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Project Summary

The Lubbock Land Treatment System Research and Demonstration Project

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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 1981, the Lubbock Land Treatment System was expanded 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).

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 groundwater level beneath the Gray farm was measured. In conjunction with the lowering of the ground-water 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.

An 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). The full report was submitted in fulfillment of CS806204 and CR807501 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.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully documented in five separate volumes (see Project Report ordering information at back).

Introduction

Agriculture is the major user of freshwater in the United States with approximately 99 percent of the agricultural water demand used for irrigation. Increasing water demands by agriculture, industry and municipalities have created severe water shortages in various regions of the United States and worldwide. Application of municipal wastewater to agricultural lands has been demonstrated to be a cost-effective treatment method. This practice results in water conservation by reducing withdrawal of freshwater from surface water and ground-water sources.

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 groundwater, 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.

The Lubbock Land Treatment System consists of two privately owned farms. In past years, the Gray farm suffered from an inadequate storage and distribution piping network to properly manage effluent produced by Lubbock's Southeast Water Reclamation Plant (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 10 years prior to 1982. Furthermore, an epidemiologic study was conducted at the Hancock farm to assess the association between human exposure to the wastewater used for irrigation and the development of new infections.

Description of Land Application System Expansion

Lubbock's 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 $5.5 \times 10^4 m^3/d$ (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 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 through three 0.38 m plastic irrigation pipelines to three separate reservoirs. 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).

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. The City of Lubbock's wastewater discharge permit for SeWRP required the plant to produce an effluent with a 30-day-average 5-day biochemical oxygen demand (BOD) 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:

	Average Monthly Effluent BOD_5 Produced by Lubbock SeWRP	
Month	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. Table 1 characterizes SeWRP effluent produced in 1980 and 1981.

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.

The sewage treated by SeWRP was primarily derived from domestic sources with less than 30 percent contributed from industrial sources. Trace metals 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.

The low hydraulic loading to the Gray farm 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.

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., strazine and propazine) and byproducts 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. 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.

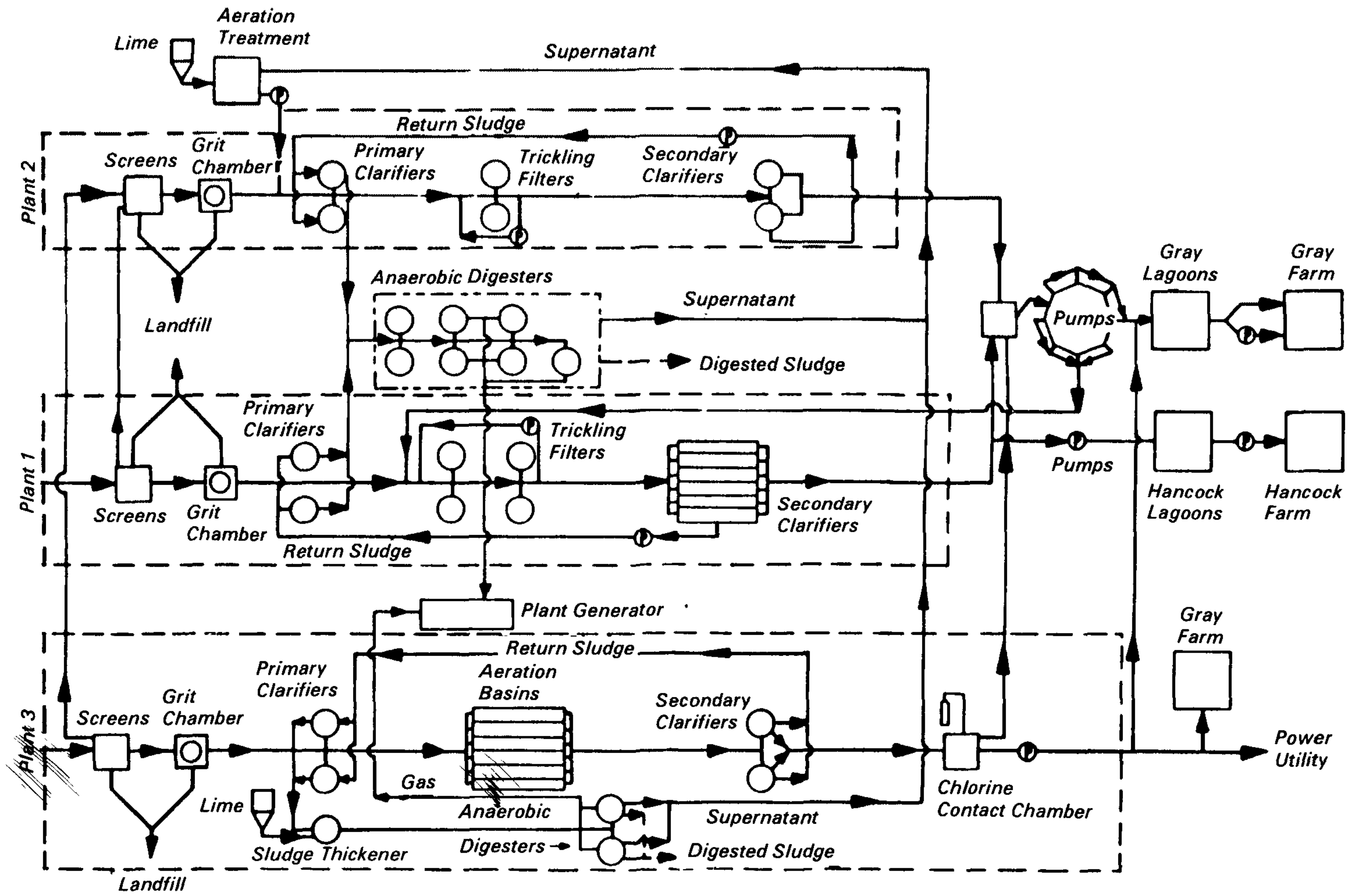

Figure 1. *Southeast Water Reclamation Plant flow diagram.*

The average fecal coliform concentration in the waste stream pumped to the center pivot irrigation machine exceeded EPA guidelines throughout the study period. The 1981 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 irrigation except for human food crops to be eaten raw."

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

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 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. 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.

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*

Table 2. *Concentration of Trace Elements in Treated Wastewater*

Element	*Wastewater Effluent*		*Median Concentration (mg/l)*	
	Range (mg/l)*	*Median* (mg/l)*	*SeWRP*	*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.*

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.

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 destroyed over 8.09 × 10^5 ha (2 × 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.

During the summer of 1983, less than 2.5 cm (1 inch) of rain was recorded from the end of June through mid-October.

Gray Farm

Secondary treated effluent from SeWRP was delivered to the Gray farm through three pipelines to three storage reservoirs. 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. Any other irrigation (the remaining six months), with no storage, had to be put on winter crop or grazing area. 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, 304 ha (750 ac) of wheat, and 121 ha (300 ac) of soybeans were planted on the Gray farm.

Conclusions

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 decreases 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 of effluent, the cotton yields for the farm were 48 percent greater than the Lubbock County average. Cotton yields for 1983 may have been limited by possible nutrient shortages, bollworm 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 microorganisms 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.

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The complete report consists of five volumes entitled "The Lubbock Land Treatment System Research and Demonstration Project:"(Set Order No. PB 86-173580/AS; Cost $128.50, subject to change).

"Volume I. Demonstration/Hydrogeologic Study," (Order No. PB 86-173598/AS; Cost $46.95, subject to change).

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"Volume V. Executive Summary," (Order No. PB 86-173630/AS; Cost $16.95, subject to change).

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