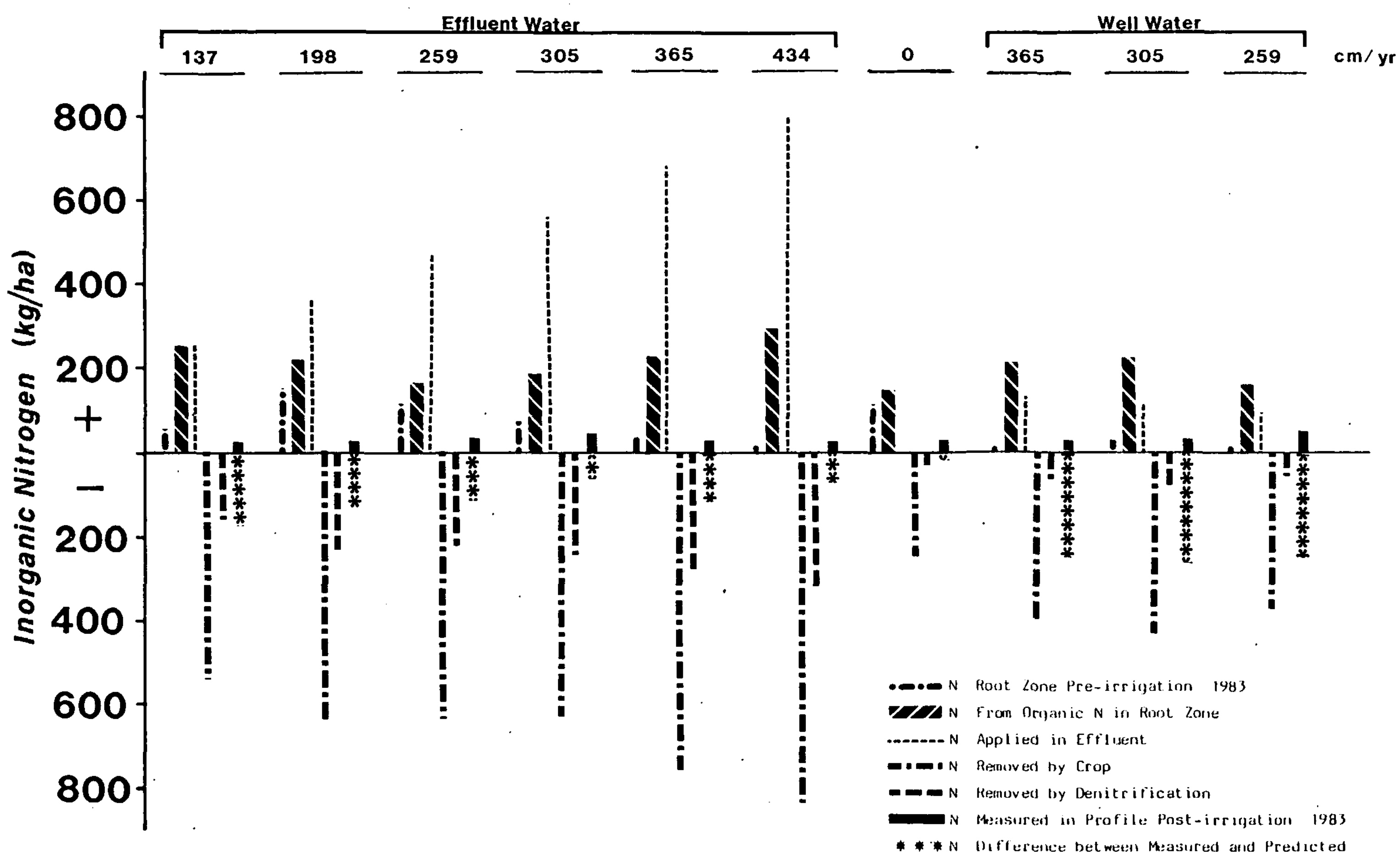

Figure 13. Nitrogen Mass Balance for Trial 16000 Alfalfa plots

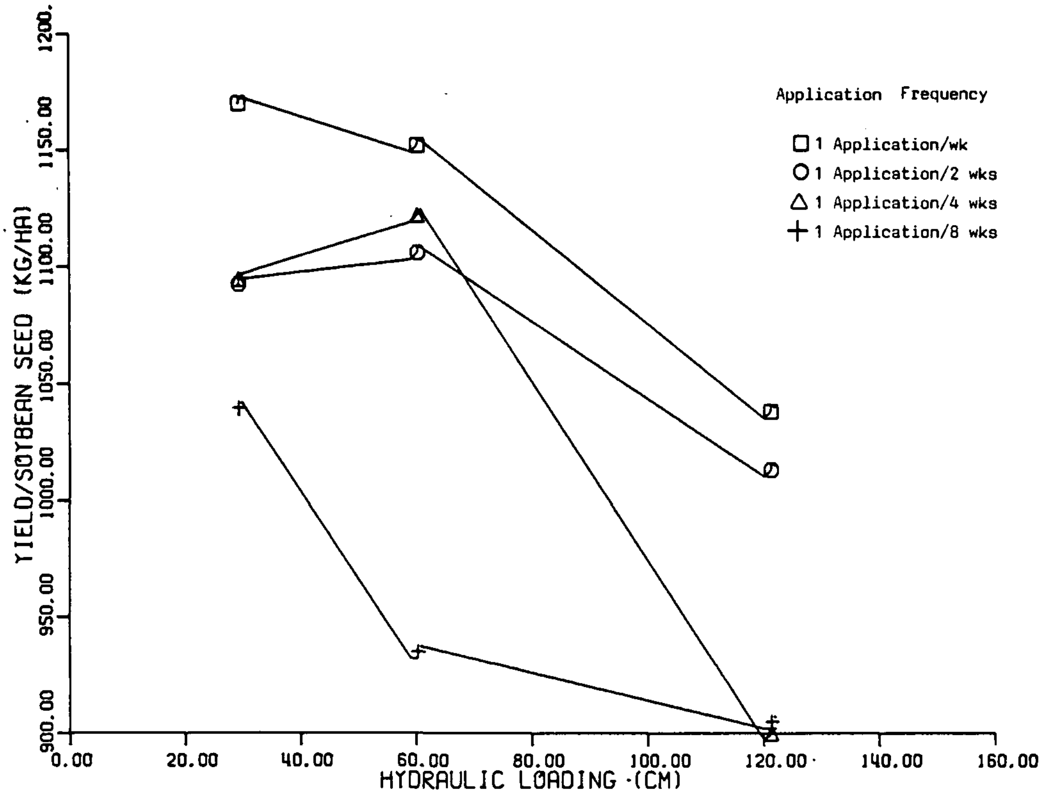

Figure 14. Soybean Seed Yield vs Hydraulic Loading - Trial 17000

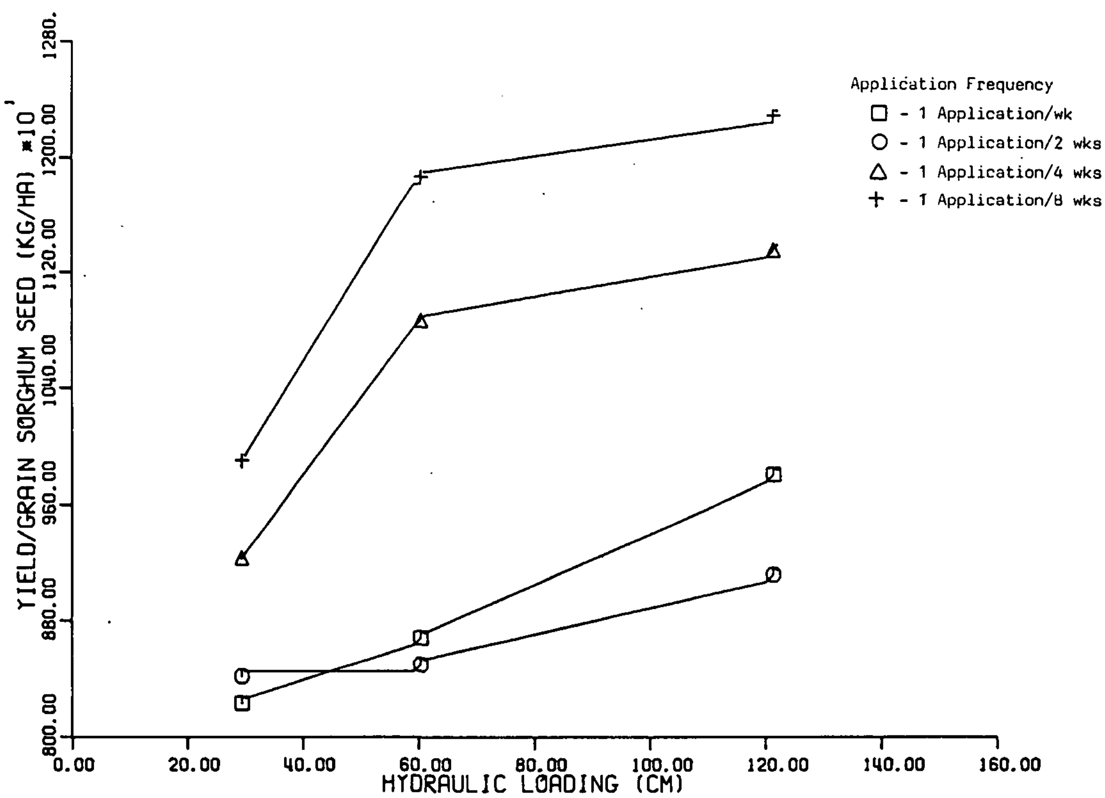

Figure 15. Milo Whole Plant Yield vs Hydraulic Loading - Trial 17000

At an annual hydraulic loading of 30 cm/yr, symbiotic nitrogen fixation apparently provided inorganic nitrogen to the soybeans. Once the hydraulic loading was increased to 61 cm/yr, sufficient nitrogen mass was applied to soybeans to inhibit nitrogen fixation. In the soybean test plots inorganic nitrogen leached through the 183 cm soil profile when 122 cm of effluent/yr was applied at irrigation intervals greater than once per week. Similarly, nitrogen was leached from the 91 cm profile within the grain sorghum test plot irrigated with 122 cm/yr.

Sodium increased in the grain sorghum at low irrigation rates. Leaching of Na within the plots resulted when greater quantities of water were applied per irrigation period. Consequently, less Na was available for the crop. Grain sorghum, with a deeper more extensive root system, was not affected by minor changes in loadings or frequencies of application, while a small shift of either of these factors on the soybean crop changed the availability of sodium.

Soil--

The ability of the crop to adapt to water stress conditions was a factor which influenced Na accumulation within the soil profile. Due to the shorter growing season in 1982, soybeans with a more shallow root system and possibly greater water requirements than sorghum, utilized water within the upper 61 cm of soil. Consequently, the greatest Na levels as a percent of base saturation was observed in the upper 61 cm of the soil. In addition, higher water application frequency appeared to increase ESP values in the upper soil profile.

Water utilized by grain sorghum caused an accumulation of Na at greater soil depths than soybeans. Upward migration of water due to capillary action during water stress periods (increased time intervals between irrigation) may have caused an increase in Na in the upper profile.

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APPENDIX A

Demonstration/Hydrogeologic Study
Agricultural Cropping Patterns

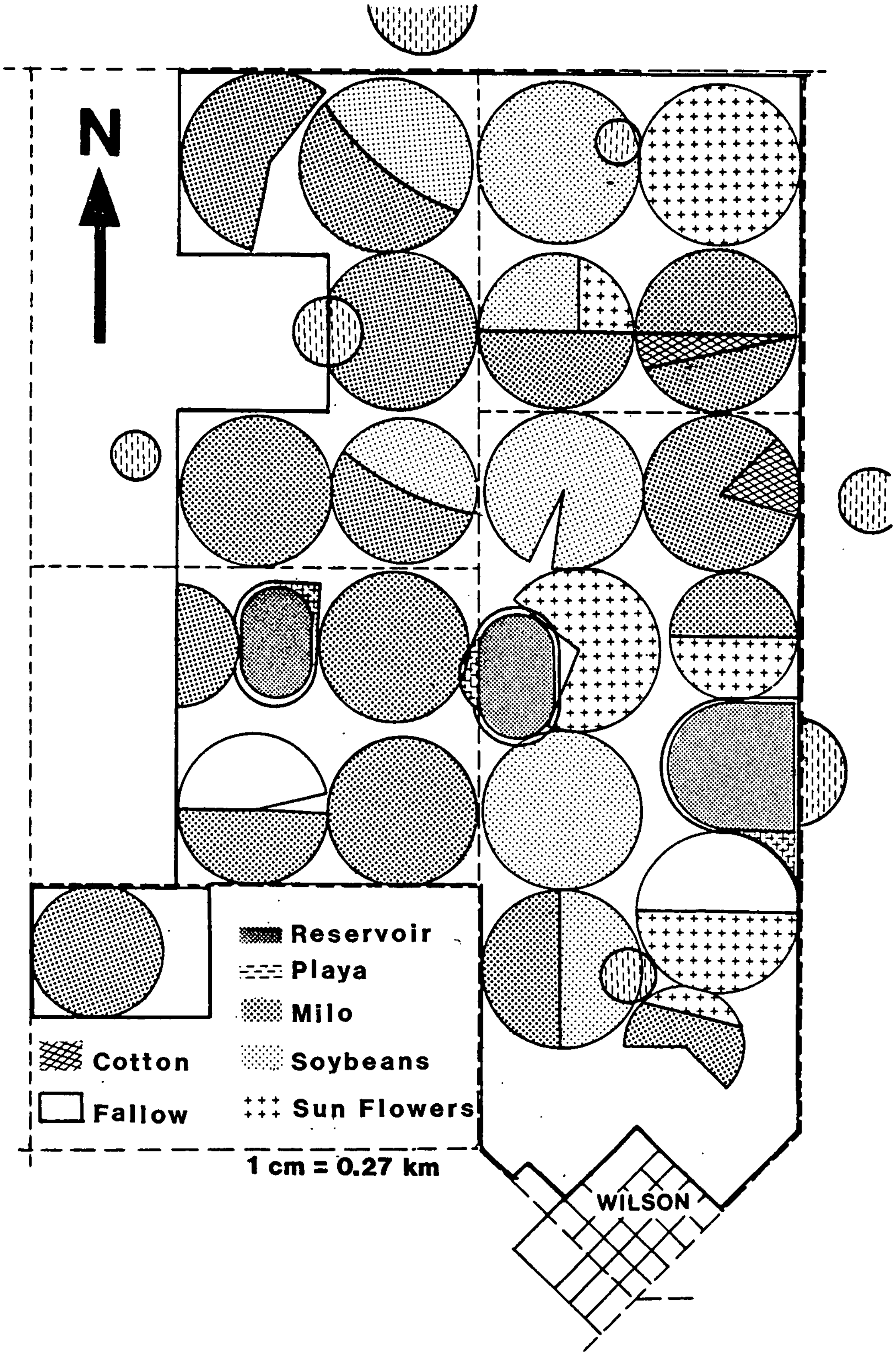


Figure A.1. Summer 1982 cropping pattern for Hancock Farm

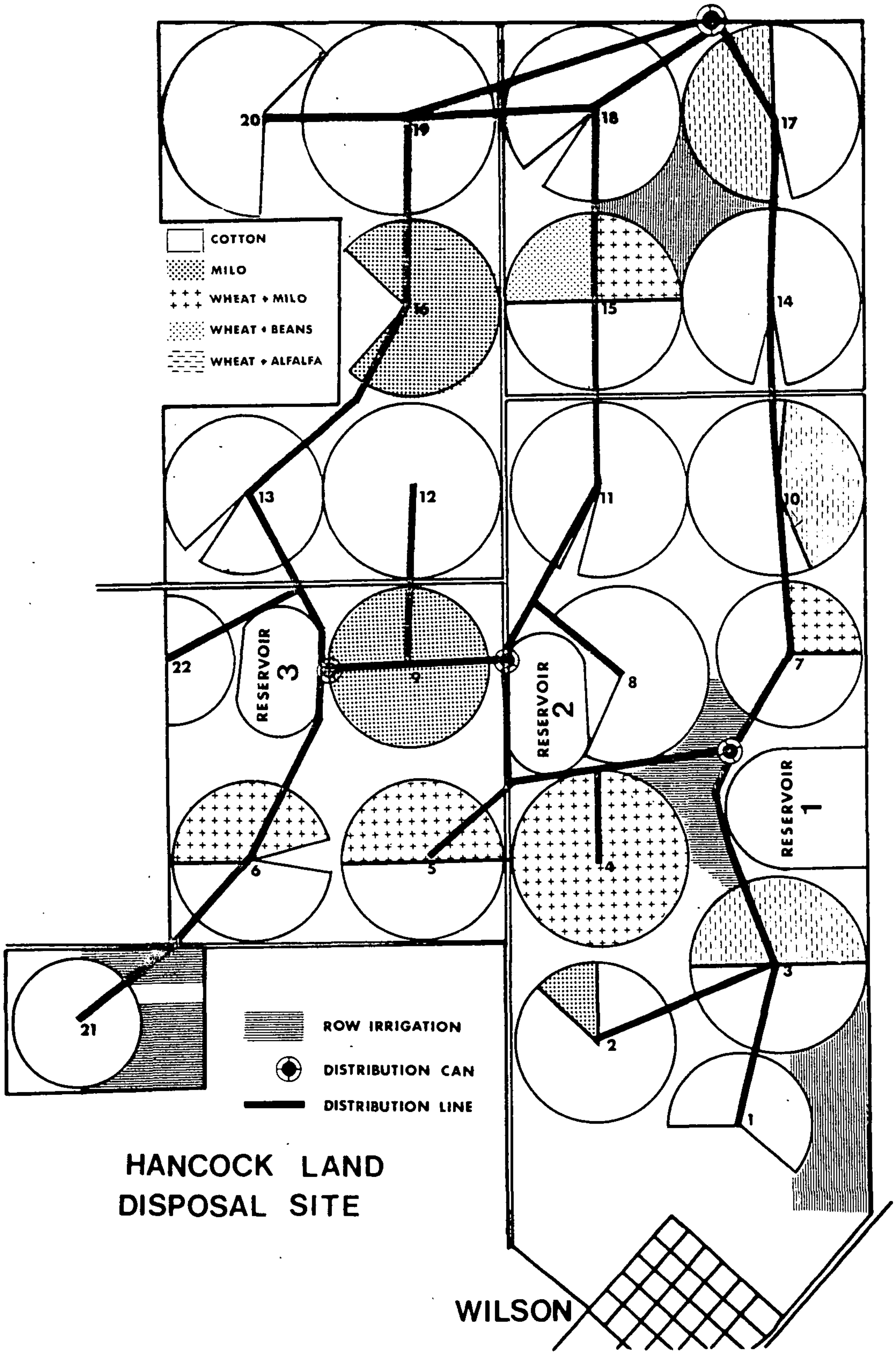


Figure A.2. Summer 1983 cropping pattern, Hancock Farm

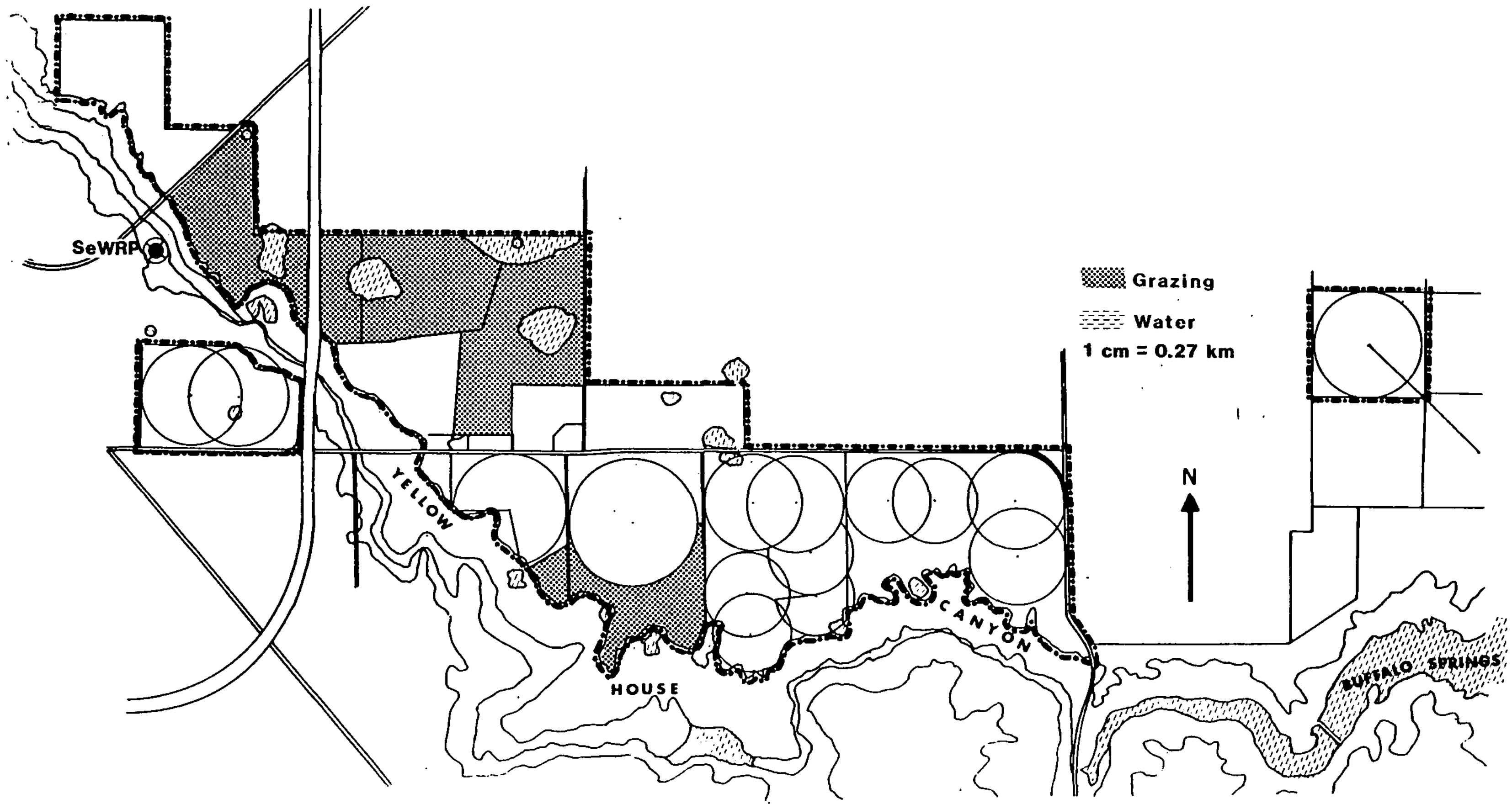


Figure A.3. Winter 1982 crop and grazing areas at Gray Farm

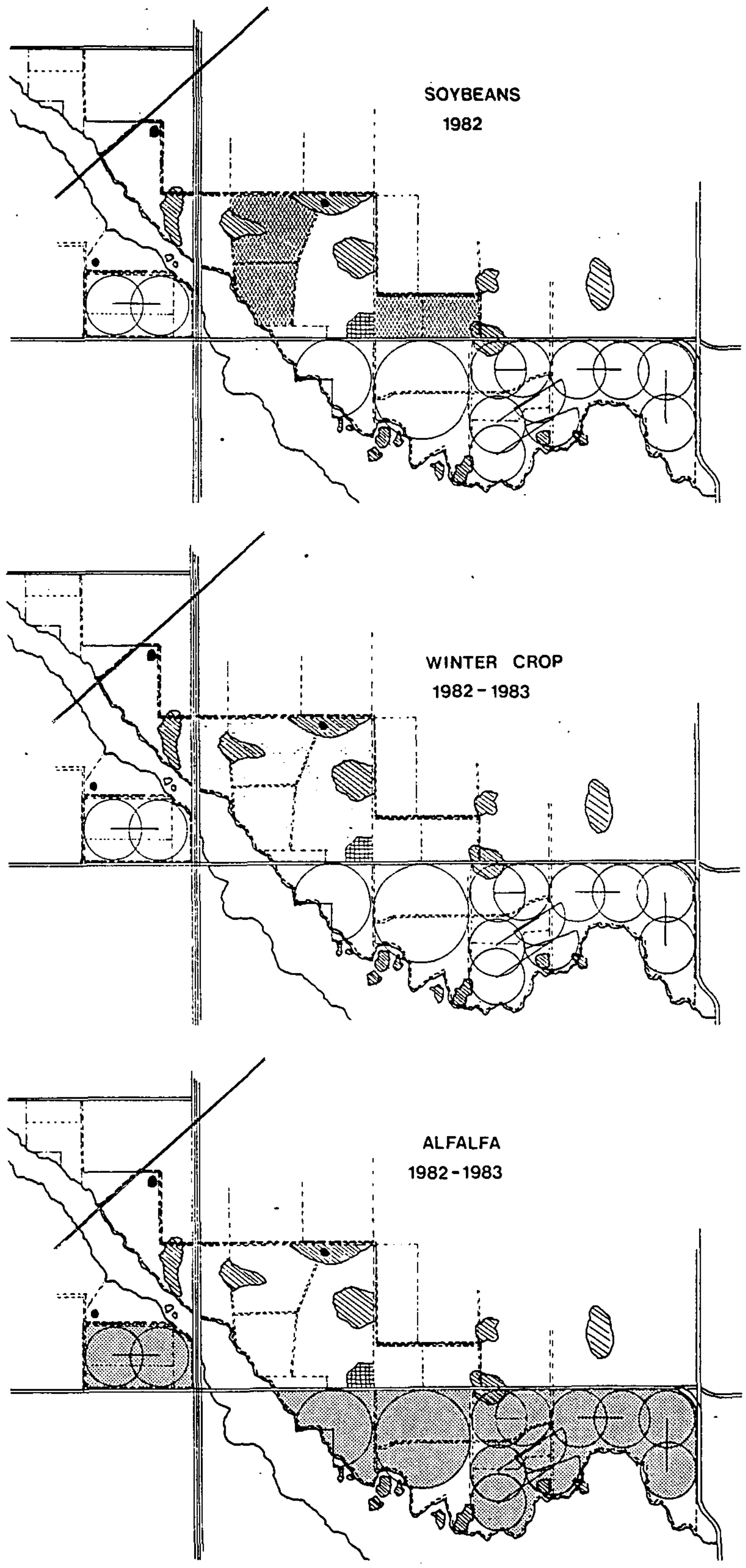


Figure A.4. Cropping patterns on Gray Farm during 1982 and 1983

APPENDIX B

Supplemental Figures and Tables
for Section 3 (Project Design)

TABLE B.1. WATER ANALYSIS

Alkalinity, mg/l $CaCO_3$	Nickel (Ni), mg/l*
Total Organic Carbon (TOC), mg/l	Potassium (K), mg/l*
Specific Conductance, µmhos/cm	Selenium (Se), mg/l*
Total Dissolved Solids (TDS), mg/l	Silver (Ag), mg/l*
pH	Sodium (Ag), mg/l*
Chloride (Cl), mg/l	Thallium (Tl), mg/l*
Total Kjeldahl Nitrogen (TKN), mg N/l	Zinc (Zn), mg/l*
Nitrite plus Nitrate (NO_2+NO_3), mg N/l	Anthracene/phenathrene (µg/l)
Ammonia (NH_3), mg N/l	Atrazine (µg/l)
Total Phosphorus (TP), mg P/l	Benzene (µg/l)
Orthophosphate Phosphorus (PO_4), mg P/l	Benzeneacetic acid, (µg/l)
Organic Phosphorus (Org P), mg P/l	4-t-butylphenol, (µg/l)
Chemical Oxygen Demand (COD), mg/l	Carbontetrachloride, (µg/l)
Sulphate (SO_4), mg SO_4/l	4-chloroaniline, (µg/l)
Total Coliform (TC)/100 ml	Chlorobenzene, (µg/l)
Fecal Coliform (FC)/100 ml	Chloroform, (µg/l)
Fecal Streptococci (FS)/100 ml	2-chlorophenol, (µg/l)
Salmonella/300 ml	1-chlorotetradecane, (µg/l)
Aluminum (Al), mg/l*	Dibutylphthalate, (µg/l)
Arsenic (As), mg/l*	2,3-dichloroaniline, (µg/l)
Barium (Ba), mg/l*	3,4-dichloroaniline, (µg/l)
Boron (B), mg/l*	Dichlorobenzene M,P,O, (µg/l)
Calcium (Ca), mg/l*	Dichloromethane, (µg/l)
Cadmium (Cd), mg/l*	2,4-dichlorophenol, (µg/l)
Cobalt (Co), mg/l*	Diethylphthalate, (µg/l)
Chromium (Cr), mg/l*	Diisooctylphthalate, (µg/l)
Copper (Cu), mg/l*	Dioctylphthalate, (µg/l)
Iron (Fe), mg/l*	Dodecanoic acid, (µg/l)
Lead, (Pb), mg/l*	Ethyl Benzene, (µg/l)
Magnesium (Mg), mg/l*	Heptadecane, (µg/l)

(continued)

TABLE B.1, continued

Manganese (Mn), mg/l*	Hexadecane, (μg/l)
Mercury (Hg), mg/l*	Hexadecanoic acid, (μg/l)
Molybdenum (Mo), mg/l*	Methyheptadecanoate, (μg/l)
Methylhexadecanoate, (μg/l)	Phenol, (μg/l)
1-methylnaphthalene, (μg/l)	Propazine, (μg/l)
2-methylphenol, (μg/l)	α-terpineol, (μg/l)
4-methylnaphthalene, (μg/l)	Tetrachloroethylene, (μg/l)
Naphthalene, (μg/l)	Toluene, (μg/l)
Octadecane, (μg/l)	Trichloroethylene, (μg/l)

*Total and Dissolved

TABLE B.2. SOIL ANALYSIS

Alk, mg/g as Ca_2CO_3	Ba, mg/g*	Dibutylphthalate, (μg/kg)
TOC, mg/g	B, mg/g*	2,3-dichlorotetradecane, (μg/kg)
Specific Conductance, μmhos/cm	Ca, mg/g*	3,4-dichlorotetradecane, (μg/kg)
TDS, mg/g	Cd, mg/g*	Dichlorobenzene, (g/kg) M,P,O (3)
pH	Co, mg/g*	Dichloromethane, (μg/kg)
Cl, mg Cl/g Total	Cr, mg/g*	2,4-dichlorophenol, (μg/kg)
TKN, mg N/g Total	Cu, mg/g*	Diethylphthalate, (μg/kg)
NO_2+NO_3, mg N/g	Fe, mg/g*	Diisooctylphthalate, (μg/kg)
NH_3, mg N/g	Pb, mg/g*	Dioctylphthalate, (μg/kg)
P, mg P/g	Mg, mg/g*	Dodecanoic acid, (μg/kg)
PO_4, mg P/g	Mn, mg/g*	Ethylbenzene, (μg/kg)
SO_4, mg S/g	Hg, mg/g*	Heptadecane
$CaCO_3$, mg/g as $CaCO_3$	Mo, mg/g*	Hexadecane, (μg/kg)
Cationic Exchange	Ni, mg/g*	Hexadecanoic acid, (μg/kg)
Anionic Exchange	K, mg/g*	Methylheptadecanoate, (μg/kg)
Organic Matter	Se, mg/g*	Methylhexadecanoate, (μg/kg)
Buffer Capacity	Ag, me/g*	1-methylnaphthalene (μg/kg)
Solution Cations, mg/g	Na, mg/g*	2-methylphenol, (μg/kg)
Sulfur, mg/g	Tl, mg/g*	4-methylphenol, (μg/kg)
Specific Gravity	Zn, mg/g*	Napthalene, (μg/kg)
Texture	Acenaphthylene, (μg/kg)	4-nonylphenol, (μg/kg)
Bulk Density	2-chlorophenol, (μg/kg)	Octadecane, (μg/kg)
Consistency	Atrazine, (μg/kg)	Phenol, (μg/kg)
Color	Benzene, (μg/kg)	Propazine, (μg/kg)
Humus, mg/g	Benzeneatic acid, (μg/kg)	α-terpineol, (μg/kg)
Total Coliform/g	4-t-butylphenol, (μg/kg)	Tetrachloroethylene, (μg/kg)
Fecal Coliform/g	Carbontetrachloride, (μg/kg)	Toluene, (μg/kg)
Fecal Strep/g	4-chloroaniline, (μg/kg)	Trichloroethane, (μg/kg)
Actinomycetes/g	Chlorobenzene	Trichloroethylene (μg/kg)
Fungi/g	Chloroform, (μg/kg)	
Al, mg/g*	Anthracene/phenanthrene, (μg/kg)	
As, mg/g*	1-chlorotetradecane, (μg/kg)	

*Total and Available

TABLE B.3. CROP ANALYSIS PROTOCOL

COTTON

Lint, Seed, Burs, Stems:
- TC, FC, FS
- TKN, TP
- K, Ca, Mg, Na, Zn, Mn, Fe, B, Al, Cd, As

Seed:
- Protein, Cl, Oil

GRAIN SORGHUM (MILO)

Grain, Stalk, Leaf:
- TC, FC, FS
- TKN, TP, Cl
- K, Ca, Mg, Na, Zn, Mn, Fe, B, Al, Cd, As

Stalks, leaf:
- HCN, Fiber

Grain:
- Protein, Starch, Oil

ALFALFA, BERMUDA

Whole Plant:
- TC, FC, FS
- TKN, TP, Protein, Cl
- K, Ca, Mg, Na, Zn, Mn, Fe, B, Al, Cd, As
- Fiber

SOYBEANS, SUNFLOWERS

Leaf, Stem, Seed:
- TC, FC, FS
- TKN, TP, Cl
- K, Ca, Mg, Na, Zn, Mn, Fe, B, Al, Cd, As

Seed:
- Protein, Oil

WHEAT, OATS

Leaf, Stem, Seed:
- TC, FC, FS
- TKN, TPS, Protein, Cl
- K, Ca, Mg, Na, Zn, Mn, Fe, B, Al, Cd, As

Seed:
- Starch

TABLE. B.4. WATER QUALITY ANALYSIS SCHEDULE FOR PERCOLATE SAMPLES

Parameter	Group Classification
Alkalinity	A
COD	A
TDS	A
Specific Conductance	A
pH	A
Total Kjeldahl Nitrogen	A
NH_3	A
$NO_2 + NO_3$	A
Total Phosphorus	A
Organic Phosphorus	A
Orthophosphate Phosphorus	A
TOC	A
Ca	B
Cl	A
K	A
Mg	B
Na	A
SO_4	B
Heavy Metals Ag, As, Ba, Cd, Cr, Cu, Fe, Hg, Ni Pb, Se, Zn, Co, Al, Mn, Tl, Mo, B	C
Trace Organics	D
Fecal Coliform	C
Viruses	C

Key: A - weekly; B - Monthly; C - Quarterly; D - Yearly

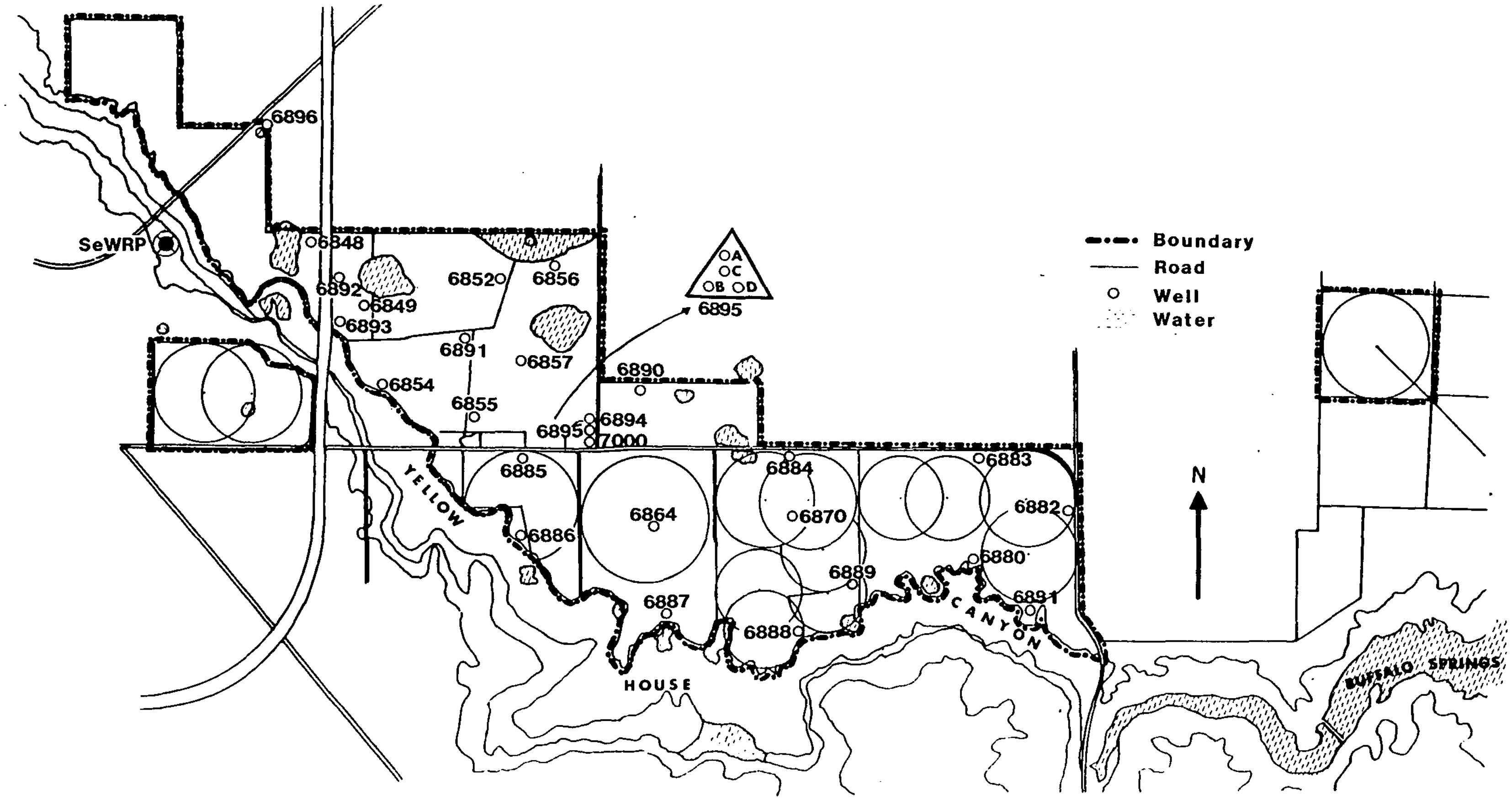


Figure B.1. Gray Farm ground water monitoring locations

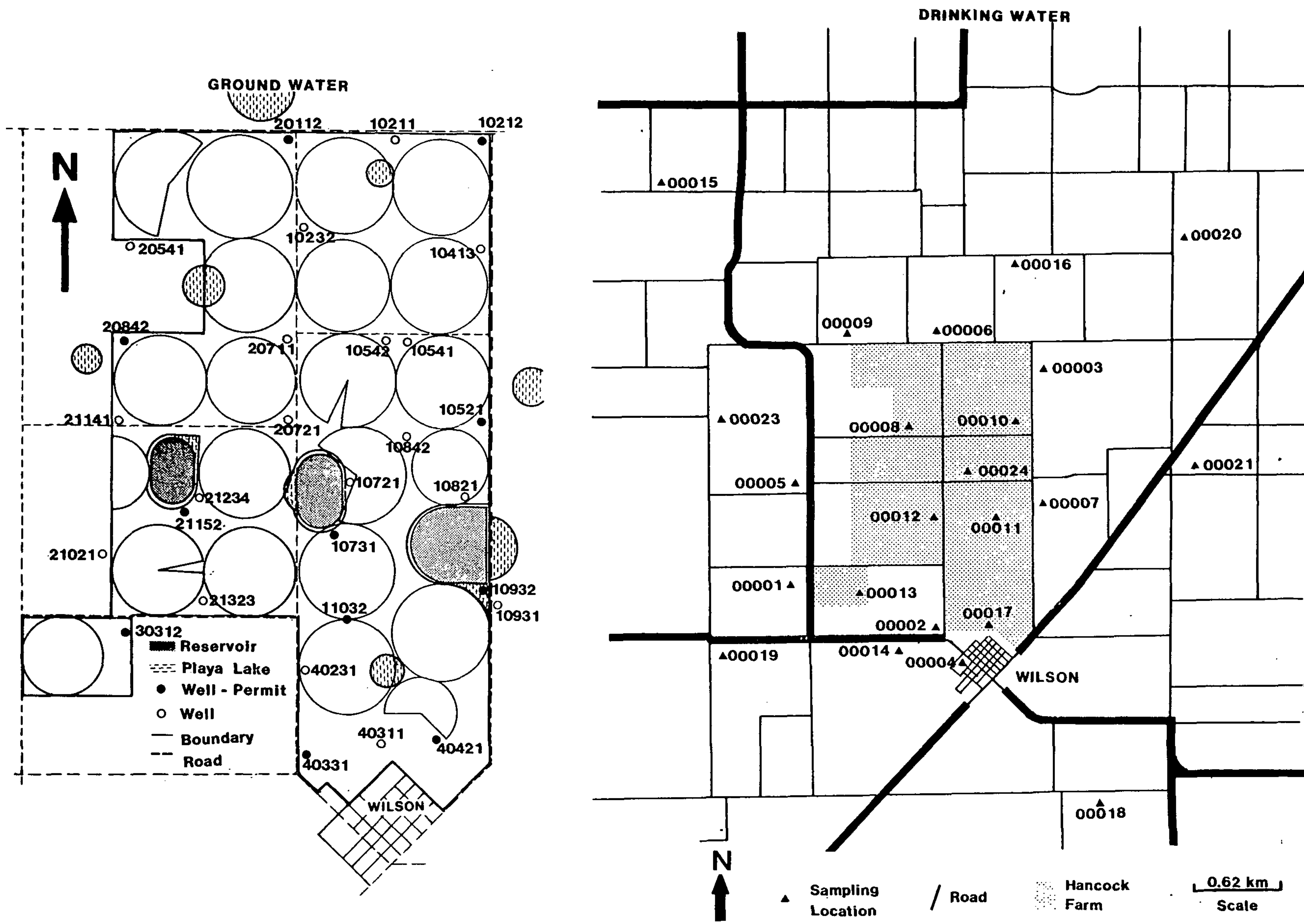


Figure B.2. Hancock Farm Ground Water and Drinking Water Monitoring Locations

APPENDIX C

Supplemental Figures and Tables for Section 4 (Summary of Findings)

TABLE C.1. GROUND WATER QUALITY - GRAY WELLS

Parameter	Monitoring Period June 1980-Jan. 1982	Monitoring Period Feb. 1982-Dec. 1983
Alkalinity (mg $CaCO_3$/l	224-402	140-439
Conductivity (μmhos/cm)	1,244-2,882	1,098-3,846
TDS (mg/l)	1,010-2,271	723-2,812
pH	7.10-7.72	7.28-8.13
Cl (mg/l)	208-680	154-686
SO_4 (mg/l)	149-795	148-1,067
TKN (mg N/l)	0.28-6.97	0.20-7.65
NO_2 + NO_3 (mg N/l)	5.05-35.89	0.77-33.43
NH_3 (mg/l)	0.02-2.05	<0.01-6.96
TP (mg P/l)	0.10-3.49	<0.01-1.94
PO_4 (mg P/l)	<0.01-0.84	<0.01-1.68
Org P (mg P/l)	0.08-2.31	<0.01-0.23
COD (mg/l)	27.2-125.4	11.4-100.3
TOC (mg/l)	12.2-38.6	1.1-9.9
TC (Counts/100 ml)	0-300,000,000	0->31,700
FC (Counts/100 ml)	0->3603	0-30,000
FS (Counts/100 ml)	0-4,501	0-26,660
Metals, Dissolved (mg/l)		
Al	0.080-3.530	0.153-1.477
As	<0.058-0.243	<0.005-0.038
Ba	0.058-0.243	0.019-0.250
B	0.521-3.671	<0.100-1.174
Ca	47.7-161.7	44.1-175.1
Cd	<0.001-0.004	<0.001-0.004
Co	<0.005-0.012	<0.005-0.030
Cr	<0.005-0.025	<0.005-0.023
Cu	<0.005-0.106	<0.005-0.020
Fe	0.021-0.556	0.021-1.105
Pb	<0.002-0.060	0.003-0.041

(continued)

Table C.1, continued

Parameter	Monitoring Period June 1980-Jan. 1982	Feb. 1982-Dec.1983
Mg	22-138	38-149
Mn	0.002-0.260	<0.001-1.464
Hg	<0.001-0.003	NR
Mo	<0.003-0.055	NR
Ni	<1.005-0.077	<0.005-0.271
K	8-40	7-65
Se	<0.005-0.009	<0.005-0.015
Ag	<0.005	<0.001-0.009
Na	73-476	36-638
Tl	<0.005-0.007	<0.005
Zn	0.027-0.591	0.036-0.571
Metals, Total (mg/l)		
Al	0.146-36.340	0.128-0.704
As	<0.005-0.018	<0.005-0.006
Ba	0.028-4.750	0.019-0.091
B	<0.100-5.10	NR
Ca	30-394	49
Cd	<0.001-0.011	NR
Co	<0.005-0.096	<0.005-0.006
Cr	0.003-0.096	<0.005-0.055
Cu	<0.005-0.137	<0.005-0.032
Fe	0.172-34.3	<0.020-2.780
Pb	<0.002-0.53	<0.002-0.005
Mg	24-152	79-229
Mn	0.009-4.310	<0.001-0.082
Hg	NR	NR
Mo	<0.005-0.630	NR
Ni	<0.005-0.630	<0.005
K	10-61	17-70

(continued)

Table C.1, continued

Parameter	Monitoring Period June 1980-Jan. 1982	Feb. 1982-Dec.1983
Se	<0.005-0.017	<0.002-0.013
Ag	<0.005-0.031	<0.001
Na	93-434	118-573
Tl	<0.005-0.012	<0.005
Zn	0.061-0.923	<0.020-1.568
Organics (ppb)		
Acenaphthylene	<5.0	<2.0-4.3
Anthracene	<2.0-2.9	<2.0-5.2
Atrazine	<2.0-5.7	4.7-10.0
Benzene	<1.0-11.9	<1.0-6.2
4-t-butylphenol	<2.0-3.4	<1.0-3.0
Carbon tetrachloride	<5.0	2.4-6.5
4-chloroaniline	<10.0	<10.0
Chlorobenzene	<1.0-1.2	<1.0
Chloroform	<1.0-8.4	<1.0-2.5
2-chlorophenol	<2.0-3.3	<1.0-3.0
1-chlorotetradecane	<2.0-5.7	<2.0-4.9
Dibutylphathalate	<2.0-14.1	<1.0-8.8
2,3-Dichloroaniline	<5.0-8.1	<2.0-8.9
3,4-Dichloroaniline	<2.0-2.6	<2.0-2.6
Dichlorobenzene meta	<2.0-3.2	<1.0-1.7
Dichlorobenzene para	<2.0-2.1	<1.0-1.7
Dichlorobenzene ortho	<2.0-4.2	<1.0-1.9
Dichloromethane	NR	NR
2,4-Dichlorophenol	<2.0-4.6	<2.0-3.0
Diethylphthalate	<2.0-11.7	<2.0-862.1
Diisooctylphthalate	<2.0-757.7	<2.0-475.0
Dioctylphthalate	<2.0-34.4	<2.0

(continued)

Table C.1, continued

Parameter	Monitoring Period June 1980-Jan. 1982	Monitoring Period Feb. 1982-Dec.1983
Ethyl Benzene	<1.0-2.1	<1.0-2.1
Heptadecane	<2.0-3.0	<2.0
Hexadecanoic Acid	9.0-111.0	NR
Methylheptadecanoate	<2.0-14.1	<2.0-2.3
Methylhexadecanoate	<2.0-6.9	<2.0
1-Methylnapthalene	<2.0-2.9	<1.0-1.9
2-Methylphenol	<2.0-2.7	<1.0-1.9
4-Methylphenol	<5.0-5.2	<2.0-31.0
Naphthalene	<2.0-7.5	<1.0-4.0
4-nonylphenol	2.09 (1 data point)	<2.0 (1 data point)
Octadecane	<2.0-4.4	<2.0-4.0
Phenol	<10.0	<1.0-10.5
Propazine	<2.0-2.3	<1.0-2.1
α-terpineol	<2.0-2.3	<1.0-2.1
Tetrachloroethylene	<1.0-5.4	<1.0-5.3
Toluene	<1.0-4.6	<1.0-2.2
Trichloroethane	<5.0	<5.0-10.4
Trichloroethylene	1.4-4.6	<1.0-7.2

TABLE C.2. RANGE OF AVERAGES WATER QUALITY CONSTITUENTS - HANCOCK FARM

Parameter	Monitoring Period 6/80-1/82	Monitoring Period 2/82-12/83
Alkalinity (mg $CaCO_3$)	230-349	238-382
Specific Conductivity (μmhos/cm)	504-1287	694-1933
TDS (mg/l)	363-989	462-1250
pH	7.32-7.2	7.33-8.14
Cl (mg/l)	22-246	17-345
SO_4 (mg/l)	32-243	44-271
Total N (mg N/l)	0.10-4.21	0.11-24.89
NO_2 + NO_3 (mg N/l)	0.79-10.90	0.10-14.99
NH_3 (mg N/l)	0.03-1.36	0.03-15.15
Total P (mg P/l)	0.08-0.58	0.02-1.02
Ortho P (mg P/l)	<1.01-0.29	<0.01-0.85
Org P (mg P/l)	<0.01-5.50	<0.01-0.08
COD (mg/l)	6.6-116.7	5.8-84.3
TOC (mg/l)	7.1-53.3	0.9-15.4
Total Coliform (counts/100 ml)	0-200,004,032	65-43,275
Fecal Coliform (counts/100 ml)	0-150,002,752	0-45,005
Fecal Strep (counts/100 ml)	0->4,604	8-19,200
Metals-Dissolved (mg/l)		
Al	0.124-9.180	0.173-4.656
As	<0.005-0.018	<0.010-0.010
Ba	0.042-0.369	0.022-0.236
B	0.188-1.186	0.510-2.175
Ca	24-150	29-118
Cd	<0.001-0.004	<0.001-0.003
Co	<0.005-0.016	<0.005-0.008
Cr	<0.005-0.031	<0.005-0.008
Cu	<0.005-0.090	<0.005-0.126

(continued)

Table C.2., continued

Parameter	Monitoring Period 6/80-1/82	2/82-12/83
Fe	0.170-4.688	0.337-8.885
Mg	21-70	28-69
Mn	0.006-0.650	0.009-1.642
Mo	0.004-0.058	NR
Ni	<0.005-0.162	<0.005-0.190
K	7-13	6-17
Se	<0.005-0.011	<0.005-0.134
Ag	<0.005	<0.001-0.005
Na	30-148	34-181
Tl	0.028-0.247	<0.005-0.007
Metals, Total (mg/l)		
Al	0.114-6.650	0.379-2.850
As	<0.003-0.020	0.002-0.011
Ba	0.059-0.482	0.059-0.150
B	<0.100-0.792	NR
Ca	29-103	20-137
Cd	<0.001-0.008	NR
Co	0.003-0.005	<0.005-
Cr	0.002-0.047	<0.005-
Cu	0.004-0.112	<0.005-0.006
Fe	0.113-3.710	0.580-6.410
Pb	<0.002-0.022	<0.002-0.006
Mg	37-85	31-55
Mn	0.003-1.230	0.020-0.132
Mo	0.010-0.085	NR
Ni	<0.005-0.133	<0.005
K	8-15	11-18
Se	0.001-0.009	<0.005-0.009
Ag	<0.005	<0.001
Na	78-686	78-159

(continued)

Table C.2., continued

Parameter	Monitoring Period 6/80-1/82	2/82-12/83
Tl	0.001-0.009	<0.005
Zn	0.072-0.0436	<0.020-0.096
Organics (ppb)		
Acenapththylene	<5.0-5.9	<3.0-3.9
Anthracene	<2.0-4.4	<2.0-7.2
Atrazine	<2.0-38.9	4.7-13.9
Benzene	<1.0-2.3	<1.0-3.7
4-t-Butylphenol	<2.0-75.9	1.3-2.5
Carbon Tetrachloride	<5.0-193.0	2.8-5.4
4-Chloroaniline	<10.0-11.1	<10.0
Chlorobenzene	<1.0	<1.0-1.6
Chloroform	<1.0-7.4	<1.0-12.2
2-Chlorophenol	<2.0	<2.0
1-Chlorotetradecane	<2.0-52.2	<2.0-8.9
Dibutylphathalate	<2.0-111.0	2.6-16.4
2,3-Dichloroaniline	<5.0-9.2	2.8-8.2
3,4-Dichloroaniline	2.0-7.1	<2.0-8.3
Dichlorobenzene meta	<2.0-3.9	<2.0
Dichlorobenzene para	<2.0-9.6	<2.0
Dichlorobenzene ortho	<2.0-3.6	<2.0
2,4-Dichlorophenol	<2.0-5.8	<2.0-5.8
Diethylphthalate	<2.0-16.7	3.0-62.3
Diisooctylphthalate	9.9-223.8	<2.0-378.0
Dioctylphthalate	<2.0-62.2	<2.0-2.9
Ethylbenzene	<1.0-2.6	<1.0-1.8
Heptadecane	<2.0-3.7	<2.0-3.1
Hexadecane	<2.0-2.5	<2.0
Hexadecanoic Acid	17.6-36.0	<1.0
Methylheptadecanoate	<2.0-36.0	<2.0-3.4

(continued)

Table C.2., continued

Parameter	Monitoring Period 6/80-1/82	Monitoring Period 2/82-12/83
Methylhexadecanoate	<2.0-560.0	<2.0-4.3
1-Methylnaphthalene	<2.0-2.1	2.0-3.2
2-Methylphenol	<2.0-2.8	<2.0
4-Methylphenol	<5.0-6.8	<5.0
Naphthalene	<2.0-7.0	<2.0-3.4
Octadecane	<2.0-6.7	<2.0-6.1
Phenol	<10.0-24.9	<10.0
Propazine	<2.0-4.5	5.6-9.8
α-terpineol	<2.0-4.4	2.0
Tetrachloroethylene	<1.0-	<1.0-4.9
Toluene	<1.0-12.3	<1.0
Trichloroethane	<5.0-11.5	<5.0
Trichloroethylene	<1.0-8.9	<1.0-5.8

TABLE C.3. DEPTH OF PERCOLATE INTERCEPTED BY LYSIMETER UNITS OVER STUDY PERIOD AT THE HANCOCK FARM

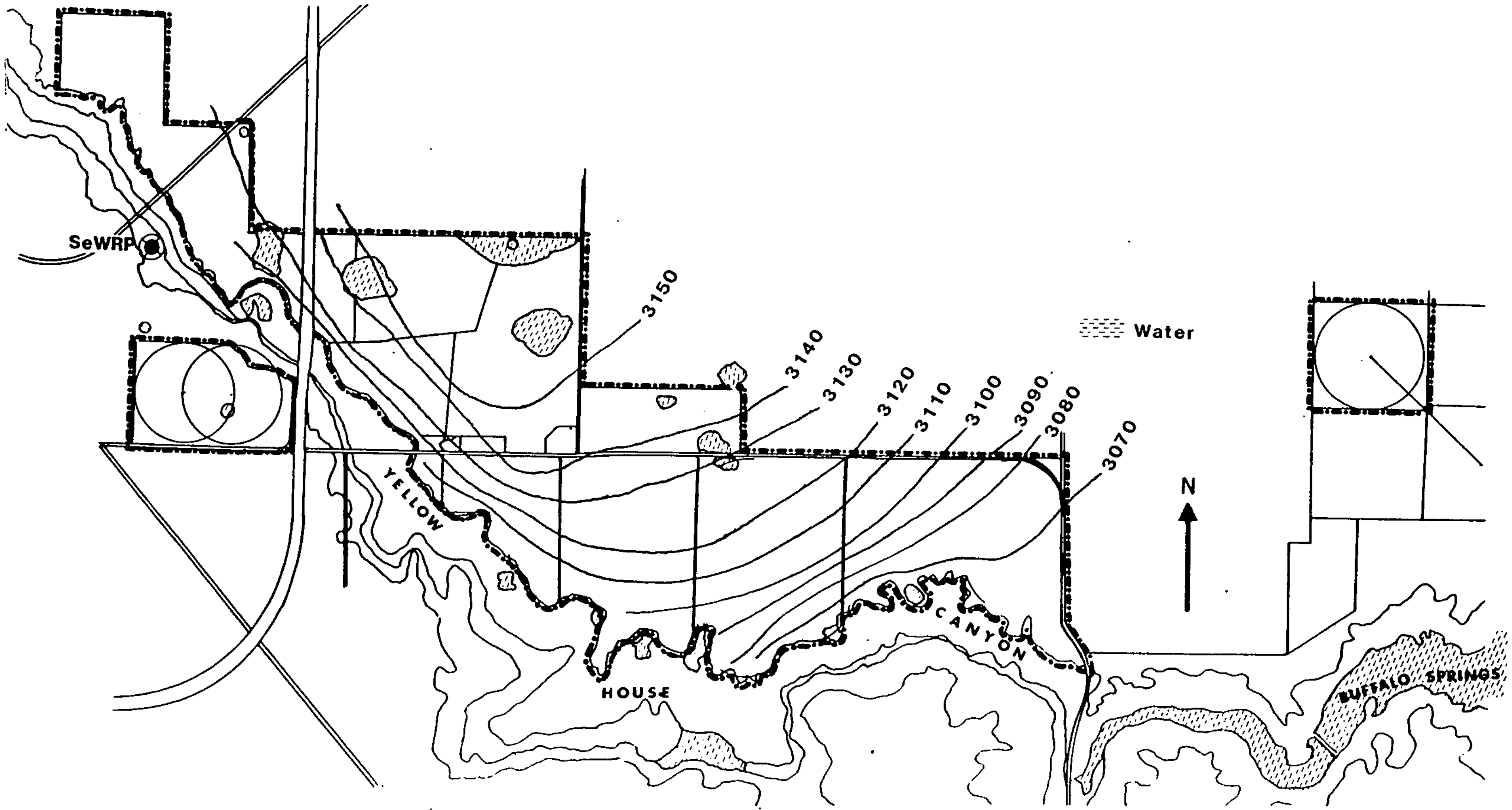
Location	Bermuda Units	Depth (cm)	Grain Sorghum Units	Depth (cm)	Cotton Units	Depth (cm)
Tray						
0.61 m	101[a]	5.1	201	0.8	301	Neg
	102	12.2	202	1.7	302	3.9
	103	4.4	203	---	303	3.9
	Avg.[b]	7.2	Avg.	1.25	Avg.	3.5
1.22 m	104	0.9	204	0.8	304	3.5
	105	0.9	204	0.8	304	3.2
	106	Neg.	206	---	306	0.9
	Avg.	1.1	Avg.	0.8	Avg.	1.6
1.83 m	107	0.3	207	0.3	307	0.7
	108	4.1	208	Neg	308	2.9
	109	---	209	Neg	309	0.8
	Avg.	2.2	Avg.	0.3	Avg.	1.5
Tube						
1.22 m	111	---	211	---	311	10.8
	112	0.1	212	0.5	312	1.2
	Avg.	0.1	Avg.	0.5	Avg.	6.0
1.83 m	113	108.1	213	Neg	313	2.0
	114	43.1	214	1.4	314	2.0
	Avg.	75.6	Avg.	1.4	Avg.	1.2
2.44 m			215	---		
			216	---		
Controls			Avg.			
1.22 m	121	171.3				
	122	155.3				
	Avg.	163.3				
1.83 m	123	113.3				
	124	114.9				
	Avg.	114.1				

[a] Unit code -- the first digit identifies the plot and the next two identify lysimeter type and depth.
[b] Average of producing units.

TABLE C.4. DEPTH OF PERCOLATE INTERCEPTED BY LYSIMETER UNITS OVER STUDY PERIOD AT THE GRAY SITE

Location	Bermuda Units	Depth (cm)	Cotton Units	Depth (cm)	Grain Sorghum Units	Depth (cm)
Tray						
0.6 m	101[a]	---	201	12.3	301	17.2
	102	Neg	202	3.6	302	33.2
	103	6.1	203	6.6	303	15.5
	Avg.[b]	6.1	Avg.	7.5	Avg.	22.0
1.22 m	104	0.3	204	5.2	304	1.7
	105	1.8	205	0.6	305	7.2
	106	0.6	206	4.3	306	---
	Avg.	0.9	Avg.	3.4	Avg.	4.5
1.83 m	107	3.3	207	2.9	307	1.3
	108	4.1	208	0.2	308	1.0
	109	1.5	209	2.0	309	4.3
	Avg.	3.0	Avg.	1.7	Avg.	2.2
Tube						
1.22 m	111	31.1	211	5.8	311	5.0
	112	10.8	212	6.7	312	18.8
	Avg.	21.0	Avg.	6.3	Avg.	11.9
1.83 m	113	10.1	213	0.4	313	17.0
	114	14.1	214	0.4	314	33.1
	Avg.	12.1	Avg.	0.4	Avg.	25.1
2.44 m	115	28.9				
	116	25.1				
	Avg.	27.0				

[a]Unit code -- the first digit identifies the plot and the next two identify lysimetr type and depth.
[b]Average of producing units.



CONTOUR ELEVATIONS IN FEET (.3048 M/ft)

Figure C.1. Water Level Contours, December 1981, Gray Farm

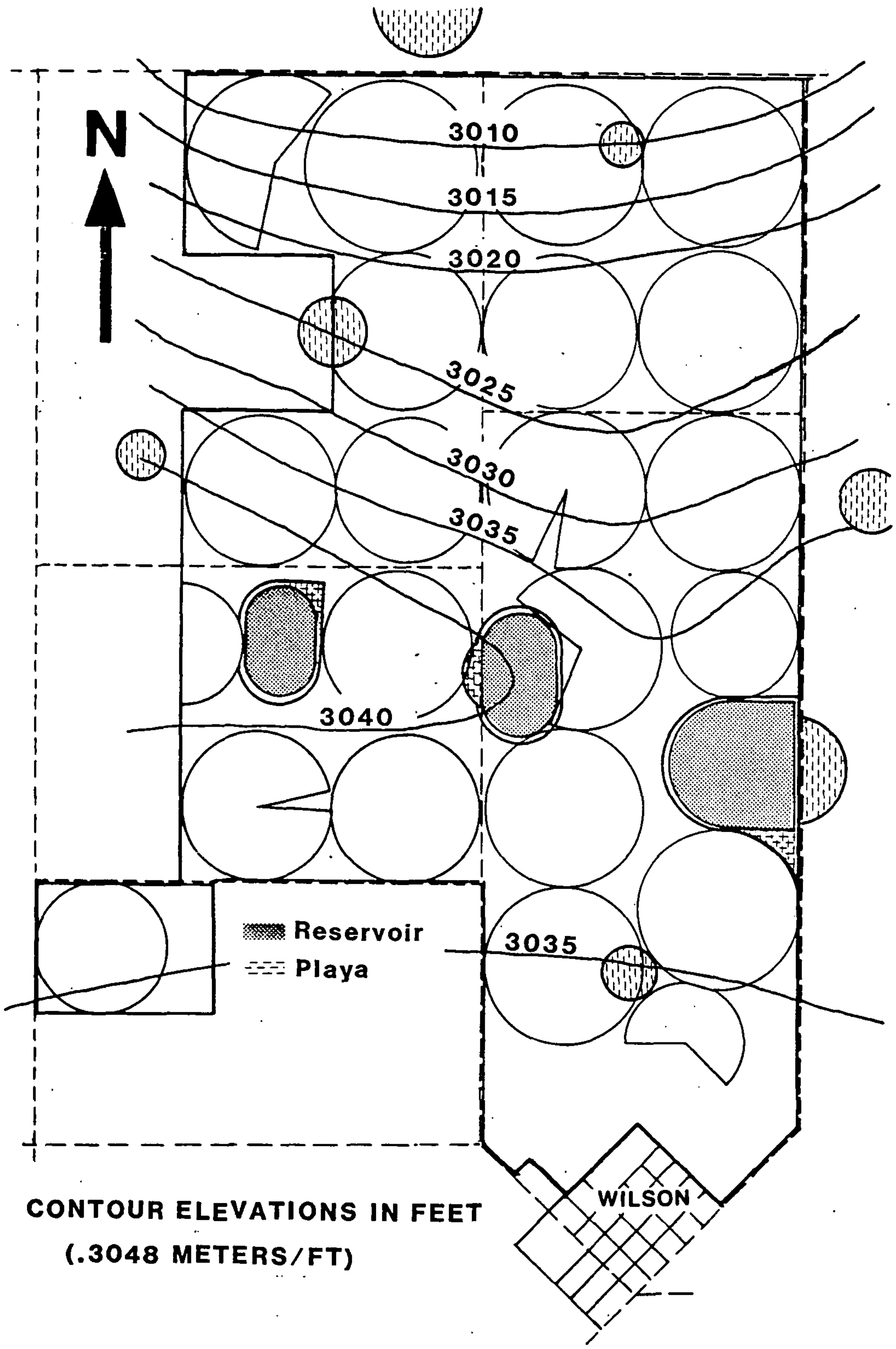


Figure C.2. Water Level Contours, December 1981, Hancock Site