SOIL TREATMENT PERFORMANCE AND COLD WEATHER OPERATIONS OF DRIP DISTRIBUTION SYSTEMS

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ABSTRACT

As the population increases, suitable land for wastewater treatment and dispersal decreases. Drip distribution of wastewater is becoming more popular as an alternative form of on-site wastewater dispersal. This method of dispersal distributes the wastewater in small uniform doses, allowing the soil system more opportunity to treat the wastewater before it reaches the groundwater, even on less suitable soil types. This protects the environment as well as human health.

During the summer of 1999, soil samples were collected to a depth of 105 cm (42 in.) beneath six drip distribution sites in Wisconsin to evaluate the treatment performance of the soil. Three of the sites received septic tank effluent (STE), one site received recirculating gravel filter (RGF) effluent and two sites received effluent treated by aerobic treatment units (ATU). The soils at these sites ranged from coarse sand to clay loam. The depth of the driplines ranged from 10-50 cm (4-20 in.) below the ground surface.

The systems receiving STE showed very low fecal coliforms at 45-60 cm (18-24 in.) below the dripline with no detects below 60 cm (24 in.). The systems with pretreatment showed even better results, both for the RGF, which was very heavily loaded, and the ATU systems. This could probably allow for a reduction in the separation distance to 45 cm (18 in.) for systems receiving STE and 30 cm (12 in.) if the effluent is aerobically pretreated to a fecal coliform level of <1,000 colonies/100 ml. The nitrate-nitrogen levels exiting the system at 105 cm (42 in.) below the dripline had median values in the range of 26-83 mg N/L of soil water, regardless of treatment type. However, these concentrations are similar to the background levels, which were unexplainably high. The ammonium-nitrogen levels at 105 cm (42 in.) were also similar to background levels.

Temperatures were monitored at four of these sites from December 1, 1998 - March 30, 1999 and at five of these sites from December 1, 1999 - March 14, 2000. Although these were two mild winters for Wisconsin, air temperatures did fall below 0 C (32 F) for an extended period of time at each of the sites. In most cases, negative temperatures (Celsius) were also found in the soil at the depth of the dripline, as well as 10 cm (4 in.) below the dripline, often lasting a week at a time below 0 C (32 F). Soil temperatures at 10 cm (4 in.) below the depth of the dripline reached minimums of -1 C (30 F) in the southern portion of the state to -12 C (10 F) in the north. However, none of the systems studied encountered operational problems due the cold temperatures. With proper design and installation, drip distribution systems are an excellent alternative system for wastewater dispersal in cold climates.

KEYWORDS. Drip/Trickle irrigation, Soil, Fecal coliforms, Bacteria, Nitrate, Nutrient removal, Temperature, Wisconsin, Freezing, Cold climate.

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INTRODUCTION

As the population increases, suitable land for development is decreasing. The limiting factor in determining the suitability of land for development is often the soil necessary for a successful on-site wastewater treatment system. The majority of suitable land remaining in Wisconsin is that of agricultural fields. To avoid the development of prime agricultural land, alternative on-site wastewater treatment systems must be used.

In the 1960s, Wisconsin adopted a separation distance of 90 cm (3 ft.) from the infiltrative surface to a limiting condition of bedrock or seasonal saturation. During the summer of 2000, the code was updated to allow a reduction of this separation distance to 60 cm (2 ft.) if BOD and TSS are < 30 mg/L and fecal coliforms are < 10,000 colonies/100 ml. More uniform distribution with time dosing may also provide better soil treatment thus allowing a reduction in separation distance. This may be done with the use of drip distribution.

Drip distribution systems consist of several lines of small diameter, flexible, polyethylene tubing with very small emitters through which the wastewater is dosed. This allows for the wastewater to be dosed in very small amounts over a larger area, thereby providing an optimum environment for the soil bacteria to treat the wastewater before it reaches the groundwater. A system of this nature should allow for a smaller separation distance because of the better soil treatment performance. These systems have been used successfully for several years in warm climates. There are some concerns, however, that these systems may be prone to freezing in northern climates due to the recommended shallow burial depth of the driplines.

The objectives of this study were to: 1) evaluate the treatment performance of the soil beneath the drip distribution network and 2) monitor these systems for cold weather operation.

SITE DESCRIPTIONS

Six drip distribution systems in Wisconsin were studied (Bohrer, 2000). Three of these systems received septic tank effluent (STE), one received effluent treated through a recirculating gravel filter (RGF) and two systems received aerobically pretreated effluent through aerobic treatment units (ATU).

Barron County Site

One of the STE sites was located in Barron County, which is located in the northwestern portion of the state. The system serves a rest area, which includes a sanitary dump station. Two test pits in the distribution area indicated 18-23 cm (7-9 in.) of weak to moderate, subangular blocky, fine loamy sand. This horizon appeared to be fill material as a result of the highway construction several years earlier. This was followed by structureless, single grain sand, with up to 60% gravel, cobbles and boulders down to a depth of at least 210 cm (84 in.).

The site was designed for 22,713 Lpd (6,000 gpd), with the majority of flow accumulated on the weekends, and less flow during the week. The system was designed to dose each of the 6 zones with a loading rate of 1,041 L/dose (275 g/dose). The driplines were installed with a chisel plow, at depths that vary from about 10 cm (4 in.) to as deep as 30 cm (12 in.) below the surface. Following the installation of the driplines, approximately 20 cm (8 in.) of sandy loam topsoil, taken from what had been cut off of the hill, was spread over the surface of the distribution network. This resulted in dripline depths ranging from 30-50 cm (12-20 in.) below the final grade.

The Barron County drip system, installed in 1998, consists of the highly computerized Perc-Rite[§] system, which filters septic tank effluent (Wastewater Systems, Inc., 1999). The effluent is time-dosed to the distribution network, which consists of 6 zones. Zones 1 and 2 are 34 m (113 ft.) long by 5.5 m (18 ft.) wide (187 m^2, 2,034 ft^2) and zones 3-6 are 37 m (121 ft.) long by 5.5 m (18 ft.) wide (204 m^2, 2,178 ft^2). Therefore, the design soil loading rates are 22 L/d/m^2 (0.54 gpd/ft^2) for zones 1 and 2 and 21 L/d/m^2 (0.51 gpd/ft^2) for zones 3-6 (Table 1). Zones 3-5 were the focus of this study. The driplines are spaced 0.3 m (1 ft.) on center with each zone (zones 3-5) containing 664 linear meters (2,178 linear ft.) of Netafim tubing with 1,089 pressure compensating emitters at a flow rate of 2.5 L/hour (0.65 gph) per emitter. A heavy cover of a mixture of typical highway vegetation has been established with the vegetation cut on occasion.

Table 1. Calculated or Estimated Loading Rates for Each Site.

Site Name	**Effluent Quality**	**Loading Rates** **Landscape** gpd/linear foot	 **Landscape** L/d/linear meter	 **Areal** gpd/ft^2	 **Areal** L/d/m^2
Jackson	Treated	1.2	15	0.60	24
Monroe	Treated	24	300	0.60	24
Rock	Treated	1.8	22	0.60	24
Barron[a]	Septic	9.1	113	0.51	21
Zone 3	Septic	4.8	59	0.26	11
Zone 4	Septic	13	167	0.75	30
Zone 5	Septic	4.8	59	0.26	11
Fond du Lac (Clay)	Septic	1.1	14	0.08	3.1
Fond du Lac (Sand)	Septic	1.1	14	0.23	9.3
Wood	Septic	3.4	42	0.11	4.6

[a] The first set of numbers are the design loading rates for zones 3-5. The loading rates presented individually for each zone are estimates due to the faulty check valves in these zones.

Fond du Lac County Site

Another STE system served a residence in Fond du Lac County, which is located in the east-central portion of the state. This system served a three-bedroom home, with an average water usage of 462 liters per day (122 gpd) during the time of this study. Soil borings collected by a certified soil tester showed a moderate, subangular blocky silt loam soil down to 23-35 cm (9-14 in.) below the ground surface, followed by 25-50 cm (10-20 in.) of weak to moderate, subangular blocky silty clay loam, followed by 50-95 cm (20-38 in.) of structureless, massive clay loam down to the bottom of the soil borings. Redoximorphic features indicated shallow seasonal saturation at 35 cm (14 in.) so a modified mound was constructed on the surface. Construction consisted of placing approximately 15 cm (6 in.) of coarse sand on top of the tilled ground surface, placement of the drip tubing, and placing 5 cm (2 in.) of sand over the

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[§] Use of product and company names is for illustrative purposes and does not constitute endorsement of the product or company.

tubing, followed by 15 cm (6 in.) of sandy loam soil. Two sets of loading rates were calculated to account for the different properties of the sand and clay loam layers. The sand loading rate is based on the daily flow rate over the zone 2 area (1.5 by 29 m, 5 by 95 ft.), resulting in a loading rate of 9.3 L/d/m^2 (0.23 gpd/ft^2). The clay loam loading rate is based on the basal area consisting of the zone 2 footprint and the sand area down slope of zone 2 (4.6 by 29 m, 15 by 95 ft.) resulting in a loading rate of 3.1 L/d/m^2 (0.08 gpd/ft^2) (Table 1). This was done because the effluent percolates through the sand and then moves laterally over the surface of the clay loam before infiltrating this layer. This results in a smaller areal loading rate for the clay loam layer than the sand layer.

This system consists of a hydraulic unit designed by American Manufacturing Company, Inc., which filters the septic tank effluent (American Manufacturing Company, Inc., 1997). The system is time-dosed and applies 128 L/dose (33.8 g/dose) and uses Netafim tubing with pressure compensating emitters. The tubing was divided into 2 zones with each zone 1.5 m (5 ft.) wide by 29 m (95 ft.) long with 0.3 m (1 ft.) spacing between zones. The driplines were placed by hand, 15 cm (6 in.) apart, with approximately 20 cm (8 in.) of soil cover. Zone 2, located down slope of zone 1, was active throughout the course of this study, while zone 1 remained inactive to provide a control for the temperature data.

Wood County Site

The third STE site, installed in June 1998, was located in Wood County, which is in the central portion of the state. This system serves a 100 student elementary school with no kitchen, but with plans to expand the school to accommodate 350 students, so the system was designed for the larger number. The effluent from the school is treated in a recirculating gravel filter (RGF) before entering the drip distribution system, however, the RGF was off-line during the time of this study. This site also contains the highly computerized Perc-Rite system, similar to that used at the Barron County site (Wastewater Systems, Inc., 1999).

Soil borings at this site showed moderate granular loam with 5-10% gravel down to a depth of about 25 cm (10 in.) changing to moderate subangular blocky loam to about 50 cm (20 in.) below the soil surface. A thick, moderate, prismatic to subangular blocky, gravelly sandy clay layer exists from about 50-75 cm (20-30 in.), followed by structureless, massive clay to sandy clay, with some gravel, down to the bottom of the bore hole at 165 cm (66 in.) below the ground surface. Redoximorphic features show seasonal saturation at 38 cm (15 in.) below the ground surface.

There are four equally sized zones of 9.1 m by 31.7 m (30 by 104 ft.; 288.5 m^2, 3120 ft^2). The driplines used are Netafim brand with pressure compensating emitters. The emitters are spaced every 0.6 m (2 ft.) along the dripline and the driplines are spaced 0.6 m (2 ft.) apart resulting in 0.37 m^2 (4 ft^2) of infiltrative surface per emitter. The driplines were installed at a depth of 20-25 cm (8-10 in.) using a vibratory plow. The design flow rate is 9,464 Lpd (2,500 gpd). During the time of this study, the average actual flow was about 2,650 Lpd (700 gpd). Zones 1 and 2 were the only active zones during this study with an actual areal loading rate of 4.6 L/d/m^2 (0.11 gpd/ft^2) (Table 1).

Monroe County Site

The fourth system, located in Monroe County in the west central portion of the state, was installed at a seasonal campground in June of 1998 and operates between mid-May and mid-October. It was designed to serve 84 campsites as well as a sanitary dump station. The soil at this site consists of about 18 cm (7 in.) of weak, granular loamy sand, followed by 15-38 cm (6-15 in.) of weak, angular blocky, loamy sand, followed by structureless, single grained, fine to medium sand for the remaining depth of the soil borings, down to 235 cm (94 in.). Redoximorphic features were present in several borings showing seasonal saturation at 100 cm (40 in.) while other borings showed none.

The two zones at this site contain Geoflow tubing with turbulent flow emitters that are spaced every 0.6 m (2 ft.) along the length of the dripline. Each zone is 12.2 m (40 ft.) by 40.2 m (132 ft.) (490 m^2, 5,280 ft^2), with both zones being dosed concurrently on a demand basis. The dispersal zones are located in a heavily wooded pine area with very little undergrowth. When the driplines were installed, the ground surface was first cleared of most of the debris. The driplines were then laid on the ground surface, trying to maintain 0.6 m (2 ft.) spacing where possible. Approximately 15-20 cm (6-8 in.) of loamy sand was spread over the top of both zones and the area was planted with grass seed. This system was designed with a capacity of 22,713 liters per day (6,000 gpd). Estimated daily flows are closer to 23,470 liters per day (6,200 gpd). The calculated areal loading rate was 24 L/d/m^2 (0.6 gpd/ft^2) (Table 1). The wastewater is treated through an Orenco recirculating gravel filter (RGF), with the effluent discharged from a pump chamber to two dispersal zones.

Jackson County Site

One of the ATU sites was in Jackson County, which is in the west-central portion of the state. This system served a three-bedroom home, with an average water usage of 458 Lpd (121 gpd). The system is located in a slightly wooded area with large pine trees and a manicured lawn. The soil at this site consists of 13-38 cm (5-15 in.) of weak, columnar loamy fine sand. This is followed by structureless, single grained, fine sand to the bottom of the soil borings, at a depth of 143 cm (57 in.) below the ground surface. Redoximorphic features indicate no seasonal saturation to bottom of borings.

The dripline, consisting of Geoflow tubing with turbulent flow emitters, was installed using a vibratory plow at depths varying from 10-20 cm (4-8 in.). The lines were installed approximately 0.6 m (2 ft.) apart, with a few deviations to avoid the trees. This dispersal area consists of two zones, each containing 2 runs of 30.5 m (100 ft.) of dripline per run. During this study, the effluent was discharged on demand to one run in one of the zones, resulting in an actual areal loading rate at this site was 24 L/d/m^2 (0.6 gpd/ft^2) (Table 1).

Rock County Site

The other ATU system was in Rock County, which is located in south central Wisconsin. This system was installed in the fall of 1995 to serve a three-bedroom home. During the time of this study, there were two people in the home, with an average flow of 757 Lpd (200 gpd). The effluent is treated through a trash tank with the pump dosing to the Multi-Flo unit on regular intervals. The soil at this site consisted of 0-20 cm (0-8 in.) of moderate, granular, sandy loam followed by 20-80 cm (8-32 in.) of weak to moderate, subangular blocky, gravelly sandy clay, followed by structureless, single grained, loamy sand (80-135 cm, 32-54 in.), which finally becomes single grained sand and gravel at 135 cm (54 in.) below the ground surface, down to a depth of at least 250 cm (100 in.). Redoximorphic features were found in one of three borings at 225 cm (90 in.) beneath the surface.

There were 5 zones installed at this site using a vibratory plow. The dripline used was a Geoflow tubing with turbulent flow emitters. Each zone consists of two lines at a length of 30.5 m (100 ft.) each, spaced 1.8 m (6 ft.) on center, with a single dripline between rows of black walnut trees. Each zone was buried at varying nominal depths of 15, 25, 40, 60 and 75 cm (6, 10, 16, 24 and 30 in.). During the course of this study, the only zone in operation was the 15 cm (6 in.) depth. Only the north half of this zone was active in order to compare temperatures of the active zone with the zone not in operation. This system is demand-dosed at a rate of 227 L/dose (60 g/dose). Although the driplines are spaced 1.8 m (6 ft.) on center, the areal loading rate was calculated assuming a 0.37 m^2 (4 ft^2) area per emitter. The actual areal loading rate, based on one dripline, was 24 L/d/m^2 (0.6 gpd/ft^2) (Table 1).

METHODS AND MATERIALS

Soil Performance

Effluent samples were collected from each pump chamber periodically throughout the course of this study, as well as during each soil sampling trip. The pump chamber acted as the compositor with the sample collected in a one-liter bottle next to the pump. These samples were analyzed for solids, BOD, Total Kjeldahl Nitrogen (TKN), ammonium-nitrogen, nitrate-nitrogen, COD, TOC, chloride, EC, total and fecal coliforms, *E. coli*, total alkalinity and pH according to Standard Methods (APHA, 1992).

Soil samples were collected from each site, both beneath and adjacent to the distribution network. The samples were collected at 15 cm (6 in.) intervals down to 105 cm (42 in.) below the dripline at an emitter. A modified Oakfield probe with a sterilized 2.5 cm (1 in.) diameter hollow core was used to collect the bacteria sample. A 2.5 cm (1 in.) deep sample was collected directly at the emitter with a sterilized spoon. Samples were also collected with a sterilized spoon at the ground surface and 10 cm (4 in.) above the emitter, to determine if the effluent was moving up during the dose events. These samples were analyzed for fecal coliforms and *E. coli* by the Most Probable Number (MPN) method according to Standard Methods (APHA, 1992). After each bacteria sample was collected, a 7.5 cm (3 in.) diameter bucket auger was used to collect the soil from around the previously collected 2.5 cm (1 in.) diameter core. These samples were analyzed for total nitrogen (TN), ammonium-nitrogen (NH_4-N) and nitrate-nitrogen (NO_3-N). For the TN analysis, the samples were digested with sulfuric acid, salicylic acid and a catalyst and analyzed through flow injection analysis (UWEX, 1987). The NH_4 and NO_3 samples were extracted with potassium chloride and analyzed through flow injection analysis (UWEX, 1987). At each sampling time, two profiles beneath emitters and two profiles adjacent to the distribution network were taken, along with a pump chamber effluent sample. Each site was sampled 3 times during the summer and fall of 1999. Additional effluent samples were also collected prior to, during and after the soil sampling phase and are included in this study.

Cold Weather Operation

The second part of this study was to monitor drip distribution systems for cold weather performance. To accomplish this, a number of thermocouples were installed at each site to measure the soil temperatures at various depths in the dispersal area, the air temperature and the temperature of the effluent in the pump chamber. The thermocouples were installed at the emitter, as well as 10 cm (4 in.) directly above and below the emitter. Thermocouples were also placed between emitters (0.3 m (1 ft.) along the tube from an emitter) as well as 10 cm (4 in.) directly above and below. These groupings of thermocouples were located in both active zones and control areas to monitor the background soil temperatures. Each active zone contained three sets of thermocouples at three depths located at emitters and two sets of thermocouples between emitters (one set on each side of one emitter), for a total of 15 thermocouples per zone. The control areas contained a similar combination of thermocouples when possible. Temperature data were recorded six times a day (every four hours) from around December 1 through March 1998-2000. Additional details are available from Bohrer, 2000.

RESULTS AND DISCUSSION

Soil Performance

Characteristics of the effluent entering the distribution networks are given in Table 2. For the Barron and Wood County sites additional samples were taken following the disk filters to determine filter performance. Due to the layout of other systems, samples could only be collected prior to filtration. Median values are reported throughout this discussion instead of averages, as one or two numbers can skew average values.

Table 2. Characteristics of Effluent Entering the Distribution Network Based on Median Values of All Samples Collected.

Characteristic	Units	STE			RGF	ATU	
		Barron[a] (Rest Area)	**Fond du Lac** (Home)	**Wood**[a] (School)	**Monroe** (Camp-ground)	**Jackson** (Home)	**Rock** (Home)
BOD$_5$	mg/L	173	110	218	24	20	1
TSS	mg/L	51	20	49	11	25	2
Total Coliforms	col/100 ml	1,500,000	35,000,000	2,100,000	900,000	16,000	3,150
Fecal Coliforms	col/100 ml	380,000	11,000	180,000	52,000	600	37
E. coli	MPN/100 ml	2,400,000	26,000	182,000	58,000	100	100
Total Nitrogen	mg N/L	185	45	92	59	32	28
NH$_4$-N	mg N/L	167	36	77	33	11	0.2
NO$_3$-N	mg N/L	0.3	0.2	0.5	10	17	28
COD	mg/L	510	300	590	75	78	10
TOC	mg/L	170	92	213	25	29	4
EC	mos/cm	1,860	4,300	1,230	720	500	2,180
Chloride	mg/L	114	1,051	93	61	55	476
Total Alkalinity	mg/L CaCO$_3$	656	418	403	213	35	253
pH		7.81	7.92	6.34	6.55	6.34	7.89
DO	mg/L				1.92	4.67	7.59

[a] Effluent samples were collected following disk filtration.

For the three STE systems, the median five-day biochemical oxygen demand (BOD) ranged from 110-218 mg/L, which is typical for a septic tank effluent. Total suspended solids (TSS) were also typical, with median values ranging from 20-51 mg/L. Fecal coliform and *E. coli* median values ranged from 11,000-380,000 col/100ml and 26,000-2,400,000 MPN/100 ml, respectively. Median ammonium-nitrogen values from the Barron and Wood County sites were higher than those typically seen for STE, due to the wastewater only coming from sinks and toilets at these sites.

The RGF performed well in producing a BOD and TSS of 24 and 11 mg/L, respectively, but nitrification and denitrification processes were inhibited, as the ammonium-nitrogen level of 33 mg N/L was considerably higher than expected. Also, the fecal coliform and *E. coli* median values appear to be higher than expected at 52,000 colonies/100 ml and 58,000 MPN/100 ml, respectively. This performance may be linked to overloading and the source of the wastewater being primarily from toilets, sinks and showers.

The two ATU sites had very low median BOD and TSS values, ranging from 1-20 and 2-25 mg/L, respectively. These systems also produced low median fecal coliform levels of 37-600 col/100 ml and low median *E. coli* levels of 100 MPN/100 ml. Median ammonium-nitrogen values ranged from < 1 to 11 mg N/L and median nitrate-nitrogen values were 17-28 mg N/L for these ATU sites.

At the Barron and Wood County sites it was possible to collect effluent samples both prior to and following the disk filters. Table 3 shows the effluent characteristics from both sets of samples to give an indication of the removal efficiency of these filters. Following filtration, BOD levels at Barron County were reduced by 26%, while suspended solid levels were reduced by 38%. Reductions were also seen with all of the other parameters evaluated. At Wood County there was a 27% reduction BOD and a 26% reduction in suspended solids after filtration. A negative reduction is shown for fecal coliforms, however these values are within the same order of magnitude. Several small reductions occur with the other effluent parameters, with the exception of an increase in nitrate-nitrogen, total alkalinity and temperature following filtration.

Table 3. Percent Removal of Effluent Characteristics Following Filtration Based on Median Values of All Samples Collected.

Characteristic	**Units**	**Barron County**			**Wood County**		
		Before	After	% Removal	Before	After	% Removal
BOD$_5$	mg/L	234	173	26	300	218	27
TSS	mg/L	82	51	38	66	49	26
Total Coliforms	col/100 ml	16,600,000	1,500,000	91	2,800,000	2,100,000	25
Fecal Coliforms	col/100 ml	750,000	380,000	49	140,000	180,000	-29
E. coli	MPN/100 ml	3,100,000	2,400,000	23	214,000	182,000	15
Total Nitrogen	mg N/L	201	188	6	93	92	1
NH$_4$-N	mg N/L	174	167	4	77	77	0
NO$_3$-N	mg N/L	0.7	0.4	43	0.4	0.5	-25
COD	mg/L	543	510	6	600	590	2
TOC	mg/L	189	170	10	213	213	0
EC	mos/cm	1,925	1,860	3	1,250	1,230	2
Chloride	mg/L	124	114	8	85	83	2
Total Alkalinity	mg/L CaCO$_3$	696	630	9	379	403	-6
pH		7.92	7.82	1	6.54	6.34	3
Data Temp	C	14.9	13.5	9	9.8	11.2	-14

Fecal coliform profiles both above and below the distribution network are shown in Table 4. These are the median values from 6 sets of soil samples. Many of these samples reported values below detection limits of <1 or <2 MPN/gram of dry soil. To calculate statistics on these samples a value of 0.5 was used in place of a reported value of <1 and a value of 1 was used for reported values of <2.

At Barron County, a most probable number (MPN) of 152 fecal coliforms per gram of dry soil was found at a depth 10 cm (4 in.) above the dripline. This was apparent during sampling as a visible biomat was protruding above the dripline. Directly below the dripline the fecal coliform level was highest at 6,567 MPN per gram of dry soil and dies-off to 1 MPN/gram of dry soil at depths greater than 45 cm (18 in.) below the dripline. The effluent, during the time the soil samples were collected, had a median value of 4,100,000 fecal colonies per 100 ml (Table 2). There was a prevalent biomat at this site, which was unexpected due to the coarse texture of the soil. However, this system was heavily loaded during peak use periods with septic tank effluent with a median BOD of 173 mg/L. Also, during the grading of the site, heavy machinery was apparently driven over the area in which the distribution network was to be installed, which may have resulted in a soil compaction, thereby assisting in the development of a biomat.

Table 4. Median Fecal Coliform Concentrations in Soil Samples in MPN/gram of Dry Soil.

Sample Interval	**STE**			**RGF**		
	Barron (Rest Area)	**Fond du Lac** (Home)	**Wood** (School)	**Monroe** (Camp-ground)	**Jackson** (Home)	**Rock** (Home)
Soil Surface	1[a]	11	3	1,910	3	1
10 cm (4") Above Dripline	152	1	149	1,337	1	1
Depth Below Dripline						
0-2.5 cm (0-1")	6,567	19	553	3,781	8	1
2.5-15 cm (1-6")	1,806	19	80	164	12	1
15-30 cm (6-12")	2	2	24	1	2	1
30-45 cm (12-18 ")	5	3	84	6	4	1
45-60 cm (18-24")	1	1	9	5	2	1
60-75 cm (24-30")	1	1	1	4	1	2
75-90 cm (30-36")	1	1	1	1	1	1
90-105 cm (36-42")	1	1	1	1	1	1
Effluent (col/100 ml)						
During Soil Sampling[b]	4,100,000	16,000	180,000	870,000	1,100	33
All Samples	380,000	11,000	180,000	52,000	600	37
Soil at Dripline	Coarse Sand	Coarse Sand	Silt Loam	Fine Sand	Sandy Loam	Sandy Loam
Dominant Soil Type	Coarse Sand	Clay Loam	Clay Loam	Fine Sand	Sandy Loam	Sandy Loam

[a] A value of 1 is considered to be below detection limits.

[b] During Soil Sampling: Samples taken at time of soil sampling consisting of the median value of three samples. All Samples: Median value of all samples taken before, during and after soil sampling trips.

At the Fond du Lac County site, the fecal die-off followed a similar pattern, again with the highest values (19 MPN/gram of dry soil) being within 15 cm (6 in.) below the dripline. This concentration is reduced to 1 MPN/gram of dry soil at depths greater than 45 cm (18 in.) below the dripline. Effluent distributed from the pump chamber during the time of soil sampling had a median fecal coliform concentration of 11,000 col/100 ml (Table 2), which is very low for typical septic tank effluent and may be a factor in the die-off rate at this site. The high value of 11 MPN/gram of dry soil located at the surface was apparently not from the effluent as there was no sign of effluent surfacing.

The Wood County site showed a most probable number of 149 colonies per gram of dry soil at a depth 10 cm (4 in.) above the dripline. This can be justified due to some observed surfacing of the effluent during some of the sampling trips. A high median value of 553 MPN/gram of dry soil was found at the depth of the dripline, with 1 MPN/gram of dry soil at a depth of 60 cm (24 in.). During the time of the soil sampling, the effluent entering the system had a median value of 180,000 col/100 ml.

The site at Monroe County, which was treated with a recirculating gravel filter, showed very high fecal coliform levels at depths above the dripline, which were caused by what is known as the chimney effect. The instantaneous loading rate exceeds the capacity of the soil to move the effluent away from the emitters, resulting in effluent moving upward to the surface through small channels created in the fine sand at this site. Once these pathways have been created, the effluent will continue to flow upward, following the path of least resistance. This phenomenon explains the very high median fecal coliform counts of 1,910 MPN/gram of dry soil at the soil surface. The median count of 3,781 MPN/gram of dry soil 2.5 cm (1 in.) below the dripline was reduced to 1 MPN/gram of dry soil at depths greater than 75 cm (30 in.) below the dripline, with values ≤ 6 MPN/gram of dry soil at 15-75 cm (6-30 in.) below the dripline. The fecal coliform count in the effluent following the recirculating gravel filter was 870,000 col/100 ml during the time of soil sampling, which appears to be high for a RGF.

Both sites with aerobic treatment units (Jackson and Rock Counties) showed low fecal coliform levels throughout the profile. The very low fecal coliform levels in the effluent (33-1,100 colonies/100 ml) can explain these low values in the soil.

The results from the *E. coli* analysis in the soil are shown in Table 5. The reported values of <1 and < 2 were replaced by values of 0.5 and 1, respectively, in order to calculate statistics. The *E. coli* results are very similar to those for fecal coliforms. At all three sites with septic tank effluent (Barron, Fond du Lac and Wood Counties), *E. coli* levels are highest within 2.5 cm (1 in.) below the dripline. These values decline dramatically to a median value of 1 MPN/gram of dry soil at depths greater than 60 cm (24 in.) below the dripline. The die-off is most dramatic at the Barron County site, where *E. coli* levels are at 2,081 MPN/gram of dry soil at the dripline and decrease to 1 MPN/gram of dry soil at depths > 15 cm (6 in.) below the dripline.

Table 5. Median *E. coli* Concentrations in Soil Samples in MPN/gram of Dry Soil.

	STE			**RGF**		
Sample Interval	**Barron**	**Fond du Lac**	**Wood**	**Monroe**	**Jackson**	**Rock**
Soil Surface	1[a]	10	3	432	2	1
10 cm (4”) Above Dripline	17	1	195	646	1	1
Depth Below Dripline						
0-2.5 cm (0-1”)	2,081	19	358	1,581	2	1
2.5-15 cm (1-6”)	402	19	74	142	1	1
15-30 cm (6-12”)	1	2	24	1	1	1
30-45 cm (12-18 “)	1	4	84	2	1	1
45-60 cm (18-24”)	1	1	72	1	1	1
60-75 cm (24-30”)	1	1	1	2	1	2
75-90 cm (30-36”)	1	1	1	1	1	1
90-105 cm (36-42”)	1	1	1	1	1	1
Effluent (col/100 ml)						
During Soil Sampling[b]	3,500,000	26,000	180,000	38,000	100	100
All Samples	2,400,000	26,000	180,000	58,000	100	100

[a] A value of 1 is considered to be below detection limits

[b] During Soil Sampling: Samples taken at time of soil sampling consisting of the median value of three samples. All Samples: Median value of all samples taken before, during and after soil sampling trips.

At the Monroe county site, the results showed *E. coli* levels at 1-2 MPN/ gram of dry soil at 15-30 cm (6-12 in.). The upward movement of water has also carried some *E. coli* with it. Both of the sites with aerobic treatment units (Jackson and Rock Counties) had median *E. coli* levels of 2 MPN/gram of dry soil or less throughout the profile, mainly due to the low influent *E. coli* concentrations.

Organic nitrogen beneath and adjacent to the system appears typical for soil conditions (Table 6). As expected, there is a gradual decrease with profile depth at most of the sites. The Barron County site reflects a rather constant organic nitrogen concentration as the top layer of soil was removed prior to installation of the system, exposing the sub horizons. The high median value of 236 mg N/kg of dry soil at the depth of the dripline is an indication of the biomat that was present at this depth. The Fond du Lac County organic nitrogen values beneath and adjacent to the system are as expected. The lower value in the 2.5-15 cm (1-6 in.) interval is typical for sand fill as the system is a modified mound with 15 cm (6 in.) of sand beneath the driplines. The high organic nitrogen values from 15-45 cm (6-18 in.) below the dripline occur because this interval was originally the soil surface, before the sand fill was installed. At the lower depths organic nitrogen levels approach background levels.

Table 6. Median Organic Nitrogen Concentrations in Soil Samples in mg N/kg of Dry Soil.

	STE			RGF		
Sample Interval	**Barron**	**Fond du Lac**[a]	**Wood**	**Monroe**	**Jackson**	**Rock**
Depth Below Dripline						
2.5-15 cm (1-6”)	236	230	494	781	722	379
15-30 cm (6-12”)	97	2,027	257	386	288	316
30-45 cm (12-18 “)	111	2,084	206	344	199	218
45-60 cm (18-24”)	120	575	194	268	93	150
60-75 cm (24-30”)	136	406	178	131	91	102
75-90 cm (30-36”)	120	286	158	124	38	55
90-105 cm (36-42”)	129	222	135	91	61	54
Background (Equivalent Depth)						
0-15 cm (0-6”)	121	2,327	681	225	296	421
30-45 cm (12-18 “)	124	645	334	115	49	68
60-75 cm (24-30”)	165	292	228	113	19	117
90-105 cm (36-42”)	107	269	188	108	43	81
Effluent (col/100 ml)						
During Soil Sampling	20	8	11	9	4	0.7
All Samples	17	10	11	6	4	0.2

[a] 0-15 cm (0-6”) background interval is equivalent to 15-30 cm (6-12”) interval beneath dripline for Fond du Lac County site. This adjustment was made before statistical analysis.

The results for the ammonium-nitrogen analysis are shown in Table 7. The Barron, Wood and Monroe County sites have relatively high ammonium-nitrogen values down to about 45 cm (18 in.) below the driplines in comparison to the other three sites. This apparently reflects the higher portion of the wastes contributed by the toilets at the Barron, Wood and Monroe County sites. The Monroe County site also had a high ammonium effluent concentration due to a lack of nitrification in the pretreatment unit, indicating that the unit is not working properly (Table 2). For the three residence sites (Fond du Lac, Jackson and Rock Counties), the ammonium values are lower than the previously mentioned sites, most likely due to dilution from greywater. At all of the sites ammonium-nitrogen levels below 45 cm (18 in.) are similar to background levels, but from 2.5-45 cm (1-18 in.) these values are much lower for some unexplained reason.

Table 8 lists the nitrate-nitrogen results in mg N/kg of dry soil. To determine the concentration of the nitrate-nitrogen that has the potential to travel in the soil water, the moisture content of each sample must be taken into account. Table 9 shows the nitrate-nitrogen concentrations in mg N/L of soil water.

The nitrate values at 105 cm (42 in.) below the dripline ranged from 26 to 83 mg N/L of soil water for all samples. These values are very similar to results found by Converse et al. (1994) and Bates (1999) for nitrates leaving mound systems. Similar results were also found by Converse et al. (1991) for nitrates leaving at-grade systems and Converse et al. (1998) beneath modified mounds and at-grade systems receiving aerobically treated effluent. The nitrate concentrations approach the background levels at the lower depths in four of the six sites. However, this background data, appears to be very high compared to other studies. Nitrate

Table 7. Median Ammonium-Nitrogen Concentrations in Soil Samples in mg N/kg of Dry Soil.

	STE			RGF		
Sample Interval	**Barron**	**Fond du Lac**	**Wood**	**Monroe**	**Jackson**	**Rock**
Depth Below Dripline						
2.5-15 cm (1-6”)	61	10	24	58	7	7
15-30 cm (6-12”)	22	15	24	26	9	6
30-45 cm (12-18 “)	11	12	29	28	8	6
45-60 cm (18-24”)	120	575	194	268	93	150
60-75 cm (24-30”)	136	406	178	131	91	102
75-90 cm (30-36”)	120	286	158	124	38	55
90-105 cm (36-42”)	129	222	135	91	61	54
Background (Equivalent Depth)						
0-15 cm (0-6”)	121	2,327	681	225	296	421
30-45 cm (12-18 “)	124	645	334	115	49	68
60-75 cm (24-30”)	165	292	228	113	19	117
90-105 cm (36-42”)	107	269	188	108	43	81
Effluent (col/100 ml)						
During Soil Sampling	193	37	86	48	14	0.1
All Samples	167	36	77	33	11	0.2

Table 8. Median Nitrate-Nitrogen Concentrations in Soil Samples in mg N/kg of Dry Soil.

	STE			RGF		
Sample Interval	**Barron**	**Fond du Lac**	**Wood**	**Monroe**	**Jackson**	**Rock**
Depth Below Dripline						
2.5-15 cm (1-6”)	11	10	5	4	3	7
15-30 cm (6-12”)	7	10	3	6	6	6
30-45 cm (12-18 “)	8	9	3	5	7	7
45-60 cm (18-24”)	8	9	3	4	6	8
60-75 cm (24-30”)	7	6	4	4	3	7
75-90 cm (30-36”)	9	5	4	3	4	6
90-105 cm (36-42”)	10	5	4	4	3	6
Background (Equivalent Depth)						
0-15 cm (0-6”)	7	7	2	1	2	5
30-45 cm (12-18 “)	7	5	2	1	1	5
60-75 cm (24-30”)	8	5	3	1	1	5
90-105 cm (36-42”)	11	5	3	1	0	5
Effluent (col/100 ml)						
During Soil Sampling	0.4	0.1	0.9	3	21	28
All Samples	0.3	0.2	0.5	10	17	28

values beneath the system may be lower than some of the background samples probably due to an increased occurrence of denitrification beneath the system compared to the background samples due to higher soil moisture content.

Table 10 shows the median moisture contents of the soil samples on a dry weight basis. These results confirm that in most cases, there is a greater amount of moisture beneath the distribution network than in the background samples.

Table 9. Median Nitrate-Nitrogen Concentrations in Soil Samples in mg N/L of Soil Water.

	STE			RGF		
Sample Interval	**Barron**	**Fond du Lac**	**Wood**	**Monroe**	**Jackson**	**Rock**
Depth Below Dripline						
2.5-15 cm (1-6”)	118	99	26	18	13	36
15-30 cm (6-12”)	96	31	16	49	35	30
30-45 cm (12-18 “)	83	36	16	37	41	37
45-60 cm (18-24”)	83	34	19	39	48	42
60-75 cm (24-30”)	61	29	25	50	28	41
75-90 cm (30-36”)	91	29	30	33	40	53
90-105 cm (36-42”)	83	26	26	37	35	49
Background (Equivalent Depth)						
0-15 cm (0-6”)	80	24	13	15	17	37
30-45 cm (12-18 “)	90	18	21	25	19	31
60-75 cm (24-30”)	94	25	34	28	23	41
90-105 cm (36-42”)	128	27	35	24	12	79
Effluent (col/100 ml)						
During Soil Sampling	0.4	0.1	0.9	3	21	28
All Samples	0.3	0.2	0.5	10	17	28

Table 10. Median Moisture Contents of Soil Samples Reported as grams of water/gram of Solid.

	STE			RGF		
Sample Interval	**Barron**	**Fond du Lac**	**Wood**	**Monroe**	**Jackson**	**Rock**
Depth Below Dripline						
2.5-15 cm (1-6”)	0.10	0.09	0.18	0.21	0.20	0.20
15-30 cm (6-12”)	0.08	0.32	0.18	0.12	0.20	0.22
30-45 cm (12-18 “)	0.11	0.28	0.16	0.11	0.14	0.20
45-60 cm (18-24”)	0.12	0.26	0.16	0.09	0.10	0.18
60-75 cm (24-30”)	0.14	0.23	0.15	0.09	0.12	0.17
75-90 cm (30-36”)	0.12	0.19	0.14	0.08	0.11	0.12
90-105 cm (36-42”)	0.14	0.18	0.13	0.09	0.06	0.12
Background (Equivalent Depth)						
0-15 cm (0-6”)	0.08	0.28	0.20	0.06	0.10	0.13
30-45 cm (12-18 “)	0.07	0.27	0.15	0.03	0.05	0.15
60-75 cm (24-30”)	0.08	0.19	0.17	0.03	0.04	0.11
90-105 cm (36-42”)	0.10	0.17	0.15	0.04	0.06	0.07

Cold Weather Operation

The second objective of this study was to monitor the operation of drip distribution systems in cold weather. Therefore, the main concern is to identify the soil temperatures that occurred, and observe whether there were any operational problems of the system at these temperatures. For this reason, there will be no specific discussion as to the frost depth in these soils or the extent of frozen water within the soil system. In the discussion for this study, a soil temperature below 0 C (32 F) will represent a soil that is susceptible to freezing.

The temperatures at Barron County were only monitored during the winter of 1999-2000. During this time period this site received 15-25 cm (6-10 in.) of snow by January 21, and the snow depth increased to 41-51 cm (16-20 in.) by February 16. Table 11 shows a summary of the ambient air and soil temperatures recorded at this site from December 19, 1999 through March 6, 2000. The average air temperature was -7 C (20 F) with a range from -29 C (-20 F) to 23 C (73 F) during the monitoring period. Temperatures remained below freezing for 22 consecutive days from January 15, 2000 through February 5, 2000. Due to mechanical difficulties, effluent temperatures were not recorded during this time period.

Table 11. Temperature Summary in Degrees Celsius at Barron County from December 12, 1999 through March 6, 2000.

	Zone 1 (Active)						Zone 2 (Active)						Air Temp.	Effluent Temp.
	At Emitter			Between Emitters			At Emitter			Between Emitters				
	Above	At	Below	Above	At	Below	Above	At	Below	Above	At	Below		
Median	-1.5	-1.1	-1.1	-1.2	-1.0	-0.9	-1.7	-1.4	-1.2	-1.5	-1.3	-1.1	-6.4	
Mean	-1.6	-1.2	-1.2	-1.3	-1.1	-0.9	-1.8	-1.5	-1.3	-1.5	-1.3	-1.2	-6.6	
Std Dev	1.1	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.1	1.1	8.8	
Max	2.2	2.9	2.6	2.7	2.8	2.6	2.3	2.4	2.6	2.5	2.4	2.7	23.0	
Min	-10.9	-10.7	-10.5	-10.2	-11.5	-10.3	-10.9	-11.0	-10.5	-10.6	-10.4	-10.4	-28.6	

	Zone 3 (Active)						Zone 4 (Active)						Air Temp.	Effluent Temp.
	At Emitter			Between Emitters			At Emitter			Between Emitters				
	Above	At	Below	Above	At	Below	Above	At	Below	Above	At	Below		
Median	2.5	2.3	2.5	No Data			2.0	2.2	2.4	1.3	1.6	1.7	-6.4	
Mean	2.5	2.4	2.6				2.1	2.3	2.5	1.4	1.6	1.7	-6.6	
Std Dev	1.9	1.6	1.6				1.6	1.6	1.6	0.5	0.5	0.5	8.8	
Max	10.8	10.8	10.9				10.1	10.1	10.2	4.3	4.7	4.6	23.0	
Min	-11.3	-11.7	-11.0				-11.4	-11.3	-11.0	-0.4	-0.3	0.0	-28.6	

	Zone 5 (Active)						Zone 6 (Active)						Air Temp.	Effluent Temp.
	At Emitter			Between Emitters			At Emitter			Between Emitters				
	Above	At	Below	Above	At	Below	Above	At	Below	Above	At	Below		
Median	2.6	2.0	2.1	1.5	1.7	1.8	1.5	1.9	2.1	No Data			-6.4	
Mean	2.8	2.2	2.4	1.5	1.8	1.8	1.7	2.4	2.3				-6.6	
Std Dev	1.5	1.7	1.7	2.4	2.2	2.2	1.7	1.9	1.7				8.8	
Max	10.3	10.2	10.4	9.7	9.7	9.6	9.8	9.9	10.5				23.0	
Min	-4.1	-11.7	-11.6	-14.4	-11.6	-12.1	-11.9	-11.8	-11.7				-28.6	

This site received much more use than was expected, so all of the zones were required to remain in operation during the winter of 1999-2000. For this reason, there were no zones to serve as controls during this time period. The driplines were buried at depths ranging from 30-50 cm (12-20 in.) below the ground surface in coarse sand. This system received septic tank effluent and a heavy vegetative cover of mixed highway grasses was established over the distribution network.

In zones 1 and 2, soil temperatures reached a minimum of -11 C (12 F) at the depth of the dripline, which was an average depth of 45 cm (18 in.) below the ground surface, to a maximum of around 3 C (37 F). In these zones, temperatures remained below 0 C (32 F) at the depth of the dripline for up to two consecutive months. Across zones 3-6 the soil temperatures were warmer than those seen in zones 1 and 2 with maximum temperatures at the depth of the dripline around 10 C (50 F). Across zones 3-6, the minimum temperatures at the depth of the dripline ranged from around 0 C (32 F) in the southern portion of each zone to -11 C (12 F) in the northern portions. The average depth of the driplines in these zones was 33 cm (13 in.) below the ground surface.

The system in Fond du Lac County was installed as a modified mound consisting of 20 cm (8 in.) of sand over 15 cm (6 in.) of sandy loam with a vegetative cover of a mixture of highway grasses. The driplines were spaced 15 cm (6 in.) apart, and were buried in the sand 20 cm (8 in.) below the ground surface.

Table 12 lists a summary for the soil, air and effluent temperatures recorded at the site in Fond du Lac County, combined over both winter seasons. The average ambient air temperature during these two winter seasons was -4 C (25 F), with temperatures ranging from -23 to 16 C (-9 to 61 F). During this time, the effluent temperature ranged from 4-12 C (39-54 F), with an average of 8 C (46 F).

Table 12. Temperature Summary in Degrees Celsius at Fond du Lac County from Both Winter Seasons Combined.

	Active Zone						Control Zone						Air Temp.	Effluent Temp.
	At Emitter			Between Emitters			At Emitter			Between Emitters				
	Above	At	Below	Above	At	Below	Above	At	Below	Above	At	Below		
Median	0.9	1.4	1.8	1.1	1.5	2.0	0.9	1.5	1.7	0.5	1.3	1.5	-3.5	7.6
Mean	0.9	1.4	1.8	1.2	1.6	2.1	1.1	1.7	1.7	0.6	1.4	1.6	-3.7	7.9
Std Dev	1.1	1.0	1.0	1.1	1.0	0.9	1.0	0.7	0.7	0.8	0.7	0.6	6.5	1.4
Max	6.1	5.3	4.7	6.6	5.0	5.0	7.0	4.9	4.7	5.5	4.4	3.9	15.6	11.8
Min	-4.3	-3.2	-2.8	-2.8	-2.1	-1.4	-0.6	0.1	0.1	-1.2	-0.3	0.1	-23.4	3.7

During the first winter season, a snow fence was used to encourage snow cover over the system, in order to provide insulation to the system since the system was installed in late fall with minimal vegetative cover. This resulted in a 1.5 m (5 ft.) layer of snow over the control zone while the test zone only had a 0.3 m (1 ft.) snow cover. For this reason, comparisons between the control and test zones are inconclusive. A heavy grass cover was established by the following winter season, so the snow fence was not used.

In the active zone, at the depth of the dripline, the average soil temperature was around 1 C (34 F), with temperatures ranging from -3 to 5 C (27-41 F). In the control zone, at the depth of the dripline, the soil temperatures ranged from 0 to 5 C (32-41 F), with an average temperature of 2 C (36 F).

The system at Jackson County was installed in a wooded area with a manicured lawn of Kentucky bluegrass over the top of the distribution network. The average burial depth of the driplines was 23 cm (9 in.). Table 13 shows a summary of the collected temperature data from both winter seasons combined.

The average air temperature at this site was - 5 C (23 F), with a range from -32 to 16 C (-26 to 61 F). Effluent temperatures had a range from 5 to 13 C (41-55 F), with an average temperature of 8 C (46 F). The average temperature in the active zone was around 0 C (32 F) at the depth of the dripline, with a temperature range from -4 to 4 C (25-39 F). These temperatures were very similar in the control zone, ranging from -5 to 4 C (23-39 F), with an average of 0 C (32 F).

Table 13. Temperature Summary in Degrees Celsius at Jackson County from Both Winter Seasons Combined.

	Active Zone						Control Zone						Air Temp.	Effluent Temp.
	At Emitter			Between Emitters			At Emitter			Between Emitters				
	Above	At	Below	Above	At	Below	Above	At	Below	Above	At	Below		
Median	-0.6	-0.2	0.4	-0.5	0.0	0.5	-0.5	-0.2	0.2	-0.7	-0.1	0.3	-4.6	7.4
Mean	-0.8	-0.2	0.6	-0.6	-0.1	0.4	-1.0	-0.4	0.1	-1.4	-0.5	-0.2	-6.0	7.5
Std Dev	0.9	0.9	1.1	0.9	0.8	0.7	1.2	1.0	0.8	1.6	1.2	1.4	7.9	1.1
Max	5.4	3.5	5.5	5.1	2.6	2.4	3.4	4.1	3.0	5.1	2.6	2.4	16.3	12.5
Min	-5.0	-3.8	-2.1	-4.7	-3.6	-2.3	-5.5	-4.5	-2.4	-7.4	-4.2	-5.2	-32.4	5.2

The driplines in the Rock County system were plowed into the soil, between rows of black walnut trees with a vegetative cover of unmowed grass, to a depth of 10-15 cm (4-6 in.). A summary of the temperatures from both winter seasons is shown in Table 14. The air temperature ranged from -26 to 17 C (-15-63 F) with an average temperature of -4 C (25 F). The effluent temperature ranged from 3-12 C (37-54 F) with an average temperature of 7 C (45 F). In the active zone, soil temperatures ranged from -1 C to 6 C (30-43 F) with an average temperature of 1 C (34 F) at the depth of the dripline. At an equivalent depth, the control zone had an average soil temperature of around 1 C (34 F), with temperatures ranging from -2 to 5 C (28-41 F).

Table 14. Temperature Summary in Degrees Celsius at Rock County from Both Winter Seasons Combined.

	Active Zone						Control Zone						Air Temp.	Effluent Temp.
	At Emitter			Between Emitters			At Emitter			Between Emitters				
	Above	At	Below	Above	At	Below	Above	At	Below	Above	At	Below		
Median	0.6	0.9	1.3				-0.1	0.4	0.0	-0.5	-0.2	0.2	-3.3	6.9
Mean	0.8	1.2	1.6				0.1	0.5	0.2	-0.4	0.0	0.3	-4.0	7.3
Std Dev	1.1	1.0	1.2		No Data		1.4	0.9	1.1	1.1	0.8	0.7	6.5	1.4
Max	7.7	5.7	6.7				7.9	5.0	4.6	7.4	3.8	3.3	16.6	11.9
Min	-2.4	-0.8	-0.8				-3.0	-1.9	-4.7	-5.7	-6.2	-5.2	-25.5	2.8

The site in Wood County consisted of four zones, with the driplines buried at an average depth of 20 cm (8 in.). Two of the zones were active during the time of this study, with the remaining zones serving as controls. The system was installed in the summer of 1998, with the vegetative cover of mixed highway grasses being established in September 1998. By the winter of 1999-2000, this vegetative cover was dense, standing at over 1 m (3 ft.) tall in most areas. The temperature summary from both winters combined at this site is shown in Table 15.

The average air temperature at this site was -7 C (19 F), ranging from -28-15 C (-18-59 F). Effluent temperatures ranged from -2-8 C (28-46 F), with an average temperature of 5 C (41 F). The soil temperatures at the depth of the dripline for the two active zones had an average of -1 C (30 F). These temperature ranged from -5 to 2 C (23-36 F) in zone 1 and from -6-2 C (21-36 F) in zone 2. The soil temperatures in the control zone were slightly cooler than those in the active zone, with average temperatures of 0 C (32 F) in zone 3 and -1 C (30 F) in zone 4. In zone 3, these temperatures ranged from -3-2 C (27-36 F), while temperatures ranged from -4-1 C (25-34 F) in zone 4.

Table 15. Temperature Summary in Degrees Celsius at Wood County from Both Winter Seasons Combined.

	Zone 1 (Active)						Zone 2 (Active)						Air Temp.	Effluent Temp.
	At Emitter			Between Emitters			At Emitter			Between Emitters				
	Above	At	Below	Above	At	Below	Above	At	Below	Above	At	Below		
Median	-0.8	-0.4	-0.1	-0.7	-0.3	0.0	-0.8	-0.4	-0.1	-0.6	-0.3	-0.1	-6.1	5.3
Mean	-1.0	-0.6	-0.3	-0.9	-0.5	-0.2	-1.1	-0.7	-0.4	-0.9	-0.5	-0.3	-6.9	4.8
Std Dev	0.8	0.8	0.8	0.6	0.7	0.8	0.9	1.1	1.1	0.9	1.0	1.1	7.7	1.7
Max	3.0	1.9	1.8	2.2	1.6	1.6	0.7	1.7	1.8	0.6	1.2	1.6	14.6	7.7
Min	-5.5	-4.6	-4.8	-3.1	-2.8	-2.6	-5.4	-5.7	-4.9	-4.8	-4.8	-4.3	-28.1	-1.7

	Zone 3 (Control)						Zone 4 (Control)						Air Temp.	Effluent Temp.
	At Emitter			Between Emitters			At Emitter			Between Emitters				
	Above	At	Below	Above	At	Below	Above	At	Below	Above	At	Below		
Median	-0.1	0.2	0.5	-0.3	0.1	0.5	-0.5	-0.1	0.2	-0.4	-0.1	0.4	-6.1	5.3
Mean	-0.7	-0.3	0.0	-0.8	-0.4	-0.1	-1.1	-0.7	-0.4	-1.1	-0.8	-0.3	-6.9	4.8
Std Dev	1.0	1.1	1.2	1.0	1.1	1.1	1.1	1.2	1.2	1.3	1.3	1.3	7.7	1.7
Max	1.0	1.7	1.8	1.4	1.2	1.8	0.5	1.1	1.7	0.6	1.0	1.7	14.6	7.7
Min	-3.6	-3.3	-3.0	-3.5	-3.2	-3.1	-4.0	-3.7	-3.4	-4.1	-3.9	-3.4	-28.1	-1.7

It is difficult to make generalizations as to the behavior of these systems under cold weather conditions because of the numerous variations between systems. From the temperatures observed in the soil, it is evident that the effluent being dosed provides some heat to the soil system. The heat provided from the addition of wastewater also travels above and below the dripline, which can be seen in the soil temperatures observed. Some of this heat travels along the length of the dripline, which can be seen when comparing the data for temperatures at versus between emitters, and comparing these numbers with the control zones.

Figure 1 shows the soil temperatures at 10 cm (4 in.) above the dripline, at the depth of the dripline (23 cm (9 in.) below the ground surface) and 10 cm (4 in.) below the dripline for one of the sets of thermocouples at Jackson County. The depth 10 cm (4 in.) above the dripline does not show any large temperature fluctuations and is most likely affected more by the air temperature. At the depth of the dripline and at a depth 10 cm (4 in.) below the dripline, large temperature fluctuations can be seen at the times the system had dosed. Dosing of the effluent appears to raise the soil temperature by almost 2 degrees C (4 F), with the warm temperatures remaining in the soil for almost 2 hours.

Figures 2 and 3 compare the soil temperatures in the active zone to those in the control zone at the depth of the dripline and 10 cm (4 in.) below the dripline, with the soil temperature slightly cooler in the control zone. Both the active and control zones show similar temperature peaks through the month of December and part of January. These peaks are most likely due to varying air temperatures. As the air temperature decreases and remains below freezing for extended periods of time, the control zone no longer exhibits these temperature variations. However, the repetitive temperature increases and decreases are still obvious in the active zone. These repetitive peaks in temperature are created as a result of the warm effluent being dosed into the soil. The wastewater being dosed appears to momentarily increase the soil temperature by 2-4 C (3-7 F). These patterns are also shown at a depth 10 cm (4 in.) below the dripline, as shown in Figure 3. This suggests that the heat provided by the addition of the effluent to the soil travels vertically through the soil profile.

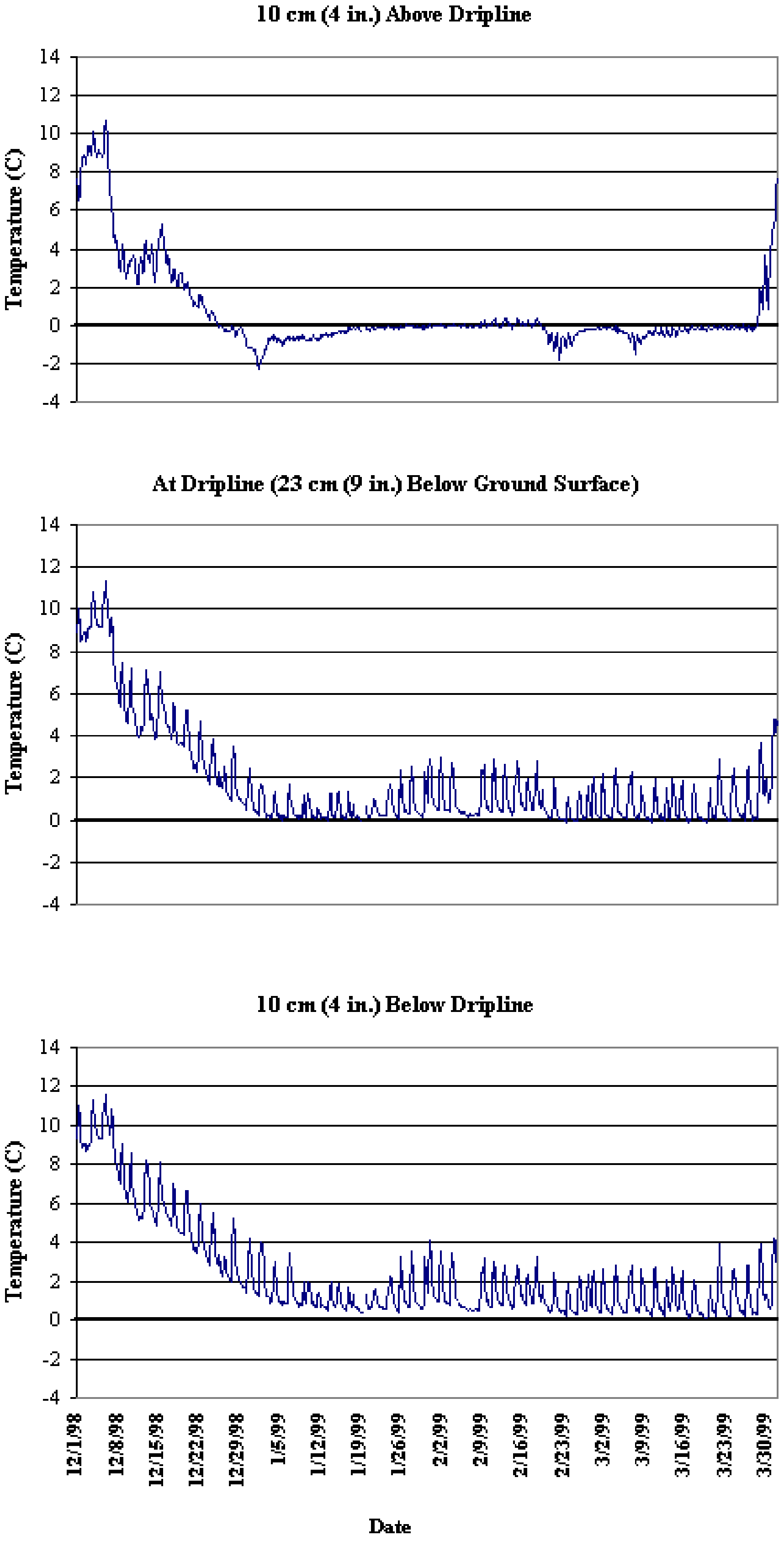

Figure 1. Soil Temperatures at Three Depths in the Active Zone at Jackson County from December 1, 1998 through March 31, 1999.

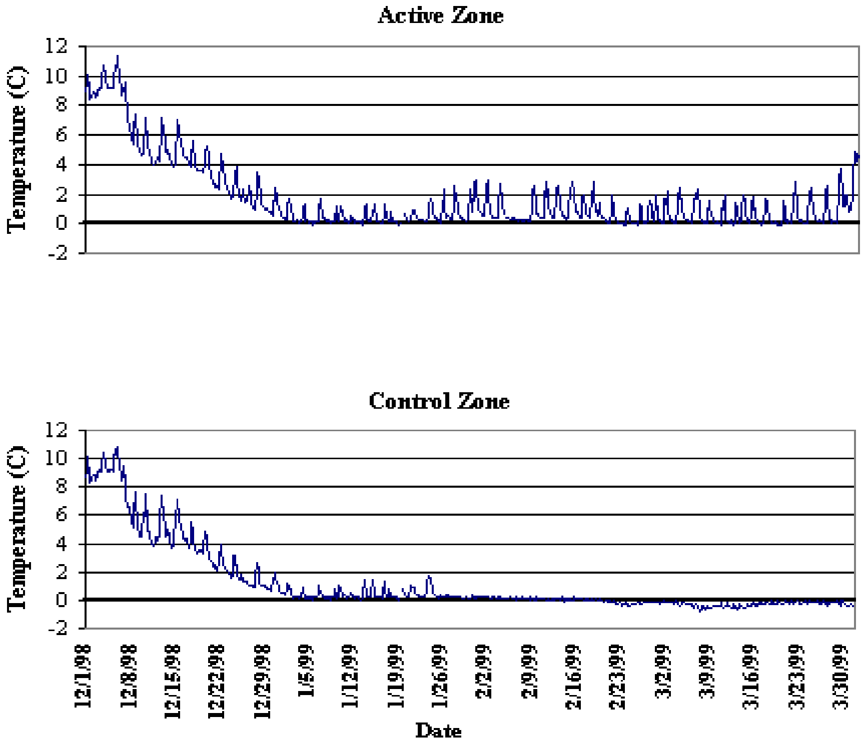

Figure 2. Active Versus Control Zone Soil Temperatures in the Active Zone at Jackson County at the Depth of the Dripline (23 cm (9 in.) Below the Ground Surface) from December 1, 1998 through March 31, 1999.

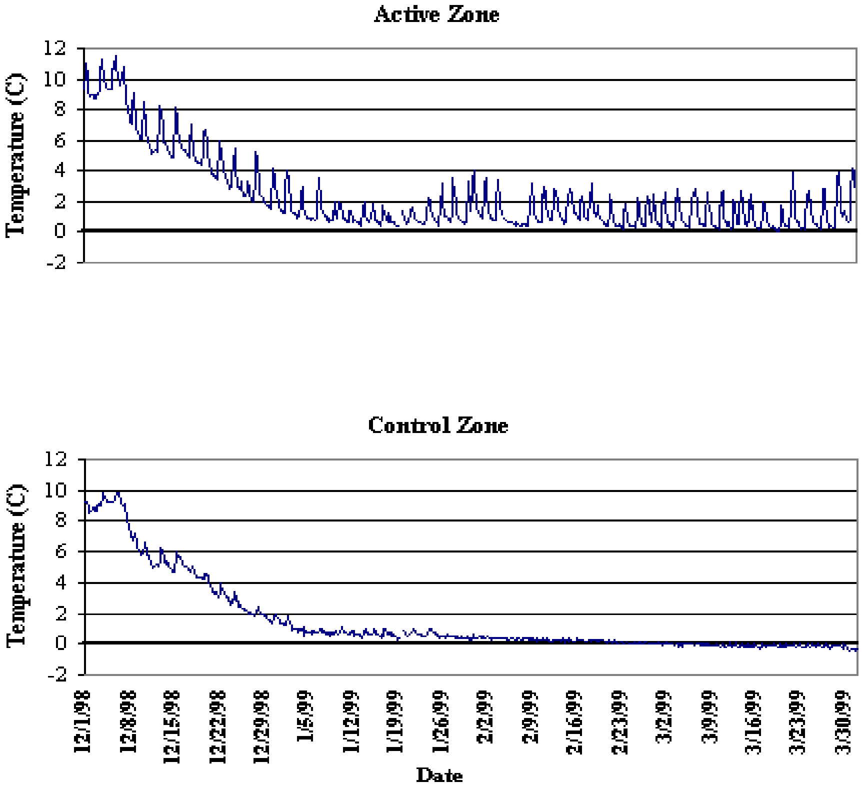

Figure 3. Active Versus Control Zone Soil Temperatures in the Active Zone at Jackson County 10 cm (4 in.) Below the Dripline from December 1, 1998 through March 31, 1999.

The heat provided by the dosing of the effluent is also evident in Figures 4 and 5, which compare the soil temperatures at the emitters to those between emitters at the depth of the dripline and 10 cm (4 in.) below the dripline. At the depth of the dripline, peaks in the soil temperatures appear at the location between the emitters similar to those that occur at the emitter, but not as great in magnitude. However, it appears that there is no difference between the soil temperatures at the emitters and those between emitters at this depth. This suggests that the effluent is moving along the length of the dripline as it is dosed. At a depth 10 cm (4 in.) below the dripline, the influence of the emitters becomes more apparent. Although peaks are still evident in the soil temperatures between the emitters, those locations directly below emitters exhibit much higher peaks in temperature. All of the temperatures appear to decrease to near 0 C (32 F) a few hours after the system has dosed. The other systems showed similar trends (Bohrer, 2000).

SUMMARY AND CONCLUSIONS

Soil Performance

Six drip distribution systems in Wisconsin were studied to determine the treatment performance of the soil beneath the distribution network. Of the six systems studied, three received septic tank effluent (STE), one received effluent treated by a recirculating gravel filter (RGF) and two sites were treated by aerobic treatment units (ATU). Soil conditions varied at these sites, ranging from coarse sand to clay loam. Three of these systems were on residential sites (1 STE, 2 ATU), one STE system served a rest area and the other served an elementary school. The RGF system served a seasonal campground. The driplines were installed from 10-50 cm (4-20 in.) below the ground surface.

Six sets of soil profiles from each site were collected from below the drip distribution network throughout the summer of 1999. These soil samples were analyzed for fecal coliforms, *E. coli*, organic nitrogen, ammonium-nitrogen and nitrate-nitrogen. Six additional sets of soil profiles were collected from each site, adjacent to the distribution network, to determine the background levels of these parameters.

For the 3 STE sites, with median fecal coliform and *E. coli* influent concentrations from all samples of 140,000 colonies/100 ml and 138,000 MPN/100 ml, respectively, fecal coliform and *E. coli* concentrations were below detection limits at depths greater than 60 cm (24 in.) below the dripline.

The RGF site showed median fecal coliform concentrations below detection limits at depths greater than 75 cm (30 in.) below the dripline, with a median influent concentration of 870,000 colonies/100 ml. However, the fecal coliform concentration was ≤ 6 MPN/gram of dry soil from 15-75 cm (6-30 in.) below the dripline. The system was demand dosed and overloaded, resulting in effluent surfacing via small channels above each emitter (chimney effect). *E. coli* results for this site had concentrations at 1 or 2 MPN/gram of dry soil at depths greater than 15 cm (6 in.) below the dripline. Median *E. coli* concentration of the influent was 58,000 MPN/100 ml.

For the two ATU sites, fecal coliform and *E. coli* concentrations were at or below detection limits at depths greater than 2.5 cm (1 in.) below the dripline, based on median values. The median fecal coliform and *E. coli* concentrations of the influent from both sites combined together was also quite low at 250 colonies/100 ml and 100 MPN/100 ml, respectively.

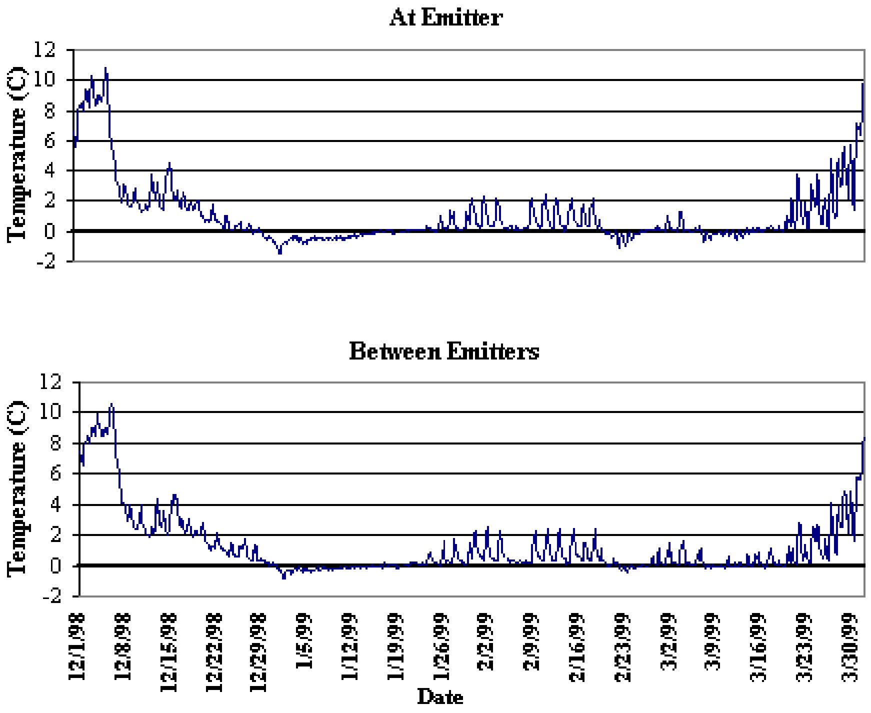

Figure 4. Soil Temperatures Comparing At Versus Between Emitters in the Active Zone at Jackson County at the Depth of the Dripline (23 cm (9 in.) Below the Ground Surface) from December 1, 1998 through March 31, 1999.

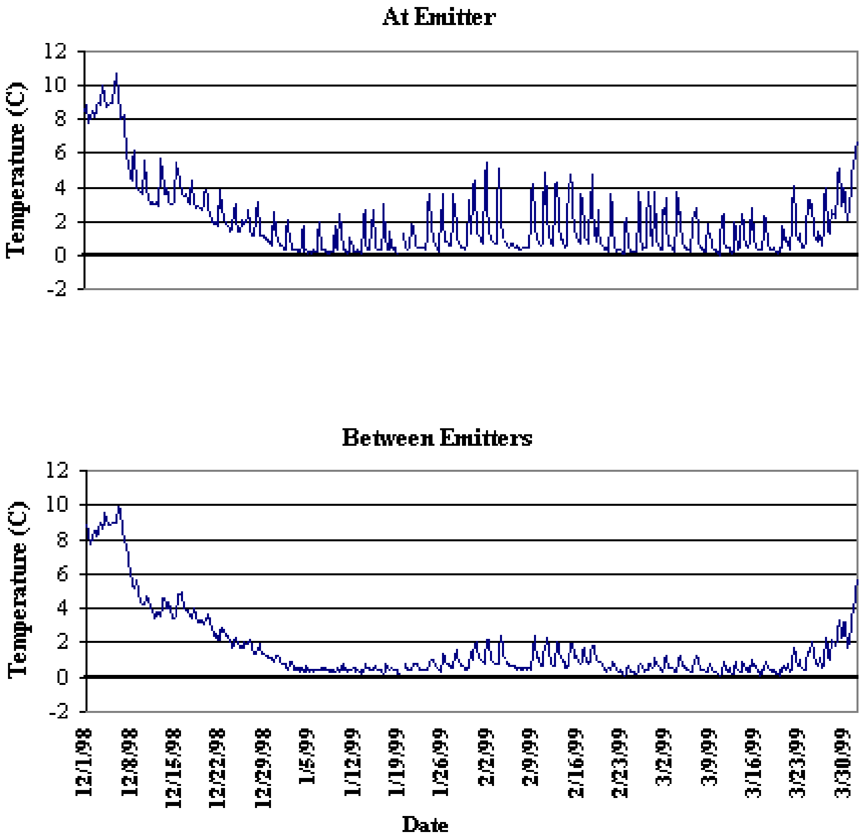

Figure 5. Soil Temperatures Comparing At Versus Between Emitters in the Active Zone at Jackson County 10 cm (4 in.) Below the Dripline from December 1, 1998 through March 31, 1999.

Based on this research and using median values as the criteria, the separation distance from the infiltrative surface to a limiting condition for drip systems receiving STE could be reduced to 45 cm (18 in.). Systems receiving aerobically treated effluent with very low fecal coliforms and *E. coli* (< 1,000 colonies/ 100 ml, < 1,000 MPN/100 ml, respectively) could have separation distances at 30 cm (12 in.). Both of these distances are dependent upon level of risk acceptable as there were very few fecal coliforms and *E. coli* concentrations below that distance.

There is a significant difference in organic nitrogen concentration with depth, showing higher values at the shallower depths. This significant difference exists both beneath and adjacent to the systems. The only site that shows a significant difference in organic nitrogen between the profiles beneath the distribution network and those adjacent to it is the RGF site (Monroe County). This site consists of a very fine sand profile and was heavily loaded. For the remaining sites, the addition of wastewater to the system does not significantly effect the concentration of organic nitrogen in the soil.

The ammonium-nitrogen concentrations beneath the system were near background levels for three of the sites. The three other sites (Barron, Monroe and Wood Counties) had higher influent ammonium-nitrogen concentrations with medians ranging from 48 to 193 mg N/L, as the wastewater was mainly toilet and sink water. These three sites showed a significant impact from ammonium-nitrogen on the soil system due to the addition of wastewater.

Nitrate-nitrogen concentrations in the soil, on a soil water basis, had median values ranging from 26-83 mg N/L of soil water at depths 90-105 cm (36-42 in.) below the dripline, regardless of treatment type. However, these values are similar to those found adjacent to the system. The high background levels are difficult to explain. The nitrogen impact from these systems was inconclusive due to the high, unexplainable background values.

Cold Weather Operations

Five drip distribution systems in Wisconsin were monitored to evaluate the performance of these systems in cold weather. Thermocouples were installed in various locations in the soil within the distribution network, as well as away from the active zones. Thermocouples measuring the ambient air and pump chamber effluent temperatures were also installed. These temperatures were recorded six times a day from December 1, 1998 through March 31, 1999 and from December 1, 1999 through March 14, 2000.

Despite two relatively mild winters in Wisconsin, soil temperatures within the distribution network did drop below 0 C (32 F) and remained below this for several days. Soil temperatures at 10 cm (4 in.) below the depth of the dripline reached minimums of -1 C (30 F) in the southern portion of the state to -12 C (10 F) in the north. Periods of negative temperatures (Celsius) were sustained in the soil system for several weeks at a time at most sites. With these temperatures, none of the systems studied encountered operational problems due to the cold weather.

From the results of this study, the potential of operational problems for drip distribution systems in northern climates does not appear to be a great concern under the conditions experienced during this study. However, the air temperatures were slightly above average for Wisconsin during this two-year study. There were several incidences in which the soil system surrounding the driplines sustained negative temperatures (Celsius) for extended periods of time. Regardless of these low temperatures, there was no occurrence of system malfunction due to the cold weather. With proper design and installation, drip distribution systems are an excellent alternative system for wastewater dispersal in cold climates.

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