Performance of an Aerobic Treatment Unit and Drip Dispersal System for the Treatment of Domestic Wastewater at the Northeast Regional Correction Center

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I. Introduction

An estimated half million homes in Minnesota are not connected to public sewer systems. Along with the growing use of lakeshore cabins and the conversion of cabins into year-round homes, many have the potential to degrade surface and groundwater resources as they depend primarily on individual sewage treatment systems (ISTSs) for the treatment and dispersal of domestic wastewater. Unfortunately, many are in noncompliance with state standards or are hydraulically failing to the surface. Effective treatment options are needed for the thousands of locations with restrictive soil and site conditions. Many of these sites occur along lakes and streams, creating a potential health hazard to swimmers and others using surface water for drinking water and recreation, leading to increased algal blooms, aesthetic nuisances and degraded fish habitat.

The suspended-growth wastewater treatment process is commonly used by municipal wastewater treatment facilities. This biological treatment process is also available at smaller scales for both individual and multiple home use, and are commonly referred to as aerobic treatment units or ATU's. Since the mid-1990's, systems using both the suspended-growth and fixed-film treatment processes were evaluated for single-family home use in northern Minnesota (McCarthy et al., 1997, 1998, 1999; 2001; Henneck et al., 1999, 2001; Axler et al., 1999, 2000; Monson Geerts et al., 2000, 2001; Pundsack et al., 2001). This paper provides an overview of the operation and performance of one brand of aerobic treatment unit and a drip dispersal system tested at the northern Minnesota research facility.

II. System Design and Construction

A single aerobic treatment unit (ATU) was installed at the Northeast Regional Correction Center (NERCC) on October 17, 1997. The ATU was a Whitewater® Aerobic Wastewater Treatment Unit, model DF50, from Delta Environmental Products, Inc. (Delta Environmental Products, Inc. 1997). The unit uses the biological treatment processes of activated sludge and extended aeration to breakdown solids and organic matter and reduce pathogenic organisms in wastewater. The design treatment capacity of this model unit is 500 gallons/day and treats residential strength effluent at a BOD_5 loading rate of 1.25 lb/day. At the start of the study, the ATU was loaded with ~250 gallons/day of septic tank effluent (STE), as per most of the other alternative systems at NERCC.

The unit was installed on the east side of the demonstration site adjacent to the supply shed (Figure 1). Representatives from the local distributor, The Compendium, Ltd, were present at NERCC to install the unit, with the assistance of NRRI staff. The Whitewater® ATU is composed of a cylindrical molded fiberglass shell with a convex cover containing an access port, 6.0 ft. diameter by 5.8 ft. high, with a total volume of 916 gallons. STE was pumped from the research facility's 2,200 gallon common head tank to the ATU six times each day.

A conical fiberglass clarifier within the ATU shell separates the aeration chamber (containing anaerobic septic tank effluent) from the clear water zone in the settling chamber (contained the treated effluent). The STE was pumped to the ATU through a 1.5 inch PVC supply line, buried at a depth of 24 inches, and into the outer aeration chamber. Once in the aeration chamber, STE is mixed with air passing from an air pump to the air-drop lines located around the outer wall of the chamber. The aerated liquid enters the clarifier at the bottom, past a deflector, and travels upward in the settling chamber through non-turbulent flow that allows the solids to settle and re-enter the aeration chamber. The clarified effluent is discharged through a 4-inch PVC pipe, which contains a sampling port outside of the ATU. Thermocouples were placed in both the aeration and settling chambers to monitor temperature changes throughout the winter.

The ATU effluent gravity flows to a 500-gallon concrete dose tank. The effluent is pumped, on demand, to a drip field for final treatment and subsurface dispersal. Drip tubing was installed in a wooded area using a gas-powered, hand-driven ditcher. Four 100 foot long laterals were buried 10-12 inches deep at a two-foot spacing, with a supply and return manifold located at opposite ends of the field. The entire drip network was constructed to drain back to the dose tank. The drip tubing was 0.5 inch diameter, non-pressure compensating Geoflow™ flexible polyethylene tubing, with Rootguard® protected emitters 2 feet on center. The flow rates were set using a pressure regulator at ~1.1 gallons/hour at 15 psi. Thermocouples were located along side the drip tubing, at emitters and between emitters, to monitor temperatures year-round. After the drip system was completed, the area was covered with 12 inches of hay for insulation. The drip field was not mowed and no additional hay was placed on the system prior to the second winter of use.

III. Monitoring Methods

The discharge from the ATU was monitored every three weeks for ~15 months from October 1997 through January 1999. Between February 1998 and May 1998, an additional effluent sample was collected from the drip dose tank to obtain a composite sample of ATU effluent. Sample analysis was provided by the Western Lake Superior Sanitary District (WLSSD) for total suspended solids (TSS), biochemical oxygen demand (BOD_5), fecal coliform bacteria and total phosphorus (TP) (APHA, 1995). All nitrogen (total-N [TN], ammonia-N [NH_3-N], and [nitrate+nitrite]-N [NO_3-N], pH, and alkalinity were analyzed at the NRRI (APHA, 1995, Ameel et al., 2000). Temperature, conductivity and dissolved oxygen of the effluent, in both the aeration and settling chambers, were monitored in the field using a YSI85 multi-sensor meter. The water meter in the head monitoring box verified inflow.

Since the installation of the ATU at NERCC, influent wastewater strengths were near the high end of typical residential strength STE. Crites and Tchobanoglaus (1998) identify typical septic tank effluent as follows: BOD_5 (150-250 mg/L), TSS (40-140 mg/L), TP (12-20 mg/L) and TN (50-90 mg/L).

IV. Performance Results

1. Solids, organic matter and pathogens

Treatment performance data for the ATU is summarized in Table 1. The inflow STE represents average values for the entire study period (October 1997 through May 1999) since there was little difference in STE quality between winter and summer periods. The average hydraulic loading to the ATU was 193 gallon/day in the winter (November through April) and 189 gallon/day in the summer (May through October), slightly less than the target flow of 250 gallons/day (Table 1).

The product specifications indicate that the unit should provide an effluent quality <30 mg/L TSS, <30 mg/L BOD_5 and <10 mg/L nitrate-N. During this study, the unit did not consistently achieve the level of performance specified by the manufacturer for solids, organic matter or nitrogen. The average effluent TSS varied considerably between the two seasonal periods, from 44 mg/L TSS (12% TSS removal) during the summer to 75 mg/L TSS (-50% TSS removal) during the winter. Effluent BOD_5 ranged from 56 mg/L (81% removal) in summer to 91 mg/L (66% removal) in winter. At a flow of 193 gallons/day and a BOD_5 of 275 mg/L, the organic loading to the ATU was ~0.4 lbs /day, or about 30% of its organic loading design. Fecal coliform bacteria reductions ranged from 90 to 96% removals, with slightly better performance during the summer period (19,000 cfu/100mL) as compared to the winter (42,000 cfu/100mL).

A number of strategies were investigated by The Compendium to improve system performance, in cooperation with NRRI staff, and included the following: 1) installation of an improved sample port (thereby reducing sampling error); 2) adding a filter basket in the head tank and flushing out the supply lines; 3) pumping-out the unit and replacing STE with water and starting over; and 4) changing the controller on the compressor to alleviate over-agitation (excessive oxygen) in the unit. A list of all medications and chemicals was provided by NERCC medical, custodial and kitchen staff to determine if harmful products were being used that would upset the beneficial microorganisms in the unit. None of these approaches were successful in noticeably improving its performance. In February1999, the supply line from the head tank to the ATU froze, and it was idle for the remainder of the winter.

2. Nutrients

Removal of phosphorus and nitrogen by the ATU was generally low as compared to the other alternative systems monitored at NERCC (McCarthy et al., 1998, 1999; Monson Geerts et al., 2000, 2001; Henneck et al.,1999, 2001; Axler et al. *in prep.*). TP was minimally removed and effluent levels were 12 mg/L TP (14% removal) in the winter and 14 mg/L TP (no removal) in the summer. Overall, TN removal was slightly better in the winter at 69 mg/L TN (20% removal) than in the summer at 77 mg/L TN (10% removal). The ATU effluent was partially nitrified, with 35 mg/L NO_3-N (winter) and 54 mg/L NO_3-N (summer), while NH_4-N was present at 34 mg/L NH_4-N (winter) and 24 mg/L NH_4-N (summer). Although the ATU nitrified the effluent year-round, performance was better during the summer period with ~70% nitrification, presumably due to warmer temperatures and its beneficial effects on *Nitrosomonas* and *Nitrobacter,* the bacteria responsible for nitrification under favorable operational and environmental conditions.

Table 1. Performance of Delta Environmental Products Inc. Whitewater® ATU at NERCC.

NERCC Aerobic Treatment Unit					
Parameter	Inflow[1]	WINTER		SUMMER	
	STE	Effluent[2]	% - Removal[3]	Effluent[2]	% - Removal[3]
Q (gpd)		193		189	
TSS (mg/L)	50 (14)	75	-50	44	12
BOD_5 (mg/L)	271 (50)	91	66	56	81
TP (mg/L)	14 (2.4)	12	14	14	0
TN (mg/L)	86 (9.5)	69	20	77	10
NH_4-N (mg/L)	80 (9.9)	34	56	24	71
NO_3-N (mg/L)	0.03 (0.03)	35	(nitrification)	54	(nitrification)
fecal coliforms[4]	$4.6x10^5$ ($3.2x10^5$)	$4.2x10^4$	90	$1.9x10^4$	96
Temp (C°)	17.1 (2.8)	8.5	na	17.6	na
DO (mg/L)	0.23 (0.17)	3.0	na	1.7	na
EC25 (umhos)	1225 (120)	902	na	909	na
pH	7.16 (0.12)	6.62	na	6.05	na
Alkalinity (mg/L)	443 (29)	344	21	21	96

Total number of sampling events=9 winter, 11 summer, between December 1997 and January 1999;
[1]average during the time period (± Standard deviation);
[2]average seasonal values;
[3]Percent removal based on Effluent: ((inflow-outflow)/inflow) x 100 = % removed;
[4]the geometric mean colony-forming units (cfu) per 100ml.

3. Other Parameters

In addition to solids, organic matter and nutrients, a number of other parameters were measured, and included temperature, dissolved oxygen (DO), specific electrical conductivity (EC25), pH and alkalinity. The temperature of STE remained fairly consistent throughout the study, averaging 17.1°C. However, there was a wide difference in mean temperature of effluent inside the clarifier (near the surface) during the winter period (8.5°C) and the summer period (17.6°C). Effluent DO was slightly higher in the winter (3.0 mg/L) as compared to summer (1.7 mg/L). There was a 26% reduction in effluent EC25, and there was little difference between winter and summer conductivities. The effluent pH decreased by <1 unit as compared to inflow pH, and the effluent had a pH of 6.1 in summer and 6.6 in winter, less than the optimum pH (7.2-9.0) range for maximum nitrification (Crites and Tchobanoglous, 1998). Alkalinity did not appear to limit the conversion of ammonium-nitrogen to nitrate-nitrogen during the winter (344 mg/L), but it was reduced to 21 mg/L $CaCO_3$ (96% removal) in the summer when higher nitrification occurred.

4. Drip dispersal system

During two winters of monitoring the drip system, temperatures in the drip field remained above freezing, even though the system was not operational after February 1999 because of freezing in the forcemain to the ATU. The temperature of ATU effluent was fairly warm (~10°C) throughout the first winter, but dropped to near freezing (~2°C) during the second winter when the ATU sat idle (Figure 2). There were small differences in soil temperature at the drip tubing/soil interface placed at emitters (where ATU effluent discharged into the soil) and between emitters along the tubing. The temperature at these locations were warmer (~1.5-3°C) the first winter, when the system was regularly dosed, as compared to the second winter of operation (0.5-2°C), when the system sat idle.

Several precautions were taken to minimizing freezing of the drip system. The drip field was located in a wooded area and it was covered with 12 inches of hay immediately following installation in October 1997 while the ground was still fairly warm. The entire drip network was constructed to drain back to the dose tank. The manifolds and air release valve were also insulated with 12 inches of hay.

In northeast Minnesota, snow typically begins to accumulate on the ground in mid-December and melts in March-April. Snow provides an effective layer of insulation during the coldest times of the year in undisturbed areas (not plowed to remove snow), and helps to minimize the depth of frost penetration in the soil.

Based on 50 years of snow data from the National Weather Service (Figure 3), these two winters represent a time of limited snow that the region experiences periodically. The 50-year average snowfall is about 80 inches, with 13 inches of snow on the ground. At NERCC, there was only 6-8 inches of snow on the ground for a brief period (6 weeks) in 1998; otherwise, the ground was bare of snow. Throughout most of the second winter, the drip field was essentially bare of snow, except for 3-4 inches that covered the ground in January 1999.

Despite the lack of snow and cold winter temperatures (-20°C), there was no evidence of effluent surfacing or freezing in the manifold piping, drip tubing or air-release valve. The practices used at this location successfully prevented the drip system from freezing during two winters of less than normal snowfall in1997-1998 and 1998-1999.

V. Summary and Conclusions

The Whitewater® ATU was operated as per the recommendation of the local distributor and it was monitored by NRRI at the NERCC research facility for ~15 months, from October 1997 through January 1999. During this time, the ATU unit did not consistently achieve the manufacturer's treatment performance standards for solids (<30 mg/L TSS), organic matter (<30 mg/L BOD_5) or nitrogen (<10 NO_3-N). Solids averaged 44 to 75 mg/L TSS (12% and -50% removal), summer and winter, respectively. Organic matter averaged 56 to 91 mg/L BOD_5 (81% and 66% removal), summer and winter, respectively. At a daily flow of 250 gallons/day (the high end of loading the ATU at NERCC) with 275 mg/L BOD_5, the ATU received ~0.6 lbs BOD_5/day, or 50% of its design organic loading. Effluent NO_3-N averaged 35 to 54 mg/L NO_3-N, winter and summer, respectively.

The average annual removal of nutrients (nitrogen and phosphorus) by the ATU was low, with TN <20% removal and TP <14% removal. The removal of TN was slightly better in the winter (20 % TN removed) than in the summer (10% TN removed). The ATU nitrified the effluent year-round, with a higher level (~70%) of nitrification during the summer, presumably due to warm temperatures and its beneficial effects on nitrifying bacteria. Fecal coliform bacteria levels were reduced by 90-96%, with slightly better performance in the summer (19,000 cfu/100mL) than in the winter (42,000 cfu/100mL).

The overall performance of the ATU was better during the warmer months, with decreased performance during colder periods of the year. The ATU was removed from NERCC after the manufacturer and local distributor were unable to resolve the operational problems associated with the unit.

The drip tubing, installed at a depth of 10-12 inches and covered with 12 inches of hay, did not freeze during two winters of use. The practices used at NERCC effectively prevented the manifold, drip tubing and air-release valve from freezing during two winters with less than average snow.

An aerobic treatment unit, coupled with drip dispersal, was one of several types of onsite wastewater treatment system tested in Minnesota since 1995. Other systems have included single pass sand filters (McCarthy et al., 1997, 1998, 1999; Pundsack et al., 2001), recirculating sand filters (Christopherson et. al, 2001), recirculating gravel filters (McCarthy et al., 1998), single pass in-ground and modular peat filters (McCarthy et al., 1997, 1998; Monson Geerts et al., 2000, 2001; Pundsack et al. 2001), subsurface flow constructed wetlands (Axler et al., 1999, 2000, in prep.; Henneck et al., 1999, 2000; Pundsack et al., 2001), a textile filter, polishing sand filter and shallow trenches (McCarthy et al., 2001) and drip distribution using septic tank effluent. The web site http://www.bae.umn.edu/septic/LCMR provides a compilation of these and other publications from the project.

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Figure 1. Layout of the NERCC demonstration site.

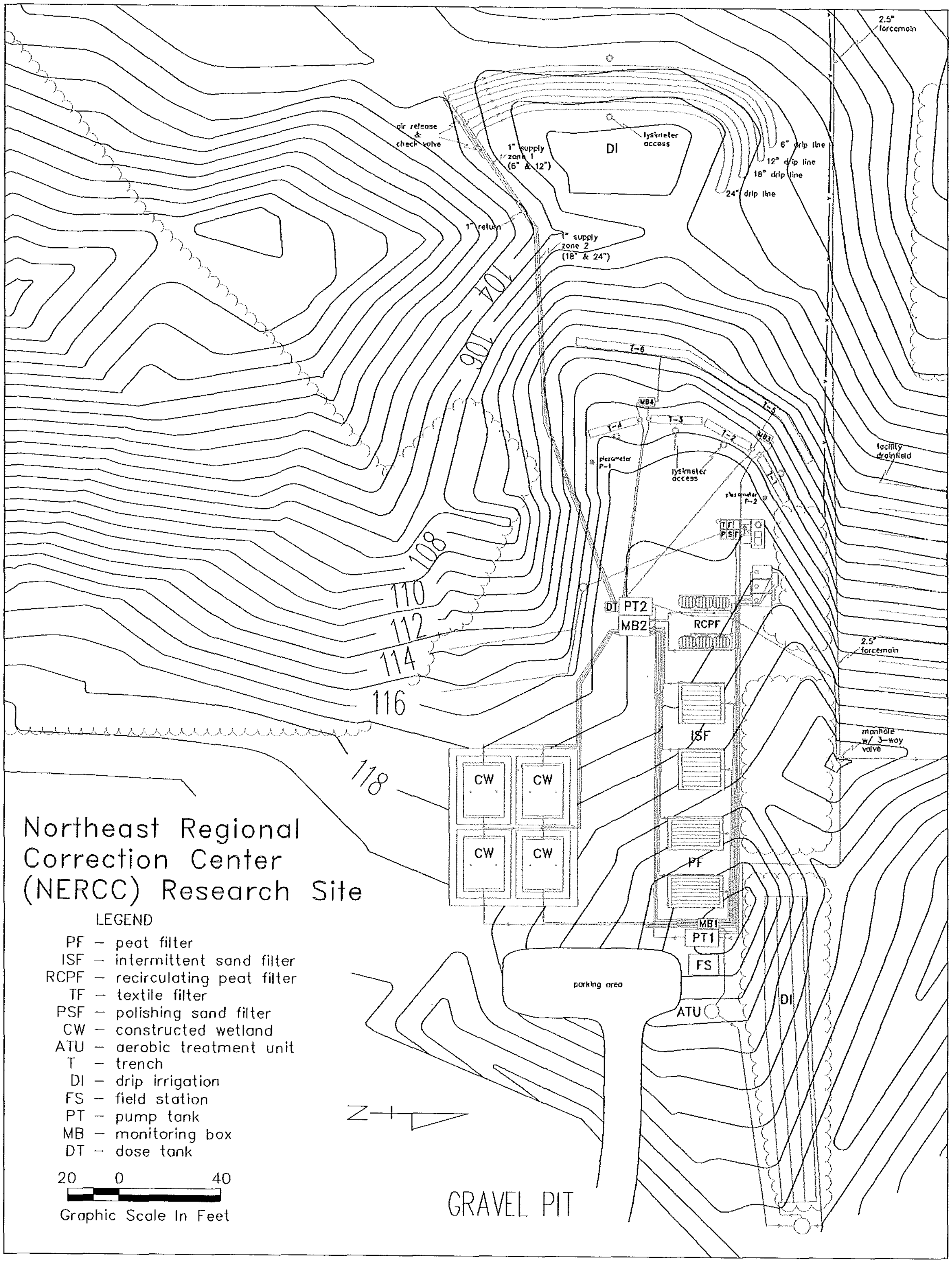

Figure 2. Temperature adjacent to the drip tubing (Geoflow) installed at a depth of 10-12 inches in the soil at NERCC. The temperature was routinely monitored between Oct 1997 and May 1999 at 4 locations on the drip distribution network. The drip field was covered with hay after construction in Oct 1997.

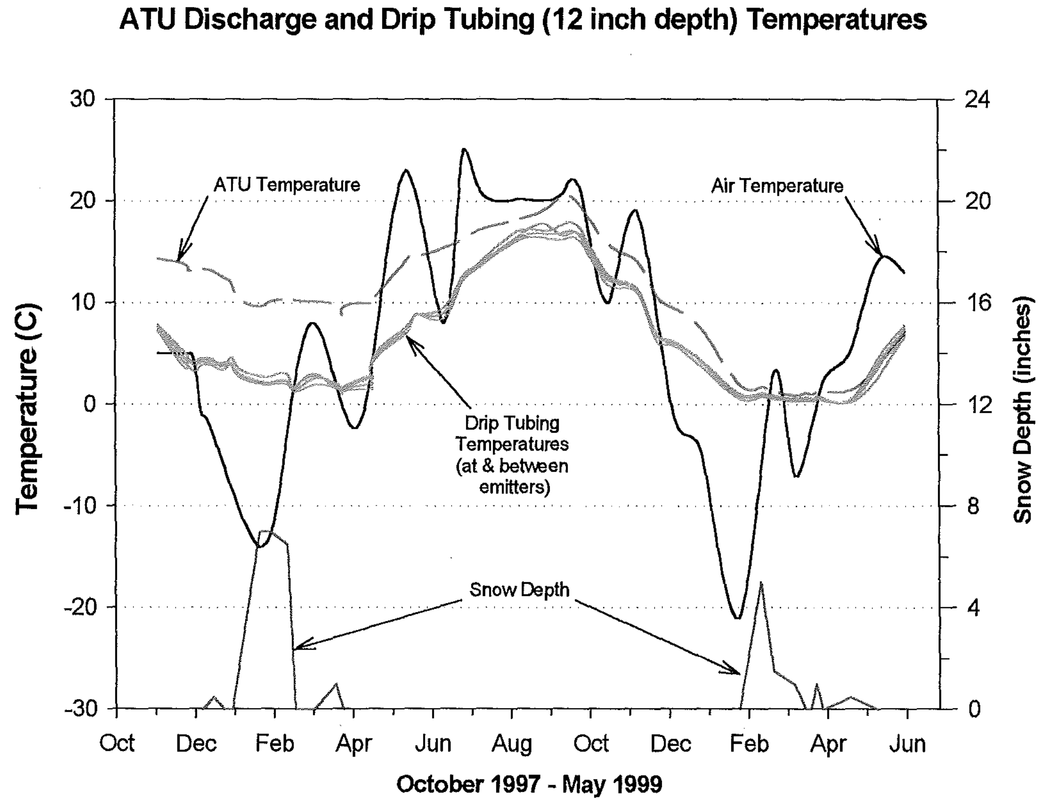

Figure 3. Total annual snowfall (inches) and snow depths (inches) measured on the ground and recorded by the National Weather Service at the Duluth International Airport for 50 years (1950-2000).