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THE LUBBOCK LAND TREATMENT SYSTEM RESEARCH AND DEMONSTRATION PROJECT: VOLUME II. PERCOLATE INVESTIGATION IN THE ROOT ZONE

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Volume II. Percolate Investigation in the Root Zone

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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 an 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. Percolate investigations, described in this volume, evaluated the fate of infiltrating nutrients from applied wastewaters in the root zone at test plots located on both study farms.

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THE LUBBOCK LAND TREATMENT SYSTEM RESEARCH AND DEMONSTRATION PROJECT

VOLUME II

Percolate Investigation in the Root Zone

by

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DISCLAIMER

The information in this document has been funded in part by the United States Environmental Protection Agency under assistance agreement No. CS806204 to Lubbock Christian College Institute of Water Research who contracted with Texas Tech University for this research. It has been subjected to the Agency's peer and administrative review and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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
Clinton W. Hall, Director
Robert S. Kerr Environmental Research Laboratory

ABSTRACT

An investigation of the amounts and quality of percolate generated by the land application of secondary effluent from the Southeast Water Reclamation Plant at Lubbock, Texas was conducted at two sites. One site was located on the Frank Gray farm (Friona Soil Series) which had served as a land treatment site for four decades. The other site located on the Gene Hancock farm (Amarillo Soil Series) near Wilson, Texas, was receiving its initial applications of treated wastewater. Three test plots were constructed at each site and equipped with 3 replicates of 3 extraction tray lysimeters placed under layers of undisturbed soil at 61, 122 and 183 cm depths. Two pairs of 76 cm diameter tube lysimeters, 122 cm and 183 cm in length, containing cores of undisturbed soils, were also emplaced on the plot with their top surface 30 cm below the surface. One plot at each site was planted to bermuda grass, one to grain sorghum, and one to cotton. The amounts of treated effluent applied to the plots during the project period were less than the design amount. This greatly decreased the amount and frequency of daily percolate collected from the lysimeters during the project period and reduced the effectiveness of the study results. Periodic quality analysis was made of percolate samples. The nutrient parameters in percolate samples, with the exception of nitrate and potassium, were generally reduced by a factor of 10 or more from those of the applied water where more than one water quality test for the constituent was performed. The mass of cations and anions contained in the amounts of percolate with pH levels in a range of 7.4 to 8.8 measured in the root zone would adversely impact the quality of the ground water underlying the Hancock site.

This report, covering the period from January 1, 1980 to completion on September 30, 1984, is submitted in fulfillment of EPA Grant CS806204 to Lubbock Christian College Institute of Water Research.

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ACKNOWLEDGEMENT

This report was prepared- under a contract with the Lubbock Christian College Institute of Water Research with funds provided by EPA Grant CS806204. The authors would like to acknowledge the help and cooperation of the Institute staff in the performance of the project activities.

SECTION I

INTRODUCTION

Since 1939, the Frank Gray farm, located east of Lubbock, Texas, had served as a land application site for the city's treated wastewater. During the seventies, this facility experienced difficulties in handling the additional wastewater that had been generated by the growth of the city. The hydraulic loading rates used on the farm were in excess of the rates recommended for slow rate systems by both the EPA and the State of Texas. A new land application site north of Wilson, Texas, was developed to reduce the loadings being experienced at the Frank Gray farm.

In conjunction with the construction of the new site, a research effort was initiated to evaluate the effects of the soil-crop matrix on the quality and quantity of the applied wastewaters percolating through the soil normally penetrated by the roots of field crops. These upper soil layers, known collectively as the soil root zone, possess physical, chemical, and biological characteristics that affect the agricultural productivity of the site.

Successful implementation of land application systems for municipal wastewater treatment is predicated on the effective removal and stabilization of wastewater constituents in the soil profile. Monitoring of the ground water under and adjacent to the site is necessary to insure that the land application system is functioning as intended. Evaluating the percolate quantity and quality as it leaves the root zone should provide information on potential detrimental conditions that would enable changes to be made in the operational procedures of the land application system to lessen pollutional impacts on the underlying ground water. A current problem associated with the monitoring of ground water under and adjacent to land application sites is that by the time poor quality conditions are noted in ground water, corrections in the system's operation will have little short-term effect because of the mass of pollutants already in transit through the soil profile. The uncertainties associated with ground water movement under the test sites, a depth to ground water ranging from 3.0 to 27.4 m, and variations in the physical properties of the soil profile could cause problems in monitoring short-term effects of the land application systems on the ground water under the two sites used by the City of Lubbock.

The study devised for the investigation of impacts resulting from physical, chemical, and biological activities in the soil root zone on percolate flow and quality had two objectives. As stated in the original proposal, these were:

(1) To obtain information on the amount and rate of water movement in the unsaturated zone under different cropping management systems; and

(2) To obtain data on the quality of water applied to the soil and that drawn from different soil depths in the unsaturated zone.

To accomplish these objectives, test facilities were constructed at the Gray and Hancock sites. The test facility on the Gray site was located in an area adjusting to a lower hydraulic loading while the test area at the Hancock site was constructed in an area just being subjected to irrigation with treated wastewater.

Measurements were made of the precipitation and of 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.

Considerable biological and chemical activity occurs in the near-surface zone among the life forms inhabiting the soil and the various and complex soil, soil-water, and soil-atmosphere interfaces present. To monitor percolate flow and possible quality changes with soil depth, lysimeter systems were installed so that percolate could be obtained at three different levels in the root zone under each test plot.

SECTION II

CONCLUSIONS

1. The extraction lysimeters utilized in the study are not suitable for use as monitoring devices in operational land treatment systems primarily because of the high costs associated with their installation and operation when compared to conventional ground water monitoring.

2. Hydraulic loading rates utilized during this study were insufficient to produce percolate for quantity and quality analysis for use in evaluating current design criteria for test crop conditions using slow-rate land application procedures.

3. The inability to apply design hydraulic loadings to the test plots, to intercept percolate in the soil profile, and to accurately measure evapotranspiration on the test plots caused unexplained losses of such magnitude that accurate and meaningful water or solute balance determinations for the substances measured during the project can not be developed.

4. The lysimeter techniques utilized in the project cannot reproduce the conditions of soils in their natural state nor detect the subtleties inherent in the hydraulic responses of undisturbed soils at a specific locale.

5. The mass of cations and anions contained in the small amounts of percolate at pH levels in a range from 7.4 to 8.8 measured in the root zone of the test plots irrigated with wastewater effluent may adversely impact the quality of the ground water underlying the Hancock site if irrigation with wastewater effluent is continued at design rates over a period of years.

6. Except for nitrates and potassium, the nutrient parameters, in percolate collected from lysimeters where more than one water quality test for the parameter was performed, were generally reduced by a factor of 10 or more from the applied water.

7. Test facilities utilized on the project were subjected to flood damage and operational delays as a result of piping actions caused by fissures in the soil profile.

8. Experiences in this study indicated that better techniques must be developed to measure and adjust vacuum levels employed in extraction lysimeters.

9. From an operational basis, slow-rate land application systems utilizing forage crops offer less conflicting interactions among weather factors, crop

cultural needs, farm machinery use, and wastewater irrigation schedules than other crops.

SECTION III

RECOMMENDATIONS

1. A long-term study would be essential to determine the influence of crop production and biological activities in the root zone on the flow patterns and quality of percolate generated by the land application of municipal wastewater.

2. The areal occurrence, frequency of flow events, and magnitude of the mass of water-borne solutes and pathogens transported through macropores in the soil matrix should be investigated at land application sites. When ponding of wastewaters on the surface occurred, macropores flowed under hydrostatic pressure.

3. Appropriate tracer materials should be added to irrigation water in order that the rates of water and solute movement can be determined under different rates of hydraulic loading.

SECTION IV

RESEARCH APPROACH

SITE CHARACTERISTICS

The selection of the test areas on the Hancock and Gray farms was originally predicated on the soil characteristics of the facilities, past management practices, and surface drainage.

Hancock Site

Because of the locations preempted for center pivot irrigation units, the test sites available for selection on the Hancock farm were restricted to corner areas. The site chosen is indicated in Figure 1.

In previous years, when ground water had been available for furrow irrigation, the row orientation was from north to south. The test plots occupied the head row area that had existed during the early irrigation era. This could imply that greater amounts of irrigation water had percolated down through the soil profile of the test area than in those areas located further down slope.

Site location had impacts on both the availability and quality of water used during project activities. The distribution system installed on the site could not be designed for maximum flexibility of operations. The location of the test area on the farm prescribed that the water supply line be connected to an 0.38 m diameter pipeline on the eastern boundary of the site. This pipeline was the primary transmission line for conveying treated wastewater from Lubbock to a 1.48×10^6 m^3 storage lagoon. The irrigation water applied at the test site was generally water that had been pumped from Lubbock rather than water from the storage lagoon.

Gray Site

The test facility at the Gray site was selected from among the field areas which had the longest histories of treated effluent irrigation. The location of the facility is shown in Figure 2. The ditches adjacent to these roads prevented highway runoff from entering the plot area. The land slope of the test area was from east to west at less than 1 percent. The field plots were supplied with irrigation water from a wastewater effluent storage lagoon located approximately 1.5 km northwest of the site.

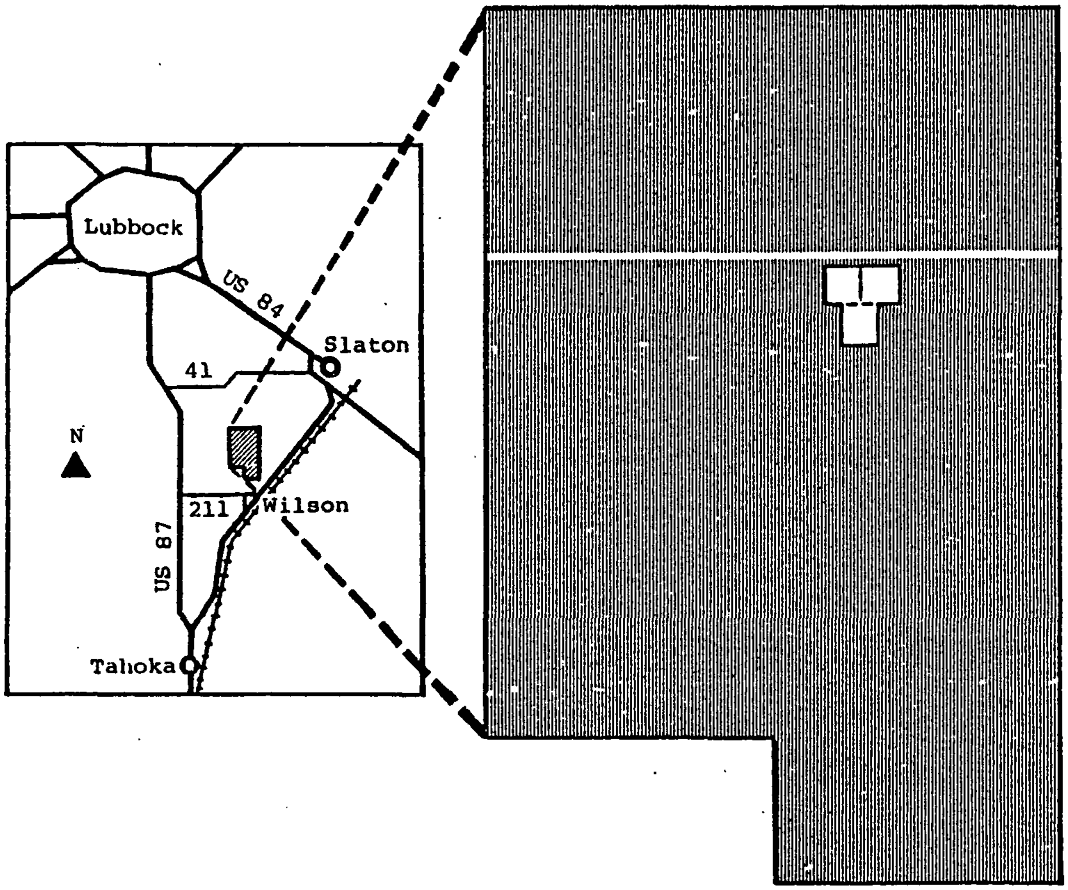

Figure 1. Location of the Hancock Farm Test Site

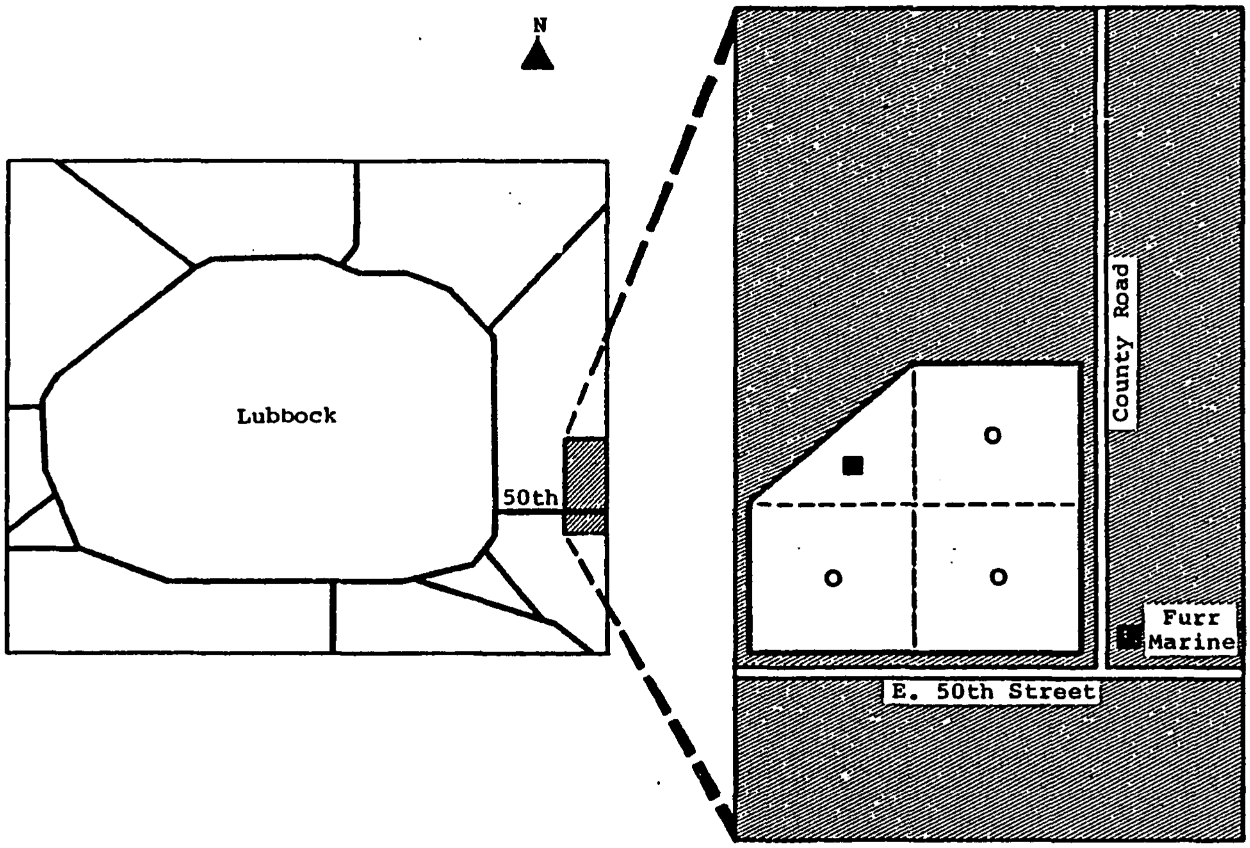

Figure 2. Location of the Gray Farm Test Site

Plot Layout

The crop systems selected for both test areas were cotton, grain sorghum and bermuda grass. These crops were of economic importance in the region and also exhibit varied ranges of water and nutrient requirements during growth (Table 1). Only one plot for each crop was planned at each test area.

Three adjoining 0.84 ha plots (91.5 m per side) were laid out and enclosed by a cyclone fence. The percolate collection facility was located at the center of each plot. The 45-m distance from the plot boundary to the test facility was assumed to be sufficient to eliminate boundary effects caused by other land uses on areas adjacent to the test plots (15).

Soil Characterization

The test areas at the Gray and Hancock farms were located on the soil types that the county soil survey publications for Lubbock and Lynn counties (3, 12) showed to comprise the largest acreage on the farm. The Gray test area was located on a soil of the Friona series and the Hancock area was located on one of the Amarillo series. Both are loamy soils located on uplands and formed in calcareous, loamy eolian deposits. Typical profile descriptions of the soil are provided in Appendix A.

TABLE 1

SEASONAL WATER AND NUTRIENT USE BY CROP TYPES UTILIZED IN STUDY

Crop	Total consumptive use of water[a] (cm)	Nitrogen (kg/ha)	Nutrients phosphorous[b] (kg/ha)	Potash (kg/ha)
Bermuda grass[c]	102[d]	400-675	35-45	225
Cotton	76	75-110	15	40
Grain Sorghum	46	135	15	70

[a] Hansen et al. (18).
[b] Process Design Manual Land Treatment of Municipal Wastewater (18).
[c] Nutrient figures are for coastal bermuda grass.
[d] Water use figures are for pastures.

SYSTEM DESIGN AND MONITORING PROCEDURES

Lysimeter Systems Design

Two types of nonweighing lysimeters using undisturbed soil profiles were installed on the test plots. The first type, hereafter referred to as tube lysimeters, consists of a form made of appropriate siding material to be pushed down through the soil profile at the sampling site (4). After reaching the appropriate depth, the form with its encased soil core is removed. After equipping the unit with a percolate collection system, the enclosed soil core is used as the test material. The test unit can be installed in the laboratory or at a field site. The other type involved employs trays filled with a disturbed soil to capture soil percolate; these are placed under, and in contact with, the overlying undisturbed soil profile by means of horizontal excavations (7). The tray technique is site specific.

Vacuum devices were used to obtain percolate from the lysimeters. The vacuum level was adjusted to the level measured by a tensiometer located in adjacent undisturbed soil. If soil characteristics were uniform, this practice would insure that the area of influence on moisture transport in the profile above the tray or tube is no greater or less than a comparable area in the undisturbed profile.

Replicates of the two lysimeter techniques for collecting soil percolate were utilized on each test 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 containing the necessary support equipment for the installed vacuum extractors was installed at the center of each test plot. The lysimeters were placed in the soil 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. The use of a circular chamber allowed the units to be placed within a small area, thus minimizing both differences in soil characteristics and in plot size. A plan view of a test facility is shown in Figure 3. A detailed description of the units, their installation, the supporting facilities, and operational characteristics follows.

Tube Lysimeters--

The tube lysimeters were constructed from used 76.2 cm OD steel pipe with a wall thickness of 0.95 cm. The soil area within pipe sections was 0.434 m^2. The number and length of the tube lysimeters installed on the project were: 14 with a length of 107 cm, 14 with a length of 168 cm, and 4 with a length of 229 cm.

Three angle iron ears were welded at points 120 degrees apart on the pipe surface at about 30 cm from the top of the pipe. These served as attachment points for chains used for either lifting or positioning the pipe

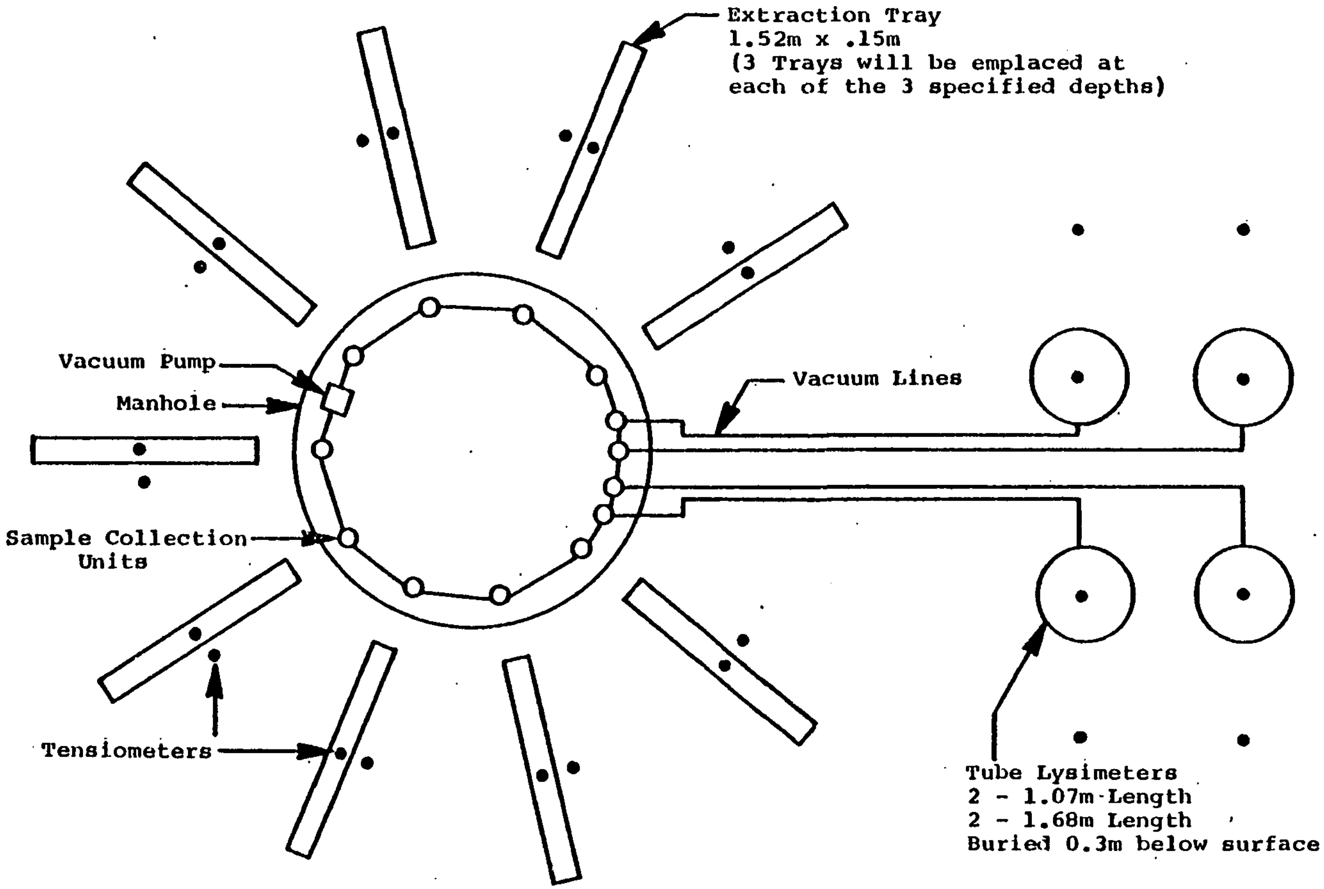

Figure 3. Plan of Test Facility

sections. The pipe sections were taken to the test area and placed at points that had been randomly selected on the plot map around the proposed locations of the percolate extraction facilities. Each point on the surface at the site was assumed to overlie material of the same soil type and to exhibit uniform profile conditions. The processed units from each farm area were later indiscriminately assigned to one of the three test facilities at each site.

At the designated location, the top 30 cm of soil was scraped off and the pipe section was placed vertically on this surface then driven into the soil under existing site conditions. Water was not applied to wet the soil material. Only in very few instances did the pipe advance exceed 2.5 cm per blow. Generally, the penetration was 1/20 to 1/5 of this value. Excavation of the soil around the outside of the pipe after driving the pipe into the ground a few centimeters was found to increase the depth per blow. After the pipe sections had been driven to their final depth, the units were lifted and loaded for transport to a processing area.

In the processing area, each pipe section was inverted, exposing the bottom of the soil profile for further processing (Figure 4). The lower 15 cm of soil in the original profile was removed and two percolate extraction units were installed so that, if failure in one unit occurred, percolate collection from the lysimeter continued through the remaining unit. Each unit utilized three porous ceramic, round-bottomed, straight-wall cups, rated at 1 bar under high flow conditions; these were 4 cm in diameter by 19 cm in length. The cups were connected together with tygon vacuum tubing having 6 mm I.D. and 4.8 mm wall thickness. The cup connection to the vacuum tubing consisted of a short length of glass tubing which passed through a rubber stopper cemented in the end of the cup, and was inserted into the vacuum tubing. The vacuum tubes for each unit passed through a hole constructed in the side of the lysimeter. Rubber grommets were fitted around the tubing and coated with silicone sealer to provide an effective water barrier.

At this time, a control tensiometer, consisting of a porous ceramic cup with a suction value of 1 bar, cemented and sealed with cold-setting silicone rubber to tygon tubing was installed. The tubing (11 mm I.D. and 1.6 mm wall thickness) for this unit also passed through a grommetted hole (19 mm diameter) in the side of the lysimeter. After inspection, the soil taken from the bottom of the lysimeter was replaced and packed by hand around the extraction units. The remaining void was then filled with soil that had originally been taken from the unit. A bottom plate was placed on this surface and tack-welded to the pipe. The pipe section was then inverted and the bottom plate was welded to the pipe section. The welded joint, after cleaning and inspection, was sealed with a coating of silicone.

The prepared tubes were transported to the test facilities where a crane was used to place each lysimeter on earth footings that had been leveled to the proper depth in the excavation. Tygon vacuum tubing was laid in a prepared trench from the test facility to each lysimeter and connected by a polyethylene male-female connection to the short piece of tubing that had been provided on each extraction unit. The connections were cemented together and sealed with a cold setting silicone rubber. Tygon tubing from

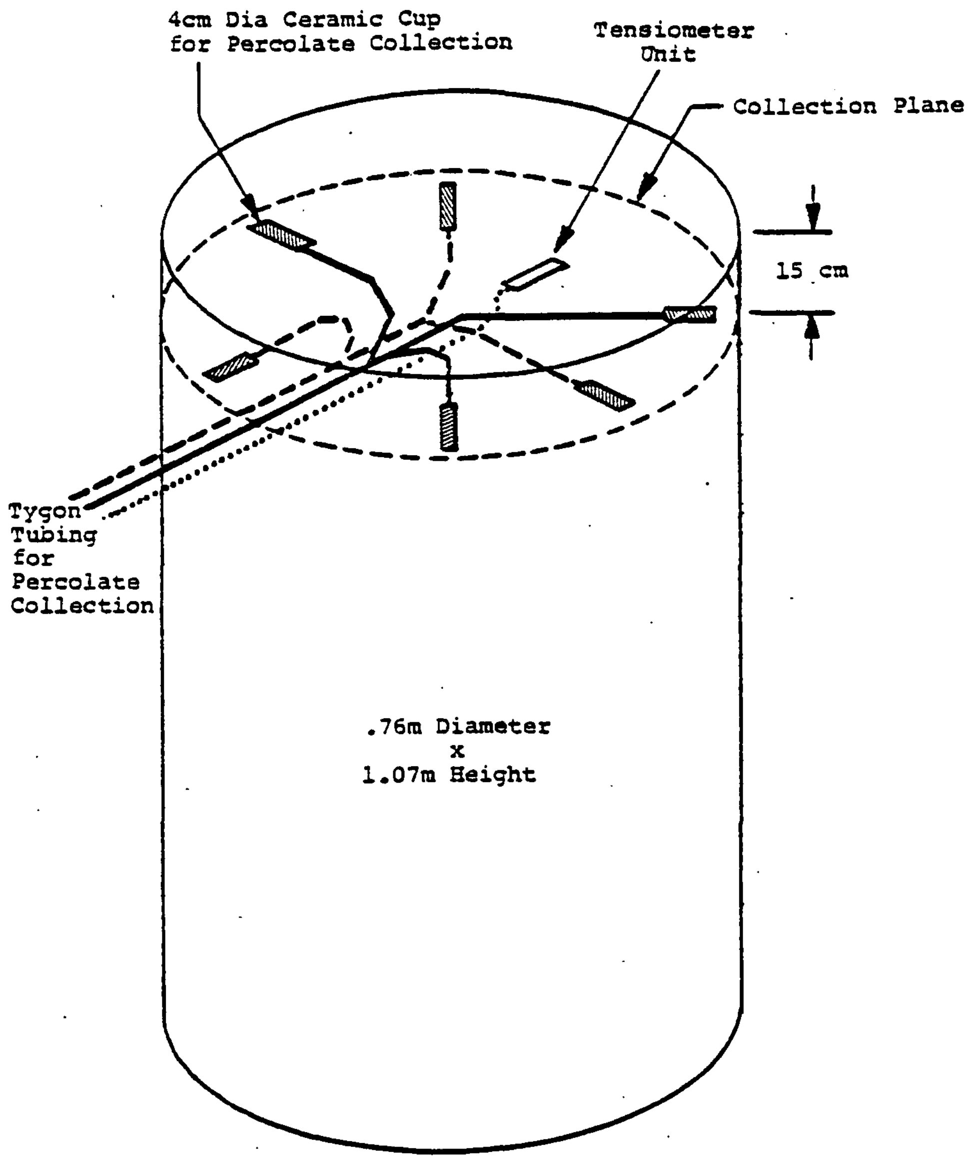

Figure 4. Arrangement of Percolate Collection Units in Tube Lysimeter

the test manhole was connected to the control tensiometer at this time also. After inspection of all connections, the tube lysimeters were buried with material excavated from the lysimeter trench. Stored topsoil was then spread over the tops of the tube lysimeters to a depth of 30 cm.

Soil compaction did occur during the process of driving the pipe sections into the soil profile. Excavation of the bottom 15 cm of soil from the unit was difficult in all cases, indicating that the density of the soil in the lysimeter may have been greater than that observed and experienced at adjacent depths outside of the driven pipe sections. Two permeability tests using a falling head permeameter with no pressure were conducted on soil samples taken from the bottom of two units. Results gave rates of permeability below 1×10^{-8} cm/sec. These results and the packing of the soil that was evident in the removal of the lower 15 cm of soil from the test units caused concern about the validity of comparisons between percolate flows in field soils and those found within the tube lysimeters.

Tray Lysimeters--

The design and installation of the tray lysimeters utilized in the project were based upon the extraction devices developed by Duke and Haise (6). The 56 trays used on the project were 15 cm wide, 20 cm deep, and 150 cm long. The top area of each tray was 0.232 m^2. Four trays utilized for extracting percolate samples for priority organic analysis were constructed of stainless steel (fittings and tubing were constructed from teflon material) whereas the others were constructed of 18-gauge galvanized sheet metal.

The tray lysimeters were installed in horizontal cavities dug radially outward from the plot's underground equipment shelter. A plan view is shown in Figure 3. The underground equipment shelter (manhole) was constructed in an excavation that had been obtained by boring a 3.35 m diameter hole at the center of the test plot to a depth of 3.35 to 3.65 m. The placement of the boring rig and, subsequently, the travel of other vehicles on the test plot, were restricted to the sector where a later excavation was to be made to place the tube lysimeters. The side walls of the manhole were formed into a 10-sided polygon, 3.2 m in diameter and 2.8 m high. Treated tongue-and-groove lumber, 5 cm thick, was bolted to three angle-iron "hoops." The exterior corner joints on each side were covered with a strip of 20.3 cm-wide galvanized flashing material. The completed, painted wall units were lowered into the prepared excavation.

After leveling the wall sections, rectangular openings, 25 x 30 cm, were cut into the wooden walls at each tray lysimeter location so that the rectangular cavity could be drilled for installing the tray. Once the holes were cut, metal flashing was placed around the rectangular openings to hold back pea gravel poured to fill the void space between the soil and the wooden wall. The gravel provided a rapid drainage pathway for the percolate intercepted by the manhole roof. It was found that a grouting operation was necessary to stabilize the pea gravel around the rectangular cavities.

The hydraulic soil coring and sampling machine that had been modified and used by Dukes at Colorado State was employed to dig the horizontal cavity. The horizontal cavities for the trays were dug in two steps. A 10 cm diameter pilot hole was drilled with a flight auger to a distance of 2.5 to 3 m horizontally into the earthen wall. Loss of control in vertical alignment of the pilot hole caused a dome to form in the final cavity roof in the first four holes drilled. These holes were modified by redrilling and increasing the cavity length until a flat section was available for the 1.52 m tray. Stabilization of the boring unit so that horizontal and vertical alignment was maintained during construction of the cavity was essential.

After completion of the pilot hole, a rectangular coring device with a sharp front edge that sheared the soil to produce the final rectangular-shaped cavity was pushed into the soil by hydraulic pressure. The sheared soil was stored in the interior of the coring device. A portion of soil removed during the coring phase was placed in plastic garbage bags and used to fill the tray installed in that particular cavity. The three holes at each depth were drilled 108 degrees apart to provide as large a sampling area as possible.

Holes were punched in the end of the tray nearest to the manhole. The hole location and dimensions are shown in Figure 5. An inflatable air bag was constructed for each tray. The inflated air bag was to keep the tray in contact with the roof of the cavity in a manner similar to that used in the Colorado State study. Lay-flat butyl tubing, 10 cm in diameter, was cut into 1.5 m segments to form the air bag. A valve stem from a truck tire was attached by vulcanization to each segment. The ends of each bag were folded and sealed by vulcanization. An air bag was then glued to the bottom of each tray. An airhose assembly, that had been previously checked for leaks by submersion in a water bath while attached to an inflated bag, was then connected to the valve stem and the air bag was inflated. Air pressure was maintained for at least a week for leak detection. The air bag assembly was then deflated and remained in the deflated state until after the tray had been inserted into the cavity.

The extraction units consisted of five ceramic tubes fastened together. These tubes were made by sawing off the closed ends of flat-bottom straight-wall porous ceramic cups 30 cm in length; they had a one bar bubbling pressure. The modified cups were joined by cementing a tygon tubing sleeve to two adjacent units. One end of each complete unit was connected to a plastic fitting that passed through the end of the tray during installation and was joined to a length of tygon vacuum tubing during the installation process. The vacuum tubing from the two extraction units in the tray would be joined to a Y-connection located in the manhole which provided two separate percolation collection systems. If one extraction unit failed it could be sealed off and the other used.

The other end of the extraction unit was fitted to a length of 3 mm-I.D. tygon tubing. During installation this piece of tygon tubing was folded back and buried in the fill soil of the tray. The remainder of the tubing was passed through a separate hole in the end of the tray closest to the manhole and was terminated in the manhole. The ends of the tubing were tightly crimped to prevent air entry. This small tube could be used to flush out the

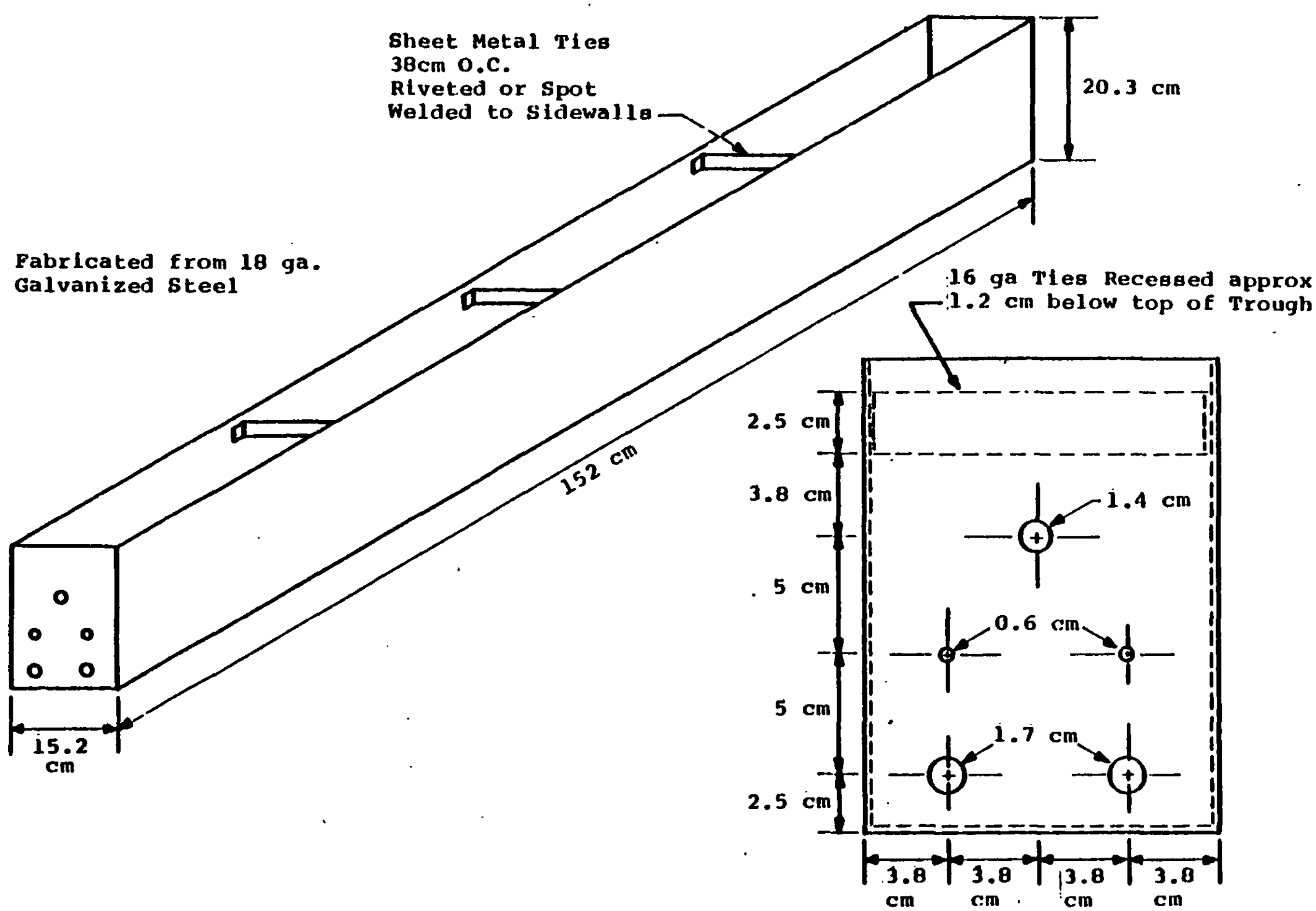

Figure 5. Extraction Tray Design

ceramic tubes if a slime buildup were to occur. The wick assembly is shown in Figure 6.

The installation of each tray lysimeter began with the placement of sifted soil (wire mesh with 1 cm between strands) in the bottom of the tray to a depth of 2 to 2.5 cm. Two wick units were placed on the soil bed in the bottom of the tray. The tygon tubing and plastic fittings were inserted through the proper holes then sealed with grommets in the end of the tray. A coating of silicone sealer was placed over each grommet both on the inside and outside of the tray. Soil was then gently placed around and over the ceramic candle. The remaining space in the tray was filled by placing thin layers of sifted soil in the tray and firming these layers by hand. A tensiometer unit consisting of a porous ceramic cup glued to a length of tygon tubing sufficient to reach the manhole cavity was installed just below the soil surface in the tray.

After filling and leveling the soil in the tray, a thin layer of soil was sifted over the tray. The tray was then moved from the assembly point to the entrance of its respective cavity and pushed into the cavity beneath the undisturbed soil zone. After the lengths of vacuum tubing were glued to the plastic fittings and coated with silicone sealer, the tray was pushed to its permanent position.

When all the trays had been installed, the air bags were inflated to raise the trays to positions where they were in contact with the roofs of the cavities. About half the bags deflated within 24 hours. The 75 to 80 kg weight of some 0.045 m^3 of soil in the tray imposed greater stress on the inflated bags than had been experienced in the pre-installation leak test under no-load conditions. Rather than repair the air bags, a decision was made to place wooden wedges under each tray. Three pairs of wedges were forced into position between the sides of the cavity and the inflatable bag.

After installation of the tray lysimeters, the manhole structures were completed. Each unit was floored and a sump pump was installed in a reservoir under the floor. The outfall of the sump pump was a gravel bed buried at a depth of 60 cm below the soil surface and located 6 m from the edge of the manhole. An earth-covered roof was constructed over each unit. Access to the unit was by means of a manhole 1 m in diameter. An air vent system was installed to produce an air circulation pattern that reduced humidity levels in the manhole facility.

Vacuum System--

The lysimeters in each battery were in close proximity and the number of units in each battery ranged from 13 to 17. A vacuum system similar to the system employed by Dr. Harold Dukes of Colorado State University (7), was used in this study. The volume of space in the wick system and the connecting vacuum tubing lines was estimated for the respective lysimeter batteries to determine the volume evacuated. One vacuum unit with a 38 liter reservoir serviced the lysimeters in each battery.

The lysimeters were attached individually to the vacuum unit through a loop system. Each lysimeter unit had an individual control panel. This

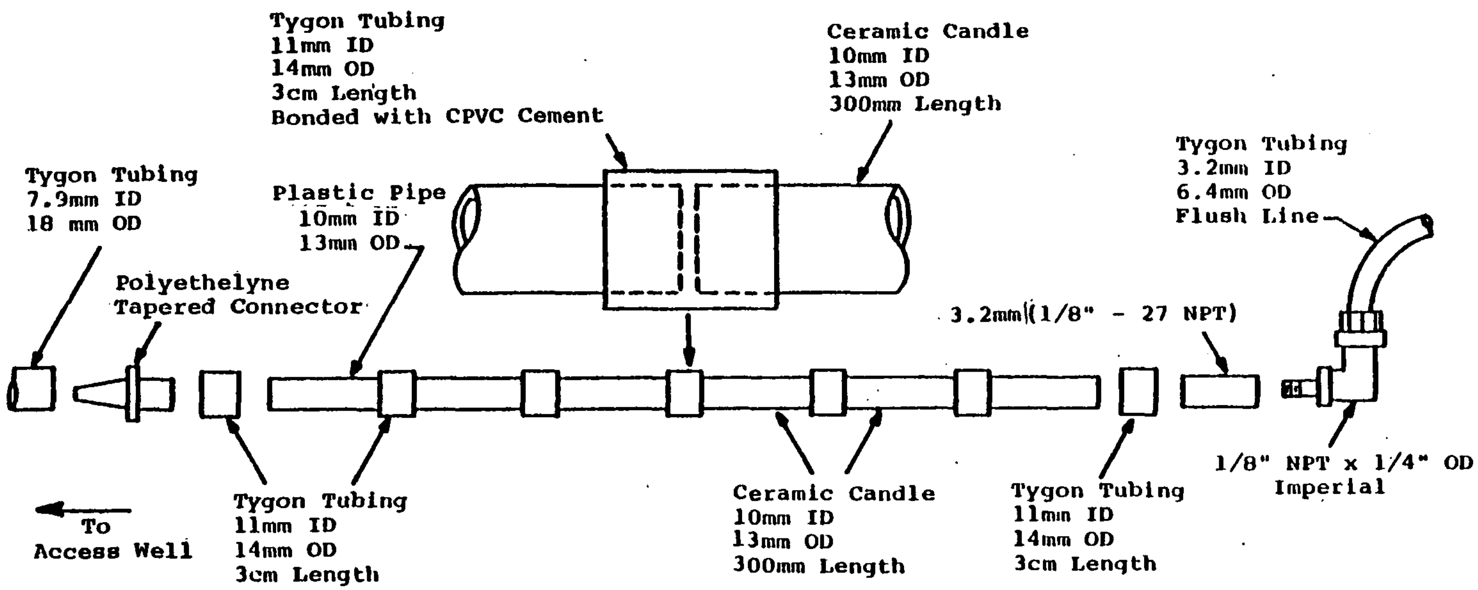

Figure 6. Wick Assembly

system adequately handled the wide range of vacuum requirements experienced among the lysimeters in each battery.

The design for the control panel utilized for each tray or tube lysimeter has been outlined in previous studies (6, 7). A schematic diagram of the vacuum system control panel used on each lysimeter is shown in Figure 7.

In the original design, the control of the vacuum in each lysimeter was regulated by using the readings taken on two tensiometers. One of these was a reference tensiometer located in the undisturbed soil and the other was a tensiometer installed in the lysimeter. The tensiometers were installed horizontally from the manhole so that less equipment would be present on the soil surface.

A reference tensiometer, consisting of a porous ceramic cup glued to a section of thin-wall tygon tubing was placed in the undisturbed soil approximately 30 to 60 cm to the side of the tube or tray lysimeter. The water reservoir for the tensiometer was also connected to a manometer in which air was the fluid between the mercury in the manometer and the water in the reservoir.

The tensiometer in the lysimeter was implanted in the top of the tray lysimeter when the tray was being filled with soil and the tubing was extended through the end of the tray. In the case of the tube lysimeters, the tensiometer unit was installed in the bottom of the tube at the same time the percolate collection units were installed. The tubing from the tray and/or tubes was also connected to water reservoirs consisting of plastic pipe. These units were hooked to mercury manometers in the same manner as the reference tensiometers.

Originally, the first step in the lysimeter operational procedure was to adjust the needle valve on the control panel to regulate the vacuum level in the candle so that eventually the tray tensiometer manometer reading would equal that of the reference unit in the undisturbed soil. A series of needle valve adjustments over time would be necessary to bring about agreement between the reference tensiometer and the tensiometer in the tray or tube. Under the planned schedule of irrigation, divergence in the tensiometer readings was not expected since the moisture content of the soil was anticipated to remain at or near field capacity during the projected period.

Irrigation System Design

Treated municipal wastewaters were to be applied to the test plots by sprinkler irrigation. The hydraulic loading rates for the project cropping system were developed in accordance with the recommended EPA design procedures (18).

Hydraulic Loading Rates--

The design rates for a land application system may be dependent on one or a combination of soil characteristics at the site, concentration of materials in the wastewater, and/or climatic conditions.

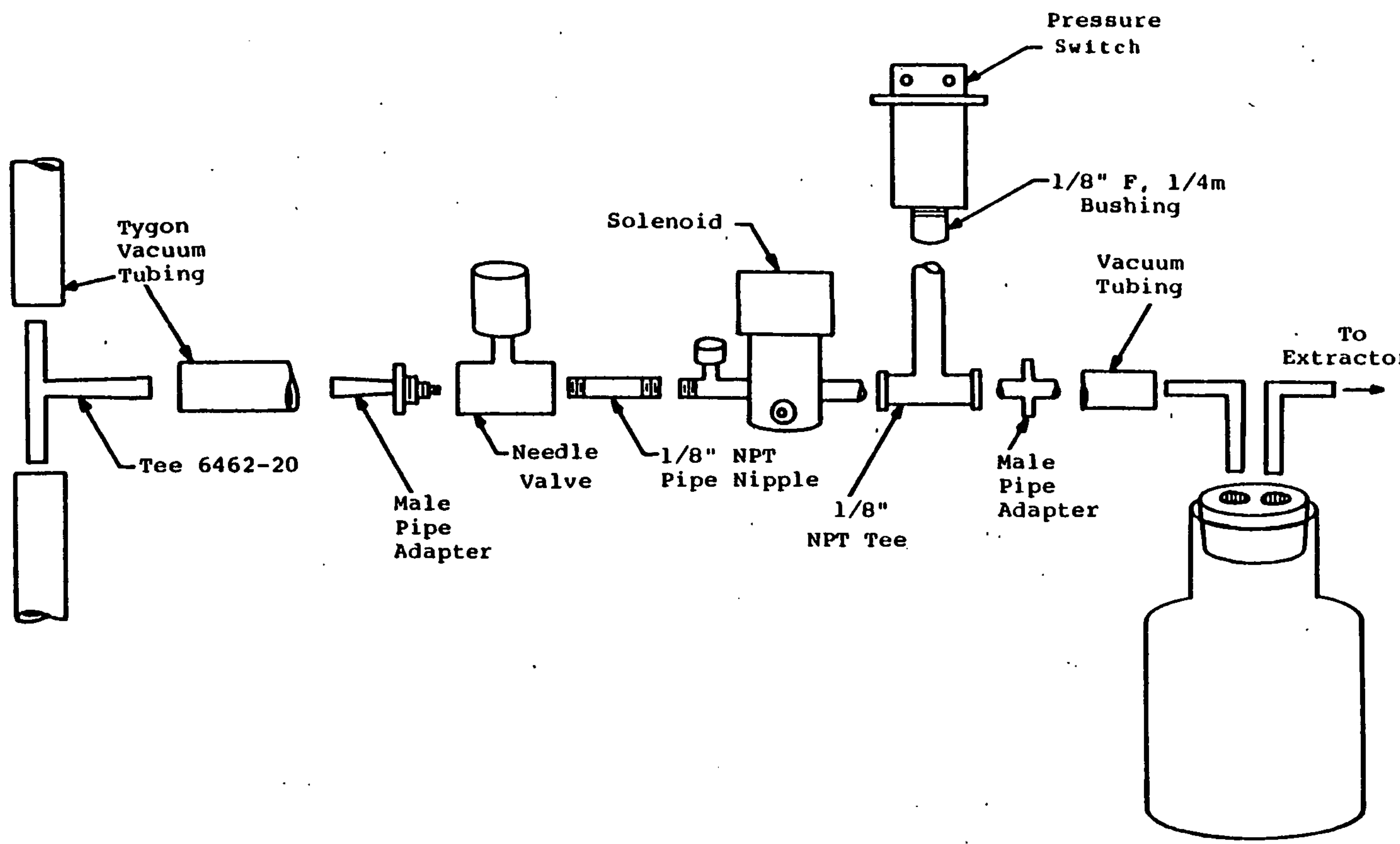

Figure 7. Lysimeter Control Panel Design

Climatic factors--The following discussion presents the development of precipitation and evapotranspiration conditions required for calculations.

Precipitation--Forty years of monthly precipitation data obtained at Lubbock were used to determine monthly design values for use in the EPA procedure. The National Weather Service recording station at the Lubbock International Airport was approximately 12 km NW of the test plot at the Gray site and 33.8 km NNW of the Hancock site in Lynn County. Frequency analysis was employed to determine the monthly precipitation that will occur at least once in a five-year period. The recurrence interval (R.I.) was calculated by the formula:

$$R.I. = \frac{N + 1}{M} \qquad (1)$$

where N = number of monthly values, and
M = rank of individual value.

The monthly values obtained using the analysis outlined in the EPA manual are shown in Table 2.

TABLE 2

PRECIPITATION VALUES FOR 5-YEAR RETURN PERIOD

Month	cm
January	1.96
February	2.95
March	4.11
April	4.76
May	10.11
June	10.85
July	9.53
August	9.27
September	10.44
October	8.76
November	2.74
December	2.60
TOTAL	78.08

Evapotranspiration rates--The calculation of specific evapotranspiration rates consisted of two tasks. The first task was to calculate the potential evapotranspiration rate. This value is representative of a well-watered crop of alfalfa which is under no moisture stress (9). The second task was to determine the water needs of the crops, consisting of bermuda grass and annual crops of cotton, grain sorghum and winter wheat, to be used on the test plots during their growth and development.

Potential evapotranspiration rates used in determining the hydraulic rates for the test plots were estimated by means of the Jensen-Haise procedure (9). This procedure, classified as a "radiation method," utilizes local temperature and percentage of sunshine.

The basic equation for calculating the potential daily evapotranspiration (ET_p) in langleys/day as defined for a well-watered alfalfa crop is:

$$ET_p = C_T (T - T_x) R_s \tag{2}$$

where T = average monthly temperature in °C.

The other factors in equation (2) are variables developed from the following equations. C_T is a temperature coefficient defined as:

$$C_T = \frac{1}{C_1 + C_2 C_H} \tag{3}$$

where $C_1 = 20 - [(2°C)(\text{elevation in m above MSL})/305]$,

$C_2 = 7.6°C$, and

$C_H = 50 \text{ mb}/(e_2 - e_1)$

The values e_2 and e_1 are the saturation vapor pressure in millibars (mb) at the mean maximum and mean minimum temperatures for the warmest month at the site.

T_x is a constant defined as:

$$T_x = -2.5 - 0.14 (e_2 - e_1)°C/\text{mb} - (\text{elevation in m above MSL})/550 \tag{4}$$

R_s, the incoming solar radiation, is defined to be:

$$R_s = (0.35 + 0.61S)R_{so} \tag{5}$$

where S = ratio of actual to possible sunshine, and

R_{so} = average cloudless-day solar radiation for the month in question and the latitude position of the site.

The average monthly temperature, percentage of possible sunshine, and temperature values for determining e_1 and e_2 were obtained from a climatological summary for Lubbock published by the National Weather Service. The latitude and elevation of the Lubbock International Airport weather station were used rather than those at the individual sites since the maximum difference in latitude between the station and the sites was approximately 18 minutes and the elevation difference was less than 65 m. The conversion of langleys/day to mm/d of water was based upon the change of enthalpy at the average monthly temperature. The monthly values of ET_p are given in Table 3.

To adjust the potential evapotranspiration requirements which were calculated for alfalfa to evaporation requirements for crops grown on the site, crop coefficient (kc) values were developed. The procedure utilized for determining the kc values is that outlined in Guidelines for Predicting Crop Water Requirements, published by the Food and Agricultural Organization (FAO) of the United Nations (5). The monthly ET_p values were multiplied by the appropriate kc values to determine the monthly values for each particular crop. Evapotranspiration values for each cropping season were developed including both periods when bare soil and/or crops were present. The results obtained for cotton, grain sorghum, and bermuda grass systems are given in Table 3. For months when bare soils and crops were present, a proportion of the ET for each condition was computed and summed to obtain the kc value.

TABLE 3

MONTHLY ET_p AND ET_{crop} VALUES FOR CONDITIONS AT LUBBOCK, TEXAS

		ET_{crop}		
Month	ET_p (cm)	Cotton (cm)	Bermuda (cm)	Grain Sorghum (cm)
January	3.91	2.97*	1.40***	2.97**
February	6.01	3.97*	2.16***	3.97**
March	10.01	5.21*	6.00	5.21**
April	15.84	6.50*	15.84	6.50**
May	20.80	13.10**	20.80	10.92
June	26.31	11.57	26.31	17.10
July	25.98	24.03	25.98	28.32
August	24.15	29.00	24.15	25.12
September	16.77	19.96	16.77	10.90
October	11.78	11.07	11.78	6.83**
November	6.18	3.46**	3.59***	2.97**
December	4.12	2.39*	1.50***	2.39**
Total	171.00	133.23	156.28	123.20

*bare soil
**partially bare soil and part cover
***dormant vegetation

Hydraulic Loading Calculations--

The hydraulic loading rate for each test plot was determined using both water and nitrogen balances as design criteria (18). These two calculations and the crop coefficients used to adjust evapotranspiration values are described in the following sections.

Water balance criteria--Initially, permeability data published in the Soil Conservation Service (SCS) Soil Survey for Lubbock County, Texas (3) were utilized as the basis for design. These data had been obtained from representative profiles of the soil series and served as an estimate of soil water flow conditions at the site. The results obtained with these data gave conservative values in that the capacity of the soil profile to transmit water (LW_p in cm per month) was used as the basis for the hydraulic loading rates. In light of these conservative figures a series of infiltration tests was made at each site in July 1982 and used as the basis for determining percolation rates. The split-ring infiltrometer tests yielded the following steady state infiltration rates:

Friona Ap series - 46 mm/hr,
Friona B22t - 179 mm/hr,
Amarillo At - 62 mm/hr, and
Amarillo B22t - 84 mm/hr.

Using the lower values of these data as the limiting condition for percolate determination, new hydraulic loading rates were computed.

The monthly hydraulic loading rate (LW_p) in cm of water, assuming that the surface runoff of precipitation is zero, can be defined as:

$$LW_p = ET_c - P_r + P_w \qquad (6)$$

where ET_c = monthly rate of evapotranspiration of crop in cm,

P_r = monthly precipitation (5-yr return period) in cm, and

P_w = monthly probable soil percolation rate in cm (18).

The loading rates obtained for the three cropping systems are presented in Appendix B. The monthly values of P_w are based on the number of operating days at each site each week (2.5 days) imposed by the irrigation priorities adopted for the project.

Nitrogen balance criteria--The nitrogen balances were based on a total Kjeldahl nitrogen content of 27 mg/l N measured in the wastewater collected at the Gray site and on 24 mg/l N wastewater produced at the Lubbock wastewater treatment plant in July 1982. The configuration of treatment processes used at the Lubbock treatment plant produced different effluent streams which caused the variations in nitrogen content.

The seasonal nitrogen needs of the crop were taken from the EPA design manual (18). The monthly nitrogen use values were calculated by multiplying the seasonal nitrogen need by the ratio obtained when each monthly value of evapotranspiration for the crop was subtracted from the precipitation (Pr–ET) value for the crop and the result was divided by the (Pr–ET) value for the growing season.

The monthly hydraulic load $LW_{(N)}$ in cm of water was computed by use of the following equation:

$$LW_{(N)} = \frac{C_p\,(Pr\text{-}ET_{crop}) + U\,(10)}{(1 - f)\,C_N - C_p} \qquad (7)$$

where C_p = nitrogen content in mg/l in percolating water (10 mg/l under EPA guidelines),

$Pr\text{-}ET_{crop}$ = net evapotranspiration in cm,

U = nitrogen uptake by crop in kg/ha during the month,

f = fraction of applied nitrogen removed by denitrification and volatilization (0.2 used for determinations), and

C_N = nitrogen concentration in mg/l in applied wastewater.

The values obtained for $LW_{(N)}$ at both sites are given in Appendix B. The hydraulic loading rates computed for each crop at both sites are presented in column 5 of these tables. The design loading rate (LW_D) in cm of water applied per month presented in column 6 of Tables C-1 to C-3 for each crop will be limited by the nitrogen content of the wastewater rather than by soil permeability.

<u>Irrigation System</u>

During the planning phase it was assumed that a permanent-set sprinkler irrigation system would be employed on each plot. Economic constraints did not allow utilization of this system.

A traveling gun system* was subsequently selected which utilized pressurized treated wastewater from a permanent pump station on each site. Buried pipe was laid from the pump station to risers. The unit was equipped with a sprinkler nozzle which sprayed in a circular segment over the area where the gun had previously traveled. The device was capable of delivering 800 liters (210 gallons) per minute at 552 kN/m² (80 psi) over a half circle with a diameter of 97.5 m under no-wind conditions. The travel rate of the unit could be altered through a three-speed gear box and by changing sizes of an internal vane device which affected the initial travel speed controlled by the gear box.

The amounts of water applied in each pass could also be varied through

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*Green Field Traveler, model LD6330. Manufactured by Boss Irrigation Equipment Company, Lubbock, Texas.

gear box adjustments. The speed of movement desired was from 0.15 to 0.45 m (0.5 to 1.5 ft) per minute, which was sufficient to give an application volume in each irrigation event of from 4.0 to 6.4 cm over the test areas at a flow rate of 800 liters/minute through the gun. The rate of water application over a half circle with a diameter of 97.5 m was 0.213 mm/m^2/minute. The rates of infiltration for the two soils in the study were high (1.5 to 5.1 cm/hr for the Friona soil, and 5.1 to 15.2 cm/hr for the Amarillo soil) (3) and thus no problem from surface runoff was anticipated prior to the operational phase.

Irrigation Schedule--

The weekly irrigation sequence for each plot is given in Table 4. The irrigation unit would be at each site for a 2.5-day period each week. The bermuda grass plots were irrigated at both sites on Wednesdays. In this manner, it was possible to irrigate the bermuda plots at each site three times and the other two plots twice during the 2.5-day irrigation interval.

Also presented are the approximate number of hours that were projected for irrigating the plots at the time the irrigation system was designed and ordered. The variations in time were caused by differences in travel path lengths and the speed of the gun. The hydraulic loading rates used for the irrigation system design were based on the rates of soil percolate movement in the profile. The maximum amount of wastewater to be applied under the original design was 32 cm/month. The alterations in project loading rates brought about by field infiltration tests resulted in an undersized unit for project needs.

Measurement of Irrigation Water--

Because of the variable area coverage of the irrigation water applied over the plot due to wind, a "catch-can" measurement system was developed. Four plastic cylinders, 10 cm in diameter and 15 cm in height, with weighted bases, were placed in a diamond pattern in which two cans were in line with the manhole cover and parallel to the line of travel of the gun. The distance between adjacent cans was from 10 to 15 meters. The volumes of water caught in these four cans were measured with a graduated cylinder as soon as the irrigation gun plume had moved past the test area adjacent to the manhole.

Irrigation Gun Pathways--

The location of the test sites with respect to state highways, county roads, and activities on adjacent parcels restricted the number of paths across each plot to one. Spray drift caused by wind was the primary constraint. The paths of the gun at each site are given in Figures 8 and 9. At the Hancock site, the bermuda grass plot contained the four control-tube lysimeter units in addition to the two pairs of 122 cm and 183 cm units. The group of eight tube lysimeters at this location was placed in an excavation that had been dug in the quadrant southwest from the manhole; the traveling gun crossed over this installation on a path which had been selected so that it was normally just upwind of the lysimeter battery installation in the direction of the prevailing SW winds. Though this was to have insured that the plot area overlying the test units got a uniform coverage of water in a majority of irrigation events, it actually influenced the amount of percolate

TABLE 4

WEEKLY IRRIGATION SCHEDULE

Day	Site	Irrigation sequence and approximate time in hours		
		First	Second	Third
Monday	Hancock	Bermuda (3.7h)[a]	Cotton (2.2h)[b]	Grain Sorghum (1.4h)[b]
Tuesday	Hancock	Bermuda (3.7h)	Cotton (2.2h)	Grain Sorghum (1.4h)
Wednesday	Hancock-Gray	Bermuda (3.7h)	Bermuda (2.5h)	---
Thursday	Gray	Bermuda (2.5h)	Grain Sorghum (2.5h)	Cotton (2.3h)
Friday	Gray	Bermuda (2.5h)	Grain Sorghum (2.5h)	Cotton (2.3h)

[a]Speed of 0.3 m/minute
[b]Speed of 0.45 m/minute

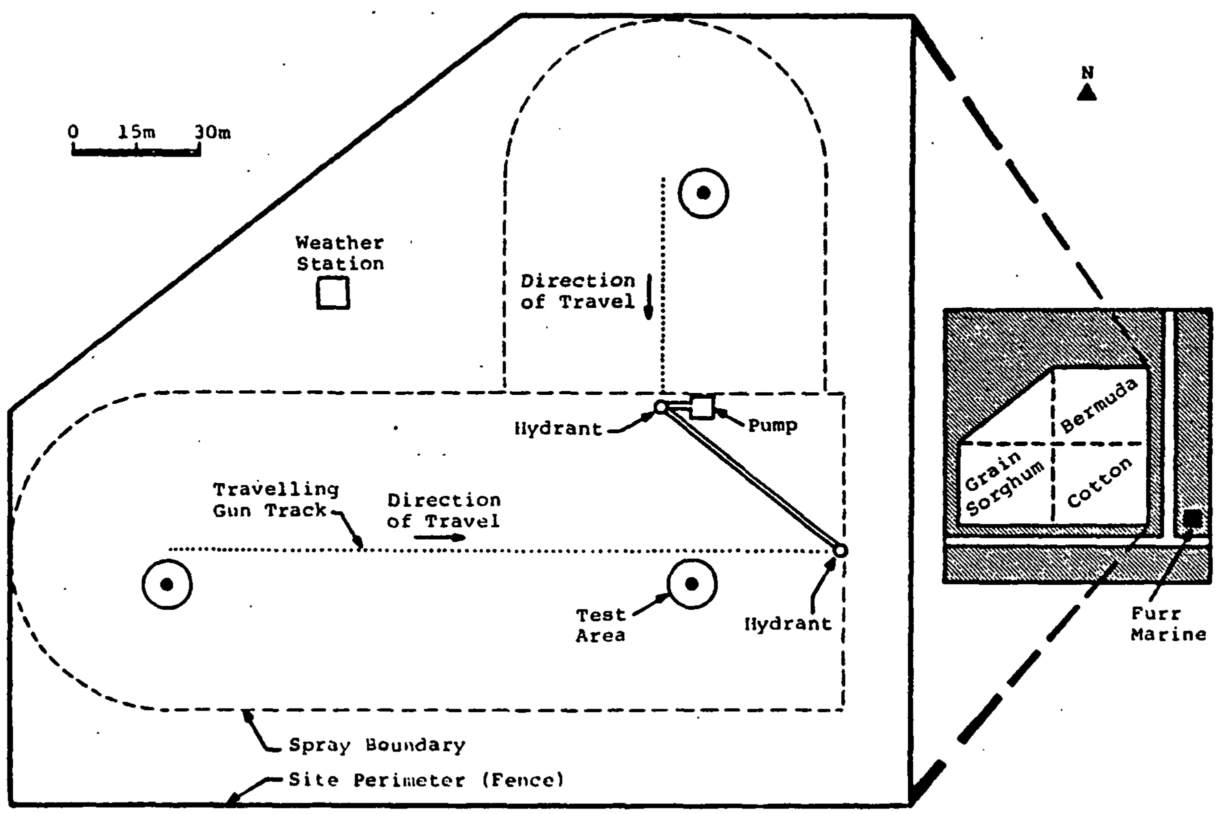

Figure 8. Irrigation Coverage of Test Plot at the Gray Site

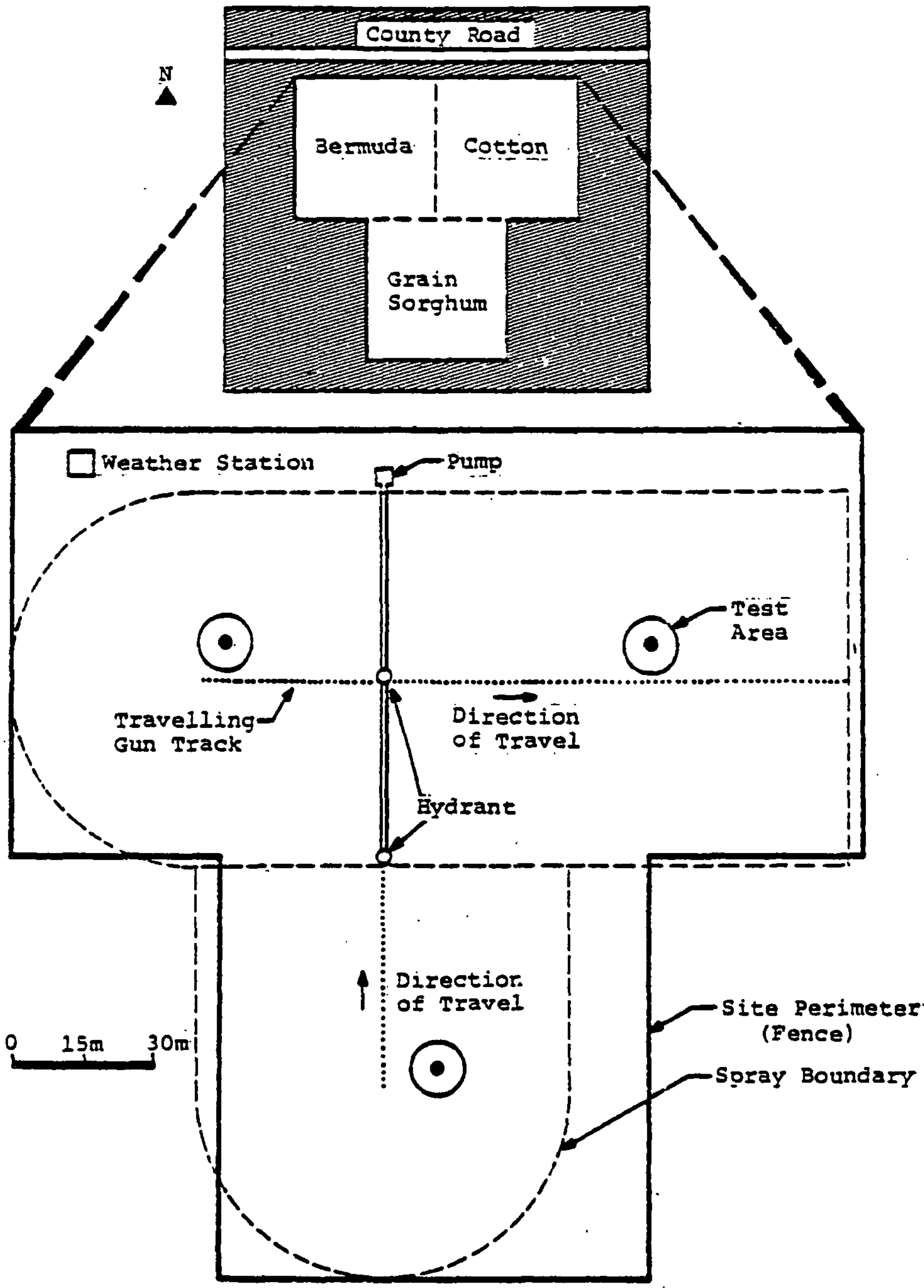

Figure 9. Irrigation Coverage of Test Plot at the Hancock Site

captured by some of the tube lysimeters on this plot. Moreover, the reduced water coverage on a plot probably increased the oasis effect experienced by the vegetation grown over the lysimeters during the hot, dry and windy weather that prevailed over the region during much of the two growing seasons.

Control Lysimeters--

Two pairs of tube lysimeters collecting soil percolate at the 1.2 and 1.8m depths on the bermuda plot at the Hancock site served as the control system for the project. A metal structure with a removable roof was installed over these lysimeters. The sides of the structure were forced into the ground to prevent surface runoff from entering the enclosed area. The roof was placed on the structure during wastewater irrigation periods but was removed during the interim periods to expose the bermuda grass in the structure to sunlight and precipitation.

Initially, each irrigation event on the control units consisted of flooding the surface of the enclosed area with 15 cm of Lubbock's tap water. In the 1983 crop season, a configuration of plastic pipe was used to sprinkle the water uniformly over the surface area.

The water amounts applied to the control plots were to be the same as the design amounts of treated wastewater applied by irrigation. Approximately 15 cm of water was applied weekly to the plots from June 1982 through the second week of November 1982. Eighteen irrigations were applied to the control plots in the interval from March 26, 1983 to August 18, 1983.

Crops and Cultural Practices

The agricultural crops utilized in the test plots were bermuda grass, cotton, grain sorghum, and wheat. The same crops were grown each season. The grass plots were sown with the NK37 strain of bermuda grass. The winter wheat used was TAM105. In 1982, Richardson Y-303A® was the grain sorghum variety used, while GSA 1310A was sown in 1983. The cotton varieties planted were Paymaster 303® and Delta Pine Rio 875®. The latter variety was a short-season type used during the 1982 crop season for replanting after hail damage.

Project Cultural Activities--

Upon completion of the manhole facility, the plot areas were filled and graded in September and October 1981. Areas encompassing the manhole and in the vicinity of the aluminum access tubes for the neutron probe measurements were tilled with a garden-type self-propelled rototiller and by hand tools. Wheat was sown on all test plots. Calibration of all the percolate collection systems under the same crop and water management was anticipated. With no irrigation water available at the site and the low rainfall that occurred during the fall of 1981 (3.2 cm at the Hancock site from 20 October through 31 December, 1981, and 3.5 cm at the Gray site for the same period), a poor stand of wheat resulted. No attempt was made to harvest the wheat prior to plot preparation in March and April 1982. The plots were cross-disked and harrowed prior to planting.

A flat field surface was provided for planting. No herbicides were applied on either the cotton or grain sorghum plots since the use of herbicides might affect the organic content of the percolate.

Wet conditions caused delays in planting and seedling emergence during the last two weeks of May. Establishment of the crops was hampered by cold wet soil conditions and hail damage. The final planting of cotton took place during the first week of July, 1982.

The grain sorghum plots were disked and wheat was sown in mid-November. The unseasonable cold weather which began the last week of November 1982 and persisted through February 1983 reduced the stand and growth. The wheat was disked during land preparation in March 1983.

Deep chiseling of the four crop plots was performed in March 1983. Because of the weed control problems experienced during the 1982 season, herbicide use was planned for the 1983 season. Treflan® was applied and incorporated into the soil on the cotton plots at each site. The plots were then disked and listed on the contour in May, 1983. Milogard® was incorporated in the grain sorghum plots in mid-May.

Planting of the grain sorghum and cotton plots was completed May 1 at the Hancock site and May 24 at the Gray site. A post-emergence herbicide, 2-4D, was used on the grain sorghum plots in June. The interrow areas were plowed twice after seedling emergence.

Weather Monitoring Activities

Measurements of precipitation and meteorological data at each site were needed to interpret the results of percolate collection activities. The location of the instrumentation group in the weather station constructed at each test site is shown in Figures 1 and 2. The parameters measured at each site, type instruments used, and frequency of the measurements are listed in Table 5.

Water, Soils and Crop Analysis

Water Analysis--

The amounts and quality of the water applied to the soil surface and the amounts and quality of the water collected as percolate by the vacuum extraction lysimeters were the prime interests of the data collection effort.

Quantity determinations--The input water to the plot areas consisted of precipitation and irrigation with treated wastewater. The precipitation amounts for each test site were measured with both recording and non-recording rain gages located in the weather station at each site. Precipitation was assumed to have been applied uniformly over the 2.5 ha site. The amount of treated wastewater applied during the irrigation event was determined by the catch-can procedure described previously.

During the operational phase of the project, daily inspections were made of the lysimeters attached to the manhole vacuum systems. The percolate

TABLE 5

MEASUREMENT FREQUENCY OF WEATHER PARAMETERS

Parameters	Type Equipment	Measurement Frequency
Barometric pressure	Microbarograph	Continuous chart
Pan evaporation	Standard evaporation pan	Daily
Pan maximum water temperature	Maximum thermometer	Daily
Pan minimum water temperature	Minimum thermometer	Daily
Precipitation	Standard weighing/recording rain gages	Daily and continuous chart
Radiation - global	Pyranograph	Continuous chart
Radiation - net	Net-radiometer	Continuous chart
Relative humidity	Hygrothermograph	Continuous chart
Temperature	Hygrothermograph	Continuous chart
Temperature - wet bulb	Sling psychrometer	Daily
Temperature - maximum	Maximum thermometer	Daily
Temperature - minimum	Minimum thermometer	Daily
Wind speed at 2 meters	Totalizing anemometer with event recorder	Daily
Wind speed at 0.6 meters	Totalizing anemometer	Daily

collected in the 20-liter glass bottle which functioned as the specific percolate storage unit for the lysimeter was measured in a graduated cylinder.

Sample collection--Grab samples were taken using all or a portion of the daily volume collected from a lysimeter. These were collected when a lysimeter first began percolate production, resumed percolate collection after several days with no percolate collection, and during designated sample collection events.

Weekly composite samples were prepared by taking a portion of each daily collection volume from the lysimeter. Composite samples were also taken with and without an acid preservative. The composited samples were stored in 4°C-refrigerators at each site until the end of the sampling interval.

Samples of irrigation water were obtained from the plastic containers used for determining applied water volumes. The collected water from the four containers used in the volume determination was composited as an irrigation water sample for each event on the plot. The sample was collected as soon as the plume from the traveling gun had cleared the container layout on the plot.

Quality determination--Percolate and irrigation water samples were analyzed for the parameters presented in Table 6. The procedures used are presented in Volume I of Lubbock Land Treatment System Research and Demonstration Project. The original sampling schedule is listed in Table 7. The parameters that were analyzed in group classification A in Table 7, were accorded 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. The collection schedule given in Table 8 consisted of weekly periods in which composite or grab samples were taken from the lysimeter percolate. The weekly composite samples from units at both sites were taken on an as-collected basis or acid-fixed. Based upon the amount of sample present, the analyses to be run on each type of composite sample were prioritized as follows. For the samples not acid-fixed, the analyses were: 1) pH; 2) chemical oxygen demand (COD); 3) total dissolved solids (TDS); 4) sulfate (SO_4); and 5) alkalinity (alk). For the acid-fixed samples they were: 1) nitrite plus nitrate ($NO_2 + NO_3$); 2) ammonia (NH_4); 3) total Kjeldahl nitrogen (TKN); 4) COD; 5) Minerals [i.e., sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg)]; 6) chloride (Cl); and 7) total organic carbon (TOC).

Grab samples were taken once a week from each lysimeter that had collected percolate over the previous 24-hour period during the designated periods shown in Table 8. The sample analysis priorities to be followed under the grab sample collection schedule were: 1) conductivity; 2) NO_3; 3) orthophosphate; 4) bromide; 5) total phosphorous; and 6) organic phosphorous.

In an effort to determine whether solute changes were occurring on a daily basis, two periods in which daily grab samples were taken from each contributing lysimeter unit from Monday to Friday were scheduled. Applications of 2 kilograms of sodium bromide were made over the soil surface

TABLE 6
WATER ANALYSES

Alkalinity (Alk) mg/l of $CaCO_3$	Copper (Cu) mg/l*	3,4-dichloroaniline PPB**
Total Organic Carbon (TOC) mg/l	Iron (Fe) mg/l*	Dichlorobenzene PPB M,P,O
Conductivity mhos	Lead (Pb) mg/l*	Dichloromethane PPB
Total Dissolved Solids (TDS) mg/l	Magnesium (Mg) mg/l*	2,4-dichlorophenol PPB
pH	Manganese (Mn) mg/l*	Diethylphthalate PPB
Chloride (Cl) mg/Cl/l	Mercury (Hg) mg/l*	Diisooctylphthalate PPB
Total Kjeldahl Nitrogen (TKN) mg N/l	Molybdenum (Mo) mg/l*	Dioctylphthalate PPB
Nitrite plus Nitrate (NO_2+NO_3) mg N/l	Nickle (Ni) mg/l*	Dodecanoic acid PPB
Ammonia (NH_3) mg N/l	Potassium (K) mg/l*	Ethyl benzene PPB
Total Phosphorus (Total P) mg P/l	Selenium (Se) mg/l*	Heptadecane PPB
Orthophosphate (Ortho P) mg P/l	Silver (Ag) mg/l*	Hexadecane PPB
Organic Phosphate (Org. P) mg P/l	Sodium (Na) mg/l*	Hexadecanoic acid PPB
Biochemical Oxygen Demand (BOD) mg/l	Thallium (Tl) mg/l*	Methylheptadecanoate PPB
Chemical Oxygen Demand (COD) mg/l	Zinc (Zn) mg/l*	Methylhexadecanoate PPB
Sulfate (SO_4) mg SO_4/l	Anthracene/phenathrene PPB	1-methylnaphthalene PPB
Total coliform/100 ml	Atrazine PPB	2-methylphenol PPB
Fecal Coliform/100 ml	Benzene PPB	4-methylnaphthalene PPB
Fecal Strep/100 ml	Benzeneacetic Acid PPB	Naphthalene PPB
Salmonella/300 ml	4-t-butylphenol PPB	4-nonylphenol PPB
Aluminum (Al) mg/l*	Carbontetrachloride PPB	Octadecane PPB
Arsenic (As) mg/l*	4-chloroaniline PPB	Phenol PPB
Barium (Ba) mg/l*	Chlorobenzene PPB	Propazine PPB
Boron (B) mg/l*	Chloroform PPB	α-terpineol PPB
Calcium (Ca) mg/l*	2-chlorophenol PPB	Tetrachloroethylene PPB
Cadmium (Cd) mg/l*	1-chlorotetradecane PPB	Toluene PPB
Cobalt (Co) mg/l*	Dibutylphathalate PPB	Trichloroethane PPB
Chromium (Cr) mg/l*	2,3-dichloroaniline PPB	Trichloroethylne PPB

*Total and Available
**PPB = Parts Per Billion

TABLE 7

SAMPLING SCHEDULE FOR PERCOLATE

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

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

TABLE 8

SAMPLING SCHEDULE FOR MAY 1983 TO AUGUST 1983

	Percolate						Water Quality	
	Composite Samples		Grab Samples		Five Day Daily Discrete Samples		Five Day Daily Discrete Samples	
Month	Hancock	Gray	Hancock	Gray	Hancock	Gray	Hancock	Gray
May	Week 1	Week 1						
			Week 2	Week 2				
	Week 3*	Week 3*						
			Week 4	Week 4			Week 4	Week 4
June	Week 1	Week 1						
			Week 2	Week 2		Week 2		
				Week 3	Week 3			
	Week 4*	Week 4*					Week 4	Week 4
July			Week 1	Week 1				
			Week 2		Week 2			
						Week 3		
	Week 5	Week 5						
August			Week 1	Week 1			Week 1	Week 1
	Week 2*	Week 2*						
			Week 3	Week 3				
	Week 4	Week 4						

*Acid fixed

overlying the lysimeters the week prior to the first 5-day sampling period at each test area in hopes of tracing the movement of percolate water through the profile.

Also, irrigation waters applied to the test plots were to be analyzed for 1) nutrients (TKN, NO_3, NH_3, Total P, PO_4, Organic P); 2) minerals (i.e., Na, K, Ca, Mg); 3) COD; and 4) TDS. The five-day periods in which this test was scheduled are listed in the right hand column of Table 8.

Soil Analysis--

Core analysis--Soil cores were taken within 6.0 m of the ends of the lysimeter trays at various time intervals over the life of the project. Each core was divided into 30-cm sections, then those from the same depth at each test plot were composited to make a sample. Soil samples obtained with the auger were not subdivided.

A part of each sample was put into a glass screw-cap jar immediately after segmentation for priority organic analysis. The rest of the sample was put into a sterile polyethylene bag and sealed. The samples were then put into an ice chest and taken to Lubbock Christian College Institute of Water Research (LCCIWR) for analysis. The physical, chemical, and bacterial analyses that were performed on the soil samples are shown in Table 9. The procedures used are presented in Volume I of Lubbock Land Treatment System Research and Demonstration Project. A complete analysis was run during the first (March 1981) and last (November 1983) sampling periods. Partial analyses were run on samples taken in January 1982 and March 1983 from a few plots.

Bromide analysis--Movement of bromide through the soil profile can simulate movement of nitrate (18). An application of sodium bromide was made over different 6 m by 6 m test areas on each crop plot each spring during the test phase. Soil cores taken to depths of 1.8 m at each test area in subsequent seasons were analyzed for bromide so that the rate of movement of the bromide front could be determined.

Soil moisture determinations--Weekly monitoring of soil moisture data began in the spring of 1982 with a neutron probe, and continued through August 1983 except for a few periods during wet field or frozen soil conditions. Three access tubes were emplaced on each plot from 5 to 6 m from the center of the manhole. The average of the three readings at each depth on the plot was assumed to represent the soil moisture conditions in the vicinity of the test system. The readings were made at 15.2 cm intervals from the surface to depths of 1.5 to 2.1 meters.

Crop Analysis--

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. On the bermuda plots, the grass was cut from a grid block with an area of 1 m^2 that had been selected by a random number generation process for each subplot. The harvested material was put into plastic bags and taken to LCCIWR for weight, moisture content, and the constituent determinations (Table 10).

TABLE 9

SOIL ANALYSES

Alk mg/g $CaCO_3$**	Al mg/g*	Chloroform PPB
TOC mg/g**	As mg/g*	2-chlorophenol PPB
Conductivity mhos**	Ba mg/g*	1-chlorotetradecane PPB
TDS mg/g**	B mg/g*	Dibutylphthalate PPB
pH**	Ca mg/g*	2,3-dichlorotetradecane PPB
Cl^- mg/Cl^- Total**	Cd mg/g*	3,4-dichloroaniline PPB
TKN mg/g N Total**	Co mg/g*	Dichlorobenzene PPB
NO_2/NO_3 mg/g N**	Cr mg/g*	Dichloromethane PPB
NH_3 mg/g N**	Cu mg/g*	2,4-dichlorophenol PPB
Total P mg/g P**	Fe mg/g*	Diethylphthalate PPB
Ortho P mg/g P**	Pb mg/g*	Diisooctylphthalate PPB
SO_4^{2-} mg/g S**	Mg mg/g*	Dioctylphthalate PPB
Organic P**	Mn mg/g*	Dodecanoic acid PPB
	Hg mg/g*	Ethylbenzene PPB
	Mo mg/g*	Heptadecane PPB
Organic Matter**	Ni mg/g*	Hexadecane PPB
	K mg/g*	Hexadecanoic acid PPB
	Se mg/g*	Methylheptadecanoate PPB
Sulfur mg/g	Ag mg/g*	Methyhexadecanoate PPB
Specific Gravity	Na mg/g*	1-methylnapthalene PPB
Texture**	Tl mg/g*	2-methylphenol PPB
Bulk Density**	Zn mg/g*	4-methylphenol PPB
	Acenaphthylene PPB***	Napthalene PPB
Color**	Anthracene/ phenanthrene PPB	4-nonylphenol PPB
	Atrazine PPB	Octadecane PPB
Total Coliform/g**	Benzene PPB	Phenol PPB
Fecal Coliform/g**	Benzeneactic acid PPB	Propazine PPB
Fecal Strep/g**	4-t-butylphenol PPB	α-terpineol PPB
Actinomycetes/g**	Carbontetrachloride PPB	Tetrachloroethylene PPB
Fungi/g**	4-chloroaniline PPB	Toluene PPB
	Chlorobenzene PPB	Trihloroethane PPB
		Trichloroethylene PPB

*Total and Available
**Parameters sampled during partial analysis.
***PPB = Parts Per Billion

TABLE 10

CROPS ANALYSES

pH	B mg/g Total
TKN mg/g N	Ca mg/g Total
NH_3 mg/g N	Cd mg/g Total
Total P mg/g P	Co mg/g Total
Oil mg/g	Cr mg/g Total
Protein mg/g	Cu mg/g Total
KCN mg/g	Fe mg/g Total
Fatty Acid mg/g	Pb mg/g Total
Sulfur mg/g S	Mg mg/g Total
Starch mg/g	Mn mg/g Total
Niacin mg/g	Hg mg/g Total
Fiber mg/g	Mo mg/g Total
Biotin mg/g	Ni mg/g Total
Total Coliform/g	Se mg/g Total
Fecal Coliform/g	Se mg/g Total
Fecal Strep/g	Ag mg/g Total
Al mg/g Total	Na mg/g Total
As mg/g Total	Tl mg/g Total
Ba mg/g Total	Zn mg/g Total

Yields of cotton and grain sorghum were determined by harvesting the grain head and lint over three one-meter lengths of row from a position on each sub-plot selected by random number generation. Weight, moisture content, and the constituents, shown in Table 10, of the bagged samples were analyzed by LCCIWR.

SECTION V

SYSTEM OPERATIONS

LYSIMETERS

A number of problems developed in the lysimeter facilities during the project. In the sections that follow the problem areas and the resultant corrective actions will be discussed.

Flooding of Manholes

Inundation of the manholes with resultant damage to the percolate collection system elicited the most concern. The flooding events were the result of piping conditions which developed when the soil surface around the test facility was flooded from excessive precipitation. The tube lysimeters were minimally affected.

Piping of water into the cavity of some of the tray lysimeters at the 60 cm level occurred on project sites as a result of ponding of applied irrigation water from both sprinkler and flood irrigation events, and also of ponding of surface water from excessive precipitation. Piping failure in fill material occurred at one manhole causing water to enter the manhole via the vacuum tube trench leading from the tube lysimeter battery. In a few instances, piping developed in an area between the pea-gravel layer and the soil surrounding the manhole assembly. In these cases, water entered the manhole through tray cavities at the 1.2 and 1.8 meter depths.

Flooding from piping events occurred at least once in each of the manholes during the project period. Damage to the systems in the west manhole at the Hancock site and the north manhole at the Gray site was not appreciable since the water depth never rose to the level where the percolate collection system was located. Flood damage at other manholes was extensive and required the rebuilding of the percolate collection system. In the aftermath of these flood events, the vacuum pump unit had to be removed and repaired. Corrosion of the components on the control panels in the aftermath of flooding was responsible for at least two vacuum pump unit failures during the 1983 crop season. Each flood event usually deposited enough sediment to cover the bottom of the manhole to a depth of 30 to 60 cm. The south manhole at the Hancock site required rebuilding three times during the active project phase and each of the other three units that suffered major flood damage required two renovations.

Sump pumps with capacities of 19 to 30 liters per minute were not effective when piping occurred because of the large amount of sediment that entered the manhole. Usually the volume of water entering the manhole was so great that the sump pump could not have handled the inflow without damage occurring to the percolate collection system.

Problems associated with flooding were not limited to damage of the system components. There was also concern that the flows in some instances were sufficient to erode soil from the zone of contact between the soil in the top of the tray and the roof of the cavity at the 60 cm level. The slope of the manhole roof was such that only a 10 or 12 cm opening remained for the cavity entrance at the 0.6 meter level; this prevented inspection of these units. Water from flood events entering the cavities at the 1.2 and 1.8 meter levels caused collapse of the wall sections in some instances. This could have led to a poor interface connection between the roof and the top of the tray.

In the aftermath of a flood event, the channels which had developed from piping action were located. After the soil had dried, the channels were dug out and the excavated area was backfilled. In the larger cavities, plastic bags were filled with soil and tamped into place.

<u>Vacuum System</u>

Problems developed with the original tensiometer design and in the associated operational procedures when the data collection phase was initiated. Some of these problems had been masked by the dry soil conditions which prevailed in the soil profile during the months of July through September, 1982. The moisture levels had been generally at soil matrix potentials greater than one bar and thus out of the operational range of the tensiometers. The vacuum levels in the lysimeters could not be adjusted or evaluated while the tensiometers were inoperable. The three primary problem areas were:

(1) The use of deaerated water in the tensiometers, not having prevented gas bubbles from forming in the horizontal tubing, led to inconsistent manometer readings.

(2) The use of the flexible thin-wall tubing in the assembly of the tensiometers caused a varying tubing geometry which led to poor reliability in manometer readings.

(3) The use of air, a compressible fluid, as the connecting fluid between the mercury in the manometers and the water in the tensiometer unit caused a lag in readings.

The delay in manometer response was solved by replacing the air with water. The inability to solve the first two problems listed above led to a decision to eliminate the original system in August 1982. In September 1982, commercial tensiometers were installed as reference units to provide soil matrix potential data so that the vacuum levels in the tube and tray lysimeters could be adjusted. One unit each was installed at the 60 cm and 120 cm depths for controlling the three tray lysimeters on the bermuda and cotton plots. A reference tensiometer was placed adjacent to the 120 cm tube lysimeters on these plots. Tensiometers 180 cm in length were not installed that fall because of the low matrix potential readings that were obtained from the 120 cm tensiometers. The vacuum levels in the lysimeters at the 180 cm level during the fall and winter season were set to correspond to the readings obtained by the reference tensiometers located at the 120 cm level. No tensiometers were installed on the grain sorghum plots since winter wheat was to be planted. The vacuum in the lysimeters on the grain sorghum plots was set to correspond to the readings obtained in the bermuda grass.

Shelters, filled with insulating material, had been constructed around the tensiometers. Despite this, several units froze during a cold period that occurred in the last week of November 1982. Vacuum levels in the other lysimeters were thereafter set by using the readings obtained from the workable reference units at the same level. This approach created a problem in that some of the reference tensiometers had stabilized and portrayed high matrix potential readings because of the increased soil water content from late fall irrigation events and precipitation. Units that were later found to be inoperable continued to record these high readings after soil moisture content in the profile had decreased.

The installation pattern used for the commercial-type tensiometers was not sufficient for project control. Only one tensiometer was installed at each depth in the manhole to control the vacuum in the three trays at that level and one tensiometer was installed at the reference depth in undisturbed soil adjacent to each pair of tube lysimeters. Because of the soil variability that existed around each manhole, this was probably an inaccurate way to control the vacuum in individual trays.

The vacuum level in the lysimeters after installation of the commercial tensiometers was controlled through a system in which a mercury manometer was connected to the vacuum line downstream from the control panel. The needle valve at the control panel was adjusted to give the desired reading on the manometer. The set point was based on the values obtained from the reference tensiometer for that depth.

<u>Vacuum System Air Leakage</u>

The number of connections between the wick assembly in the tray or tube lysimeter and the remaining units in the percolate collection system were minimized to reduce sites from which leaks could occur. Each connection was coated with silicon sealer to ensure an airtight joint. The connections made between the wick assembly in the tube lysimeter and the vacuum tube leading to the manhole were such that the two pieces to be joined were taped together and then sealed with silicon to ensure that the joint was firmly connected and would remain sealed after burial. In addition, a slack length of vacuum tubing was provided near each joint so that the soil stresses on the buried lines would not pull the connection apart. The vacuum lines from the tube lysimeter to the manhole area were covered with soil by hand before the remaining soil was placed in the excavation by mechanical means.

The primary area where air leakage occurred was in the wick assemblies of both the tray and tube lysimeters. In the first season of operation the reference tensiometers initially installed could not be used as control mechanisms for the vacuum system. The vacuum level in each lysimeter unit was set approximately at the same point through adjustment of the needle valve on the control panel. Air leakage into the system in some manholes was high and the number of hours of operation of the vacuum pumps was excessive. Adjustment of the vacuum levels in the individual manholes was performed to satisfy the criterion that the number of hours of operation generally did not exceed five to six hours during a 24-hour period. In the unit adjustment phase it was noted, by the frequency of switch operations, that some lysimeters leaked more than others. These were taken off line.

The tube lysimeters in the north manhole at the Gray site exhibited excessive air leakage when initially put on line. In the aftermath of a series of precipitation events in the spring of 1982, air leakage decreased even though no percolate was collected.

The wetting of the soil profile during the fall and winter of 1982 led to decreased air leakage in all the manholes. Many tray and tube lysimeters began to collect percolate and continued to perform through the spring and early summer of 1983. As the soil dried out due to the deficiency in amounts of irrigation water applied, the vacuum level in each lysimeter unit was increased in response to the readings on the reference tensiometers. This caused increased vacuum pump operation during the 24-hour period. Those units with noticeable air leakage were again taken off line. As vacuum requirements increased, the cycle of tray-lysimeter shutdowns followed in 1982 was again implemented. The unit with the highest frequency of percolate collection was left on line and the other two trays at that depth were disconnected from the vacuum system. Even so, several electric motors burned out as a result of excessive operation caused by the vacuum requirement in the manhole or by a malfunctioning solenoid valve on a control panel.

IRRIGATION

Problems experienced with the irrigation system were the result of the operational characteristics of the traveling gun system and the proposed irrigation schedule.

Operational Problems

The planned schedule of irrigation operations at the two sites was quickly found to be too inflexible with the single irrigation unit allowed by budget constraints. Being able to apply the planned amounts of water during the growing season depended upon the irrigation unit operating 40 hours per week. Any problems resulting from irrigation unit maintenance needs, stages of crop growth, weather, water availability at the site, field conditions, labor, or other project activities would disrupt the irrigation schedule. The amounts of water applied to the plot areas were much reduced during the two growing seasons, thereby aggravating problems associated with percolate collection from the lysimeters. Insufficient water application from irrigation led to reduced amounts of water that could drain freely under the influence of gravity.

Field Percolation Rates--

Movement of the applied water through the soil profile was not as rapid as had originally been expected. Hence the soil surface was much wetter than anticipated at the end of the 24-hour drying period between irrigation runs. The use of the 2.5-day weekly irrigation schedule at each site caused the irrigation gun to retrace its path across the plots for two or three consecutive days after drying intervals of only 15 to 24 hours. The consequence of this was that the soil structure was destroyed as a result of the kneading of the soil by traffic over the path area and deep ruts developed. This treatment of the soil decreased infiltration rates and promoted muddy conditions. Accordingly, the time for setup of the system prior to operation rapidly increased after irrigation was started each season due to the depth and expanse of mud that had to be traversed. Due to the operational sequence followed in the project, greater stresses were imposed by the mud on both the vehicle used to transport and position the irrigation gun at the plot and on the irrigation gun itself during the test phase than would have occurred in normal field operations with a similar system.

Surface Sealing--

A factor which proved influential throughout the project was the impact of the water plume from the irrigation gun on the soils at the test plots. The height of the rise of the plume (7 to 10 m above the ground surface) and the subsequent return of large drops or contiguous volumes of water to ground caused severe erosion. The erosion effects caused by impact of the plume led to the destruction of soil aggregates. This, in turn, resulted in a reduction of infiltration during the irrigation events. The surface crust formed by the disaggregated particles, with possible assistance from the salts contained in the irrigation water during the drying cycle, was sufficient to prevent crop seeds from sprouting and to reduce the infiltration rates in subsequent precipitation or irrigation events.

Crop Damage--

The impact of irrigation water on emerging seedlings caused a reduction in the plant numbers either through the washout of the seedlings or from breaking the stalks of young plants. Plant damage was also noted at later stages of crop development in the form of broken branches, stripped leaves, removal of seed or cotton bolls and broken, bent, or matted stalks and leaves in forage crops.

Surface Runoff--

The wash or scour caused by the irrigation water impact and flow was sufficient to destroy beds or furrows formed in tillage operations after two to three irrigation events. In the initial year of the project operation, a flat field surface was provided so that the travel of the gun over the plots would be less restricted. The project soils were assumed to be capable of infiltrating water at high rates, thus decreasing the need for planting on the bed and letting the excess water fill the adjacent furrows. The high infiltration rates of the test plot soils were substantiated by tests made with a split ring infiltrometer.

As the 1982 crop season progressed, the need for a change in the form of the field surface became apparent. Large amounts of the applied water became surface run-off and collected in the ruts of the irrigation unit path or flowed to low points on or outside the test area. The amounts of water that were collected in the catch-cans were not representative of the water infiltrating into the soils over the test units in view of the runoff observed during the irrigation events. The flat field surface and the scour action of the water upon impact, which sealed the soil surface, aided in the generation of surface runoff.

Field Activities--

The accumulations of runoff in the low areas increased the difficulty of performing cultivation and of setting up the irrigation gun system prior to an irrigation event. In some instances, because of the persistent expanse of mud along the irrigation unit path, turn rows were constructed during cultivation along the boundary of the muddy areas, thus destroying additional test plot vegetation.

Corrective Measures

The problem areas previously outlined were addressed during the operational phase of the project as discussed below. Remedial actions taken to minimize or eliminate operational problems experienced in 1982 are presented in the following discussion.

Plume Impact--

A plume dispersion device was installed on the irrigation gun late in the 1982 crop season. This aided in the dispersion of the water jet and helped modify the rates of erosion from soil splash and surface scour.

Crop Damage--

Irrigation events were delayed on the crop plots during the 1983 growing season until cotton and grain sorghum seedlings had emerged and were in the early phases of the crop development stage (crop ground cover >10%). This increased the stand of plants on the crop plots but eliminated the amounts of wastewater that were scheduled for application during that time interval.

Surface Runoff--

A major concern during early months of the 1982 growing season was that the amount of applied water could not be correlated with the amounts of water infiltrating into the soil over the test lysimeters because of the observed runoff during irrigation. Water was held on the site by constructing dikes in September 1982 around the test area containing the lysimeters. The plan was to dike three plots of similar size parallel to the path of the traveling gun. The center plot area had 15 m sides. This length was somewhat greater than the diameter of the lysimeter battery (9 m). The plots adjacent to the center plot were to be used for crop yield measurement.

Crop and weed residue on the cotton and grain sorghum plots produced a mixture of organic and inorganic material in the dike. The resistance of this mixture to the scour of the plume was lower than that which would have occurred with soil alone. The dikes on the crop plots became ineffective after only 2 or 3 sequential irrigations in the fall of 1982.

Construction of the dikes in the bermuda grass plots was hindered by wet soil conditions and the thick grass sod. The addition of irrigation water, however, caused the sod in the dike material to begin new growth. This regrowth provided much more stability to the dikes in the bermuda grass areas than was experienced on the crop plots. The applied water was effectively retained in the diked plots during the fall and winter months.

In March 1983, the dikes around the bermuda grass plots were reconstructed prior to new vegetal growth. Because of the observed failure of the dikes on the crop plots during the previous fall, contour furrows on the crop plots were constructed with a lister after running guide rows with a level. The contour furrows were eroded by plume scour but were maintained over the crop season by cultivation. Problems still resulted with the excessive mud in the vicinity of the path of the traveling gun since in all plots the path of the gun was generally perpendicular to the contour rows. These wet areas caused problems in cultivation. Nonetheless, surface runoff from the plots was reduced by employment of the contour rows.

The expanse of mud created by the movement of the gun in a path perpendicular to the contour rows and the roughness of the traveling gun path in the aftermath of furrow construction or reconstruction by cultivation increased the time required to set up the system prior to an irrigation event above that experienced in the previous crop season. Field roughness, resulting from the crossing of each furrow and bed, also added to the stresses imposed on the irrigation and transport units, causing an increase in down time of both the traveling gun and the transport system during the 1983 crop season.

SECTION VI

RESULTS AND DISCUSSION

Results of this study ideally would be presented in tabular form so the changes in mass flux of the quality parameters resulting from input, output, and storage in the root zones of the test plots for specific time periods could readily be seen. Since movements of organic and inorganic constituents of concern in municipal wastewater land application systems are dependent on the water flux in the soil profile, the occurrence, composition, state, and rates of water flow in the profile must be known to determine the transport and fate of wastewater constituents. Failure to apply the design rates of treated wastewater on the test plots caused soil moisture levels in the profile that were insufficient to generate percolate continuously during the project. The inability to intercept the percolate that was generated with the installed collection devices, and to measure evapotranspiration accurately over the project period on the test plots has made it impossible to calculate accurate and meaningful water balances and have, thereby, diminished the utility of the project results.

The inability to account for the water flux also limits the interpretations that can be made about the fate of the various constituents of concern in municipal wastewater land application systems since the transport of these materials is dependent on the water flux. In addition, good and complete data regarding solute concentration, mass, and location in the profile were unavailable, as was a definite knowledge of the interactions (i.e., sorption, precipitation, dissolution, etc.) occurring between the soil matrix and the soil water. Quantification of all this information would be essential in order to determine the fate of pollutants in the soil matrix, ground water, or crops, and in order to obtain a complete understanding of the many chemical, physical, and biological processes which comprise the system.

The hydrologic portion of the study was planned to obtain information that could be used to evaluate the masses involved in the following equation:

$$\text{(Precipitation + Wastewater Applied in Irrigation)} = \text{(Evapotranspiration + Percolate Flow from the Root Zone} \\ \text{+ Change in Root Zone Water Storage)} \qquad (8)$$

Information on the solutes that posed possible quality impacts to the soil, crops, or the underlying ground water was sought to help evaluate the terms (in kg/ha) of the following equation:

(Mass applied in Irrigation Water) = (Mass removed in Harvested Crops + Change of Mass in the Internal Storage Elements in the Root Zone Profile + Mass Transported out of the Root Zone in Percolate + Mass Transported out of the Root Zone as Gas) (9)

As an example of what was expected in the study, the design hydraulic loading rates from Table C-1 and the climatological data recorded at the site from May 1, 1982, to November 17, 1982, were used to develop a scenario of what should have happened on the bermuda grass plot at the Hancock site for water, total nitrogen, and total phosphorous. The following data and assumptions were used to estimate the results:

(a) The bermuda grass that was planted in May, 1982, was irrigated with the design requirement for May as shown in Table C-1 (55 cm).

(b) The irrigation water applied to the plot exhibited a total nitrogen content of 37.7 mg/l and total phosphorous of 9.06 mg/l throughout the irrigation season. (These values represent the geometric mean of five analyses of each constituent obtained from five samples of irrigation water collected in catch cans on the Hancock site in the summer of 1983.)

(c) The amounts of bermuda grass produced and the protein content of the harvested grass are proportional to the amount of nitrogen applied in the irrigation water (16). [Estimates of the hay produced and the protein content were developed by extension of log--log diagrams constructed from yield data presented in a Texas Agricultural Extension Service publication. (22)]

(d) The nitrogen content of the dried bermuda grass was 16 percent of the protein content (13).

(e) Since applied nitrogen governs crop production to a large extent, the amount of phosphorous removed by the crop was dependent on the amount of nitrogen applied to the grass. [Removal rates were from 35 to 45 kg-P/ha over the range of nitrogen applications from 400 to 675 kg-N/ha (18).]

(f) Denitrification and volatilization caused a 25 percent loss in the amount of applied nitrogen (18).

(g) The nitrogen not utilized in the growth of the bermuda grass or volatilized remained in the soil water.

(h) The phosphorous in the applied water was removed in the root zone by specific adsorption and precipitation (10), while no nitrogen was stored in the root zone.

(i) Evapotranspiration losses from the bermuda grass were similar to those calculated by the following equation (5):

$$ET_{crop} = (K_p)(K_c)(E_{pan}) \qquad (10)$$

where ET_{crop} = monthly crop evapotranspiration in cm

K_p = pan coefficient

K_c = crop coefficient

ET_{pan} = monthly Class A pan evaporation in cm

The values obtained for the hydrologic factors during the May to November time interval were as follows:

[60.5 cm (precipitation) + 305 cm (applied wastewater)] = [86.18 cm (evapotranspiration) + X cm (percolate flow from the root zone)].

The depth of percolate flowing to the ground water was calculated from this analysis to be 279.32 cm. The volume of percolate per hectare flowing from the root zone would thus have been 28,000 m^3.

Using the total nitrogen and total phosphorous concentration of the wastewater and the design irrigation rates, the amounts of the two nutrients were computed employing the assumptions previously made. These values were inserted into the equation for solutes as follows:

Calculations for total nitrogen,

[780 kg N/ha (applied in irrigation water)] = [(0.25 x 780) kg N/ha (volatile losses) + 0 kg N/ha (storage in the root zone) + (0.122 x 0.16 x 21,000) kg N/ha (removed in the harvested crop) + Y kg N/ha (transported out of the root zone in the percolate)].

The value obtained for Y was 173 kg N/ha. Using the values calculated for nitrogen and the percolate, the concentrations of nitrogen in the percolate flowing from the root zone would have been 6.18 mg N/l. This value meets the design criterion for percolate flowing into underlying ground waters (18).

Calculations for total phosphorous,

[276 kg P/ha (applied in irrigation water)] = [Z kg P/ha (storage in the root zone) + 48 kg P/ha (removed in the harvested crop) + 0 kg P/ha (transported out of the root zone in the percolate)].

The value of Z was 228 kg P/ha. This amount should have been accumulated in the soil during the 1982 growing season.

In contrast to what should have happened, data that were obtained from the project were used to compute corresponding values in equations (8) and (9). The rainfall and the evapotranspiration values used were the same as in the previous evaluation. The actual irrigation amount, 99.17 cm (Table 12), that was applied was only 32.5 percent of the design amount. The average depth of percolate intercepted by the surface area of the five tray lysimeters operative during the period was 0.4 cm. Utilizing the measured hydrologic data, the following results were obtained:

[60.5 cm (precipitation) + 99.17 cm (applied wastewater)] = 86.18 cm (evapotranspiration) + 0.4 cm (percolate flow from the root zone) + Y cm (unexplained losses)].

The unexplained losses in the 183 cm depth of soil that was monitored on this plot during the 1982 crop season amounted to a depth of approximately 73 cm of water. The data collection techniques used were incapable of detecting this loss.

The total nitrogen and total phosphorous values used in the solute equation were developed from crop, soil, and percolate samples. The nitrogen and phosphorous associated with crop production were developed from grass production figures on the test plot (Table 19) multiplied by the average total nitrogen (30.4 mg N/g) and the average total phosphorous (3.04 mg P/g) obtained from analysis of grass samples harvested from the plot during the 1982 season. Values of organic nitrogen-N, NH_3-N, $NO_2 + NO_3$-N, and total phosphorous-P obtained from soil samples taken on the plot (March 1981 and February 1983 for NH_3 and $NO_2 + NO_3$, and March 1981 and November 1983 for organic nitrogen and total phosphorous) were used to determine the change in the mass of nitrogen and phosphorous in the 183-cm profile depth. The estimated mass of soil (25,560 metric tons) was derived from soil bulk density values obtained from samples taken on the plot. Average percolate concentrations for total kjeldahl nitrogen, $NO_2 + NO_3$-N, and total phosphorous for the tray lysimeters on the plot (Table D-1) were used to determine the amounts of the two nutrients transported in the percolate. Use of these values in the solute equation gave the following results:

Calculations for nitrogen,

[780 kg N/ha (applied in irrigation water)] = [3,440 kg N/ha (decrease in storage) + 72.4 kg N/ha (removed in the harvested crop) - 4.0 kg N/ha (transported out of the root zone in the percolate) + Y kg N/ha (unexplained losses)].

Calculations for phosphorous,

[276 kg P/ha (applied in irrigation water)] = [424 kg P/ha (increase in storage) + 7.1 kg P/ha (removed in the harvested crop) + 0.002
kg P/ha (transported out of the root zone in the percolate) + Z kg P/ha (unexplained gains)].

The value of the unexplained losses in nitrogen, Y, was calculated to be 2,584 kg N/ha, whereas the unexplained gains, Z, in phosphorous were approximately 141 kg P/ha. Even if 100 percent of the applied nitrogen was assumed to be converted to gas through volatilization of ammonia and denitrification, an unexplained loss of 1800 kg N/ha occurred that was not accounted for in the percolate or in crop removal. The solution obtained for nitrogen was in contradiction with the expected result. The result obtained for phosphorous, a material easily removed in the soil matrix, was satisfactory and would have been even better had the geometric mean of the wastewater total phosphorous content been used. However, there are some questions associated with the data obtained for total phosphorous in the soil profiles during the March 1983 and the November 1983 sampling events (Table 26). Average profile values for March 1983 showed an increase since the initial sampling period in March 1981 in 5 of the 6 plots. The results obtained in November 1983 showed that, in 4 of the 6 plots, the average values of total phosphorous in the profile had decreased below the values obtained in March 1981. Results obtained with mass balance calculations were changed from unexplained losses to unexplained gains when using the different sets of data as the basis for calculations.

Conducted in a manner similar to that used for N and P, a mass balance for chloride, calculated for the same time period, showed that 3,300 kg Cl/ha was applied and that the soil content of chloride in the 183 cm depth increased by 1,330 kg Cl/ha. Crop use and percolate flow accounted for losses of 1.5 kg Cl/ha and 32.3 kg Cl/ha, respectively. Unexplained losses of chloride in the soil profile on this plot amounted to 1,928 kg Cl/ha.

The magnitude of the unexplained losses in the soluble components transported out of the profile during the 1982 crop season on this one plot illustrates the difficulty associated with attempting to utilize mass balance determinations to explain the phenomena occurring on and below the test plots in this study.

Moreover, irrigation loadings during the primary seasonal growth periods on the other plots were smaller percentages of the design load (Tables C-1, C-2, C-3, 11, 12, 13, and 14). Crop yields on the test plots were lower than those attained on similar area sites irrigated with ground water. The erratic yield and infrequent occurrence of percolate events led to even greater infrequencies in percolate quality sampling events and analyses (Table D-1). Also, the study procedures used were incapable of monitoring the water and solute flux in the internal storage elements of the soil matrix in an adequate and timely manner. These irregularities in the project operation, coupled with inadequate data collection, would require unjustified manipulation of the available information in order to obtain mass balance determinations. Therefore, the use of material balances in the explanation of the project results was not attempted. In the following sections, the results that were obtained during the project period are presented and discussed in the context of the observed events.

PERCOLATE COLLECTION ACTIVITIES

Hydraulic Loadings

Lysimeter operations began at both sites in May 1982 and continued through September 1983. The precipitation and irrigation records at the two sites for the two growing seasons are shown in Tables 11 and 12 for the 1982 season and Tables 13 and 14 for the 1983 season. Annual estimated evapotranspiration amounts, shown as ET_o in the tables, were calculated using actual pan evaporation data obtained at the site and a pan coefficient multiplier, K_p, that was selected using monthly geometric means of wind speed and relative humidity as criteria (5). Also shown are estimates of ET_{crop}

TABLE 11

HYDROLOGIC FACTORS AT THE GRAY SITE FOR 1982

	Input				Output			
		Applied Wastewater				ET_{crop} [b]		
Month	Precipitation (cm)	Bermuda (cm)	Cotton (cm)	Grain Sorghum (wheat)(cm)	ET_o [a] (cm)	Bermuda (cm)	Cotton (cm)	Grain Sorghum (cm)
January	0.41				3.06[c]			
February	0.48				8.04[c]			
March	1.42				14.21			
April	4.04				15.77			
May	19.30				10.88	8.70	5.44	5.44
June	15.52				12.26	11.03	7.23	9.26
July	4.75	21.35	5.35	14.16	18.11	16.30	17.93	19.74
August	1.80	20.29	10.05	11.80	14.38	12.94	17.26	14.60
September	4.42	18.93	14.34	14.57	13.33	12.00	15.86	7.83
October	1.50	31.55	7.78		11.26	10.13	10.75	
November	3.53			4.44	6.43	3.21	4.63	
December	3.30			3.55	4.15[c]			
TOTAL	60.47	92.12	37.52	48.52	131.88	74.31	79.10	56.87

[a]Summation of daily data measured during month that was multiplied by pan coefficient K_p (5). In each month there were some daily data missing because of ice, rain, or the water level in the pan being too low for accurate measurements.

[b]$ET_{crop} = K_c(ET_o)$ where K_c is a crop coefficient (5).

[c]Ice in the pan for several days.

TABLE 12

HYDROLOGIC FACTORS AT THE HANCOCK SITE FOR 1982

	Input				Output			
		Applied Wastewater				ET_{crop}[b]		
Month	Precipitation (cm)	Bermuda (cm)	Cotton (cm)	Grain Sorghum (wheat)(cm)	ET_o[a] (cm)	Bermuda (cm)	Cotton (cm)	Grain Sorghum (cm)
January	0.78				4.58[c]			
February	0.58				6.33[c]			
March	3.20				12.46			
April	2.16				18.99			
May	18.64				14.90	11.92	7.45	7.45
June	19.74	13.31	8.85	1.73	12.62	11.36	7.45	9.53
July	11.28	14.22	12.33	13.11	20.33	18.30	20.13	22.16
August	2.72	14.05	13.00	8.77	19.10	17.19	22.92	19.39
September	4.42	18.84	16.81	13.03	13.20	11.88	15.71	7.76
October	0.83	22.00	6.45	1.50	13.54	12.19	12.93	
November	2.95	16.75			6.68	3.34	4.81	
December	3.14				4.26[c]			
TOTAL	70.14	99.17	57.44	38.14	146.99	86.18	91.40	66.29

[a]Summation of daily data measured during month that was multiplied by pan coefficient K_p (5). In each month there were some daily data missing because of ice, rain, or the water level in the pan being too low for accurate measurements.

[b]$ET_{crop} = K_c(ET_o)$ where K_c is a crop coefficient (5).

[c]Ice in the pan for several days.

TABLE 13

HYDROLOGIC FACTORS AT THE GRAY SITE FOR JANUARY 1 TO SEPTEMBER 30, 1983

	Input				Output			
		Applied Wastewater				ET_{crop}[b]		
Month	Precipitation (cm)	Bermuda (cm)	Cotton (cm)	Grain Sorghum (wheat)(cm)	ET_o[a] (cm)	Bermuda (cm)	Cotton (cm)	Grain Sorghum (cm)
January	5.00				1.48[c]			
February	0.78				5.24			
March	0.45	6.39			9.46	7.57		
April	1.58	4.81	4.78	3.10	14.58	13.12		
May	11.08	5.56			18.45	16.61	9.23	9.23
June	5.54	16.74			16.07	14.46	9.48	12.13
July	3.38	4.86	4.87	6.57	20.68	18.61	20.47	22.60
August	0.00	4.74	8.84	3.67	9.29[d]			
September	0.60	5.99	2.41	5.92				
TOTAL	28.41	49.09	20.90	19.26	95.25[e]	70.37[e]	39.18[e]	43.96[e]

[a] Summation of daily data measured during month that was multiplied by pan coefficient K_p (5). In each month there were some daily data missing because of ice, rain, or the water level in the pan being too low for accurate measurements.

[b] $ET_{crop} = K_c(ET_o)$ where K_c is a crop coefficient (5).

[c] Ice in the pan for several days.

[d] Pan water level too low for accurate measurements.

[e] Totals do not represent data from entire growing season.

TABLE 14

HYDROLOGIC FACTORS AT THE HANCOCK SITE FOR JANUARY 1 TO SEPTEMBER 30, 1983

	Input				Output			
		Applied Wastewater				ET_{crop}[b]		
Month	Precipitation (cm)	Bermuda (cm)	Cotton (cm)	Grain Sorghum (wheat)(cm)	ET_o[a] (cm)	Bermuda (cm)	Cotton (cm)	Grain Sorghum (cm)
January	3.20				3.13[c]			
February	0.41				3.84[c]			
March	0.76	12.22			10.12	8.10		
April	2.59	9.02	6.63	4.60	12.94	11.65		
May	6.89	16.29			13.65	12.29	6.83	6.83
June	3.20	24.98	4.87		20.63	18.57	12.17	15.58
July	3.12	19.92	14.65		23.20	20.88	22.97	25.36
August		8.44	16.02	14.04	17.40	15.66	20.88	17.66
September	0.60	59.70	40.60	5.92				
TOTAL	20.77	150.57	82.77	18.64	111.46[d]	87.15[d]	62.85[d]	65.43[d]

[a]Summation of daily data measured during month that was multiplied by pan coefficient K_p (5). In each month there were some daily data missing because of ice, rain, or the water level in the pan being too low for accurate measurements.

[b]$ET_{crop} = K_c(ET_o)$ where K_c is a crop coefficient (5).

[c]Ice in the pan for several days.

[d]Totals do not represent data from entire growing season.

which were calculated using the estimated ET_0 and a crop coefficient multiplier, K_p, selected by using wind speed, relative humidity, and stage of crop growth as criteria (5).

The hydraulic loadings applied to the control plot at the Hancock site are not shown in Table 11 or Table 13. The bermuda grass on this plot was irrigated with potable water from the Lubbock system over both growing seasons in the test period. The hydraulic loading rates (approximately 240 cm in 1982 and 270 cm in 1983) and the water quality differences between the control plot and the test plots were so different that no meaningful relationships could be developed using the control plot data.

The percentages of the design irrigation application rates (Tables C-1 to C-3) that were actually applied in 1982 to the bermuda grass, cotton, and grain sorghum plots were 27%, 83.5%, and 60.7% at the Gray site. The calculated values for ET_{crop} for the three test crops in Tables 11 and 12 were lower than those which were used to estimate the design hydraulic loads (Table 3). Monthly totals of applied irrigation water and precipitation exceeded the calculated values for ET_{crop} over the 1982 growing season on the bermuda grass plot at the Gray site and for all months of the growing season except August at the Hancock site. The calculated ET_{crop} for cotton exceeded the water inputs in July, August, October, and November at the Gray site, and in August, October, and November at the Hancock site. Hydrologic loadings exceeded the calculated ET_{crop} for the grain sorghum except for the months of July and August at the Gray site, and for the month of August at the Hancock site.

The monthly amounts of irrigation water applied to the plots during the 1983 growing season, shown in Tables 13 and 14, were below design loads. The percentages of the design application rates applied to the plots for the bermuda grass, cotton, and the grain sorghum at the Hancock site were 44.8%, 17.5%, and 18.4%, respectively. At the Gray site, the respective rates were 15.8%, 46.6%, and 24.4% of the design loadings for bermuda grass, cotton, and grain sorghum. The calculated values of ET_{crop} for bermuda grass were greater than the applied hydraulic loadings except for the months of April and August at the Hancock site and for the month of June at the Gray site. On the cotton and grain sorghum plots at both sites, the hydraulic loadings were greater than the calculated values of ET_{crop} only in the month of May during the period March through August, 1983, after which pan evaporation data collection was discontinued at both sites.

Soil moisture conditions during the growing seasons were much drier than the ET_{crop} values that were predicted using pan evaporation data. Soil moisture values calculated using recorded percolate events from the lysimeters gave evidence of dry soil conditions. The inability to apply irrigation water at the design rates during the two growing seasons was the cause of the low number of percolate collection events recorded during those periods critical to the study. Problems experienced during the two growing seasons accounting for the decreased irrigation amounts are presented in the following subsections.

1982 Season--

Precipitation recorded at the sites in the six months prior to May 1982 were 73.5 percent of the long term average at the Gray site and 69.5 at the Hancock site. Irrigation water became available for use at the Hancock site in April and at the Gray site in May. No pre-plant irrigations were applied at either site because of the timing of the availability of irrigation water at the sites and the existing time constraints imposed by equipment and labor availability for land preparation and planting operations of the three crops at the two sites.

Storm conditions in May and early June caused delays in planting, problems with seedling emergence, and hail damage to seedlings. Additionally, the vacuum units had to be repaired and the percolate collection systems rebuilt after the manholes on the cotton and grain sorghum plots at both sites were flooded in the aftermath of high intensity precipitation events during this time period. The grain sorghum plots were replanted in late May and the final replanting of the cotton plots with a short season variety occurred in early July.

After the delays caused by the replanting operations and the repairs of the flooded manholes, irrigation applications were started in June at the Hancock site. Startup problems occurred with the pump station. Construction debris in the pipe laid to the test site clogged the pump impellers several times during the initial pumping period, causing multi-day delays. When irrigation operations were started at the Gray site in July, the clogging of the pump impellers in the booster pump at the site caused further delays in the irrigation schedule at both sites. Additional problems experienced during the growing season, which collectively aided in reducing the amounts of irrigation water applied to the plots, were: (a) postponing irrigation to prevent seedling damage (cotton plot at the Gray site), (b) delaying irrigation so that the crop plot soils would dry enough to cultivate for weeds, (c) maintenance problems with the traveling gun system, (d) maintenance problems with the vehicles used to position the traveling gun system, and (e) the inability to obtain water at the Hancock site prior to midmorning.

1983 Season--

One prewatering event was applied to each crop plot in April 1983. No irrigation water was applied to the crop plots in May because of land preparation and planting operations. To prevent damage to seedlings from the irrigation gun plume, irrigation was delayed on the crop plots until sufficient growth had been attained.

When the cotton was irrigated on June 21 at the Hancock site plant damage occurred. Irrigation was then delayed further on the crop plots at both sites. This delay in initiating irrigation caused decreases in soil moisture by the end of June.

Problems with the traveling gun system developed during June. Thereafter maintenance operations associated with the muddy field conditions and the unit braking system, cable, and cable guidance system during July and August caused multi-day losses of irrigation application events. A traffic accident on August 3 disabled, for the remainder of the project, the vehicle used for positioning the traveling gun in the field and injured one of the two full-time employees on the project. The irrigation gun was subsequently operated only eight more days in August.

In an effort to raise soil moisture levels to a point where percolate could be generated in the soil profile for capture by the extraction lysimeters, wastewater effluent was applied in flood irrigation events on the cotton and bermuda grass plots at the Hancock site in September. Irrigation efforts continued during September at the Gray site using the traveling gun unit.

Percolate Quantity

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. The increased amounts of irrigation in August and September and decreased rates of evapotranspiration in the latter part of the growth period led to an improvement in soil moisture conditions and an increase in the number of percolate collection events during September and October 1982.

The buildup of moisture in the soil profiles of all the plots as a result of fall irrigation, fall precipitation, and decreased evaporation subsequently led to percolate generation in many lysimeter units that had not contributed previously. By December 31, 1982, 35 of the 41 units on the Gray site had contributed percolate, and at the Hancock, 30 of the 46 units had contributed. Percolate collection events continued on a frequent basis through February for many of the contributing lysimeters, but by March decreases were noted. Percolate events and the amount of percolate collected per event decreased through May in most lysimeter units. A low number of percolate collection events occurred during the crop growing season on all plots as a result of low soil moisture levels in the soil profiles. Percolate collection events were noted in two more units on the Gray site during 1983 so that flows from 37 of the 41 units at the Gray site occurred.

As an example of the percolate amounts and occurrence experienced during the study period, Table 15 presents the depths of percolate in mm intercepted by the surface area of the various lysimeters on the bermuda grass plot at the Gray site. The low amounts of precipitation received during the three months prior to May 1, 1983, (41 percent of average rainfall) and the 1.29 cm of rain occurring in May before a storm event of May 30 which produced 9.78 cm of precipitation had caused a decrease in the volumes of percolate produced in the lysimeters on this plot. The monthly percolate interception in all but the 183 cm and 244 cm depth tube lysimeters had decreased to below 1 mm depth by the end of May. Even though irrigation on this plot had started in March, the amounts produced by the four longer tube lysimeters continued to decrease over the next three months and had ceased by September.

Percolate was collected from tray units at all depths in October 1983 following flood irrigation of the bermuda grass plot in September. Additionally, two tray units located at the 60 cm level on the bermuda grass

TABLE 15

MONTHLY PERCOLATE DATA IN mm FOR THE BERMUDA GRASS PLOT AT THE GRAY SITE FROM OCTOBER 1982 TO SEPTEMBER 1983

	Tray Lysimeter Units									Tube Lysimeter Units					
	61 cm			122 cm			183 cm			122 cm		183 cm		244 cm	
Month	101	102	103	104	105	106	107	108	109	111	112	113	114	115	116
Oct. 1982										61.9					
Nov.										100.2					
Dec.			12.4		6.8	0.5	9.4	6.5	2.6	52.2	40.8	13.6	51.9	109.2	86.3
Jan. 1983			21.7		8.1		5.6	10.2	3.7	35.1	19.6	22.4	22.6	43.9	22.1
Feb.			20.2	2.3	2.1	5.6	5.8	15.4	4.7	46.4	32.1	29.1	39.6	65.4	68.7
Mar.			5.6	0.3	0.3		7.3	6.3	2.0	9.9	10.7	7.0	7.9	32.6	29.7
Apr.			0.4			0.6	1.9	2.9	0.4	4.0	3.9	5.7	2.7	16.6	11.6
May					0.7	0.2	0.7		0.8	<0.1	0.4	12.2	10.0	12.2	4.2
June							0.1		0.4	<0.1		5.5	3.8	3.8	4.0
July									<0.1	<0.1		3.6	1.3	4.9	1.8
Aug.											0.3	1.4	0.2	0.1	1.1
Sept.										<0.1					
TOTALS			60.2	2.6	18.0	6.9	30.3	41.3	14.6	310.2	114.1	100.5	140.0	288.6	229.5

plot at the Gray site that had never contributed percolate during the study were excavated and brought back to the laboratory for analysis. Leachate was collected by the extraction system following water application to the lysimeter surfaces. If the proper amounts of irrigation water had been available for application it is probable that more lysimeter units would have contributed percolate during the study.

The depth of percolate intercepted by the surfaces of the lysimeter units at the test sites for the two year study period are shown in Tables 16 and 17. The amounts of water that were applied through precipitation and wastewater irrigation to the test plots were insufficient to generate a pore volume of percolate in the volume of soil over the extraction assemblies in the lysimeters during the study period. The average porosities calculated from soil measurements on the Hancock and Gray sites were 0.458 and 0.451, respectively. Using the average of these two values, a pore would contain an average of 27.7, 55.4, and 83.2 cm depths of percolate for the tray lysimeters at 61, 122, and 183 cm depths. The four control units and the 122 cm tube 113, located next to a semi-permanent water puddle along the path of the traveling gun path on the bermuda grass plot on the Hancock site, were the only units that intercepted more than a pore volume during the test interval.

The amounts of percolate intercepted by all lysimeter units with the exception of the tube lysimeter on the control plot are small. The values of depth of percolate that were recorded for both years are not indicative of those that would be measured on a properly operated land application system. Much of the percolate was captured during the winter and spring when no irrigation water was applied nor vegetative growth occurring. Percolate volumes and dates of percolate occurrence at the different profile levels obtained in the study can not be used to determine the operational characteristics or the suitability of current design criteria for slow rate land application systems because of the inadequate hydraulic loadings that were realized.

It is apparent from the data in the tables that a wide variation exists in the number of collection events and the amounts of percolate collected between sites, among plots on the same site, and between units on the same plot and at the same level. Variations in hydraulic loading rates between plots, in irrigation water applications on the plot, in soil properties above the lysimeter units, in plot vegetation and cultural practices, operational characteristics of the individual lysimeter units, and operational procedures followed in operating individual lysimeters were factors that caused the differences noted among units in Tables 16 and 17.

Percolate Quality

The number of percolate collection and water quality sampling events for each lysimeter unit over the project period are presented in Table 18. Many of the water quality samples were of such small volume that only a few parameters could be measured. Also, the timing of the majority of the percolate collection events was during the winter and spring months when vegetative growth was minimal on the test plots and few irrigation events

TABLE 16

DEPTH OF PERCOLATE INTERCEPTED BY LYSIMETER UNITS
OVER STUDY PERIOD AT THE HANCOCK SITE

Location	Bermuda Units	Depth (cm)	Grain Sorghum Units	Depth (cm)	Cotton Units	Depth (cm)
<u>Tray</u>						
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	1.2	205	---	305	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
<u>Tube</u>						
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	0.3
	Avg.	75.6	Avg.	1.4	Avg.	1.2
2.44 m			215	---		
			216	---		
			Avg.			
<u>Controls</u>						
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 in which the first digit identifies the plot and the next two identify lysimeter type and depth.
[b]Average of producing units.

TABLE 17

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						
0.61 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 in which the first digit identifies the plot and the next two identify lysimeter type and depth.
[b]Average of producing units.

TABLE 18

PERCOLATE AND WATER QUALITY SAMPLING EVENTS FROM
MAY 1, 1982 TO SEPTEMBER 30, 1983

Unit	Perc.	Qual.	Unit	Perc.	Qual.	Unit	Perc.	Qual.
				Gray Site				
101	—	—	201	94	15	301	126	21
102	2	—	202	59	5	302	220	42
103	94	17	203	119	19	303	107	17
104	9	1	204	55	4	304	46	8
105	47	12	205	8	—	305	43	5
106	14	1	206	16	1	306	—	—
107	87	19	207	74	2	307	11	3
108	97	18	208	9	1	308	16	2
109	78	16	209	14	—	309	34	4
111	189	39	211	180	29	311	40	7
112	127	23	212	93	18	312	145	26
113	218	45	213	17	2	313	114	21
114	195	36	214	5	—	314	193	41
115	215	44						
116	202	38						
				Hancock Site				
101	34	12	201	25	5	301	1	—
102	78	20	202	1	—	302	11	3
103	44	11	203	—	—	303	25	12
104	9	1	204	18	2	304	14	3
105	19	3	205	—	—	305	20	3
106	1	—	206	—	—	306	12	1
107	2	—	207	1	—	307	8	2
108	54	13	208	1	—	308	15	1
109	1	1	209	1	—	309	9	4
111	—	—	211	—	—	311	73	17
112	1	—	212	—	—	312	56	11
113	305	65	213	1	—	313	53	13
114	218	39	214	10	2	314	19	3
			215	—	—			
			216	—	—			
121	415	77						
122	346	63						
123	405	79						
124	417	77						

with wastewater effluent were occurring.

The poor stands of cotton and grain sorghum and the resulting low yields obtained on the plots (Tables 19 and 20) during both growing seasons generally did not represent conditions that would occur under normal conditions in a municipal wastewater land application system. Average yields for irrigated cotton and grain sorghum in Lubbock county for 1982 and 1983 were 252 and 396 kg/cotton/ha and 3720 and 3390 kg/grain sorghum/ha, respectively (23). Grain sorghum yields at the Hancock site were higher than the county average during both seasons. The yields of bermuda grass were not reported on a county basis. Fertilization with nitrogen and irrigation were the primary determinants of yield with this crop (16). Therefore, solute levels that were measured in the percolate samples collected from the crop plots during the two growing seasons covered in the study were not representative of conditions where higher plant densities per unit area are encountered.

There is some benefit in comparing the composition of the percolate that was collected, even though the collection periods and the less-than-normal plant populations that existed on the plots were distorted, with the composition of the irrigation waters applied to the plot. The solute concentrations of the percolate that was intercepted had been impacted by previous wastewater irrigation events on the various plots. The geometric mean (G), standard deviation (SD), number of sampling events (E), coefficient of variation (CV), percentage of composite samples (%C), and the mass in kg/ha for chemical constituents analyzed in the quality samples obtained from the lysimeters over the project period are shown in Appendix D. The mass in kg/ha was calculated using the geometric mean and the depth of water intercepted by the surface area of the lysimeter unit (Tables 16 and 17).

The geometric means of selected water quality parameters in the irrigation waters applied to the test areas are shown in Table 21. The wastewater quality applied at each site varied because of the different treatment paths at the wastewater treatment plant, sources of wastewater treated in each treatment sequence, and storage practices. The water quality characteristics of the water applied to the control plot were obtained from water sample analyses made at the municipal water treatment plant.

Comparison of the geometric means of the constituent concentrations shown in Appendix D with those shown in Table 21 generally reveals a decrease in nutrient levels in the percolate samples. Levels of total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3-N), total phosphorous (TP), orthophosphate phosphorous (Ortho P), and organic phosphorous (Org. P) decreased by a factor of 10 or greater. The levels of the combined total of nitrogen reported as nitrite/nitrate-nitrogen (NO_2+NO_3-N) increased in the percolate. The increase in these forms 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.

The cation and anion concentrations as depicted by values of the geometric means of the collected percolate varied among similar lysimeter units at the same depth level on the test plots and between the depth levels

TABLE 19

CROP YIELDS AND GEOMETRIC MEANS OF SELECTED PARAMETERS FOR TEST CROPS GROWN IN 1982

Site	Plot	Average Yield (kg/ha)[a]	(%MC)[b]	Total Nitrogen (mg-N/g)	Total Phosphorus (mg-P/g)	Protein (%)	Sulfur (mg-S/g)	Chloride (mg-Cl/g)
Gray								
	Berm. Grass	1,900	(68.3)	45.90	3.14	28.22	8.16	84.64
	Cotton[c]	0	--	--	--	--	--	--
	Gr. Sorghum[d,e]	1,850	(33.5)	15.72	3.02	9.66	2.88	1.30
Hancock								
	Berm. Grass	2,350	(74.6)	30.43	3.04	18.75	5.37	0.65
	Cotton[c]	0	--	--	--	--	--	--
	Gr. Sorghum[d,e]	9,760	(41.0)	--	--	--	--	--

[a]Dry weight basis.
[b]Percent moisture at the time of harvest.
[c]Stand too poor to harvest for reliable results.
[d]Unthreshed grain with approximately 10 percent stalk.
[e]Damage to grain from birds and/or insects.

TABLE 20

CROP YIELD AND GEOMETRIC MEANS OF SELECTED PARAMETERS FOR TEST CROPS GROWN IN 1983

Site	Plot	Average Yield (kg/ha)[a]	(%MC)[b]	Total Nitrogen (mg-N/g)	Total Phosphorus (mg-P/g)	Protein (%)	Sulfur (mg-S/g)	Chloride (mg-Cl/g)
Gray								
	Berm. Grass	3,812	(68.2)	22.58	3.48	13.89	7.48	8.36
	Cotton[c]	816	(43.1)	9.37	1.45	5.76	9.41	0.32
	Gr. Sorghum[d,e]	0	--	15.72	3.02	9.66	2.88	1.30
Hancock								
	Berm. Grass	7,976	(67.7)	18.29	3.10	11.23	9.57	8.61
	Cotton[c]	1,349	--	9.15	1.26	5.63	8.16	0.42
	Gr. Sorghum[d]	4,123	(14.1)	--	--	--	--	--

[a]Dry weight basis.
[b]Percent moisture at the time of harvest.
[c]Stand too poor to harvest for reliable results.
[d]Unthreshed grain with approximately 10 percent stalk.

TABLE 21

GEOMETRIC MEANS OF CONCENTRATIONS FOR QUALITY PARAMETERS IN IRRIGATION WATERS APPLIED TO THE TEST AREAS OVER THE PROJECT PERIOD

PARAMETER	APPLIED WASTEWATER GRAY SITE (mg/l)	APPLIED WASTEWATER HANCOCK SITE (mg/l)	IRRIGATION WATER CONTROL PLOTS[a] (mg/l)
ALK	295	347	200
TDS	1190	1180	924
TKN	11.2	37.6	-
NO_2+NO_3-N	3.47	0.114	0.109
NH_3-N	2.75	20.9	
TOTAL P	4.00	14.4	
ORTHO P	2.30	8.27	
ORG P	0.172	0.267	
COD	116.6	245	
Cl^-	302	332	247
SO_4	215	203	181
Ca	81.5	58.0	47.1
Mg	44.1	24.3	23.3
K	19.4	18.2	
Na	256	315	223
TOC	38.8	54.6	

[a]Data compiled from records of Water Sample Analysis at the Lubbock Municipal Water Treatment Plant.

on the same plot. Differences were also apparent among the values for the same constituent at the same level between plots. The reasons for the variation were probably the same factors listed previously for the variations in the amounts of percolate collected.

Sets of equivalent ratios between the meq/l values for cations and anions and indices calculated from groupings of meq/l values for these parameters were developed where data was available using the geometric means of the percolate, applied irrigation waters, and underlying ground water at each site. Insufficient data at the Hancock site limited the number of values obtained. The ratios for the various plots are shown in Tables E-1 to E-6. The values used for the ground water at the Hancock site were geometric means developed from data taken during the baseline period (June 1980 to February 1982) before wastewater was applied.

The majority of the values developed from the percolate data are less than 1. Normally, in soils containing high levels of carbonate, the equivalence ratios are higher than unity (11). The values exhibited at all sites are an indication of the impacts from relatively higher levels of Na, Cl, and HCO_3 in the irrigation water.

The adjusted SAR values (1) exhibited for the applied waters on all test areas were sufficient to cause impacts on the soil in the form of deflocculation of clays, reductions in infiltration rates and decreases in the availability of K. Additionally, the high SAR values found in these waters were sufficient to cause phototoxicity of the test crop plant leaf surfaces and to pose difficulties in root absorption of the soil waters resulting from irrigation using these waters. The high value (20.1) of the adjusted SAR of the wastewater effluent applied at the Hancock site can be expected to cause the rapid development of soil and crop problems at that site. The adjusted SAR values for the ground water at the Gray site are much higher as a result of the long history of wastewater irrigation, than those determined for the ground water at the Hancock site.

The adjusted SAR ratios for the percolate at the Gray site were greater than the values for the irrigation water and the ground water. All values of the adjusted SAR at the Gray site indicate root adsorption problems. Adjusted SAR values for the percolate at the Hancock site (Tables E-4 through E-6) are lower than those obtained for either the applied water or the ground water. These lower values indicate that adsorption and retention of Na was occurring in the profile. The values for the two control units were slightly higher than those calculated for the other units irrigated with wastewater.

Base exchange indices (I_{BA}) given by Schoeller (14) in Mathess (11) were calculated for the applied water, percolate, and ground water. A positive index is an indication of favorable conditions for an exchange of alkalis (Na and K) in the water for alkaline earth ions (Ca and Mg) in the soil (11). A negative value of the index indicates favorable conditions for the exchange of alkaline earths in the water for alkalis in the soil. The positive value of the I_{BA} values for the percolate intercepted by the majority of the lysimeters indicated that alkalis in the soil water were being exchanged for Ca and Mg in the root zone.

The $(Cl^- - Na^+)/Cl^-$ index also establishes the value of the sign for the I_{BA}. The high sodium content of the applied waters is seen by the negative values obtained for this number. This indicator is also negative for the ground water at both sites. Negative values of $(Cl^- - Na^+)/Cl^-$ and I_{BA} are seen for percolate at four locations (3 tubes and 1 tray unit) at the Gray site. Percolate at 11 locations exhibited positive values.

Mass Transport Results for Percolate Flows

Tables F-1 to F-7 show the masses of the parameters that were measured in the quality studies of the applied irrigation water and of the percolate intercepted by the lysimeters during the project period. The average geometric mean of the parameter at the profile depth and the average depth of water calculated from the contributing lysimeters on the plot at that level were used to calculate the values shown. The seven tables also present the masses of various constituents that were contained in crops produced on each plot; these were calculated from sample analysis and crop production figures for the two crop seasons. The crop production figures for the two sites are given in Tables 19 and 20.

The mass values calculated for the control plot show close agreement between applied amounts and mass transported by the percolate. This was to have been expected with the loading applied on the control units. On the other plots, the parameters that may fall within a factor of 10 of the applied rates were alkalinity, TDS, Cl, and the cations. Tables F-1 to F-7 indicate that even with the deficits experienced in hydraulic loading on the test plots the translocation of large amounts of material (Na, Ca, Cl, SO_4, and alkalinity) occurred at different depths in the profile. Movements of the magnitudes shown in these tables may impact the quality of ground water under these sites if irrigation is continued at design rates on the sites in the future.

SOIL ANALYSIS

The soils at both sites generally followed the typical profile description presented in Appendix A. The layers of calcium carbonate, regionally referred to as caliche, varied in thickness, cementation, and hardness within the plots, between the plots, and between sites. A layer of indurated caliche was generally found at each site between 45 and 183 cm. This condition was more pronounced in the Friona soils at the Gray site.

In addition to the variability of those soils formed from eolian sediments, it was noted during excavation made for the percolate extraction facilities that the Hancock test area had previously been the site of a prairie dog colony. The burrows had subsequently filled with surface soil over a time interval. The walls of each of the three excavations showed evidence of the old burrows through color differentials exhibited by the darker surface soils occupying the old burrows in the lighter colors of the undisturbed materials in the lower horizon. The burrows noted were within 240 cm of the soil surface.

An examination of constituent changes in the soil between sampling intervals is presented in this section. Accumulations and depletions at different depth levels were noted in the same profile for many materials. Table 22 shows the variability that existed for selected cations and anions. Sodium and chloride increases are noted on all plots at the Hancock site, whereas depletions of both materials are noted in the majority of the depth intervals at the Gray site. The levels of NO_2+NO_3-N decreased in all levels on the plots at the Hancock site. The effects of the low hydraulic loadings on this constituent can be seen on the cotton and grain sorghum plots at the Gray site.

Nutrients

An examination of the variations of nitrogen compounds at both sites at 30-cm increments was made down to the 90 cm depth for the sampling events in the springs of 1981 and 1983, and in the fall of 1983. The caliche layers at the Gray site required that the soil from 90 to 180 cm depth be composited.

The average values for the depth intervals at each sampling period show a decrease in TKN (Table 23) with depth. Based upon the levels of NH_4-N shown in Table 25 for the depth intervals in these soils, the TKN for the sites was judged to be primarily organic nitrogen. Although there was little difference in the TKN measured at the two sites, the average values in the profile at the Hancock site were higher (4.6 mg N/g compared to 4.1 mg N/g). This would amount to a difference of 0.5 kg N per metric ton of soil between the two sites or 1400 kg N/ha in the top meter of soil, with an average bulk density of 1.4 g/cm^3. With the exception of the cotton plot, examination of the average values in the profile for the plots at the Hancock site to the 90 cm depth showed a general decrease in TKN during the study period. At the Gray site, the average TKN of the three plots at the 90 cm depth for each sampling period showed little change. Three of the plots (the bermuda grass and the grain sorghum plots at the Hancock site, and the cotton plot at the Gray site) exhibited their lowest values of TKN during the March 1983 sampling period.

The NO_3-N content in the soil profiles at the Hancock site were generally higher both at the start and end of the project than were the levels measured at the Gray site (Table 24). The average profile NO_3-N 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. Concentrations generally decreased as the volume of flow recorded increased.

Again, the NH_3-N data in Table 25 show that larger initial values were present in the soils at the Hancock site. Generally, decreases of NH_3-N in the profile occurred over the project interval. Also noticeable over the three project periods was the decrease of NH_3-N with depth. The grain sorghum plot on the Gray site exhibited the highest value in the 90 cm profile during the spring of 1983.

Table 26 shows the total phosphorous present in the upper 91 cm of the soil profile in the three sampling periods during the study. The profile averages for the last sampling event show that decreases in total phosphorous

TABLE 22

CHANGES IN 10^{-2} mg/g OF SOIL WITH DEPTH FOR SELECTED CATIONS AND ANIONS BETWEEN SAMPLING PERIODS IN MARCH 1981 AND NOVEMBER 1983.

Plot	Depth Interval (cm)	Na	Ca	Cl	SO_4	NO_2+NO_3-N
			Gray Site			
Bermuda	0-30	-8.2	15,780	-2.0	-8.4	-1.45
	30-60	-8.0	3,460	-8.4	-1.5	-1.00
	60-90	-52.3	14,200	1.1	15.0	-0.33
	90-180	-8.5	7,750	-4.2	-194.2	-0.35
Cotton	0-30	-8.4	-6.0	-2.8	-4.1	-1.00
	30-60	-1.1	-79.0	9.8	-205	0.18
	60-90	10.7	-384	3.8	-204	0.94
	90-180	-.5	10,900	-0.3	-161	0.94
Grain Sorghum	0-30	-11.8	223	-2.5	-231	-0.29
	30-60	-13.7	-116	-6.1	-204	0.34
	60-90	-11.7	-47.0	-4.7	-204	-0.09
	90-180	9.4	4,010	-0.8	-194	0.82
			Hancock Site			
Bermuda	0-30	4.4	1,800	1.8	-1.7	-0.29
	30-60	9.5	606	4.2	4.1	-0.60
	60-90	3.6	-490	4.7	8.4	-0.94
	90-120	-0.1	14,100	7.4	-7.7	-3.75
	120-150	0.3	6,940	13.0	-6.6	-0.76
	150-180	-8.3	15,200	13.4	-2.2	-1.22
Cotton	0-30	27.4	-10.9	15.2	-3.5	-0.43
	30-60	53	-12,100	-3.3	3.8	-0.89
	60-90	83	-833	-1.0	10.3	-0.93
	90-120	-4.6	6,570	0.5	9.3	-0.78
	120-150	-6.4	9,200	3.6	6.7	-0.72
	150-180	-9.9	6,790	-1.4	6.5	-0.76
Grain Sorghum	0-30	17.6	11	0.7	-5.9	-0.04
	30-60	16.7	-346	7.6	-1.9	-0.34
	60-90	2.0	-40	8.7	-0.7	-0.43
	90-120	410	-3,480	1.2	-3.2	-0.68
	120-150	12.0	10,300	-0.2	-4.6	-0.05
	150-180	-7.8	12,500	-3.8	-4.2	-0.03

TABLE 23

RESULTS OF SOIL ANALYSIS FOR TKN-N ON TEST PLOTS
FOR 3 SAMPLING PERIODS IN 10^{-1} mg/g OF SOIL

Site	Depth (m)	Bermuda Plot			Grain Sorghum Plot			Cotton Plot			Avg. in Depth Interval		
		3-4/81	2/83	11/83	3-4/81	2/83	11/83	3-4/81	2/83	11/83	3-4/81	2/83	11/83
Hancock	0 - .30	6.1	5.6	6.6	5.5	4.0	5.3	4.4	6.0	5.2	5.3	5.2	5.7
	.30-.61	5.8	4.6	4.9	5.0	3.9	4.9	4.4	5.5	5.4	5.1	4.7	5.1
	.61-.91	7.8	3.2	2.6	2.6	2.4	2.7	3.3	3.2	2.7	4.6	2.9	2.7
	Avg. in profile	6.6	4.5	4.7	4.4	3.4	4.3	4.0	4.9	4.4	5.0	4.3	4.5
Gray	0 - .30	5.2	5.0	5.4	6.3	5.0	4.8	6.4	4.8	6.7	6.0	4.9	5.6
	.30-.61	2.8	3.8	3.7	4.1	5.2	3.6	3.9	2.6	5.0	3.6	4.0	4.1
	.61-.91	2.2	2.2	1.1	2.5	4.8	2.7	2.8	2.8	3.6	2.5	3.3	2.5
	Avg. in profile	3.4	3.7	3.4	4.3	5.0	3.7	4.4	3.4	5.1	4.0	4.1	4.1

TABLE 24

RESULTS OF SOIL ANALYSIS FOR NO_3-N ON TEST PLOTS FOR 3 SAMPLING PERIODS IN 10^{-3} mg/g OF SOIL

Site	Depth (m)	Bermuda Plot			Grain Sorghum Plot			Cotton Plot			Avg in Depth Interval		
		3-4/81	2/83	11/83	3-4/81	2/83	11/83	3-4/81	2/83	11/83	3-4/81	2/83	11/83
Hancock	0 - .30	3.35	2.21	0.44	7.85	4.01	7.47	6.37	2.64	2.04	5.85	2.94	3.31
	.30-.61	6.32	1.64	0.36	7.93	3.52	4.54	10.57	3.19	1.67	8.26	2.78	2.19
	.61-.91	9.80	0.44	0.40	6.24	3.26	1.90	12.12	2.04	2.83	9.38	1.91	1.71
	Avg. in profile	6.48	1.42	0.40	7.34	3.59	4.63	9.68	2.62	2.17	7.82	2.54	2.40
Gray	0 - .30	14.71	1.42	2.28	15.38	1.72	2.15	6.49	2.76	1.53	12.18	1.96	1.98
	.30-.61	11.72	.14	1.72	0.32	7.74	1.28	1.19	2.13	0.58	4.41	3.33	1.19
	.61-.91	5.04	1.11	1.72	0.34	6.60	1.26	4.99	6.97	0.56	3.45	4.89	1.18
	Avg. in profile	10.47	0.84	1.90	5.34	5.35	1.56	4.22	3.95	0.89	6.67	3.39	1.45

TABLE 25

RESULTS OF SOIL ANALYSIS FOR NH_3-N ON TEST PLOTS FOR 3 SAMPLING PERIODS IN 10^{-3} mg/g OF SOIL

Site	Depth (m)	Bermuda Plot			Grain Sorghum Plot			Cotton Plot			Avg in Depth Interval		
		3-4/81	2/83	11/83	3-4/81	2/83	11/83	3-4/81	2/83	11/83	3-4/81	2/83	11/83
Hancock	0 - .30	1.22	3.46	0.25	3.31	1.38	1.18	2.47	1.10	1.17	2.33	1.98	0.86
	.30-.61	1.72	1.36	0.60	2.42	2.44	1.17	1.85	0.80	0.69	1.99	1.53	0.82
	.61-.91	3.11	0.87	1.06	1.66	1.36	0.63	1.35	0.71	0.94	2.04	0.98	0.87
	Avg. in profile	2.01	1.89	0.63	2.46	1.72	0.99	1.89	0.87	0.93	2.12	1.50	0.85
Gray	0 - .30	2.61	1.85	1.57	2.46	1.40	2.15	2.89	1.89	1.53	2.65	1.71	1.75
	.30-.61	0.44	0.86	0.82	1.16	1.44	1.28	0.76	2.13	0.58	0.88	1.48	0.89
	.61-.91	1.17	0.56	0.57	0.73	2.73	1.26	4.38	3.87	0.56	2.09	2.38	0.80
	Avg. in profile	1.40	1.09	0.99	1.45	1.85	1.56	2.67	2:62	0.89	1.87	1.85	1.15

TABLE 26

RESULTS OF SOIL ANALYSIS FOR TOTAL PHOSPHORUS-P ON TEST PLOTS FOR 3 SAMPLING PERIODS IN 10^{-1} mg/g OF SOIL

Site	Depth (m)	Bermuda Plot			Grain Sorghum Plot			Cotton Plot			Avg. in Depth Interval		
		3/81	2/83	11/83	3/81	2/83	11/83	3/81	2/83	11/83	3/81	2/83	11/83
Hancock	0 - .31	1.2	1.9	1.5	1.3	1.4	1.4	1.0	1.3	1.5	1.17	1.53	1.47
	.31-.61	2.2	2.0	1.6	1.3	1.9	1.4	1.6	1.6	1.5	1.70	1.83	1.5
	.61-.91	1.9	1.8	1.6	1.6	2.1	1.3	1.7	1.6	1.3	1.73	1.83	1.4
	Avg. in Profile	1.77	1.9	1.57	1.40	1.8	1.37	1.43	1.5	1.43	1.53	1.73	1.46
Gray	0 - .31	2.3	4.0	1.7	5.9	4.6	4.2	4.9	4.8	4.7	4.37	4.47	3.53
	.31-.61	2.1	2.4	4.2	2.1	2.9	2.5	2.7	2.7	2.6	2.3	2.67	3.1
	.61-.91	4.0	1.3	3.6	1.8	3.0	2.8	2.3	3.2	2.4	2.7	2.5	2.93
	Avg. in Profile	2.80	2.56	3.16	3.26	3.5	3.16	3.30	3.57	3.23	3.12	3.21	3.19

occurred in four of the plots. An increase in total phosphorous was observed at the profile at the bermuda grass plot on the Gray site. No change in average profile content was observed between the first and last reading made on the cotton plot at the Hancock site. A rise in the average profile total phosphorous content was noted for all plots except the bermuda grass plot at the Gray site. The average values observed for the profile at the Hancock site at the end of the project were approximately 50 percent of these at the Gray site.

Table 27 shows the orthophosphate phosphorous in the three 30 cm increments of the upper soil profile of the plots. At the end of the project period, the available soil phosphorous was two orders of magnitude less on the bermuda grass and the grain sorghum plots at the Hancock site than the values obtained on the companion plots at the Gray site. Orthophosphate phosphorous in the cotton plot at the Hancock site, however, was one order of magnitude less than what was recorded at the Gray site. Examination of the average values in the profile show that orthophosphate phosphorous levels decreased over the project period in the upper 90 cm depth at both sites.

Priority Organics

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. The location of the 20 materials identified in the project soils in November 1983 and the maximum levels of each compound, in ppb, are shown in Table 28. Thirty-six organic compounds were identified in project soils in analyses performed in the spring of 1981. Reduction in concentration of 11 of the organics found in November 1983 had occurred over the project period. Increases had occurred in the concentration of nine compounds: carbon tetrachloride, dibutylphthalate, hexadecane, methylheptadecanoate, methylhexa-decanoate, 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 mass loadings in kg/ha applied to the irrigation wastewater over the project period for these three materials were calculated for the bermuda plots at both sites because of the higher hydraulic loadings. The mean concentrations and mass loadings of those substances in the wastewaters going to the Hancock site during the project period were 5.8 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 4.7 μg/l for carbon tetrachloride (0.066 kg/ha) and 140 μg/l for dibutylphthalate (1.98 kg/ha). Hexadecane levels were not determined for the treated effluent transported to the lagoon on the Gray site.

Trace Metals

A mass balance of the metals in the soils of each plot was developed using the soil analysis data that were taken at the beginning and end of the project for each 30 cm depth of soil down to 183 cm. The mass of each 30 cm layer was determined from measured bulk density values that had been made. The net change in the metal content in mg/kg was then used to determine the

TABLE 27

RESULTS OF SOIL ANALYSIS FOR ORTHOPHOSPHATE-P ON TEST PLOTS FOR 3 SAMPLING PERIODS IN 10^{-3} mg/g OF SOIL

Site	Depth (m)	Bermuda Plot			Grain Sorghum Plot			Cotton Plot			Avg. in Depth Interval		
		3/81	2/83	11/83	3/81	2/83	11/83	3/81	2/83	11/83	3/81	2/83	11/83
Hancock	0 - .31	1.97	0.02	0.04	2.47	0.02	0.08	1.69	0.38	1.35	2.04	0.14	0.49
	.31-.61	1.01	0.08	0.01	1.05	0.02	0.05	1.55	0.13	0.02	1.20	0.08	0.03
	.61-.91	0.64	0.02	0.06	1.05	0.02	0.05	1.05	0.13	0.02	0.91	0.06	0.04
	Avg. in Profile	1.210	0.04	0.037	1.523	0.02	0.060	1.430	0.213	0.463	1.38	0.09	0.19
Gray	0 - .31	17.36	7.20	6.84	16.78	1.88	5.99	33.27	1.69	6.88	22.47	3.59	6.57
	.31-.61	15.76	6.64	4.68	24.35	19.44	9.44	34.14	1.97	5.90	24.75	11.56	6.67
	.61-.91	4.25	0.02	.02	19.69	13.76	13.47	30.90	1.25	1.19	18.24	5.01	4.89
	Avg. in Profile	12.46	4.62	3.85	20.27	11.69	9.63	32.77	1.64	4.65	21.82	6.72	6.04

TABLE 28

MAXIMUM CONCENTRATION IN PPB AND LOCATION OF ORGANICS
IN THE SOIL PROFILE AT TEST SITES IN NOVEMBER 1983

	Hancock Site						Gray Site			
	0-0.3 (m)	0.3-0.6 (m)	0.6-0.9 (m)	0.9-1.2 (m)	1.2-1.5 (m)	1.5-1.8 (m)	0-0.3 (m)	0.3-0.6 (m)	0.6-0.9 (m)	0.9-1.8 (m)
Anthracene/phenanthrene	1.6		5.4	41						
Atrazine	89			74						
Benzene	6.0	3.7	1.6	1.0	1.0	1.0	1.4	1.6	1.1	1.2
Carbon tetrachloride	4.2	3.1	2.1	2.5	2.5	3.7	3.2	2.8	2.9	2.8
Chloroform	1.8	1.1								
1-chlorotetradecane	50	82	6.2	71						
Dibutylphthalate	1110	890	140	150			40		40	
Dichlorobenzene		16								
Ethyl benzene			1.4							
Heptadecane		81	170	115		39				
Hexadecane	350	460	1150	340	260	300	200	200	280	210
Methylheptadecanoate			224							
Methylhexadecanoate				280						
2-methylphenol								14	22	
4-methylphenol								13		
Octadecane		34	102	70						
Phenol	36.8						1.9			
Propazine	141									
Tetrachloroethylene	4.5	2.9	2.0	2.6	1.5	2.0	36	2.5	3.1	2.8
Trichloroethylene	1.4									

mass change in each layer and these values were summed over the 183 cm depth. The results of this are shown in Tables 29 and 30.

The input of metals to each plot was determined from the amounts of wastewater applied on each plot and the geometric mean of the quality characteristics of the applied water. The changes in the soil profile were greater than had been anticipated from the application rates of the inorganics. In some instances, such as with sodium, the response was within the same order of magnitude. For most of the heavy metals, however, a much larger accumulation is shown in the soil data than would be warranted by the application rates utilized. Provided the data were correct, the accumulations or depletions such as those shown in Tables 29 and 30 are of definite concern. Variability in soil properties from site to site on the test plots, even when composite samples were analyzed, introduced errors that could not be eliminated unless a much larger number of samples, randomly collected from the plot, were to have been analyzed. Extrapolation of these results, using the bulk densities to determine soil mass, also contributes errors in the results.

Bromide

Soil cores to be analyzed for bromide were taken on each test area in March and November 1983. The results of the analysis are shown in Tables 31 and 32.

1982 Crop Season--

The two plots at the Hancock sites which received the greatest hydraulic loading contained little residual bromide in the 183 cm deep profile. The grain sorghum site received a hydraulic loading 66.4 percent as great as that applied on the cotton site and 38.5 percent as great as that on the bermuda grass (Table 12). It appeared from the profile data shown in Table 31 that 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 plot, with a much larger hydraulic loading (Table 11), showed a bromide ion accumulation in the 60 to 90 cm level. This corresponded to the depth of the indurated caliche layer that was encountered in placing the tray lysimeters. Moreover, this level occurred in the region of maximum moisture content that had been identified in the soil profile with the neutron probe. The movement of bromide on the other two plots was approximately 1.95 cm per centimeter of applied water.

1983 Crop Season--

The general movement rates exhibited during the 1983 crop season are presented in Table 32. The hydraulic loading during the interval was less than that shown in Table 31 because of the time period difference between analyses. The cotton and grain sorghum 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 (Tables 13 and 14). At the Gray 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

TABLE 29

APPLICATION OF METALS IN WASTEWATERS AND FATE OF METALS IN PLOT ROOT ZONE OVER PROJECT PERIOD--GRAY SITE

Metal	Bermuda		Cotton		Grain Sorghum	
	Applied in irrigation kg/ha	Δ wt in profile 1000 kg/ha	Applied in irrigation kg/ha	Δ wt in profile 1000 kg/ha	Applied in irrigation kg/ha	Δ wt in profile 1000 kg/ha
Al	1.550	141.000	0.573	105.000	0.665	-22.500
As	0.098	-0.056	0.036	0.128	0.042	0.062
Ag	0.078	4.000	0.029	0.003	0.034	0.007
Ba	5.460	2.470	2.020	-1.730	2.340	-0.595
Cd	0.031	0.016	0.012	0.005	0.014	0.009
Co	0.095	0.212	0.035	0.126	0.041	0.098
Cr	0.973	0.089	0.360	-0.301	0.418	0.414
Cu	1.590	-0.345	0.587	-0.047	0.681	-0.005
Fe	7.500	-66.600	2.770	-0.180	3.220	47.800
K	530.000	-47.000	196.100	-28.100	227.000	-12.700
Mg	442.000	-15.100	164.000	8.640	190.000	11.300
Mn	0.528	-1.620	0.195	-1.400	0.227	-2.640
Na	3730.000	0.323	1380.000	0.031	1600.000	-0.614
Ni	0.189	-0.170	0.700	-0.089	0.810	-0.420
Pb	0.111	-0.016	0.041	0.008	0.047	-0.008
Zn	1.570	-0.272	0.582	-0.088	6.780	-0.463

TABLE 30

APPLICATION OF METALS IN WASTEWATERS AND FATE OF METALS IN PLOT ROOT ZONE OVER PROJECT PERIOD--HANCOCK SITE

	Bermuda		Cotton		Grain Sorghum	
Metal	Applied in irrigation kg/ha	Δwt in profile 1000 kg/ha	Applied in irrigation kg/ha	Δwt in profile 1000 kg/ha	Applied in irrigation kg/ha	Δwt in profile 1000 kg/ha
Al	1.910	43.200	1.070	-67.200	0.443	28.600
As	0.157	0.349	0.088	0.435	0.036	0.750
Ag	0.125	0.219	0.070	0.099	0.028	0.020
Ba	5.170	0.419	2.900	0.726	1.170	0.777
Cd	0.300	0.008	0.168	0.007	0.068	0.030
Co	0.125	0.117	0.070	0.080	0.028	0.125
Cr	1.580	0.497	0.884	0.470	0.358	0.710
Cu	0.894	0.054	0.502	0.934	0.203	0.627
Fe	18.800	64.400	10.540	29.100	4.270	51.900
K	820.000	-13.400	460.000	-18.400	187.000	-5.070
Mg	741.000	12.800	416.000	7.000	168.000	13.000
Mn	0.580	-0.892	0.326	-1.640	0.132	-1.300
Na	5990.000	2.110	3360.000	0.848	1360.000	1.930
Ni	0.462	-0.201	0.259	-0.031	0.105	-0.016
Pb	3.250	-0.201	1.820	-0.069	0.738	-0.016
Zn	3.910	-0.806	2.190	-0.628	0.889	-0.545

TABLE 31

BROMIDE TRACER LOCATION IN PLOT SOILS IN MARCH 1983
AFTER APPLICATION IN MAY 1982

Sample No.	Plot	Concentration in mg/g at depths below surface			
		0-15 cm	91-102 cm	122-132 cm	168-183 cm
X198	Hancock 2 Grain Sorg.	<0.0002	0.324	4.322	1.619
X202	Hancock 1 Bermuda	<0.0002	<0.0001	<0.0002	<0.0001
X203	Hancock 3 Cotton	<0.0001	<0.0001	<0.0002	0.487
X199	Gray 3 Grain Sorghum	<0.0002	<0.0001	<0.0002	2.255
X200	Gray 1 Bermuda	<0.0002	2.288	<0.0002	<0.0001
X201	Gray 2 Cotton	<0.0001	<0.0001	1.132	1.809

Detection Limits = 0.1 mg/l in extract
or
<0.0001 mg in 100 g of soil
<0.0002 mg in 50 g of soil

TABLE 32

BROMIDE TRACER LOCATION IN PLOT SOILS IN NOVEMBER 1983
AFTER APPLICATION IN MAY 1983

Sample No.	Plot	Concentration in mg/g at depths below surface						
		0-15 cm	30-45 cm	45-60 cm	60-75 cm	75-91 cm	91-107 cm	168-183 cm
X198	Hancock 2 Grain Sorg.	.0094		<.0002	<.0002			.0037
X202	Hancock 1 Bermuda	.0050		.0029	.0254	<.0002		.0057
X203	Hancock 3 Cotton	.0100		.0059				.0044
X199	Gray 3 Grain Sorg.	.0051	<.0002	.0036			.0029	.0032
X200	Gray 1 Bermuda	.0054	.0067	.0107			.0181	.0049
X201	Gray 2 Cotton	.0051	.0108	.0036				.0032

plots similar to that shown in Table 31 for 1982. The cotton plot, with a greater hydraulic loading than the grain sorghum plot, showed an increased bromide content in the 30 to 35 cm layer.

FIELD USE OF EXTRACTION LYSIMETERS

Employment of lysimeters in the soil root zone to monitor percolate generated in the land treatment of municipal wastewater is an attractive concept for improving system management. Detection of undesirable pollutant concentrations in percolate would signal a need to initiate operational changes to reduce the application of the problem pollutant or pollutants. With present monitoring techniques, pollutants are not detected until ground water samples from monitoring wells reflect compositional changes. By the time pollutants are detected in ground waters, large amounts of the contaminating substance may be in transit both in the unsaturated zone and in the saturated zone. Early warning by detection of potential pollution problems in the root zone would reduce environmental impacts on area ground waters.

The extraction lysimeter systems utilized in this study to sample conditions in the vadose zone are not, however, suitable for use as monitoring devices in land treatment of municipal wastewaters. The primary problem is the high cost associated with the collection of useful data from extraction lysimeter systems.

Specialized equipment is required to prepare and emplace lysimeter systems. Support facilities for controlling lysimeter conditions and percolate collection must be installed. Because soil property differences, either in the undisturbed core of the tube lysimeters or in the undisturbed soil layers overlying the tray lysimeters, affect the rates of percolate movement, percolate volumes and the composition of percolate, the lysimeters must be operated continuously. If information useful in the operation of the land treatment system is to be obtained, frequent data collection and sample analysis will be required. Useful information can be obtained about the impacts of biological activities on soil water flow using either the extraction or weighing type of lysimeter. In the author's opinion, however, there is a question now, after completion of this study, as to whether any lysimeter system can reproduce the conditions of soils in their natural state or can detect the subtleties inherent in the hydraulic response of soils in the natural state at a specific location.

Study results indicated that percolate moves through the profile in erratic and unpredictable sequences. Even on the control plots, where application of water occurred at a frequent and sufficient rate to maintain soil moisture conditions at levels at which percolate flow was continuous, the arrival of the peak rates of flow at the collection unit varied over a range of 1-to-3 days after an irrigation event. Additionally, the variability of soil properties over the site and vertically in the profile affects percolate volumes and characteristics. This situation was noticeable in study results and dictates that replication of lysimeter units must be provided at the site in future studies if reliable information is to be obtained. All of these factors add to the costs associated with the use of extraction lysimeters.

The attention and expense required to operate lysimeters in the root zone limit their applicability to research activities rather than operational management of land treatment systems. Lysimeters can be useful in helping to define what occurs in the root zone. The two types of units used on the project would require modifications in system component construction and in the test environment if they are to be employed in another research application. Problem areas with the lysimeters utilized in the study that require consideration before employment in future research efforts are presented in the following lists.

Tray Lysimeters

1. The auger used to drill the pilot hole for the cavity would drift. This produced a dome-like roof area for a portion of the cavity in a few locations where vertical drift occurred.

2. The small cavity opening made it difficult to determine the shape of the roof area at greater distances from the manhole. The inability to examine roof shape thoroughly can result in conditions where no contact is made between the soils in the tray and those in the roof surface.

3. Puddling of the soil in the cavity walls occurred during the forming of the final rectangular shape of the tray cavity. The back-and-forth movement of the cutting head along the soil surface compressed and smoothed the surface zone. Packing of this surface could decrease the hydraulic conductivity of the soils in the roof area in contact with the soil surface of the tray and thus produce a soil condition less conducive to percolate flow.

4. Techniques to better position the tray surface against the cavity roof need to be developed. The positioning of the trays to obtain suitable contact with the roof surface was finally accomplished by means of wooden wedges. The additional movement and vibration of the trays during the interim could have caused both spalling of the roof soil and spillage of the tray material, thus resulting in less contact between the two surfaces.

5. Improvement is needed both in the materials used in wick assembly and in the techniques of their construction. Aging of the materials used in forming the connective joints between the ceramic candles in a moist environment may have caused the further deterioration in the vacuum seal of the wick assemblies noticed during the second season of the project.

6. Methods to prevent piping episodes in which macropores and micropores conduct ponded surface water from either precipitation or irrigation into the tray cavity area and support facilities must be perfected. Solutions will be dependent primarily on limiting the amount of ponding that occurs over the test plot. Placement of tray lysimeters at greater soil depths would decrease the probability of piping from macropores since the number and frequency of flow events in these structures are thought to decrease with depth (2). From calamities experienced during the study

period, it has been determined that it is more cost effective to prevent piping events than to respond to piping episodes by providing sufficient sump pump capacity and capabilities to handle highly variable inflows of mud and water.

Tube Lysimeters

1. The hammering action used to drive the pipe section into the soil could have altered conditions in the structure and in the position of the encapsulated soils. Any compression of the soil material in the cores would be expected to have an adverse effect on the movement of soil water through them. The tight soil conditions noted in the bottom of the lysimeters were not comparable to those observed in the bottom of the excavation from which the encapsulated cores were removed.

2. The greater densities of the soil observed in the tube lysimeters could also affect the amount of water caught. It is probable that, when water infiltrated the surface soils above the tube lysimeters, the tight soil surface on the lysimeters created a perched water table in which the free water would have flowed horizontally to the more permeable zones that existed in the backfill areas surrounding the units.

3. Concentrated efforts must be made to adequately compact backfill soil around tube lysimeter installations. In two instances settlement of fill material around tube lysimeters, caused by ponded conditions at the surface, led to piping conditions that flooded the support facility via the path of the buried percolate collection lines.

The variability in natural soils also affected study results. The differences in soil properties between test areas and within test plots in addition to management of activities on the plots affected the percolate flows that were measured. The field data recorded in each lysimeter resulted from the integrated influence of all local soil properties on flow conditions. The variations in soils, textures, densities, stratigraphy, chemical properties, biological artifacts, and structure introduced unexplainable differences in response to hydraulic loadings. Additionally, difference in soil management above the lysimeters during the project can affect soil properties which will influence study results. Since tensiometers are the easiest means presently available for measuring the matric potential in soils, their utilization to control the operation of individual extraction lysimeters will require their emplacement in the soils overlying the lysimeters. Tensiometers, access ports to lysimeter support facilities, and additional instrumentation devices located near the lysimeter may clutter the soil surface and interfere with normal surface agricultural operations as they are practiced elsewhere on the site. This factor, combined with the packing of the soil caused by operators servicing the equipment in all types of weather, can easily create an artificial soil environment not representative of field conditions.

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APPENDICES

APPENDIX A
PROFILES OF TEST SOILS

APPENDIX A

PROFILES OF TEST SOILS (3, 12)

Amarillo Series

Ap - 0 to 0.36 meters; reddish brown (5YR 5/4) fine sandy loam, dark reddish brown (5YR 3/4) moist; weak fine granular structure; hard, friable; few fine roots; mildly alkaline; abrupt smooth boundary.

B21t - 0.36 to 0.61 meters; reddish brown (5YR 4/4) sandy clay loam, dark reddish brown (5YR 3/4) moist weak coarse prismatic structure parting to weak medium subangular blocky; very hard, friable; common roots; many pores; thin discontinuous clay films on prism faces and patchy clay films on ped faces; noncalcareous; mildly alkaline; gradual wavy boundary.

B22t - 0.61 to 0.84 meters; reddish brown (5YR 5/4) sandy clay loam, reddish brown (5YR 4/4) moist; weak coarse prismatic structure parting to weak medium subangular blocky; hard, friable; few roots; common pores; nearly continuous clay films on prism faces and patchy clay films on ped faces; noncalcareous; moderately alkaline; gradual wavy boundary.

B23t - 0.84 to 1.17 meters; reddish brown (5YR 5/4) sandy clay loam, reddish brown (5YR 4/4) moist; weak coarse prismatic structure parting to weak fine to medium subangular blocky; hard, friable; common pores; few patchy clay films on ped faces; few films and threads of calcium carbonate; calcareous; moderately alkaline; gradual wavy boundary.

B24tca - 1.17 to 1.52 meters; pink (5YR 7/4) sandy clay loam, reddish yellow (5YR 6/6) moist; weak coarse prismatic structure parting to weak fine subangular blocky; hard, friable; many soft masses and weakly cemented concretions of calcium carbonate, about 30 percent by volume; calcareous; moderately alkaline; diffuse wavy boundary.

B25tca - 1.52 to 2.03 meters; pink (5YR 7/4) sandy clay loam, light reddish brown (5YR 6/4) moist; weak fine subangular blocky structure; hard, friable; few patchy clay films; many sand grains bridged with clay films; many soft masses and weakly cemented concretions of calcium carbonate; calcareous; moderately alkaline.

Friona Series

Ap - 0 to 0.20 meters; reddish brown (5YR 4/3) sandy clay loam, dark reddish brown (5YR 3/3) moist; weak fine granular structure; slightly hard, vary friable; many fine roots; mildly alkaline; abrupt smooth boundary.

B21t - 0.20 to 0.38 meters; reddish brown (5YR 4/3) clay loam, dark reddish brown (5YR 3/3) moist; moderate coarse prismatic structure parting to moderate medium subangular blocky; very hard, friable; many pores; many worm casts; thin patchy clay films, mostly on prism faces; few films and threads of calcium carbonate in lower part; calcareous; moderately alkaline, clear smooth boundary.

B22t - 0.38 to 0.66 meters; reddish brown (5YR 4/4) clay loam, dark reddish brown (5YR 3/4) moist; weak coarse prismatic structure parting to weak fine subangular blocky; hard, friable; many fine pores, common worm casts; thin patchy clay films, mostly on ped surfaces; few films, threads, and masses of calcium carbonate; calcareous; moderately alkaline; abrupt smooth boundary.

B23cam - 0.66 to 0.81 meters; pinkish white (5YR 8/2) caliche; indurated in the upper part and strongly cemented in the lower part; the upper surface is laminar and smooth; the lower part has pendants of calcium carbonate as much as 1 centimeter long; gradual wavy boundary.

B24ca - 0.81 to 1.52 meters; pink (7.5YR 8/4) sandy clay loam, pink (7.5YR 7/4) moist; weak medium subangular blocky structure; slightly hard, friable; about 50 percent calcium carbonate in soft powdery forms; calcareous; moderately alkaline.

APPENDIX B

HYDRAULIC LOADING RATES

TABLE B-1

HYDRAULIC LOADING TO BERMUDA GRASS AT THE GRAY SITE WITH SOIL PERMEABILITY AT 4.39 CM/DAY (4% OF LOWEST RATE)

(1) Month	(2) $ET_{(crop)}$ (cm)	(3) Pr (cm)	(4) Net ET (2) - (3) (cm)	(5) Percolation (cm)	(6) $LW_{(P)}$ (4) + (5) (cm)
January	1.40*	1.96	-0.56		
February	2.16*	2.95	-0.79		
March	6.00	4.11	1.89	35.12	37.01
April	15.84	4.76	11.08	52.68	63.76
May	20.80	10.11	10.69	52.68	63.37
June	26.31	10.85	15.46	52.68	68.14
July	25.98	9.53	16.45	52.68	69.13
August	24.15	9.27	14.88	52.68	67.56
September	16.77	10.44	6.33	52.68	59.01
October	11.78	8.76	3.02	52.68	55.70
November	3.59*	2.74	0.85	26.34	27.19
December	1.50*	2.60	-1.10		
Totals	156.28	78.08	78.20	430.22	510.87

*Dormant vegetation

TABLE B-2

HYDRAULIC LOADING TO BERMUDA GRASS SYSTEM AT THE HANCOCK SITE
WITH SOIL PERMEABILITY AT 5.95 CM/DAY (4% OF LOWEST RATE)

(1) Month	(2) $ET_{(crop)}$ (cm)	(3) Pr (cm)	(4) Net ET (2) – (3) (cm)	(5) Percolation (cm)	(6) $LW_{(P)}$ (4) + (5) (cm)
January	1.40*	1.96	–0.56		
February	2.16*	2.95	–0.79		
March	6.00	4.11	1.89	47.6	49.49
April	15.84	4.76	11.08	71.4	82.49
May	20.80	10.11	10.69	71.4	82.09
June	26.31	10.85	15.46	71.4	86.86
July	25.98	9.53	16.45	71.4	87.85
August	24.15	9.27	14.88	71.4	86.28
September	16.77	10.44	6.33	71.4	77.73
October	11.78	8.76	3.02	71.4	74.42
November	3.59*	2.74	0.85	35.7	36.55
December	1.50*	2.60	–1.10		
Totals	156.28	78.08	78.20	583.1	663.76

*Dormant vegetation

TABLE B-3

HYDRAULIC LOADING TO COTTON AT THE GRAY SITE WITH SOIL PERMEABILITY AT 4.39 CM/DAY (4% OF LOWEST RATE)

(1) Month	(2) $ET_{(crop)}$ (cm)	(3) Pr (cm)	(4) Net ET (2) - (3) (cm)	(5) Percolation (cm)	(6) $LW_{(P)}$ (4) + (5) (cm)
January	2.97*	1.96	1.01		
February	3.97*	2.95	1.02		
March	5.21*	4.11	1.10		
April	6.50*	4.76	1.74	13.17	14.91
May	13.10**	10.11	2.99		
June	11.57	10.85	0.72	35.12	35.84
July	24.03	9.53	14.50	35.12	49.62
August	29.00	9.27	19.73	35.12	54.85
September	19.96	10.44	9.52	17.56	27.08
October	11.07	8.76	2.31		
November	3.46**	2.74	0.72		
December	2.39*	2.60	-0.21		
Totals	133.23	78.08	55.15	136.09	182.3

*Bare soil
**Cover and bare soil in period

TABLE B-4

HYDRAULIC LOADING TO COTTON AT THE HANCOCK SITE WITH SOIL PERMEABILITY AT 5.95 CM/DAY (4% OF LOWEST RATE)

(1) Month	(2) $ET_{(crop)}$ (cm)	(3) Pr (cm)	(4) Net ET (2) - (3) (cm)	(5) Percolation (cm)	(6) $LW_{(P)}$ (4) + (5) (cm)
January	2.97*	1.96	1.01		
February	3.97*	2.95	1.02		
March	5.21*	4.11	1.10		
April	6.50*	4.76	1.74	17.85	19.59
May	13.10**	10.11	2.99		
June	11.57	10.85	0.72	47.6	48.32
July	24.03	9.53	14.50	47.6	62.10
August	29.00	9.27	19.73	47.6	67.33
September	19.96	10.44	9.52	23.8	33.32
October	11.07	8.76	2.31		
November	3.46**	2.74	0.72		
December	2.39*	2.60	-0.21		
Totals	133.23	78.08	55.15	184.45	230.66

*Bare soil
**Cover and bare soil in period

TABLE B-5

HYDRAULIC LOADING TO GRAIN SORGHUM AT THE GRAY SITE WITH SOIL PERMEABILITY AT 4.39 CM/DAY (4% OF LOWEST RATE)

(1) Month	(2) $ET_{(crop)}$ (cm)	(3) Pr (cm)	(4) Net ET (2) - (3) (cm)	(5) Percolation (cm)	(6) $LW_{(P)}$ (4) + (5) (cm)
January	2.97*	1.96	1.01		
February	3.97*	2.95	1.02		
March	5.21*	4.11	1.10		
April	6.50*	4.76	1.74	13.17	15.45
May	10.92**	10.11	0.81	17.56	18.37
June	17.10	10.85	6.25	35.12	41.37
July	28.32	9.53	18.79	35.12	53.91
August	25.12	9.27	15.85	35.12	50.97
September	10.90**	10.44	0.46		
October	6.83*	8.76	-1.93		
November	2.97*	2.74	0.23		
December	2.39*	2.60	-0.21		
Totals	123.20	78.08	45.12	136.63	180.07

*Bare soil
**Cover and bare soil in period

TABLE B-6

HYDRAULIC LOADING TO GRAIN SORGHUM AT THE HANCOCK SITE WITH SOIL PERMEABILITY AT 4.39 CM/DAY (4% OF LOWEST RATE)

(1) Month	(2) $ET_{(crop)}$ (cm)	(3) Pr (cm)	(4) Net ET (2) - (3) (cm)	(5) Percolation (cm)	(6) $LW_{(P)}$ (4) + (5) (cm)
January	2.97*	1.96	1.01		
February	3.97*	2.95	1.02		
March	5.21*	4.11	1.10		
April	6.50*	4.76	1.74	17.85	19.59
May	10.92**	10.11	0.81	23.8	24.61
June	17.10	10.85	6.25	47.6	53.85
July	28.32	9.53	18.79	47.6	53.85
August	25.12	9.27	15.85	47.6	66.39
September	10.90**	10.44	0.46		
October	6.83*	8.76	-1.93		
November	2.97*	2.74	0.23		
December	2.39*	2.60	-0.21		
Totals	123.20	78.08	45.12	184.45	227.89

*Bare soil
**Cover and bare soil in period

APPENDIX C

NITROGEN LOADINGS

TABLE C-1

NITROGEN LOADINGS WITH 27 MG/L N WASTEWATER FOR THE GRAY SITE AND 24 MG/L N WASTEWATER AT THE HANCOCK SITE AND DESIGN LOADING FOR TEST PLOTS USING EPA DESIGN CRITERIA FOR BERMUDA GRASS

(1) Month	(2) Pr-ET$_{(crop)}$ (cm)	(3) U (kg N/ha)	(4) LW$_{(N)}$ (cm)		(5)* LW$_{(P)}$ (cm)		(6)** LW$_{(D)}$ (cm)	
			Gray	Hancock	Gray	Hancock	Gray	Hancock
January	+ .56							
February	+ .79							
March	- 1.89	16.6	12.7	16.0	37.01	49.49	13	16
April	-11.08	52.9	36.0	45.5	63.76	82.49	36	46
May	-10.69	69.5	50.7	63.0	63.37	82.09	55	55
June	-15.46	87.9	62.5	78.7	68.14	86.86	55	55
July	-16.45	86.8	60.7	76.5	69.13	87.85	55	55
August	-14.88	80.7	56.7	71.5	67.56	86.28	55	55
September	- 6.33	56.0	42.8	54.0	59.01	77.73	43	54
October	- 3.02	39.3	31.3	39.4	55.70	74.42	32	21
November	- .85	10.3	8.2	10.3	27.19	36.55	8	10
December	+ 1.10							
Totals	-78.2	500.0	361.6	455.8	510.87	663.76	352	367

*Column 5 is based upon three operational days per week. These are project operational restrictions rather than what could be applied with the proper irrigation system.

**Column 6 is what can be applied in three days per week from May to August.

TABLE C-2

NITROGEN LOADINGS WITH 27 MG/L N WASTEWATER FOR THE GRAY SITE AND 24 MG/L N WASTEWATER AT THE HANCOCK SITE AND DESIGN LOADING FOR TEST PLOTS USING EPA DESIGN CRITERIA FOR COTTON

(1) Month	(2) $Pr-ET_{(crop)}$ (cm)	(3) U (kg N/ha)	(4) $LW_{(N)}$ (cm)		(5)* $LW_{(P)}$ (cm)		(6)** $LW_{(D)}$ (cm)	
			Gray	Hancock	Gray	Hancock	Gray	Hancock
January	- 1.01							
February	- 1.02							
March	- 1.10							
April	- 1.74		10.0	6.0	14.91	19.59	10.0	6.0
May	- 2.99							
June	- .72	12.0	9.7	12.3	35.84	48.32	9.7	12.3
July	-14.50	24.0	8.2	10.3	49.62	62.10	8.2	10.3
August	-19.73	29.0	8.0	10.1	54.85	67.33	8.0	10.1
September	- 9.52	20.0	9.0	11.4	27.08	33.32	9.0	11.4
October	- 2.31	11.0						
November	- .72	1.0						
December	- .21							
Totals	-55.15	97.0	44.9	50.1	182.3	230.66	44.9	50.1

*These loadings are based on two operational days per week at the cotton plots.

TABLE C-3

NITROGEN LOADINGS WITH 27 MG/L N WASTEWATER FOR THE GRAY SITE AND 24 MG/L N WASTEWATER AT THE HANCOCK SITE AND DESIGN LOADING FOR TEST PLOTS USING EPA DESIGN CRITERIA FOR GRAIN SORGHUM

(1) Month	(2) $Pr\text{-}ET_{(crop)}$ (cm)	(3) U (kg N/ha)	(4) $LW_{(N)}$ (cm)		(5)* $LW_{(P)}$ (cm)		(6)** $LW_{(D)}$ (cm)	
			Gray	Hancock	Gray	Hancock	Gray	Hancock
January	- 1.01							
February	- 1.02							
March	- 1.10							
April	- 1.74		8.0	11.0	15.45	19.59	8	11
May	- .81	7.3	5.6	7.1	18.37	24.61	11	
June	- 6.25	28.4	19.1	24.1	41.37	53.85	19	7
July	-18.79	47.0	24.3	30.7	53.91	66.39	24	31
August	-15.85	41.7	22.3	28.1	50.97	63.45	22	28
September	- .46	10.6						
October	1.93							
November	- .23							
December	.21							
Totals	-45.12	135.0	79.3	101.0	180.07	227.89	79	101

*These loadings are based on two operational days per week at the grain sorghum plots.

APPENDIX D

PERCOLATE QUALITY PARAMETERS AT THE TEST PLOTS

TABLE D-1

PERCOLATE QUALITY PARAMETERS AT TEST PLOTS

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (µg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY TRAY 103																		
G[a]	221.	8070.	4652.	8.08	1.41	1.56	.051	.29	.025			1665.	805.	280.	167.	35.9	1207.	
SD[b]	47.4		487.	.184	.240	.999	.097		.112			523.	88.3	76.2	39.6	2.65	38.9	
CV[c]	21.2		10.4	2.28	16.8	50.5	91.9		176.			29.8	10.9	26.5	23.2	7.35	3.22	
%C[d]	50	100	100									88.9	100	66.7	66.7	100	50	
E[e]	2	1	6	2	3	7	7	1	6			9	8	3	3	3	2	
kg/ha[f]	135.	4923.	2838.	4.93	.862	.949	.031	.177	.015			1016.	491.	171.	102.	21.9	736.4	
TRAY 104																		
G													530.	560.	197.	19		
SD																		
CV																		
%C															100			
E													1	1	1	1		
kg/ha													15.9	16.8	5.91	.57		
TRAY 105																		
G	398.		3982.			4.36	.026		.017		50	1591.	612.	345.	173.	24.4	807.	
SD			770.			4.31	.014		.023			245.	40.2	60.8	6.36	3.54		
CV			19.1			79.6	47.1		99.1			15.3	6.56	17.5	3.67	14.4		
%C	100		100			80	25					100	100	100	100	100	100	
E	1		3			5	4		3		1	4	5	2	2	2	1	
kg/ha	71.6		717.			.784	.005		.003		9	286.	110.	62.2	31.2	4.39	145.	

[a] G = geometric mean
[b] SD = standard deviation
[c] CV = coefficient of variation
[d] %C = percentage of composite sample in total sampling effort
[e] E = number of quality determination made for the parameter
[f] kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY TRAY 106																		
G[a]						40.2	2.29		.01									
SD[b]																		
CV[c]																		
%C[d]																		
E[e]						1	1		1									
kg/ha[f]						2.41	.137		.001									
TRAY 104-106 DEPTH AVERAGE																		
G	398		3982.			6.31	.064		.015		50.	1591.	597.	406.	181.	22.4	807.	
SD			770.			14.7	1.01		.030			245.	49.3	130.	14.3	4.40		
CV			19.1			131.	210.		181.			15.3	8.63	28.6	7.88	19.4		
%C	100		100			16.7	20					100	83.3	66.7	100	66.7	100	
E	1		3			6	5		4		1	4	6	3	3	3	1	
kg/ha	71.6		717.			.568	.006		.001		9	286.	53.7	66.1	16.3	2.02	145.	
TRAY 107																		
G	316.	4426	3058.	7.48	.26	37.5	.036		.015			1083.	488.	350.	111.	10.3	424.	
SD	12.0		439.			11.3	.030		.013			197.	151.	139.	59.4	2.40		
CV	3.80		14.3			28.6	65.5		72.6			18.0	30.2	38.3	49.9	23.3		
%C	100		100									100	100	100	100	50	100	
E	2	1	5	1	1	7	6		6			10	11	2	2	2	1	
kg/ha	104.	1461.	1009.	2.47	.086	12.4	.012		.005			357.	161.	115.	36.7	3.40	140.	

[a] G = geometric mean

[b] SD = standard deviation

[c] CV = coefficient of variation

[d] %C = percentage of composite sample in total sampling effort

[e] E = number of quality determination made for the parameter

[f] kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY TRAY 108																		
G[a]	213.	5467.	3540.	7.85	.32	57.6	.035		.012		33.	1428.	402.	334.	150.	14.	616.	
SD[b]	1.41	116.	73.6	.028		37.1	.374		.011			438.	78.2	5.66	13.4	1.41	51.6	
CV[c]	.664	2.12	2.08	.361		57.7	184.		77.2			29.9	19.1	1.69	8.92	10.1	8.36	
%C[d]	100		100						.125		100	88.8	100	50	50	50	50	
E[e]	2	2	3	2	1	7	8		8		1	8	8	2	2	2	2	
kg/ha[f]	87.3	2245.	1451.	3.27	.131	23.6	.014		.005		13.5	586.	402.	137.	61.6	5.74	253.	
TRAY 109																		
G	418.		2298.			10.8	.015		.020			549.	307.	38	64.2	16.		
SD			187.			4.49	2.19		.017			169.	43.9					
CV			8.14			39.0	233.		69.7			29.7	14.1					
%C	100		100			16.7	14.3		100			100	100	100	100			
E	1		2			5	7		5			3	8	1	1	1		
kg/ha	62.7		345.			1.63	.002		.003			82.5	46.1	5.7	9.63	2.4		
TRAY 107-109 DEPTH AVERAGE																		
G	286.	5162.	3018.	7.73	.288	30.0	.057		.015		33	1105.	402.	220.	112.	12.9	544.	
SD	86.1	607.	544.	.214	.042	30.9	1.28		.004			430.	133.	157.	46.6	2.89	118.	
CV	29.1	11.9	17.8	2.77	14.6	77.7	318.		23.2			36.5	31.8	54.5	38.6	22.3	21.3	
%C	100		100			95	4.76		5.3		100	95.4	100	80	80	40	66.7	
E	5	3	10	3	2	19	21		19		1	21	27	5	5	5	3	
kg/ha	85.7	1549.	905.	2.82	.087	9.01	.017		.004		13.5	332.	121.	66.1	33.7	3.88	163.	

[a]G - geometric mean

[b]SD = standard deviation

[c]CV = coefficient of variation

[d]%C = percentage of composite sample in total sampling effort

[e]E = number of quality determination made for the parameter

[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY TUBE 111																		
G[a]	689.	3616.	2269.	8.43	1.25	4.06	.013	.019	2.46	.02	26.9	841.	157.	119.	72.1	27.9	947.	8.44
SD[b]	59.4	321.	194.	.148	1.62	5.62	.017	.018	.905		7.64	165.	76.4	22.6	8.98	7.78	720.	5.67
CV[c]	8.53	8.84	8.54	1.75	92.7	74.2	102.9	76.6	34.8		27.9	19.2	43.7	18.9	12.4	27.3	63.9	45.5
%C[d]	100		100						11.1		50	100	100	100	100	100	100	
E[e]	2	5	8	4	5	20	19	17	9	1	2	11	10	2	2	2	8	7
kg/ha[f]	2142.	11244	7058.	26.2	3.89	12.6	.041	.058	7.66	.062	83.5	2617.	489.	370.	224.	87.0	2945.	26.2
TUBE 112																		
G	507.	4287.	2667.	7.62	.607	196.	.053	3.36	.012	.012	32.1	808.	525.	230.	76.9	11.4	528.	
SD	23.5	749.	365.	.264	.321	3.68	.086	1.25	.008	.012	31.4	240.	52.4	105.	14.8	5.21		
CV	4.64	17.2	13.6	3.47	45.9	196.	92.2	35.5	61.2	88.4	82.1	28.7	9.94	36.6	18.9	40.9		
%C	80		78.6	5.6								66.7	7.7	100	100	100	100	
E	5	18	14	18	18	10	10	5	18	11	11	18	13	9	9	9	1	
kg/ha	548.	4630.	7058.	8.23	.656	212.	.057	3/63	.013	.013	34.7	872.	567.	249.	83.1	12.3	570.	
TUBE 111-112 DEPTH AVERAGE																		
G	553.	4131.	2515.	7.76	.710	1.72	.021	.060	.072	.012	31.3	820.	327.	204.	76.0	13.4	887.	8.44
SD	94.3	738.	369.	.400	.865	5.69	.063	1.59	1.34	.012	29.0	212.	189.	113.	13.8	8.27	703.	5.67
CV	16.9	17.6	14.5	5.15	93.4	100.	145.	195.	153.	82.2	79.4	25.1	50.6	46.0	17.8	53.0	66.2	45.5
%C	85.7		86.4	4.5					3.7		7.7	79.3	47.8	100	100	100	100	
E	7	23	22	22	23	30	29	22	27	12	13	29	23	11	11	11	9	7
kg/ha	1162.	3768.	5281.	16.3	1.49	3.61	.045	.127	.152	.025	65.6	1723.	687.	429.	160.	19.9	542.	26.2

[a] G = geometric mean

[b] SD = standard deviation

[c] CV = coefficient of variation

[d] %C = percentage of composite sample in total sampling effort

[e] E = number of quality determination made for the parameter

[f] kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY TUBE 113																		
G[a]	395.	2676.	1593.	7.91	.443	1.47	.015	.033	.015	.01	77.1	466.	209.	90.3	33.6	13.1	324.	31.9
SD[b]	91.0	521.	188.	.140	.271	.989	.774	.079	.029		123.	181.	42.2	41.8	.513	6.25	23.3	29.7
CV[c]	22.6	19.0	11.7	1.77	52.3	56.8	264.	133.	127.		100.	36.2	19.9	42.8	1.53	44.6	7.08	77.2
%C[d]	100	15	100	33.3	28.6	10.7	18.2		8.3		80	100	100	100	100	100	100	100
E[e]	4	20	10	6	7	28	11	5	12	1	5	13	13	3	3	3	2	2
kg/ha[f]	399.	2702.	1609.	7.99	.447	1.49	.015	.034	.015	.010	77.8	471.	211.	91.2	33.9	13.3	327.	32.2
TUBE 114																		
G	291.	3867.	2789.	7.85	.588	.724	.026	.039	.012	.07	40.9	1035.	453.	229.	64.	20.5	609.	16.8
SD	108.	715.	130.	.165	.305	2.39	.063	.041	.009		30.2	50.5	52.6	92.6	9.76	3.21	20.5	10.0
CV	35.1	18.1	4.66	2.10	46.6	108.	131.	81.9	66.6		64.6	4.88	11.5	38.3	15.1	15.6	3.37	55.2
%C	100	7.1	100	28.6	28.6	9.52	16.7		8.3		75	100	100	100	100	100	100	100
E	4	14	11	7	7	21	12	6	12	1	4	13	12	3	3	3	2	2
kg/ha	411.	5452.	3932.	11.1	.787	1.02	.037	.054	.017	.099	57.7	1459.	639.	324.	90.2	28.9	859.	23.6
TUBE 113-114 DEPTH AVERAGE																		
G	339.	3114.	2136.	7.88	.491	1.09	.036	.036	.013	.026	58.2	695.	303.	144.	146.	16.4	448.	21.5
SD	106.	857.	627.	.150	.286	1.73	.538	.058	.022		97.7	303.	132.	102.	20.6	5.75	163.	21.5
CV	29.7	26.5	28.2	1.91	48.8	88.9	325.	107.	120.		110.	39.4	40.2	59.9	36.8	33.2	34.6	76.1
%C	100	11.8	100	30.8	28.6	10.2	4		8.3		77.8	100	100	100	100	100	100	100
E	8	34	21	13	14	49	23	11	24	2	9	26	25	6	6	6	4	4
kg/ha	411.	3767.	2585.	9.53	.595	1.31	.044	.044	.016	.032	70.4	841.	687.	174.	56.1	19.9	542.	26.0

[a]G = geometric mean

[b]SD = standard deviation

[c]CV = coefficient of variation

[d]%C = percentage of composite sample in total sampling effort

[e]E = number of quality determination made for the parameter

[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY TUBE 115																		
G[a]	296.	3479.	2224.	7.69	.641	2.89	.049	.016	.012	.01	26.7	725.	484.	232.	61.9	15.5	563.	17.5
SD[b]	75.1	489.	377.	.219	.411	1.74	.285	.025	.014		43.4	64.5	61.8	4.95	4.24	.707	1.41	14.6
CV[c]	24.8	13.9	16.7	2.85	58.9	53.6	170.	110.	96.4		107.	8.88	12.5	2.13	6.84	4.56	25.1	71.8
%C[d]	75	8	85.7	20	28.6	11.1	18.2			25	60	78.6	83.3	50	50	50	50	100
E[e]	4	25	14	10	7	27	11	10	12	4	5	14	12	2	2	2	2	2
kg/ha[f]	856.	10054	6427.	22.2	1.85	8.35	.144	.046	.036	.029	77.1	2095.	1413.	672.	179.	44.8	1627.	50.6
TUBE 116																		
G	238.	3772.	2776.	7.72	.374	10.5	.043	.01	.014	.01	33.6	924.	596.	299.	42.5	9.17	660.	15.5
SD	3.54	596.	2771.	.326	.374	6.09	.142		.034		68.6	83.45	48.8	14.8	2.12	1.13	63.6	.141
CV	1.50	15.6	99.4	4.22	76.9	53.9	152.2		148.		109.	9.00	8.16	4.96	4.99	12.3	9.61	.912
%C	100	5.6	90	18.2	33.3	15	25	16.7	9.1		50	92.3	91.7	50	50	100	50	100
E	2	18	10	11	9	20	12	6	11	1	6	13	12	2	2	2	2	2
kg/ha	597	9466.	6969.	19.4	.939	26.3	.108	.025	.036	.025	84.4	2318.	1496.	751.	107.	23.0	1658.	38.9
TUBE 115-116 DEPTH AVERAGE																		
G	275.	3599.	2439.	7.70	.474	4.99	.046	.013	.013	.01	30.3	814.	540.	263.	51.3	11.9	610.	16.5
SD	67.2	551.	421.	27.3	.398	5.77	.220	.021	.025		56.9	125.	76.5	39.3	11.6	3.72	67.9	8.86
CV	23.9	15.1	16.9	21.6	66.9	86.4	170.	114	131.		108.	16.2	14.0	14.9	22.2	30.1	11.1	49.5
%C	83.3	6.9	87.4	18.2	31.2	12.76	21.7	6.25	4.3	20	55	85.2	87.5	50	50	75	50	100
E	6	43	24	21	16	47	23	16	23	5	11	27	24	4	4	4	4	4
kg/ha	744.	9716.	6586.	20.8	1.28	13.5	.125	.036	.036	.027	81.8	2199.	1457.	712.	138.	32.2	1646.	44.5

[a]G = geometric mean
[b]SD = standard deviation
[c]CV = coefficient of variation
[d]%C = percentage of composite sample in total sampling effort
[e]E = number of quality determination made for the parameter
[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-I

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY TRAY 201																		
G[a]	228	4390	3295.	8.16	1.57	22.3	.036	401	.062		41.1	1063.	633.	278.	113.	230.		17.5
SD[b]		741.	165.	.205	.798	29.9	.102	.304	.400		8.04	93.7	64.7					
CV[c]		16.7	5.01	2.51	47.4	57.0	120.	66.8	137.		19.3	8.79	10.2					
%C[d]	100	12.5	100	25	33.3	9.0	16.7				66.7	100	100	100	100	100		100
E[e]	1	8	4	4	3	11	6	2	8		3	3	3	1	1	1		1
kg/ha[f]	280.	5400.	4052.	10.0	1.93	27.5	.045	.493	.077		50.5	1307.	779.	342.	139.	283.		21.5
TRAY 202																		
G		5302.	.344	7.81	2	13.1	.140	.01	.057		50.		524.					18.8
SD		247.		.233		17.1	.391		.192									
CV		4.67		2.99		67.6	102.		136.									
%C		50	100	50	100	25	33.3				100		100					100
E		2	1	2	1	4	3	1	3		1		1					1
kg/ha		1909.	1240.	2.81	.72	4.71	.051	.004	.020		18.		189.					6.77
TRAY 203																		
G	154	1358.	1162.	7.47	4.04	3.99	.079		.212		50.	393.	171.	62.	25.2	24		23.4
SD		256.		.431	1.12	17.3	.181		.437			33.1	49.3					
CV		18.6		5.78	27.3	95.5	98.8		115.			8.39	27.9					
%C	100	33.3	100			8.3	9.1		7.7		66.7	100	100	100	100	100		100
E	1	3	1	3	2	12	11		13		3	3	4	1	1	1		1
kg/ha	102.	897.	767.	4.93	2.67	2.63	.052		.139		33.	260.	113.	40.9	16.6	15.8		15.4

[a]G = geometric mean

[b]SD = standard deviation

[c]CV = coefficient of variation

[d]%C = percentage of composite sample in total sampling effort

[e]E = number of quality determination made for the parameter

[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY																		
TRAY 201-203 DEPTH AVERAGE																		
G[a]	187.	2027.	2790.	7.85	2.24	9.59	.068	.117	.119		45.9	647.	322.	131.	53.4	127.		19.7
SD[b]	52.3	1567.	895.	.414	1.41	27.9	.213	.335	.397		6.47	373.	237.9	152.7	62.1	146.		3.1
CV[c]	27.4	40.5	30.2	5.27	55.5	84.1	116.	109.	124.		13.9	51.1	60.7	89.9	89.9	115.		15.6
%C[d]	100	23	100	22.2	100	11.1	15		4.2		71.4	100	100	100	100	100		100
E[e]	2	13	6	9	6	27	20	3	24		7	6	8	2	2	2		3
kg/ha[f]	141.	1520.	2093.	5.89	1.68	7.20	.050	.088	.089		34.5	485.	241.	98.5	40.0	95.3		14.8
TRAY 204																		
G							.032		.842									
SD							.052		.107									
CV							94.5		12.6									
%C																		
E							4		2									
kg/ha							.016		.438									
TRAY 206																		
G							.01		.05	1.02								
SD																		
CV																		
%C										100								
E							1		1	1								
kg/ha							.009		.022	.439								

[a]G = geometric mean
[b]SD = standard deviation
[c]CV = coefficient of variation
[d]%C = percentage of composite sample in total sampling effort
[e]E = number of quality determination made for the parameter
[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY																		
TRAY 204-206 DEPTH AVERAGE																		
G[a]							.025		.106	1.02								
SD[b]							.052		.465									
CV[c]							112.		80.2									
%C[d]										100								
E[e]							5		3	1								
kg/ha[f]							.009		.036	.439								
TRAY 207																		
G				8.11		.226	.01		.049									
SD						3.59			.014									
CV						141.			28.3									
%C																		
E				1		2	1		2									
kg/ha				2.35		.065	.003		.014									
TRAY 208																		
G						.01	.39		.98									
SD																		
CV																		
%C																		
E						1	1		1									
kg/ha						.0002	.008		.020									

[a]G = geometric mean
[b]SD = standard deviation
[c]CV = coefficient of variation
[d]%C = percentage of composite sample in total sampling effort
[e]E = number of quality determination made for the parameter
[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg CaCO$_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO$_2$/NO$_3$ (mg N/l)	NH$_3$ (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO$_4$ (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY																		
TRAY 207-208 DEPTH AVERAGE																		
G[a]				8.11		.080	.063		.014									
SD[b]						2.93	.269		.537									
CV[c]						172.	134.		149.									
%C[d]																		
E[e]				1		3	2		3									
kg/ha[f]				2.35		.014	.011		.002									
TUBE 211																		
G	169.	6161.	5098.	7.93	1.33	16.5	.070	.014	.022		48.6	2142.	522.	564.	92.6	13.0		33.6
SD	14.8	719.	460.	.106	1.02	25.8	.068	.007	.050		2.31	230.6	263.					
CV	8.76	11.6	8.98	1.34	66.4	46.0	70.7	47.3	129.		4.74	10.7	40.4					
%C	100	8.3	100	50	33.3	5.3	12.5	50	8.3		66.7	100	100	100	100	100		100
E	2	12	8	2	3	19	8	2	12		3	6	8	1	1	1		1
kg/ha	98.1	3573.	2957.	4.60	.769	5.32	.041	.008	.013		28.2	1242.	303.	327.	53.7	7.54		19.5
TUBE 212																		
G	195.	4170.	2936.	7.98	.305	80.8	.060		.016		79.9	806.	416.					8.88
SD	25.2	389.	41.3	.49	.587	38.9	.108		.053		178.		59.8					2.48
CV	12.9	9.29	1.41	6.13	114.	39.8	112.		167.		126.		14.2					27.3
%C	75	15.4	100	66.7	100	14.3	66.7		33.3			100	66.7					100
E	4	13	3	3	2	14	3		6		3		3					2
kg/ha	130	2794.	1967.	5.35	.204	.040	.040		.010		53.5	540.	279.					5.95

[a]G = geometric mean

[b]SD = standard deviation

[c]CV = coefficient of variation

[d]%C = percentage of composite sample in total sampling effort

[e]E = number of quality determination made for the parameter

[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY																		
TUBE 211-212 DEPTH AVERAGE																		
G[a]	185.	5029.	4396.	7.96	.737	32.3	.067	.014	.019		62.3	1863.	491.	564.	92.6	13.0		13.8
SD[b]	24.7	1166.	1088.	.352	.959	37.8	.075	.007	.049		123.	551.	246.					14.3
CV[c]	13.2	22.6	24.1	4.42	85.0	51.3	27.3	47.3	136.		130.	28.1	42.0					82.9
%C[d]	83.3	12	100	60	60	9.1	77.4	50	16.7		83.3	100	90.9	100	100	100		100
E[e]	6	25	11	5	5	33	11	2	18		6	7	11	1	1	1		3
kg/ha[f]	117.	3169.	2763.	5.01	.464	5.32	.044	.008	.012		39.3	1173.	309.	327.	53.7	7.54		8.72
TUBE 213																		
G	196	5338.	2376.	7.84		15			.01									
SD		212.																
CV		3.97																
%C	100	50	100	100														
E	1	2	1	1		1			1									
kg/ha	7.84	214.	2957.	4.60		5.32			.0004									
TRAY 301																		
G	208.	2780.	1796.	7.46	.462	5.73	.044	.049	.014	.10	37.1	677.	255.	132.	52.9	18.9	268.	26.6
SD	7.78	142.	188.	.456	.248	6.70	1.36	.049	.064		15.8	102.	96.7	16.3	4.31	1.41		
CV	3.73	5.10	10.4	6.11	48.3	58.9	270.	56.9	196.		40.8	14.9	35.6	12.3	8.15	7.44		
%C	100	25	100	40		8.3	11.1				50	100	100	100	100	100	100	100
E	2	8	7	5	3	12	9	3	8	1	2	8	9	2	2	2	1	1
kg/ha	358.	4781.	4052.	12.8	.795	9.85	.076	.085	.025	.172	63.9	1164.	438.	227.	90.9	32.6	461.	45.8

[a] G = geometric mean

[b] SD = standard deviation

[c] CV = coefficient of variation

[d] %C = percentage of composite sample in total sampling effort

[e] E = number of quality determination made for the parameter

[f] kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY TRAY 302																		
G[a]	208.	2254.	1628.	7.60	.798	4.71	.090	.071	.051	.01	35.0	769.	264.	232.	93.8	35.9	497.	20.5
SD[b]	84.2	1336.	1336.	.366	1.21	8.49	.772	.077	.718		9.67	93.7	80.0	62.4	21.8	5.64	266.	5.78
CV[c]	38.6	52.8	52.8	4.81	96.6	64.8	239.	70.0	223.		26.9	12.1	28.8	26.1	22.8	15.6	50.2	27.7
%C[d]	75	71	64.3	11.1	11.1	3.7	5.3		4.8		40	100	90.1	100	100	100	100	50
E[e]	4	14	14	9	9	27	19	4	21	2	5	10	11	3	3	3	2	2
kg/ha[f]	691.	7484.	5404.	25.2	2.65	15.6	.299	.237	.169	.033	116.	2554.	878.	773.	311.	119.	1650.	68.0
TRAY 303																		
G		965.	707.	8.52	.257	2.57	.028	1.6	.417	.01	21.2	130.	69.8	39.	19.6	20.		15.9
SD		410.	233.	.050	.396	4.11	.058		.627		13.7	52.9	43.4					
CV		40.4	31.7	58.1	104.	99.9	107.		95.2		58.9	37.4	53.4					
%C		25	100	50		12.5	14.3				50	100	100	100	100	100		100
E		4	4	2	2	8	7	1	7	1	2	6	7	1	1	1		1
kg/ha		1496.	1095.	13.2	.398	3.99	.043	2.48	.646	.016	32.8	202.	108.	60.5	30.4	31.		24.6
TRAY 301-303 DEPTH AVERAGE																		
G	208.	2110.	1464.	7.67	.603	4.47	.059	.106	.058	.018	31.7	473.	185.	143.	59.7	26.3	434.	20.5
SD	65.5	1147.	1169.	.497	1.04	8.06	.895	.534	.636	.045	11.8	279.	115.	91.9	34.8	9.95	242.	5.51
CV	30.5	48.3	57.3	6.48	107.	72.4	284.	186.	197.	139.	34.8	47.6	512.	54.0	50.6	35.8	54.6	26.1
%C	83.3	15.4	80	25	7.1	6.4	8.6		2.8		44.4	100	96.3	100	100	100	100	75
E	6	26	25	16	14	47	35	8	36	4	9	24	27	6	6	6	3	4
kg/ha	462.	4685.	3250.	17.0	1.34	9.92	.132	.236	.129	.039	70.4	1050.	410.	318.	132.	58.5	965.	45.6

[a] G = geometric mean
[b] SD = standard deviation
[c] CV = coefficient of variation
[d] %C = percentage of composite sample in total sampling effort
[e] E = number of quality determination made for the parameter
[f] kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK ($mg\ CaCO_3/l$)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY																		
TRAY 304																		
G[a]		4090.	2082.	8.21		3.80	.043		.127	50.8		779.	359.	107.		26.		
SD[b]			20.5			.361	.107		.480			93.8	48.1					
CV[c]			.984			9.48	125.		35.5			11.9	13.3					
%C[d]			100							100		100	75	100		100		
E[e]		1	2	1		2	4		4	1		3	4	1		1		
kg/ha[f]		695.	354.	1.40		.645	.007		.022	8.64		136.	61.0	18.2		4.42		
TRAY 305																		
G			1545.			.491	.091		.01	49.7	17.9	629.	149.	120.		22.		
SD			49.5			2.06	.150					32.5	55.2					
CV			3.2			88.8	110.					5.17	35.8					
%C			50									50	50					
E			2			3	3		3	1	1	2	2	1		1		
kg/ha			1121.			.353	.066		.007	35.8	12.9	453.	107.	86.4		15.8		
TRAY 304-305 DEPTH AVERAGE																		
G		4090.	1793.	8.21		1.11	.059		.043	50.2	17.9	715.	266.	113.		23.9		
SD			312.			1.68	.118		.075	.778		107.	116.	9.19		2.83		
CV			17.2			57.6	110.		92.5	1.55		14.8	39.7	8.10		11.8		
%C			75							50		80	66.7	50		50		
E		1	4	1		5	7		7	2	1	5	6	2		2		
kg/ha		695.	807.	1.40		.500	.027		.019	22.6	12.9	352.	120.	50.9		10.8		

[a]G = geometric mean
[b]SD = standard deviation
[c]CV = coefficient of variation
[d]%C = percentage of composite sample in total sampling effort
[e]E = number of quality determination made for the parameter
[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY TRAY 307																		
G[a]	212	1058.		8.17	1.18	.983	.20	.03	.01	.01	54.9	132.	143.					
SD[b]		84.9				4.16							11.3					
CV[c]		8.01				134.							7.91					
%C[d]													50					
E[e]	1	2		1	1	2	1	1	1	1	1	1	2					
kg/ha[f]	27.6	138.		1.06	.153	.128	.026	.004	.001	.001	7.14	17.2	18.6					
TRAY 308																		
G	270	540		8.71		.17							135.					
SD																		
CV																		
%C		100		100									100					
E	1	1		1		1							1					
kg/ha	27.	54.		.871		.017							13.5					
TRAY 309																		
G		1522.		8.08	1.08	.394	.028		.10		169.		64.	18.	4.0	15.		
SD		863.				1.26	.050											
CV		52.7				100.	110.											
%C																		
E		2		1	1	3	2		1		1		1	1	1	1		
kg/ha		654.		3.47	.464	.169	.012		.043		72.7		27.5	7.74	1.72	6.45		

[a]G = geometric mean
[b]SD = standard deviation
[c]CV = coefficient of variation
[d]%C = percentage of composite sample in total sampling effort
[e]E = number of quality determination made for the parameter
[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY																		
TRAY 307-309 DEPTH AVERAGE																		
G[a]	239.	1070.		8.32	1.13	.465	.054	.03	.252	.01	96.3	132.	115.	18.	4.	15.		
SD[b]	41.0	635.		.340	.071	2.34	.096		.086		80.7		38.9					
CV[c]	17.0	53.5		4.09	6.26	.465	99.5		144.		72.1		32.1					
%C[d]	50	20		33.3									75					
E[e]	2	5		3	2	6	3	1	3	1	2	1	4	1	1	1		
kg/ha[f]	52.6	235.		1.83	.248	.102	.012	.004	.055	.001	21.2	17.2	25.3	7.74	1.72	6.45		
TUBE 311																		
G	153.	3246.	3410.	8.09	.463	12.3	.077	.024	.018	.032	26.1	13720.	696.				543.	12.2
SD	62.9	1718.	342.	.021	.834	20.5	.263	.032	.05	.021	16.3	2.83					33.3	
CV	39.0	49.1	9.99	.262	111.	97.9	131.	96.4	143.	60.6	57.1	.206					6.11	
%C	66.7	33.3	33.3	50	50	25	33.3	66.7	25	50	50		100				100	100
E	3	3	3	2	2	4	3	3	4	2	2	2	1				2	1
kg/ha	76.6	1623.	1705.	4.04	.232	6.13	.038	.012	.009	.016	13.0	6860.	348.				271.	6.1
TUBE 312																		
G	448.	3029.	2188.	7.92	.494	7.38	.035	.017	.018	.01	12.4	671.	369.	141.	56.8	20.9		
SD	84.9	871.	118.	.344	.297	22.4	.144	.012	.072		33.2	96.4	56.4	55.7	4.78	2		
CV	18.8	27.6	5.39	4.34	51.6	108.	151.	57.7	188.		125.	14.2	15.1	37.6	8.34	9.5		
%C	100		100									100	100	100	100	100		
E	2	9	9	7	8	15	15	7	13	1	2	10	9	3	3	3		
kg/ha	842.	5694.	4113.	14.9	.928	13.9	.065	.033	.033	.019	23.4	1261.	694.	265.	107.	39.4		

[a]G = geometric mean

[b]SD = standard deviation

[c]CV = coefficient of variation

[d]%C = percentage of composite sample in total sampling effort

[e]E = number of quality determination made for the parameter

[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
GRAY																		
TUBE 311-312 DEPTH AVERAGE																		
G[a]	235.	3082.	2445.	7.96	.488	8.21	.940	.019	.018	.022	18.0	756.	393.	141.	56.8	20.9	543.	12.2
SD[b]	171.	1113.	584.	.306	.389	21.4	.163	.019	.066	.016	21.4	2.84	114.	55.7	4.75	2.	33.23	
CV[c]	6158.	34.4	23.4	3.85	63.7	104.	145.	79.1	176.	60.5	77.6	.036	28.1	37.6	8.34	9.5	6.11	
%C[d]	80	8.3	9.2	11.1	10	5.3	5.5	10	5.9	33.3	25	83.3	100	100	100	100	100	100
E[e]	5	12	12	9	10	19	18	10	17	3	4	12	10	3	3	3	2	1
kg/ha[f]	280.	3667.	2909.	9.47	.580	9.77	.047	.023	.021	.026	21.4	899.	468.	265.	107.	39.4	271.	6.1
TUBE 313																		
G	279.	3869.	2780.	7.97	.452	.156	.179	.017	.016	.017	49.5	819.	417.					13.2
SD	61.7	679.	741.	.272	.467	74.7	.203	.014	.076	.014	49.5	163.	359.					9.40
CV	21.8	17.3	25.9	3.42	83.4	239.	85.6	70.7	202.	70.7	99.7	19.7	69.2					63.8
%C	66.7	18.8	100	66.7	100	18.8	50		11.1		100	100	100					100
E	3	16	4	3	2	16	4	2	9	2	3	2	4					2
kg/ha	474.	6578.	4726.	13.5	.769	2.65	.304	.029	.027	.029	84.2	1392.	708.					22.4
TUBE 314																		
G	286.	4041.	3104.	7.65	.464	10.0	.029	.014	.106	.01	41.9	955.	657.	459.	80.9	7.92	911.	6.3
SD	32.0	1170.	694.	.353	.498	21.6	.069	.034	.114		45.4	387.	178.	222.	22.6	3.65	256.	
CV	11.1	27.9	21.9	4.61	76.5	109.	121.	149.	244.		86.0	38.3	26.2	43.9	26.9	41.6	44.3	
%C	100	15	100	20	28.6	4.5	7.7		6.7		20	100	100	100	100	100	100	100
E	6	20	11	10	7	22	13	7	15	4	5	12	12	5	5	5	4	1
kg/ha	948.	11374.	10276.	25.3	1.54	33.2	.096	.046	.055	.033	137.	3162.	2175.	1519.	268.	26.2	1690.	20.9

[a]G = geometric mean

[b]SD = standard deviation

[c]CV = coefficient of variation

[d]%C = percentage of composite sample in total sampling effort

[e]E = number of quality determination made for the parameter

[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK	COND	TDS	pH	TKN	NO_2/NO_3	NH_3	TOTAL P	ORTHO P	ORG.P	COD	Cl	SO_4	Ca	Mg	K	Na	TOC
	(mg $CaCO_3$/l)		(mg/l)		(mg N/l)	(mg N/l)	(mg N/l)	(mg P/l)	(mg P/l)	(mg/P)	(pg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
GRAY																		
TUBE 313-314 DEPTH AVERAGES																		
G[a]	284.	3964.	3014.	7.72	.462	4.58	.044	.015	.016	.012	39.0	935.	586.	459.	80.9	7.92	511.	10.3
SD[b]	40.0	978.	695.	.352	.438	49.8	.132	.030	.099	.028	43.4	165.	233.	222.	22.6	3.65	256.	8.25
CV[c]	13.9	24.0	22.5	4.55	73.5	190.	133.	135.	230.	210.	84.0	16.8	36.4	43.9	27.0	41.6	44.3	69.1
%C[d]	88.9	16.7	100	30.8	44.4	10.5	17.6		8.3		50	100	100	100	100	100	100	100
E[e]	9	36	15	13	9	38	17	9	24	5	8	14	16	5	5	5	4	3
kg/ha[f]	713.	9949.	7566.	19.4	1.16	11.5	.111	.037	.041	.030	97.9	2346.	1472.	1519.	268.	26.2	1690.	25.8
G																		
SD																		
CV																		
%C																		
E																		
kg/ha																		
G																		
SD																		
CV																		
%C																		
E																		
kg/ha																		

[a]G = geometric mean
[b]SD = standard deviation
[c]CV = coefficient of variation
[d]%C = percentage of composite sample in total sampling effort
[e]E = number of quality determination made for the parameter
[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
HANCOCK.																		
TRAY 101																		
G[a]		4150.	2429.	7.79	.15	18.3	.066	.03	.031		102.	917.	179.	539.	378.	26.		
SD[b]		813.	510.	.141	.099	16.4	.067		.173		124.	152.	77.3		2.10			
CV[c]		19.6	20.7	1.81	66.	72.6	79.6		157.		85.4	16.3	40.8					
%C[d]			100									100	100	100	100	100		
E[e]		2	3	2	2	4	5	1	3		4	4	6	1	1	1		
kg/ha[f]		2117.	1239.	3.97	.077	9.35	.034	.015	.016		51.8	468.	91.2	275.	193.	13.3		
TRAY 102																		
G	238.	3570.	2831.	7.28	.490	1.52	.053	.021	.014		61.8	1121.	181.	375.	91.4	16.4	22.	14.9
SD		1089.	428.	.427	.287	9.85	.136	.024	.025		35.7	268.	59.6	90.		9.		4.88
CV		29.3	15.0	5.87	48.4	162.	137.	85.8	123.		49.8	23.3	31.4	23.5	2.30	50.		32.
%C	100	71.4	75									75	100	66.7	66.7	66.7	100	
E	1	7	4	3	6	10	11	4	6		4	8	7	3	3	3	1	2
kg/ha	290.	4355.	3454.	8.88	.598	1.85	.065	.025	.017		75.4	1368.	222.	457.	111.	19.9	26.8	8.45
TRAY 103																		
G	108.	5470.	3436.		.692	.84		.02	.01		36.9	1555.	227.					9.28
SD		70.			.131	5.02					15.2	435.	21.7					2.12
CV		1.28			18.7	177.					38.9	27.2	9.55					22.6
%C		100	100									33.3	33.3					
E	1	2	1		3	8		1	4		3	3	3					2
kg/ha	47.5	2407.	1512.	5.39	.314	.369		.009	.004		16.2	684.	99.8					4.08

[a]G = geometric mean
[b]SD = standard deviation
[c]CV = coefficient of variation
[d]%C = percentage of composite sample in total sampling effort
[e]E = number of quality determination made for the parameter
[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-I

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (μg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
HANCOCK																		
TRAY 101-103 DEPTH AVERAGE																		
G[a]	160.	3959.	2738.	7.48	.437	1.92	.057	.022	.015		64.4	1135.	188.	410.	130.	18.4	22.	11.7
SD[b]	91.9	1120.	508.	.418	.287	14.3	.116	.019	.084		85.3	352.	60.9	107.	1.43	35.7		4.57
CV[c]	53.1	27.2	18.3	5.58	52.6	181.	122.	69.0	221.		95.4	29.8	31.0	25.2	.879	179.		37.0
%C[d]	50	45.5	75									73.3	87.5	75	75	75	100	
E[e]	2	11	8	5	11	22	16	6	13		11	15	16	4	4	4	1	4
kg/ha[f]	115.	2850.	1971.	5.39	.314	1.38	.041	.016	.011		46.3	817.	135.	295.	93.8	13.2	26.8	8.45
TRAY 104																		
G						68.4	.15				50							
SD																		
CV																		
%C						100	100				100							
E						1	1				1							
kg/ha						6.15	.014				4.5							
TRAY 105																		
G			2744.			123.	.14		.01			502.3	333.	254.	177.	26.		
SD												20.5	43.8					
CV												4.08	13.1					
%C			100									100	100		100	100		
E			1			1	1		1			2	2	1	1	1		
kg/ha			247.			14.8	.017		.001			60.3	39.9	30.5	21.2	3.12		

[a]G = geometric mean
[b]SD = standard deviation
[c]CV = coefficient of variation
[d]%C = percentage of composite sample in total sampling effort
[e]E = number of quality determination made for the parameter
[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-I

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
HANCOCK																		
TRAY 104-105 DEPTH AVERAGE																		
G[a]			2744.			91.8	.145		.01		50.	502.	333.	254.	177.	.26		
SD[b]						38.9	.007					20.5	43.8					
CV[c]						40.6	4.90					4.08	13.1					
%C[d]			100			50	50				100	100	100		100	100		
E[e]			1			2	2		1		1	2	2	1	1	1		
kg/ha[f]			247.			10.1	.016		.001		4.5	60.3	39.9	30.5	21.24	3.12		
TRAY 108																		
G	128.	6866.	5193.	7.91	.759	184.	.085	.028	.01		103.	679.	232.	627.	266.	30.		47.1
SD		806.	748.	.014	1.57	229.	.131	.049			99.3	341.	30.0					
CV		11.7	14.3	.178	102.	60.2	87.9	109.			75.1	45.5	12.8					
%C			75									20		100	100	100		
E	1	2	4	2	4	8	7	2	5		4	5	5	1	1	1		1
kg/ha	52.5	2815.	2129.	3.24	.311	75.5	.035	.011	.004		42.1	278.	95.2	257.	109.	12.3		19.3
TRAY 109																		
G					1.29	446.	.10	.23			114.	1420.						17.5
SD																		
CV																		
%C																		
E					1	1	1	1			1	1						1
kg/ha																		

[a]G = geometric mean
[b]SD = standard deviation
[c]CV = coefficient of variation
[d]%C = percentage of composite sample in total sampling effort
[e]E = number of quality determination made for the parameter
[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
HANCOCK TRAY 108-109 DEPTH AVERAGE																		
G[a]	128.	6866.	5193.	7.91	.844	203.	.087	.057	.01		105.	768.	232.	627.	266.	30.		28.7
SD[b]		806.	748.	.014	1.37	215.	.122	.162			86.4	409.	29.9					20.9
CV[c]		11.7	14.3	.178	91.4	55.5	85.8	151.			67.2	47.5	12.8					64.8
%C[d]			75									66.7		100	100	100		
E[e]	1	2	4	2	5	9	8	3	5		5	6	5	1	1	1		2
kg/ha[f]	52.5	2815.	2129.	3.24	.187	44.7	.019	.013	.004		23.1	169.	95.2	257.	109.	12.3		6.32
TUBE 113																		
G	351.	2074.	1461.	7.51	.277	12.2	.034	.019	.011	.014	19.7	403.	237.	196.	118.	13.0	126.	7.27
SD	89.2	270.3	76.9	.395	.455	26.3	.112	.023	.004	.014	30.6	65.5	37.8	29.7	7.64	5.10	53.6	3.28
CV	24.8	12.9	5.26	5.26	108.	134.	137.	106.	36.1	82.9	4.3	16.0	15.7	15.0	6.44	36.6	39.9	42.0
%C	62.5	7.7	82.3		15	9.5	12	7.4			11.8	83.3	94.1	90	90	90	88.9	
E	8	39	17	22	20	42	25	27	31	17	17	18	17	10	10	10	9	11
kg/ha	3791.	22416	15790	81.2	.232	132.	.369	.203	.115	.147	213.	4354.	2561.	2120.	1280.	141.	1361.	78.6
TUBE 114																		
G	299.	2135.	1543.	7.43	.285	10.3	.045	.015	.011	.015	13.0	503.	123.	225.	75.6	15.2	79.2	4.63
SD	20.9	429.	216.	.336	2.13	15.9	.549	.016	.046	.011	10.1	94.3	13.3	74.4	18.2	9.42	8.71	1.78
CV	6.99	19.7	13.9	4.51	241.	111.	273.	84.8	205.8	62.3	66.1	18.4	10.7	31.5	23.6	55.3	10.9	35.4
%C	100	8.7	90.1	8.3	15.4	4.2	14.3		5.9	10	22.2	84.6	100	100	100	100	100	33.3
E	4	23	11	12	13	24	14	13	17	10	9	13	11	6	6	6	5	6
kg/ha	1288.	9201.	6649.	32.0	1.23	44.5	.194	.063	.048	.063	55.9	2168.	530.	971.	326.	65.6	341.	20.0

[a] G = geometric mean

[b] SD = standard deviation

[c] CV = coefficient of variation

[d] %C = percentage of composite sample in total sampling effort

[e] E = number of quality determination made for the parameter

[f] kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (µg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
HANCOCK																		
TUBE 113-114 DEPTH AVERAGE																		
G[a]	333.	2096.	1492.	7.48	.279	11.5	.038	.017	.011	.014	17.0	442.	183.	207.	100.	13.8	107.	6.20
SD[b]	77.9	337.	152.	.372	1.37	23.0	.342	.021	.028	.012	25.8	93.2	65.0	52.7	23.9	6.89	50.3	3.09
CV[c]	22.9	15.9	4.2	4.97	227.	130.	244.	101.	184.	74.5	112.	20.6	33.5	24.8	22.6	45.7	43.8	45.4
%C[d]	75	8.1	85.7	2.9	15.2	7.6	12.8	5	2.1	3.7	15.4	83.9	96.4	93.8	93.8	93.8	92.9	11.8
E[e]	12	62	28	34	33	66	39	40	48	27	26	31	28	16	16	16	14	17
kg/ha[f]	2514.	15846	11283	56.5	2.12	86.9	.284	.131	.082	.106	129.	3343.	1385.	1562.	757.	104.	807.	46.9
TUBE 121																		
G	392.	1816.	1056.	7.49	.133	.387	.017	.016	.011	.013	19.4	267	189.	187.	78.2	21.5	106.	6.94
SD	52.4	278.	211.	.231	.292	26.5	.048	.043	.004	.016	19.0	68.4	23.3	47.1	7.96	6.05	10.4	10.5
CV	13.3	15.2	19.4	3.09	111.	391.	143.	163.	39.6	95.3	84.2	24.8	12.3	24.0	10.1	27.3	9.76	107.
%C	50	4.3	59.3	7.1	13.8	8.2	11.8	2.9	2.4		21.1	66.7	95	90	90	90	88.9	26.7
E	12	46	27	28	29	49	34	35	40	24	19	27	20	10	10	10	9	15
kg/ha	6708.	31114	18095	128.	2.27	6.63	.301	.274	.199	.233	332.	4574.	3232.	3206.	1340.	368.	1817.	119.
TUBE 122																		
G	303.	1691.	1014.	7.61	.186	.236	.016	.015	.013	.013	18.0	257.	216.	157.	65.6	16.4	107.	4.04
SD	49.8	246.	164.	.262	.316	8.63	.052	.021	.165	.018	44.5	160.	51.9	30.7	7.54	5.42	13.5	2.28
CV	16.3	14.4	16.0	3.43	104.	291.	169.	101.	389.	108.	147.	54.7	23.6	19.1	11.4	31.6	12.5	50.6
%C	27.3	4.9	57.1	9.5	14.3	7.5	11.5			6.25	12.5	58.3	71.4	87.5	87.5	87.5	85.7	23.1
E	11	41	21	24	21	40	26	28	29	16	16	24	14	8	8	8	7	13
kg/ha	4699.	26257	15746	118.	2.89	3.67	.253	.233	.200	.203	280.	3996.	3362.	2444.	1019.	255.	1657.	62.7

[a] G = geometric mean

[b] SD = standard deviation

[c] CV = coefficient of variation

[d] %C = percentage of composite sample in total sampling effort

[e] E = number of quality determination made for the parameter

[f] kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (μg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
HANCOCK																		
TUBE 121-122 DEPTH AVERAGE																		
G[a]	346.	1756.	1038.	7.54	.153	.310	.017	.016	.011	.013	18.7	262.	199.	173.	72.3	19.1	106.	5.39
SD[b]	67.3	270.	192.	.252	.300	20.5	.042	.035	.107	.016	32.9	119.	40.2	43.5	9.92	5.17	11.4	8.14
CV[c]	19.1	15.2	18.2	3.34	107.	405.	152.	147.	443.	94.1	126.	42.1	19.8	24.1	13.6	30.9	10.7	111.
%C[d]	39	4.59	58.3	7.69	14	7.9	11.6	1.6	1.4	2.5	17.1	62.7	85.3	88.8	8.88	88.8	87.5	25
E[e]	23	87	48	52	50	89	60	63	69	40	35	51	34	18	18	18	14	28
kg/ha[f]	565.	28676	16943	123.	2.50	5.06	.278	.261	.181	.219	306.	4285.	3260.	2830.	1181.	312.	1736.	88.1
TUBE 123																		
G	272.	1627.	994.	7.68	.197	2.52	.028	.016	.011	.014	32.3	246.	147.	120.	82.0	25.3	99.2	7.92
SD	74.9	534.	147.	.374	.502	97.2	.091	.016	.006	.012	46.3	51.7	23.5	18.7	6.33	4.75	29.1	5.58
CV	26.6	31.7	14.6	4.86	116.	239.	145.	83.	54.8	74.2	94.0	20.5	15.8	15.4	7.69	18.5	28.3	60.0
%C	42.9	3.9	68.2	6.4	20.7	11.8	16.7	2.8	2.6	5.5	42.1	68.	80	80	20	80	77.8	38.5
E	14	51	22	31	29	51	36	36	38	18	19	25	15	10	10	10	9	13
kg/ha	3082.	18431	11260	87.0	2.23	28.6	.317	.177	.127	.157	366.	2789.	1671.	1358.	929.	287.	1124.	89.7
TUBE 124																		
G	237.	1419.	905.	7.55	.195	.521	.022	.016	.012	.014	34.5	241.	134.	117.	56.9	14.5	106.	8.07
SD	29.9	277.	73.4	.319	.788	41.6	.194	.028	.021	.021	173.	50.8	25.2	24.5	6.94	3.42	29.5	14.17
CV	12.6	18.9	8.13	4.23	193.	265.	293.	122.	128.	113.	194.	20.6	18.6	20.6	12.1	23.1	27.2	118.
%C	50	4.2	65.2	10.3	20	13.7	17.1	6.25	5.3	5.0	31.6	64	80	75	25	75	75	30.8
E	10	48	23	29	30	51	35	32	38	20	19	25	15	8	8	8	8	13
kg/ha	2415.	16306	10398	86.8	2.24	5.99	.253	.180	.140	.162	396.	2769.	1534.	1349.	655.	166.	1209.	92.7

[a]G = geometric mean

[b]SD = standard deviation

[c]CV = coefficient of variation

[d]%C = percentage of composite sample in total sampling effort

[e]E = number of quality determination made for the parameter

[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
HANCOCK																		
TUBE 123-124 DEPTH AVERAGE																		
G[a]	257.	1523.	947.	7.62	.196	1.16	.025	.016	.012	.014	33.4	243.	140.	119.	69.5	19.7	102.	7.99
SD[b]	63.3	444.	125.	.352	.657	75.5	.149	.022	.015	.017	127.	50.8	24.9	20.8	14.2	6.92	28.5	10.6
CV[c]	24.0	28.3	13.1	4.62	157.	268.	232.	107.	108.	97.3	183.	20.4	17.4	17.3	20.0	33.2	27.1	100.
%C[d]	45.8	4.	66.7	8.33	20.3	12.7	17.	4.4	3.9	5.3	36.8	66	80	77.8	77.8	77.8	76.5	34.6
E[e]	24	99	45	60	59	102	71	68	76	38	38	50	30	18	18	18	17	26
kg/ha[f]	2926.	17372	10810	86.9	2.24	13.1	.285	.178	.133	.159	381.	2777.	1601.	1355.	793.	225.	1164.	91.2
TRAY 201																		
G						4.98	.14		.029		50							23.4
SD						2.46			.036									
CV						45.2			90.1									
%C						20	100				100							100
E						5	1		3		1							1
kg/ha						.399	.011		.002		4.							1.87
TRAY 204																		
G		3130.		8.07	2.14	2.07			.01									
SD					.297	37.6												
CV					13.8	141.												
%C																		
E		1		1	2	2			1									
kg/ha		250.		.646	.171	.165			.0008									

[a]G = geometric mean
[b]SD = standard deviation
[c]CV = coefficient of variation
[d]%C = percentage of composite sample in total sampling effort
[e]E = number of quality determination made for the parameter
[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
HANCOCK TUBE 211																		
G[a]		3570.				9.17			.01									
SD[b]																		
CV[c]																		
%C[d]																		
E[e]		1				1			1									
kg/ha[f]		179.							.0005									
TUBE 214																		
G				8.08	5.25	27.0	.025		.022				507.					
SD							.007		.028									
CV							28.3		94.3									
%C													100					
E				1	1	1	2		2				1					
kg/ha				1.13	.735	3.78	.003		.003				71.0					
TRAY 301																		
G		970.																
SD																		
CV																		
%C																		
E		1																
kg/ha																		

[a] G = geometric mean

[b] SD = standard deviation

[c] CV = coefficient of variation

[d] %C = percentage of composite sample in total sampling effort

[e] E = number of quality determination made for the parameter

[f] kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
HANCOCK TRAY 302																		
G[a]		1234.		7.00	.527	11.2	.107	.01	.017		41.9	448.						13.2
SD[b]		564.			1.90	76.3	.332		.014		10.5							
CV[c]		42.6			132.	159.	140.		70.7		24.8							
%C[d]					50	33.3	33.3				50	100						100
E[e]		6		1	2	3	3	1	2		2	1						1
kg/ha[f]		370.		2.1	.158	3.40	.032	.003	.005		12.6	134.						3.96
TRAY 303																		
G	246.		1402.	7.80	.692	9.19	.061	.01	.110		53.9	433.	288.					20.5
SD					.600	9.75	.086		.011		24.7							6.15
CV					61.9	81.2	79.3		60.8		43.2							29.4
%C					40	30	50				100	100						50
E	1		1	1	5	10	6	1	5		3	1	1					2
kg/ha	95.9		547.	3.04	.269	3.58	.024	.004	.041		21.0	169.	112.					7.99
TRAY 301-303 DEPTH AVERAGE																		
G	246.	1192.	1402.	7.39	.640	9.64	.074	.01	.016		48.7	440.	288.					17.7
SD		532.		.566	.944	35.9	.191		.011		19.9	10.6						6.24
CV		41.8		7.64	85.5	177.	126.		57.6		38.8	2.41						34.0
%C					42.9	30.8	44.4				80	100						66.7
E	1	7	1	2	7	13	9	1	7		5	2	1					3
kg/ha	95.9	465.	547.	2.59	.224	3.38	.026	.004	.006		17.1	154.	112.					6.19

[a]G = geometric mean

[b]SD = standard deviation

[c]CV = coefficient of variation

[d]%C = percentage of composite sample in total sampling effort

[e]E = number of quality determination made for the parameter

[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
HANCOCK TUBE 314																		
G[a]		600.			.79	3.22	.170				45.8	28.						
SD[b]						3.52	.085				28.3							
CV[c]						86.7	47.1				56.6							
%C[d]					100	33.3	100				100	100						
E[e]		1			1	3	2				2	1						
kg/ha[f]		18.			.024	.097	.005				1.38	.18						
TUBE 313-314 DEPTH AVERAGE																		
G		2046.			.199	78.5	.088	.01	.012	.01	51.2	63.3	243.					15.9
SD		646.			.398	72.6	.091		.008		21.6	81,3						
CV		29.4			121.	51.5	79.2		55.1		39.5	95.1						
%C					66.7	20	75				100	100						100
E		11			3	15	4	4	7	4	3	2	1					1
kg/ha		246.			.024	9.42	.011	.002	.003	.002	6.15	7.59	48.6					3.18
G																		
SD																		
CV																		
%C																		
E																		
kg/ha																		

[a]G = geometric mean
[b]SD = standard deviation
[c]CV = coefficient of variation
[d]%C = percentage of composite sample in total sampling effort
[e]E = number of quality determination made for the parameter
[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
HANCOCK TRAY 304																		
G[a]		1160.	1039.			1.22	.305		.024		1.26							
SD[b]						.849	.332		.035									
CV[c]						62.4	86.3		101.									
%C[d]							50				100							
E[e]		1	1			2	2		2		1							
kg/ha[f]		81.2	7.27			.086	.021		.002		.088							
TRAY 305																		
G	214.	1177.		7.08	.10	2.11	.01	.018	.03			117.						
SD		101.				9.46												
CV		8.60				152.												
%C						33.3												
E	1	3		1	1	3	1	1	1			1						
kg/ha	68.5	377.		2.27	.032	.676	.003	.058	.001			37.4						
TRAY 306																		
G						.27	.08		.07									
SD																		
CV																		
%C																		
E						1	1		1									
kg/ha						.024	.007		.006									

[a]G = geometric mean

[b]SD = standard deviation

[c]CV = coefficient of variation

[d]%C = percentage of composite sample in total sampling effort

[e]E = number of quality determination made for the parameter

[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
HANCOCK																		
TRAY 304-306 DEPTH AVERAGE																		
G[a]	214.	1173.	1039.	7.08	.10	1.25	.092	.18	.034		1.26	117.						
SD[b]		83.5				6.65	.276		.028									
CV[c]		7.1				185.	129.		64.8									
%C[d]						16.7	25				100							
E[e]	1	4	1	1	1	6	4	1	4		1	1						
kg/ha[f]	68.5	188.	166.	2.27	.032	.199	.015	.058	.005		.088	37.4						
TRAY 307																		
G					2.83	16.6	.33				131.			67.	35.7	10.	79.	
SD																		
CV																		
%C																		
E					1	1	1				1			1	1	1	1	
kg/ha					.198	1.16	.023				9.17			4.69	2.49	.7	5.53	
TRAY 308																		
G						.27	.63		.01									
SD																		
CV																		
%C																		
E						1	1		1									
kg/ha						.078	.183		.003									

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[b]SD = standard deviation
[c]CV = coefficient of variation
[d]%C = percentage of composite sample in total sampling effort
[e]E = number of quality determination made for the parameter
[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
HANCOCK TRAY 309																		
G[a]	261.	1005.	905	7.38	.279	.915	.02	.01	.020	.01	24.							
SD[b]		81.4		.225	.481	.687	.017		.019									
CV[c]		8.09		3.05	109.	63.8	69.3		76.6									
%C[d]																		
E[e]	1	3	1	3	2	3	4	2	4	1	1							
kg/ha[f]	20.9	80.4	72.4	.591	.022	.073	.002	.0008	.002	.0008	1.92							
TRAY 307-309 DEPTH AVERAGE																		
G	261.	1005.	905	7.38	.604	1.28	.057	.01	.017	.01	56.1			67	35.7	10..	79.	
SD		81.4		.225	1.42	7.04	.253		.018		75.7							
CV		8.09		3.05	115.	175.	.143.		81.3		97.6							
%C																		
E	1	3	1	3	3	5	6	2	5	1	2			1	1	1	1	
kg/ha	20.9	80.4	72.4	.591	.091	.192	.009	.0008	.003	.0008	8.41			4.69	2.50	.7	5.53	
TUBE 311																		
G	121.	2397.	1615.	7.75	.808	41.2	.153	.013	.01	.013	2.12	421.	63.5					5.35
SD	11.3	271.	553.	.120	.198	4.67	.035	.020		.012	31.7	122.	17.1					.212
CV	9.35	11.3	33.0	1.55	24.1	11.2	22.8	112.		81.6	141.	28.2	26.3					3.96
%C	100	14.3	100	100	100	14.3	100	100		100	100	100	100					100
E	2	14	3	2	2	14	2	6	7	6	2	3	3					2
kg/ha	130.4	2589.	1743.	8.37	.873	44.5	.165	.015	.011	.014	2.29	454.	68.6					5.78

[a]G = geometric mean
[b]SD = standard deviation
[c]CV = coefficient of variation
[d]%C = percentage of composite sample in total sampling effort
[e]E = number of quality determination made for the parameter
[f]kg/ha = mass in kg/ha for material intercepted by the unit

TABLE D-1

CONT.

SOURCE	ALK (mg $CaCO_3$/l)	COND	TDS (mg/l)	pH	TKN (mg N/l)	NO_2/NO_3 (mg N/l)	NH_3 (mg N/l)	TOTAL P (mg P/l)	ORTHO P (mg P/l)	ORG.P (mg/P)	COD (pg/l)	Cl (mg/l)	SO_4 (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Na (mg/l)	TOC (mg/l)
HANCOCK TUBE 312																		
G[a]		1527.			1.74	77.0	.08	.26	.01		112	1.50	184					27.1
SD[b]		336.				10.0												
CV[c]		21.3				12.9												
%C[d]					100	10	100	100			100	100	100					100
E[e]		9			1	10	1	1	3		1	1	1					1
kg/ha[f]		183.			.209	9.24	.009	.031	.001		13.4	.18	22.1					3.25
TUBE 311-312 DEPTH AVERAGE																		
G	121.	2009.	1615.	7.75	1.03	53.5	.123	.021	.01	.013	7.96	325.	82.9					9.19
SD	11.3	509.	553.	.120	.549	19.6	.05	.093		.012	56.3	173.	61.1					12.6
CV	9.35	24.4	33.0	1.55	48.8	34.6	38.5	176.		81.6	108.	47.7	64.5					99.7
%C	100	8.7	100	100	100	12.5	100	100		100	100	100	100					100
E	2	23	3	2	3	24	3	7	10	6	3	4	4					3
kg/ha	130.	1206.	1744.	8.37	.617	32.1	.074	.012	.006	.014	4.78	195.	49.7					5.51
TUBE 313																		
G		2313.			.01	174.	.046	.01	.013	.01	64.	143.	243.					15.9
SD		391.				17.8	.028		.008									
CV		16.6				10.2	56.6		55.1									
%C					50	8.3	50				100	100						100
E		10			2	12	2	4	7	4	1	1	1					1
kg/ha		463.			.002	34.9	.009	.012	.003	.002	12.8	28.6	48.6					3.18

[a]G = geometric mean
[b]SD = standard daviation
[c]CV = coefficient of variation
[d]%C = percentage of composite sample in total sampling effort
[e]E = number of quality determination made for the parameter
[f]kg/ha = mass in kg/ha for material intercepted by the unit

APPENDIX E

EQUIVALENT RATIOS FOR WATER CHARACTERISTICS

TABLE E-1

EQUIVALENT RATIOS FOR WATER CHARACTERISTICS
ON THE BERMUDA PLOT AT THE GRAY SITE

Ratio	Irrigation	Tray Depth (cm) 61	122	183	Tube Depth (cm) 122	183	224	Ground Water
SO_4^{2-}/Cl^-	.528	.357	.374	.268	.294	.321	.489	.602
HCO_3^-/Cl^-	.692	.094	.177	.183	.478	.346	.240	.596
Ca^{2+}/Cl^-	.481	.298	.312	.353	.441	.367	.573	.423
HCO_3^-/Na^+	.531	.129	.227	.241	.287	.348	.208	.563
K^+/Na^+	.045	.027	.016	.013	.009	.022	.011	.038
Ca^{2+}/Na^+	.369	.411	.577	.464	.264	.369	.496	.400
Mg^{2+}/Ca^{2+}	.878	.984	.735	.841	.613	.530	.320	1.45
SAR[a]	13.64	23.08	23.23	20.05	38.50	21.40	28.13	12.38
$\frac{Cl^- - Na^+}{Cl^-}$	-.303	.275	.218	.241	-.668	.006	-.154	-.058
BASE EXCHANGE[b]	$-I_{BA}$	$+I_{BA}$	$+I_{BA}$	$+I_{BA}$	$-I_{BA}$	$+I_{BA}$	$-I_{BA}$	$-I_{BA}$

[a] $SAR = Na^+/((Ca^{2+} + Mg^{2+})/2)^{\frac{1}{2}}[9.4-p(K_2'-K_1')-p(Ca+Mg)-p(Alk)]$

[b] $-I_{BA}$ meq/l Cl^- < meq/l Na^+ or meq/l $(HCO_3^- + SO_4^{2-})$ > meq/l $(Mg^{2+} + Ca^{2+})$

$+I_{BA}$ meq/l Cl^- > meq/l Na^+ or meq/l $(HCO_3^- + SO_4^{2-})$ < meq/l $(Mg^{2+} + Ca^{2+})$

TABLE E-2

EQUIVALENT RATIOS FOR WATER CHARACTERISTICS
ON THE COTTON PLOT AT THE GRAY SITE

Ratio	Irrigation	Tray Depth (cm) 61	122	183	Tube Depth (cm) 122	183	224	Ground Water
SO_4^{2-}/Cl^-	.528	.366			.194			.602
HCO_3^-/Cl^-	.692	.205			.070			.596
Ca^{2+}/Cl^-	.481	.359			.054			.423
HCO_3^-/Na^+								
K^+/Na^+								
Ca^{2+}/Na^+								
Mg^{2+}/Ca^{2+}	.878	.670			.271			1.45
SAR[a]								
$\frac{Cl^- - Na^+}{Cl^-}$								
BASE EXCHANGE[b]	$-I_{BA}$	$+I_{BA}$			$+I_{BA}$			$-I_{BA}$

[a] $SAR = Na^+/((Ca^{2+} + Mg^{2+})/2)^{\frac{1}{2}}[9.4-p(K_2'-K_1')-p(Ca+Mg)-p(Alk)]$

[b] $-I_{BA}$ meq/l Cl^- < meq/l Na^+ or meq/l $(HCO_3^- + SO_4^{2-})$ > meq/l $(Mg^{2+} + Ca^{2+})$

$+I_{BA}$ meq/l Cl^- > meq/l Na^+ or meq/l $(HCO_3^- + SO_4^{2-})$ < meq/l $(Mg^{2+} + Ca^{2+})$

TABLE E-3

EQUIVALENT RATIOS FOR WATER CHARACTERISTICS ON THE GRAIN SORGHUM PLOT AT THE GRAY SITE

Ratio	Irrigation	Tray Depth (cm) 61	122	183	Tube Depth (cm) 122	183	224	Ground Water
SO_4^{2-}/Cl^-	.528	.289			.384	.463		.602
HCO_3^-/Cl^-	.692	.312			.221	.216		.596
Ca^{2+}/Cl^-	.481	.535			.330	.869		.423
HCO_3^-/Na^+	.531	.220			.199	.258		.563
K^+/Na^+	.045	.036			.023	.009		.038
Ca^{2+}/Na^+	.369	.378			.298	1.04		.400
Mg^{2+}/Ca^{2+}	.878	.688			.664	.290		1.45
SAR[a]	13.64	18.48			23.67	15.43		12.38
$\frac{Cl^- - Na^+}{Cl^-}$	-.303	-.417			-.108	.157		-.058
BASE EXCHANGE[b]	$-I_{BA}$	$-I_{BA}$			$-I_{BA}$	$+I_{BA}$		$-I_{BA}$

[a] $SAR = Na^+/((Ca^{2+} + Mg^{2+})/2)^{\frac{1}{2}}[9.4-p(K_2'-K_1')-p(Ca+Mg)-p(Alk)]$

[b] $-I_{BA}$ meq/l Cl^- < meq/l Na^+ or meq/l $(HCO_3^- + SO_4^{2-})$ > meq/l $(Mg^{2+} + Ca^{2+})$

$+I_{BA}$ meq/l Cl^- > meq/l Na^+ or meq/l $(HCO_3^- + SO_4^{2-})$ < meq/l $(Mg^{2+} + Ca^{2+})$

TABLE E-4

EQUIVALENT RATIOS FOR WATER CHARACTERISTICS
ON THE BERMUDA PLOT AT THE HANCOCK SITE

Ratio	Irrigation	Tray Depth (cm) 61	122	183	Tube Depth (cm) 122	183	224	Ground Water
SO_4^{2-}/Cl^-	.457	.122		.223		.305		.903
HCO_3^-/Cl^-	.738	.100		.118		.533		2.54
Ca^{2+}/Cl^-	.309	.639		1.445		.827		1.03
HCO_3^-/Na^+	.507					1.43		1.39
K^+/Na^+	.034					.076		.065
Ca^{2+}/Na^+	.212					2.217		.565
Mg^{2+}/Ca^{2+}	.690	.523		.703		.799		1.71
SAR[a]	20.08					4.32		5.49
$\frac{Cl^- - Na^+}{Cl^-}$	-.457					.627		-.827
BASE EXCHANGE[b]	$-I_{BA}$	$+I_{BA}$		$+I_{BA}$		$+I_{BA}$		$-I_{BA}$

[a] $SAR = Na^+/((Ca^{2+} + Mg^{2+})/2)^{\frac{1}{2}}[9.4-p(K_2'-K_1')-p(Ca+Mg)-p(Alk)]$

[b] $-I_{BA}$ meq/l Cl^- < meq/l Na^+ or meq/l $(HCO_3^- + SO_4^{2-})$ > meq/l $(Mg^{2+} + Ca^{2+})$

$+I_{BA}$ meq/l Cl^- > meq/l Na^+ or meq/l $(HCO_3^- + SO_4^{2-})$ < meq/l $(Mg^{2+} + Ca^{2+})$

TABLE E-5

EQUIVALENT RATIOS FOR WATER CHARACTERISTICS
ON THE COTTON PLOT AT THE HANCOCK SITE

Ratio	Irrigation	Tray Depth (cm) 61	122	183	Tube Depth (cm) 122	183	224	Ground Water
SO_4^{2-}/Cl^-	.457	.483			.188	.284		.903
HCO_3^-/Cl^-	.738	.396	1.30		.263			2.54
Ca^{2+}/Cl^-								
HCO_3^-/Na^+	.507			1.52				1.39
K^+/Na^+	.034			.075				.065
Ca^{2+}/Na^+	.212			.972				.565
Mg^{2+}/Ca^{2+}	.690			.88				1.71
SAR[a]	20.08			4.55				5.49
$\frac{Cl^- - Na^+}{Cl^-}$								
BASE EXCHANGE[b]								

[a] $SAR = Na^+/((Ca^{2+} + Mg^{2+})/2)^{\frac{1}{2}}[9.4-p(K_2'-K_1')-p(Ca+Mg)-p(Alk)]$

[b] $-I_{BA}$ meq/l Cl^- < meq/l Na^+ or meq/l $(HCO_3^- + SO_4^{2-})$ > meq/l $(Mg^{2+} + Ca^{2+})$

$+I_{BA}$ meq/l Cl^- > meq/l Na^+ or meq/l $(HCO_3^- + SO_4^{2-})$ < meq/l $(Mg^{2+} + Ca^{2+})$

TABLE E-6

EQUIVALENT RATIOS FOR WATER CHARACTERISTICS
ON THE CONTROL PLOT AT THE HANCOCK SITE

Ratio	Irrigation	Tray Depth (cm) 61	122	183	Tube Depth (cm) 122	183	224	Ground Water
SO_4^{2-}/Cl^-	.543				.568	.420		.903
HCO_3^-/Cl^-	.571				.935	.742		2.54
Ca^{2+}/Cl^-	.343				1.162	.870		1.03
HCO_3^-/Na^+	.412				1.50	1.16		1.39
K^+/Na^+					.109	.114		.065
Ca^{2+}/Na^+	.247				1.87	1.36		.565
Mg^{2+}/Ca^{2+}	.792				.698	.833		1.71
SAR[a]	12.89				4.65	4.69		5.49
$\frac{Cl^- - Na^+}{Cl^-}$	-.386				.378	.362		-.827
BASE EXCHANGE[b]	$-I_{BA}$				$+I_{BA}$	$+I_{BA}$		$-I_{BA}$

[a] $SAR = Na^+/((Ca^{2+} + Mg^{2+})/2)^{\frac{1}{2}}[9.4-p(K_2'-K_1')-p(Ca+Mg)-p(Alk)]$

[b] $-I_{BA}$ meq/l Cl^- < meq/l Na^+ or meq/l $(HCO_3^- + SO_4^{2-})$ > meq/l $(Mg^{2+} + Ca^{2+})$

$+I_{BA}$ meq/l Cl^- > meq/l Na^+ or meq/l $(HCO_3^- + SO_4^{2-})$ < meq/l $(Mg^{2+} + Ca^{2+})$

APPENDIX F

MASS INPUTS IN APPLIED WASTEWATER AND MASS OUTPUTS IN PERCOLATE AND CROPS HARVESTED

TABLE F-1

MASS INPUTS AND OUTPUTS IN KG/HA ON THE BERMUDA PLOT AT THE GRAY SITE OVER THE PROJECT PERIOD

		Tray Depth			Tube Depth			
Parameter	Applied Wastewater	61 cm	122 cm	183 cm	122 cm	183 cm	244 cm	Crop
ALK	4170	135	71.6	85.7	1160	411	744	
TDS	18980	2840	717	905	5280	2580	2440	
TKN	159	.862		.087	1.49	.595	1.28	147
NO_2+NO_3-N	49.0	.949	.568	9.01	3.61	1.31	13.49	
NH_3-N	38.8	.031	.006	.017	.045	.044	.125	
TOTAL P	56.5	.177			.127	.044	.036	19.5
ORTHO P	32.5	.015	.001	.004	.152	.016	.036	
ORG. P	2.43				.025	.032	.027	
COD	1650		9.0	13.5	65.6	70.4	81.7	
Cl	2080	1020	286	332	1720	841	2200	73.7
SO_4	3040	491	53.7	121	687	366	1460	130
Ca	1150	171	36.5	66.1	429	174	712	31.6
Mg	623	102	16.3	33.7	160	56.1	138	13.3
K	274	21.9	2.02	3.88	28.2	19.9	32.2	86.5
Na	3610	736	145	163	1860	542	1650	6.06
TOC	548				26.2	26.0	44.4	

TABLE F-2

MASS INPUTS AND OUTPUTS IN KG/HA ON THE COTTON PLOT AT THE GRAY SITE OVER THE PROJECT PERIOD

Parameter	Applied Wastewater	Tray Depth 61 cm	Tray Depth 122 cm	Tray Depth 183 cm	Tube Depth 122 cm	Tube Depth 183 cm	Tube Depth 244 cm	Crop
ALK	1730	141			117	7.84		
TDS	7850	2090			2760	95.0		
TKN	65.7	1.68			.464			16.8
NO_2+NO_3-N	20.3	7.20		.014	5.32	0.60		
NH_3-N	16.1	.050	.009	.011	.044			
TOTAL P	23.4	.088			.008	–		2.44
ORTHO P	13.4	.089	.036	.002	.012	.001		
ORG. P	1.0		.439					
COD	681	34.5			39.3			
Cl	861	485			1170			.26
SO_4	1260	241			309			38.0
Ca	476	98.5			327			4.92
Mg	258	40.0			53.7			2.99
K	113	95.2			7.54			9.95
Na	1490							.317
TOC	227	14.8			8.72			

TABLE F-3

MASS INPUTS AND OUTPUTS IN KG/HA ON THE GRAIN SORGHUM PLOT AT THE GRAY SITE OVER THE PROJECT PERIOD

Parameter	Applied Wastewater	Tray Depth			Tube Depth			Crop
		61 cm	122 cm	183 cm	122 cm	183 cm	244 cm	
ALK	2000	462		52.6	280	712		
TDS	9110	3250	807		2910	7570		
TKN	76.2	1.34		.248	.58	1.16		29.5
NO_2+NO_3-N	23.5	9.92	.500	.102	9.77	11.5		
NH_3-N	18.6	.132	.027	.012	.047	.111		
TOTAL P	27.1	.236		.004	.023	.037		5.82
ORTHO P	15.6	.129	.019	.055	.021	.041		
ORG. P	1.17	.039	22.6	.001	.026	.030		
COD	790	70.4	12.9	21.2	21.4	97.9		
Cl	980	1050	352	17.2	899	2350		2.90
SO_4	1460	410	120	25.3	468	1470		19.9
Ca	552	318	51.0	7.74	265	1520		4.90
Mg	299	132		1.72	107	268		4.21
K	131	58.5	10.8	6.45	39.2	26.2		9.27
Na	1730	964			39.4	1690		0.59
TOC	263	45.6			6.1	25.8		

TABLE F-4

MASS INPUTS AND OUTPUTS IN KG/HA ON THE BERMUDA PLOT
AT THE HANCOCK SITE OVER THE PROJECT PERIOD

		Tray Depth			Tube Depth			
Parameter	Applied Wastewater	61 cm	122 cm	183 cm	122 cm	183 cm	244 cm	Crop
ALK	8680	116		52.5		2510		
TDS	29620	1971	247	2130		11282		
TKN	940	.314		.187		2.11		229
NO_2+NO_3-N	2.85	1.38	10.1	44.7		86.9		
NH_3-N	521	.041	.016	.019		.284		
TOTAL P	359	.016		.013		.131		31.6
ORTHO P	207	.011	.001	.004		.082		
ORG. P	6.67					.106		
COD	6120	46.3	4.5	23.1		128.8		
Cl	8300	817	60.3	169		3340		39
SO_4	5070	135	39.9	95.2		1380		238
Ca	1450	295	30.5	257		562		41.2
Mg	607	93.8	21.2	109		757		18.6
K	455	13.2	3.12	12.3		104		116
Na	7870	26.8				807		10.8
TOC	1365	8.45		6.32		46.9		

TABLE F-5

MASS INPUTS AND OUTPUTS IN KG/HA ON THE COTTON PLOT AT THE HANCOCK SITE OVER THE PROJECT PERIOD

Parameter	Applied Wastewater	Tray Depth			Tube Depth			Crop
		61 cm	122 cm	183 cm	122 cm	183 cm	244 cm	
ALK	4870	95.9	68.5	20.9	130			
TDS	16630	547		72.0	1740			
TKN	527	.224	.032		.617	.024		12.3
NO_2+NO_3-N	1.60	3.38	.199	.192	32.1	9.42		
NH_3-N	293	.026	.015	.009	.074	.011		
TOTAL P	201	.004	.058	.008	.012	.002		1.70
ORTHO P	116	.006	.005	.003	.006	.003		
ORG. P	3.74			.008	.014	.002		
COD	3440	17.1	.088	8.41	4.78	6.15		
Cl^-	4660	154	37.4		195	7.59		.569
SO_4	2850	112			49.7	48.6		32.9
Ca	813			4.69				3.53
Mg	341			2.50				2.47
K	255			.700				10.6
Na	4420			5.53				.190
TOC	766	6.19			5.51	3.18		

TABLE F-6

MASS INPUTS AND OUTPUTS IN KG/HA ON THE GRAIN SORGHUM PLOT AT THE HANCOCK SITE OVER THE PROJECT PERIOD

Parameter	Applied Wastewater	Tray Depth			Tube Depth			Crop
		61 cm	122 cm	183 cm	122 cm	183 cm	244 cm	
ALK	1970							
TDS	6730							
TKN	214		.171			.735		141
NO_2+NO_3-N	.647	.40	.165		1.62	3.78		
NH_3-N	118	.011				.003		
TOTAL P	81.5	.002	.001		.001	.003		26
ORTHO P	47.0							
ORG. P	1.52							
COD	1390	4						
Cl	1890							35.1
SO_4	1150					71.0		377
Ca	329							27
Mg	138							27.4
K	103							94.6
Na	1790							2.78
TOC	310	1.87						

TABLE F-7.

MASS INPUTS AND OUTPUTS IN KG/HA ON THE CONTROL PLOT
AT THE HANCOCK SITE OVER THE PROJECT PERIOD

		Tube Depth		
Parameter	Applied Water	122 cm	183 cm	Crop
ALK	3270	5650	2930	
TDS	15100	16900	10800	
TKN		2.49	2.24	123
NO_2+NO_3-N	1.78	5.06	13.1	
NH_3-N		.278	.285	
TOTAL P		.261	.178	1.70
ORTHO P		.181	.133	
ORG. P		.219	.159	
COD		306	381	
Cl	4030	4300	2780	.569
SO_4	2960	3260	1600	32.9
Ca	770	2830	1350	3.53
Mg	381	1180	793	2.47
K		312	225	10.6
Na	3640	1736	1163	.190
TOC		88.1	91.2	