DESIGN & PERFORMANCE OF DRIP DISPERSAL SYSTEMS IN FREEZING ENVIRONMENTS

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ABSTRACT

Four different drip dispersal systems in Minnesota were instrumented to determine temperatures at a number of different locations within each system. Temperatures were recorded throughout the winter of 2000/2001. Generally speaking soil temperatures at the emitter line (7.5 to 30 cm of cover) were below freezing throughout the winter. Temperatures at the emitter line tended to be slightly colder (except during dosing events) than the soil temperature at a comparable depth between emitter lines on lightly loaded systems.

Different strategies for insulating of air relief valve boxes were investigated. Designs that insulate the top of the valve box while maximizing the transfer of heat from below were the most successful.

All four systems operated successfully through the Minnesota winter, despite freezing soil conditions. This can be attributed to the proper use of insulation and drainback design strategies.

INTRODUCTION

Subsurface drip distribution is gaining widespread acceptance as wastewater disposal method, especially in situations where pressure dosing is needed. However, use of drip distribution technology in northern climates has been tempered due to concerns about freezing.

Existing design manuals are derived from experience with landscape irrigation in warm climates. Drip dispersal systems used for wastewater distribution face a very different set of challenges. In freezing environments, designs must be modified substantially from the standard landscape irrigation approach.

Minnesota is considered to have a severe winter climate with winter temperatures (December through February) averaging -11.3 deg C (11.6 deg F) (NOAA, 2001). However, initial drip distribution applications indicated that freezing would not be a concern. Data collected by the Sauk River Watershed District during the winter of 1995/1996 indicated that emitter tubing with as little as 17.5 cm (7 inches) of cover would stay above freezing (Mostad, 1998). A study conducted by the University of Minnesota Natural Resources Institute during the winter of 1996/1997 reported above-freezing temperatures for emitter lines at depths between 15 and 60 cm (6 to 24 inches), although some freezing with the headworks unit was reported, despite being in a heated enclosure (McCarthy et al., 1997).

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These positive reports resulted in the installation of a number of drip distribution systems, often by designers and installers with little or no prior experience with drip. The winters of 1998/1999 and 1999/2000 were much more severe, leading to numerous reports of frozen drip systems. Because drip was a new and highly visible technology, regulatory officials began to question the suitability of drip systems (although many other onsite systems, including mounds, also froze during this period).

In retrospect, the positive early reports occurred during winters with heavy snowfall. Most importantly, snow arrived early in the winter season, effectively insulating the ground. In contrast, more recent winters have had very cold weather early in the season with no snow cover. This causes the ground to freeze quickly, creating "worst-case" conditions for onsite system freezing (Kadlec, 2000).

Several studies were done to assess frozen systems and find common causes of system failure (Golly, 2000). The most common causes of freezing were systems that did not drain back, with standing water in the system freezing, and above-ground air/vacuum relief valves which froze. Frozen air relief valves that do not open on drainback create very slow drainage conditions that contribute to system freezing, as well as other problems. Raised bed systems also appear to be more susceptible to freezing than in-ground systems.

COLD-CLIMATE DRIP SYSTEM CONFIGURATION

In 1997, North American Wetland Engineering (NAWE) began development of a "new" cold-climate drip system. Several design changes were made in 1997 and 1998 to improve system performance. Since 1998, this layout has resulted in excellent cold-weather performance.

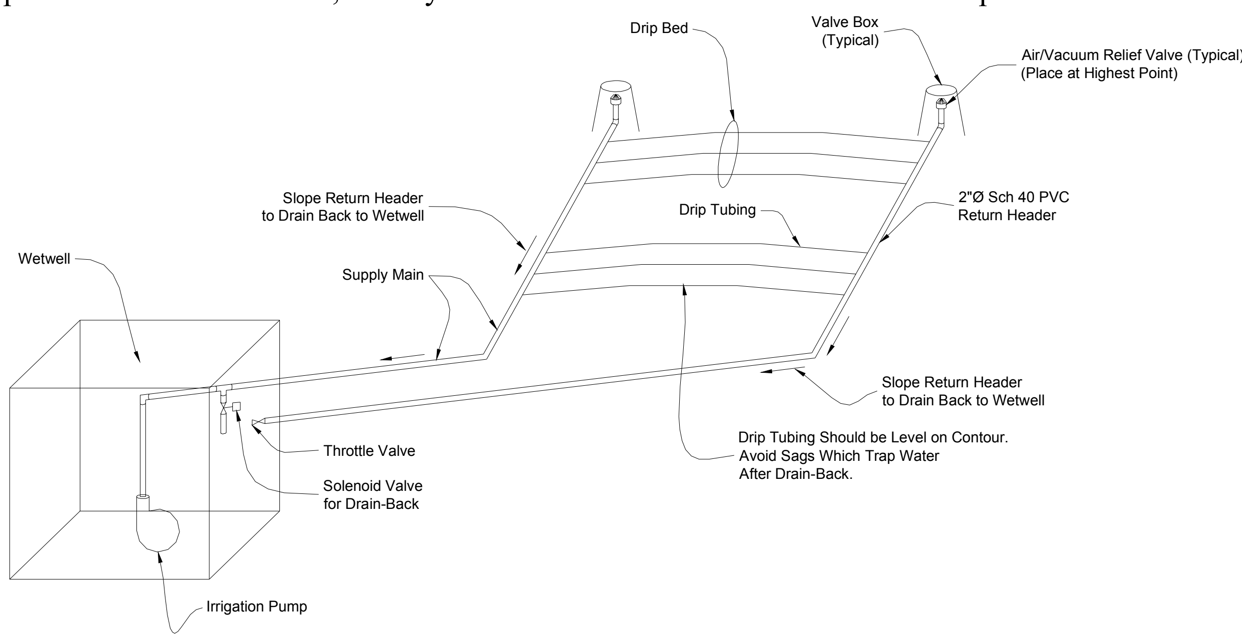

Figure 1. NAWE Cold-Climate Drip System Schematic.

This drip system design is substantially different than other commercially available systems in that there is no headworks to freeze. Eliminating the headworks results in a much simpler system, although one pump per zone is needed. On very large systems, this multiplicity of pumps may be more expensive than a headworks system.

The drip system is designed to completely drain back to the wet well. A motorized drain valve on the supply main opens when the pump shuts off, draining the system. To maintain water movement through the system, a continuous flush on the return header is used. Field pressure is manually set by throttling the return valve. Air/vacuum relief valves on both the supply main and return header are employed to permit rapid drain back. The objective of this design is to completely drain the system in 3 minutes or less. System design and installation recommendations are discussed in detail elsewhere (Wallace, 2000).

For the supply main and return header piping, 2-inch schedule 40 PVC is used to allow a high-pressure steamer hose to be inserted in the event of freezing. Other details of the system layout generally follow current design practice (Burton et al, 2001).

SYSTEM PERFORMANCE

Four systems were selected in 2000 for temperature monitoring. The objective of this study was to:

- Effectively document successful performance of drip distribution systems in cold-climate applications.
- Gain a better understanding of the heat flow within the drip system.

The four systems selected were The Greens of Dellwood, Bornholdt Residence, Columbus Elementary School, and Golly Residence. Temperatures at each site were recorded using 4-channel HOBO or submersible StowAway Tidbit data loggers. The HOBO loggers were equipped with external temperature probes with an accuracy of 0.5 deg C, while the StowAway loggers have an integral temperature sensor with an accuracy of 0.2 deg C (Onset Computer Corporation, 2000).

<u>The Greens of Dellwood</u>
This is a 11-home residential cluster system employing a septic tank effluent pump (STEP) collection system, a horizontal subsurface flow wetland with Forced Bed Aeration™, and 2-zone drip irrigation system. The system was designed by NAWE in 1997. Emitter tubing was plowed into a 60 cm (24 inch) sand blanket on top of native clay soils to provide 90 cm (36 inches) of vertical separation as required under Minnesota Rules Chapter 7080. The drip system was insulated with 15 cm (6 inches) of peat. Wasteflow PC tubing manufactured by Geoflow, Inc., was installed 60 cm (24 inches) on center, with emitters spaced every 60 cm (24 inches) along the emitter tube. The drip system has a design hydraulic loading rate of 13.8 lpd/sm (0.34 gpd/sf). The linear loading rate from the zone layout is 273 lpd/m (22 gpd/lf).

Because only one home was occupied during the study period, flows were very low relative to the design capacity of the system.

The cover material (peat) was manipulated on two plots, one to provide 7.5 cm (3 inches) of cover, the other to provide 30 cm (12 inches) of cover. Temperatures were measured at the emitter, in between emitter lines (at the same depth as the emitter line), and at a depth of 85 cm (34 inches) below ground surface. Temperatures at the return header air/vacuum relief valve was monitored for each zone, as well as air temperatures and the water temperature in the pump tank. There was one temperature probe at each monitoring point listed above. Logging frequency was every 6 hours (4 times per day).

For clarity, not all data channels are charted. Temperatures at the emitter lines vs. air temperature are summarized in Figure 2. For these two data channels, all data point are charted, however individual data point markers have been omitted to make the chart more legible.

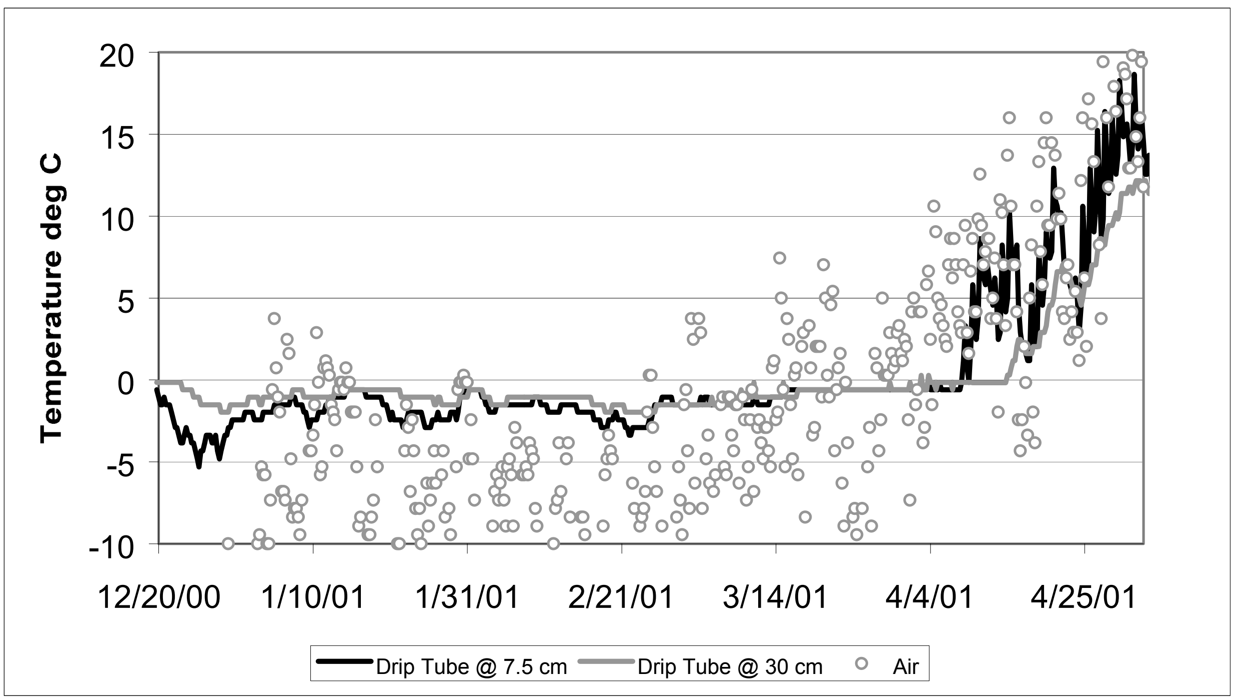

Figure 2. The Greens of Dellwood. Temperature of the Emitter Lines with 7.5 cm and 30 cm of Peat Cover.

<u>Bornholdt Residence</u>

This is a 5-bedroom home using a septic tank, vertical flow wetland, and one-zone drip dispersal system. The onsite system was designed by NAWE in 1998 to replace an existing non-compliant (straight pipe) system. Wasteflow PC tubing as manufactured by Geoflow Inc., was plowed into the native soil (fine sand) at a depth of 15 cm (6 inches). Emitter line spacing was 60 cm (24 inches), with emitters spaced every 60 cm (24 inches) along the tubing. The system received a variance from the Minnesota Pollution Control Agency to discharge into soils with less than 90 cm (36 inches) of vertical separation. The drip system has a design hydraulic loading rate of 45 lpd/sm (1.1 gpd/sf). The linear loading rate from the zone layout is 207 lpd/m (16.7 gpd/lf). The system has no operational difficulties since installation in the fall of 1999.

Temperatures were monitored at the emitter line, in between emitter lines (at same depth of 15 cm), under the drip field at a depth of 85 cm (34 inches) below ground surface, at the supply main and return header air/vacuum relief valves, and at the pump tank, in addition to air temperature. There was one temperature probe per monitoring location. For clarity, not all data channels are charted. Logging frequency was every 6 hours (4 times per day). Temperature at the emitter line compared to air temperature is summarized in Figure 3:

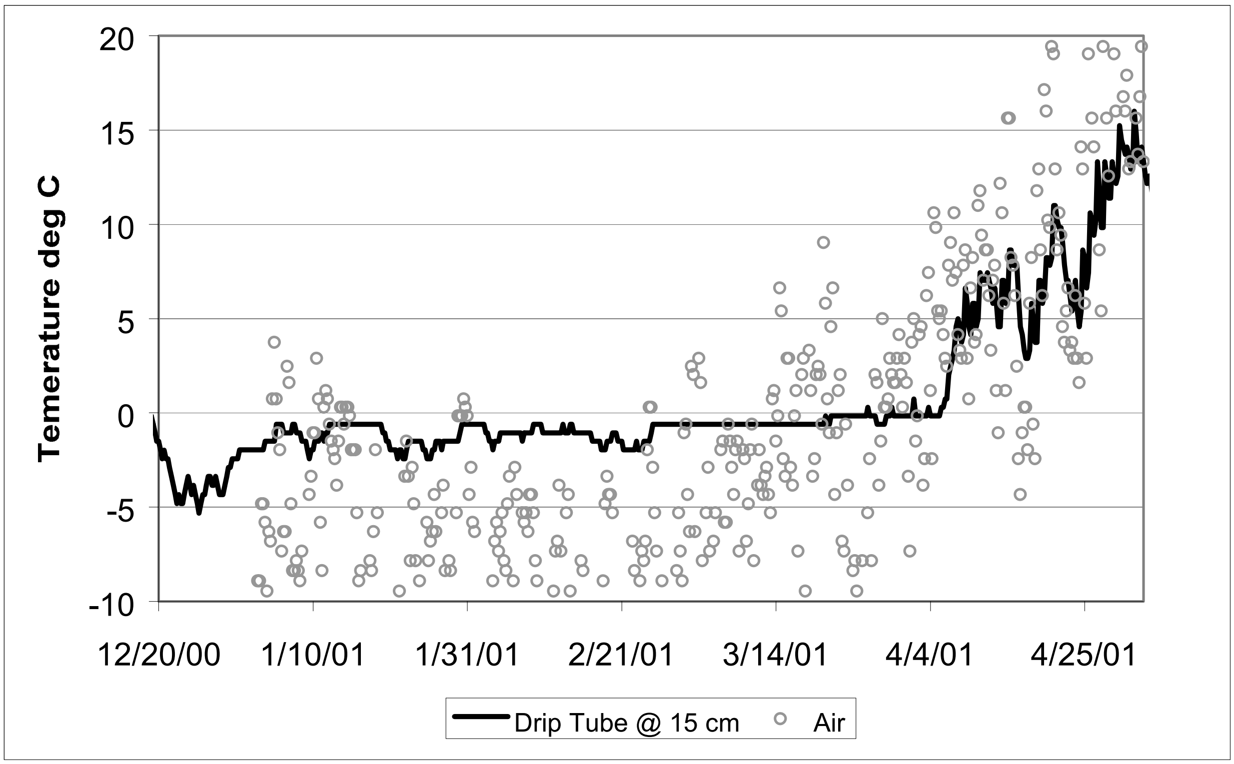

Figure 3. Bornholdt Residence. Temperature at the Emitter Lines with 15 cm of Soil Cover.

<u>Columbus Elementary School</u>

This is a 600-student elementary school with a design flow of 28,085 lpd (7,420 gpd). In 1999, a new onsite system was constructed to replace an existing drainfield system. The new onsite system was designed by NAWE in 1998. This replacement system consisted of re-using the existing septic tank, a 1,115 sm (12,000 sf) single-pass sand filter and a 1,672 sm (18,000 sf) 2-zone drip dispersal system. To maintain 30 cm (12 inches) of vertical separation, Wasteflow PC tubing as manufactured by Geoflow, Inc., was plowed into the native soil (fine sand) at a depth of 15 cm (6 inches). Emitter line spacing was 60 cm (24 inches), with emitters every 60 cm (24 inches) along the length of the tubing. The system has a design hydraulic loading rate of 16.7 lpd/sm (0.4 gpd/sf) and a linear loading rate of 329 lpd/m (26.5 gpd/lf).

One of the two drip zones froze in January 2000 when the contractor removed the drainback valves. With the valves absent, the pumps could not pressurize the system and the water level in the pump tank eventually got high enough to flood the nearest drip zone. With standing water in the emitter lines, the system quickly froze. This system has also experienced several surfacing events that were the result of installation problems or gopher damage.

Temperatures were monitored at the ground surface (under the snow blanket), at the emitter line, in-between the emitter lines (at the same 15 cm depth), and under the drip field at a depth of 90 cm (36 inches) below ground surface. There was one temperature probe per monitoring location. Logging frequency was every 30 minutes (48 times per day). Air temperatures were obtained from the nearby Bornholdt residence. For clarity, not all data channels are charted. Temperature at the emitter line vs. air temperature is summarized in Figure 4:

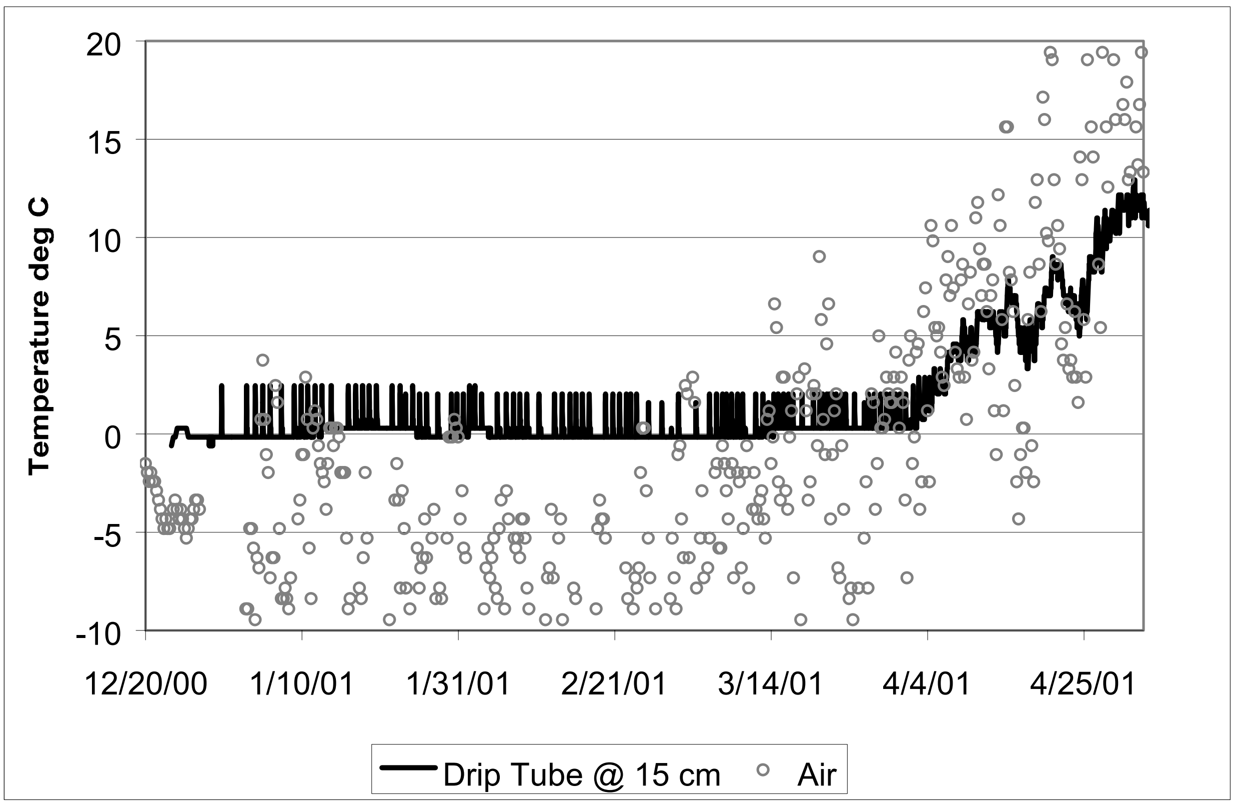

Figure 4. Columbus Elementary School. Temperature of the Emitter lines with 15 cm of Soil Cover.

<u>Golly Residence</u>

This is a new 3-bedroom residence using a 500-gallon trash tank, a Delta Whitewater DF50 aerobic treatment unit, and a one-zone drip dispersal system. The onsite system was designed by Mr. Wayne Golly. Wasteflow Classic (non-pressure compensating) tubing, as manufactured by Geoflow Inc., was plowed into native soil (sandy loam) at a depth of 15 cm (6 inches) to maintain a vertical separation of at least 90 cm (36 inches). The drip system has a design hydraulic loading rate of 40.6 lpd/sm (1.0 gpd/sf). The linear loading rate from the zone layout is 86 lpd/m (6.9 gpd/lf). The system is designed for complete drain-back, which is very similar to the NAWE system schematic shown in Figure 1.

Temperatures were monitored at the supply main, emitter line, in between emitter lines (at an equivalent soil depth), below the drip field at a depth of 90 cm (36 inches), return header, return header air/vacuum relief valve, and at the pump tank, in addition to air temperature. For clarity, not all data channels are charted. Logging frequency was every 6 hours (4 times per day). Temperature at the emitter line compared to air temperature and the pump tank is summarized in Figure 5:

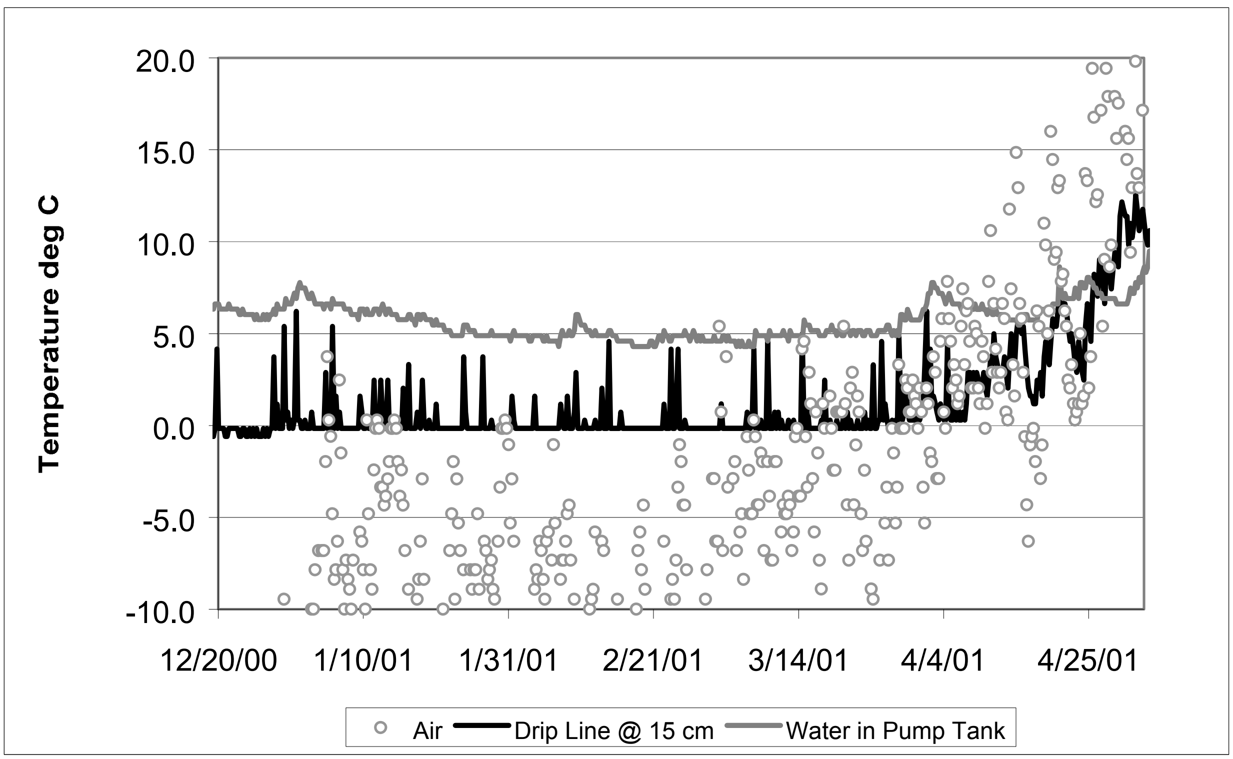

Figure 5. Golly Residence. Temperature of the Emitter Lines with 15 cm of Soil Cover. (Note temperature "spikes" representing dosing events. Temperature during dosing events closely matches the temperature of the effluent in the pump tank.)

RESULTS AND DISCUSSION

Monitoring results obtained during this study were similar to data collected by Bohrer and Converse (2001) in the sense that all systems were discharging to "frozen" soils with ambient temperatures less than 0 deg C. However, the four systems studied generally had longer and more consistent periods of freezing, which can be attributed to the colder winter conditions in Minnesota as compared to Wisconsin.

Bohrer (2000) does an excellent job of summarizing exactly what "frozen" soil means. In the context of this study, core sampling indicated that there were frost crystals in the soil matrix; however macropores were open and could conduct liquid water. The "deep" temperature probes (at a depth of 85 to 90 cm) on all four systems consistently logged temperatures well above freezing, so liquid water discharged by the emitters would not have to travel far (downward) to encounter ambient soil temperatures above freezing. Also, gas transport (including sublimation) is a significant process, even in "frozen" soils. From a practical standpoint, none of the systems experienced hydraulic failure due to "clogging" of the soil macropores by ice crystals.

Most significantly from a design standpoint, all four of these systems would have failed had they not been designed to completely drain the emitter lines. Some designers consider the emitter tubing to be "self-draining". However in the context of freeze resistance, the rate of "self-drainage" needs to be taken into account. If the emitter lines do not drain before the next scheduled dosing event, there will always be some water in the emitter lines. This is compounded by the internal drainage between high and low emitter lines. To combat this, supply mains and return headers should be well below the depth of the emitter lines. Unless the supply mains and return headers are below the frost line, they should be insulated, as shown in Figure 6.

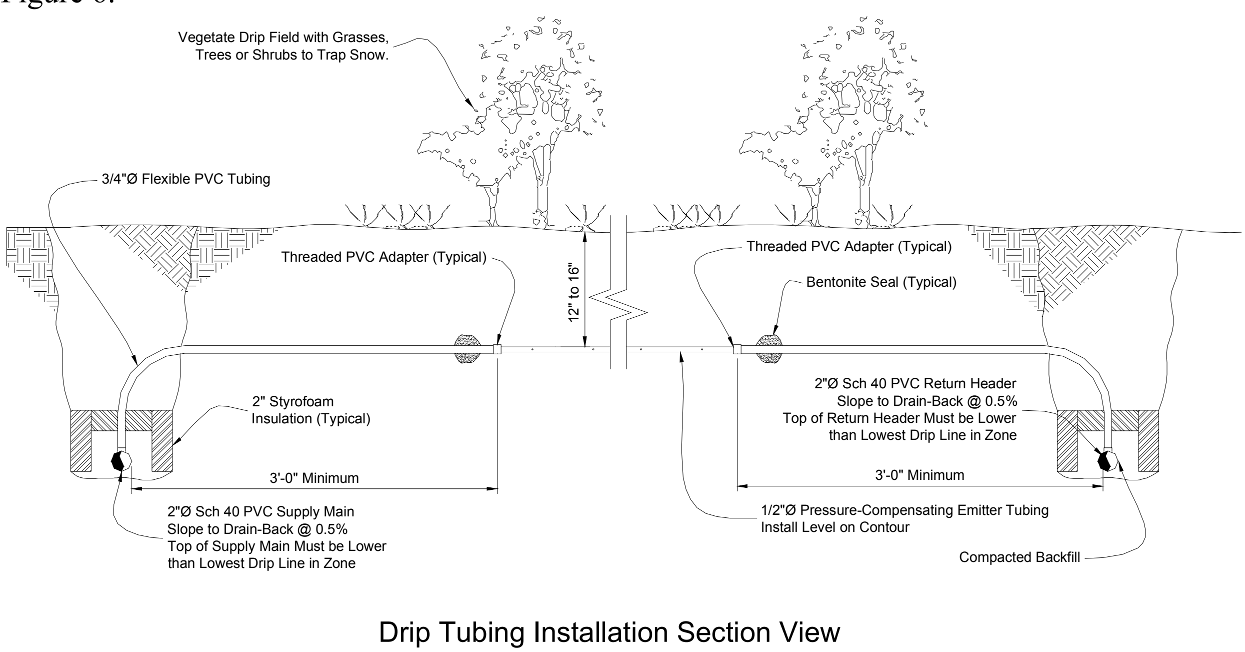

Figure 6. Recommended Configuration of Supply Mains and Return Headers to Avoid Freezing of Emitter Lines.

Practical experience by the author has shown that zones that take more than 20 minutes to drain back are susceptible to progressive freezing failure in Minnesota.

Heat Contribution by the Effluent

At the initiation of this study, there was considerable speculation by the author about the heat contribution of the effluent being delivered to the drip field. Was the heat from the effluent keeping the drip field from freezing? If so, was over-designing the drip field (using a more conservative hydraulic loading rate) “bad” in the sense that the effluent heat was spread out more broadly, making the system more susceptible to failure?

In light of the results obtained to date, the heat contribution from the effluent appears to be very small relative to ambient heat fluxes in the soil profile. When heat is contributed by the effluent, the result is short-term temperature “spikes”. These temperature spikes closely match the effluent temperature in the pump tank, as noted for the Golly Residence in Figure 5. However, heat contributed during the dosing event fails to substantially affect the average temperature at the emitter line (see Figures 4 and 5). Similar heat spikes were documented by Bohrer (2000).

This study went a step beyond Bohrer (2000) and Bohrer and Converse (2001) in that temperatures in between emitter lines (at the same depth as the emitter lines) was also logged. If heat from the effluent was substantially changing the temperature of the soil around the emitter lines, then the emitter lines should be consistently warmer than the soil (at the same depth) between the emitter lines.

Data collected to date indicates that, if anything, the reverse is generally true. Three of the four systems had average emitter line temperatures consistently **colder** than the soil between emitter lines. Only the heavily-loaded Golly Residence system (using relatively warm ATU effluent) was immune to this effect. The systems with the lightest loading (The Greens of Delwood and Bornholdt Residence) had the coldest emitter line temperatures. Differences between emitter line and soil temperatures is summarized are Figure 7.

One explanation for the colder temperatures at the emitter lines is convective airflow through the air/vacuum relief valves. When the system is not in operation, these valves are open. Air warmed by the ambient soil temperatures around each emitter line could escape through an open air/vacuum relief valve. This convective air flow would be facilitated by the recommended practice of having two air/vacuum relief valves per zone. Warm air could exit the higher valve, while cold air could enter the lower valve. This hypothesis has yet to be substantiated. However, since the time periods between dosing events are much longer than the dosing events themselves, convective air flow has the potential to more than offset any heat gains resulting from effluent dosing.

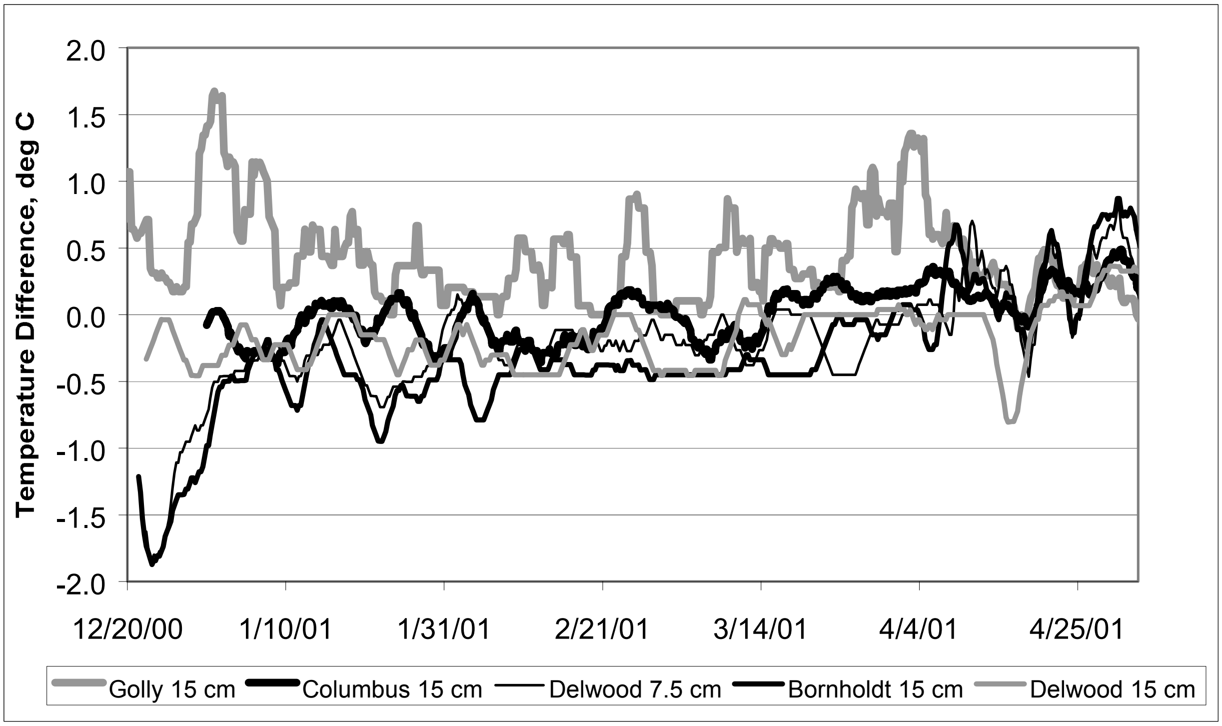

Figure 7. Temperature Difference Between the Emitter Line and the Soil Between the Emitter Lines. (Negative numbers indicate the emitter line is colder than the soil between emitter lines. Data presented is a running 3-day average of logged temperature readings).

<u>Air/Vacuum Relief Valve Insulation</u>

One objective of this study was to evaluate different strategies of insulating the air/vacuum relief valve enclosure. This was felt to be especially important since earlier studies (Golly, 2000) had implicated frozen air/vacuum relief valves (and associated slow drainbacks) as a major factor in drip system freezing.

Since 1997, NAWE has experimented with a number of different insulation methods. Early designs used no insulation (consistent with drip manufacturers design guidelines). Freezing of the air/vacuum relief valves in the winter of 1997/1998 resulted in insulation to the underside of the valve box lid. This design continued to evolve, until by 2000 the recommended insulation design was loose-fill insulation (perlite) in a plastic bag filling the valve box cavity, with 5 cm (2 inch) Styrofoam board under the valve box.

For this study, two existing air/vacuum relief valve boxes were modified to see if increasing the rate of exchange of heat from the warm soils underlying the valve boxes could be used to warm the boxes themselves. To this end, a cavity under the valve box was excavated and a 19-liter (5-gallon) bucket was installed upside-down and filled with pea gravel. In the first installation (The Greens of Dellwood) the entire bottom of the bucket was cut away. This proved to be a mistake, as the annular space between the valve box and the bucket allowed cold air to infiltrate the bucket cavity. In the second installation, the hole in the bucket bottom was cut smaller than the diameter of the valve box, resulting in superior performance. The recommended bucket insulation method is shown in Figure 8. Temperature performance of this configuration is summarized in Figure 9.

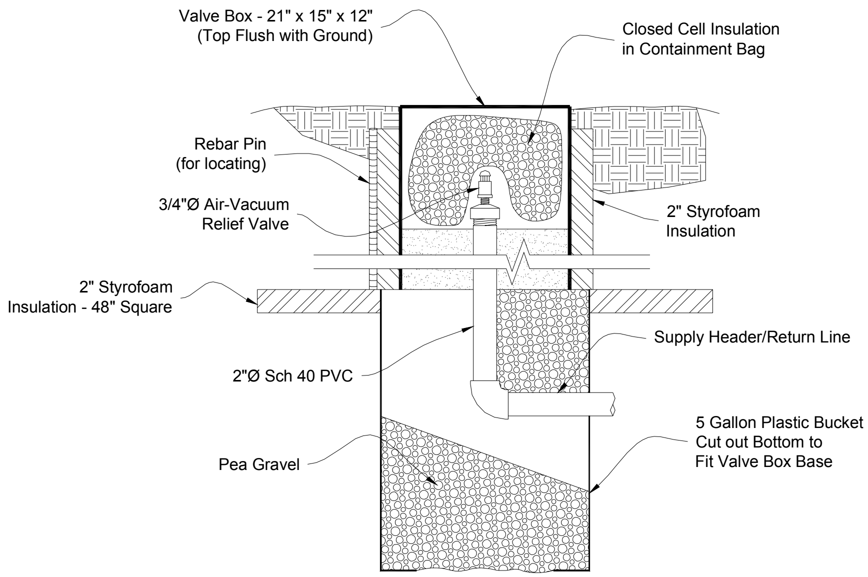

Figure 8. Recommended Air/Vacuum Relief Valve Box Insulation Method.

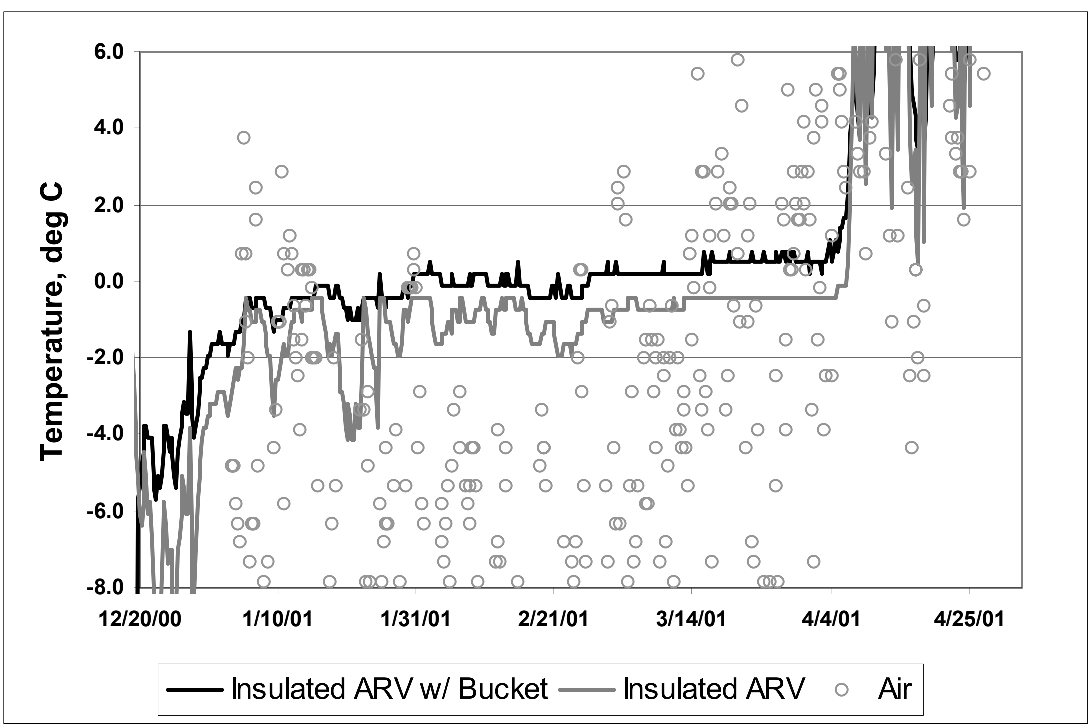

Figure 9. Performance of Valve Box Insulation Designs.

CONCLUSIONS AND RECOMMENDATIONS

Whether or not a specific drip system will experience frozen soil conditions during any given winter appears to be entirely a function of climatic events. Winters with ample early snowfall prevent the soil from freezing; winters with early cold and no snowfall create the severest freezing potential.

Both this study and the work of Bohrer and Converse (2001) indicate that drip dispersal systems must be capable of discharging effluent to "frozen" soils (ambient soil temperature less than 0 deg C) to operate successfully in cold climates. While "frozen" soils appear to be capable of accepting wastewater effluent (either through macropore movement and/or sublimation/gas transport), to sustain this, the drip dispersal system itself must not freeze. This appears, at a minimum, to entail that the drip system not be full of standing water (i.e., drainback occurs between dosing events). To date, there is not a design consensus as to how to create acceptable drainback conditions.

The speculation that application of wastewater effluent will prevent soil freezing does not appear to be valid. In three of the four systems studied, average temperatures at the emitter lines were actually colder than soils at the same depth between emitter lines. Heat loss through convective air movement through the emitter lines between dosing events is hypothesized to account for this net heat loss,

Additional work to quantify heat transfer rates is needed before system freezing can be considered to be a predictive science.

ACKNOWLEDGEMENTS

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REFERENCES

Bohrer, R. M. 2000. Drip distribution soil performance and operations in a northern climate. Masters Thesis, Department of Biological Systems Engineering, University of Wisconsin – Madison, Madison WI.

Bohrer R. M. and J. C. Converse. 2001. Soil treatment performance and cold weather operations of drip distribution systems. In: Proceedings of the Ninth National Symposium on Individual and Small Community Sewage Systems. American Society of Agricultural Engineers, St. Joseph, MI.

Burton, D. J., F. H. Hamed, B .J. Lesikar, J. F. Prochaska, and R. J. Suchecki. 2001. Design principles for drip irrigation disposal of highly treated on-site wastewater effluent. In: Proceedings of the Ninth National Symposium on Individual and Small Community Sewage Systems. American Society of Agricultural Engineers, St. Joseph, MI.

Golly, W. 2000. Cold weather design and operation of Geoflow subsurface dripline systems used to disperse sewage wastewater effluent (unpublished data).

Kadlec R. 2000. Thermal environments of subsurface treatment wetlands. In: Proceedings of the 7th International Conference on Wetland Systems for Water Pollution Control. International Water Association, Colchester UK.

McCarthy B., Axler R., Monson-Geerts S., Henneck J., Crosby J., Nordman D., Weidman P., Hagen T. 1997. Development of alternative on-site treatment systems for wastewater treatment: A demonstration project for northern Minnesota: Final report submitted to Minnesota Technology Inc., Legislative Commission for Minnesota Resources, Electric Research Power Institute. Natural Resources Research Institute, University of Minnesota, Duluth, Minnesota.

Mostad, B. 1998. Personal correspondence to Geoflow Inc. dated April 8, 1998.

NOAA (National Oceanic and Atmospheric Administration). 2001. National Climatic Data Center web page. www.ncdc.noaa.gov.

Onset Computer Corporation. 2000. Hobo & StowAway data loggers, catalog no. 18. Onset Computer Corporation, P.O. Box 3450, Pocasset MA.

Wallace, S. 2000. Drip irrigation design & installation recommendations. In: Proceedings of the MOSTCA Annual Meeting. Minnesota Onsite Sewage Treatment Contractors Association, 26 East Exchange Street, St. Paul MN.