Evaluation of Drainfield Absorption and Evapotranspiration Capacity

By

Ken Rainwater, Ph.D., P.E., DEE and Andrew Jackson, Ph.D., P.E.
Texas Tech University Water Resources Center
Box 41022
Lubbock, TX 79409-1022

Submitted to

Texas On-Site Wastewater Treatment Research Council
Texas Commission on Environmental Quality
OSSF Program MC-178
P.O. Box 13087
Austin, TX 78711-3087

January 2004

Table of Contents

List of Tables

List of Figures

1. Introduction

1.1 Problem Statement

Septic tanks and associated drainfields are used throughout the United States as on-site wastewater treatment and disposal systems for individual residences or small communities. In many locations, drainfields are strictly dependent on soil absorption of the effluent from the septic tanks. In Texas, on-site wastewater treatment facilities are under the regulatory authority of the Texas Commission on Environmental Quality (TCEQ). Under TCEQ (2001) guidance, drainfield design is based on either absorption (AB) only or evapotranspiration (ET) only. AB drainfields, which dispose of water through gravity flow and capillary action, are preferred in areas with permeable soils and relatively deep water tables, while ET drainfields, which lose water only upward to the atmosphere, are required with impermeable soils or shallow water tables. In actuality, AB fields also lose water upward due to ET, but this process is ignored in the TCEQ (2001) guidance. The annual precipitation in Texas varies from approximately 9 in/yr in the west to over 56 in/yr in the east. In the more arid portions of western Texas, permeable soils allow AB drainfields; however, hydrologically speaking, neglecting the additional water lost to ET may result in significantly over-designed drainfield installations. Potential evaporation in the more arid regions in Texas can be three to four times greater than annual precipitation. Septic system regulators and installers in the western half of Texas have suggested that current TCEQ (2001) design standards for AB and ET systems result in oversized systems. Table 1.1 shows the TCEQ (2001) values for long-term acceptance rates (LTARs) for various soil classes. Local ET rates are based on historical annual average rates at various locations across the state.

To address these concerns, the Texas On-Site Wastewater Treatment Research Council (TOSWTRC) sponsored research by the Texas Tech University Water Resources Center (TTUWRC) to demonstrate the combined contributions of ET and AB (ETA) septic system drainfields. The primary purpose of the research was to determine whether the size of ETA systems can be reduced due to the combined effect of ET and AB in arid and semi-arid regions of Texas. Phase I of this work, field demonstration of hydraulic capacity of simple drainfield trenches, was performed in 1999 to 2001 at a site at Reese Center, west of Lubbock (Rainwater et al. 2001). The specific objectives of Phase I were to (1) quantify observed loading rates between drainfield types and compare with current TCEQ standards, (2) evaluate weather

Table 1.1 Long-Term Application Rates (TCEQ 2001)

Soil Class	LTAR (gpd/ft^2)
Ia (gravelly sand)	>0.50
Ib (sand)	0.38
II (sandy loam)	0.25
III (silt or clay loam)	0.20
IV (clayey soils)	0.10

effects on ET fields, (3) report observed water quality associated with each drainfield type, and (4) recommend a new loading rate for combined ETA systems. The field site constructed for the Phase I study included trenches built for absorption only (AB, unlined trench bottom and walls, but covered to prevent upward losses), evapotranspiration only (ET, lined trench bottom and walls), and combined evapotranspiration and absorption (ETA, unlined trench bottom and walls, and no surface cover) trenches. Figure 1.1 shows the site layout schematic. The TOSWTRC required that no proprietary drainfield devices were used in the field tests, so simple gravel and local soil backfill were used in the trenches. Each trench was 20 ft long, 3 ft wide, and 2 ft deep. The water levels in the trenches were maintained at 16 inches above the trench bottoms, which corresponded to the top of the gravel fill. An artificial wastewater mixture was passed through a septic tank system for a detention time of at least 3 days prior to application to the trenches. The soils at the site were classified as types II or III, which corresponded to LTAR values of 0.25 and 0.20 gpd/ft^2, respectively.

Table 1.2 summarizes the average loading rates over the final twelve months of the Phase I tests based on three replicates for each trench type. It is apparent that the average loading values for both the AB (2 to 3 times) and ETA (4 to 5 times) trenches significantly exceeded the TCEQ (2001) values for type II and III soils. Based on these findings, it was possible to recommend that the TCEQ guidance allow ETA trench systems in type II or III soils in the Lubbock area to have LTAR values at least twice the current TCEQ (2001) AB trench guidance for those soil types, while maintaining a reasonable factor of safety, if the trenches are spaced at least 15 ft apart. The main concern about using the field data to change the current guidance was that the duration of the field experiments was not long enough to represent the typical lives of septic system drainfields. To answer this concern, a second phase of experiments was proposed.

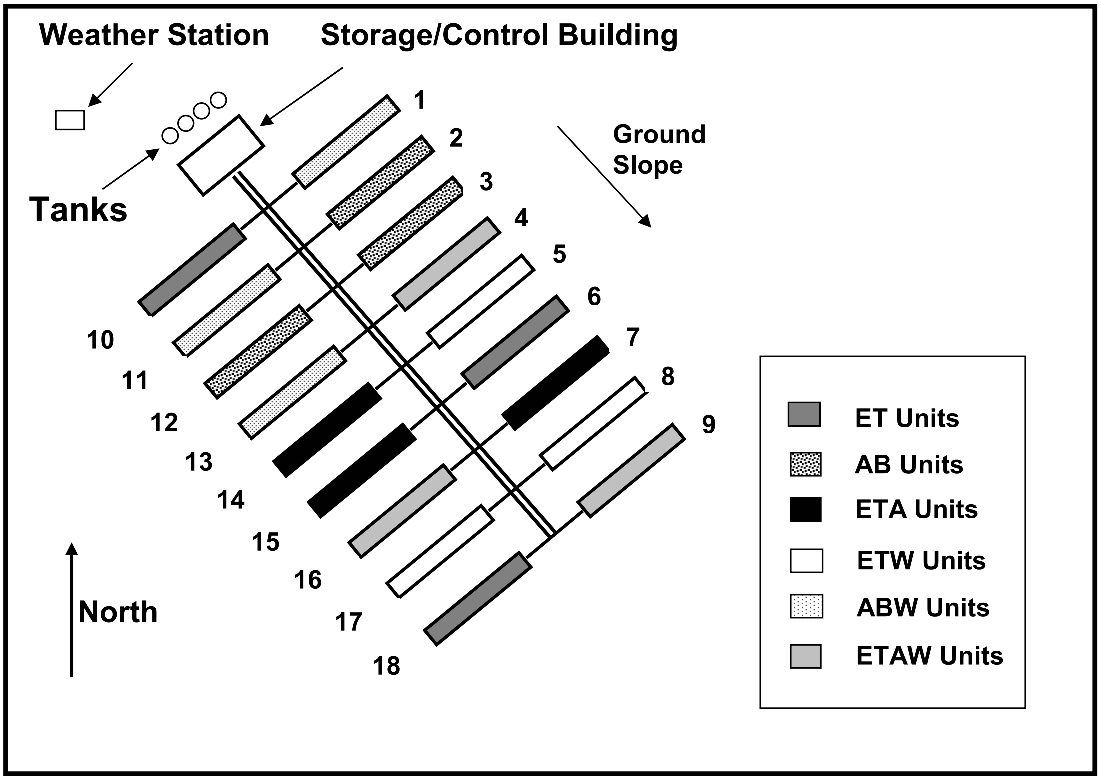


Figure 1.1 Site Layout for Phase I (W for wastewater application, others clean water)

Table 1.2 Summary of Phase I Wastewater Trench Performance

Drainfield Type	Average Loading (gpd/ft^2)	95% Confidence Interval
ETW	0.11	0.01
ABW	0.64	0.24
ETAW	1.07	0.17

1.2 Objectives

The Phase II project began in January 2002 with two primary objectives. The first objective was to perform a second set of loading tests on ETA drainfield trenches receiving septic tank effluent from an artificial wastewater. The existing field site included six ETA trenches, three that had received wastewater (4, 9, and 16 in Figure 1.1) and three that had briefly received clean water (7, 14, and 15). The test duration was to be long enough to achieve the more stable loading conditions seen in the final twelve months of the Phase I project. Water quality parameters were monitored on a biweekly basis. The second objective was to develop of loading rate recommendations for ETA drainfields at other locations in the State of Texas. This hydrologic effort included evaluation of soil characteristics, precipitation, and potential ET, which can affect the performance of ETA systems, and comparison of those values to those found at the Lubbock test facility. The combination of the field test observations and the hydrologic study were used to propose regional guidelines for ETA systems. This report documents the Phase II efforts for these two objectives.

In another attempt to understand the fate of septic system effluents near ETA trenches, a companion modeling study was carried out during Phase II. This study used a numerical computer model that can describe unsaturated flow, MODFLOW-SURFACT, to simulate wastewater application to an ETA trench under the same conditions observed at trench 9 during 1/15/2000 to 12/31/2000. The work and results effort were reported in a separate document by Waghdhare et al. (2003). The findings of the modeling study indicated that, for the type II and III soil and local climatic conditions at the Lubbock site, most of the water applied to the trench is lost to ET from above and around the trench, rather than downward infiltration. It should be noted that the current state of the art in unsaturated flow modeling is relatively imprecise due to the limitations in numerical representation of the complex processes of gravity flow, capillary suction, and ET that can simultaneously occur within a soil matrix. The findings and limitations were presented in detail by Waghdhare et al. (2003) for the interested reader.

2. Phase II Field Demonstration

2.1 Operation of Field Site

2.1.1 Wastewater Loading

As reported previous, Phase II of the project was requested by the TOSWTRC to extend observation of ETA trench behavior. The field site was shut down completely for approximately nine months between Phases I and II. As shown in Figure 1.1, there were six total ETA trenches at the site. Three received septic tank effluent in Phase I (4, 9, and 16), while three received clean water for a short time (7, 14, and 15). In Phase II, all six of these trenches received septic tank effluent under the same loading conditions as those used in Phase I. The effluent levels in the trenches were maintained within 0.5 in of the top of the gravel envelope, and the flow to each trench was monitored. All other operational practices were similar to those used in Phase I. The units were brought on-line in a staggered fashion from early April into July, as the high initial hydraulic loading rates challenged the capacity of the water well supplying the site. As seen in Phase I, the loading rates decreased significantly after several weeks. The daily operational procedure began with recording the flow totalizer readings for each trench and the wastewater septic tank outlet. All readings were taken at the same time each day to provide consistent data. Artificial wastewater was mixed once or twice daily depending on the loading demanded by the wastewater units. The target artificial wastewater quality parameters, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), and total suspended solids (TSS), are shown in Table 2.1, and the concentrations were the same as those in Phase I. The artificial wastewater mixture, shown in Table 2.2, was also the same as that used in Phase I, with one exception beginning in January 2003. After the beginning of Phase II, the TOSWTRC| requested a separate addition of fats, oil, and grease (FOG) in the mixture. As of the end of January 2003, after the flows in all trenches had been somewhat stable for a few months, cooking oil was added to each batch for at 100 mg/L. The target FOG concentration was typical of domestic wastewater (Qasim 1999; Tchobanoglous and Schroeder 1985).

Table 2.1 Target Wastewater Quality (as in Phase I)

Parameter	Concentration in Raw Mixture (mg/L)
BOD_5 (without oil)	195
COD	502
TKN	32
TSS	87

Table 2.2 Artificial Wastewater Mixture

Ingredient	Concentration in Raw Mixture
Reduced Calorie Beer	2.51 mL/L
Flour	53 mg/L
Kaolin-USP Grade	40 mg/L
Triton X	24 mg/L
Urea	65 mg/L
Cooking Oil (after January 2003)	100 mg/L

2.1.2. Weather Data Collection

An on-site weather station monitored precipitation and climatic conditions during the test period. Daily potential free-water ET and precipitation amounts were calculated for evaluation of the units' responses to weather changes. The weather station was a GroWeather™ model manufactured by Davis Instruments. Air temperature, humidity, and dew point were measured using the temperature/humidity sensor. In addition, the GroWeather™ recorded solar radiation, barometric pressure, precipitation, wind speed and wind direction. All weather records could be viewed by using the keyboard unit mounted in the control building. A data logger was connected to this unit to record weather conditions every thirty minutes and to calculate ET each hour. ET was calculated by the software from hourly averages of solar radiation, air temperature, vapor pressure, and wind speed using a Penman-type equation calibrated by Pruitt and Doorenbos (1977). The data logger was downloaded daily to a computer using the GroWeatherLink™ software. Backup weather data were also available from a second weather station at Reese Center maintained by the Texas Tech University Wind Engineering Research Center.

2.1.3 Water Quality Data Collection

Water samples were collected approximately biweekly from the wastewater header tank and each trench. COD, total nitrogen (TN), and TSS were monitored with appropriate analytical methods taken from APHA (1998). These water quality parameters were measured to insure that the septic tank effluent supplied to the trenches remained similar to typical wastewater effluent.

2.2 Results

Phase II began with staggered initial loading of the six ETA trenches. The first trenches began receiving septic tank effluent in April 2002, and by July 2002 all six trenches were under loading. Each trench required several weeks for loading rates to stabilize. Trench 15 was subject to repeated malfunctions of its flow control system in 2003, and flow to that trench was terminated in May 2003. Loading of the remaining five trenches was terminated in on July 8, 2003. At that time, the flow control systems had been experiencing occasional flow control problems, and complete replacement of the flow control valves and level sensors for all trenches would have been too costly for the project funding level. In the following sections, the results and discussion emphasize the observations after the loading rates stabilized.

2.2.1 Weather Observations

The primary weather data of interest were daily ET and precipitation. Figures 2.1 and 2.2 show the daily precipitation and free-water ET amounts, respectively, for the period of interest.

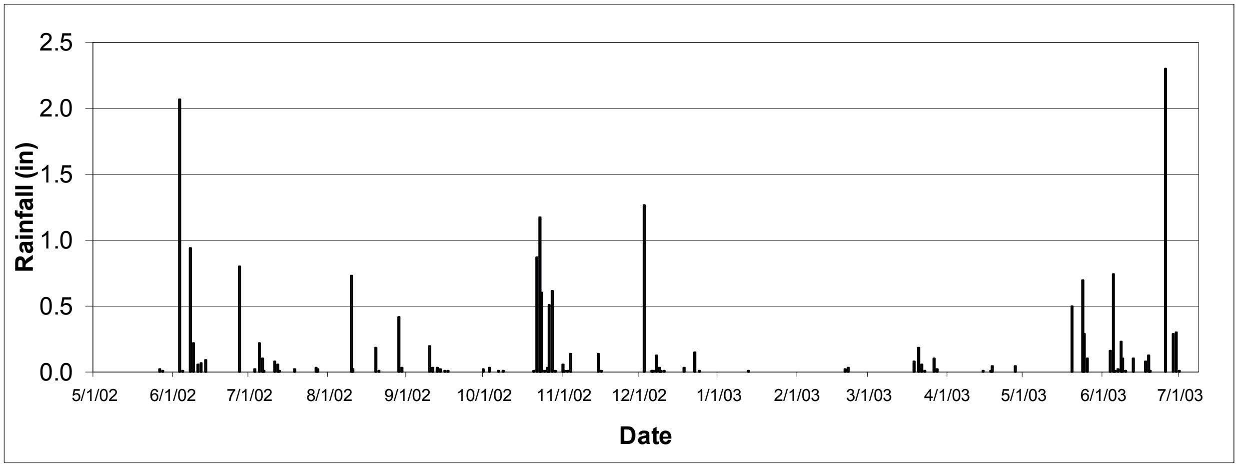


Figure 2.1 Daily Precipitation for Phase II

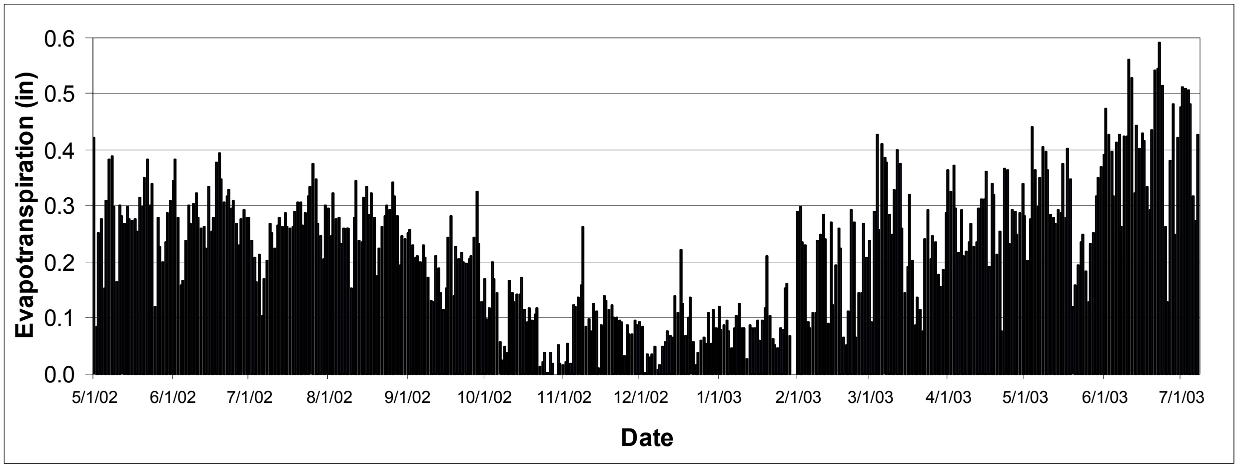


Figure 2.2 Daily Evapotranspiration for Phase II

Table 2.3 summarizes the monthly amounts of ET and rainfall for Phase II. It should be noted that only the first eight days of July 2003 are included. Examination of Figure 2.1 shows the erratic nature of the precipitation events, as rainfall at the site was primarily from short-term term convective thunderstorms rather than more persistent frontal or cyclonic storms. The greatest monthly rainfall totals were for June 2002 and June 2003, and in both cases over half the rainfall came on a single day. It should be noted that calendar year 2003 was the second driest on record for the National Weather Service station at Lubbock International airport. The daily ET values, while quite noisy from one day to the next, generally followed the expected seasonal trends with greater ET in the summer months and lesser values in October through January.

Table 2.3 Monthly ET and Rainfall Totals for Phase II

Month	ET (in)	(in)
5/02	8.62	0.03
6/02	8.69	4.26
7/02	8.06	0.57
8/02	8.39	1.40
9/02	6.10	0.31
10/02	2.82	3.93
11/02	2.86	0.37
12/02	2.23	1.67
1/03	2.66	0.01
2/03	5.26	0.05
3/03	3.37	0.47
4/03	8.37	0.12
5/03	8.99	1.59
6/03	12.25	4.50
7/03*	3.51	0.01
Total	92.16	19.29

* July 1-8 only

2.2.2 Loading Results

Tables 2.4 and 2.5 display the average monthly loading rates (gpd/ft^2) and flow rates (gpd) for the trenches, respectively. As expected, the initial loading rates for the ETA trenches were relatively high, as the initially dry soil beneath and adjacent to the trenches accepted significant amounts of water into the pore space. The loading rates were calculated for each day

Table 2.4 Average Monthly Loading Rates (gpd/ft^2) with 95% Confidence Intervals

	4		7		9		14		15		16		Overall	
Month	Mean	Conf.	Mean	Conf.	Mean	Conf.	Mean	Conf.	Mean	Conf.	Mean	Conf.	Mean	Conf.
4/02	4.17	0.87	off	off	off	off	5.19	0.47	off	off	off	off	4.68	0.67
5/02	1.65	0.24	3.06	0.32	2.56	0.74	3.08	0.47	2.84	0.58	off	off	2.64	0.47
6/02	1.23	0.10	2.58	0.27	1.78	0.31	2.17	0.20	2.13	0.18	off	off	1.98	0.21
7/02	1.24	0.07	1.81	0.20	1.34	0.07	1.77	0.14	1.69	0.15	3.91	1.45	1.96	0.34
8/02	1.08	0.06	1.32	0.10	1.09	0.06	1.89	0.26	1.42	0.14	1.81	0.15	1.43	0.13
9/02	0.84	0.04	0.91	0.04	0.89	0.05	1.51	0.19	1.06	0.04	1.44	0.10	1.11	0.08
10/02	0.65	0.06	0.80	0.07	0.73	0.12	1.20	0.10	0.73	0.11	1.10	0.09	0.87	0.09
11/02	0.63	0.03	0.85	0.03	0.87	0.03	1.13	0.04	0.67	0.03	1.08	0.09	0.87	0.04
12/02	0.65	0.06	0.83	0.07	0.81	0.09	1.04	0.09	0.64	0.05	1.03	0.08	0.83	0.07
1/03	0.90	0.04	0.94	0.04	0.85	0.04	1.12	0.05	0.76	0.04	1.05	0.05	0.94	0.04
2/03	0.95	0.08	1.11	0.10	1.04	0.17	1.23	0.11	0.94	0.08	1.26	0.18	1.09	0.12
3/03	0.89	0.14	1.50	0.32	0.91	0.21	1.07	0.17	0.94	0.13	1.59	0.20	1.15	0.20
4/03	0.83	0.13	1.15	0.15	0.80	0.12	1.17	0.19	1.00	0.14	1.25	0.18	1.03	0.15
5/03	0.78	0.08	1.03	0.11	0.99	0.18	1.00	0.11	0.89	0.16	1.13	0.15	0.97	0.13
6/03	0.61	0.07	0.93	0.11	0.75	0.12	0.81	0.11	off	off	0.94	0.12	0.81	0.11
7/03*	0.44	0.12	0.70	0.23	0.51	0.22	1.03	0.83	off	off	0.70	0.19	0.68	0.32

*July 1-8 only, 2.9 in rain in last week of June.

Table 2.5 Average Monthly Flow Rates (gpd) with 95% Confidence Intervals

	4		7		9		14		15		16		Overall	
Month	Mean	Conf.	Mean	Conf.	Mean	Conf.	Mean	Conf.	Mean	Conf.	Mean	Conf.	Mean	Conf.
4/02	442	93	off	off	off	off	550	50	off	off	off	off	496	71
5/02	175	25	324	34	271	78	327	50	301	61	off	off	280	50
6/02	130	10	274	28	189	33	230	21	226	20	off	off	210	22
7/02	131	7	192	21	142	7	188	15	179	15	414	154	208	37
8/02	115	7	140	10	116	6	200	28	150	14	192	16	152	13
9/02	89	5	97	4	95	5	160	20	113	4	152	10	118	8
10/02	69	7	84	7	78	13	127	11	78	12	116	9	92	10
11/02	67	4	90	3	92	3	120	4	71	3	115	10	93	4
12/02	69	6	87	7	86	9	110	10	67	6	109	9	88	8
1/03	95	4	99	4	90	4	119	5	81	4	112	5	99	5
2/03	101	9	118	11	111	18	130	12	99	9	134	19	115	13
3/03	94	14	159	34	97	22	113	18	99	14	168	22	122	21
4/03	88	14	122	16	85	13	124	20	106	14	133	19	110	16
5/03	83	8	109	12	104	19	106	11	94	17	119	15	103	14
6/03	64	7	99	12	79	13	86	11	off	off	99	13	85	11
7/03*	47	13	74	24	54	23	109	88	off	off	75	20	72	34

* July 1-8 only, 2.9 in rain in last week of June.

by dividing that day's flow rate in gpd by the absorption area of 106 ft^2, which included the bottom area of the trench plus 1 ft up the side walls. If any trench was subject to a malfunction that caused zero or too much flow for a given day, that day's flow data were removed from the dataset prior to statistical analyses. Average values and 95% confidence intervals of loading and

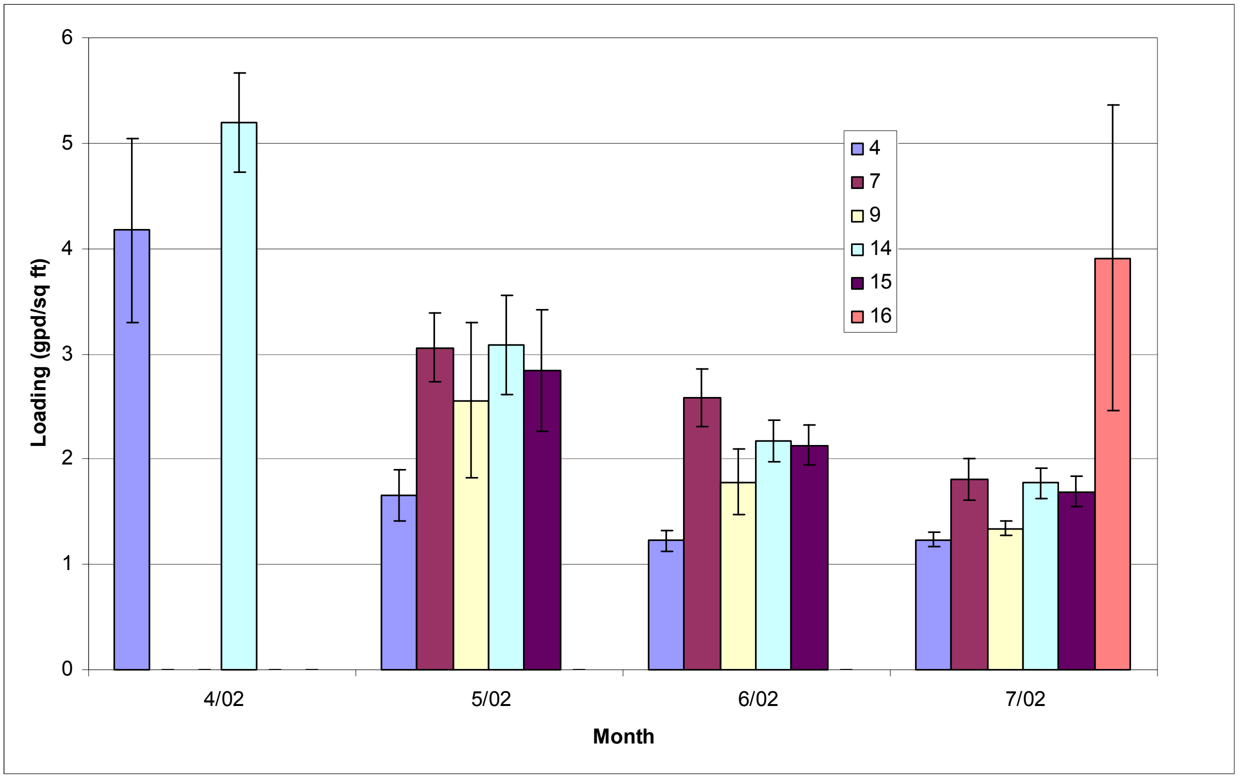


Figure 2.3 Average Values and 95% Confidence Intervals for Loading in April-July 2002

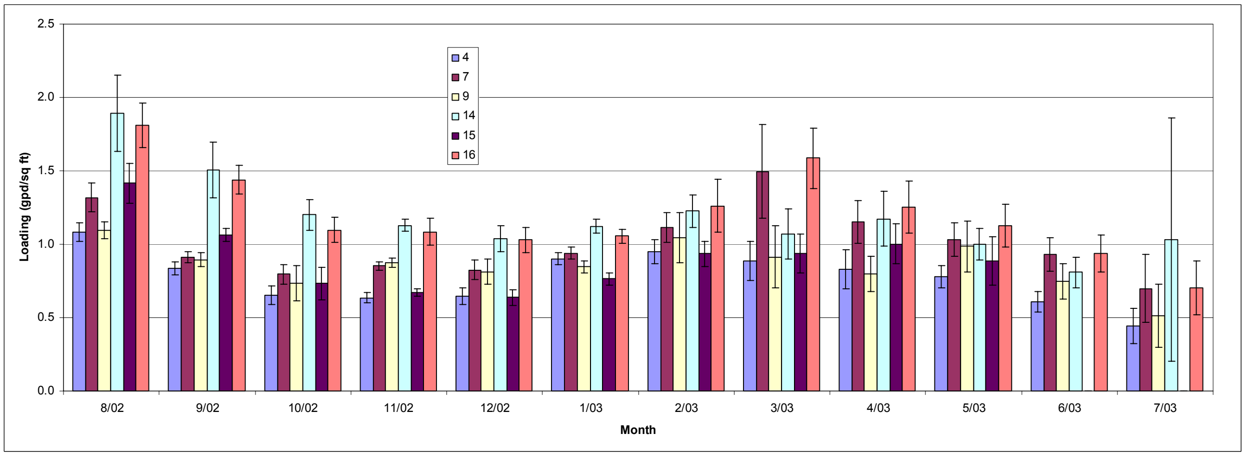


Figure 2.4 Average Values and 95% Confidence Intervals for Loading in August 2002-July 2002

flow rate were calculated for each trench for each month. Figure 2.3 shows histograms of the monthly loading averages and confidence intervals for the first four months of Phase II with the scale on the loading axis sized to show the large initial values. Figure 2.4 is a similar plot for the remainder of Phase II. It should be noted that only the first eight days of July 2003 three were included in the Phase II dataset. Approximately 2.9 in of rainfall were measured at the field site on the last two days of June 2003, which appeared to significantly affect the wastewater inputs to the ETA trenches in the first week of July 2003. Had the experiment continued further through the rest of July 2003, it is likely that the impacts of the late June storm would be dissipated over time.

The observed loading rates at the trenches did vary somewhat after stabilizing near 1 gpd/ft^2. The addition of cooking oil after January 2003 did not appear to have significant impact on loading rates. In general, trench 4 had the lowest loading rates while trenches 7, 14, and 16 had the highest loading rates. As noted in Phase I, the soil conditions in the six trenches were not exactly identical, and there were some variations in the results of initial double-ring infiltrometer tests and observed loading rates. Double-ring infiltrometer tests were also performed at the end of Phase II, and those results are presented in a later section. Table 2.6 summarizes the average loading rates for the ETA trenches that received septic tank effluent in both Phase I and Phase II. For both phases, the last 12 months of operation were used to represent a relatively longer-term condition after the flows had stabilized in all trenches. The November-December 2002 period was used to compare with the lowest flow observations in November-December 2000 in Phase I, which might be more meaningful for design considerations. The April-May 2003 average loading rates were compared to the same two-month period in 2001 in Phase I. Table 2.6 shows that the 12-month and November-December averages were very close for the two experiments, while the April-May average loading rate appeared to be somewhat higher for Phase II than Phase I. It was apparent that the average loading rates were still much greater than the AB-only guidance of 0.20 to 0.25 gpd/ft^2 set by the TCEQ (2001) for the local soils. Before making further conclusions about those comparisons, it was important to do post-test evaluation of the water content and infiltration measurements near the trenches. That work is presented in a later section following the presentation of the water quality observations.

Table 2.6 Phase I and II Comparison of ETAW Trenches

	Phase I (4, 9, 16)		Phase II (4, 7, 9, 14, 15, 16)	
Time Period	Average Load (gpd/ft^2)	95% Confidence	Average Load (gpd/ft^2)	95% Confidence
Final 12 months	1.07	0.21	1.04	0.15
November-December	0.70	0.24	0.85	0.15
April-May	0.78	0.23	1.00	0.12

2.2.3 Water Quality Data

Figures 2.5, 2.6, and 2.7 display the observed concentrations of COD, TN, and TSS, respectively for the septic tank effluent at the header tank as well as at the sampling location in each trench. Table 2.7 summarizes the average values and 95% confidence intervals for the three parameters for the entire Phase II. COD values were relatively stable around 260 to 280 mg/L, with only occasional outliers. TN was typically near 40 mg/L except during August to October 2002, when concentrations were nearer 60 mg/L. TSS was typically near 25 mg/L except for a few measurements in June 2002 and January 2003. It is not clear whether the higher TN and TSS values were due sampling or analytical errors, or to actual differences in system behavior. It should be noted that this project was not intended to quantify treatment in the trenches, but rather the water quality data were to demonstrate the stability in the test conditions.

2.2.4 Post-Treatment Investigation

During July 2003, after the end of the septic tank effluent loading, three types of field investigations were done to evaluate the hydrogeologic conditions at and near trenches 4, 7, 9, 14, and 16. Field 15 was not included as it had been taken off-line two months earlier. The purpose of the investigations was to determine whether significant biological growth in the soil near the trenches could be the cause of the lower long-term loading rates. One criticism of the Phase I and II field studies could be that neither was long enough to allow significant build-up of microorganisms or "biological mat" along the bottom and walls of the trenches, at the interface between the gravel and native soil. A related concern was the distribution of moisture in the soil beneath and adjacent to the trenches. In the previous report on Phase I, Rainwater et al. (2001) proposed that the added hydraulic capacity of the ETA trenches beyond that assumed in the guidance for AB-only trenches was due to an ET area for each trench that was much larger than the rectangular top of the trench excavation. To evaluate these concerns, several different post-treatment tasks were done. First, the extent of enhanced vegetation above and around each trench was measured and recorded. Second, geoprobe samples were taken through and near the trenches to quantify vertical and lateral variations in water content. The water contents in the samples near the trenches were compared to those at similar depths at two control sample locations at the field site that were never exposed to the septic system effluent. Third, a backhoe was used to carefully excavate to the bottom of each trench and expose the presence or absence of the "biological mat." This task was recorded with photographs. Fourth, a double-ring

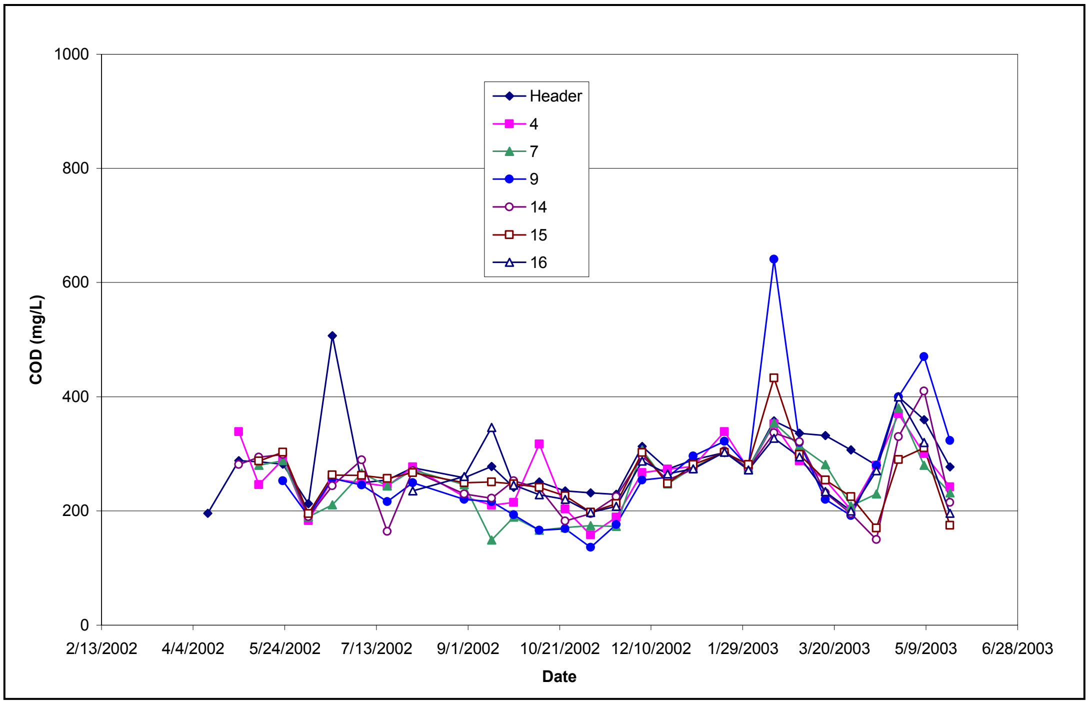


Figure 2.5 Observed COD Concentrations

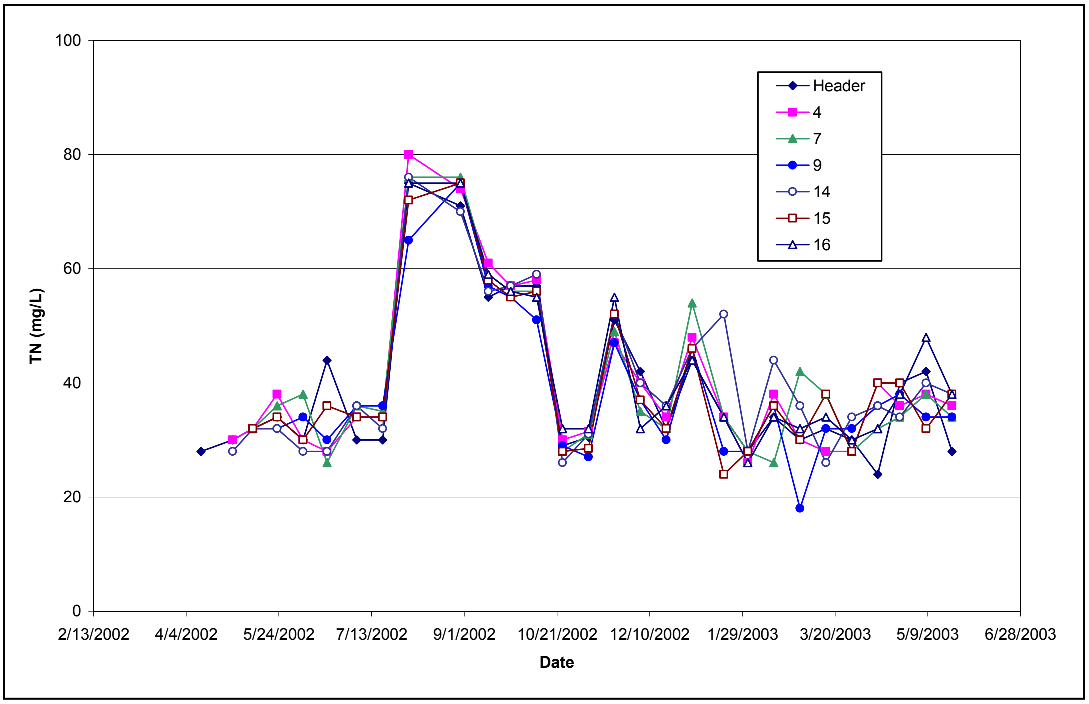


Figure 2.6 Observed TN Concentrations

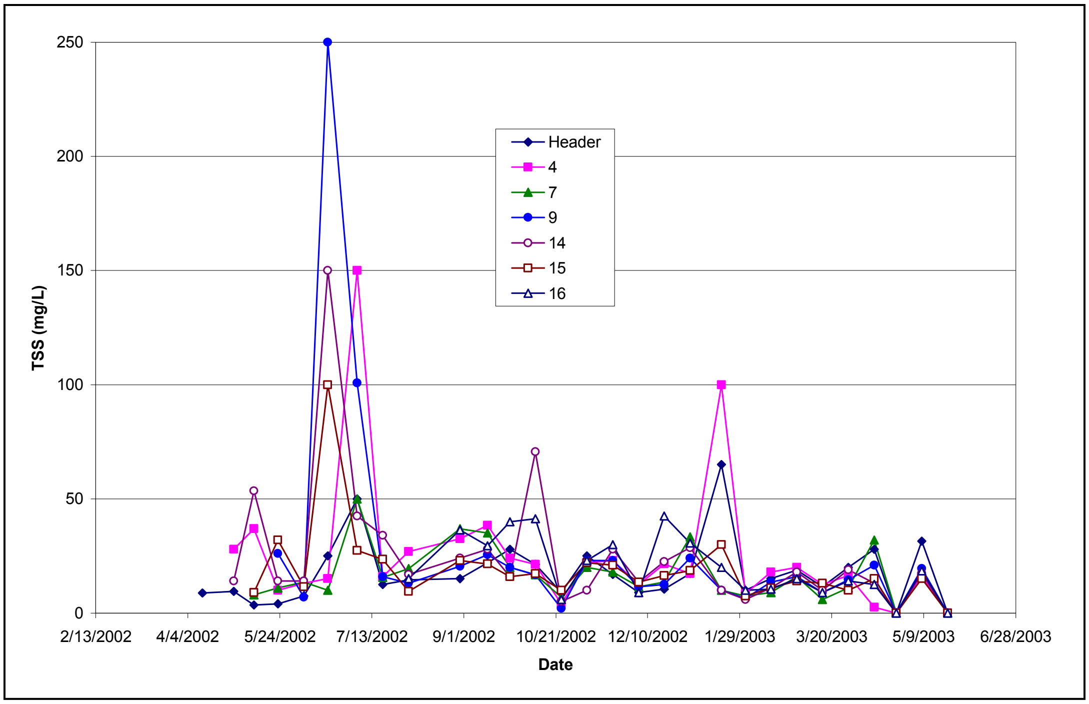


Figure 2.7 Observed TSS Concentrations

Table 2.7 Average and 95% Confidence Interval Values for COD, TN, and TSS

Location	COD (mg/L)		TN (mg/L)		TSS (mg/L)	
	Average	Conf.	Average	Conf.	Average	Conf.
Header	289	22.6	38.7	4.8	17.6	5.1
4	261	19.6	40.0	5.2	25.2	11.3
7	248	22.3	40.3	5.3	16.6	4.4
9	267	40.8	38.6	5.0	27.0	18.9
14	256	21.6	40.5	4.9	24.6	10.8
15	260	19.7	39.8	5.0	18.8	6.8
16	266	22.9	42.7	6.2	19.7	5.7

infiltrometer test was performed in each trench using the same procedures as in the initial trench excavations in Phase I.

2.2.4.1 Extent of Vegetation

During Phase I, vegetation was encouraged above all ETA and ET trenches by seeding with turfgrass. The turfgrass did grow with other local weeds. In Phase II, the same vegetation also flourished above the ETA fields. In the Phase I report, Rainwater et al. (2001) estimated the total effective ET area around an ETA trench based on the difference in hydraulic loading between the ET only, AB only, and ETA trenches. The average contributing area is shown in Figure 2.8, with the effective ET area extending 5.8 ft beyond the rectangular trench excavations. As part of the Phase II study, the area of flourishing vegetation around the ETA trenches was used as an indication of the total effective ET areas. The vegetation extent measurement was made in July 2003 after termination of loading. The distance to the end of the enhanced vegetation was measured near each of the four corners of the ETA trench excavations, and a single average ET radius was calculated for each trench, as shown in Table 2.8.

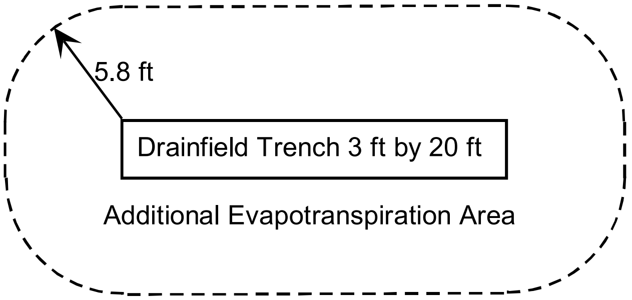


Figure 2.8 Phase I Estimated ET Area for Wastewater ETA Trenches (Rainwater et al. 2001)

Table 2.8 Estimated ET Radius Beyond ETA Trench

Trench	Radius (ft)
4	7.9
7	6.9
9	10.5
14	8.5
16	7.2

The values in Table 2.8 all exceeded the 5.8 ft that was estimated based on the Phase I loading results. The average ET radius beyond the trenches was 8.2 ft. This finding helped quantify the lateral movement of water from the ETA trenches. The current TCEQ (2001) guidelines encourage a minimum separation of 3 ft between trenches in AB drainfields. Recognition of the impact of ET in ETA trenches would encourage greater minimum spacing between trenches. Based on the Phase II findings, ETA trenches in the Lubbock area with soils similar to those at the Reese Center test site should be separated by 15 to 20 ft where possible. This greater separation would take greater advantage of the ET mechanism for disposal of the septic tank effluent.

2.2.4.2 Geoprobe Sampling

On July 15 and 17, 2003, a geoprobe rig and operator from ESA Environmental, Inc., were brought to the field site. The purpose was to collect 1.5-in diameter geoprobe samples to a target depth of 12 ft at locations beneath and adjacent to fields 4, 7, 9, 14, and 16. The geoprobe positions are shown relative to the distribution pipe in each trench in Figure 2.9. Position 1 was sampled directly through the backfill, gravel, and native soil beneath the trench. Position 2 was just beyond the trench wall. Positions 3 and 4 were intended to be within and just outside the ET area, respectively. Geoprobe samples were also taken at two control locations, C-1 at 120 ft east northeast of the control building, and C-2 at 80 ft east northeast of the control building. Figure 2.10 shows the geoprobe rig and operator. As the samples were collected, there were occasional problems with sample compression and recovery, as is normal to geoprobe technology. Photographs were taken immediately upon production of the samples, as the material inside the transparent acetate sleeve was readily visible. Figure 2.11 shows the sample from trench 9 that included the interface between the gravel bed material, heavily blackened by biological growth (to the right in the photo), and the native soil beneath the trench bottom (to the left). It was obvious in the samples at position 1 in each trench that biological growth in the gravel pack was significant, coating some of the gravel and taking up some of the pore space. The soil immediately beneath the trench also had some darkening due to moisture and biological growth, and the biological material was no longer visible a few ft lower.

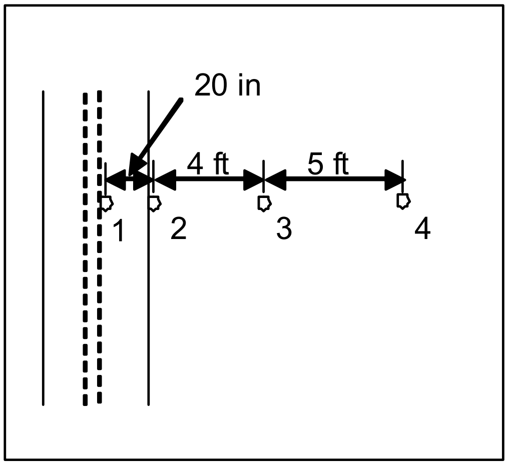


Figure 2.9 Geoprobe Positions Relative to Trench Centerline

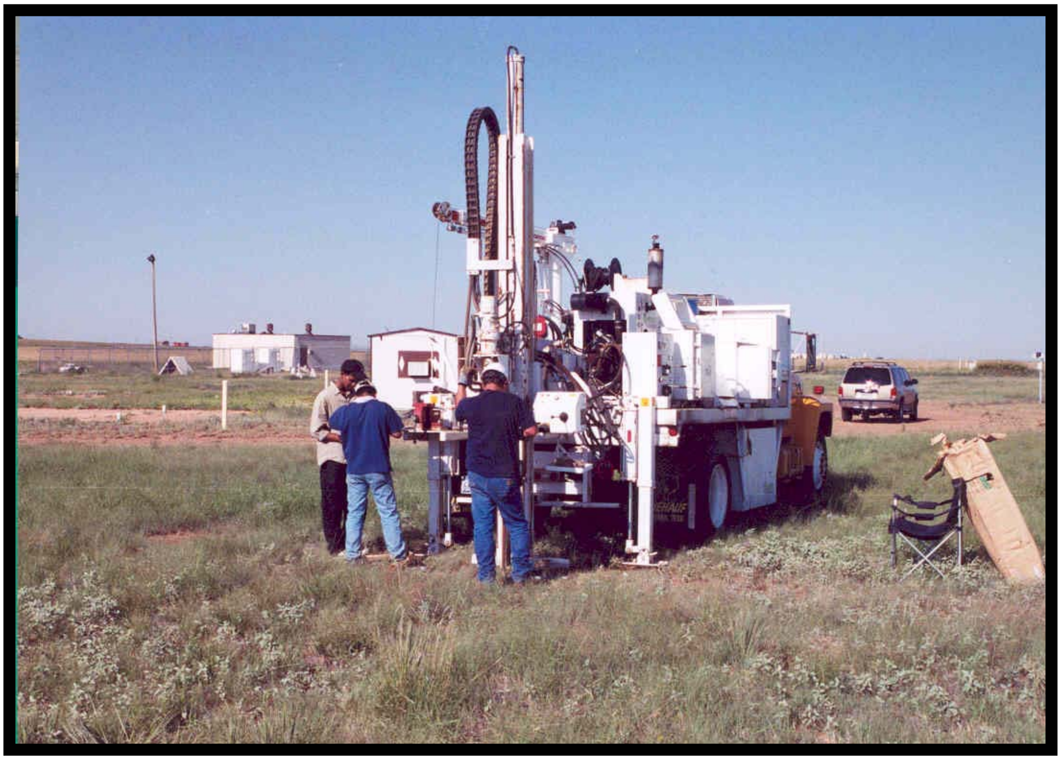


Figure 2.10 Geoprobe Rig (ESA Enviromental, Inc)

Figure 2.11 Geoprobe Sample 9-1, with Interface at Trench Bottom

Soil samples were taken from the geoprobe sleeves and analyzed for gravimetric water content and gravimetric volatile solids content (percent of dry soil weight). Water content was found by drying 60 to 100 g of moist soil in a 104°C oven, then comparing before and after weights. Volatile solids (VS) content was estimated by taking the oven-dried soil, firing it in a 550°C muffle furnace, then comparing before and after weights. It is recognized that the volatile solids can include any organic matter in the soil, such as plant material and biological growth associated with the wastewater effluent. Figures 2.12 to 2.16 display the comparisons of the water content measurements at trenches 4, 7, 9, 14, and 16, respectively, with the values from the two control positions. Occasionally on the plots, single data points are shown without connection by a line to the other datapoints. That condition occurs when one of the datapoints, such as depth of 4 ft at geoprobe holes 4-1 and 4-2 in Figure 2.8, is missing because a soil sample could not be accurately associated with that depth. It should be noted that the collected soil was subject to some compression or occasional reduced recovery in the 4-ft long plastic sleeves, such that it was sometimes impossible to have a soil mass for every depth in each hole.

It is apparent that the average water content in the controls was about 0.08 down to the 10-ft depth. At all five trenches, the water contents in geoprobe holes at positions 1, 2, and 3 were greater than the water contents in the controls for depths of 10 ft or less. At position 4, furthest from the trench, the water content was typically closest to that in the controls at the 2 ft depth, but was then greater than that for the controls for depths below 4 ft. For positions 2, 3, and 4 that had samples at the 12-ft depth, the water contents often were lower at 12 ft than at 10 ft, and closer to the 12-ft value at C-2. At trenches 4 and 7, the water contents in position 1 at depths beneath the trench bottom of 2 ft were typically relatively high, while the water contents at the same depths in position 1 in trenches 9, 14, and 16 were similar to those at the other three geoprobe positions. These results indicate that wastewater loading in the trenches typically at least doubled the gravimetric water contents in the unsaturated soil nearby. It was also useful to estimate the volumetric water saturation levels in the unsaturated soil samples. Water saturation, S, is given by

$$S = \frac{V_w}{V_v} = \frac{\dfrac{m_w}{\rho_w}}{\dfrac{\phi}{1-\phi}V_s} = \frac{\dfrac{m_w}{\rho_w}}{\dfrac{\phi}{1-\phi}\left(\dfrac{m_s}{\rho_s}\right)} = w\left(\frac{1-\phi}{\phi}\right)\left(\frac{\rho_s}{\rho_w}\right) \tag{2.1}$$

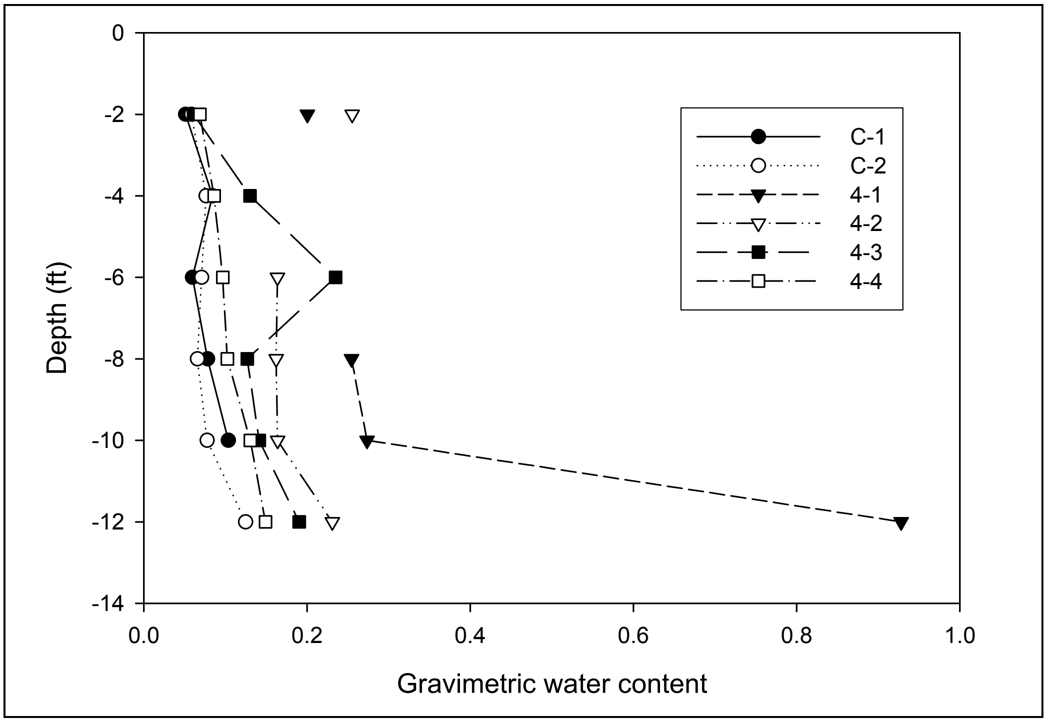


Figure 2.12 Water Contents Near Trench 4 as Compared to Controls

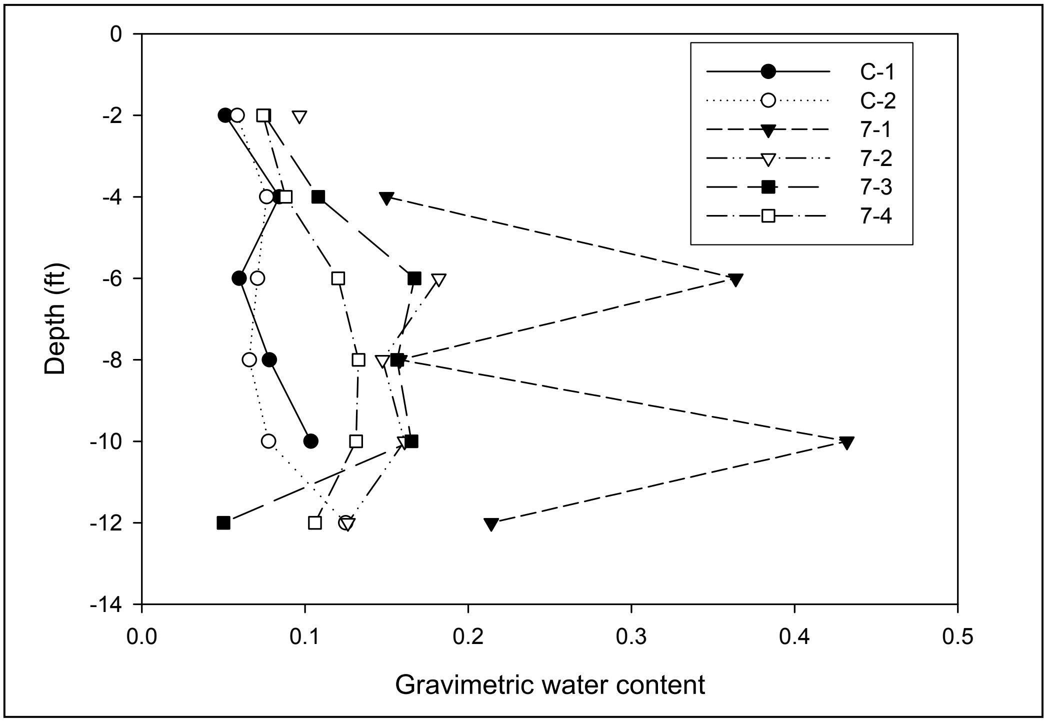


Figure 2.13 Water Contents Near Trench 7 as Compared to Controls

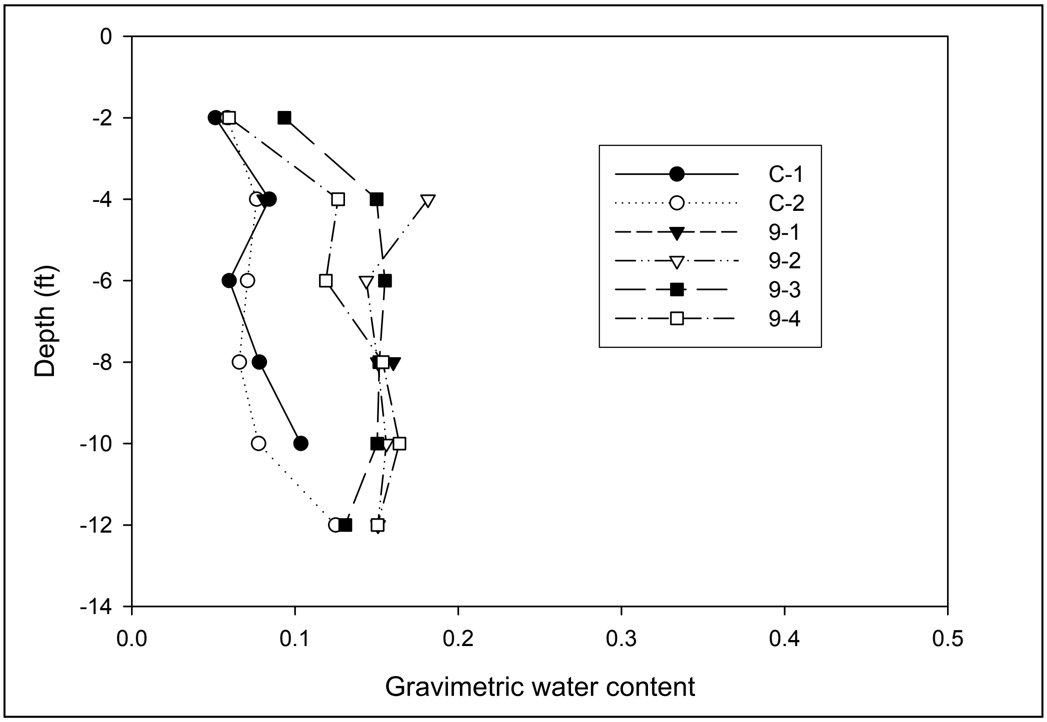


Figure 2.14 Water Contents Near Trench 9 as Compared to Controls

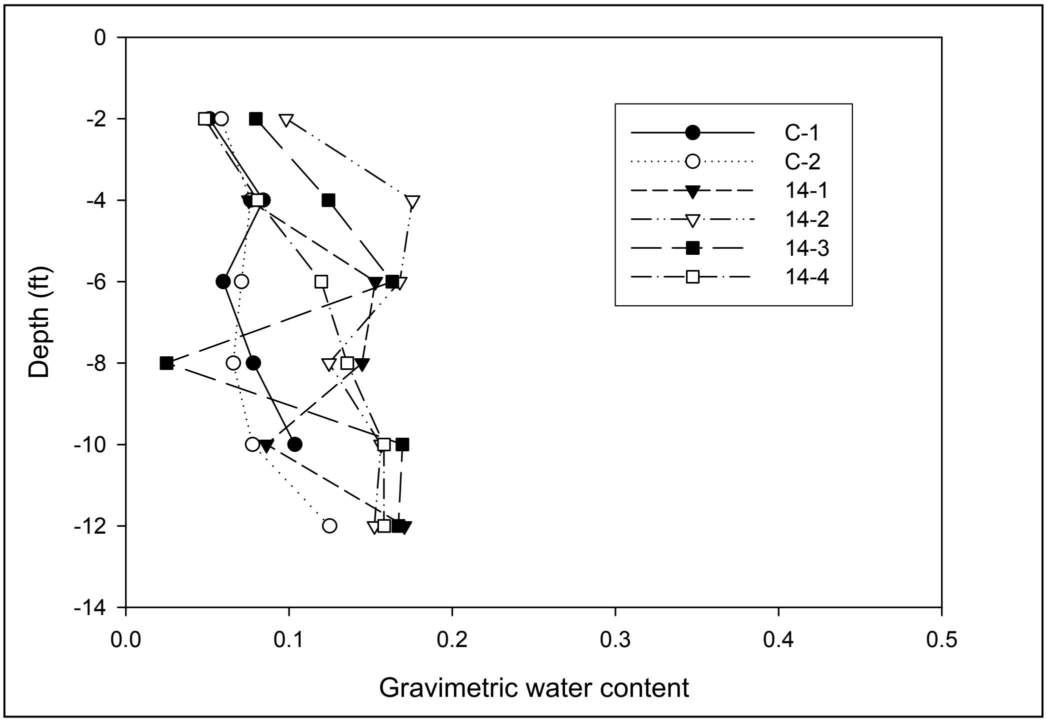


Figure 2.15 Water Contents Near Trench 14 as Compared to Controls

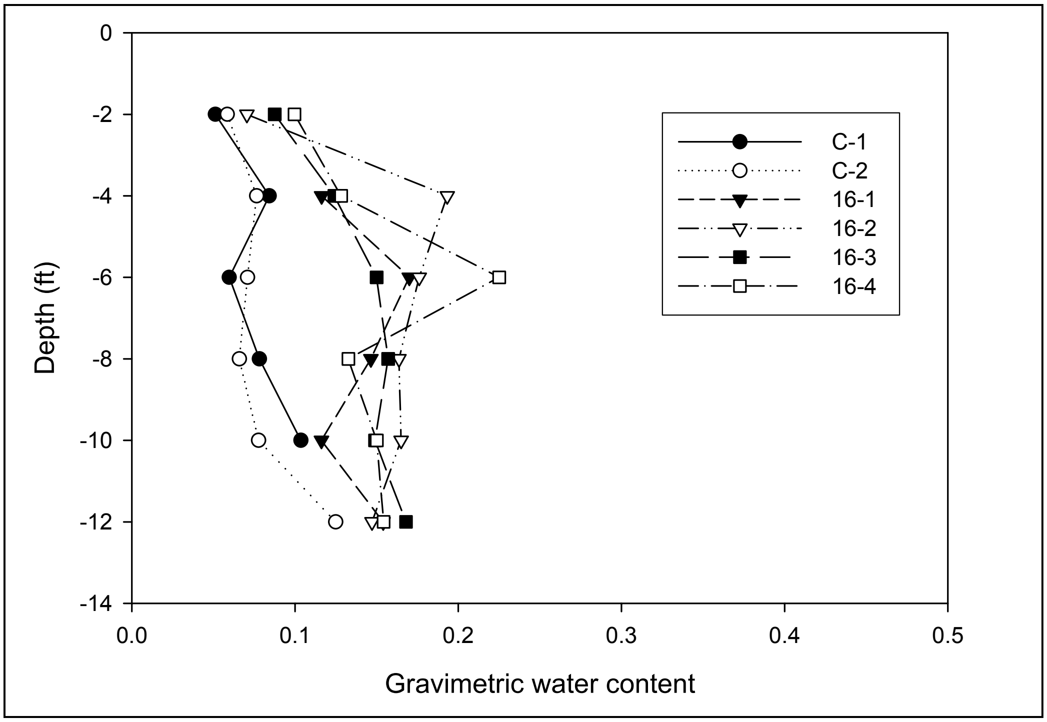


Figure 2.16 Water Contents Near Trench 7 as Compared to Controls

where V_w = water volume (cc), V_v = void volume (cc), m_w = water mass (g), m_s = soil mass (g), ρ_w = water density (1.0 g/cc), ρ_s = soil density (2.67 g/cc), ϕ = porosity, and w = gravimetric water content. The value of w, as the ratio of m_w over m_s, was known from the gravimetric analysis, and the two density values were typical for water and soil particles, respectively. Undisturbed porosities were not known for the soil samples, but typical values of 0.35, 0.40, and 0.45 were used to represent a plausible range. Equation 2.1 was then used to calculate S for each soil sample, and Table 2.9 summarizes the average, S_{avg}, maximum, S_{max}, and minimum, S_{min}, values for each geoprobe sample hole.

The saturation values are directly related to the water content values, but the S values merit some separate discussion. It is recognized that a number of the S values for samples near the centers of trench 4 and 7 were above 1.0. Complete saturation corresponds to S = 1. Some of the geoprobe samples were so wet that as the sample was removed from the plastic sleeve, some of the water from surrounding soil was accidentally collected. Otherwise, the typical S for the controls was about 0.4, 0.3, and 0.2 for the porosities of 0.35, 0.40, and 0.45, respectively. At the sample locations near the trenches, the typical S values were about 0.8, 0.6, and 0.4 for the

Table 2.9 Calculated Saturation Levels for Possible Porosities

Hole	0.35			0.4			0.45		
	S_{avg}	S_{max}	S_{min}	S_{avg}	S_{max}	S_{min}	S_{avg}	S_{max}	S_{min}
C-1	0.37	0.51	0.25	0.30	0.42	0.21	0.20	0.28	0.14
C-2	0.39	0.62	0.29	0.32	0.50	0.23	0.21	0.33	0.16
4-1	2.05	4.60	0.99	1.66	3.72	0.80	1.11	2.48	0.54
4-2	0.91	1.15	0.80	0.73	0.93	0.65	0.49	0.62	0.43
4-3	0.73	1.17	0.30	0.59	0.94	0.24	0.39	0.63	0.16
4-4	0.52	0.74	0.34	0.42	0.60	0.28	0.28	0.40	0.18
7-1	1.31	2.14	0.74	1.06	1.73	0.60	0.70	1.15	0.40
7-2	0.71	0.90	0.48	0.57	0.73	0.39	0.38	0.49	0.26
7-3	0.60	0.83	0.25	0.48	0.67	0.20	0.32	0.45	0.13
7-4	0.54	0.66	0.37	0.44	0.53	0.30	0.29	0.35	0.20
9-1	0.65	0.79	0.40	0.52	0.64	0.32	0.35	0.43	0.22
9-2	0.78	0.90	0.71	0.63	0.73	0.58	0.42	0.48	0.38
9-3	0.69	0.77	0.46	0.56	0.62	0.37	0.37	0.41	0.25
9-4	0.64	0.81	0.30	0.52	0.66	0.24	0.34	0.44	0.16
14-1	0.63	0.85	0.37	0.50	0.68	0.30	0.34	0.46	0.20
14-2	0.72	0.87	0.49	0.58	0.70	0.39	0.39	0.47	0.26
14-3	0.60	0.84	0.12	0.49	0.68	0.10	0.32	0.45	0.07
14-4	0.58	0.78	0.24	0.47	0.63	0.19	0.31	0.42	0.13
16-1	0.70	0.84	0.58	0.56	0.68	0.47	0.38	0.45	0.31
16-2	0.76	0.96	0.35	0.61	0.77	0.28	0.41	0.52	0.19
16-3	0.69	0.83	0.43	0.56	0.67	0.35	0.37	0.45	0.23
16-4	0.74	1.12	0.49	0.59	0.90	0.40	0.40	0.60	0.27

porosities of 0.35, 0.40, and 0.45, respectively. As seen with the gravimetric water contents, S values near the trenches were approximately twice the values noted at the control locations. It is most likely that the actual porosity of the field site soils ranges from about 0.40 to 0.45, based on additional soil analyses done by Waghdhare et al. (2003) in their numerical modeling of flow in the unsaturated soil near trench 9. In those simulations, significant water flow occurred while S values remained in the 0.40 to 0.65 range, which compared well to the calculated S values for porosities of 0.40 and 0.45.

The results of the gravimetric VS analyses are shown in Figures 2.17 through 2.21. Volatile solids that are removed during firing in a muffle furnace include any organic matter, whether plant roots or microorganisms. It is apparent that the gravimetric VS values are somewhat variable in each hole, but the values at both the controls and the holes near the

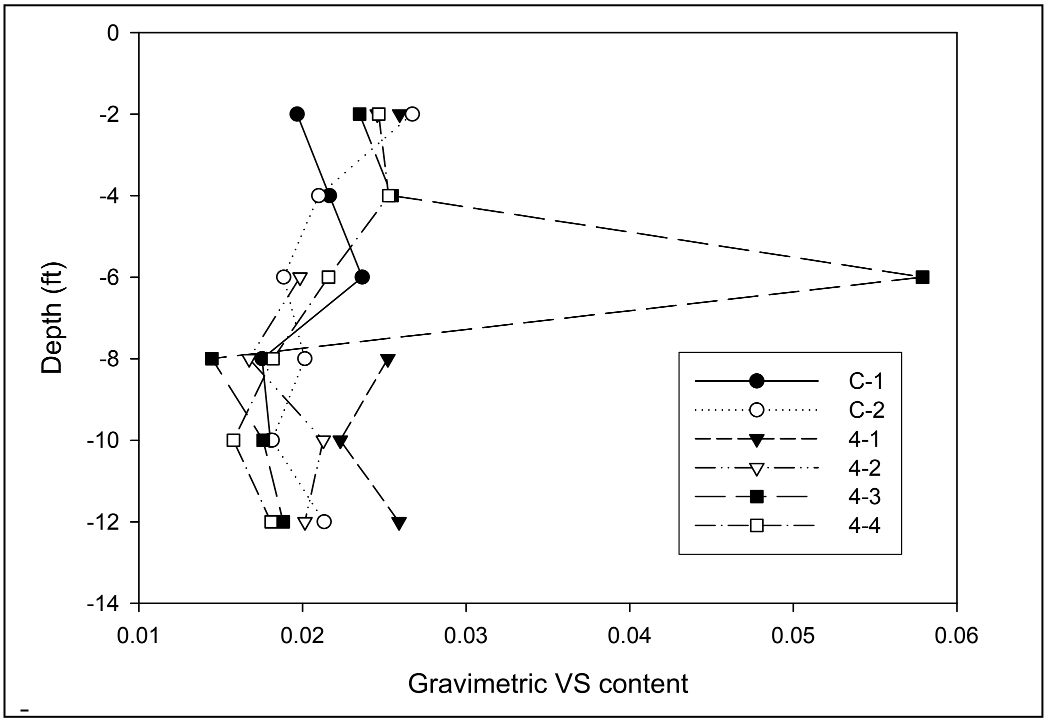


Figure 2.17 Volatile Solids Contents Near Trench 4 as Compared to Controls

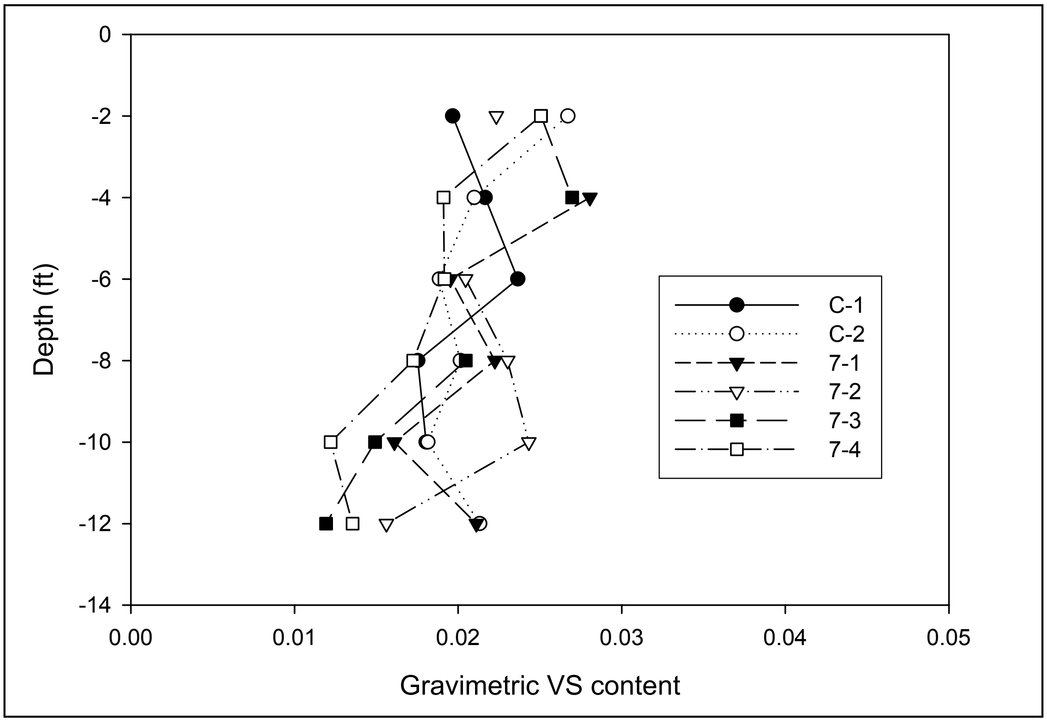


Figure 2.18 Volatile Solids Contents Near Trench 7 as Compared to Controls

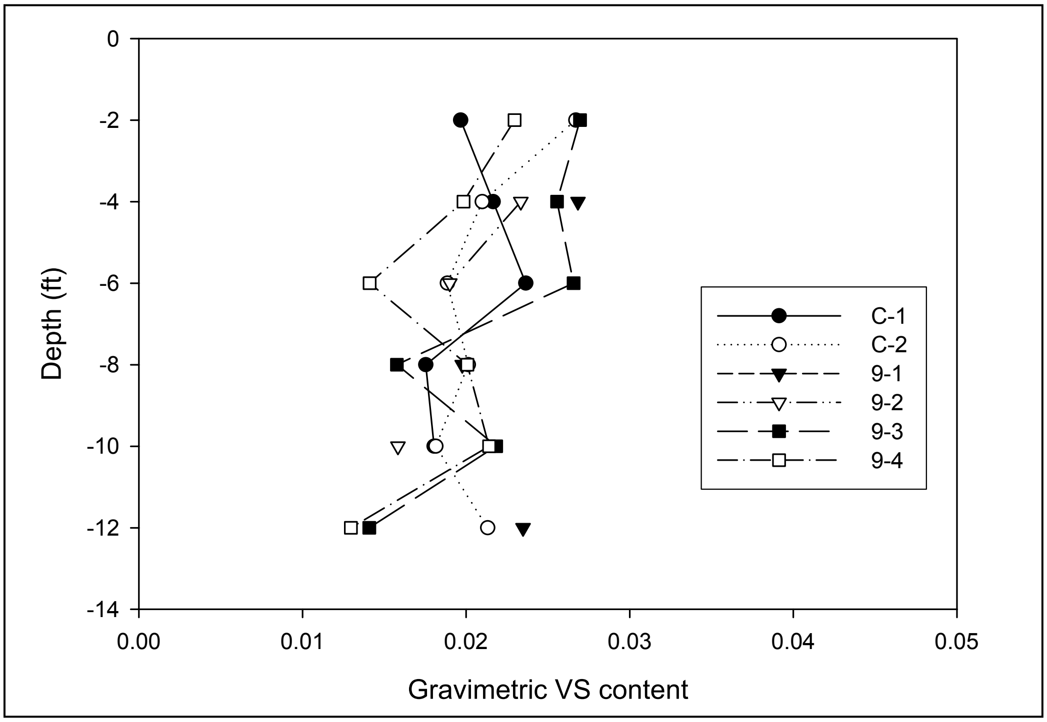


Figure 2.19 Volatile Solids Contents Near Trench 9 as Compared to Controls

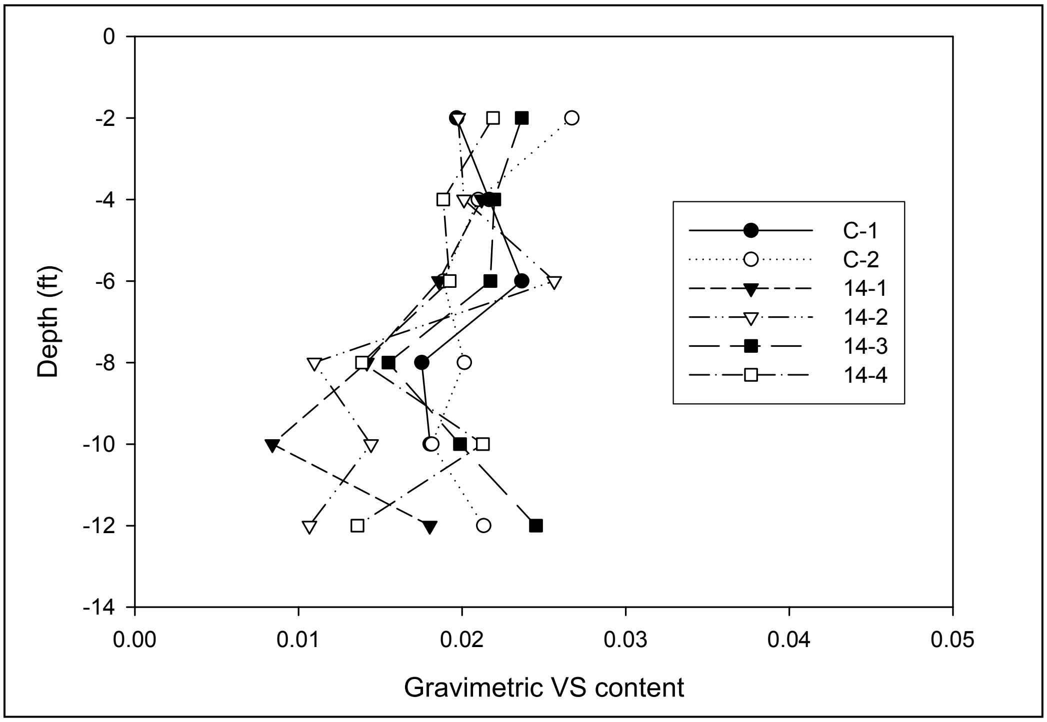


Figure 2.20 Volatile Solids Contents Near Trench 14 as Compared to Controls

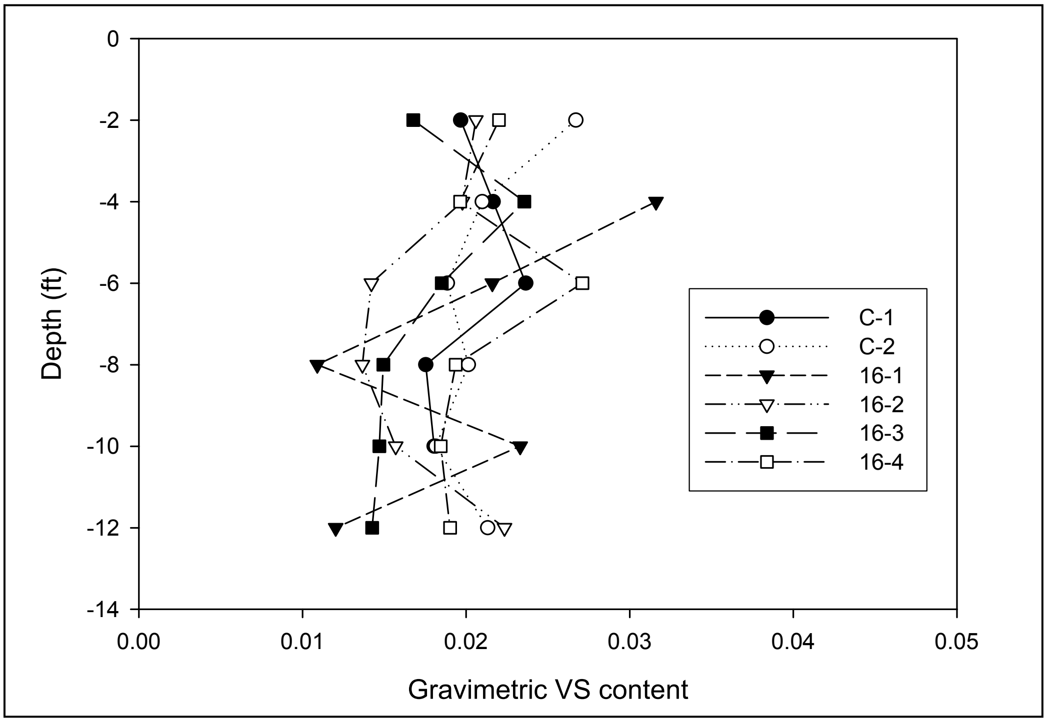


Figure 2.21 Volatile Solids Contents Near Trench 16 as Compared to Controls

trenches overlap and thus cannot be statistically distinguished. No additional analyses were made to identify microbial or plant growth changes.

2.2.4.3 Excavation of Trenches

Soon after the geoprobe sampling event, a backhoe operator was hired to excavate into the trenches to identify the presence or absence of a microbial biomat near the trenches and to allow double-ring infiltrometer tests. The operator was instructed to cut across the trench's 3-ft width, deep enough to clear the gravel from the trench bottom for and wide enough to allow safe entry for the double-ring infiltrometer test. Photographs were taken immediately on the day of the excavations, and the infiltrometer tests were done a few days later.

Figures 2.22 and 2.23 display photos from the excavation of trench 9, and similar conditions were observed at trenches 4, 7, 14, and 16. Figure 2.24 shows the bottom of trench 14. In Figure 2.22, the distribution pipe, geotextile fabric, gravel and native soil backfill, and trench bottom are all clearly visible. The soil beneath the gravel is obviously darkened to a bluish-black color. The darkening was caused by the presence of biological growth, evident by the slimy nature of the material and the septic odors. Figure 2.23 is a close-up photo of the

Figure 2.22 View of Biomat at Bottom of Trench 9

Figure 2.23 Closer View of Biological Growth at Bottom of Trench 9

Figure 2.24 View of Double-Ring Infiltrometer in Trench 14

interface at the bottom of the trench. These photos, with the addition observations in the geoprobe samples through the trenches, prove that the biological growth was significant in all five trenches.

One double-ring infiltrometer test was performed in each trench excavation by Dr. Heyward Ramsey, the same TTUWRC researcher who carried out the initial tests at the beginning of Phase I. The rings were installed in the floor of the excavation, and care was taken to insure that the disturbance of the trench bottom was minimal at the test location. Table 2.10 compares the results of the 24-hr infiltration rates from Phase I (average of three tests in each trench) and Phase II. The final infiltration rates were much lower that the initial values in all five trenches, about one-third to one-tenth of the original values. The decrease in infiltration rate was most likely caused by the presence of microbial growth within the pore space beneath the trench. The infiltrometer test values compare reasonably well with the average observed loading rate of the ETA trenches. As shown in Table 2.6, the average loading rate was approximately 1.0 gpd/ft^2, which converts to 0.07 in/hr for the infiltration area of 106 ft^2. These findings also provide evidence that the loading test duration was long enough to generate significant biomat

Table 2.10 Infiltrometer Results after 24 hr of Saturation

Trench	Initial Infiltration Rate[1] (in/hr)	Final Infiltration Rate[2] (in/hr)
4	0.20	0.05
7	0.38	0.07
9	0.29	0.03
14	0.61	0.24
16	0.69	0.07

Notes: 1. Average of three tests in new trench.
2. Result of one test after Phase II.

growth beneath the ETA trenches.

3. Soil and Hydrologic Study

3.1 Problem Statement and Tasks

Under current TCEQ (2001) guidance, drainfield design is based on either ET only or AB only trenches for wastewater disposal. Sites with low permeability soils and/or shallow water tables favor ET drainfields, which lose water only upward to the atmosphere. ET drainfields are lined, allowing only upward loss of water to plant roots or evaporation. Sites with permeable soils and relatively deep water tables are preferred for AB drainfields, which dispose of water through gravity flow and capillary action. Actually, AB drainfields lose water through both gravity flow and ET, as capillary forces can move water laterally and upward in the unsaturated soil, making the moisture available for plant roots or direct evaporation into the atmosphere. These combined processes are ignored in the TCEQ (2001) guidance. Annual potential ET varies from about 50 in/yr in far east Texas to over 90 in/yr in far west Texas, as stated in the TCEQ (2001) design manual. The annual precipitation across Texas varies greatly from less than 10 in/year in the far west to almost 60 in/year in the far east. Many different types of soils and vegetation are encountered across this large state, with sandier soils dominating in the west and clayey soils dominating toward the Gulf Coast. In the more arid portion of western Texas, permeable soils and low water tables encourage AB drainfields, but neglecting the additional water lost through ET may result in significantly over-designed drainfield installations. This effort considered the combined effects of ET and AB (referred to as ETA when combined) that might be sufficient to warrant significant changes in the TCEQ guidance for at least some parts of Texas. Previous work in Phase I of the TTUWRC research (Rainwater et al. 2001) indicated that ETA systems in the Lubbock area could be made significantly smaller than the current AB guidance requires.

This study had four specific objectives. First, a subset of 13 of the state’s 254 counties was selected to represent significant variations in climate, soil, and hydrologic conditions. Second, soil, climate, and hydrologic data were collected for each of the selected counties. Third, the data were analyzed to determine local values of annual precipitation, annual ET, and soil hydraulic conductivity for selected dominant soils for each county. Finally, the conditions in each county were compared to those at the TTUWRC test site with the intent of recommending separate LTAR values for ETA systems in the selected soils and counties.

3.2 Selected Counties

Thirteen counties were selected to represent the variations in climate, soils, and hydrologic conditions across the state of Texas. Figure 3.1 shows the counties by location on a map of Texas. The counties (Texas Climate Division in parentheses) included Angelina (East Texas), Baylor (Low Rolling Plains), Bexar (South Central), Cameron (Lower Valley), Dallas (North Central), El Paso (Trans-Pecos), Jefferson (Upper Coast), Lubbock (High Plains), Pecos (Trans-Pecos), Potter (High Plains), Tom Green (Edwards Plateau), Webb (Southern) , and Wharton (Upper Coast). The counties are somewhat uniformly distributed across the state and hopefully represent a range of conditions from arid to marine climate, sandy to clayey soils, low to high ET, and low to high precipitation. Contour maps of ET and precipitation are shown in a later section. The counties were all easily connected to current TCEQ (2001) ET drainfield guidance. It should be noted that before setting any final ETA guidance by TCEQ, all 254 counties should be considered separately. This subset was used to demonstrate the procedure and allow for critical evaluation. Any final adjusted procedure could then be applied to all 254 counties in the state.

3.3 Data Collection

3.3.1 Soil Characteristics

The TCEQ (2001) guidelines use Figure 3.2 and Table 1.1 to connect soil classification to LTAR. Soil classification is dependent on grain-size distribution. Permeability of the soil matrix is affected by grain-size distribution as well as the soil's hydrologic condition, whether tightly packed, unconsolidated, or vegetated. The information for soil description, texture, grain-size distributions, and permeability ranges were obtained from the Natural Resources Conservation Service (NRCS) soil surveys for each of the 13 counties. The individual citations are shown in the reference list at the end of this report. In each county, there could be dozens of different soils as categorized by the soil scientists. Often, many of the different named soil types had similar or overlapping grain-size distributions and permeability ranges. To make the datasets more manageable, only the two most abundant soil types based on their percentages of land area in the county were selected for further analyses. Table 3.1 shows the data for the selected soils. The textural descriptions were used to assign TCEQ (2001) soil classes. The soil depths and permeability values must be recognized as typical values, such that site-specific values might vary significantly.

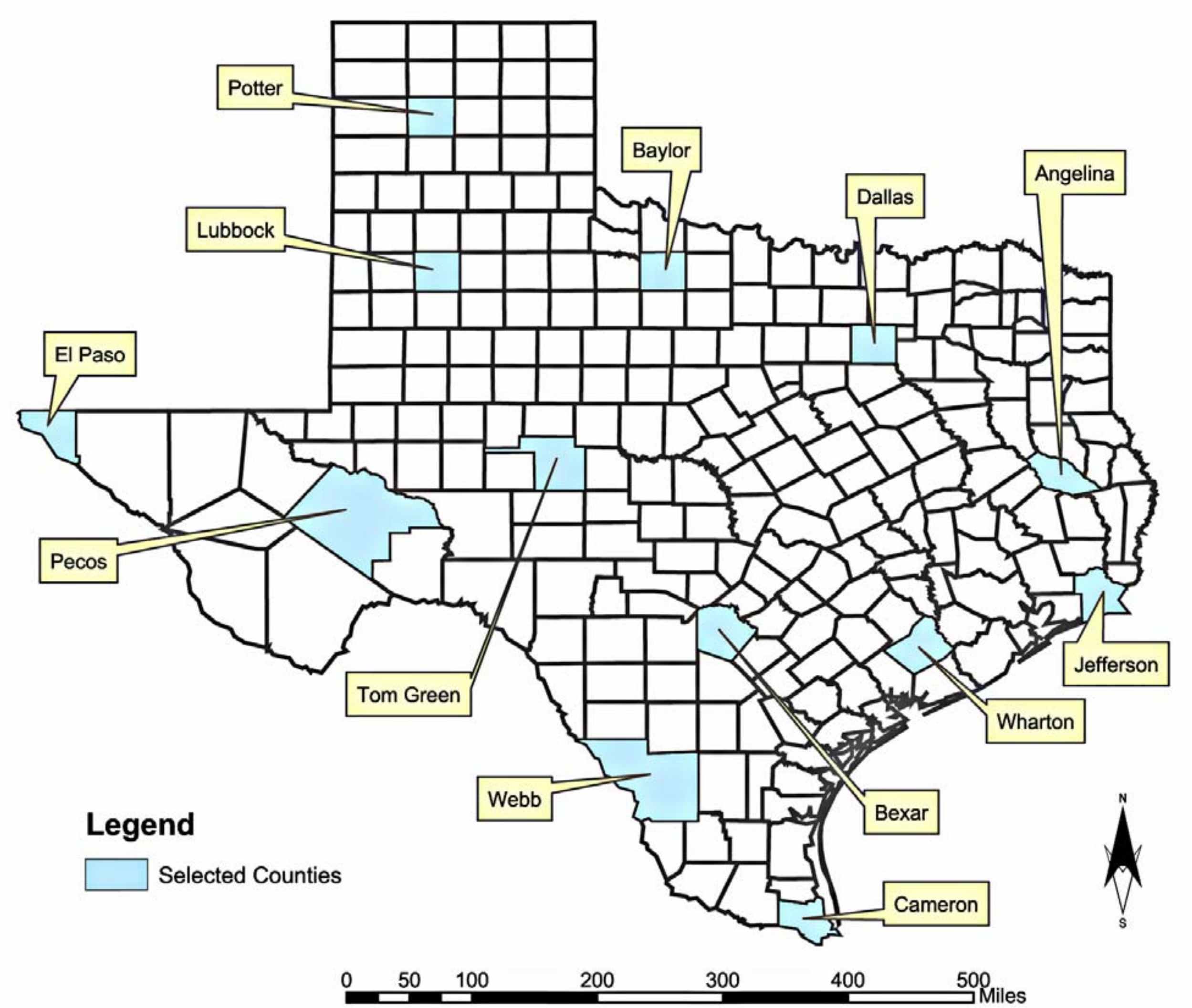
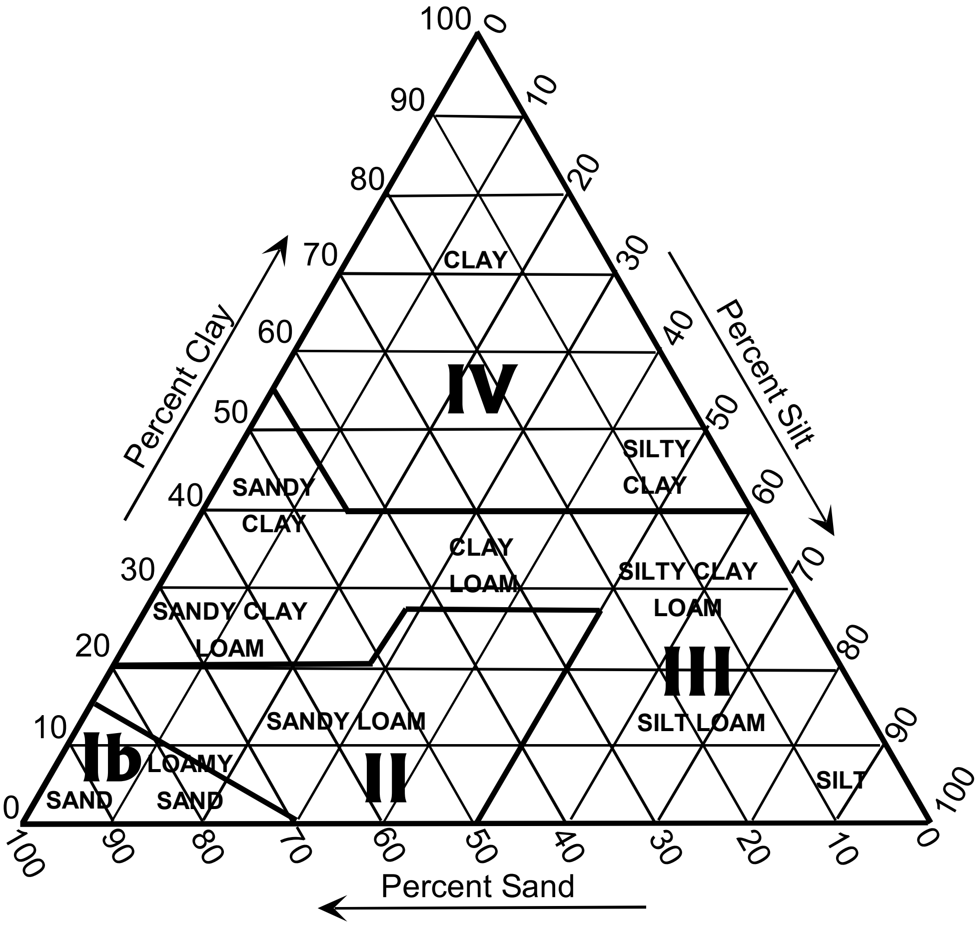


Figure 3.1 Selected Counties

3.3.2 Hydrologic Data

The historic average annual precipitation for Texas were obtained from the Natural Resources Conservation Service web site as a shape file (NRCS 2002) for the years 1967 through 2001. Using this dataset, a contour map of average annual precipitation was projected with ArcGIS™. By converting this contour layer to a grid layer, the average annual precipitation contours were divided into five classes using natural breaks. The generated map is shown in Figure 3.3.

Estimation of potential ET can be done in several ways, as a number of theoretical and



Note: Class **Ia** soils contain >30% gravel, and are not shown here.

Figure 3.2. USDA Soil Textural Classification with TCEQ Soil Classes

empirical approaches are available, with debatable relative precision. For this study, monthly values of ET were taken from Borrelli et al. (1998), who provided a manual for the Texas Water Devleopment Board that compiles estimates of free-water evaporation and crop ET for locations throughout Texas. The estimates are based on the Borrelli-Sharif equation, which considers variations in solar radiation, temperature, humidity, and wind speed. The free-water ET estimates were selected for use in this project as representing potential ET, rather than crop-specific values, as the vegetation atop ETA drainfields would likely vary significantly across the state. Monthly values were accumulated into typical annual ET values for 58 spatially referenced city locations across the state, then entered into a spreadsheet and saved as dbase4 file (.dbf file). This dataset was then manipulated in ArcMap™ as an attribute table. Next, the

Table 3.1 Soil Characteristics (NRCS soil surveys)

County	Major Soils	Percent Area	USDA Soil Texture	Soil Depth (in)	Permeability (in/hr)	Percentage Passing Sieve No.				TCEQ Soil Class
						4	10	40	200	
Angelina	1) Fuller fine sandy loam, 1-4% slopes	8.3	Fine Sandy Loam	0-39	0.6-2.0	98-100	98-100	95-100	40-60	II
			Silty Clay Loam,Clay Loam,Weathered Bedrock	39-58	<0.06	98-100	98-100	95-100	51-75	III
			Weathered Bedrock	58-70	N/A	N/A	N/A	N/A	N/A	N/A
	2) Alazan very fine sandy loam, 0-4% slopes	7.6	Very Fine Sandy Loam	0-16	2.0-6.0	100	96-100	90-100	51-80	II
			Loam, Sandy Clay Loam	16-72	0.6-2.0	100	96-100	90-100	51-85	III
Bexar	1) Tarrant association gently undulating	7.8	Clay Loam	0-10	1.0-1.2	60-95	60-90	N/A	60-85	III
	2) Lewisville silty clay, 0-1% slopes	5.8	Silty Clay	0-44	1.0-1.2	99	100	98	88	IV
			Silty Clay Loam	44-62	1.0-1.2	87	83	80	70	III
Baylor	1a) Owens-Vernon association, rolling, Owens	15.5	Clay	0-18	<0.06	95-100	95-100	90-100	80-95	IV
			Shaly Clay	18-60	<0.06	90-100	85-100	80-90	55-80	IV
	1b) Owens-Vernon association, rolling, Vernon		Clay	0-26	<0.06	95-100	90-100	90-100	80-95	IV
			Shaly Clay	26-40	<0.06	90-100	85-100	65-100	65-90	IV
	2) Vernon clay, 3-8% slopes	11.5	Clay	0-26	<0.06	95-100	90-100	90-100	80-95	IV
			Shaly Clay	26-40	<0.06	90-100	85-100	65-100	65-90	IV
Cameron	1) Laredo silty clay loam, 0-1% slopes	10.4	Silty Clay Loam	0-8	0.63-2	100	100	100	85-100	III
			Silty Clay Loam, Silt Loam	8-72	0.63-2	100	100	100	70-99	III
	2) Harlingen clay	8.1	Clay	0-11	<0.06	100	100	100	95-100	IV
			Clay	11-35	<0.06	100	100	100	95-100	IV
			Clay	35-71	<0.06	100	100	100	95-100	IV
Dallas	1) Houston Black-urban land complex, 0-4% slopes	7.9	Clay	0-6	<0.06	95-100	95-100	95-100	85-100	IV
			Clay, Silty Clay	6-70	<0.06	95-100	95-100	95-100	85-100	IV
	2) Houston Black clay, 1-3% slopes	7.8	Clay	0-6	<0.06	95-100	95-100	95-100	85-100	IV
			Clay, Silty Clay	6-70	<0.06	95-100	95-100	95-100	85-100	IV

Table 3.1 Continued

County	Major Soils	Percent Area	USDA Soil Texture	Soil Depth (in)	Permeability (in/hr)	Percentage Passing Sieve No.				TCEQ Soil Class
						4	10	40	200	
El Paso	1) Hueco	19.0	Loamy Fine Sand	0-4	2-6.3	100	100	70-85	0-10	Ib
			Fine Sandy Loam	4-26	2-6.3	100	100	80-95	15-30	II
			Indurated Caliche	26-30	N/A	N/A	N/A	N/A	N/A	N/A
	2) Wink	19.0	Fine Sandy Loam	0-4	0.63-2	100	95-100	95-100	20-35	II
			Cemented Caliche	4-26	2-6.3	N/A	N/A	N/A	N/A	N/A
			Gravelly Loam	26-30	N/A	90-95	70-85	65-80	25-45	II
Jefferson	1) Beaumont clay	29.0	Clay	0-32	0.05-0.2	90-100	80-100	N/A	55-75	IV
			Clay	32-44	0-0.5	95-100	90-100	N/A	65-80	IV
			Clay	44-60	0-0.05	95-100	90-100	N/A	80-90	IV
	2) Morey silt loam	24.2	Silt Loam	0-12	0.2-0.8	95-100	90-100	N/A	70-90	III
			Silty Clay	12-36	0-0.05	90-100	89-100	N/A	70-90	IV
			Silty Clay Loam	36-60	0-0.05	90-100	75-100	N/A	60-85	III
Lubbock	1) Acuff loam, 0-1% slopes	19.2	Loam	0-12	0.6-2.0	100	95-100	95-100	51-70	III
			Clay Loam, Sandy Clay Loam, Loam	12-38	0.6-2.0	100	95-100	95-100	65-75	III
			Clay Loam, Sandy Clay Loam, Loam	38-80	0.6-2.0	95-100	90-100	90-100	60-75	III
	2) Olton clay loam, 0-1% slopes	19.2	Clay Loam	0-10	0.6-2.0	100	95-100	85-100	55-80	III
			Clay Loam, Silty Clay Loam, Clay	10-42	0.2-0.6	95-100	90-100	90-100	60-95	III
			Clay Loam, Sandy Clay Loam, Loam	42-80	0.2-0.6	90-100	85-100	80-100	60-85	III
	Reese Center, Acuff loam, 0-1% slopes	N/A	Sandy Clay Loam	0-12	N/A	N/A	N/A	N/A	N/A	III
			Sandy Clay Loam	12-24	N/A	N/A	N/A	N/A	N/A	II-III
			Sandy Loam	24-36	N/A	N/A	N/A	N/A	N/A	II

Table 3.1 Continued

County	Major Soils	Percent Area	USDA Soil Texture	Soil Depth (in)	Permeability (in/hr)	Percentage Passing Sieve No.				TCEQ Soil Class
						4	10	40	200	
Pecos	1) Ector-Rock outcrop association, steep	16.8	Stony Clay Loam	0-11	0.6-2.0	45-80	40-75	35-70	20-60	Ib
			Unweathered Bedrock	11-30	N/A	N/A	N/A	N/A	N/A	N/A
	2a) Reagan-Hodgins association, nearly level, Reagan	15.0	Silty Clay Loam	0-32	0.6-2.0	95-100	95-100	90-100	70-95	III
			Silty Clay, Silty Clay Loam, Loam	32-60	0.6-2.0	95-100	95-100	85-100	65-95	III
	2b) Reagan-Hodgins association, nearly level, Hodgins		Silty Clay Loam	0-8	0.6-2.0	95-100	95-100	90-100	70-95	III
			Clay Loam, Silty Clay Loam,Silty Clay	8-66	0.6-2.0	95-100	95-100	85-100	65-96	III
Potter	1a) Veal-Paloduro association, undulating, Veal	9.6	Loam	0-16	0.6-2	90-100	85-100	70-98	36-75	III
			Sandy Clay Loam, Clay Loam, Loam	6-14	0.6-2	85-100	80-100	80-100	40-80	III
			Clay Loam, Sandy Clay Loam, Loam	14-60	0.6-2	85-100	80-100	65-100	35-80	III
	1b) Veal-Paloduro association, undulating, Paloduro		Clay Loam	0-12	0.6-2	95-100	95-100	80-95	40-75	III
			Loam, Clay Loam, Sandy Clay Loam	12-80	0.6-2	95-100	95-100	80-95	40-75	III
	2) Pullman Clay Loam, 0-1% slopes	8.6	Clay Loam	0-7	0.2-0.6	100	100	95-100	70-90	III
			Clay, Silty Clay	7-54	<0.06	100	100	95-100	85-98	IV
			Clay Loam, Clay, Silty Clay	54-80	0.06-0.2	95-100	90-100	80-100	75-95	III-IV
Tom Green	1) Tarrant association, hilly	18.6	Cobbly Clay	0-10	0.2-0.63	80-100	80-100	70-90	70-75	IV
			Hard Limestone	10-12	0.2-0.63	80-100	80-100	70-90	70-75	IV
	2) Angelo clay loam, 0-1% slopes	16.2	Clay Loam, Silty Clay	0-12	0.63-2	90-100	90-100	85-100	60-90	III-IV
			Clay	12-28	0.2-0.63	90-100	90-100	85-100	70-93	IV
			Silty Clay Loam	28-58	0.63-2	60-100	60-100	60-100	50-90	III
			Clay Loam	58-92	0.63-2	90-100	90-100	75-100	60-90	III

Table 3.1 Continued

County	Major Soils	Percent Area	USDA Soil Texture	Soil Depth (in)	Permeability (in/hr)	Percentage Passing Sieve No.				TCEQ Soil Class
						4	10	40	200	
Webb	1a) Maverick-Catarina complex, gently rolling, Maverick	13.3	Clay	0-6	0.06-0.2	75-100	65-100	55-100	51-100	IV
			Clay, Clay Loam	6-15	0.06-0.2	98-100	95-100	90-100	80-100	III-IV
			Clay, Clay Loam	15-25	0.06-0.2	98-100	90-100	85-100	75-95	III-IV
			Shaly Clay	25-60	<0.06	90-100	85-100	80-100	60-95	IV
	1b) Maverick-Catarina complex, gently rolling, Catarina		Clay	0-10	<0.06	85-100	82-100	82-100	80-98	IV
			Clay, Silty Clay	10-37	<0.06	85-100	82-100	82-100	80-98	IV
			Clay, Silty Clay	37-60	<0.06	95-100	90-100	85-100	80-95	IV
	2) Montell clay, saline, 0-2% slopes	9.9	Clay	0-12	<0.06	80-100	75-100	75-100	75-100	IV
			Clay, Silty Clay	12-28	<0.06	80-100	75-100	75-100	75-100	IV
			Clay, Silty Clay	28-60	<0.06	80-100	75-100	75-100	75-100	IV
Wharton	1) Lake Charles clay, 0-1% slopes	22.7	Clay	0-63	<0.06	100	100	98-100	90-98	IV
	2) Crowley fine sandy loam	17.3	Fine Sandy Loam	0-15	0.63-2	100	100	100	45-55	II
			Clay	15-22	<0.06	100	100	100	60-80	IV
			Sandy Clay	22-38	0.06-0.2	100	100	100	50-60	III
			Sandy Clay	38-62	0.06-0.2	100	100	100	50-55	III

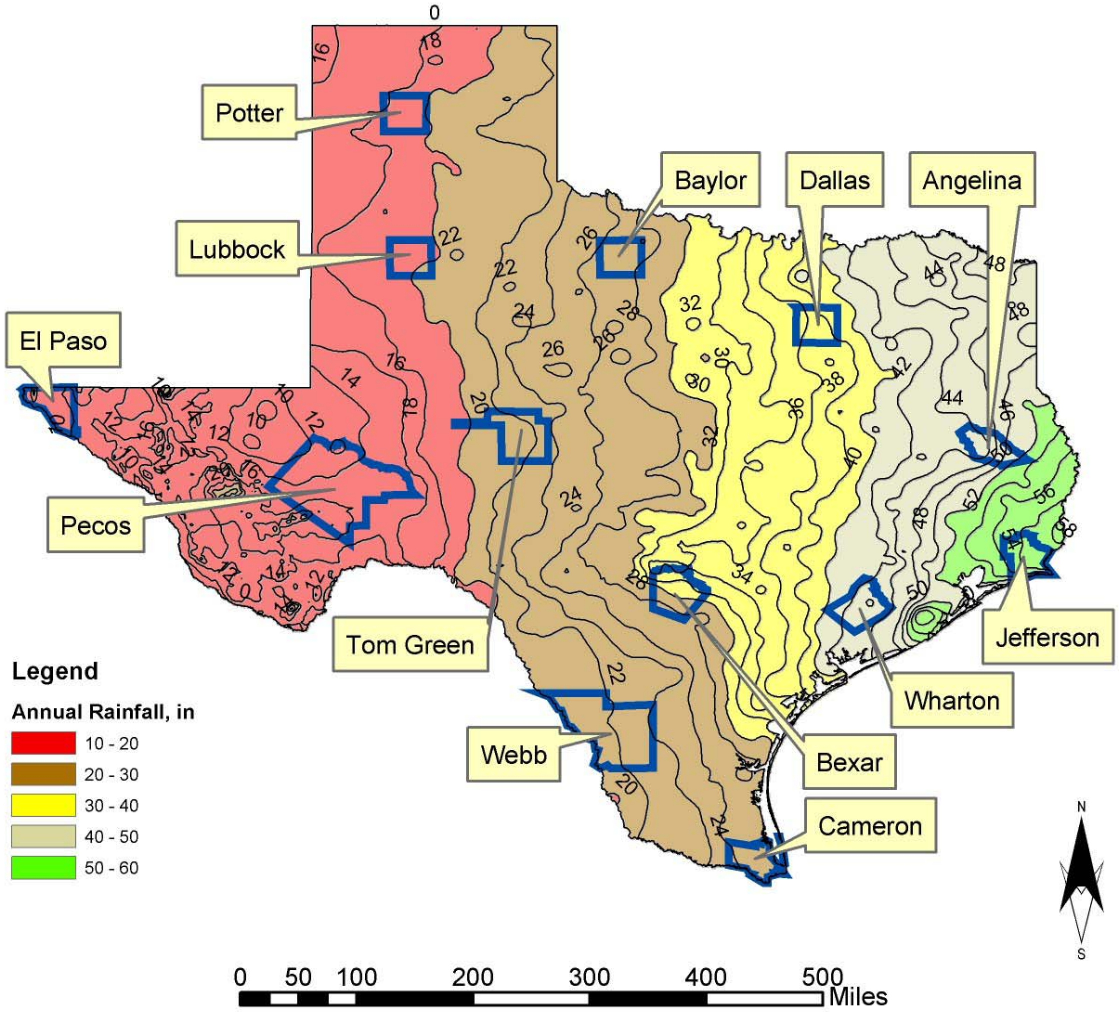


Figure 3.3 Contour Map of Average Annual Precipitation (source: NRCS 2002)

Spatial Analyst™ in ArcMap™ was used to create a contour map. The kriging method with the software's default parameters was used to contour the ET data. By converting this contour map to a grid layer, the ET data were divided into five classes using natural breaks. The resulting map is shown in Figure 3.4.

It is recognized that different values of average annual precipitation and potential ET can be found with different datasets or estimation procedures. The precise absolute values are not as important to this study as the variations across the state. Table 3.2 summarizes the values for each county location for those readers interested in specific values of annual precipitation or potential ET for the selected counties. The annual potential ET values calculated by Borrelli et

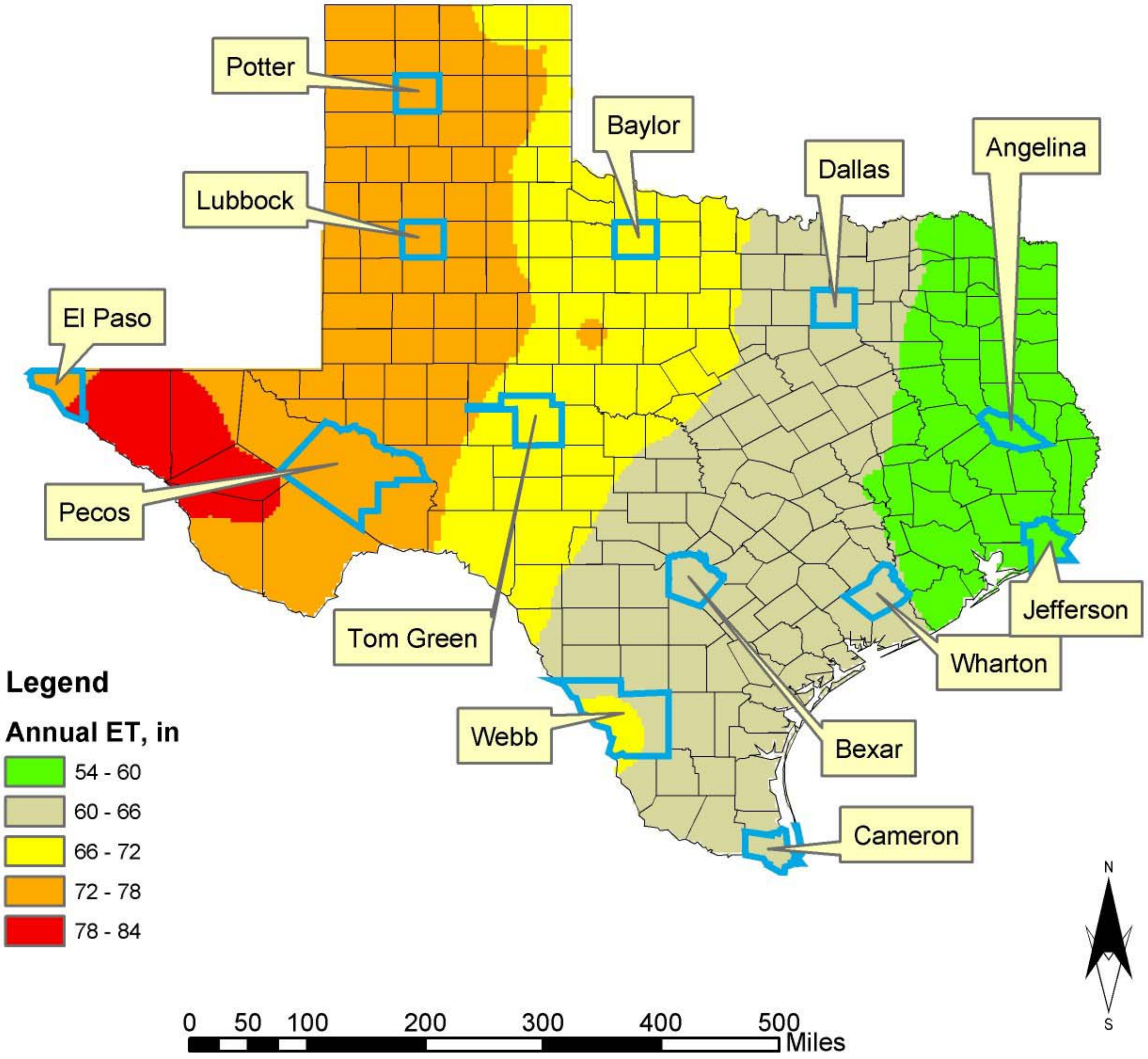


Figure 3.4 Contour Map of Potential Evapotranspiration

al. (1998) were converted to in/d for comparison with the net evaporation rates assigned for the 13 locations by the TCEQ (2001) guidance. The method used to calculate the net evaporation value, known R_{et} in in/d, is not clear in the TCEQ (2001) guidance. The table heading in the TCEQ (2001) manual states that net evaporation is evaporation minus precipitation, while the footnote on the table states that a 20 percent runoff consideration was included.

Table 3.2 Annual Rainfall (Figure 3.3) and ET Estimates (Figure 3.4, TCEQ [2001])

County	Rainfall (in/yr)	Borrelli et al. (1998) ET[1]		TCEQ (2001) Net Evap[2]	
		Annual (in)	Daily (in/d)	Annual (in)	Daily (in/d)
Angelina	54	58.5	0.160	21.9	0.060
Baylor	27	68.3	0.187	69.4	0.190
Bexar	29	64.6	0.177	54.8	0.150
Cameron	25	64.5	0.177	54.8	0.150
Dallas	40	65.1	0.178	51.1	0.140
El Paso	10	75.5	0.207	94.9	0.260
Jefferson	56	56.2	0.154	14.6	0.040
Lubbock	20	72.7	0.199	76.7	0.210
Pecos	16	76.6	0.210	91.3	0.250
Potter	19	75.2	0.206	76.7	0.210
Tom Green	22	70.4	0.193	84.0	0.230
Webb	22	67.4	0.185	65.7	0.180
Wharton	42	60.3	0.165	36.5	0.100

Note 1. Free-water ET estimate.
2. Net evap is evaporation minus rainfall, including “20% runoff consideration.”

3.4 Comparison of County Soil Types and ET and AB Conditions

One method of data analysis was to demonstrate the impact of the soil types described for the selected counties on current guidance for AB and ET drainfield sizing. This exercise indicated the uncertainties in the connection between TCEQ (2001) soil classification by grain-size distribution and USDA textural descriptions. As seen in Table 3.1, the NRCS county soil surveys include four columns of data on percent passing number 4, 10, 40, and 200 sieves. The material that passes number 200 sieves includes both silt and clay. The relative amounts of silt and clay have significant influence on both the actual permeability of the soil matrix and the TCEQ (2001) soil classification. Hydrometer tests are required to separate the silt and clay fractions, but these test results are not usually available in the soil surveys. If the soil percent passing the 200 sieve is large, like the 40 percent or more for the Fuller fine sandy loam in Angelina County (first line of Table 3.1), differing amounts of silt and clay percentage can still lead to the same total of 40 percent, while giving different TCEQ (2001) soil classes. Increasing the clay content moves the TCEQ soil class from II to III, which then changes the LTAR for sizing of AB drainfields. Table 3.3 shows the results of this exercise for the major soil groups in the thirteen counties. It is recognized that this same exercise could be performed for all the soils in every county in Texas, but this procedure should be evaluated for its utility before considering dozens of soils in 254 counties.

In Table 3.3, the TCEQ (2001) soil classes were identified so that the LTAR values, also referred to as R_a in gpd/ft^2, could be selected from Table 1. The area required for an absorption drainfield, A_a, in ft^2 was found by (TCEQ 2001)

$$A_a = \frac{Q}{R_a} \tag{3.1}$$

where Q = average daily sewage flow (gpd). For demonstration purposes, the calculations used a Q of 300 gpd for a single-family, three-bedroom dwelling with less than 3,500 ft^2 and no water-saving devices (TCEQ 2001). For comparison, the area required for an ET drainfield, A_{et} in ft^2, was also found by (TCEQ 2001)

$$A_{et} = \frac{1.6\ Q}{R_{et}} \tag{3.2}$$

where R_{et} = net local evaporation rate (in/d). The net local evaporation rates were taken from Table 3.2, which was based on Table VII in the TCEQ (2001) guidance, and are not affected by soil type. The R_{et} values for Angelina, Baylor, and Wharton counties were not specified in Table VII, so the missing values were interpolated from nearby counties for which the R_{et} values were specified. Due to the simple nature of Equation 3.1, A_a is inversely proportional to R_a and becomes smaller as the soils become coarser. Similarly, as R_{et} gets small, A_{et} gets large, such that sites with clayey soils in the wetter parts of the state can require as much as 12,000 ft^2 for the example loading situation. For most of the soil types, at least two different TCEQ (2001) soil classes are possible within the range of sand, silt, and clay combinations, which can increase A_a by as much as 100 percent (III to IV). In some of the loamy soils, three different TCEQ (2001) soil classes are possible, which can change the required A_a by as much as a factor of 2.5 (II to IV).

The second type of data analysis was to compare different permeability estimates that can be associated with the soil textural descriptions and grain-size distributions. The current TCEQ (2001) guidance for LTAR values considers only Figure 3.2. Figure 3.2 includes both sand/silt/clay percentages and textural descriptors that can be taken from NRCS county soil

Table 3.3 Comparison of AB and ET Area Requirements for Q=300 gpd

County	Major Soils	USDA Soil Texture	Sand (%)	Clay (%)	Silt (%)	TCEQ Class	R_a (gpd/ft^2)	R_{et} (in/d)	A_a (ft^2)	A_{et} (ft^2)
Angelina	1) Fuller fine sandy loam, 1-4% slopes	Fine Sandy Loam	60	40	0	III	0.20	0.06	1500	8000
			60	30	10	III	0.20	0.06	1500	8000
			60	20	20	III	0.20	0.06	1500	8000
			60	10	30	II	0.25	0.06	1200	8000
			60	0	40	II	0.25	0.06	1200	8000
		Silty Clay Loam, Clay Loam	50	50	0	III	0.20	0.06	1500	8000
			50	30	20	III	0.20	0.06	1500	8000
			50	20	30	II	0.25	0.06	1200	8000
			50	0	50	II	0.25	0.06	1200	8000
	2) Alazan very fine sandy loam, 0-4% slopes	Very Fine Sandy Loam	35	65	0	IV	0.10	0.06	3000	8000
			35	50	15	IV	0.10	0.06	3000	8000
			35	30	30	III	0.20	0.06	1500	8000
			35	15	50	II	0.25	0.06	1200	8000
			35	0	65	III	0.20	0.06	1500	8000
		Loam, Sandy Clay Loam	35	65	0	IV	0.10	0.06	3000	8000
			35	50	15	IV	0.10	0.06	3000	8000
			35	30	30	III	0.20	0.06	1500	8000
			35	15	50	II	0.25	0.06	1200	8000
			35	0	65	III	0.20	0.06	1500	8000
Baylor	1a) Owens-Vernon association, rolling, Owens	Clay	20	80	0	IV	0.10	0.19	3000	2526
			20	60	20	IV	0.10	0.19	3000	2526
			20	40	40	IV	0.10	0.19	3000	2526
			20	20	60	III	0.20	0.19	1500	2526
			20	0	80	III	0.20	0.19	1500	2526
		Shaly Clay	45	55	0	IV	0.10	0.19	3000	2526
			45	40	15	IV	0.10	0.19	3000	2526
			45	25	25	II	0.25	0.19	1200	2526
			45	15	40	II	0.25	0.19	1200	2526
			45	0	55	III	0.20	0.19	1500	2526
	1b) Owens-Vernon association, rolling, Vernon	Clay	20	80	0	IV	0.10	0.19	3000	2526
			20	60	20	IV	0.10	0.19	3000	2526
			20	40	40	IV	0.10	0.19	3000	2526
			20	20	60	III	0.20	0.19	1500	2526
			20	0	80	III	0.20	0.19	1500	2526
		Shaly Clay	35	65	0	IV	0.10	0.19	3000	2526
			35	50	15	IV	0.10	0.19	3000	2526
			35	30	30	III	0.20	0.19	1500	2526
			35	15	50	II	0.25	0.19	1200	2526
			35	0	65	III	0.20	0.19	1500	2526
	2) Vernon clay, 3-8% slopes	Clay	20	80	0	IV	0.10	0.19	3000	2526
			20	60	20	IV	0.10	0.19	3000	2526
			20	40	40	IV	0.10	0.19	3000	2526
			20	20	60	III	0.20	0.19	1500	2526
			20	0	80	III	0.20	0.19	1500	2526

Table 3.3 Continued

County	Major Soils	USDA Soil Texture	Sand (%)	Clay (%)	Silt (%)	TCEQ Class	R_a (gpd/ft^2)	R_{et} (in/d)	A_a (ft^2)	A_{et} (ft^2)
Baylor	2) Vernon clay, 3-8% slopes	Shaly Clay	35	65	0	IV	0.10	0.19	3000	2526
			35	50	15	IV	0.10	0.19	3000	2526
			35	30	30	III	0.20	0.19	1500	2526
			35	15	50	II	0.25	0.19	1200	2526
			35	0	65	III	0.20	0.19	1500	2526
Bexar	1) Tarrant association, gently undulating	Clay Loam	30	70	0	IV	0.10	0.15	3000	3200
			30	50	20	IV	0.10	0.15	3000	3200
			30	35	35	III	0.20	0.15	1500	3200
			30	20	50	III	0.20	0.15	1500	3200
			30	0	70	III	0.20	0.15	1500	3200
	2) Lewisville silty clay, 0-1% slopes	Silty Clay	12	88	0	IV	0.10	0.15	3000	3200
			12	50	38	IV	0.10	0.15	3000	3200
			12	44	44	IV	0.10	0.15	3000	3200
			12	38	50	III	0.20	0.15	1500	3200
			12	0	88	III	0.20	0.15	1500	3200
		Silty Clay Loam	30	70	0	IV	0.10	0.15	3000	3200
			30	50	20	IV	0.10	0.15	3000	3200
			30	35	35	III	0.20	0.15	1500	3200
			30	20	50	III	0.20	0.15	1500	3200
			30	0	70	III	0.20	0.15	1500	3200
Cameron	1) Laredo silty clay loam, 0-1% slopes	Silty Clay Loam	15	85	0	IV	0.10	0.15	3000	3200
			15	60	25	IV	0.10	0.15	3000	3200
			15	40	40	IV	0.10	0.15	3000	3200
			15	25	60	III	0.20	0.15	1500	3200
			15	0	85	III	0.20	0.15	1500	3200
		Silty Clay Loam, Silt Loam	30	70	0	IV	0.10	0.15	3000	3200
			30	50	20	IV	0.10	0.15	3000	3200
			30	35	35	III	0.20	0.15	1500	3200
			30	20	50	III	0.20	0.15	1500	3200
			30	0	70	III	0.20	0.15	1500	3200
	2) Harlingen clay	Clay	5	95	0	IV	0.10	0.15	3000	3200
			5	75	20	IV	0.10	0.15	3000	3200
			5	40	40	IV	0.10	0.15	3000	3200
			5	20	75	III	0.20	0.15	1500	3200
			5	0	95	III	0.20	0.15	1500	3200
		Clay	15	85	0	IV	0.10	0.15	3000	3200
			15	60	25	IV	0.10	0.15	3000	3200
			15	40	40	IV	0.10	0.15	3000	3200
			15	25	60	III	0.20	0.15	1500	3200
			15	0	85	III	0.20	0.15	1500	3200
		Clay	15	85	0	IV	0.10	0.15	3000	3200
			15	60	25	IV	0.10	0.15	3000	3200
			15	40	40	IV	0.10	0.15	3000	3200
			15	25	60	III	0.20	0.15	1500	3200
			15	0	85	III	0.20	0.15	1500	3200

Table 3.3 Continued

County	Major Soils	USDA Soil Texture	Sand (%)	Clay (%)	Silt (%)	TCEQ Class	R_a (gpd/ft^2)	R_{et} (in/d)	A_a (ft^2)	A_{et} (ft^2)
Dallas	1) Houston Black-urban land complex, 0-4% slopes	Clay	15	85	0	IV	0.10	0.14	3000	3429
			15	60	25	IV	0.10	0.14	3000	3429
			15	40	40	IV	0.10	0.14	3000	3429
			15	25	60	III	0.20	0.14	1500	3429
			15	0	85	III	0.20	0.14	1500	3429
		Clay, Silty Clay	15	85	0	IV	0.10	0.14	3000	3429
			15	60	25	IV	0.10	0.14	3000	3429
			15	40	40	IV	0.10	0.14	3000	3429
			15	25	60	III	0.20	0.14	1500	3429
			15	0	85	III	0.20	0.14	1500	3429
	2) Houston Black clay, 1-3% slopes	Clay	15	85	0	IV	0.10	0.14	3000	3429
			15	60	25	IV	0.10	0.14	3000	3429
			15	40	40	IV	0.10	0.14	3000	3429
			15	25	60	III	0.20	0.14	1500	3429
			15	0	85	III	0.20	0.14	1500	3429
		Clay, Silty Clay	15	85	0	IV	0.10	0.14	3000	3429
			15	60	25	IV	0.10	0.14	3000	3429
			15	40	40	IV	0.10	0.14	3000	3429
			15	25	60	III	0.20	0.14	1500	3429
			15	0	85	III	0.20	0.14	1500	3429
El Paso	1) Hueco	Loamy Fine Sand	90	10	0	Ib	0.38	0.26	789	1846
			90	5	5	Ib	0.38	0.26	789	1846
			90	0	10	Ib	0.38	0.26	789	1846
		Fine Sandy Loam	85	15	0	Ib	0.38	0.26	789	1846
			85	10	5	Ib	0.38	0.26	789	1846
			85	5	10	Ib	0.38	0.26	789	1846
			85	0	15	Ib	0.38	0.26	789	1846
	2) Wink	Fine Sandy Loam	80	20	0	II	0.25	0.26	1200	1846
			80	10	10	Ib	0.38	0.26	789	1846
			80	0	20	Ib	0.38	0.26	789	1846
		Gravelly Loam	75	25	0	II	0.25	0.26	1200	1846
			75	15	10	II	0.25	0.26	1200	1846
			75	10	15	II	0.25	0.26	1200	1846
			75	0	25	Ib	0.38	0.26	789	1846
Jefferson	1) Beaumont clay	Clay	45	55	0	IV	0.10	0.04	3000	12000
			45	40	15	IV	0.10	0.04	3000	12000
			45	25	25	II	0.25	0.04	1200	12000
			45	15	40	II	0.25	0.04	1200	12000
			45	0	55	III	0.20	0.04	1500	12000
		Clay	35	65	0	IV	0.10	0.04	3000	12000
			35	50	15	IV	0.10	0.04	3000	12000
			35	30	30	III	0.20	0.04	1500	12000
			35	15	50	II	0.25	0.04	1200	12000
			35	0	65	III	0.20	0.04	1500	12000

Table 3.3 Continued

County	Major Soils	USDA Soil Texture	Sand (%)	Clay (%)	Silt (%)	TCEQ Class	R_a (gpd/ft^2)	R_{et} (in/d)	A_a (ft^2)	A_{et} (ft^2)
Jefferson	1) Beaumont clay	Clay	20	80	0	IV	0.10	0.04	3000	12000
			20	60	20	IV	0.10	0.04	3000	12000
			20	40	40	IV	0.10	0.04	3000	12000
			20	20	60	III	0.20	0.04	1500	12000
			20	0	80	III	0.20	0.04	1500	12000
	2) Morey silt loam	Silt Loam	30	70	0	IV	0.10	0.04	3000	12000
			30	50	20	IV	0.10	0.04	3000	12000
			30	35	35	III	0.20	0.04	1500	12000
			30	20	50	III	0.20	0.04	1500	12000
			30	0	70	III	0.20	0.04	1500	12000
		Silty Clay	30	70	0	IV	0.10	0.04	3000	12000
			30	50	20	IV	0.10	0.04	3000	12000
			30	35	35	III	0.20	0.04	1500	12000
			30	20	50	III	0.20	0.04	1500	12000
			30	0	70	III	0.20	0.04	1500	12000
		Silty Clay Loam	40	60	0	IV	0.10	0.04	3000	12000
			40	45	15	IV	0.10	0.04	3000	12000
			40	30	30	III	0.20	0.04	1500	12000
			40	15	45	II	0.25	0.04	1200	12000
			40	0	60	III	0.20	0.04	1500	12000
Lubbock	1) Acuff loam, 0-1% slopes	Loam	50	50	0	III	0.20	0.21	1500	2286
			50	30	20	III	0.20	0.21	1500	2286
			50	20	30	II	0.25	0.21	1200	2286
			50	0	50	II	0.25	0.21	1200	2286
		Clay Loam, Sandy Clay Loam, Loam	35	65	0	IV	0.10	0.21	3000	2286
			35	50	15	IV	0.10	0.21	3000	2286
			35	30	30	III	0.20	0.21	1500	2286
			35	15	50	II	0.25	0.21	1200	2286
			35	0	65	III	0.20	0.21	1500	2286
		Clay Loam, Sandy Clay Loam, Loam	40	60	0	IV	0.10	0.21	3000	2286
			40	45	15	IV	0.10	0.21	3000	2286
			40	30	30	III	0.20	0.21	1500	2286
			40	15	45	II	0.25	0.21	1200	2286
			40	0	60	III	0.20	0.21	1500	2286
	2) Olton clay loam, 0-1% slopes	Clay Loam	45	55	0	IV	0.10	0.21	3000	2286
			45	40	15	IV	0.10	0.21	3000	2286
			45	25	25	II	0.25	0.21	1200	2286
			45	15	40	II	0.25	0.21	1200	2286
			45	0	55	III	0.20	0.21	1500	2286
		Clay Loam, Silty Clay Loam, Clay	40	60	0	IV	0.10	0.21	3000	2286
			40	45	15	IV	0.10	0.21	3000	2286
			40	30	30	III	0.20	0.21	1500	2286
			40	15	45	II	0.25	0.21	1200	2286
			40	0	60	III	0.20	0.21	1500	2286

Table 3.3 Continued

County	Major Soils	USDA Soil Texture	Sand (%)	Clay (%)	Silt (%)	TCEQ Class	R_a (gpd/ft^2)	R_{et} (in/d)	A_a (ft^2)	A_{et} (ft^2)
Lubbock	2) Olton clay loam, 0-1% slopes	Clay Loam, Sandy Clay Loam, Loam	40	60	0	IV	0.10	0.21	3000	2286
			40	45	15	IV	0.10	0.21	3000	2286
			40	30	30	III	0.20	0.21	1500	2286
			40	15	45	II	0.25	0.21	1200	2286
			40	0	60	III	0.20	0.21	1500	2286
	Reese Center, Acuff loam, 0-1% slopes		57	22	21	III	0.20	0.21	1500	2286
			61	20	19	II-III	0.23	0.21	1333	2286
			78	11	11	II	0.25	0.21	1200	2286
Pecos	1) Ector-Rock outcrop association, steep	Stony Clay Loam	80	20	0	II	0.25	0.25	1200	1920
			80	10	10	Ib	0.38	0.25	789	1920
			80	0	20	Ib	0.38	0.25	789	1920
	2a) Reagan-Hodgins association, nearly level, Reagan	Silty Clay Loam	30	70	0	IV	0.10	0.25	3000	1920
			30	50	20	IV	0.10	0.25	3000	1920
			30	35	35	III	0.20	0.25	1500	1920
			30	20	50	III	0.20	0.25	1500	1920
			30	0	70	III	0.20	0.25	1500	1920
		Silty Clay, Silty Clay Loam, Loam	35	65	0	IV	0.10	0.25	3000	1920
			35	50	15	IV	0.10	0.25	3000	1920
			35	30	30	III	0.20	0.25	1500	1920
			35	15	50	II	0.25	0.25	1200	1920
			35	0	65	III	0.20	0.25	1500	1920
	2b) Reagan-Hodgins association, nearly level, Hodgins	Silty Clay Loam	30	70	0	IV	0.10	0.25	3000	1920
			30	50	20	IV	0.10	0.25	3000	1920
			30	35	35	III	0.20	0.25	1500	1920
			30	20	50	III	0.20	0.25	1500	1920
			30	0	70	III	0.20	0.25	1500	1920
	2b) Reagan-Hodgins association, nearly level, Hodgins	Clay Loam, Silty Clay Loam, Silty Clay	35	65	0	IV	0.10	0.25	3000	1920
			35	50	15	IV	0.10	0.25	3000	1920
			35	30	30	III	0.20	0.25	1500	1920
			35	15	50	II	0.25	0.25	1200	1920
			35	0	65	III	0.20	0.25	1500	1920
Potter	1a) Veal-Paloduro association, undulating, Veal	Loam	60	40	0	III	0.20	0.21	1500	2286
			60	30	10	III	0.20	0.21	1500	2286
			60	20	20	III	0.20	0.21	1500	2286
			60	10	30	II	0.25	0.21	1200	2286
			60	0	40	II	0.25	0.21	1200	2286
		Sandy Clay	60	40	0	III	0.20	0.21	1500	2286
			60	30	10	III	0.20	0.21	1500	2286
			60	20	20	III	0.20	0.21	1500	2286
			60	10	30	II	0.25	0.21	1200	2286
			60	0	40	II	0.25	0.21	1200	2286
		Clay Loam, Sandy Clay Loam, Loam	60	40	0	III	0.20	0.21	1500	2286
			60	30	10	III	0.20	0.21	1500	2286
			60	20	20	III	0.20	0.21	1500	2286
			60	10	30	II	0.25	0.21	1200	2286
			60	0	40	II	0.25	0.21	1200	2286

Table 3.3 Continued

County	Major Soils	USDA Soil Texture	Sand (%)	Clay (%)	Silt (%)	TCEQ Class	R_a (gpd/ft^2)	R_{et} (in/d)	A_a (ft^2)	A_{et} (ft^2)
Potter	1b) Veal-Paloduro association, undulating, Paloduro	Clay Loam	60	40	0	III	0.20	0.21	1500	2286
			60	30	10	III	0.20	0.21	1500	2286
			60	20	20	III	0.20	0.21	1500	2286
			60	10	30	II	0.25	0.21	1200	2286
			60	0	40	II	0.25	0.21	1200	2286
		Loam, Clay Loam, Sandy Clay Loam	60	40	0	III	0.20	0.21	1500	2286
			60	30	10	III	0.20	0.21	1500	2286
			60	20	20	III	0.20	0.21	1500	2286
			60	10	30	II	0.25	0.21	1200	2286
			60	0	40	II	0.25	0.21	1200	2286
	2) Pullman clay loam, 0-1% slopes	Clay Loam	30	70	0	IV	0.10	0.21	3000	2286
			30	50	20	IV	0.10	0.21	3000	2286
			30	35	35	III	0.20	0.21	1500	2286
			30	20	50	III	0.20	0.21	1500	2286
			30	0	70	III	0.20	0.21	1500	2286
		Clay, Silty Clay	15	85	0	IV	0.10	0.21	3000	2286
			15	60	25	IV	0.10	0.21	3000	2286
			15	40	40	IV	0.10	0.21	3000	2286
			15	25	60	III	0.20	0.21	1500	2286
			15	0	85	III	0.20	0.21	1500	2286
		Clay Loam, Clay, Silty Clay	25	75	0	IV	0.10	0.21	3000	2286
			25	45	30	IV	0.10	0.21	3000	2286
			25	30	45	III	0.20	0.21	1500	2286
			25	0	75	III	0.20	0.21	1500	2286
Tom Green	1) Tarrant association, hilly	Cobbly Clay	25	75	0	IV	0.10	0.23	3000	2087
			25	45	30	IV	0.10	0.23	3000	2087
			25	30	45	III	0.20	0.23	1500	2087
			25	0	75	III	0.20	0.23	1500	2087
		Hard Limestone	25	75	0	IV	0.10	0.23	3000	2087
			25	45	30	IV	0.10	0.23	3000	2087
			25	30	45	III	0.20	0.23	1500	2087
			25	0	75	III	0.20	0.23	1500	2087
	2) Angelo clay loam, 0-1% slopes	Clay Loam, Silty	40	60	0	IV	0.10	0.23	3000	2087
			40	45	15	IV	0.10	0.23	3000	2087
			40	30	30	III	0.20	0.23	1500	2087
			40	15	45	II	0.25	0.23	1200	2087
			40	0	60	III	0.20	0.23	1500	2087
		Clay	30	70	0	IV	0.10	0.23	3000	2087
			30	50	20	IV	0.10	0.23	3000	2087
			30	35	35	III	0.20	0.23	1500	2087
			30	20	50	III	0.20	0.23	1500	2087
			30	0	70	III	0.20	0.23	1500	2087
		Silty Clay Loam	50	50	0	III	0.20	0.23	1500	2087
			50	30	20	III	0.20	0.23	1500	2087
			50	20	30	II	0.25	0.23	1200	2087
			50	0	50	II	0.25	0.23	1200	2087

Table 3.3 Continued

County	Major Soils	USDA Soil Texture	Sand (%)	Clay (%)	Silt (%)	TCEQ Class	R_a (gpd/ft^2)	R_{et} (in/d)	A_a (ft^2)	A_{et} (ft^2)
Tom Green	2) Angelo clay loam, 0-1% slopes	Clay Loam	40	60	0	IV	0.10	0.23	3000	2087
			40	45	15	IV	0.10	0.23	3000	2087
			40	30	30	III	0.20	0.23	1500	2087
			40	15	45	II	0.25	0.23	1200	2087
			40	0	60	III	0.20	0.23	1500	2087
Webb	1a) Maverick-Catarina complex, gently rolling, Maverick	Clay	50	50	0	III	0.20	0.23	1500	2087
			50	30	20	III	0.20	0.23	1500	2087
			50	20	30	II	0.25	0.23	1200	2087
			50	0	50	II	0.25	0.23	1200	2087
		Clay, Clay Loam	20	80	0	IV	0.10	0.23	3000	2087
			20	60	20	IV	0.10	0.23	3000	2087
			20	40	40	IV	0.10	0.23	3000	2087
			20	20	60	III	0.20	0.23	1500	2087
			20	0	80	III	0.20	0.23	1500	2087
		Clay, Clay Loam	25	75	0	IV	0.10	0.23	3000	2087
			25	45	30	IV	0.10	0.23	3000	2087
			25	30	45	III	0.20	0.23	1500	2087
			25	0	75	III	0.20	0.23	1500	2087
		Shaly Clay	40	60	0	IV	0.10	0.23	3000	2087
			40	45	15	IV	0.10	0.23	3000	2087
			40	30	30	III	0.20	0.23	1500	2087
			40	15	45	II	0.25	0.23	1200	2087
			40	0	60	III	0.20	0.23	1500	2087
	1b) Maverick-Catarina complex, gently rolling, Catarina	Clay	20	80	0	IV	0.10	0.23	3000	2087
			20	60	20	IV	0.10	0.23	3000	2087
			20	40	40	IV	0.10	0.23	3000	2087
			20	20	60	III	0.20	0.23	1500	2087
			20	0	80	III	0.20	0.23	1500	2087
		Clay, Silty Clay	20	80	0	IV	0.10	0.23	3000	2087
			20	60	20	IV	0.10	0.23	3000	2087
			20	40	40	IV	0.10	0.23	3000	2087
			20	20	60	III	0.20	0.23	1500	2087
			20	0	80	III	0.20	0.23	1500	2087
		Clay, Silty Clay	20	80	0	IV	0.10	0.23	3000	2087
			20	60	20	IV	0.10	0.23	3000	2087
			20	40	40	IV	0.10	0.23	3000	2087
			20	20	60	III	0.20	0.23	1500	2087
			20	0	80	III	0.20	0.23	1500	2087
	2) Montell clay, saline, 0-2% slopes	Clay	25	75	0	IV	0.10	0.23	3000	2087
			25	45	30	IV	0.10	0.23	3000	2087
			25	30	45	III	0.20	0.23	1500	2087
			25	0	75	III	0.20	0.23	1500	2087
		Clay, Silty Clay	25	75	0	IV	0.10	0.23	3000	2087
			25	45	30	IV	0.10	0.23	3000	2087
			25	30	45	III	0.20	0.23	1500	2087
			25	0	75	III	0.20	0.23	1500	2087

Table 3.3 Continued

County	Major Soils	USDA Soil Texture	Sand (%)	Clay (%)	Silt (%)	TCEQ Class	R_a (gpd/ft^2)	R_{et} (in/d)	A_a (ft^2)	A_{et} (ft^2)
Webb	2) Montell clay, saline, 0-2% slopes	Clay, Silty Clay	25	75	0	IV	0.10	0.23	3000	2087
			25	45	30	IV	0.10	0.23	3000	2087
			25	30	45	III	0.20	0.23	1500	2087
			25	0	75	III	0.20	0.23	1500	2087
Wharton	1) Lake Charles clay, 0-1% slopes	Clay	10	90	0	IV	0.10	0.10	3000	4800
			10	60	30	IV	0.10	0.10	3000	4800
			10	45	45	IV	0.10	0.10	3000	4800
			10	30	60	III	0.20	0.10	1500	4800
			10	0	90	III	0.20	0.10	1500	4800
	2) Crowley fine sandy loam	Fine Sandy Loam	60	40	0	III	0.20	0.10	1500	4800
			60	30	10	III	0.20	0.10	1500	4800
			60	20	20	III	0.20	0.10	1500	4800
			60	10	30	II	0.25	0.10	1200	4800
			60	0	40	II	0.25	0.10	1200	4800
		Clay	40	60	0	IV	0.10	0.10	3000	4800
			40	45	15	IV	0.10	0.10	3000	4800
			40	30	30	III	0.20	0.10	1500	4800
			40	15	45	II	0.25	0.10	1200	4800
			40	0	60	III	0.20	0.10	1500	4800
		Sandy Clay	50	50	0	III	0.20	0.10	1500	4800
			50	30	20	III	0.20	0.10	1500	4800
			50	20	30	II	0.25	0.10	1200	4800
			50	0	50	II	0.25	0.10	1200	4800
		Sandy Clay	50	50	0	III	0.20	0.10	1500	4800
			50	30	20	III	0.20	0.10	1500	4800
			50	20	30	II	0.25	0.10	1200	4800
			50	0	50	II	0.25	0.10	1200	4800

surveys. County soil surveys include estimates of permeability ranges as summarized in Table 3.1. The NRCS values may be based on actual infiltrometer tests or the experience of the authors of the surveys. Equations are also available from the soil science literature to calculate saturated hydraulic conductivity, another phrase for permeability. Marshall (1958) developed an equation that recognized the mixing of multiple classes of grain sizes:

$$K_s = \left(\frac{g\rho}{8\nu}\right)\left(\frac{\phi^x}{n^2}\right)\sum_{i=1}^{m}(2i-1)R_i^{\,2} \tag{3.3}$$

where K_s = saturated hydraulic conductivity (cm/s), g = gravitational acceleration (cm/s^2), ρ = density (g/cm^3), ν = kinematic viscosity (cm^2/s), R_i = average pore radius in the ith porosity class (cm), ϕ = total porosity, x = pore interaction exponent (1.33), and n = total pore size classes. Rawls et al. (1982) applied Equation 3.3 for various USDA soil textures and proposed a simplified relation that retained n, the number of pore size classes, and used an average R_i for each soil texture. The simplified equation was given by

$$K_s\left(\frac{\text{in}}{\text{hr}}\right) = 1.74x10^7 \frac{R_i^2(\text{cm})\phi^{1.33}}{n^2} \tag{3.4}$$

which gives the hydraulic conductivity in units of in/hr, allowing porosity to be specified to represent different soil packing conditions. Table 3.4 shows the values of n and R_i recommended for use in Equation 3.4 for different soil textures.

Table 3.4 Parameters for K_s Estimation (Rawls et al., 1982)

Soil Texture	n	R_i (cm)
Sand	12	0.0193
Loamy Sand	18	0.0171
Sandy Loam	30	0.0100
Loam	40	0.0133
Silt Loam, Silt	37	0.0072
Sandy Clay Loam	37	0.0054
Clay Loam	44	0.0058
Silty Clay Loam	50	0.0045
Sandy Clay	47	0.0051
Silty Clay	53	0.0043
Clay	53	0.0040

As shown in Table 3.3, the two major soil classes in each county could be subdivided into multiple USDA soil textures listed in Table 3.4. In each of the multiple soil textures, it was also possible that a range of porosities might be encountered. Equation 3.4 was applied to each soil texture for possible porosity values of 0.30, 0.35, 0.40, and 0.45. The spreadsheet used for these calculations was too long for reproduction in this report, but it is available upon request. For this report, the ranges of K_s values for the two major soil classes in each county were extracted for comparison to the range of permeabilities from the NRCS soil surveys. In general, the calculated

K_s and NRCS permeability ranges were similar. The ranges of values are shown in Tables 3.5, 3.6, and 3.7.

3.5 Comparison of Selected Counties with TTUWRC Test Site Conditions

As stated previously, the fourth task was to determine if the findings of the ETA drainfield tests at the TTUWRC Reese Center site in Lubbock County could be applied at other locations around the state. The field tests at Reese Center were conducted to establish the hydraulic capacity of ETA trenches in the TCEQ (2001) type II and III soils at that site. Those tests showed that the hydraulic capacity of ETA trenches under these conditions was over four times the LTAR loading capacities for AB trenches for type II and III soils. The conclusion from these field tests was that the large observed loading capacity was due to the ET losses that occur above and adjacent to the trench, as lateral and upward movement of septic effluent was apparently greater than downward infiltration. The combination of relatively coarse soils with the high ET, low precipitation conditions in Lubbock County all contribute to the loading capacity.

Based on these findings, the soil and hydrologic conditions in the twelve other counties were compared to those in Lubbock County. Locations with similar permeable soils and high ET/low rainfall likely have similar ETA loading capacities to that seen in Lubbock County. Locations with low permeability soils will not have much potential for increased loading capacity for ETA systems. Also, locations with low ET and or high rainfall conditions will not support high ETA system performance. It was noted that the data from the thirteen counties appeared to fall into three categories: [A] high ET/low rainfall conditions with permeable soils, [B] medium ET/high to medium rainfall conditions, perhaps with low permeability soils, and [C] low ET/high rainfall conditions with low permeability soils. Tables 3.5, 3.6, and 3.7 break the county/soil combinations into these three categories. Category A locations should be appropriate for the same ETA loading guidance as Lubbock County. The current recommendation in this report is to allow ETA systems in type II and III soils with low groundwater tables to be up to twice the LTARs allowed for AB systems. Category C locations do not have proper conditions to justify greater loading rates for ETA systems. Category B locations could be amenable to somewhat higher loading rates for ETA systems, but will not have as large a “factor of safety” as the category A locations.

As shown in Table 3.5, all five Category A county/soil combinations have annual ET

Table 3.5 Class A County/Soil Combinations

County	Calculated Annual ET (in)	Annual Rainfall (in/yr)	County Soil Survey Descriptions	NRCS Permeability (in/hr)		Calculated Hydraulic Conductivity (in/hr)	
				low	high	low	high
El Paso	75.5	10	Hueco	2	6.3	0.39	15.5
			Wink	0.63	2	0.07	5.42
Lubbock	72.7	20	Acuff loam, 0-1% slopes	0.6	2	0.02	0.67
			Olton clay loam, 0-1% slopes	0.2	2	0.02	0.67
Pecos	76.6	16	Ector-Rock outcrop association, steep	0.6	2	0.39	5.42
			Reagan-Hodgins association, nearly level	0.6	2	0.02	0.67
Potter	75.2	19	Veal-Paloduro association, undulating	0.6	2	0.04	1.09
			Pullman clay loam, 0-1% slopes	<0.06	0.6	0.02	0.66
Tom Green	70.4	22	Tarrant association, hilly	0.2	0.63	0.02	0.23
			Angelo clay loam, 0-1% slopes	0.2	2	0.02	0.67

Table 3.6 Class B County/Soil Combinations

County	Calculated Annual ET (in)	Annual Rainfall (in/yr)	County Soil Survey Descriptions	NRCS Permeability (in/hr)		Calculated Hydraulic Conductivity (in/hr)	
				low	high	low	high
Bexar	64.6	29	Tarrant association, gently undulating	1.0	1.2	0.02	0.66
			Lewisville silty clay, 0-1% slopes	1.0	1.2	0.02	0.66
Cameron	64.5	25	Laredo silty clay loam, 0-1% slopes	0.63	2	0.02	0.66
			Harlingen clay	<0.06	<0.06	0.02	0.23
Webb	67.4	22	Maverick-Catarina complex, gently rolling	<0.06	0.2	0.02	0.67
			Montell clay, saline, 0-2% slopes	<0.06	<0.06	0.02	0.23

depths greater than 70 in and annual rainfall depths of 22 in or less (rainfall depth less than one-third of calculated ET depth). The two most prominent soil types in each county tend to be TCEQ (2001) type II and III with “high-end” permeabilities on the order of 0.6 in/hr and higher. All five counties are in the western third of the state. The western third of the state could be identified by the area with ET of at least 70 in/yr, from about Tom Green County west on the ET map in Figure 3.4. It should be noted that locations with low permeability, type IV soils in this area would not be appropriate sites for ETA systems.

Table 3.7 Class C County/Soil Combinations

County	Calculated Annual ET (in)	Annual Rainfall (in/yr)	County Soil Survey Descriptions	NRCS Permeability (in/hr)		Calculated Hydraulic Conductivity (in/hr)	
				low	high	low	high
Angelina	58.5	54	Fuller fine sandy loam, 1-4% slopes	<0.06	2	0.04	0.67
			Alazan very fine sandy loam, 0-4% slopes	0.6	2	0.02	0.67
Baylor	68.3	27	Owens-Vernon association, rolling	<0.06	<0.06	0.02	0.67
			Vernon clay, 3-8% slopes	<0.06	<0.06	0.02	0.67
Dallas	65.1	40	Houston Black-urban land complex, 0-4% slopes	<0.06	<0.06	0.02	0.23
			Houston Black clay, 1-3% slopes	<0.06	<0.06	0.02	0.23
Jefferson	56.2	56	Beaumont clay	<0.06	0.2	0.02	0.67
			Morey silt loam	<0.06	0.8	0.02	0.67
Wharton	60.3	42	Lake Charles clay, 0-1% slopes	<0.06	<0.06	0.02	0.23
			Crowley fine sandy loam	<0.06	2	0.02	0.67

The Class C county/soil combinations shown in Table 3.7 include four (Angelina, Dallas, Jefferson, and Wharton) that have annual rainfall depths that are greater than 60 percent of annual calculated ET. All five have soil descriptions that include large clay fractions, leading to small "low-end" permeabilities. The low ET/high rainfall area in the eastern quarter of the state could be approximated by the 40-in rainfall contour on the annual precipitation map in Figure 3.3. This area has enough annual precipitation to seriously impede ETA system capacity, even at locations with type II or III soils. The Baylor county/soil combination has lower annual rainfall, but the two prominent soils have relatively low permeabilities as compared to the Category A combinations. The Class C county/soil combinations do not warrant larger LTAR values for ETA drainfields.

The three Class B county/soil combinations shown in Table 3.6 lie between the Category A and C conditions. The Webb County combination has medium ET/low rainfall with low permeability soils, while the Bexar and Cameron combinations have medium ET/medium rainfall with lower to medium permeability soils. These intermediate conditions do not provide as strong justification for larger ETA LTAR values as seen in the Category A combinations.

Recent studies by Reed et al. (2001, 2002) indicated that the most reported reason for septic system drainfield failures in Texas was improper soil conditions. Most often, tightly packed clay soils prevent proper leaching of wastewater effluent from the trenches. For effective utilization of ETA trenches, soils should be classified as type II or III with vegetative cover that maximizes ET, such as turfgrass.

4. Conclusions and Recommendations for ETA Trench LTARs

The primary objectives of this Phase II project were to (1) perform additional field experiments for hydraulic loading capacity of ETA trenches and (2) determine the potential for extrapolating the results from the Lubbock County site to other locations in Texas based on local soil and hydrologic conditions. The combination of the field observations and the hydrologic study provide sufficient evidence to recommend guidance for ETA trench LTAR values in locations with similar soil and hydrologic situations as those found at the field site. The resulting conclusions and recommendations can be stated as follows.

- The Phase II field experimental results for six ETA trenches receiving artificial wastewater were similar to those seen in the Phase I experiments with three ETA trenches. Average hydraulic loading rates for the last twelve months of the field tests were approximately 1.0 gpd/ft^2 in both experiments. Addition of cooking oil to the artificial wastewater mix did not affect the loading rates.
- The combination of type II and III soils with annual ET $\geq$ 70 in and annual rainfall $\leq$ 22 represent the conditions at the Reese Center test site in Lubbock County and the western third of Texas. Recommended ETA loading rates are 0.50 gpd/ft^2 for type II soils and 0.40 gpd/ft^2 for type III soils in these locations, double the guidance for AB trenches but still allowing a hydraulic factor of safety of about 2. If that recommendation appears too risky, the ETA loading rates could be set at 0.38 gpd/ft^2 for type II soils and 0.30 gpd/ft^2 for type III soils in these locations, 1.5 times the guidance for AB trenches but still allowing a hydraulic factor of safety of about 3. ETA trenches must be separated by 15 to 20 ft to maximize the ET effects.
- Type IV soils can have very low permeabilities that restrict vertical and lateral movement of moisture from the drainfield trenches. No field tests were done in type IV soils in the TTUWRC field demonstration projects. At this time there is not sufficient justification for making ETA LTAR values in type IV soils larger than those currently assigned by the TCEQ (2001) for AB drainfields. It is possible that additional field tests in type IV soils in arid areas could eventually justify adjustment for locations with type IV soils, high ET, and low rainfall.
- Type Ib soils can have very high permeabilities due to their high sand contents, and the nature of their porosity may mean that less lateral movement takes place by capillary

action than in loamy type II and III soils. Type Ib soils were not tested in the TTUWRC field demonstrations. At this time there is not sufficient justification for making ETA LTAR values in type Ib soils larger than those currently assigned by the TCEQ (2001) for AB drainfields. It is possible that additional field tests in type IV soils in arid areas could eventually justify adjustment for locations with type Ib soils, high ET, and low rainfall.

- Drainfields in eastern Texas where the local annual rainfall is ≥ 60 percent of the annual ET do not likely experience as large a combination of ET and absorption as in the arid western third of the state. These locations should not be assigned larger values of LTAR beyond the current TCEQ (2001) guidance for AB drainfields.
- The central portion of Texas is characterized by intermediate values of annual ET and annual rainfall, with varying soil conditions. At this time, there is not sufficient justification to allow ETA LTAR values above the current TCEQ (2001) guidance for AB drainfields. It is possible that additional field tests in the various soil types in this region could eventually justify adjustment for locations with type II or III soils.

5. References

American Public Health Association, 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed., APHA/AWWA/WEF, APHA Publications, Washington, DC.

Blackstock, D.A., 1979. Soil Survey of Lubbock County, Texas, Natural Resources Conservation Service, United States Department of Agriculture, 105 p.

Borrelli, J., Fedler, C.B., and Gregory, J.M., 1998. Mean Crop Consumptive Use and Free-Water Evaporation for Texas, Report to Texas Water Development Board, Austin, Texas.

Coffee, D.R., Hill, R.H., and Ressel, D.D., 1980. Soil Survey of Dallas County, Texas, Natural Resources Conservation Service, United States Department of Agriculture, 153 p.

Crout, J.C., Symmank, D.G., and Peterson, G.A., 1965. Soil Survey of Jefferson County, Texas, Natural Resources Conservation Service, United States Department of Agriculture, 73 p.

Dolezel, R. 1988. Soil Survey of Angelina County, Texas, Natural Resources Conservation Service, United States Department of Agriculture, 203 p.

Environmental Protection Agency, 1980. Design Manual – On-site Wastewater Treatment and Disposal Systems, EPA625/1-80-012, U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio.

Ingram, W. W., 2000. Evaluation of Septic System Drainfields, Master's Thesis, Department of Civil Engineering, Texas Tech University, Lubbock, Texas, 183 p.

Jaco, H.B., 1971. Soil Survey of Angelina County, Texas, Natural Resources Conservation Service, United States Department of Agriculture, 60 p.

Johnson, R. W., Brasfield, J.F., and Beville, B., 1974. Using Soil Survey Information to Plan Home Sewage Disposal Systems, in Home Sewage Disposal, Proceedings of the National Home Sewage Disposal Symposium, ASAE Publication Proc–175. American Society of Agriculture Engineers, St. Joseph, Michigan, pp. 210-214.

Marshall, T.J. 1958. A Relationship Between Permeability and Size Distribution of Pores, Journal of Soil Science, Vol. 9, pp. 1-8.

McEwen, H.F. and Crout, J., 1974. Soil Survey of Webb County, Texas, Natural Resources Conservation Service, United States Department of Agriculture, 43 p.

Natural Resources Conservation Service, 2002. Texas Precipitation Data/Maps, National Cartography and Geospatial Center, United States Department of Agriculture, website http://www.ncgc.nrcs.usda.gov/branch/gdb/products/climate/data/precipitation-state/tx.html, last accessed December 2003.

Otis, R. J., Converse, J. C., Carlile, B. L., and Witty, J. E., 1977. Effluent Distribution, in Home Sewage Treatment, Proceedings of the Second National Home Sewage Treatment Symposium, ASAE Publication 5-77, American Society of Agricultural Engineers, St. Joseph, Michigan, pp. 61-85.

Penman, H.L., 1948. Natural Evaporation from Open Water, Bare Soil and Grass, Proceedings of the Royal Society of London, Vol. A193, pp. 129-145.

Pringle, F.B., 1980. Soil Survey of Potter County, Texas, Natural Resources Conservation Service, United States Department of Agriculture, 139 p.

Rainwater, K.A., Jackson, W.A., Ingram, W., Lee, C.Y., Thompson, D.B., Mollhagen, T.R., Ramsey, R.H., and Urban, L.V., 2001. Effects of Combining Absorbic and Evaporative Disposal Methods on Drainfield Sizing in Arid and Semiarid Areas, Final Report to Texas On-Site Wastewater Disposal Research Council, Texas Natural Resource Conservation Commission, Austin, Texas, 119 p.

Rawls, W.J., D.L. Brakensiek, and S.D. Logsdon, 1982. Predicting Saturated Hydraulic Conductivity Utilizing Fractal Principles. Soil Science Society of America Journal, Vol. 57 pp. 1193-1197.

Reed, Stowe & Yanke, LLC, 2001. Study to Determine the Magnitude of, and Reasons for, Chronically Malfunctioning On-Site Sewage Facility Systems in Texas, Final Report to Texas On-Site Wastewater Disposal Research Council, Texas Natural Resource Conservation Commission, Austin, Texas, 115 p.

Reed, Stowe & Yanke, LLC, 2002. Study to Conduct Further Research Regarding the Magnitude of, and Reasons for, Chronically Malfunctioning On-Site Sewage Facility Systems in South Texas, Final Report to Texas On-Site Wastewater Disposal Research Council, Texas Natural Resource Conservation Commission, Austin, Texas, 37 p.

Rives, J.L., 1980. Soil Survey of Pecos County, Texas, Natural Resources Conservation Service, United States Department of Agriculture, 97 p.

Rogers, C.A., Passmore, G.D., and Risinger, W.M., 1976. Soil Survey of Baylor County, Texas, Natural Resources Conservation Service, United States Department of Agriculture, 70 p.

Sanders, R.R and Gabriel, W.J., 1985. Soil Survey of Webb County, Texas, Natural Resources Conservation Service, United States Department of Agriculture, 145 p.

Taylor, R.B., Hailey, R.B., and Richmond, D.L. 1991. Soil Survey of Bexar County, Texas, Natural Resources Conservation Service, United States Department of Agriculture, 126 p.

Texas Commission for Environmental Quality, 2001. On-Site Sewage Facilities. Title 30 Texas Annotated Code Chapter 285. Texas Register, Austin, Texas.

Waghdhare, N., Rainwater, K.A., and Jackson, W.A., 2003. Numerical Simulation of Flow Near a Septic System Drainfield, Final Report to Texas On-Site Wastewater Treatment Research Council, Texas Commission on Environmental Quality, Austin, Texas, 306 p.

Wiedenfeld, C.C. and Flores, P.H., 1976. Soil Survey of Tom Green County, Texas, Natural Resources Conservation Service, United States Department of Agriculture, 59 p.

Williams, D., Thompson, C.M., and Jacobs, J.L., 1977. Soil Survey of Cameron County, Texas, Natural Resources Conservation Service, United States Department of Agriculture, 94 p.

Appendix A. Daily Flow Data

Table A.1 Daily Flow Data

Date	Flow (gpd)						Comments
	4	7	9	14	15	16	
4/5/2002							
4/6/2002	606.7			494.5			
4/7/2002	837.5			644.9			
4/8/2002	392.0			365.7			
4/9/2002	488.8			578.5			
4/10/2002	571.5			683.3			
4/11/2002	582.3			733.1			
4/12/2002	185.6			273.1			
4/13/2002	582.3			733.1			
4/14/2002	398.5			645.4			
4/15/2002	330.5			840.9			
4/16/2002				630.5			
4/17/2002	656.4			583.0			
4/18/2002	40.6			579.4			
4/19/2002				533.2			#4 level problems
4/20/2002				531.7			#4 level problems
4/21/2002	645.3			431.2			
4/22/2002	445.2			521.9			
4/23/2002				528.6			#4 level problems
4/24/2002	607.6			647.5			
4/25/2002	385.9			419.1			
4/26/2002	157.3			443.0			
4/27/2002	239.1			424.0			
4/28/2002	248.3			496.0			
4/29/2002				509.0			#4, level rod fell off
4/30/2002				483.7			#4, level rod fell off
5/1/2002				242.0			#4, level rod fell off
5/2/2002	501.0	668.6		614.9			
5/3/2002	142.6	601.8		560.7	955.2		
5/4/2002	282.5	368.7		217.4	511.7		
5/5/2002	198.0	391.5		0.6	454.6		
5/6/2002	213.4	388.2		788.0	427.4		
5/7/2002	105.3	225.1		263.1	69.0		
5/8/2002	191.4	270.6		477.0	0.0		
5/9/2002	210.3	348.4	524.4	527.3	1.9		
5/10/2002	144.0	248.6	1027.6	244.7	183.3		
5/11/2002	167.6	293.7	510.9	299.4	322.8		
5/12/2002	196.0	333.4	349.6	350.2	378.5		
5/13/2002	191.2	323.9	269.4	339.6	365.4		
5/14/2002	103.4	194.6	150.5	194.6	213.1		
5/15/2002	167.1	280.8	213.0	294.8	310.3		
5/16/2002	157.0	275.7	204.4	290.3	295.7		
5/17/2002	146.4	255.8	196.6	265.1	272.5		
5/18/2002	161.2	300.6	218.8	306.3	306.8		
5/19/2002	155.3	286.6	202.9	290.6	284.7		
5/20/2002	169.4	300.5	214.7	306.1	294.3		
5/21/2002	198.5	364.0	251.2	372.2	348.2		
5/22/2002	163.1	299.9	202.5	306.6	283.3		
5/23/2002	155.4	299.0	198.0	300.0	281.6		

Table A.1 Continued

Date	Flow (gpd)						Comments
	4	7	9	14	15	16	
5/24/2002	153.5	296.3	192.9	296.7	276.3		
5/25/2002	139.6	302.7	197.7	283.5	279.7		
5/26/2002	122.8	273.9	175.5	264.4	248.4		
5/27/2002	153.9	315.1	188.5	298.6	283.4		
5/28/2002	140.8	311.8	193.2	285.2	274.0		
5/29/2002	127.8	279.2	175.8	260.7	247.2		
5/30/2002	143.8	307.0	181.2	288.8	268.5		
5/31/2002	151.9	318.5	195.0	303.5	277.4		
6/1/2002	145.5	319.0	196.2	306.4	277.3		
6/2/2002	151.1	300.9	179.9	294.6	263.5		
6/3/2002	156.2	317.4	194.9	308.1	274.6		
6/4/2002	65.8	155.8	93.9	145.0	134.1		
6/5/2002	85.6	206.2	606.1	137.3	140.5		
6/6/2002	198.3	489.3	361.4	405.0	390.7		
6/7/2002	123.3	317.3	204.2	274.4	257.8		
6/8/2002	118.4	280.5	181.3	237.5	227.5		
6/9/2002	85.5	256.7	157.9	197.0	188.0		
6/10/2002	89.6	202.9	121.0	167.2	161.6		
6/11/2002	149.8	340.7	214.4	150.4	275.6		
6/12/2002	129.3	325.6	199.6	264.8	262.4		
6/13/2002	115.7	284.4	175.1	216.9	229.7		
6/14/2002	109.2	277.6	169.6	240.5	224.2		
6/15/2002	139.5	352.5	209.8	265.4	283.9		
6/16/2002	136.0	319.2	203.1	273.9	259.0		
6/17/2002	114.2	252.7	152.8	204.2	200.9		
6/18/2002	135.2	298.7	186.5	226.4	240.6		
6/19/2002	141.9	305.8	189.3	237.4	248.7		
6/20/2002	106.8	210.6	132.8	170.3	170.9		
6/21/2002	156.9	308.8	194.4	243.5	248.4		
6/22/2002	182.2	349.7	224.4	276.2	287.3		
6/23/2002	126.0	224.1	135.9	190.2	183.2		
6/24/2002	139.6	244.9	150.6	215.9	195.1		
6/25/2002	158.0	279.8	173.6	243.6	221.9		
6/26/2002	123.1	127.9	132.1	187.2	172.7		
6/27/2002	102.4		126.0	167.2	165.3		#7 relay problem
6/28/2002	138.6		150.0	218.6	200.4		#7 relay problem
6/29/2002	162.5	166.2	160.6	247.2	234.5		
6/30/2002	115.5	147.2	98.1	174.7	163.0		
7/1/2002	169.6	319.0	206.8	247.7	255.9		
7/2/2002	135.5	235.1	143.5	198.2	201.7		
7/3/2002	132.0	221.0	138.1	190.0	198.1		
7/4/2002	173.0	21.3	188.2	242.6	250.0		
7/5/2002	118.2	5.1	139.7	171.2	181.9		
7/6/2002	105.3	106.3	133.1	166.6	172.9		
7/7/2002	132.1	223.8	157.3	156.7	190.9		
7/8/2002	137.8	222.3	154.4	183.2	188.6		
7/9/2002	133.4	218.7	147.5	99.8	183.6		
7/10/2002	184.0	217.6	149.6	149.0	182.1		
7/11/2002	83.7	218.4	148.4	135.3	183.0		

Table A.1 Continued

	Flow (gpd)						
Date	4	7	9	14	15	16	Comments
7/12/2002	117.5	218.7	146.2		178.9		#14 relay problem
7/13/2002	134.5	238.1	162.0		199.4		#14 relay problem
7/14/2002	132.7	208.2	143.3		116.0		#14 relay problem
7/15/2002	125.5	197.9	130.0				#14, #15 relay problem
7/16/2002	147.7	230.9	159.1				#14, #15 relay problem
7/17/2002	115.2	177.6	121.6				#14, #15 relay problem
7/18/2002	140.5	223.5	148.9		20.3		#14, #15 relay problem
7/19/2002	131.5	197.3	138.6		180.2		#14 relay problem
7/20/2002	117.4	191.4	135.0	189.9	173.2		
7/21/2002	144.7	220.4	145.3	258.5	196.2		
7/22/2002	114.7	167.0	119.2	182.2	155.3		
7/23/2002	128.9	186.6	126.8	197.4	170.2	527.6	
7/24/2002	130.1	195.6	135.4	198.9	202.2	965.9	
7/25/2002	129.9	194.9	132.2	198.2	188.1	492.4	
7/26/2002	154.5	234.2	155.3	240.2	225.2	429.1	
7/27/2002	127.8	189.1	134.5	196.7	182.0	312.8	
7/28/2002	104.8	154.4	109.4	159.5	148.6	239.9	
7/29/2002	114.0	161.5	118.4	173.0	154.9	252.0	
7/30/2002	126.3	183.5	125.8	198.1	174.1	267.0	
7/31/2002	120.5	169.7	120.3	185.8	165.6	242.5	
8/1/2002	130.7	185.4	135.6	201.9	176.7	258.2	
8/2/2002	103.9	146.4	102.7	162.5	144.4	199.7	
8/3/2002	126.8	180.6	132.6	199.4	173.8	246.4	
8/4/2002	125.3	183.1	127.0	200.4	176.2	240.6	
8/5/2002	101.2	142.9	103.1	154.3	136.8	189.1	
8/6/2002	126.5	182.1	129.3	195.1	175.7	237.4	
8/7/2002	117.6	166.8	118.8	111.7	160.6	226.1	
8/8/2002	110.1	152.6	114.1		147.6	199.4	#14 relay problem
8/9/2002	122.1	176.8	129.8		169.0	234.8	#14 relay problem
8/10/2002	85.5	111.6	97.0	176.5	118.2	159.1	
8/11/2002	103.6	135.9	120.3	135.2	122.2	161.2	
8/12/2002	109.7	148.4	114.5	163.2	161.8	260.9	
8/13/2002	108.2	144.5	118.3		142.3	214.3	#14 relay problem
8/14/2002	116.7	158.0	137.5		154.9	157.6	#14 relay problem
8/15/2002	133.6	178.6	147.9		172.2	237.6	#14 relay problem
8/16/2002	108.5	141.9	119.4		140.8	141.3	#14 relay problem
8/17/2002	107.3	138.8	110.4		136.9	130.5	#14 relay problem
8/18/2002	112.9	149.2	125.7	188.5	147.4	171.1	
8/19/2002	117.8	153.7	127.0	119.4	149.7	157.2	
8/20/2002	86.5	126.1	114.4	463.8	122.8	207.3	
8/21/2002	114.8	143.8	120.5	268.7	142.8	98.0	
8/22/2002		97.1	77.3	169.0	61.4		#4 relay problem, #16 level control problem
8/23/2002	178.9	136.7	127.9	253.5	323.3	265.2	
8/24/2002	106.5	86.0	85.8	163.8	125.6	142.5	
8/25/2002	151.7	139.5	131.8	266.8	184.5	227.5	
8/26/2002	108.7	105.1	108.2	197.9	133.9	171.9	
8/27/2002	107.0	106.8	95.8	197.9	133.1	175.0	
8/28/2002	105.1	106.8	111.6	199.8	131.9	175.7	
8/29/2002	98.6	103.7	117.9	221.2	134.1	189.6	

Table A.1 Continued

Date	Flow (gpd)						Comments
	4	7	9	14	15	16	
8/30/2002	90.6	85.6	76.3	176.3	106.2	152.9	
8/31/2002	120.6	115.7	115.7	224.8	144.0	123.9	
9/1/2002	105.5	103.9	109.2	109.7	128.1	259.3	
9/2/2002	95.5	94.6	88.1	143.5	117.0	163.6	
9/3/2002	121.5	119.8	124.6	0.0	146.2	204.7	#14 relay problem
9/4/2002	98.7	94.5	94.1	116.7	115.3	161.5	
9/5/2002	110.6	109.1	113.6	85.9	133.1	187.2	
9/6/2002	77.4	81.7	81.4	86.6	97.4	135.4	
9/7/2002	102.0	105.9	113.7	121.2	128.4	178.8	
9/8/2002	87.0	90.8	88.6	125.8	112.3	155.2	
9/9/2002	89.1	97.7	97.1	78.6	115.4	154.8	
9/10/2002	92.1	99.4	105.1	103.0	120.3	155.2	
9/11/2002	87.7	88.7	103.1	206.5	112.0	143.1	
9/12/2002	84.8	93.4	89.2	184.1	110.1	145.0	
9/13/2002	78.8	92.0	87.9	163.7	109.3	141.1	
9/14/2002	58.1	83.0	98.7	175.6	102.6	125.3	
9/15/2002	61.6	68.7	63.9	169.3	88.1	110.8	
9/16/2002	76.8	91.5	99.6	207.8	110.8	142.6	
9/17/2002	87.3	89.0	61.0		109.8	139.3	#14 relay problem
9/18/2002	95.7	101.7	113.3	237.3	119.9	151.5	
9/19/2002	83.4	95.4	95.5	211.4	110.5	134.7	
9/20/2002	87.2	97.6	90.8	214.5	111.0	142.9	
9/21/2002	76.1	81.1	78.9	166.2	93.1	117.5	
9/22/2002	88.1	98.2	88.5	194.6	108.0	141.4	
9/23/2002	94.0	104.7	103.2	212.2	118.0	154.1	
9/24/2002	100.0	113.0	108.2	224.1	123.3	160.8	
9/25/2002	82.6	96.9	86.1	183.5	103.5	134.6	
9/26/2002	94.9	107.7	103.2	205.1	115.8	152.4	
9/27/2002	76.2	85.1	72.9	158.5	91.3	117.4	
9/28/2002	100.1	114.3	102.9	204.5	120.9	159.8	
9/29/2002	81.9	100.5	89.3	167.0	101.9	129.5	
9/30/2002	89.6	102.4	93.9	172.9	107.6	173.6	
10/1/2002	84.9	103.8	97.0	168.6	107.5	91.9	
10/2/2002	82.4	95.1	87.8	153.5	99.7	113.5	
10/3/2002	74.4	90.2	80.7	135.5	93.1	119.5	
10/4/2002	72.2	83.1	80.7	131.7	86.4	113.3	
10/5/2002	95.0	110.9	101.9	169.7	117.8	150.6	
10/6/2002	84.0	95.9	90.1	149.1	105.4	131.1	
10/7/2002	71.0	81.4	68.6	127.6	89.3	114.3	
10/8/2002	63.9	84.5	79.2	131.6	94.1	115.3	
10/9/2002	67.7	82.6	77.0	131.1	91.9	119.6	
10/10/2002	76.8	89.0	82.0	133.6	96.2	122.7	
10/11/2002	68.5	85.4	76.5	133.9	98.2	121.4	
10/12/2002	74.5	84.9	76.3	127.7	93.9	118.3	
10/13/2002	101.7	123.8	117.8	186.1	136.6	173.3	
10/14/2002	55.8	67.0	52.3	101.4	74.9	95.1	
10/15/2002	79.5	93.4	88.4	140.5	104.5	133.4	
10/16/2002	83.5	93.9	85.6	143.4	44.0	135.4	
10/17/2002	70.2	82.6	76.2	121.8	0.0	114.9	

Table A.1 Continued

Date	Flow (gpd)						Comments
	4	7	9	14	15	16	
10/18/2002	55.1	71.4	67.6	100.1	5.5	92.4	
10/19/2002	76.1	85.0	73.4	129.5	66.6	124.1	
10/20/2002	69.4	83.2	76.2	121.4	69.1	118.4	
10/21/2002	75.5	88.6	77.7	129.6	76.9	127.9	
10/22/2002	61.8	76.7	81.1	109.7	62.2	109.3	
10/23/2002							Septic tank problems
10/24/2002							Septic tank problems
10/25/2002							Septic tank problems
10/26/2002	62.5	87.6	168.8	139.3	71.1	123.3	
10/27/2002	50.4	64.8	36.3	99.4	58.4	108.1	
10/28/2002	24.1	49.2	0.0	67.3	42.0	67.0	#14 relay problem
10/29/2002	42.5	54.1	0.0	89.6	47.5	99.9	#14 relay problem
10/30/2002	87.1	116.8	140.4	141.2	107.1	152.2	
10/31/2002	26.6	36.1	40.7	46.0	30.4	46.4	
11/1/2002	49.1	91.1	88.2	108.4	71.5	110.5	
11/2/2002	58.4	95.4	86.2	118.0	74.1	121.6	
11/3/2002	65.2	96.9	84.9	125.7	77.3	127.3	
11/4/2002	53.6	87.4	85.4	103.9	66.7	104.0	
11/5/2002	66.6	103.8	103.7	136.2	81.2	40.7	
11/6/2002	57.2	83.3	89.5	111.0	67.7	216.3	
11/7/2002	84.8	113.7	117.7	154.8	95.5	161.7	
11/8/2002	65.4	91.0	90.6	120.0	73.4	123.2	
11/9/2002	73.9	95.6	96.3	131.6	81.8	131.2	
11/10/2002	67.2	84.5	87.6	116.6	71.1	114.2	
11/11/2002	70.3	90.9	93.3	123.0	74.6	118.2	
11/12/2002	81.2	103.2	106.6	138.6	85.1	131.2	
11/13/2002	59.9	77.4	85.6	108.5	64.2	98.5	
11/14/2002	81.9	102.2	103.6	139.1	82.2	126.0	
11/15/2002	37.6	86.4	90.1	110.0	66.1	97.1	
11/16/2002	79.3	93.0	97.3	118.6	66.5	105.2	
11/17/2002	63.9	84.9	85.1	112.0	62.7	100.4	
11/18/2002	64.2	83.9	85.3	113.5	64.4	100.8	
11/19/2002	81.0	102.4	113.6	138.6	77.9	120.3	
11/20/2002	65.9	86.8	88.2	115.1	65.1	100.6	
11/21/2002	74.7	94.6	99.7	126.1	72.3	109.9	
11/22/2002	63.7	80.8	77.8	108.8	64.4	100.7	
11/23/2002	66.7	84.2	95.0	111.3	65.2	107.7	
11/24/2002	73.2	88.9	86.9	122.5	70.8	119.5	
11/25/2002	64.6	82.7	81.0	104.7	61.1	101.3	
11/26/2002	71.3	89.2	92.4	118.7	68.3	115.8	
11/27/2002	68.5	85.5	89.9	112.2	65.4	110.4	
11/28/2002	72.6	90.0	96.5	121.0	69.0	121.5	
11/29/2002	64.9	77.4	84.2	104.7	60.8	102.0	
11/30/2002	70.3	81.9	86.0	112.1	64.9	111.4	
12/1/2002	64.3	80.0	83.7	106.3	63.0	105.8	
12/2/2002	76.1	87.1	95.9	118.2	70.0	126.6	
12/3/2002	33.6	59.7	76.7	68.3	45.0	65.2	
12/4/2002	56.6	68.8	77.2	98.1	49.7	88.9	
12/5/2002	70.9	81.4	90.6	109.4	61.0	96.9	

Table A.1 Continued

	Flow (gpd)						
Date	4	7	9	14	15	16	Comments
12/6/2002	65.6	88.8	93.0	116.0	67.1	109.2	
12/7/2002	66.6	89.3	88.3	116.4	68.8	113.7	
12/8/2002	62.9	92.7	99.2	119.8	70.0	107.3	
12/9/2002	116.9	151.9	166.4	198.4	117.3	182.9	
12/10/2002	64.8	87.6	93.7	114.4	68.3	98.8	
12/11/2002	20.0	29.7	27.6	34.8	21.2	39.6	Heavy rain
12/12/2002	73.7	101.3	105.3	125.8	74.8	126.2	
12/13/2002	62.4	84.6	56.8	106.1	63.4	101.1	
12/14/2002	69.8	94.4	85.3	117.8	70.6	112.5	
12/15/2002	70.9	77.0	114.7	78.2	82.0	134.4	
12/16/2002	61.0	95.5	20.0	140.7	51.6	76.3	
12/17/2002	62.1	79.3	72.1	102.6	63.4	114.0	
12/18/2002	69.8	85.0	85.2	114.7	70.6	117.3	
12/19/2002	80.8	99.8	104.0	129.5	81.3	126.2	
12/20/2002	54.3	68.5	59.6	84.2	53.1	90.3	
12/21/2002	73.6	89.1	81.8	113.3	72.2	123.1	
12/22/2002	94.1	111.8	108.2	143.6	90.5	146.0	
12/23/2002	56.5	78.1	79.9	86.2	59.3	90.1	
12/24/2002	79.5	98.6	88.4	117.0	75.3	120.0	
12/25/2002	53.4	64.1	60.9	77.2	50.3	79.5	
12/26/2002	89.7	106.6	108.8	130.5	84.4	125.8	
12/27/2002	73.9	89.1	89.8	106.6	68.6	116.0	
12/28/2002	74.8	90.5	82.0	107.0	68.6	104.1	
12/29/2002	74.4	91.7	94.6	107.9	69.5	112.0	
12/30/2002	75.1	97.6	86.2	107.8	68.7	119.0	
12/31/2002	79.4	92.7	88.1	111.0	72.2	114.9	
1/1/2003	78.6	88.0	87.8	106.2	68.5	109.7	
1/2/2003	75.7	80.2	79.2	96.0	63.0	91.9	
1/3/2003	93.2	100.5	93.9	119.2	72.7	118.5	
1/4/2003	94.6	97.2	95.7	116.0	71.8	113.7	
1/5/2003	70.7	67.5	65.0	90.3	54.4	96.5	
1/6/2003	104.0	102.3	95.1	123.1	78.1	109.3	
1/7/2003	104.4	103.2	97.6	125.6	79.7	130.3	
1/8/2003	76.6	80.6	72.7	92.6	59.0	82.8	
1/9/2003	111.5	105.6	108.3	134.1	86.1	122.5	
1/10/2003	86.6	90.4	76.6	104.9	68.7	95.6	
1/11/2003	114.8	116.7	107.0	139.2	89.8	132.2	
1/12/2003	86.3	86.8	75.9	103.4	67.8	108.9	
1/13/2003	108.4	117.1	100.5	130.7	86.1	119.4	
1/14/2003	90.3	88.3	76.4	105.0	69.3	97.2	
1/15/2003	108.0	112.7	102.4	134.0	90.2	127.8	
1/16/2003	95.6	101.9	83.5	121.5	82.5	118.8	
1/17/2003	93.4	97.8	88.0	115.3	81.8	102.9	
1/18/2003	79.0	89.2	106.9	120.2	70.9	102.1	
1/19/2003	106.8	109.2	70.1	112.2	92.0	120.3	
1/20/2003	96.9	105.6	89.8	123.8	87.0	105.5	
1/21/2003	102.7	108.6	98.4	133.7	92.0	134.6	
1/22/2003	80.8	90.6	77.8	106.3	74.7	86.5	
1/23/2003	115.2	122.9	109.3	145.3	104.8	135.1	

Table A.1 Continued

	Flow (gpd)						
Date	4	7	9	14	15	16	Comments
1/24/2003	87.3	92.6	86.4	111.2	81.6	99.4	
1/25/2003	109.3	111.8	96.2	134.9	100.1	127.1	
1/26/2003	100.9	107.6	96.5	127.2	91.3	116.4	
1/27/2003	99.6	103.6	86.0	125.7	90.9	110.6	
1/28/2003	99.3	103.2	90.1	126.4	92.0	124.6	
1/29/2003	101.7	108.0	97.6	129.0	93.3	114.8	
1/30/2003	99.6	103.8	94.0	125.0	91.9	109.6	
1/31/2003	86.4	90.6	72.5	111.0	79.8	101.4	
2/1/2003	121.7	129.4	109.6	156.4	115.1	137.1	
2/2/2003	98.4	106.1	97.0	126.4	91.8	117.9	
2/3/2003	108.7	115.9	105.2	140.1	103.4	124.2	
2/4/2003	100.0	108.2	97.8	128.8	97.6	98.5	
2/5/2003	108.7	120.2	104.4	135.4	103.7		#16 flow control problem
2/6/2003	96.8	108.7	93.8	122.6	93.4		#16 flow control problem
2/7/2003	99.7	113.1	96.8	127.4	97.5		#16 flow control problem
2/8/2003	117.4	129.5	52.9	146.4	112.2		#16 flow control problem
2/9/2003	108.8	115.0	161.1	131.7	100.4		#16 flow control problem
2/10/2003	113.1	121.6	105.9	143.5	107.7		#16 flow control problem
2/11/2003	80.7	93.0	76.4	101.3	77.6		#16 flow control problem
2/12/2003	111.6	127.6	99.3	139.5	106.8		#16 flow control problem
2/13/2003	119.4	139.6	113.6	149.5	115.8		#16 flow control problem
2/14/2003	80.5	91.2	76.8	102.8	77.1		#16 flow control problem
2/15/2003	120.7	139.4	112.2	157.3	116.7	146.2	
2/16/2003	111.9	134.0	105.4	148.3	113.2	157.1	
2/17/2003	111.8	133.9	105.5	148.3	113.2	157.1	
2/18/2003	106.8	127.5	102.5	144.0	110.6	154.0	
2/19/2003	120.4	143.5		162.0	125.4	166.1	#9 water level lead problem
2/20/2003	110.2	132.6		144.5	115.9	161.1	#9 water level lead problem
2/21/2003	46.4	57.6		60.4	48.7	68.6	#9 water level lead problem
2/22/2003	91.6	115.1	55.6	88.6	73.5	130.1	
2/23/2003	77.3	95.3	89.4	124.1	86.8	110.7	
2/24/2003	113.0	152.1	112.3	149.1	117.6	180.5	
2/25/2003	79.6	99.8	288.8	101.3	78.6	110.3	
2/26/2003	110.3	149.3	150.8	150.8	117.2	172.9	
2/27/2003	23.7	28.3		26.4	20.7	24.3	#9 water level lead problem
2/28/2003	128.2	176.5	142.6	179.7	136.9	190.1	
3/1/2003	102.3	130.0	285.7	135.7	106.7	148.6	
3/2/2003	34.4	52.7		50.9	38.5	76.2	#9 water level lead problem
3/3/2003	58.9	74.4	8.2	0.9	52.9	78.6	
3/4/2003	73.7	109.8	72.5	134.8	95.2	158.6	
3/5/2003	114.2	170.4	132.2	163.9	130.1	230.6	
3/6/2003	81.9	118.8	97.8	113.7	87.9	167.4	
3/7/2003	92.1	126.0		122.3	94.3	174.1	#9 water level lead problem
3/8/2003	92.6	142.7	135.4	136.0	107.6	198.7	
3/9/2003							Bad data all fields
3/10/2003	65.4	104.7	33.6	52.1	36.3	113.0	
3/11/2003	110.7	155.9	86.5	148.5	95.5	191.2	
3/12/2003	136.5	181.2	130.3	165.9	143.7	255.0	
3/13/2003	46.1	76.7	54.3	62.7	63.7	97.4	

Table A.1 Continued

Date	Flow (gpd)						Comments
	4	7	9	14	15	16	
3/14/2003	110.4	164.1	69.7	94.8	81.2	174.9	
3/15/2003	122.5	178.5	132.1	164.2	141.2	226.1	
3/16/2003	77.1	231.1	89.3	113.9	112.5	174.6	
3/17/2003	145.0	505.5	139.5	147.3	116.0	216.5	
3/18/2003	99.3	69.4	135.4	167.9	110.1	206.6	
3/19/2003	35.6	260.9	58.8	78.1	82.2	119.1	
3/20/2003	178.1	218.4	111.0	114.4	139.3	207.4	
3/21/2003	113.8	190.2	116.8	141.4	127.5	209.8	
3/22/2003	107.7	191.1	120.2	136.1	121.3	195.1	
3/23/2003	20.8	35.8	19.6	26.0	22.8	35.0	Problems in control building, no flow
3/24/2003	82.6	121.7	35.1	79.6	74.6	132.6	
3/25/2003	45.6	90.4	21.9	41.4	58.6	88.3	
3/26/2003	133.6	210.0	97.7	162.7	158.3	234.2	
3/27/2003	129.2	191.0	113.3	154.1	144.4	225.9	
3/28/2003	124.9	179.4	126.0	149.5	136.1	204.1	
3/29/2003							Problems in control building, no flow
3/30/2003							Problems in control building, no flow
3/31/2003							Problems in control building, no flow
4/1/2003							Problems in control building, no flow
4/2/2003	178.9	130.9	122.7	26.7	165.1	114.6	
4/3/2003	11.7	156.8	18.5	232.3	42.7	135.3	
4/4/2003	91.7	146.4	81.4	151.5	119.0	165.6	
4/5/2003	57.0	78.0	59.8	78.2	62.0	86.3	
4/6/2003	49.8	56.2	7.7	1.0	30.8	58.0	
4/7/2003	82.5	135.2	70.3	141.4	109.0	143.5	
4/8/2003	102.0	143.2	100.3	144.2	116.4	171.5	
4/9/2003	59.9	88.0		86.5	70.0	94.4	#9 water level lead problem
4/10/2003	105.4	150.5	109.6	163.8	116.4	165.1	
4/11/2003	98.7	113.5	90.0	137.0	119.6	136.5	
4/12/2003	88.4	148.5	107.6	129.5	91.2	150.3	
4/13/2003	92.1	131.5	98.4	142.5	112.1	139.6	
4/14/2003	97.0	125.3	99.6	143.2	112.6	146.5	
4/15/2003	32.3	43.3	30.9	47.1	38.2	44.8	
4/16/2003	32.3	43.3	30.8	47.1	38.2	44.8	
4/17/2003	143.0	211.5	104.6	179.0	130.5	211.4	
4/18/2003	53.9	69.4	25.9	81.7	55.6	86.9	
4/19/2003	102.8	120.1	146.7	197.0	140.0	188.7	
4/20/2003	142.2	180.0	70.0	132.5	133.2	154.7	
4/21/2003	115.8	142.3	106.1	148.9	129.1	158.2	
4/22/2003	103.8	124.8	95.3	136.5	116.0	139.1	
4/23/2003	101.5	128.6	92.4	135.3	114.0	148.7	
4/24/2003	119.9	148.3	106.2	160.7	136.5	170.6	
4/25/2003	111.9	139.4	101.7	151.0	127.3	158.5	
4/26/2003	106.1	143.0	96.0	120.4	138.1	149.7	
4/27/2003	100.9	117.5	95.8	158.8	96.2	150.8	
4/28/2003	89.1	136.6	104.2	152.6	176.5	108.3	
4/29/2003	12.8	24.0		25.6		0.0	#9 water level lead problem
4/30/2003	61.5	163.4	110.8	154.0	140.4	233.4	
5/1/2003	108.4	141.5	119.4	140.6	128.8	165.1	

Table A.1 Continued

	Flow (gpd)						
Date	4	7	9	14	15	16	Comments
5/2/2003	106.3	134.9	116.8	127.4	118.6	151.1	
5/3/2003	57.4	68.3		65.9	61.8	76.7	
5/4/2003	136.0	169.3	157.0	158.1	144.0	179.8	
5/5/2003	85.6	110.2	114.5	118.0	98.3	111.0	
5/6/2003	11.7	15.9		18.2	14.1	0.0	#9 water level lead problem
5/7/2003	114.4	168.0	125.4	189.7	122.8	213.2	
5/8/2003	77.5	96.3		103.7	84.4	110.7	
5/9/2003	89.0	115.7	105.1	116.0	97.8	131.5	
5/10/2003	89.6	115.3		124.8	101.6	130.3	#9 water level lead problem
5/11/2003	93.4	124.4	110.1	124.4	108.7	137.4	
5/12/2003	81.2	101.6		94.8	91.5	117.3	
5/13/2003	71.7	94.5		94.0	84.9	97.1	#9 water level lead problem
5/14/2003	59.5	73.2	58.6	67.8	58.7	91.0	
5/15/2003	63.6	90.6		79.0		112.4	#9 water level lead problem, #15 failed
5/16/2003	88.7	117.9	64.8	114.0		151.5	
5/17/2003	99.3	125.2	127.1	126.4		151.2	
5/18/2003	51.4	77.7		76.8		68.3	#9 water level lead problem
5/19/2003	61.7	67.2		68.4		107.4	
5/20/2003	84.2	116.0	201.8	105.1		118.4	
5/21/2003	101.4	122.2	0.0	118.8		146.3	
5/22/2003	108.2	178.0		143.2		213.4	#9 water level lead problem
5/23/2003	61.6	39.6	110.1	66.6		47.1	
5/24/2003	98.3	123.9	127.7	121.1		137.2	
5/25/2003	74.7	108.6		98.3		102.7	#9 water level lead problem
5/26/2003	71.1	104.3	87.0	94.0		84.3	
5/27/2003	71.1	104.3	87.0	94.0		84.4	
5/28/2003	85.0	117.9	98.6	109.6		140.3	
5/29/2003	92.4	128.3	106.4	117.5		93.7	
5/30/2003	88.2	120.9		110.0		116.0	#9 water level lead problem
5/31/2003	81.6	108.4	67.6	97.3		116.1	
6/1/2003	77.6	110.2	91.4	93.5		112.6	
6/2/2003	74.1	96.2	78.5	90.0		96.9	
6/3/2003	83.2	110.9		101.0		114.6	#9 water level lead problem
6/4/2003	87.1	114.7	106.3	103.4		112.4	
6/5/2003	67.3	99.5		83.5		103.6	#9 water level lead problem
6/6/2003	67.3	109.3	94.4	88.8		120.5	
6/7/2003	77.1	109.0	95.0	102.4		129.0	
6/8/2003	72.5	114.1	91.2	94.4		79.4	
6/9/2003	73.9	112.4	90.4	94.6		141.7	
6/10/2003	67.9	115.5	86.6	94.0		75.7	
6/11/2003	77.5	119.9		103.3		104.2	#9 water level lead problem
6/12/2003	69.9	106.4	123.7	91.3		149.2	
6/13/2003	77.5	117.6	99.3	102.5		40.5	
6/14/2003	70.2	115.4	93.8	95.1		132.3	
6/15/2003	70.2	115.4	93.8	95.1		132.3	
6/16/2003	74.0	116.2	94.3	99.4		136.4	
6/17/2003	71.1	106.2	86.0	95.2		82.0	
6/18/2003	71.2	110.4	88.1	94.5		124.2	
6/19/2003	56.1	111.1	81.7	76.0		85.5	

Table A.1 Continued

Date	Flow (gpd)						Comments
	4	7	9	14	15	16	
6/20/2003	75.7	135.0	99.7	104.6		100.2	
6/21/2003	68.0	108.8	83.9	95.1		114.6	
6/22/2003	64.5	103.9	80.0	94.4		129.6	
6/23/2003	64.5	103.9	80.0	94.4		129.6	
6/24/2003	84.9	133.6	103.9	130.1		89.6	
6/25/2003	32.2	52.3		65.6		110.1	#9 water level lead problem
6/26/2003							Bad data all fields
6/27/2003	17.4	28.0	15.5			23.5	#14 flow problem
6/28/2003	29.9	39.7	1.8	6.2		45.0	
6/29/2003	19.1	44.4	11.1	8.1		62.8	
6/30/2003	18.0	0.0	9.2	0.1		2.0	
7/1/2003	26.4	29.2	0.3	0.1		33.1	
7/2/2003	31.8	43.6	31.8	215.1		54.6	
7/3/2003	31.8	43.5	31.8	215.0		54.6	
7/4/2003	69.8	117.9	91.3	80.4		97.9	
7/5/2003	75.5	125.9	100.9	36.5		121.7	
7/6/2003	53.6	89.8	71.1			92.3	#14 flow problem
7/7/2003	43.5	71.6	53.7			71.0	#14 flow problem
7/8/2003	43.4	71.6	53.7			71.0	#14 flow problem