WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

VADOSE ZONE MONITORING AT TREE TOP LAND APPLICATION SITE IN SELAH, WASHINGTON, JUNE-DECEMBER 1992

August 1994

Water Body No. WA-39-1010 GW
Publication No. 94-148
printed on recycled paper

For additional copies of this publication, please contact:

Department of Ecology
Publications Distributions Office
at P.O. Box 47600
Olympia, Washington 98504-7600
(206) 407-7472
Refer to Publication Number 94-148

WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Vadose Zone Monitoring at Tree Top Land Application Site in Selah, Washington, June-December 1992

by

Barbara M. Carey and
Joseph A. Jacobson

Environmental Investigations and Laboratory Services Program
Olympia, Washington 98504-7710

August 1994

Water Body No. WA-39-1010 GW
Publication No. 94-148
printed on recycled paper

Table of Contents

Table of Contents (Continued)

Appendices

List of Figures

List of Tables

Acknowledgements

We would like to recognize several people who provided inspiration, ideas, and brute strength in completing this study. Bernard Strong helped design and build the lysimeters as well as, install field equipment. Denis Erickson lead the installation effort and provided thoughtful ideas and feedback on the study design and report.

Bob Raforth of Ecology's Central Regional Office provided the basic design for the barrel lysimeter as well as crucial assistance in purging samplers prior to sampling. Bob also helped install lysimeters. Merl Frost and Jeff Davis of Tree Top assisted in choosing and securing sampling sites. They also provided information on the day-to-day operations needed to conduct the study.

Ed Brincken and Allen Zulauf of the U.S. Soil Conservation Service conducted the soils study and arranged for sample analysis by the SCS Soils Laboratory in Lincoln, Nebraska.

The Ecology Manchester Laboratory helped us get as much information as possible from the small sample volumes available. Pam Marti and Jon Bennett also assisted in collecting field samples. Art Larson, Denis Erickson and Bob Raforth provided helpful reviews.

We are grateful for the efforts of all these people.

Abstract

Vadose zone sampling equipment was installed and sampled at two locations on the Tree Top land application site near Selah, Washington. Fruit processing wash water is applied at the site to irrigate pasture grass grazed by cattle. The purpose of the study was to evaluate wastewater treatment in the unsaturated zone and to test two devices for sampling soil pore water. Hollow glass bricks and barrel lysimeters were used to obtain water quality samples and to estimate water movement. Tensiometers tracked the movement of irrigation-induced wetting fronts. Chemical oxygen demand (COD), total nitrogen (total N), chloride, dissolved iron, conductivity, and total dissolved solids were sampled five times between June 26, 1992, and December 7, 1992.

Vadose zone monitoring showed that COD and total N were treated in the top 18 inches. The mean COD treatment was 85% (S.D.=3.8); that for total nitrogen 92% (S.D.=6.8).

Biological oxygen demand (BOD_5) was estimated from COD concentrations. Estimated BOD_5 application rates were two-four times the monthly permit limits. Nitrogen application rates were two-five times higher than monthly permit limits.

Barrel samplers worked better than brick samplers in the gravelly, sandy soils. Both samplers were difficult to install. However, all four barrels worked well, while only two of the twelve glass bricks yielded samples.

COD concentrations in monitoring wells adjacent to lysimeters were less than half those in the lysimeters indicating dilution by ground water. Elevated chloride concentrations in some of the lysimeters and monitoring wells compared to the effluent indicate possible leaching of chloride previously accumulated in the soil.

Summary

General conclusions of the study are:

1. Vadose zone monitoring is a more sensitive measure of nutrient loading to ground water than ground water monitoring based on differences in concentrations between lysimeters and adjacent shallow monitoring wells.

2. Vadose zone studies are difficult in areas with large concentrations of gravel and cobbles.

Conclusions specific to the Tree Top site are:

Soil Water Movement

- Soil water moves slowly through the topsoil layer and about 100 times faster in the subsoil. It takes 5-16 days for water applied at the surface to reach ground water during the summer.

- Tensiometer data collected at frequent intervals near lysimeters are useful for estimating time-of-travel. Time-of-travel information is likewise useful for scheduling lysimeter sample collection to coincide with the arrival of a wetting front.

Estimated Application Rate

- Estimated application rates prior to July, August, and October sampling events were:

BOD_5:	45-100 lb/acre/day
COD:	230-530 lb/acre/day
Total N:	9-30 lb/acre/day
Water:	6.8-9.5 inches/day

- The estimated BOD_5 application rate was two-four times the monthly permit limits. The total N rate was two-five times higher than monthly permit limits. The highest loading was in October; the lowest in August.

- A potential for nitrogen overapplication exists if fertilizer amendments do not take into account nitrogen from effluent application.

- The permit limit of 17 hours maximum per sprinkler set was exceeded prior to each sampling event.

Treatment

- Mean treatment values for COD and total N based on results from the barrels were:

  COD and BOD_5: 85%, S.D.= 3.8
  Total N: 92%, S.D.= 6.8

- BOD_5 treatment was 10-15% lower than found in similar studies.

- Total N treatment was about 15% higher than found in similar studies.

- Higher COD and total N treatment at Site 2 than Site 1 are probably due to higher application rates at Site 1 immediately prior to sampling.

- COD treatment estimates from the brick results were similar to those from the barrels, although few data were available for the bricks.

Water Quality

- COD concentrations in monitoring wells (mean=12 mg/L) were 62% lower than those in the barrel lysimeters (mean=32 mg/L).

- The average estimated BOD_5 concentration in the barrels, 6.4 mg/L, was three times higher than that typically found at land application sites.

- Nitrate+nitrite values were below the criterion for ground water in the barrels and monitoring wells on all dates. In the bricks, however, nitrate+nitrite values exceeded the criterion by 1.7-2.6 times on one occasion. (In this case, the criterion is not applicable above the water table.)

  Higher nitrate+nitrite levels in the bricks may have resulted from recent sampler installation combined with higher than normal nitrogen application prior to sampling.

- Chloride concentrations in the barrels and bricks were up to four times greater than in the applied water. This may be due to leaching of chloride accumulated prior to land application. If so, concentrations in the lysimeters and monitoring wells should eventually decrease as the accumulated chloride is depleted.

Comparison of Lysimeters

- Barrel lysimeters worked better than brick lysimeters at the Tree Top site for these reasons:
  - Barrels were more reliable,
  - Barrels were easier to install, and
  - More water was collected in the barrels than in the bricks,
- Both barrel and brick samplers were difficult to install in the gravelly, cobbly soils
- Total costs for the two samplers are comparable.

Recommendations

General recommendations are:

1. Consider including vadose zone monitoring in land application permits. Advantages include:
   - Vadose monitoring can help detect potential problems before they are evident in ground water; and
   - Vadose zone monitoring information can be used to evaluate and modify treatment operations to improve effectiveness.
2. Improvements for similar future studies:
   - Measure quantity and quality of applied water at sampling sites;
   - Compare smaller diameter barrel samplers, *i.e.*, less than 16-inch diameter;
   - Allow barrel samplers to settle after installation and before sampling;
   - Glass brick samplers should not be used where a large percentage of the soil is gravel or cobbles;
   - To improve the effectiveness of the glass brick lysimeter in capturing percolating water, a rim should be attached around the perimeter of the top surface (Barbee and Brown, 1986); and

- Using existing hydrogeologic data and loading rates of COD passing through the vadose zone, estimate changes in down-gradient COD concentrations in ground water.

Recommendations specific to Tree Top vadose zone monitoring are:

1. Add COD and Total Kjeldahl-N to parameters required for compliance monitoring of effluent and monitoring wells in order to estimate application and treatment rates.

2. COD treatment could be improved by applying clean irrigation water at least two days after effluent applications rather than immediately following.

Introduction

Treated wastewater is applied to land at many locations in Washington for further treatment and to irrigate crops. Also referred to as "spray irrigation," this technique uses uptake by vegetation and natural soil processes to treat the waste. Land application replaces discharge of effluent to streams and rivers. This technique is becoming increasingly popular for three reasons:

1) It alleviates a source of surface water quality degradation by not discharging to surface water,

2) Irrigation water is becoming more difficult to acquire, and

3) Further treatment of many constituents can occur in the soil.

In some parts of the state, wastewater applications are substantial. Of 65 facilities with permits for land application, 15 are allowed to discharge up to one million gallons per day. The associated nutrient or chemical loading may exceed the soil's capacity to treat the waste resulting in contamination of underlying ground water.

Self-monitoring is used at permitted land application sites to determine whether treatment and uptake of wastes in the soil adequately protects ground water. Self-monitoring usually includes ground water sampling downgradient, and sometimes upgradient, of the land application site. However, such monitoring cannot provide an early warning of ground water degradation, because percolating water mixes with ambient ground water and becomes diluted before reaching the wells. In addition, by the time degradation is detected in ground water, the effects are often widespread and difficult to remedy if at all possible.

Vadose zone sampling (sampling of water in the unsaturated soil pores above the water table) is conducted at a few permitted land application sites to observe the concentration of selected chemicals after treatment in the soil and before mixing with ground water. However, the reliability and representativeness of such sampling is under debate.

Purpose

Ecology's Water Quality Program requested that the EILS Program conduct a vadose zone field study at a site similar to others in the state where treatment was expected to be good. In this way two variables of interest could be tested:

1) Effectiveness of lysimeter devices for monitoring land application sites. (A **lysimeter** extracts water from soil pores above the water table.)

2) Effectiveness of land application for treating wastewater in a common environmental setting.

We chose the Tree Top site in Selah for the first study after it was nominated by Ecology's Central Regional Office. Wash water from fruit processing, a major waste type in central Washington, is treated at the site. In addition, the site's environmental setting is similar to many land application sites in the area. The sprayfield is located near the Yakima River and has alluvial soils underlain by a shallow water table. The Selah site is also important because the projected irrigation rate is substantial; close to one million gallons per day applied to 360 acres.

Scope

This report describes the soil water study at the Tree Top land application site in Selah, Washington, conducted from June through December 1992. The study addresses the following objectives:

1) Install and evaluate the effectiveness of two gravity lysimeter designs for water quality sampling and flow rate estimates;

2) Characterize soil pore water quality at two locations, especially in terms of chemical oxygen demand (COD) and biological oxygen demand (BOD_5);

3) Estimate the treatment of COD and estimated BOD_5 and total nitrogen in the vadose zone during the growing and non-growing season;

4) Estimate the rate of liquid movement through the vadose zone, and

5) Make recommendations for the Tree Top site and for similar land application monitoring efforts.

Limitations

Estimates of reduction for COD and BOD_5 do not take into account waste loading from cattle that graze on the site. We assume that electrical fencing around the sampling devices prevented any new loading. Effects of residual organic material deposited before our study are not addressed. Seasonal effects of snowmelt and land application in spring are also not assessed.

The site was first used for land application in the fall of 1991, and 1992 was the first full year of operation. This study does not address possible cumulative effects over time.

Site Description

The Tree Top land application site is located near Selah, Washington, about five miles north of Yakima on the west bank of the Yakima River as shown in Figure 1.

Historically the site has been grazed by cattle and irrigated with Yakima River water via Taylor Ditch. Since the autumn of 1991, treated effluent from the Selah fruit packaging plant has been mixed with Taylor Ditch irrigation water and applied to the 360-acre site as shown in Figure 2. Before mixing with irrigation water, wastewater is treated in nearby aerated lagoons.

Hydrogeology and Soils

The sprayfield is underlain by a water-table aquifer composed of alluvial deposits and glacial outwash from the Pleistocene Epoch (Pearson, 1985). The unconsolidated deposits consisting of silt, sand and gravel, range up to several hundred feet thick (Bentley and Campbell, 1983). The aquifer supplies a substantial amount of water to the Yakima River, especially just upstream of Selah Gap and downstream of the sprayfield (Pearson, 1985). The estimated depths of fourteen active domestic wells in the area range from about 28 to 140 feet.

During 1992, the depth to water in the sprayfield ranged from about two to ten feet below ground surface according to facility monitoring data. Irrigation causes higher water levels during the summer than in winter. The direction of ground water flow on the site is generally toward the southeast (Yakima River) and to the southwest (Town of Selah) (Sweet Edwards/EMCON, 1990).

According to the Soil Conservation Service soils map for Yakima County (SCS, 1985), the three main soil types on the site which are shown in Figure 2 are:

1) Weirman sandy loam (channeled) on the northeast portion of the site where the river bends. This soil is somewhat excessively drained with gravelly sand from about 21 to 60 inches depth.

2) Weirman fine sandy loam (wet) in the western and southern parts of the site. This is underlain by gravelly sand.

3) Weirman fine sandy loam in the northern tip of the site.

All three soils have rapid permeability and low available water capacity. Gravel and cobbles are widespread.

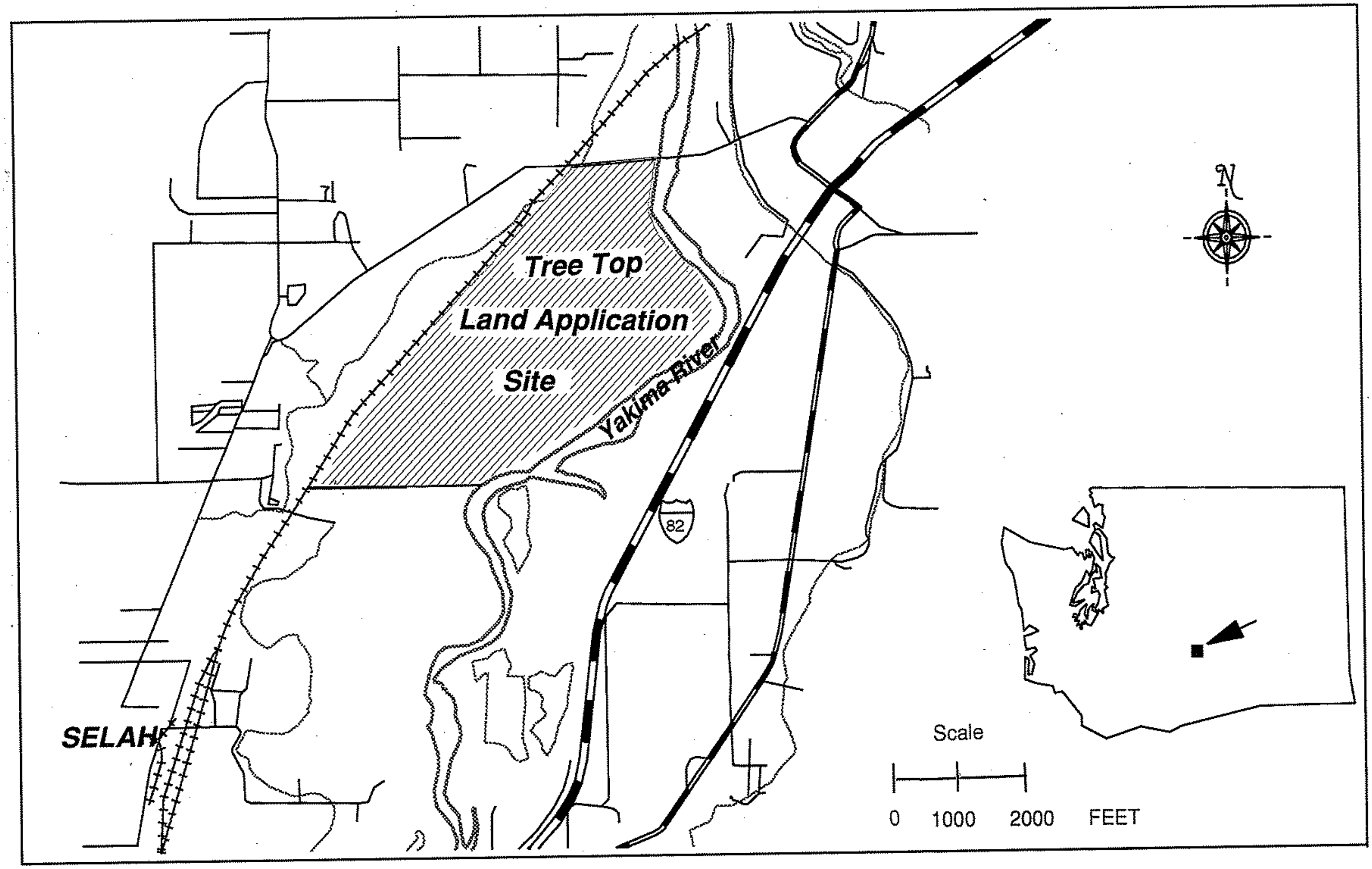


Figure 1. Tree Top Land Application Study Site near Selah, Washington.

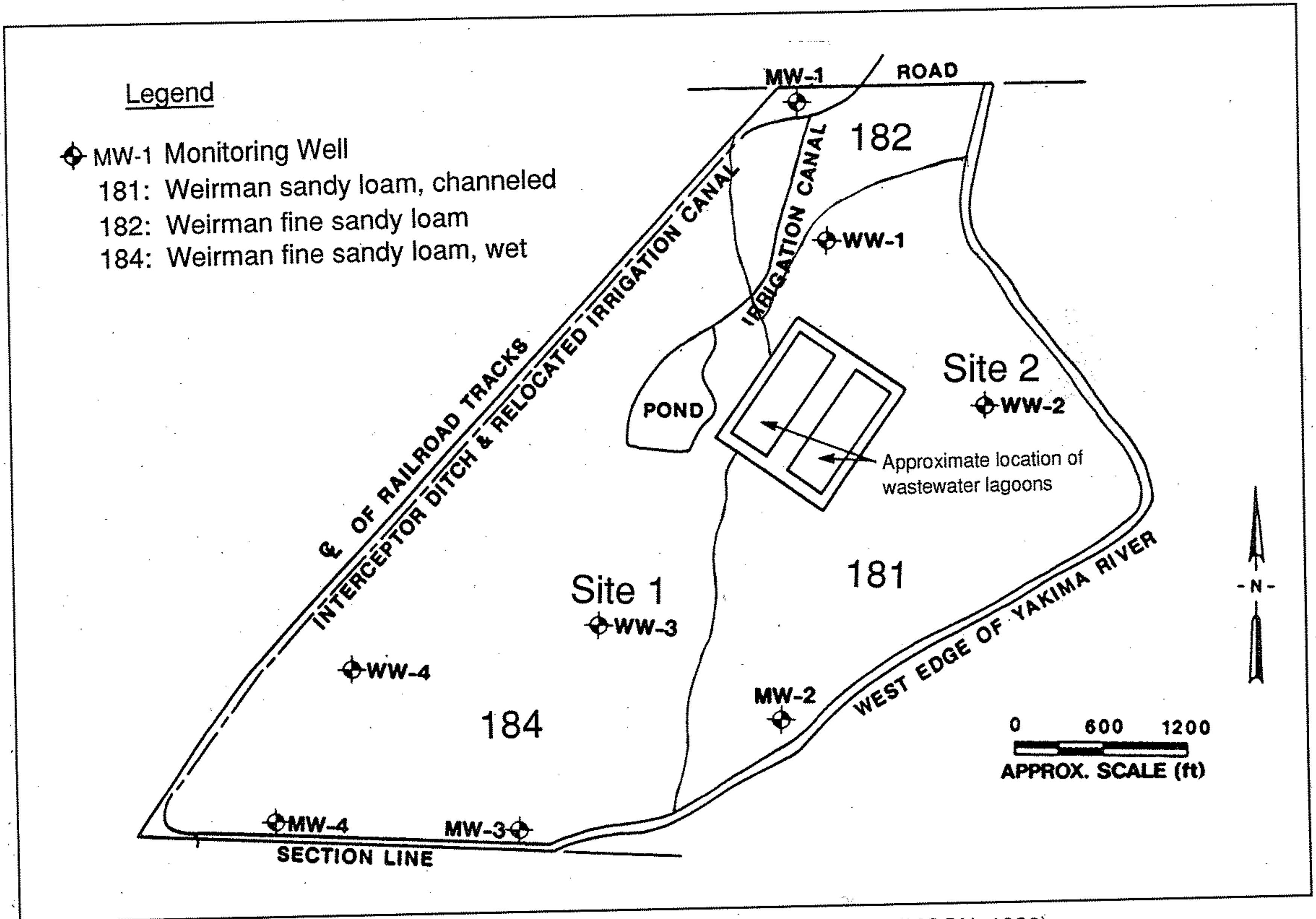


Figure 2. Tree Top soil types and monitoring well locations (from SCS, 1985 and SE/EMCON, 1990).

The predominant sand and gravel of the Weirman sandy loam is mixed with 6-10% clay and 17-22% silt in the top 14 inches according to soil samples collected at Site 1 (Appendix A, Brincken and Zulauf, 1992). However, below an abrupt boundary at 10-16 inches, sand and gravel comprise 70% of the soil. Organic carbon is highest in the top 5 inches (1.34%) decreasing to less than 0.5% below 5 inches. The soils are somewhat excessively drained with slopes of 0-2%.

Soil properties vary over the site based on results from 28 test pits (Sweet Edwards/ EMCON, 1990). However, most test pits had a shallow topsoil layer, above a gravelly, cobbly sand layer similar to that found at Site 1.

Land Application System

Effluent and non-effluent irrigation water are applied to the site through a system of buried pipelines with small diameter vertical risers every 150 feet. Effluent is mixed with non-effluent irrigation water before it is applied. Sprinklers are manually fitted and removed between the risers (Frost, 1993). Daily irrigation is limited to a 20-acre area. Sprinklers are rotated between areas so that each receives a mixture of effluent and non-effluent irrigation water at roughly 18-20-day intervals.

Tree Top (1990) estimates that the average application rate is about 0.34 inch/hour. Average irrigation is 67 inches/year, 27% of which is effluent. The ratio of effluent to clean irrigation water was 1:1 during each sampling event. In July and August non-effluent irrigation water was applied for several hours following the mixed effluent application at each site.

Methods

We sampled soil pore water with two types of devices: glass brick lysimeters and barrel lysimeters. Both samplers rely on gravity to collect water. In addition, we used tensiometers at two depths to observe moisture movement. We chose two sampling sites for their proximity to a monitoring well and for differences in soils. Procedures used to construct and install sampling devices are described in Appendix B.

Water Quality Sampling

One to two days after installing the sampling equipment we collected the first samples. We also sampled once in July, August, October and December, 1992. Three to four days prior to a scheduled sampling event, all lysimeters were purged to remove any accumulated water. Wastewater mixed with irrigation water was then applied to the two study sites, followed by clean irrigation water in July and August. Lysimeters, wells and effluent were sampled one to three days after the application. Precipitation never occurred between the time lysimeters were purged and the time they were sampled.

Exceptions to the typical purge/land application/sampling scenario occurred during the October and December sampling events. In October 1992, effluent was applied only to Site 1. The irrigation system was shut down for the winter in November 1992. Therefore neither site received wastewater prior to the December 7, 1992, sampling.

Appendix C contains descriptions of the field sampling procedures for the lysimeters, monitoring wells, and effluent. We sampled for the following parameters in order of priority when sample volume was limited.

Sampling parameters and sample types.

Parameter	Lysimeters	Monitoring Wells	Mixed Effluent
Volume of water	X		
COD	X	X	X
Chloride	X	X	X
Ammonia	X	X	X
$NO_3 + NO_2$	X	X	X
TKN or TPN*	X	X	X
Specific Conductance	X	X	X
Total Dissolved Solids		X	X
Dissolved Iron	X	X	X
BOD_5		X	X

* TKN= Total Kjeldahl Nitrogen
TPN= Total Persulfate Nitrogen

COD was the constituent of primary interest. Due to limited sample volumes from the lysimeters, analyses lower in priority were not always completed. Test methods and detection limits are listed in Appendix C, Table C.1. Sample handling procedures are described in Appendix C.

Calculations

The calculations used to analyze the data are described in Appendix E, including the rate of water movement, application rates, and percent treatment.

Quality Assurance

Quality assurance procedures and results are described in Appendix F.

Results and Discussion

Soil Water Movement

Estimates of average linear velocity and time-of-travel through the upper vadose zone are presented below for the three sampling devices.

Barrels

The average linear velocity of soil water, based on barrel measurements at Site 2, was 0.1-0.3 cm/hour for July and August sampling events (Table 1). At these rates the average travel time through the top 15 inches (38 cm) of soil is 5-16 days.

Similar velocity calculations are not available for Site 1, because the estimated volume of applied water exceeded the barrel capacity by 2-4 times. Exceedence of their capacity was confirmed, because sample volumes from the barrels at Site 1 were always at the reservoir capacity.

Bricks

The average linear velocity for soil water at Site 1 was 0.01-0.34 cm/hour for July-October using brick results. However, this is based on results from only one brick as shown in Table 2.

Results from the Site 2 brick were always 0.01 cm/hour, indicating possible equipment malfunction.

Tensiometers

Tensiometer data collected during four wetting cycles were used to estimate velocity between 12 and 24 inches at Site 2 as shown in Figure 3. Average linear velocity ranged between 15 and 60 cm/hour. A time lag of 0.5 hour was assumed when the wetting front passed through the 12-24-inch strata in less than one hour. Assuming the same linear velocity between 15 inches and the average summer water table depth of 6 feet, travel time from the bottom of the topsoil to the water table would be 2-7 hours.

Table 1. Estimates of average linear velocity based on volumes of water in the barrels at Site 2 using a range of effective porosity values (0.25–0.40).

Date	Velocity (cm/hr) when Porosity= 0.25*	Velocity (cm/hr) when Porosity= 0.30*	Velocity (cm/hr) when Porosity= 0.35*	Velocity (cm/hr) when Porosity= 0.40*
07/13/92	0.28	0.24	0.20	0.18
08/11/93	0.13	0.11	0.09	0.08

* Average linear velocity = Q/(Effective porosity x Area). Each value represents the mean of two replicate barrels. The area of each barrels was 1,297 cm2.

Table 2. Estimates of average linear velocity at Sites 1 and 2 based on volumes of water in the bricks using a range of effective porosity values (0.25–0.40).

Date	Velocity (cm/hr)= when Porosity= 0.25*		Velocity (cm/hr) when Porosity= 0.30*		Velocity (cm/hr) when Porosity= 0.40*	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
07/13/92	0.09	0.01	0.07	0.01	0.06	0.01
08/11/92	0.01	0.01	0.01	0.01	0.01	0.01
10/21/92	0.34	—	0.29	—	0.21	—

* Average linear velocity = Q/(Effective porosity x Area). Each value represents results from one brick sampler.

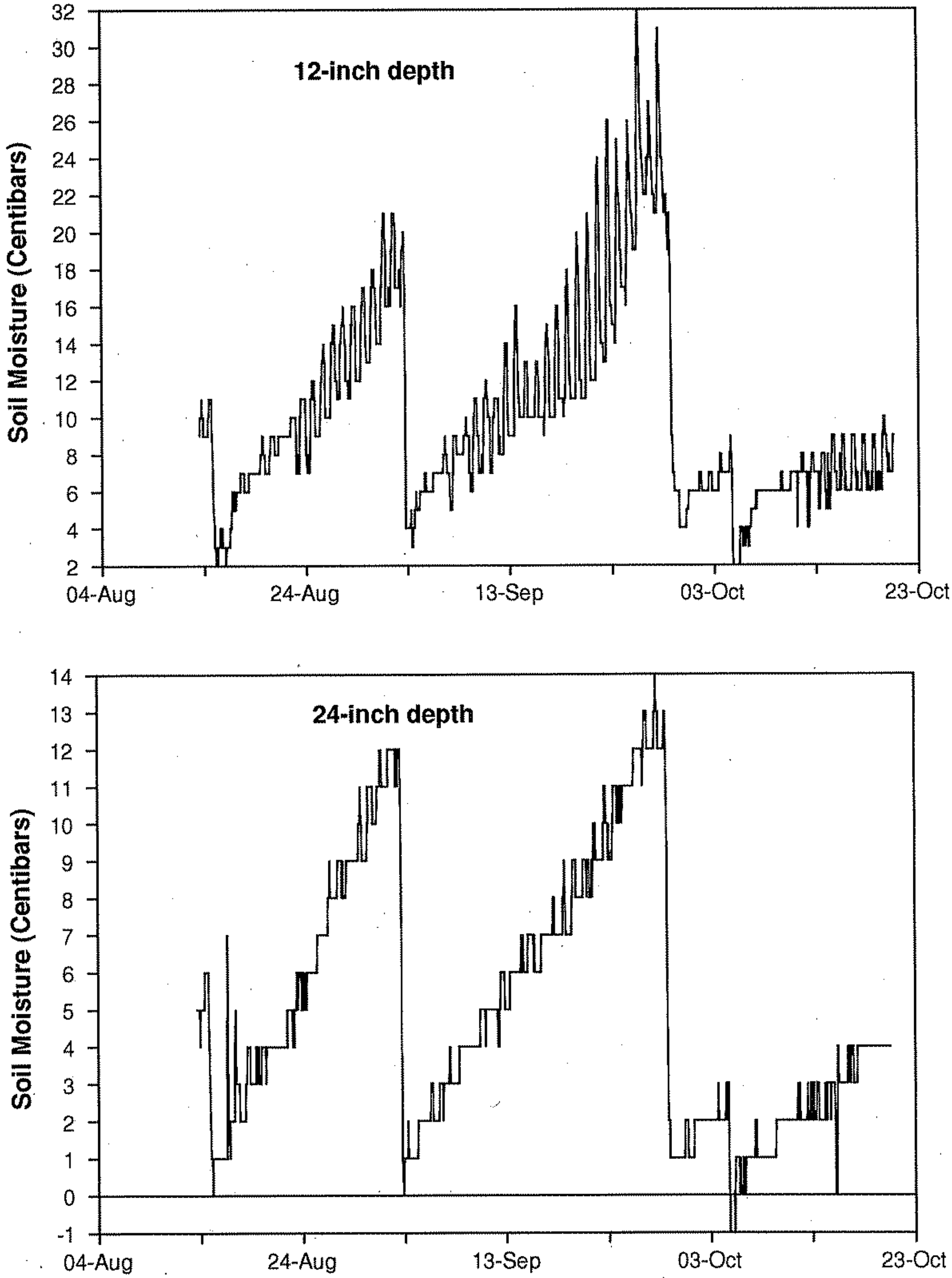


Figure 3. Soil moisture tension measurements at 12- and 24-inches depth at Site 2.

Interpretation of soil water movement information

Average linear velocity through the topsoil layer at Site 2 (0.1-0.3 cm/hour) was two orders of magnitude lower than the underlying more cobbly strata (15-60 cm/hour) based on the barrel estimates. The abrupt increase in rate of movement is due to the change in soil texture at 12-18 in (30-46 cm), from gravelly loam to gravelly loamy sand with cobbles (Brincken, 1993).

The barrel estimates for average linear velocity are approximate. Samples volumes were measured 2-3 days after effluent and irrigation water were applied. Therefore, the wide range of soil water velocities that occurred over that time is integrated into one value.

Based on the estimated velocities, most of the travel time for water percolating at Site 2 is spent in the topsoil layer (5-16 days). Beneath the topsoil, water moves rapidly to the water table. Assuming a summer water table depth of six feet, time-of-travel for a wetting front through the cobbly sand layer below the topsoil to the water table would be 2-7 hours.

Although velocity data were not available for Site 1, Brincken and Zulauf (1992) found more silt and clay and less gravel at Site 1 than at Site 2 (Appendix A). More fine-grained material in the topsoil at Site 1 may result in slower travel times than at Site 2. However, the somewhat thinner topsoil layer at Site 1 (10-14 in or 25-35 cm) would decrease travel times.

Limited data from the bricks indicate that the average linear velocity increased substantially at Site 1 after a longer than normal application event of 28 hours in October (Table 2).

Water Quality

Figure 4 shows the concentrations of COD, total N, and chloride in the lysimeters and monitoring wells. See Appendix G for water quality data.

Mean COD and total N concentrations from the brick lysimeters tended to be higher than those from the barrels. However, we have limited confidence in the brick data, since replicates were not available.

Chloride values in the bricks were higher than those in the barrels. Values from both samplers exceeded the mean applied water chloride value.

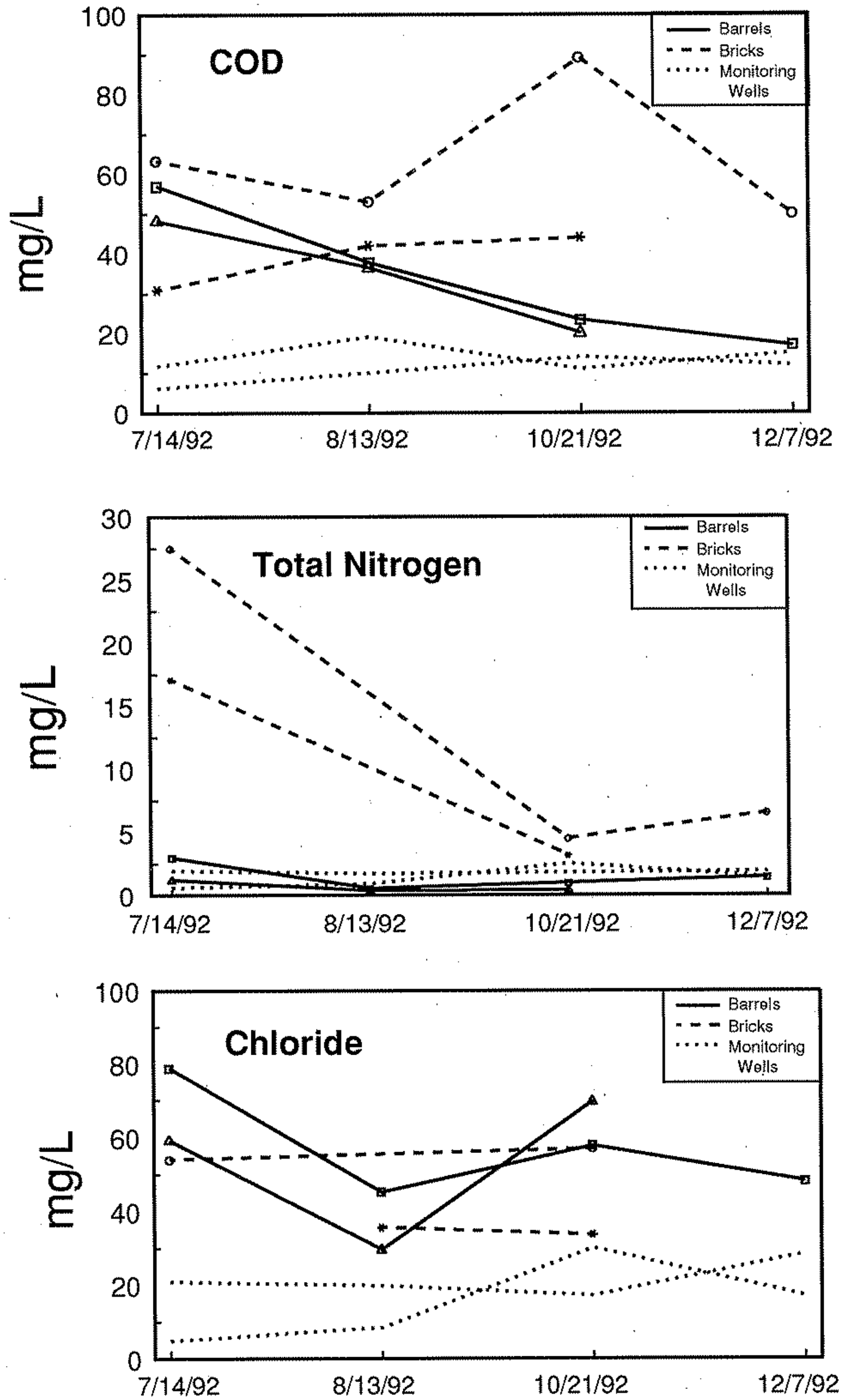


Figure 4. COD, total N, and chloride concentrations observed at Sites 1 and 2 from barrels, bricks, and monitoring wells.

Mean concentrations and standard deviations for samples and applied water were:

Sample Type	COD (mg/L)		Total N (mg/L)		Chloride (mg/L)	
	Concentration	n	Concentration	n	Concentration	n
Applied water*	200 +/- 118	6	9.4 +/- 6.4	6	36 +/- 25	6
Barrels	32 +/- 16	13	0.87 +/- 0.5	13	54 +/- 15	13
Bricks	53 +/- 9.2	7	5.2 +/- 1.9	5	45 +/- 9	4
Monitoring Wells	12.4 +/- 2.4	8	1.7 +/- 0.5	8	18 +/- 6	8

* Estimated concentration for application events, i.e., mixed effluent and non-effluent irrigation water.
n= Number of mean values or the number of sampling dates.

Results for dissolved iron, BOD_5, total dissolved solids (TDS), and total suspended solids (TSS) analyzed in monitoring wells and effluent samples are listed in Appendix G.

Results are discussed below in terms of sample site comparison, vadose zone and ground water comparison, changes over time, and comparison with similar studies.

Comparison of sites

COD, total N, and chloride concentrations were similar at Sites 1 and 2, especially in the barrels and monitoring wells as shown in Figure 4. Agreement between the brick values at the two sites was not as close as the barrels. However, values from the bricks are less reliable, because they are based on only one sample at each site. Barrel results, on the other hand, are based on two samples per site.

Comparison of vadose zone and ground water

COD and chloride concentrations were about 2-4 times higher in the lysimeters (barrel and brick types) than in the monitoring wells as shown in Figure 4. Lower concentrations in the wells are due to dilution by ground water.

It is important to note that monitoring well samples collected at the same time as lysimeter samples do not represent the same parcel of applied water. Samples from monitoring wells represent a combination of applied water and ground water affected by upgradient activities that is flowing through the well.

Unlike COD and chloride, total N concentrations were often higher in wells than in the barrels. We assumed that most of the organic N in the barrels would be converted to nitrate-N before reaching the water table, although this may not be valid based on the roughly 50% of monitoring well total N in the organic form. However, all total N values were low relative to applied water and to the criterion for nitrate-N in ground water, 10 mg/L as shown in Figure 5.

COD and total N concentrations in the bricks were somewhat higher than those taken from the barrels and ground water (Figures 5 and 6). However, the difference is not significant, due to high standard deviations and lack of brick replicates.

Changes over time

Chloride concentrations in both types of lysimeter always exceeded concentrations in the applied effluent as shown in Figure 7. While chloride data from monitoring wells in this study do not show a dramatic increase over the 6-month study period, several of the monitoring wells on and around the site monitored by the facility indicate an upward trend between September 1991 and December 1992 as shown in Figure 8. As discussed in the Treatment section below, chloride that may have built up prior to land application may have been leaching out of the soil. If so, chloride concentrations in monitoring wells should eventually decrease as the residual is depleted.

Comparison with other studies

As shown in Table 3, the range of BOD_5 estimates from the barrel samplers was 2.7-11.1 mg/L (mean= 6.4 mg/L) based on the ratio of COD to BOD in the effluent. This is higher than the concentrations found at five sites treating municipal wastewater around the country summarized by EPA (1981). BOD_5 at those sites with sandy to loamy soils was below 2 mg/L after percolating through 3.5-14 feet of soil. In addition, 80% of the lysimeter BOD_5 values at Tree Top were also outside the range of 1-5 mg/L that Loehr and Overcash (1985) classified as typical of well designed and operated municipal and industrial land application systems.

Comparison with Ground Water Quality Standards

Although the ground water standards are not directly applicable to the vadose zone (Ecology, 1993), for reference purposes, nitrate values were compared to the ground water quality criterion (10 mg/L Nitrate-N, Chapter

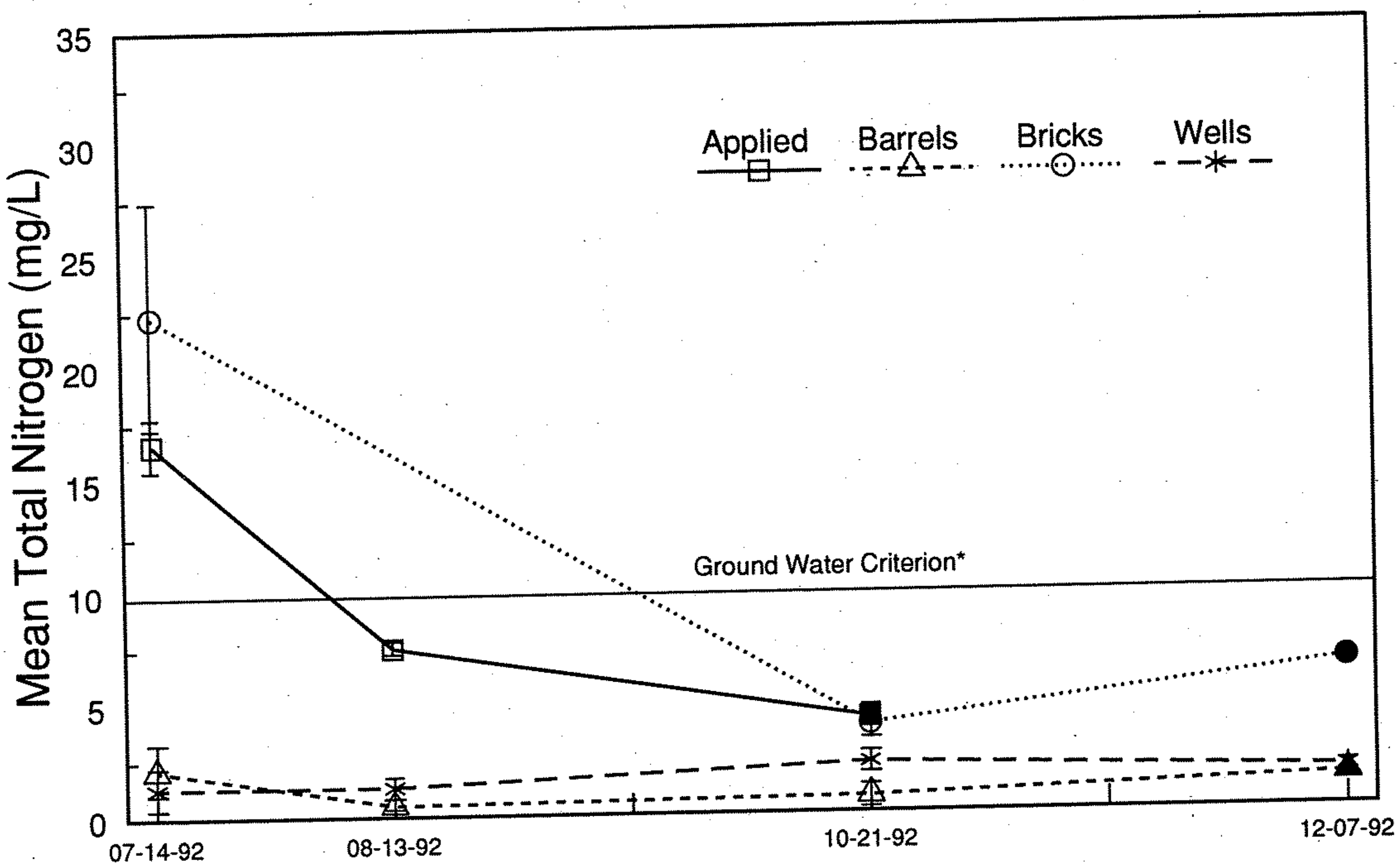


Figure 5. Mean total N concentrations and standard deviations in applied water, barrels, bricks, and monitoring wells. Barrel values represent means of 3–4 samples (1–2 at each site). Brick values represent individual samples at one or both sites. Monitoring well means represent one sample per site. (*from Ground Water Quality Standards: Chapter 173–200). Filled symbols represent only one sample.

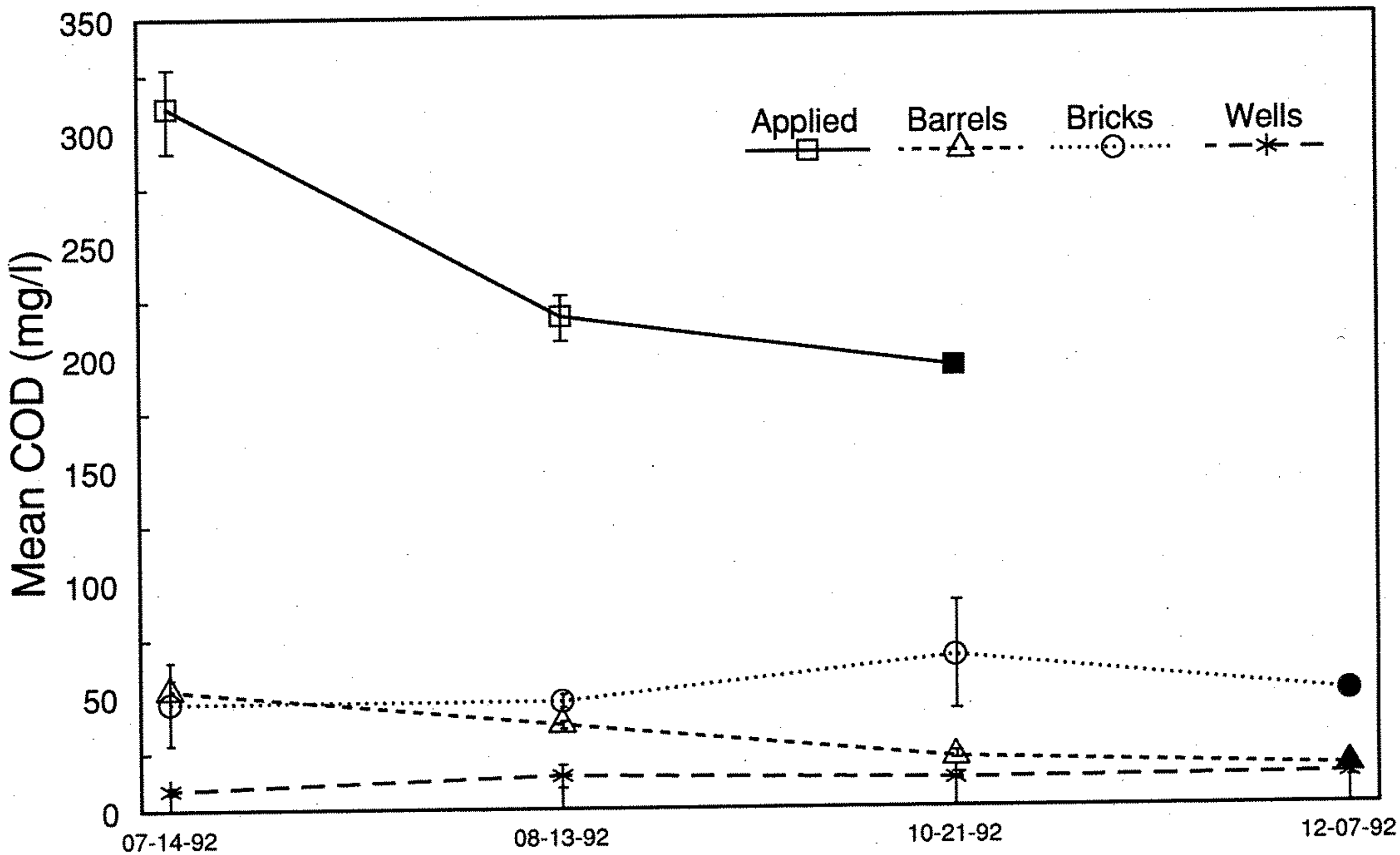


Figure 6. Mean COD concentrations and standard deviations in applied water, barrels, bricks, and monitoring wells. Barrel values represent means of 3–4 samples (1–2 at each site). Brick values represent individual samples at one or both sites. Monitoring well means represent one sample per site. Filled symbols represent one value.

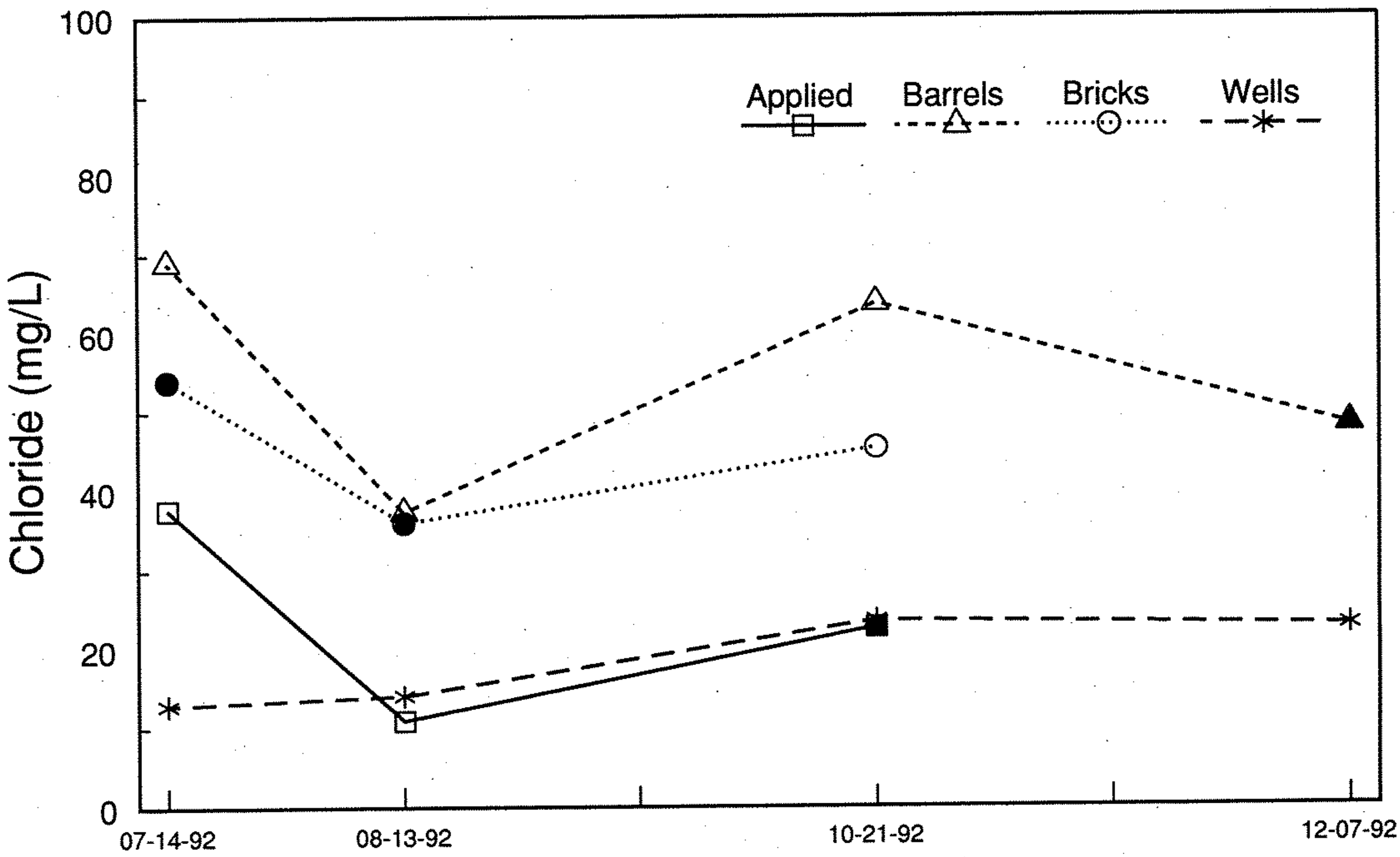


Figure 7. Mean chloride concentrations and standard deviations in applied water, barrels, bricks, and monitoring wells. Barrel values represent means of 3–4 samples (1–2 at each site). Brick values represent individual samples at one or both sites. Monitoring well means represent one sample per site. Filled symbols represent one value.

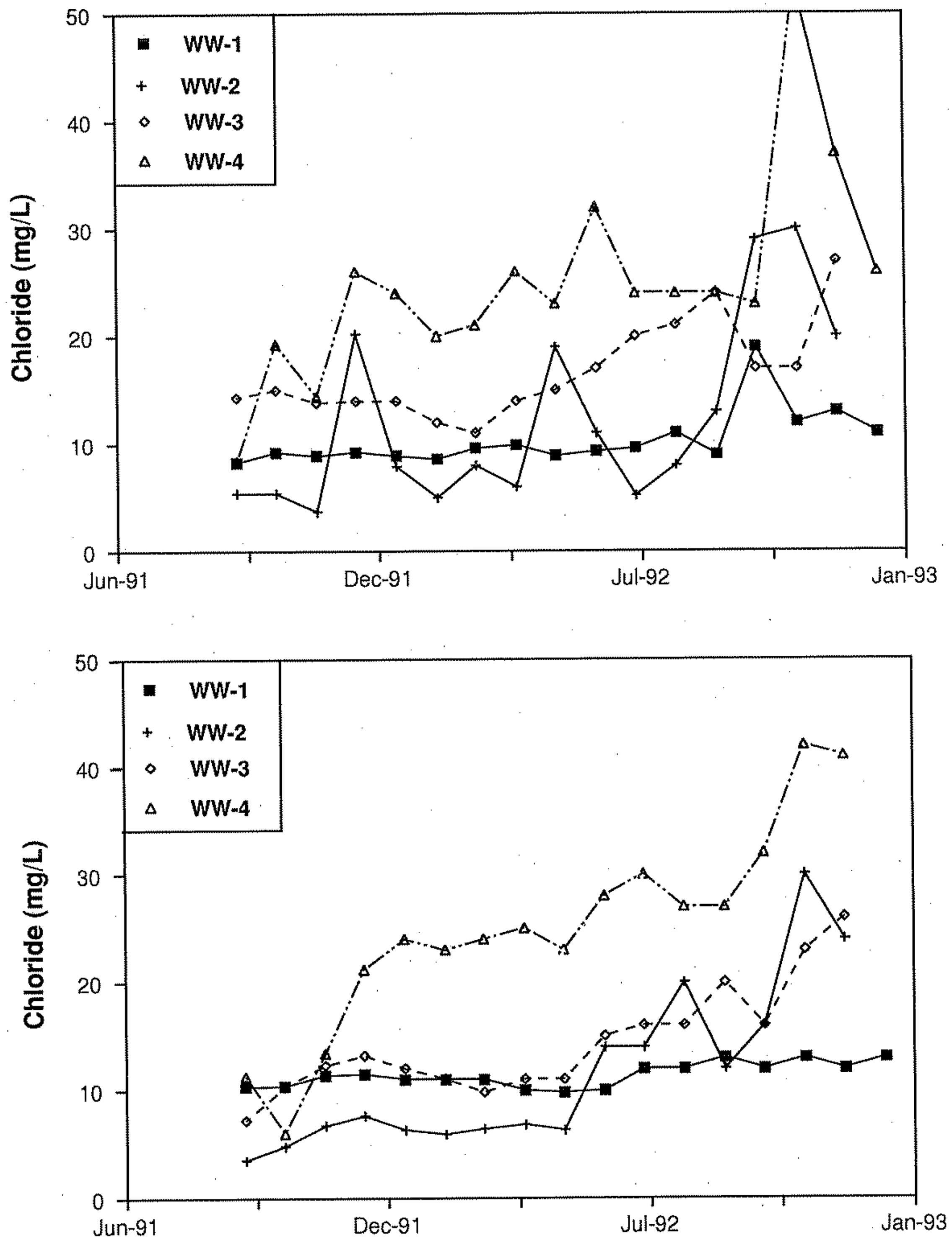


Figure 8. Chloride concentrations from monitoring wells inside the sprayfield (above) and around the perimeter of the sprayfield (below). Data were provided by Tree Top for permit compliance.

Table 3. BOD5 estimated as (0.19) x COD concentrations (mg/L).

Site	Date	COD		Estimated BOD5
Site 1				
Barrel 1	06/26/92	340		64.6
Barrel 1*	07/13/92	55.3		10.5
Barrel 1*	08/11/92	42.5		8.1
Barrel 1	10/21/92	14	B	2.7
Barrel 1	12/07/92	17		3.2
Barrel 2	06/26/92	465		88.4
Barrel 2	07/13/92	58.4		11.1
Barrel 2	08/11/92	33		6.3
Barrel 2*	10/21/92	32.5		6.2
Brick 1	07/13/92	63.3		12.0
Brick 1	08/11/92	53		10.1
Brick 1	10/21/92	89		16.9
Brick 1	12/07/92	50		9.5
Site 2				
Barrel 3	07/13/92	52.8		10.0
Barrel 3	08/11/92	32		6.1
Barrel 3	10/21/92	14	B	2.7
Barrel 4	07/13/92	43.5		8.3
Barrel 4	08/11/92	41		7.8
Barrel 4	10/21/92	26		4.9
Brick 2	07/13/92	30.8		5.9
Brick 2	08/11/92	42		8.0
Brick 2	10/21/92	44		8.4

* COD value for this date is the mean of duplicate samples.

173-200 WAC). All nitrate+nitrite values were below 10 mg/L except those from the brick samplers at both sites on July 13. We assume that nitrate+nitrite which was analyzed in this study consists almost entirely of nitrate (Sawyer and McCarty, 1978).

Possible reasons for higher nitrate in the bricks than in the barrel samplers on July 13 include:

- Shallower depth (bricks at 10 inches compared to barrels at 18 inches).
- Greater disturbance to the overlying soil during brick installation two weeks earlier. (Cracks or large pores may create preferential flow paths that decrease treatment.)
- Higher than normal total N application rate in July compared to other dates (Table 4).

Application Rates

The estimated range of effluent application prior to sampling events was:

COD:	**230-455 lb/acre/application**
Total N:	**8-25 lb/acre/application**
Chloride:	**11-130 lb/acre/application**

Table 4 shows the data for each date. Effluent application rates are discussed below in terms of differences between sites, comparison with the facility's projected application rates, and changes over time.

Comparison of study sites

Effluent mixed with irrigation water was applied near the two study sites (followed by clean irrigation water only in July and August) for 19-28 hours during the three sampling events. The dates and times for application are shown in Table 5. The estimated depth of water applied at Site 1 during July and August (7 inches) was about 40% more than that applied at Site 2 (4 inches), presumably because of differences in distances to the sprinklers.

COD and total N application rates were 35-40% higher at Site 1 than at Site 2 based on the volume of water obtained in the barrels. In addition, chloride application rates at Site 1 were double those at Site 2. We attribute these differences also to the sampler locations relative to the sprinklers.

Table 4. Total application for water, COD, total N, and chloride immediately prior to sampling.

Date	Water* (Inches)	COD^ (lb/acre)	Total N^ (lb/acre)	Chloride^ (lb/acre)
SITE 1				
07/10–11/92	6.9	455	25	55
08/07/92	6.8	320	11	62
10/20–21/92	9.5	419	25	130
SITE 2				
07/10–11/92	2.9	302	9	36
08/07/92	3.1	229	8	11
10/20/92	NA	NA	NA	NA

* Application rate assumed to be 0.34 inches/hour (0.86 cm/hour) at Site 1 and 0.21 in/hour (0.53 cm/hr) at Site 2. We used times for Sprinkler 8–03 for Site 1 in July and October; 8–04 in August; and Sprinkler 20–06 for Site 2.

^ Concentrations of applied COD, total N, and chloride are shown in Appendix I. See Appendix J for loading calculations.

Table 5. Number of hours irrigated and volumes of sample collected from barrels at Sites 1 and 2 prior to sampling in July, August, and October.

Site	Date	No. of Hour Watered*	Mean Volume of Sample in Barrels (L)	S.D.	Number of samples
Site 1	07/10–13/92	20.5	8.7	3.0	2
Site 2	07/10–13/92	19.3	4.5	1.4	2
Site 1	08/07–11/92	20.2	8.2	0.6	2
Site 2	08/07–11/92	21.1	2.9	0.2	2
Site 1	10/20–21/92	28	9.3	1.0	2

* We used timing for Sprinkler 8–03 for Site 1 in July and October; 8–04 in August; and 20–06 for Site 2.

Comparison with permit limits

The range of estimated BOD_5 application rates was 45-100 lb/acre/day as shown in Table 6. These rates are 1.6-4.5 times the monthly average permit limit. Total N application rates, 9-28 lb/acre/day, were two-five times the monthly permit limits (Table 7). Maximum application rates for both constituents occurred in July.

Treatment

Treatment values for COD and total N based on comparison of concentrations applied and those found in lysimeters as described in Appendix E were:

COD:	**81-93%** (mean= 85%, S.D.=3.8, n=10)
Total N:	**73-97%** (mean= 92%, S.D.=6.8, n=10)

These estimates are based on results from the barrels only, because much fewer data were available for the bricks. Treatment values for each site and date are shown in Table 8.

Although we did not expect chloride to be treated in the soil, increases in chloride concentrations were higher than expected compared to the applied water. As shown in Table 9, concentrations in the barrels ranged between one and four times those expected.

Several aspects of treatment will be discussed below, including a comparison of estimates at the two study sites, comparison of estimates from the barrel and brick results, effects of application rate and seasonality, comparison with other studies, and implications for other parts of the site.

Comparison of study sites

COD and total N treatment were slightly higher at Site 2 than at Site 1 based on soil water quality in the barrels (Figure 9 and 10). Lower application rates for COD and total N at Site 2 likely account for higher treatment efficiency than at Site 1. BOD_5 treatment rates are assumed to be proportional to COD rates.

Unlike COD, BOD_5, and nitrogen, chloride is a conservative parameter such that no treatment or loss is expected in the vadose zone. A slight increase in chloride (10-30%) is expected due to evapotranspiration. However, chloride was up to four times more concentrated in the barrels than the estimated concentration in applied water (Table 9), indicating a chloride source in

Table 6. COD and estimated BOD5 application rates for 1992 compared to monthly average permit limits for BOD5.

Date	COD 1992 Application Rate (lb/acre/day)*	Estimated 1992 BOD Application Rate (lb/acre/day)**	Permit daily ave. BOD 5 Application (lb/acre/day)	1992 Application Rate as % of Projected Rate
SITE 1				
07/10-11/92	533	101	22.4	450
08/07/92	380	72	29.4	250
10/20/92	235	45	27.2	160
SITE 2				
07/10-11/92	375	71	22.4	320
08/07/92	261	50	29.4	170

* Loading to barrels = [(0.86 cm/hr) at Site 1 or (0.38 cm/hr) at Site 2 x)hours applied) x (effluent concentration)/(area of the barrels)]. See Appendix Table J.1. for details.

** COD loading x (0.19)

Table 7. Total N loading compared with monthly permit limits.

Date	Total N applied 1992 (lb/acre/day)*	Permit Monthly Total N Application Rate (lb/acre/day)**	1992 Application Rate as % of Monthly Permit Limit
SITE 1			
07/10-11/92	28	6.0	470
08/07/92	13	7.4	180
10/20/92	14	5.5	250
SITE 2			
07/10-11/92	11	6.0	180
08/07/92	9	7.4	120

* Loading to barrels = [(0.86 cm/hr) at Site 1 or (0.38 cm/hr) at Site 2 x (hours applied) x (effluent concentration)/(area of the barrels)]. See Appendix Table J.2. for details.

Table 8. Percent treatment for COD and total N and increases for chloride. Barrels 1 and 2 are replicates; 3 and 4 are replicates.

Site	Date	COD Treatment (%)+	Total N Treatment (%)+	Chloride Increase (%)++
Site 1				
Barrel 1	07/13/92	82	73	243
Barrel 1	08/11/92	81	93	483
Barrel 1	10/21/92	93	95	121
Barrel 1	12/07/92	NA	NA	NA
Barrel 2	07/13/92	81	91	186
Barrel 2	08/11/92	85	92	361
Barrel 2	10/21/92	83	91	69
Brick 1	07/13/92	79	−66	147
Brick 1	08/11/92	76	—	—
Brick 1	10/21/92	55	62	95
Brick 1	12/07/92	NA	NA	NA
Site 2				
Barrel 3	07/13/92	86	94	106
Barrel 3	08/11/92	88	97	127
Barrel 3	10/21/92	—	—	—
Barrel 4	07/13/92	88	94	154
Barrel 4	08/11/92	85	95	336
Barrel 4	10/21/92	—	—	—
Brick 2	07/13/92	93	—	—
Brick 2	08/11/92	84	—	279
Brick 2	10/21/92	—	—	—

+ Treatment (%) = 1 − (Lysimeter Concentration/Expected Concentration) x 100. See Appendix H for calculations.

++ Increase (%) = (Lysimeter Concentration/Expected Concentration) x 100. See Appendix H for calculations.

Table 9. Chloride increase in lysimeters compared to expected concentration in barrel and brick lysimeters.

Chloride Increase*	7/13/92		8/11/92		10/21/92	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
BARRELS**	2.0	1.1	4.1	2.1	1.0	—
BRICKS***	1.4	—	—	2.5	1.0	—

* Calculated as: (Cl in sampler (mg/L)/Estimated Cl due to evapotranspiration and no Cl loss (mg/L)). See Appendix H for details.

** Each value represents the mean of four samples: two from each of two replicate samplers.

*** Each value represents one individual measurement.

Table 10. Rates of application and treatment for COD and total N (lb/acre/day) based on a comparison of concentrations applied and those found in the barrel lysimeters.

		7/13/92		8/11/92		10/21/92
		Site 1	Site 2	Site 1	Site 2	Site 1
COD	Application Rate (lb/acre)	455	302	320	229	419
	Treatment Rate (%)	82	87	83	87	88
Total N	Application Rate (lb/acre)	25	9	11	8	NA
	Treatment Rate (%)	82	93	93	96	NA

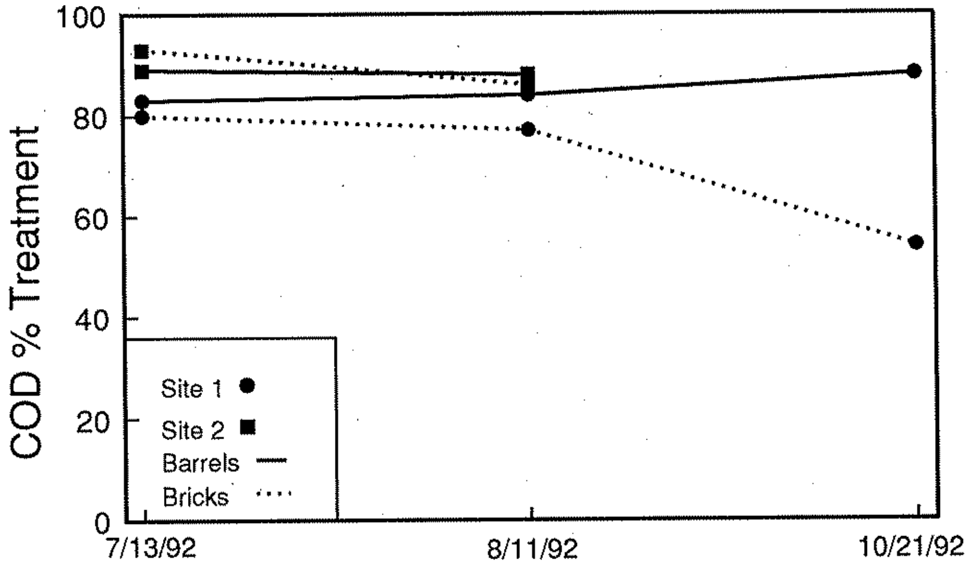


Figure 9. COD percent treatment at Sites 1 and 2 based on barrel and brick measurements.

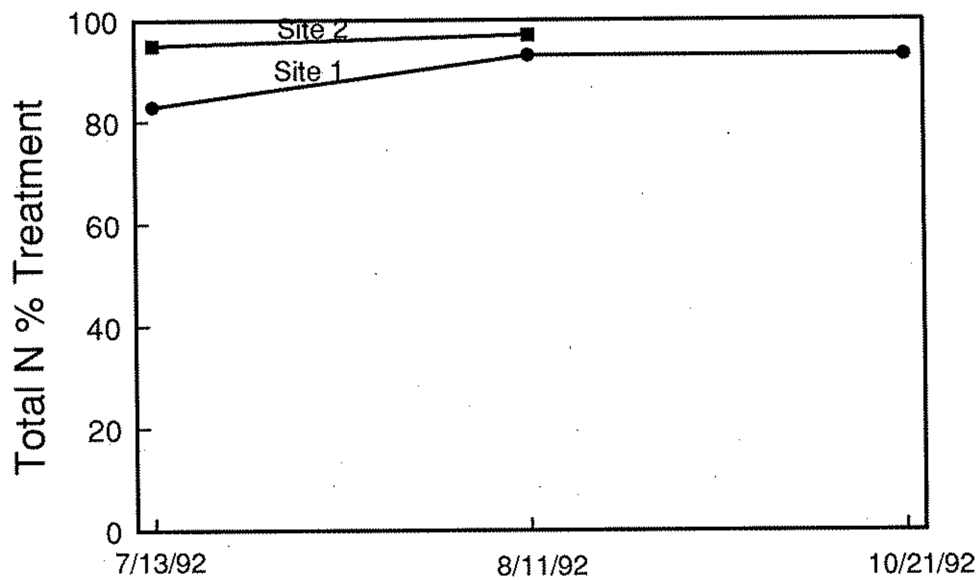


Figure 10. Total N percent treatment at Sites 1 and 2 based on barrel values.

addition to the applied effluent. Possible sources of residual chloride in the soil are: 1) past wastewater applications at low rates, and 2) animal wastes from grazing cattle. Residual chloride may now be leaching out due to increased application rates.

Comparison of estimates from the barrels and bricks

Treatment estimates for COD based on results of the barrel and brick samplers are similar. However, nitrogen data from the bricks are too limited for comparison with the barrel results. COD treatment estimates for the barrels and bricks were similar in July and August. After the longest observed application at Site 1, 28 hours in October, however, treatment in the brick lysimeter was only 54%, while that from the barrels was 88%. We do not know why results from the two types of samplers diverged on this date, although the high application rate may have affected the shallower brick sampler (10 inches) more than the barrels (18-24 inches). See the following subsection for further discussion of application rate.

Estimates for total N treatment based on results from the bricks were only available for Site 1 on two dates. Both values were lower than those based on the barrel results; -58% in July and 61% in October compared to 83-93% in the barrels. This difference may indicate that at 10 inches the bricks were not a good measure of nitrogen treatment at this site. Additional nitrogen uptake would be expected at depths below the samplers due to plant uptake.

Effects of application rate and seasonality

As shown in Table 10, COD treatment estimates were the same at the two sites in July and August, despite 35-45% higher loading in July than in August. Only barrel estimates were used in this comparison, because the variability in brick results is unknown.

COD treatment in October was the same as on other dates based on the barrel results, despite the extended application period of 28 hours and lower evapotranspiration rates than during the growing season (Table 10). However, the brick result indicated less treatment in October than previously observed: 54% compared to about 80% during July and August.

Total N treatment rates at Site 2 were similar in July and August (93-96%), although the application rate was two times higher in July than in August (Table 10). At Site 1, on the other hand, total N treatment at Site 1 increased from 82% to 93% between July and August, perhaps due to the 50% lower application rate in August.

Comparison with other studies

Mean COD treatment from the barrel data, 85%, is less than the BOD_5 mean of 95% found at five spray irrigation sites around the country (EPA, 1981). (Due to their basic similarity, we assume that BOD_5 treatment is similar to COD.) BOD_5 application rates and observed concentrations at the other sites were similar to those observed and estimated in this study. However, the EPA sites referenced were used to treat municipal rather than food processing wastewater.

Loehr and Overcash (1985) cite studies of industrial and municipal wastewater treatment where BOD_5 treatment efficiencies are typically 96% and greater based on comparison of percolate and applied water.

BOD_5 loading at Tree Top was relatively low compared to food processing land application systems reviewed by Crites (1982). Based on this review, up to 500 lb/acre/day of BOD_5 loading is usually acceptable compared to 40-100 lb/acre/day at Tree Top.

Possible reasons for lower treatment at Tree Top compared to other sites are:

- Poorly developed soil structure at the Tree Top site due to predominant sand and gravel,
- Excessive application when effluent was followed by clean irrigation water, *i.e.*, 6-9 inches total liquid/application. Rapid percolation and lowered treatment would be expected at such high rates.
- Shallower sampling depths at Tree Top (18 inches at Tree Top; 3.5-14 feet at the other sites with sandy to loamy soils), although COD treatment mainly occurs in the top few inches of soil (Tare and Bokil, 1982),
- Differences in samplers and sampling methods.

Mean total N treatment based on the barrel results exceeded that reported at the above-cited five spray irrigation sites: 92% in the barrels compared to 77% at the other sites (EPA, 1981).

Implications for other areas of the site

COD, BOD_5 and total N treatment found in this study are probably similar to areas of the site with similar topsoil composition and topography. Similar to Sites 1 and 2, over 85% of the 28 test pits on the site had silt and sand topsoil layers about 1-3 feet thick (Sweet Edwards/EMCON, 1990). Site 2 and some of the test pits also had substantial gravel in the topsoil layers. Sweet Edwards/EMCON (1990) found no topsoil layer at 15% of the soil test pits excavated.

Treatment at locations on the site with soil and topography conditions similar to Sites 1 and 2 would likely be similar to that found in this study. However, at locations where no topsoil is present or where depressions occur, treatment would probably be less effective.

Comparison of Lysimeters

Advantages and disadvantages of the barrel and brick lysimeters for this study are discussed below. The samplers are compared in terms of reliability, ease of installation, representativeness, variation between replicates, volume collected, costs, and time required for completion. Table 11 summarizes this information.

Reliability

Barrel samplers were more reliable than bricks. All four barrels yielded samples except on December 7, when the temperature was below freezing, and ice was visible in the sample tubing. Only two out of twelve glass bricks functioned. Samples collected from both types of lysimeter were clear and free of suspended material.

Barbee and Brown (1986) found that brick samplers work well in fine-grained materials, unlike those in this study, and have advantages over the more commonly used tension lysimeters for sampling large, rapidly-moving pulses of water.

Ease of installation

Both the brick and barrel samplers were difficult to install in the cobbly, sandy soil. Problems with the barrels included:

- Cobbles made it difficult to drive barrels into the ground even with heavy equipment,
- The large size and weight of the filled barrels made them unwieldy and difficult to manipulate,

Table 11. Comparison of barrel and brick lysimeters at the Tree Top site.

Performance Criteria	Barrel	Brick
Reliability	Very good	Poor
Ease of installation	Difficult	Difficult
Representativeness		
1) Disturbance to overlying soil	Good	Poor
2) Relevance to bottom of root zone	Poor	Poor
3) Residual water left after sampling	Good	Poor
Velocity estimate	Good	Poor
Variation between replicates	Good	Not applicable
Volume of sample	Good	Poor
Cost per unit (construction and installation)	High ($650)	High ($400)
Time to construct and install per unit	6 hours	6 hours

Table 12. Range of percent standard error values for replicate barrel lysimeters.

Parameter	% Standard Error *	
	Site 1	Site 2
COD	2.7–40	9.6–30
Ammonia–N	38–58	27
Nitrate + Nitrite–N	0–62	0–95
Total Kjeldahl N	4–25	15
Total Persulfate N	52	5
Chloride	7.4–27	5–45

* % Standard Error = (standard deviation/square root of n)/mean x 100.

- Jarring by the hydraulic hammer used to drive the barrels into the soil introduced gaps between the soil plug and the barrel sides that filled within one month.

It may be possible to install a smaller diameter barrel to a deeper depth if the soil is free of cobbles and cohesive enough to remain in the barrel when it is withdrawn. Problems with the bricks included:

- Close contact between the top of the brick and the overlying soil, required for the sampler to function, was nearly impossible to achieve due to gravel and cobbles,

- We could not construct flat overlying surfaces for slots at the shallower depth (8-10 inches).

- At four feet, vertical sidewalls needed for installation were impossible to construct due to caving.

Representativeness

We refer to two aspects of representativeness in this discussion:

1) The extent that soils overlying the samplers were undisturbed;

2) Relevance of results to conditions at the bottom of the root zone (about four feet depth).

Disturbance to the soil profile was minimal due to the barrels but significant for the bricks as discussed under **Ease of installation** above.

Neither sampler provided information on conditions at the bottom of the root zone. However, most treatment of COD, the constituent of primary concern in this study, is expected to occur in the top one foot or less. The barrel sampler was designed to sample only the top 18 inches.

The two functioning bricks were about ten inches deep. None of the brick samplers installed at four feet yielded samples. However, these samplers have been used successfully in more favorable soil conditions (Thomas, 1993).

It should be noted that the rolling interior surface of the brick forms depressions that hold about 200 ml of water that cannot be removed once the brick is installed (Everett, 1993). This residual water can affect the validity of subsequent samples.

Velocity estimates

Barrels were more reliable for estimating average linear velocity of soil water than the bricks. Poor performance of the bricks was probably due to insufficient contact between the brick and overlying soil.

Variation between replicates

Little variation was found between pairs of barrel samplers at the same site. The range of standard error of the mean for COD in replicate barrels was 2.7-40% (See Table 12). Replicates were not available for the bricks.

Volume of sample collected

Barrels produced larger sample volumes than bricks except for one date. The volume available for storing sample is about 5.6 l (1.5 gal) in the brick and 9.5 l (2.5 gal) in the barrel, assuming 50% void in the pea gravel. Brick samplers were never filled, while the barrels often contained almost the maximum estimated volume.

Costs and time

Materials used for the barrel samplers were more expensive than for the bricks ($500 per barrel compared to $200 per brick). However, since several bricks were installed in each trench, excavation costs per brick are variable. Excavation costs are therefore not directly comparable. We estimated about $800 to dig one trench. Each barrel cost about $180 to install.

The time needed to install the two samplers is comparable. Each barrel required about six hours, including four hours for pre-field construction and two hours for field installation. Bricks likewise required about six hours to complete: three hours for construction and three hours for installation after the trenches were dug. Several brick samplers can be installed in one trench.

References

Barbee G. C. and K. W. Brown, 1986. Comparison between suction and free-drainage soil solution samplers. Soil Science, 141(2):149-154.

Bentley, R. D. and N. D. Campbell, 1983. Geologic map of the Yakima Quadrangle: Geologic Map GM-29, State of Washington, Department of Natural Resources.

Brincken, E. and A. Zulauf, 1992. Soils description field sheet. U.S. Department of Agriculture, SCS.

Brincken, E., 1993. Personal communication. U.S. Department of Agriculture, SCS.

Brown, K. W., 1986. Monitoring the Unsaturated Zone, in Land Treatment, A Hazardous Waste Management Alternative, Water Resources Symposium No. 13. ed. by R. C. Loehr and J. F. Malina. U. of Texas, Austin.

Crites, R.W., 1982. Land treatment and reuse of food processing waste. Proceedings of the Industrial Wastes Symposia, WPCF Conference, St. Louis, Mo., Oct. 3-8, 1982.

Ecology, Washington State Department of, 1993. Final draft: Implementation Guidance for the Ground Water Quality Standards, Water Quality Program, 101p.

EPA, 1981. Process Design Manual: Land Treatment of Municipal Wastewater. EPA 625/1-81-013.

Everett, L., 1993. Vadose Zone Investigations and Remediation. Short course, October 5-7, 1993, Seattle Washington, Environmental Education Enterprises, Inc.

Fetter, C.W., 1988. Applied Hydrogeology. Merrill Publishing Co. 592p.

Frost, M., 1993. Personal communication. Tree Top facility.

Gray, D.M., Editor, 1970. Handbook on the Principles of Hydrology. Water Information Center, Inc., Port Washington, New York.

Loehr, R.C. and M.R. Overcash, 1985. Land treatment of wastes: Concepts and general design. J. of Environmental Quality 3(2):141-160.

Metcalf and Eddy, Inc., 1991. Wastewater Engineering: Treatment, Disposal and Reuse. 3rd edition, McGraw-Hill, Inc., 1,334 p.

NOAA (National Oceanic and Atmospheric Administration), 1992. Climatological Data for Yakima, Washington, July-October, 1992, Asheville, North Carolina.

Pearson, H.E., 1985. Hydrology of the Upper Yakima River Basin, Washington: State of Washington Water Supply Bulletin 52, 220 p.

Sawyer, C.N. and P.L. McCarty, 1978. Chemistry for Environmental Engineering, 3rd Edition. McGraw Hill, New York, New York, 532 p.

Small, P., 1993. Personal communication. Land Profile Services, Yakima, Washington.

Small, P., 1990. Draft Edaphological Assessment & Report, Congdon Orchards Sprayfield Site, Yakima, Washington.

SCS (U.S. Soil Conservation Service), 1985. Soil Survey of Yakima County Area, Washington, 345 p.

Sweet Edwards/EMCON, 1990. Draft EIS: Tree Top Process Waste Water Disposal, Volume II. Yakima County Planning Department.

Thomas, J. 1993. Personal communication. University of Texas, Austin.

Tree Top, Inc., 1990. Selah Operations: Land Application of Process Wastewater, Engineering Report.

U.S. Army Corps of Engineers Seattle District, 1978a. Yakima Valley Regional Water Management Study. Volume 3: Water Budget.

U.S. Army Corps of Engineers Seattle District, 1978b. Yakima Valley Regional Water Management Study. Volume 4: Geology and Ground Water.

Washington State University PAWS (Public Agriculture Weather System) Network, 1993. WSU Research Station, Prosser, Washington.

APPENDICES

Appendix A.

Table A.1. Soil descriptions based on Brincken and Zulauf (1992) field characterization of Sites 1 and 2.

Site 1

Horizon	Depth (In)	Texture	Boundary	% > 2mm
A1	0–5	Loam	Clear, smooth	
A2	5–10	Loam	Clear, smooth	
AC	10–14	Very gravelly sandy loam	Abrupt, smooth	
2C1	14–22	Very–extremely gravelly loamy sand	Gradual, smooth	82
2C2	22–35	Extremely gravelly sand	Gradual, smooth	80
2C3	35–60	Extremely gravelly sand		88

Site 2

Horizon	Depth (In)	Texture	Boundary	% > 2mm
A1	0–6	Gravelly loam	Clear, smooth	25
A2	6–12	Gravelly, sandy loam	Clear, smooth	37
AC	12–18	Gravelly, sandy loam	Abrupt, smooth	45
2C1	18–23	Extremely gravelly, loamy sand	Gradual, smooth	70
2C2	23–60	Extremely gravelly sand		70

Table A.2. Particle size distribution and organic carbon data for Site 1.

*** PRIMARY CHARACTERIZATION DATA ***
(YAKIMA COUNTY, WASHINGTON)

S92WA-077-001

PRINT DATE 07/27/93

SAMPLED AS : WEIRMAN ; SANDY-SKELETAL, MIXED, MESIC TORRIFLUVENTIC HAPLOXERALF
REVISED TO : ;

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
SOIL SURVEY LABORATORY
NATIONAL SOIL SURVEY CENTER
LINCOLN, NEBRASKA 68508-3866

SSL - PROJECT 92P 136, (CP92WA208) YAKIMA
- PEDON 92P 727, SAMPLES 92P 4418- 4423
- GENERAL METHODS 1B1A, 2A1, 2B

-1--	-2--	-3--	-4--	-5--	-6--	-7--	-8--	-9--	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-	-18-	-19-	-20-
			(- - -TOTAL	- - -)		(- -CLAY-	-)	(- -SILT-	-)	(- - - -	- -SAND-	-	- - -	-)	(-COARSE FRACTIONS(MM)-)				(>2MM)
															- - - - WEIGHT		- - - -		WT
SAMPLE NO.	DEPTH (CM)	HORIZON	CLAY LT .002	SILT .002 -.05	SAND .05 -2	FINE LT .0002	CO3 LT .002	FINE .002 -.02	COARSE .02 -.05	VF .05 -.10	F .10 -.25	M .25 -.50	C .5 -1	VC 1 -2	2 -5	5 -20	20 -75	.1- 75	PCT OF WHOLE SOIL
			<- - - -	- - - -	- - - -	- - - -	- PCT OF <2MM	(3A1)	- - - -	- - - -	- - - -	- - - -	- - - -	- - ->	<- PCT OF	<75MM(3B1)		->	
92P4418S	0- 13	A1	10.4	21.8	67.8			11.3	10.5	13.1	29.0	20.2	4.4	1.1	1	1	--	56	2
92P4419S	13- 25	A2	7.5	17.9	74.6			7.1	10.8	16.8	29.1	23.5	4.6	0.6	1	5	--	60	6
92P4420S	25- 36	AC	5.7	16.8	77.5			7.1	9.7	9.2	28.6	31.2	6.0	2.5	1	20	40	88	61
92P4421N	36- 56	2C1	--	1.8	98.2			0.2	1.6	0.2	2.5	32.3	42.2	21.0					
92P4422N	56- 89	2C2	--	4.7	95.3			1.7	3.0	2.6	11.8	38.5	31.7	10.7					
92P4423N	89-152	2C3	3.1	3.3	93.6			2.0	1.3	3.1	17.7	44.5	21.5	6.8					

DEPTH (CM)	ORGN C 6A1c PCT
0- 13	1.34
13- 25	0.44
25- 36	0.38
36- 56	0.07
56- 89	0.11
89-152	0.31

Appendix B. Lysimeter Design and Construction

During the week of June 25, 1992, we installed twelve glass brick lysimeters, four barrel lysimeters, and four tensiometers in the sprayfield at two sites. The sites had slightly different soils: Weirman sandy loam (channeled) and Weirman fine sandy loam (wet) (Figure B.1). We chose the sites for proximity to a monitoring well and for differences in soils. Sampling equipment was installed within 20-70 feet of the monitoring well and close to a sprinkler head.

Pre-installation

Most of the design and construction of the glass brick and barrel lysimeters occurred prior to field installation. These activities are described below followed by field installation procedures.

Glass brick lysimeters

Nine, 1/2-inch diameter holes were drilled in 12-inch x 12-inch x 4-inch rectangular, hollow, glass bricks used for collection lysimeters (K. W. Brown & Associates, College Station, Texas). (See Figure B.2.) Eight of the holes were drilled in the top to allow percolating water to enter the brick. The hole on one, 4-inch side allowed for extraction of accumulated sample water through polypropylene tubing. Sample tubing was housed inside a flexible conduit and PVC pipe leading through shallow trenches to a central sampling station at each site. A fiberglass cloth was glued on top of the brick to enhance the connection with the overlying soil. Each lysimeter had a capacity of 1.5 gallons (5.5 liters).

Barrel lysimeters

Each barrel consisted of a 24-inch length of 16-inch diameter steel well casing (Figure B.3). The bottom edge of the casing was bevelled for inserting into the ground. A PVC cap covered the bottom to capture percolating pore water.

Polypropylene sample tubing enclosed in flexible conduit and PVC pipe lead from the hole in the cap to the ground surface. We installed an 8-inch long PVC pipe and threaded cap to protect the sample tubing. Tubing was also connected to an air vent drilled into the lower side of the barrel to prevent a vacuum when samples were extracted.

Installation

Glass brick lysimeters

Twelve bricks were installed: two in each of three trenches at the two sites (Figure B.2). Bricks were rinsed with deionized water and installed in individual slots carved into the semi-vertical side of a 5-6-foot deep trench. One brick in each trench was installed at about eight to ten inches, the other at about four feet. Using mason's trowels and screwdrivers, slots were dug about 1.5 feet into the trench wall and a few inches larger

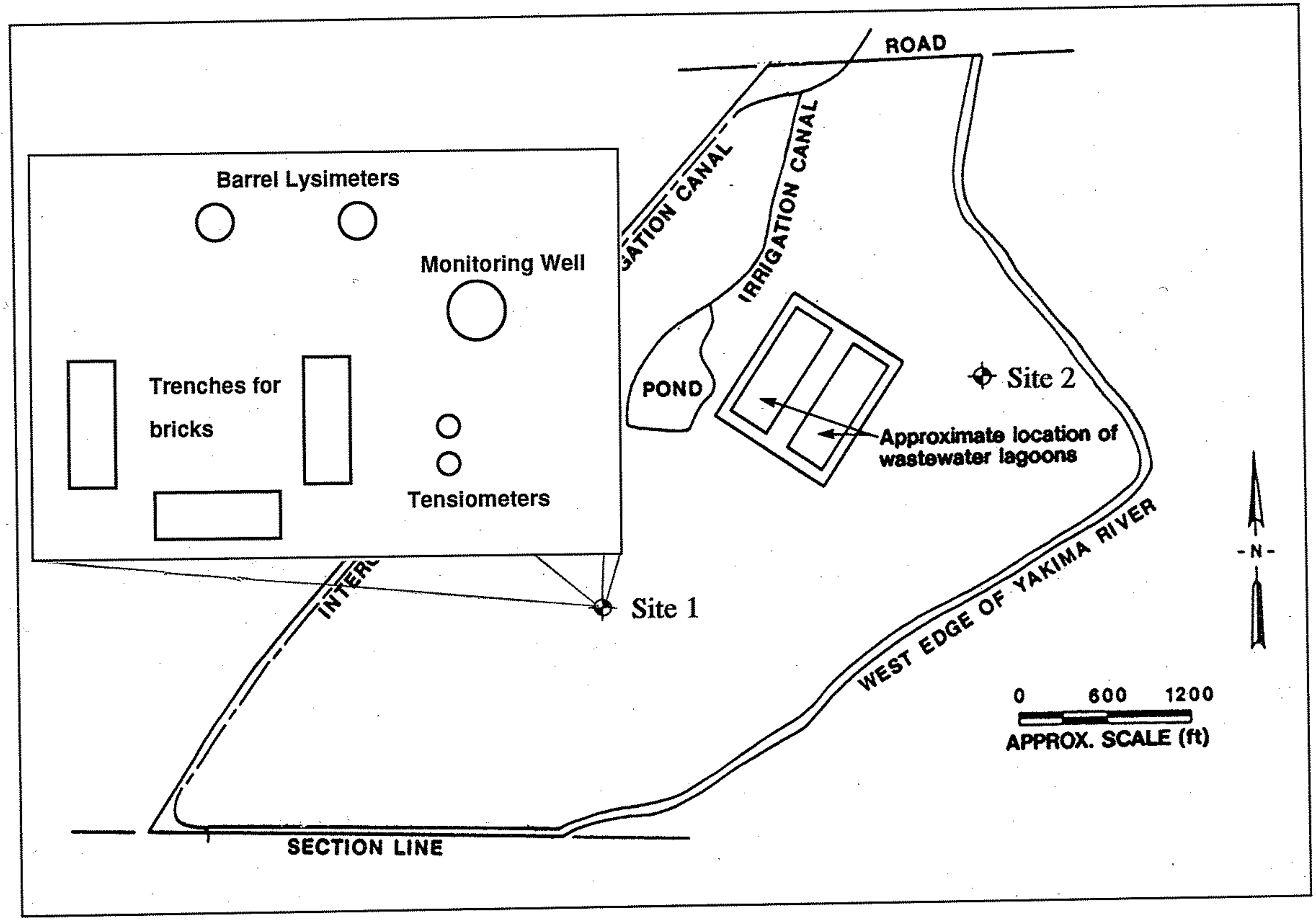


Figure B.1. Site 1 and 2 locations with diagram of equipment placement at Site 1. Equipment placement at Site 2 similar to Site 1.

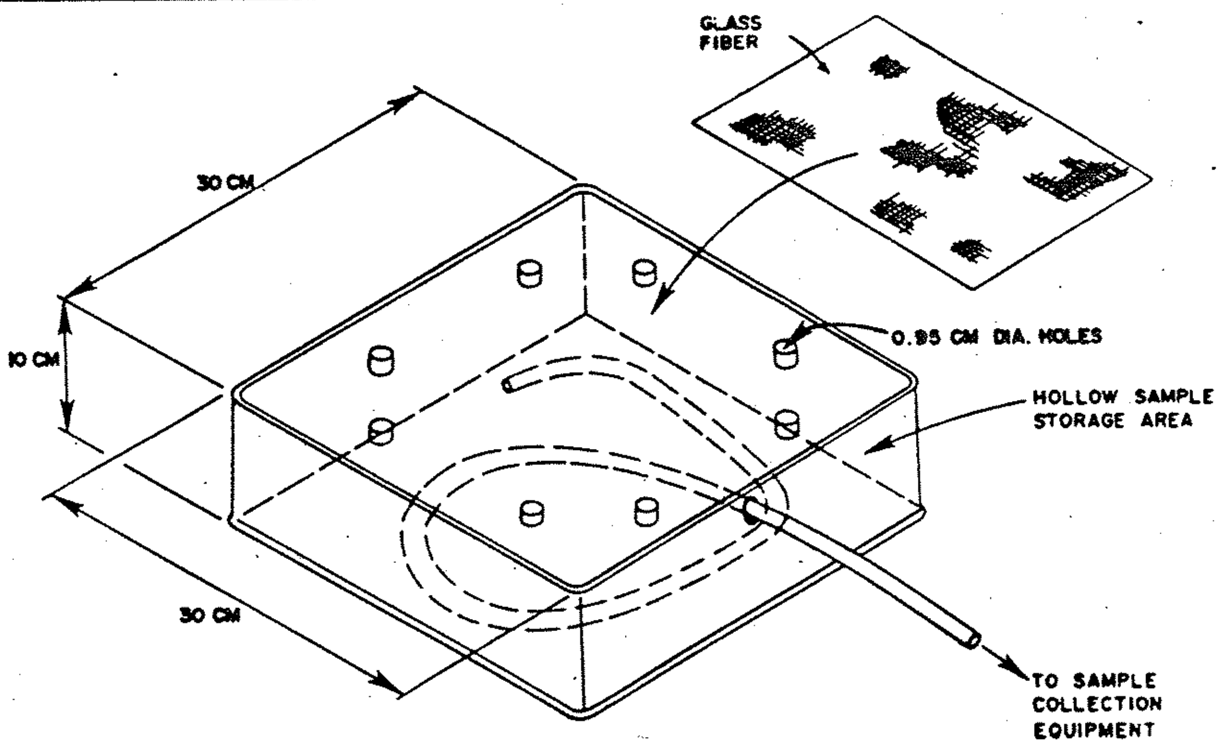


Figure B.2. Diagram of glass brick lysimeter (from Brown, 1986).

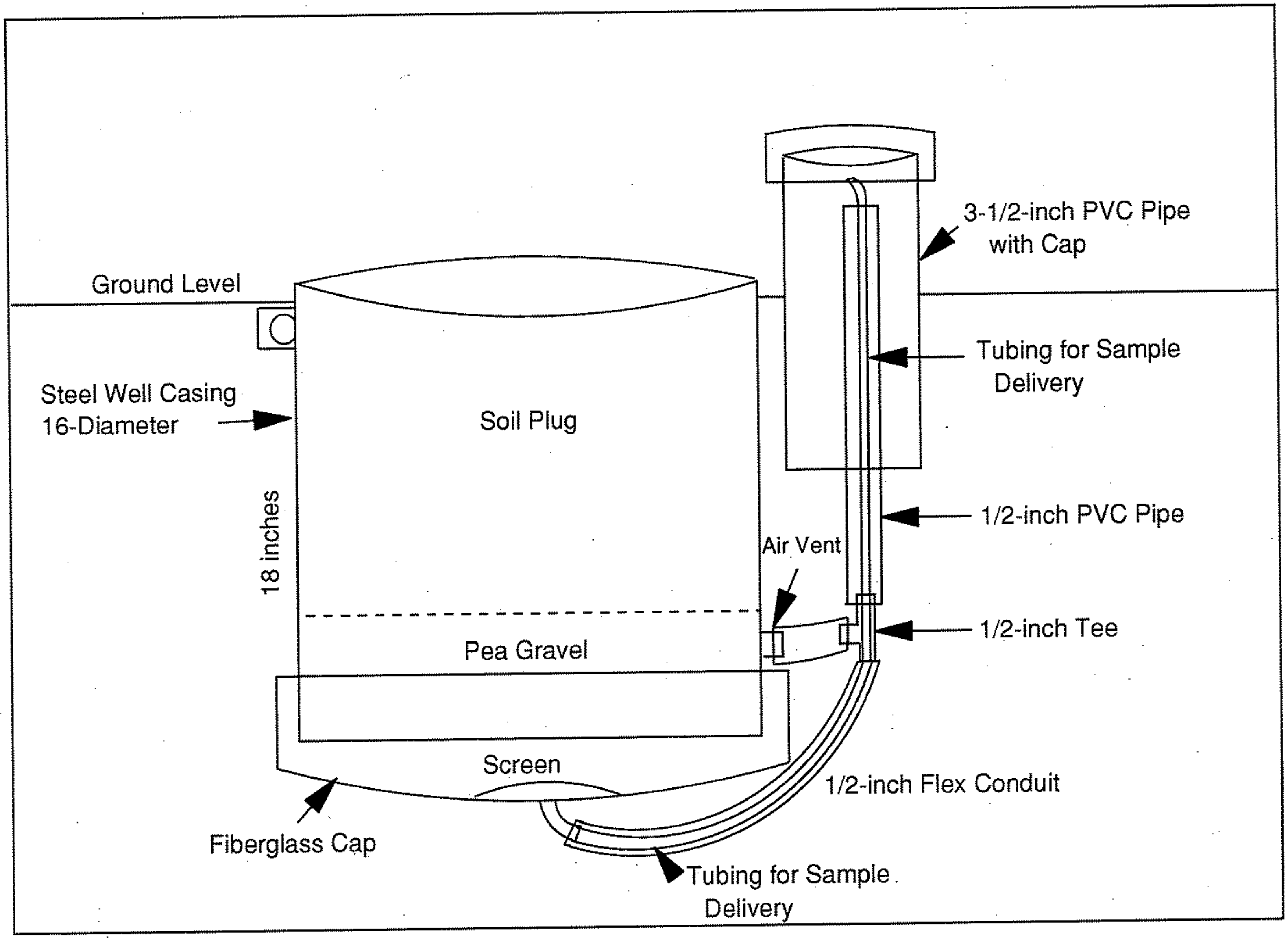


Figure B.3. Diagram of barrel lysimeter.

than the brick on each side. After inserting the glass bricks, slots were repacked with sifted (1/2-inch mesh), sandy, onsite soil and sealed with a bentonite/water mixture.

Gravel and cobbles below 8-10 inches made carving difficult. Although the soil above the shallow brick was relatively undisturbed, good soil-to-brick contact was difficult to achieve.

Trench caving was a problem at 3-4 feet. Therefore, we dug inclined and greatly enlarged "slots." We then laid the bricks in the slot and backfilled with sifted sand.

Barrel lysimeters

We installed four barrel lysimeters: two at each site (Figure B.1 and B.3). Barrel samplers were filled with soil by driving the barrel, bevelled bottom edge first, into the ground with a hydraulic hammer attached to a backhoe. Cobbles in the soil made this process difficult. The backhoe then extracted the barrel containing relatively undisturbed soil using a chain hooked to two steel tabs on the top end of the barrel.

To complete the installation, we laid the barrel upside down on the ground; replaced the bottom 6 inches of soil with pea gravel sandwiched between two layers of filter fabric to prevent soil from moving into the pea gravel; and epoxied the cap onto the bottom of the barrel with pre-attached sample tubing and housing.

The backhoe enlarged the original hole and placed the barrel with the soil monolith back in the ground. The barrels were then leveled on 2x4-inch cedar boards, and backfilled so that the top of the barrel sampler about 1-2 inches above the ground surface.

Tensiometers

We installed two tensiometers (soil moisture tension measuring devices) at each site, one at one-foot depth and another at two feet (Soilmoisture Corp, Santa Barbara, CA. Jet Fill Tensiometers, Figure B.4). We had also planned to place tensiometers at four-foot depths at each site, but cobbles prevented installation beyond two feet.

We set the ceramic tips of the tensiometers at the bottom of each hole in a silica sand slurry. We then backfilled around the tensiometers with screened soil. We then packed the top few inches to ground level with a bentonite/water mixture.

Transducers were used to convert soil moisture tension measurements into continuous analog output which was recorded on a Unidata data logger. To conserve battery power, a relay timer activated the data logger periodically. Because the timer was not as reliable as expected, we chose a recording period of 15 minutes per hour. This scheme logged data at Site 2 during the period of August 13-October 22, 1992.

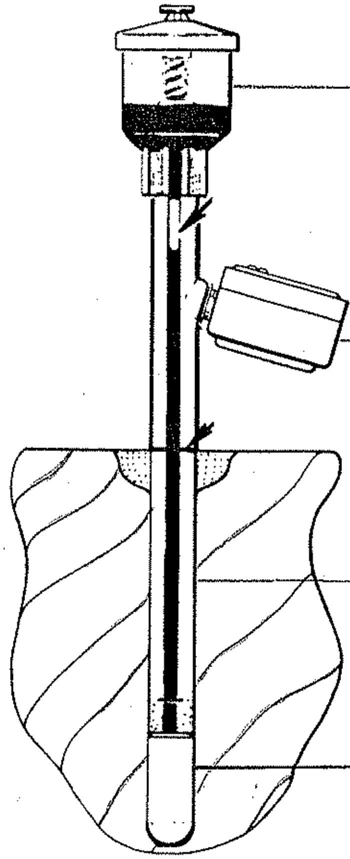


Figure B.4. Diagram of jet–fill tensiometer (Soilmoisture Corp.).

Appendix C. Water Quality Sampling

We used the following procedures for sampling water quality at the Tree Top site.

Lysimeters

A peristaltic pump was used to collect samples from the lysimeters. A side-arm collection flask was connected to the lysimeter tubing via 1/4-inch polypropylene tubing. Collection flasks were washed with Alconox@ and warm water, rinsed with tap water followed by a nitric acid rinse, and finally rinsed at least four times with deionized water.

Monitoring wells

On the same day that lysimeter samples were collected, Tree Top staff collected samples from the nearby monitoring wells. These wells, WW-3 (Site 1) and WW-2 (Site 2), are screened between 6 and 15 feet below ground. Well logs are shown in Appendix D.

Tree Top staff collected well samples using a teflon bailer. They purged a minimum of three well volumes prior to sample collection. Samples for nitrate + nitrite-N were split in the field between Ecology and Tree Top staff.

Effluent

We collected grab samples of mixed effluent/irrigation water two times during each sampling event, except in August when only one sample was collected and December when the irrigation system was off. Samples of effluent mixed with clean irrigation water were taken from a spigot next to the pump house. These samples were assumed to be representative of the effluent/irrigation water mixture applied one to three days previously. However, estimated application rates also took into account clean irrigation water applied immediately after the effluent mixture was applied prior to the July and August sampling events. (See Appendix E for details of application rate calculations.)

Sample handling

Samples were stored in coolers at 4 degrees C immediately after collection. Coolers were shipped to the Ecology/EPA Laboratory in Manchester, Washington. The Manchester Laboratory and contract laboratories conducted the analyses.

Parameters

The following parameters were measured:

- Volume of water
- Chemical Oxygen Demand (COD)
- Chloride
- Ammonia
- Nitrate+Nitrite-N

Total Persulfate N (TPN) or Total Kjeldahl N
(TKN)
Specific Conductance
Total Dissolved Solids (TDS)
Dissolved Iron

Because sample volumes from the lysimeters were usually limited, not all analyses could be completed on each sampling date. Test methods and detection limits are listed in Table C.1.

Table C.1. Analytical parameters, methods, and method detection limits for Tree Top land application study.

Parameter	Method of Analysis	Reference	Method Detection Limit
Temperature	Beckman temperature probe	NA	0.1 C
pH	Beckman pH Meter	NA	0.1 Std Unit
Specific Conductance (field)	Beckman Conductivity Bridge	NA	10 umhos/cm
Specific Conductance (lab)	Std Method #2510	APHA (1989)	10 umhos/cm
Chemical Oxygen Demand	Std Method #508C	APHA (1989)	4 mg/L
Biological Oxygen Demand	Std Method #5210B	APHA (1989)	1 mg/L
Ammonia–N	EPA #350.1	EPA (1983)	0.01 mg/L
Nitrate+ Nitrite–N	EPA # 353.2	EPA (1983)	0.01 mg/L
Kjeldahl–N	Std Methods #4500–N org	APHA (1989)	
Total Persulfate N	EPA #353.2	EPA (1983)	0.1 mg/L
Chloride	Std Methods #4110B	APHA (1989)	0.1 mg/L
Total Dissolved Iron	Std Methods #3120B	APHA (1989)	0.007 mg/L
Total Suspended Solids	EPA #160.2	EPA (1983)	10 mg/L
Total Dissolved Solids	Std Method #209B	APHA (1989)	10 mg/L

EPA, 1983. Methods for Chemical Analysis of Water and Wastes, EPA–600/4–79–020. Revised March 1983.

American Public Health Association, 1989. Methods for the Examination of Water and Wastewater, 17th Edition.

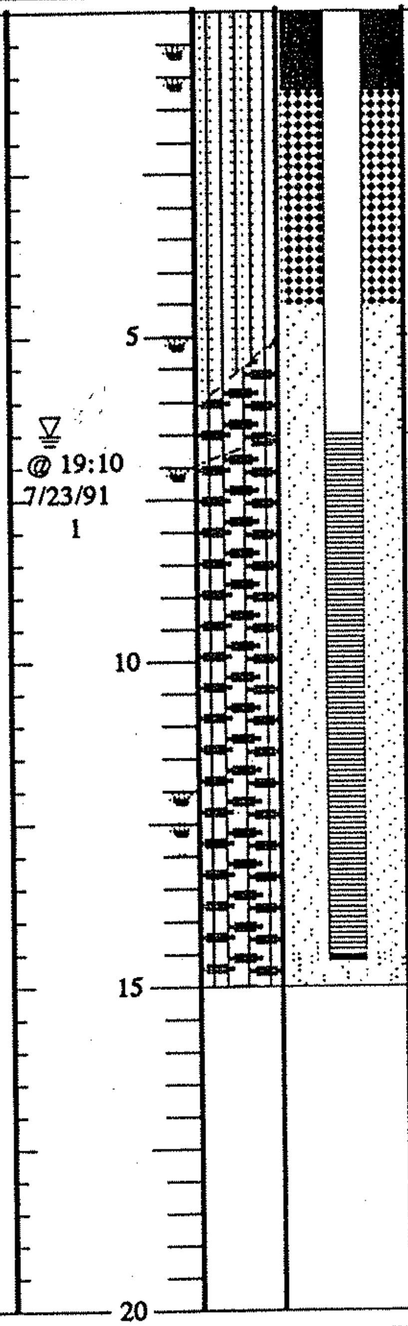
Appendix D. Well logs for Site 1 (WW-3) and Site 2 (WW-2).

LOG OF EXPLORATORY BORING

PROJECT NAME	Tree Top/Waste Water Wells	BORING NO.	WW-2
LOCATION	Selah, Washington	PAGE	1 OF 1
DRILLED BY	Ponderosa	REFERENCE ELEV.	1119.00'
DRILL METHOD	Air Rotary	TOTAL DEPTH	15.00'
LOGGED BY	Anne Udaloy	DATE COMPLETED	07/24/91

SAMPLING METHOD	SAMPLE DEPTH (feet)
GRAB	0.5-1.5
GRAB	5.0-5.5
GRAB	7.0-7.5
GRAB	12-13

GROUND WATER LEVELS | DEPTH IN FT. | SAMPLES | LITHOLOGIC COLUMN | WELL DETAILS



LITHOLOGIC DESCRIPTION

0 - 5.5 feet: SILTY SAND (SP-SM), yellow-brown, fine to medium, few non-plastic fines, trace fine gravel, damp. Includes SANDY SILT (ML) from 0.6 to 1.0 feet. (TOPSOIL/ALLUVIUM)

5.5 - 7.0 feet: SILTY GRAVEL (GM), light gray, fine to coarse, little sand, few fines, damp. (ALLUVIUM)

7.0 - 15.0 feet: SANDY GRAVEL (GP-GM), grayish brown, fine to medium, some fine to medium sand, few fines, wet. (ALLUVIUM)

WELL COMPLETION DETAILS

+2.5 to 6.5 feet: 2-inch-diameter flush-threaded Schedule 40 PVC blank.

6.5 to 14.5 feet: 2-inch-diameter flush-threaded Schedule 40 PVC screen with 0.010-inch machined slots.

14.5 to 14.6 feet: 2-inch PVC slip-cap attached with one stainless steel screw.

0 - 1.2 foot: concrete.
1.2 - 4.5 feet: bentonite.
4.5 - 15.0 feet: 20 x 40 sand.

Total depth drilled and sampled = 15.0 feet.

REMARKS

(1) Reference elevation is ground surface. (2) Top of casing elevation is 1121.35 feet. (3) Elevations are measured relative to U.S. Geological Survey vertical datum.

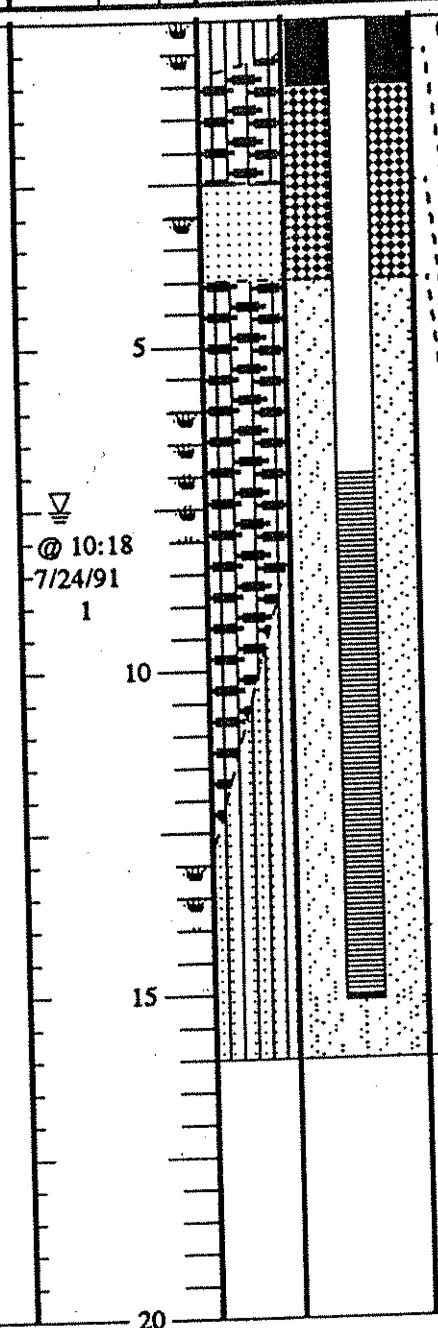
SWEET-EDWARDS/EMCON

T95-01.05.TREE2.30/sd:2.9/12/91

LOG OF EXPLORATORY BORING

PROJECT NAME	Tree Top/Waste Water Wells	BORING NO.	WW-3
LOCATION	Selah, Washington	PAGE	1 OF 2
DRILLED BY	Ponderosa	REFERENCE ELEV.	1112.50'
DRILL METHOD	Air Rotary	TOTAL DEPTH	16.00'
LOGGED BY	Anne Udaloy	DATE COMPLETED	07/24/91

SAMPLING METHOD	SAMPLE DEPTH (feet)
GRAB	0-1.0
GRAB	3-3.5
GRAB	6-8
GRAB	13-14



LITHOLOGIC DESCRIPTION

0 - 0.7 feet: SANDY SILT (ML), dark to medium brown, some fine to medium sand, trace gravel, few cobbles, very stiff, damp. (TOPSOIL/ALLUVIUM)

0.7 - 2.5 feet: SILTY GRAVEL (GM), medium brown, some sand, little low plasticity fines, few cobbles, damp. Gradational upper contact. (ALLUVIUM)

2.5 - 4.0 feet: SAND (SP), yellow-brown, fine to medium, little gravel, trace fines, damp. (ALLUVIUM)

4.0 - 14.0 feet: SILTY GRAVEL (GM-GP), grayish brown, fine to medium, little sand, few fines, damp to wet. Lower contact uncertain. (ALLUVIUM).

14.0 - 16.0 feet: SILTY SAND (SM), gray, fine to coarse, some gravel, little fines, wet. (ALLUVIUM)

Total depth drilled and sampled = 16.0 feet.

REMARKS
(1) Reference elevation is ground surface. (2) Top of casing elevation is 1114.89 feet. (3) Elevations are measured relative to U.S. Geological Survey vertical datum.

SWEET-EDWARDS/EMCON

T95-01.05.TREE2.30/sd:2.9/12/91

LOG OF EXPLORATORY BORING

PROJECT NAME	Tree Top/Waste Water Wells	BORING NO.	WW-3
LOCATION	Selah, Washington	PAGE	2 OF 2
DRILLED BY	Ponderosa	REFERENCE ELEV.	1112.50'
DRILL METHOD	Air Rotary	TOTAL DEPTH	16.00'
LOGGED BY	Anne Udaloy	DATE COMPLETED	07/24/91

SAMPLING METHOD	SAMPLE DEPTH (feet)		GROUND WATER LEVELS	DEPTH IN FT.	SAMPLES	LITHO-LOGIC COLUMN	WELL DETAILS	LITHOLOGIC DESCRIPTION
				25				
				30				
				35				
				40				

WELL COMPLETION DETAILS

+2.5 to 7.0 feet: 2-inch-diameter flush-threaded Schedule 40 PVC blank.

7.0 to 15.0 feet: 2-inch-diameter flush-threaded Schedule 40 PVC screen with 0.010-inch machined slots.

15.0 to 15.1 feet: 2-inch PVC slip-cap attached with one stainless steel screw.

0 - 1.0 foot: concrete.
1.0 - 4.0 feet: bentonite.
4.0 - 16.0 feet: 20 x 40 sand.

REMARKS
(1) Reference elevation is ground surface. (2) Top of casing elevation is 1114.89 feet. (3) Elevations are measured relative to U.S. Geological Survey vertical datum.

SWEET-EDWARDS/EMCON

T95-01.05.TREE2.30/sd:2.9/12/91

Appendix E. Calculations

Calculations used to estimate the rate of water movement, application rates, and treatment for COD and total N are described below.

Rate of water movement

Two methods were used to estimate the rate of soil water movement:

1) Volume of water collected in the barrels divided by the time between application and sampling, and

2) Time for wetting fronts to move through the soil, as measured by the one- and two-foot deep tensiometers.

The average linear velocity, based on the volume of water collected in the barrels, was estimated as:

$v = Q/(n_e \times A)$ (Fetter, 1988)

where

v = Average linear velocity, (cm/hr)

Q = Rate of discharge, i.e., volume collected/time between application and sampling (cm^3/hr)

n_e = Effective porosity (0.25-0.40 used)

A = Area of the barrel (1,297 cm^2)

This method assumes that water can flow freely into the barrel reservoir. Therefore this method is only valid if the reservoir capacity is not exceeded.

Tensiometer measurements recorded hourly at Site 1 were also used to estimate soil water velocity between August 13 and October 20, 1992. We assumed that a substantial decrease in soil moisture tension indicated an increase in soil moisture due to irrigation, since no rainfall was measured at Yakima during this period (NOAA, 1992). The time difference between a decrease in soil tension at one foot and a subsequent decrease at two feet was converted to velocity by the equation:

$v = D/T$

where

D = Vertical distance between tensiometers (cm)

T = Time for the front to travel between tensiometers (hr)

Application rates

Application rate refers here to the amount of a substance applied through irrigation to an area over a period of time. As described below, the concentration of the substance of interest was multiplied by the volume applied to obtain the application rate.

Application Rate = (Volume Applied x Concentration x Conversion Factor)/Time

Volume Applied (L) = Rate of effluent and irrigation water applied (cm/hr) x Hours applied x Area (cm^2)/(1,000 cm^3/L)

Concentration Applied (mg/L) = [(Mixed effluent COD (mg/L)) x Fraction of mixed effluent applied] + [(Irrigation COD (mg/L)) x Fraction of irrigation water applied]

Time Applied (days) = Number of days orfraction of days water applied per irrigation episode

Conversion Factor = 2.2×10^{-3} lb/mg

At Site 1, the volume of water applied was estimated using a watering rate of 0.34 inch/hour (0.86 cm/hour) based on the facility engineering report (Tree Top, 1990). Estimated watering rates were used at Site 2, because observed sample volumes were much smaller than at Site 1. The watering rate at Site 2 was calculated using the observed sample volumes in barrels and assuming that about 20% of the applied water was held in the soil. This resulted in a mean watering rate of 0.21 in/hr (0.53 cm/hour) at Site 2.

To compare 1992 application rates for BOD_5 with projections in the Tree Top Engineering Report (1990), the ratio of BOD_5 to COD was used, because sample volumes were insufficient for direct BOD_5 analysis. Based on the mean BOD_5/COD ratio for five effluent samples taken between July and October 1992, BOD_5 concentration was 0.19 times the effluent COD concentration. (This is lower than the average fraction of COD, which is around 0.4-0.8 according to Metcalf and Eddy (1991) but common for food processing wastewater (Small, 1993)).

During the irrigation events observed, the total time that effluent and non-effluent water were applied was 19-28 hours. Effluent mixed with irrigation water was applied for several hours followed by an equal or longer period of irrigation water without effluent in July and August. In October only the mixed effluent was applied.

Treatment

COD, BOD_5, total N, and chloride treatment were estimated by comparing the concentrations applied to those observed in the lysimeters. Decreases due to dilution by clean irrigation water and increases due to evapotranspiration were accounted for volumetrically.

Steps to account for dilution were:

1) Determine the total time effluent and irrigation water were applied:

$$T_{Total} = T_{Mix} + T_{Irr}$$

where

T_{Mix} = Hours mixed water applied (effluent + irrigation water)
T_{Irr} = Hours irrigation water only applied
T_{Total} = Total time water applied

2) Determine the fraction of time mixed water is applied and the fraction of the time irrigation water only is applied:

$$F_{Mix} = T_{Mix}/T_{Total};$$
$$F_{Irr} = T_{Irr}/T_{Total}$$

where

F_{Mix} = Fraction of time effluent + irrigation water applied
F_{Irr} = Fraction of time irrigation water only applied

T_{Mix} = Hours effluent + irrigation water applied
T_{Irr} = Hours irrigation water only applied
T_{Total} = Total time water applied

3) Calculate the actual concentration applied:

$$C_{Applied} = (C_{Mix})(F_{Mix}) + (C_{Irr})(F_{Irr})$$

where

$C_{Applied}$ = Concentration of COD or total N applied (mg/L)
C_{Mix} = Concentration of COD or total N in mixed effluent/irrigation water (mg/L)
C_{Irr} = Concentration of COD or total N in irrigation water (mg/L)

Concentrations were also adjusted for evapotranspiration by calculating a concentration factor based on the evapotranspiration at Cowiche, Washington, 12 miles northwest of the site (WSU, PAWS Network). The total evapotranspiration for the days when water was applied plus the following day (before sampling) was subtracted from the estimated amount of water applied. Evapotranspiration for well-watered pasture grass at Cowiche, Washington, 12 miles northwest of the site, is shown below for the periods following application and prior to sampling (WSU PAWS Network).

Date	Evapotranspiration (Inches/Day)*
7/10/92	0.16
7/11/92	0.20
Total	0.36

Date	Evapotranspiration (Inches/Day)*
8/7/92	0.20
8/8/92	0.23
Total	0.43

Date	Evapotranspiration (Inches/Day)*
10/19/92	0.04
10/20/92	0.04
Total	0.08

* Evapotranspiration is based on the Penman method (Gray, 1970).

The result of subtracting evapotranspiration from the applied water is an estimate of the volume of water available for percolation.

$$AV = (T_{Total} \times AR) - ET$$

where

AV = Inches of percolating water available after evapotranspiration
AR = Inches/hour applied
ET = 3-day evapotranspiration for Cowiche, Washington (Inches)

The ratio of the total amount of water applied to the adjusted amount is referred to as the concentration factor (CF).

$$CF = T_{Total} \times AR/AV$$

Concentration factors are shown in Table E.1.

The expected concentration of the substance if no losses other than evapotranspiration were to occur in the soil is estimated as:

$$C_{Expected} = C_{Applied} \times CF$$

where
$C_{Expected}$ = Concentration expected
$C_{Applied}$ = Concentration applied

The observed loss is calculated as:

$$Treatment = 1 - (C_{Lysim}/C_{Expected}) \times 100$$

where
C_{Lysim} = Concentration in the lysimeter
$C_{Expected}$ = Concentration expected

Chloride increase
Chloride, relatively non-reactive in the soil, was expected to increase in the samplers relative to that applied due to evapotranspiration:

$$\%\ Increase = C_{Lysim}/C_{Expected}$$

Table E.1. Concentration factor calculations.

Date	Site	Hours water or effluent applied*	Application rate (In/hr)	Total Amount Applied (In)	Evapotranspiration on day applied and following day (In)	Water Available for Percolation (In)	Concentration Factor
7/10-11/92	1	20.4	0.34	6.9	0.36	6.6	1.05
7/10-11/92	2	19.2	0.15	2.9	0.36	2.5	1.14
08/07/92	1	20.0	0.34	6.8	0.43	6.4	1.07
08/07/92	2	21.1	0.15	3.2	0.43	2.7	1.16
10/19/92	1	28.0	0.34	9.5	0.08	9.4	1.01

* Sprinkler 8-03 for Site 1 and Sprinkler 20-06 for Site 2.

Appendix F. Quality Assurance

Quality Assurance Procedures

Standard laboratory quality assurance procedures were followed for all samples, including calibration standards, spikes, and laboratory duplicates. In addition, blind duplicate samples were collected at one barrel and the well at Site 1 for each sampling event except for December 7, 1992, when insufficient sample was available.

Rinsate blanks were also collected on each sampling occasion. These samples consisted of laboratory deionized water pumped into the lysimeter collection flask and poured into sample bottles. Blank samples were collected for all major constituents.

Quality Assurance Results

All data were usable, although most total Kjeldahl-N (TKN) values for October 21, 1992, are qualified. All samples on that date with reported values less than five times the blank value (0.23 mg/L) are qualified with a "B" in Appendix G.

Relative Percent Difference

Relative percent difference values (RPD) were calculated for duplicate samples collected at Site 1 on each date using the following formula:

$$[(C_1-C_2)/(\text{mean of } C_1 \text{ and } C_2)] \times 100$$

where C_1 = Concentration of one sample
C_2 = Concentration of other sample

Relative percent difference was used to measure the effects of combined field and laboratory errors on data precision. Results are shown in Table F.1.

COD

Results for COD duplicate samples were generally close. RPD values ranged from 2.2 to 21.5%. Barrel duplicates generally had lower RPD's than well samples. The mean RPD for the barrel duplicates was 8.7% compared to 16.8% for the Site 1 well. Higher precision in the barrel results may be related to higher COD concentrations in the barrels (usually greater than 30 mg/L) compared to the well (10-20 mg/L).

Total Nitrogen

Two analytical methods were used to determine total nitrogen concentrations. Total persulfate N (TPN) was used for the June and July samples, while total Kjeldahl N (TKN) was used for the August and October samples. Both methods were used for the December samples.

Appendix Table F.1. Relative percent difference values for duplicate samples in mg/L.

Date		Chemical Oxygen Demand	Ammonia as N	Nitrate+ Nitrite as N	Total Persulfate Nitrogen-N	Total Kjeldahl Nitrogen-N	Biological Oxygen Demand	Chloride	Conduc- tivity (Laboratory)	Total Diss. Solids	Dissolved Iron
Site 1-B1											
07/14/92		54.7	0.05 U	3.1	4.4			91.5	545		
07/14/92		55.9	0.05 U	2.66	4.66			86.8	547		75.7
	RPD =	2		15	6			5	0		
08/13/92		43	0.08	0.02 U		0.58		51.4	523		
08/13/92		42	0.05 U	0.02 U		0.49		51.8	528		
	RPD =	2				17		1	1		
Site 1-B2											
10/21/92		29	0.021	0.01 U		1.1		40.8	338		
10/21/92		36	0.018	0.01 U		1.0		43.3	338		
	RPD =	22	15			10		6	0		
WW3											
07/13/92		10.4	0.05 U	1.74	1.96		4	20.9	569	367	8.9 P
07/13/92		12.9	0.05 U	1.6	1.94		4	20.8	565	380	6.6 P
	RPD =	21		8	1			0	1	3	30
08/12/92		21	0.01 U	1.5		0.31	2	19.7	577	338	6.2 P
08/12/92		17	0.01 U	1.4		0.22	2	19.7	579	350	26
	RPD =	21		7		34		0	0	3	123
10/21/92		10	0.01 U	1.18		0.63	4	17.0	536	303	
10/21/92		12	0.01 U	1.19		0.63	4	17.1	536	308	
	RPD =	18		1		0		1	0	2	
12/7/92		15	0.01 U	1.53	1.84	0.40	2	28.6	591	369	21 B
12/7/92	RPD =	16	0.01 U	1.51	1.93	0.49	2	28.6	591	363	9.6 PB
		6		1	5	20		0	0	2	75

B = Value less than 5 times the rinsate blank.

U = Analyte not detected above listed detection limit.

P = Analyte detected above the instrument detection limit but below the established minimum quantitation limit.

RPD = Relative percent difference (ratio of the difference of duplicate results divided by the mean and expresed as a percent).

TKN = Total Kjeldahl Nitrogen (as performed by contracted lab).

In December 1992, the RPD for TPN was lower than for TKN for split samples from the Site 1 well. The RPD for TPN was 4.8% compared to 20.2% for TKN. Likewise the maximum RPD for TPN during the study, 5.7%, was less than for TKN, 34%.

The TPN and TKN analyses are not directly comparable, since TPN includes both organic and inorganic fractions, while TKN does not include inorganic forms. Both analyses include ammonia and organic nitrogen, however. When nitrate+nitrite-N is subtracted from the TPN value, the results are comparable.

No significant difference was found between the TPN and TKN results in December 1992 after nitrate+nitrite was subtracted from the TPN values as shown in Table F.2.

Nitrate
Results for nitrate samples split between Tree Top and Ecology were in close agreement. Table F.3. shows the relative percent difference between results for eight samples. The mean relative percent difference is less than 7%. If the Ecology data are rounded to two significant figures the differences are negligible.

Rinsate Blanks
Results for rinsate blanks are shown in Table F.4. Sample values less than five times the blank value on that date are qualified with a "B" in Appendix G.

Table F.2. Total Persulfate Nitrogen (TPN) and Total Kjeldahl Nitrogen (TKN) results on December 7, 1992.

Site	Total Persulfate N minus Nitrate+nitrite-N (mg/L)	Total Kjeldahl N (mg/L)
LY1-B1	0.43	0.52
WW-2	0.35	0.39
WW-3	0.37	0.40

Table F.3. Relative percent difference between Tree Top and Ecology nitrate data.

Date	Tree Top Nitrate-N (mg/L)	Ecology Nitrate + Nitrite-N (mg/L)	Mean of Tree Top and Ecology (mg/L)	Relative % Difference*
Site 1				
7/13/92	1.8	1.67	1.74	7.5
8/11/92	1.3	1.45	1.38	10.9
10/21/92	1.2	1.19	1.20	0.8
12/07/92	1.5	1.52	1.51	1.3
Site 2				
7/13/92	0.3	0.313	0.31	4.2
8/11/92	0.5	0.47	0.49	6.2
10/21/92	1.3	1.62	1.46	21.9
12/07/92	1.1	1.09	1.10	0.9

* Relative % difference = [(Treetop Nitrate-Ecology Nitrate+Nitrite)/(Mean of the Treetop and Ecology values) x 100.

Table F.4. Rinsate blank results in mg/L.

Date	Chloride	Conduc-tivity (Laboratory)	Ammonia as N	Nitrate+ Nitrite as N	Total Persulfate Nitrogen	Total Kjeldahl Nitrogen	Chemical Oxygen Demand	Dissolved Iron
06/26/92	0.11	1.4	0.01 U	0.01 U	0.01 U		5 U	
07/14/92	0.18	28.4	0.05 U	0.05 U	0.05 U		5 U	5.0 U
08/11/92	0.13	2.72	0.01 U	0.02 U		0.13	6.1	5.0 U
10/21/92	0.18	6.3	0.01 U	0.027		0.23	5	5.0 U
12/07/92	0.23	0.6	0.01 U	0.01 U	0.01 U	0.05	5 U	

U = Analyte not detected above listed detection limit

Appendix G. Water quality data.

Table G.1. Lysimeter water quality data. Duplicates are shown as means(*). Concentrations are in mg/L except iron which is in ug/L.

Site	Date	Conductance (Lab)	COD	Ammonia-N	NO3+NO2 N	Total Persulfate-N	Total Kjeldahl-N	Total N+	Chloride	Iron Total	Iron Diss	TSS	TDS
Site 1													
Barrel 1	06/26/92	693	340	0.048	12	18.4		18.4	90.6			8	
Barrel 1*	07/13/92	546	55.3	0.05	2.88	4.53		4.53	89.2		75.7		
Barrel 1*	08/11/92	526	42.5	0.065	0.02		0.535	0.537	51.7				
Barrel 1	10/21/92	466	14 B	0.01	0.01 U		0.63 B	0.63	73.4				
Barrel 1	12/07/92	309	17	0.029	0.014	0.445	0.52	0.50	48.2				
Barrel 2	06/26/92		465						78.2				
Barrel 2	07/13/92	632	58.4	0.111	0.67	1.42		1.42	68.2				
Barrel 2	08/11/92	490	33	0.17	0.02 U		0.58	0.58	38.6				
Barrel 2*	10/21/92	338	32.5	0.020	0.01 U		1.05 B	1.05	42.1		69.1		
Brick 1	07/13/92	670	63.3	0.05	27.6	27.5		27.5	54		76.9		
Brick 1	08/11/92		53										
Brick 1	10/21/92	602	89	0.034	1.34		3.2	4.54	57.3				
Brick 1	12/07/92		50	0.073	4.74	6.57		6.57					
Site 2													
Barrel 3	07/13/92	610	52.8	0.079	0.050 U	1.15		1.15	48.3				
Barrel 3	08/11/92	481	32	0.08	0.020 U		0.31	0.31	16.2				
Barrel 3	10/21/92	466	14 B	0.01	0.01 U		0.63 B	0.63	73.4				
Barrel 4	07/13/92	651	43.5	0.137	0.050 U	1.27		1.27	70.1				
Barrel 4	08/11/92	582	41	0.14	0.020 U		0.42	0.42	42.9				
Barrel 4	10/21/92	568	26	0.01	0.224		0.86 B	1.08	66.0				
Brick 2	07/13/92		30.8	0.050	17.1	15.9		17.1					
Brick 2	08/11/92	516	42						35.6				
Brick 2	10/21/92	473	44	0.123	1.19		2.0	3.19	33.7		52.9		

+: Total N = Either Total Persulfate N or the sum of Total Kjeldahl N and Nitrate+nitrite.

B: Measurement is less than 5 times the transport blank value.

U: Analyte was not detected at or above the reported result.

Table G.2. Water quality data for monitoring wells and effluent. Duplicates are shown as means (*). Well 1 is at Site 1; Well 2 at Site 2.

Site	Date	Conductance (Lab)	COD	Ammonia-N	NO3+NO2 N	Total Per-sulfate-N	Total Kjel-dahl-N	Total N+	Chloride	BOD	Iron Total	Iron Diss	TSS	TDS
Well 1*	07/13/92	567	11.7	0.050	1.67	1.95		1.95	20.9	4 U		7.8	374	
Well 1*	08/11/92	578	19 B	0.01	1.45		0.265	1.71	19.7	2 U		26		
Well 1*	10/21/92	536	11 B	0.01	1.19		0.63	1.82	17.1	4 U		11		306
Well 1*	12/07/92	591	15	0.01	1.52	1.89	0.40	1.89	28.6	2 U			7.5	366
Well 2	07/13/92	272	6.11	0.050	0.313	0.601		0.601	4.9	4 U		9.1		
Well 2	08/11/92	256	10 B	0.010	0.47		0.45	0.92	8.4	2 U		6.0		
Well 2	10/21/92	440	14 B	0.01	1.62		0.90	2.52	30.1	4 U		14		304
Well 2	12/07/92	335	12	0.01	1.09	1.44	0.39	1.44	17.1	4 U			152	232
Effluent-1	06/25/92	503	650	1.40	0.020	15.9		15.9	62.4		1,220			
Effluent-1	07/13/92	538	598	0.17	2.05	30.7 J		30.7	74.3	140	1,730		643	
Effluent-1	08/11/92	384	700	0.03	0.03		25	25	30.8	68	1,060			
Effluent-1	10/21/92	602	220	0.075	1.81		9.8	11.6	60.4	40	295		127	385
Effluent-2	06/25/92	477	620	0.983	0.013	10.1		10.1	57.0				680	
Effluent-2	07/13/92	533	587	0.161	1.99	34.9 J		34.9	67.2	120 J	1,520		700	
Effluent-2	10/21/92	603	170	0.075	1.71		10	11.7	60.2	42	220		130	374
Irrigation Water	08/11/92	153	14	0.01	0.02 U		0.21	0.21	2.5	3.3	456		32	95

\+ Total N = Either Total Persulfate N or the sum of Total Kjeldahl N and Nitrate+nitrite-N.

B: Measurement is less than five times the transport blank value.

J: Estimated value.

Appendix H. Data used to estimate percent treatment for COD and total N and percent increase for chloride. Duplicates are shown as means(*). Concentrations are in mg/L.

Site	Date	COD	Total N	Cl	COD Applied+	Concentration Factor++	COD Expected^	% COD Treated^^	Total N Applied+	Total N Expected^	% N Treated^^	Chloride Applied	Chloride Expected^	% Chloride Increase^^^
Site 1														
Barrel 1*	07/13/92	55.3	4.53	89.2	291	1.1	320	83	15.8	17.4	74	35	39	232
Barrel 1*	08/11/92	42.5	0.537	51.7	207	1.1	228	81	7.2	7.9	93	10	11	470
Barrel 1	10/21/92	14	0.63	73.4	195	1.0	195	93	11.7	11.7	95	60	60	122
Barrel 1	12/07/92	17	1.44	48.2	NA									
Barrel 2	07/13/92	58.4	1.42	68.2	291	1.1	320	82	15.8	17.4	92	35	39	177
Barrel 2	08/11/92	33	0.58	38.6	207	1.1	228	86	7.2	7.9	93	10	11	351
Barrel 2*	10/21/92	32.5	1.05	42.1	195	1.0	195	83	11.7	11.7	91	60	60	70
Brick 1	07/13/92	63.3	27.5	54	291	1.1	320	80	15.8	17.4	-58	35	39	140
Brick 1	08/11/92	53	NA	NA	207	1.1	228	77						
Brick 1	10/21/92	89	4.54	57.3	195	1.0	195	54	11.7	11.7	61	60	60	96
Brick 1	12/07/92	50	6.57	NA	NA									
Site 2														
Barrel 3	07/13/92	52.8	1.15	48.3	331	1.3	430	88	18.1	23.5	95	40	52	93
Barrel 3	08/11/92	32	0.31	16.2	229	1.3	298	89	8.0	10.4	97	11	14	113
Barrel 3	10/21/92	14	0.63	73.4	NA									
Barrel 4	07/13/92	43.5	1.27	70.1	331	1.3	430	90	18.1	23.5	95	40	52	135
Barrel 4	08/11/92	41	0.42	42.9	229	1.3	298	86	8.0	10.4	96	11	14	300
Barrel 4	10/21/92	26	1.08	66.0	NA									
Brick 2	07/13/92	30.8	17.1	NA	331	1.3	432	93						
Brick 2	08/11/92	42	NA	35.6	229	1.3	298	86				11	14	249
Brick 2	10/21/92	44	3.2	33.7	NA									

\+ Concentration Applied = (Concentration in mixed effluent/irrigation water x Fraction of mixed effluent in applied water) + (Concentration in irrigation water x Fraction of irrigation water only applied). See Appendix I for details.

++ Concentration Factor = Total estimated water applied/[(Total estimated water applied) – (3–day Evapotranspiration)].

^ Expected concentration = Applied concentration x Concentration Factor.

^^ % Treatment = 1–(Lysimeter concentration/Expected concentration) x 100.

^^^ % Increase = (Lysimeter concentration/Expected concentration) x 100.

Appendix I. Applied concentration estimates for COD, total N, and chloride. Concentrations are in mg/L.

Date	Effluent COD*	Effluent Total N*	Effluent Chloride*	Applied COD^	Applied Total N^	Applied Chloride^
Site 1						
07/13/92	593	32	70.8	291	15.8	35
08/11/92	700	25	30.8	207	7.2	10
10/21/92	195	12	60.3	195	11.7	60
Site 2						
07/13/92	593	32	70.8	331	18.1	40
08/11/92	700	25	30.8	229	8.0	11
Irrigation water						
08/11/92	14	0.21	2.5			

* Mean of two samples except on 8/11/92 when only one sample was available.

** (Number of hours effluent applied)/(Total number of hours water applied).

^ Concentration applied = (Concentration in effluent x Fraction of effluent in applied water) + [Concentration in irrigation water x (1−Fraction of effluent in applied water)]. See Appendix J for details.

Appendix J. Application rate calculations.

Table J.1. COD application rate calculations.

Date	Type of water	Hours Applied	Depth Applied (cm)*	Volume applied/Barrel (L)**	Applied COD (mg/L)***	Mixed COD (mg/L)+	COD Load (g/Barrel)	COD Load (g/cm2)	COD Load (lb/ft2)	COD Load (lb/acre)	COD Load (lb/acre/day)++
SITE 1											
07/10–	Effluent mix	9.8	8.4	10.9	593	291	6.6	0.005	0.010	455	533
07/11/92	Clean	10.7	9.2	11.9	14 ^						
08/07/92	Effluent mix	5.7	4.9	6.3	700	207	4.7	0.004	0.007	320	380
	Clean	14.5	12.5	16.2	14 ^						
10/19/92	Effluent mix	28	24.1	31.2	195	195	6.1	0.005	0.010	419	235
SITE 2											
07/10–	Effluent mix	10.6	5.6	7.3	593	331	4.4	0.003	0.007	302	375
07/11/92	Clean	8.7	4.6	6.0	14 ^						
08/07/92	Effluent mix	6.6	3.5	4.6	700	229	3.3	0.003	0.005	229	261
	Clean	14.5	7.7	10.0	14 ^						

* Depth (cm) = (Hours applied) x (Application rate (cm/hr)). Site 1 application rate is 0.34 in/hr (0.86 cm/hr); Site 2, 0.21 in/hr (0.53 cm/hr).

** Depth of water (cm) x area of the barrel (1,297 cm2).

*** Mean of two samples except on 8/11/92, when only one sample collected.

\+ Mixed COD = Time–averaged mean of applied COD in effluent mix and clean irrigation water applied in July and August.

++ Loading rate assumed to be mass/area applied divided by number of days applied.

^ COD concentration in ditch water (14 mg/L) based on one sample collected 8/11/92.

Table J.2. Total nitrogen application rate calculations.

Date	Type of water	Hours Applied	Depth Applied (cm)*	Volume applied/ Barrel (L)**	Applied Total N (mg/L)+	Mixed Total N (mg/L)++	Total N Load (g/ Barrel)	N Load (g/cm2)	N Load (lb/ft2)	N Load (lb/acre)	N Loading Rate (lb/ acre/day)+++
SITE 1											
07/10-11/92	Effluent mix	9.8	8.4	10.9	32.8	15.8	0.4	0.0003	0.00057	25	29
	Clean	10.7	9.2	11.9	0.2 ^						
08/07/92	Effluent mix	5.7	4.9	6.3	25.0	7.2	0.2	0.0001	0.00025	11	13
	Clean	14.5	12.5	16.2	0.2 ^						
10/19/92	Effluent mix	28	24.1	31.2	11.7	11.7	0.4	0.0003	0.00058	25	14
	Clean										
SITE 2											
07/10-11/92	Effluent mix	10.6	5.6	7.3	32.8	18.1	0.1	0.0001	0.00021	9	11
	Clean	8.7	4.6	6.0	0.2 ^						
08/07/92	Effluent mix	6.6	3.5	4.6	25.0	8.0	0.1	0.0001	0.00018	8	9
	Clean	14.5	7.7	10.0	0.2 ^						

* Depth (cm) = Hours applied x Application rate (cm/hr). Application rate assumed to be 0.34 inches/hour (0.86 cm/hour) at Site 1 and 0.21 in/hr (0.53 cm/hr) at Site 2.

** Depth of water (cm) x area of the barrel (1,297 cm2).

\+ Mean of two samples except on 8/11/92, when only one sample collected.

++ Time-weighted mean of applied total N and clean irrigation water applied after effluent mix in July and August.

+++ Loading rate assumed to be mass/area applied divided by the number of days applied.

^ Total N concentration in clean irrigation water (0.21 mg/L) based on sample collected 8/11/92.

Table J.3. Chloride application rate calculations.

Date	Type of Water	Hours Applied	Depth Applied (cm)	Volume applied/ Barrel (L)**	Applied Chloride (mg/L)***	Mixed Chloride (mg/L)+	Chloride Load (g/ Barrel)	Combined Cl Load (g/ Barrel)	Chloride Load (g/cm2)	Chloride Load (lb/ft2)	Chlorid Load (lb/acre)	Cl Loading Rate (lb/ acre/day)++
SITE 1												
07/10-11/92	Effluent mix	9.8	8.4	10.9	70.8	35	0.8	0.800	0.0006	0.00126	55	64
	Clean	10.7	9.2	11.9	2.5 ^							
08/07/92	Effluent mix	5.7	4.9	6.3	30.8	10	0.2	0.235	0.0002	0.00037	16	19
	Clean	14.5	12.5	16.2	2.5 ^							
10/19/92	Effluent mix	28	24.1	31.2	60.3	60	1.9	1.883	0.0015	0.00297	130	73
	Clean											
SITE 2												
07/10-11/92	Effluent mix	10.6	5.6	7.3	70.8	40	0.5	0.528	0.0004	0.00083	36	45
	Clean	8.7	4.6	6.0	2.5 ^							
08/07/92	Effluent mix	6.6	3.5	4.6	30.8	11	0.2	0.165	0.0001	0.00026	11	13
	Clean	14.5	7.7	10.0	2.5 ^							

* Depth (cm) = Hours applied x Application rate (cm/hr). Application rate assumed to be 0.34 inches/hour (0.86 cm/hour) at Site 1 and 0.21 in/hr (0.53 cm/hr) at Site 2.

** Depth of water (cm) x area of the barrel (1,297 cm2).

*** Mean of two samples except on 8/11/92, when only one sample collected.

\+ Time-weighted mean of applied chloride in effluent mix and clean irrigation water applied immediately after effluent mix .

++ Loading rate assumed to be mass/area applied divided no of days applied.

^ Chloride concentration in ditch water (2.5 mg/L) based on sample collected 8/11/92.