Tile Drainage in WISCONSIN

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Understanding and Locating Tile Drainage Systems

Subsurface drainage is used for agricultural, residential and industrial purposes to remove excess water from poorly drained land. An important feature statewide, drainage enhances Wisconsin agricultural systems, especially in years with high precipitation. Drainage systems improve timeliness of field operations, enhance growing conditions for crop production, increase crop yields on poorly drained soils and reduce yield variability. In addition to agronomic benefits, subsurface drainage can improve soil quality by decreasing soil erosion and compaction.

To maintain agricultural productivity and protect water quality, producers, consultants and agency personnel must understand tile drainage, locate drainage systems and properly maintain them.

"Once the tiles are located, producers or consultants should develop accurate maps and keep copies (both electronic and paper) in a secure file system. Modifications to existing systems or the installation of new tiles should also be identified. Your local Land Conservation Departments should be able to provide copies of aerial photos or base maps."

Tile Drainage Systems in Wisconsin

Subsurface drainage is not a new management practice. Evidence of these systems dates as far back as ancient Rome. In Wisconsin, drainage systems were originally constructed using short (1-foot) segments of clay or cylindrical concrete "tiles." Tiles were initially installed manually, requiring hand excavation. Modern drain tiles are corrugated, perforated plastic pipes typically installed mechanically using a trencher. These plastic pipes are available in a variety of diameters to accommodate different flow rates. They are typically installed at a depth of 3 to 6 feet below the soil surface and discharge into drainage ditches, streams or wetlands.

The majority of tile-drained land in Wisconsin is located in the eastern and southern portions of the state **(Figure 1)**, although county records indicate that tile drainage is prevalent statewide. Tile drainage systems in Wisconsin differ from systems in other eastern corn-belt states, such as Indiana, Ohio, Illinois and Iowa. Tile drained soils in these states are often large, flat, poorly drained areas where tiles are installed in a uniform or grid pattern. In Wisconsin's rolling landscape, tile drains are often installed in a random pattern, following depressional areas.

Two primary factors influencing tile system design in Wisconsin are soil type and topography. In eastern Wisconsin, mediumtextured silt (loess) soils overlay fine-textured glacial material **(Figure 2)**. In these soils water drains freely through the upper part of the soil profile (typically 3 to 8 inches), but the more restrictive sub-soil impedes downward water movement. This results in saturation of the upper portion of the soil profile. Tile drainage is needed in these soils to eliminate seasonally high water tables. In the unglaciated, or "Driftless" region of southwest Wisconsin, tiles are used to drain springs and sidehill seeps that saturate upland portions of the landscape. Tile drains are also installed to drain closed depressional areas throughout the state. And they are used to drain areas with perched water tables or sand lenses causing seasonally high water tables. In addition, producers use tiles to drain organic "muck" soils for improved agricultural production.

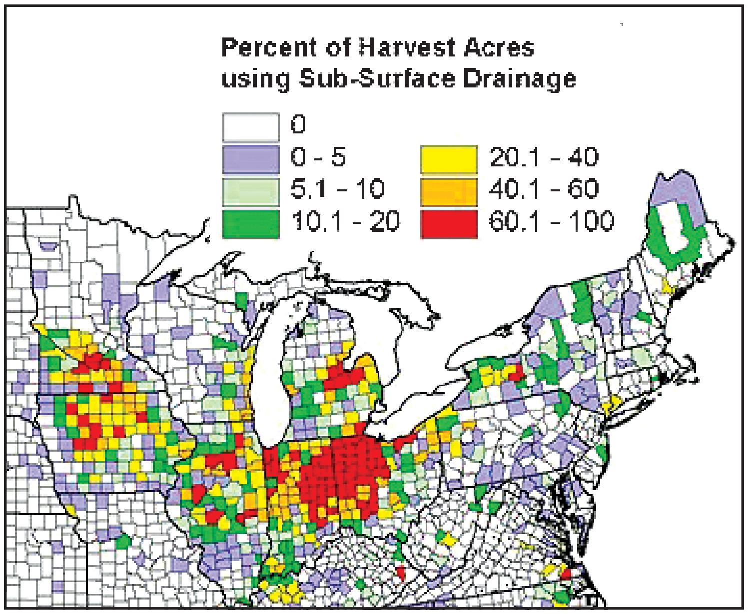

Figure 1: Extent of subsurface drainage (1992).

Source: 1992 NRI: 1992 Census of Agriculture; Gary Sands, Agricultural Drainage 101.

Locating Tile Drains

Knowing the location and extent of tile drains is a challenge facing producers, consultants and agency personnel. Records of main, lateral and outlet tile locations are often lacking. To properly use and maintain an existing tile drainage system, producers must

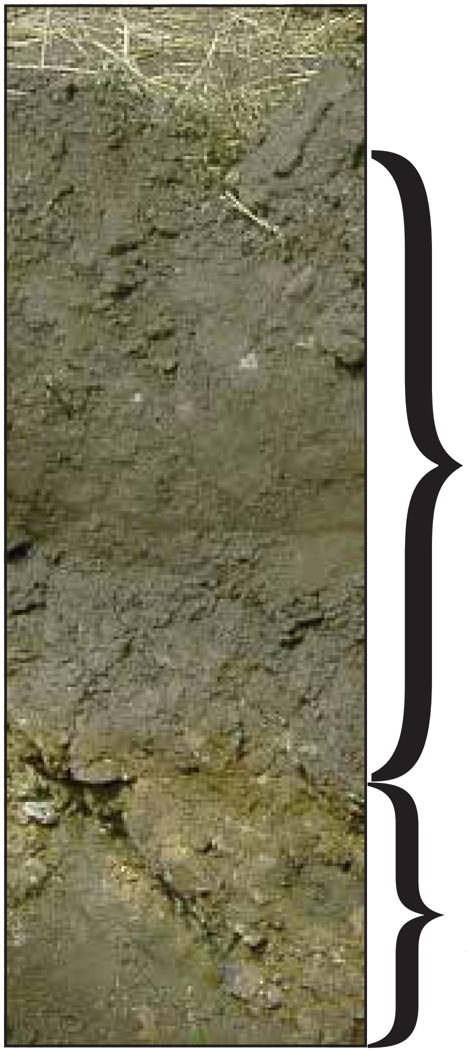

Figure 2: Typical eastern Wisconsin soil profile

Figure 3: Typical tile vents/surface inlets.

Figure 4: Typical tile outlet for discharge into soil or water.

be able to locate tile lines and outlets. Although it is often hard to identify old tile systems in agricultural settings, there are a number of resources available to help. The local Natural Resources Conservation Service (NRCS) or Land Conservation Department (LCD) offices may have maps or other materials if a previous land owner worked with these agencies. Information from these maps should be field-verified.

There are also three readily identifiable drainage features that can indicate the presence of tiles: vents, surface inlets and outlets. Modern tile systems often include vents to increase water removal efficiency and maintain atmospheric pressure within the drain system. Air vents consist of a perforated orange or white pipe protruding a few feet above the ground **(Figure 3)**. Surface water inlets look similar to air vents and are typically installed in low areas lacking a surface outlet. Surface inlets are designed with aboveground openings to allow surface water to directly enter tiles. Producers must take special care when applying manure, fertilizers and chemicals close to inlets, given the high potential for direct entry into the system and into surface waters.

Another identifiable feature is a tile outlet, where the tile system discharges to drainage ditches, waterways, streams and/or wetlands **(Figure 4)**. Tile outlets should be located and marked in the field for future reference. Producers should inspect outlets and clear debris that could impede flow. A sink hole can occur when a tile outlet is blocked. Blockage creates back pressure within the tile, and the surrounding soil becomes saturated. When the pressure within the drain drops, the saturated soil next to the pipe will get sucked into the tile, resulting in a sink hole. Sink holes can also result from large (> 10x) changes in tile line grade or when the flow velocity exceeds approximately 4 feet per second.

Newer technologies, such as monochrome and color infrared aerial photographs **(Figure 5)**, can be useful in mapping tile lines. Aerial maps from NRCS soil surveys may show tile line locations by differences in soil color. There is a period of time shortly after spring frost-out where drain locations will appear lighter in color than the surrounding soil because drained soils dry more quickly. Advances in ground penetrating radar, geomagnetic surveying, electromagnetic induction, resistivity and other emerging technologies will likely result in more effective and efficient methods of locating subsurface drains.

There are less scientific methods used by drainage professionals to locate existing tile drains. Observing soil moisture and crop growth patterns at various periods and conditions can be useful in identifying existing tile lines. In most instances, growth and yield of crops are enhanced directly over tile lines in both dry and wet years due to improved soil aeration, moisture conditions, biological activity and chemical factors. The following conditions may be used to help to identify existing tiles:

1. During and just after snowmelt, water will pond in fields. As these localized ponds begin to disappear, drier soil conditions will appear over tile compared to the surrounding soils. This condition may last from a few hours to a few days.
2. From April to June, drier soil conditions will appear over tiles compared to the rest of the field immediately after a significant precipitation event (usually over 0.5 inches of rain). This will last only 2 to 3 hours after the precipitation event.
3. If June conditions are wet and cool, knee-high corn will often be a deeper green color over tile lines due to improved moisture environment and nutrient availability.
4. Watch the dew on the alfalfa at sunrise (facing east). Tile line locations will reflect more sunlight, attributed to greater leaf density over tiles.
5. During moisture deficient conditions, deep-rooted crops such as alfalfa will be taller over tile lines than in the rest of the field. This is due to extended moisture availability closer to tiles.
6. When soybeans first start blossoming, the plants over tile lines will flower up to a week earlier due to accelerated plant growth and maturity.
7. In fields with foxtail, the weed will be absent over tiles since foxtail favors conditions with compacted soils and excess moisture.
8. Review of GPS yield monitoring data can indicate yield increases on short, localized areas over tile lines in corn and soybeans during both wet and dry years.

If you are having trouble locating tile drains using standard methods, contact your local drainage professional for assistance. Once tiles have been located, develop accurate maps and keep them in electronic and paper formats. Always record modifications to existing systems or the installation of new tiles.

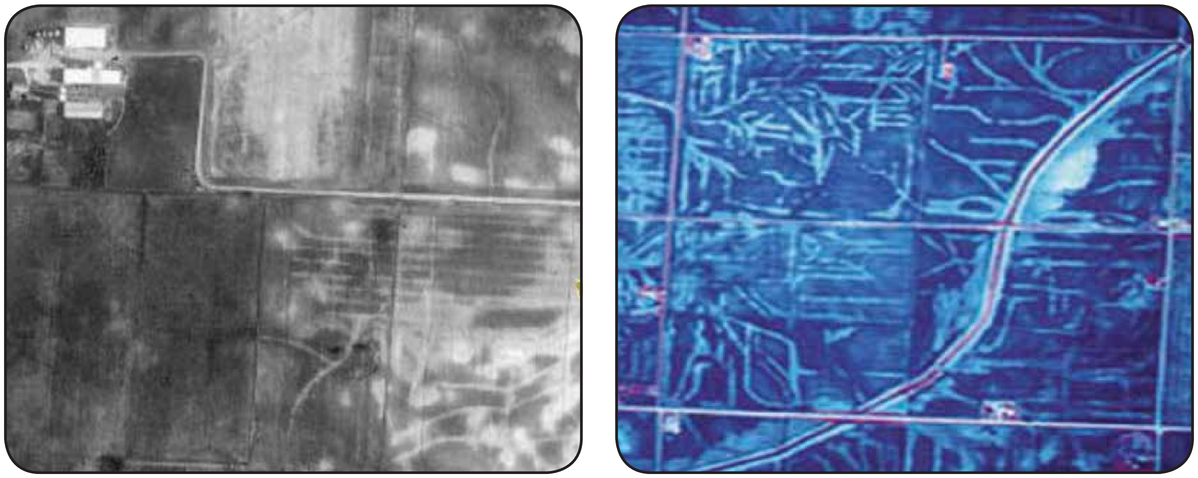

Figure 5: Monochrome and color infrared aerial photos showing tile locations.

Source: USDA-NRCS Web Soil Survey

Source: Verma, A. , R. Cooke and L. Wendte. 1996. Mapping subsur face drainage systems with color infrared aerial photographs. In Proc. of the America Water Resources Association Symposium on GIS and Water Resources. AWRA. Ft . Lauderdale, Fl.

Maintaining Tile Drainage Systems

Figure 1: Tile outlet with a rodent guard.

Tile drains play an important role in Wisconsin's agricultural production systems. Drains alleviate saturated soil conditions, maintaining optimal root zone moisture for plant growth. Saturated soils can kill or damage crops by depriving roots of oxygen. Saturated soils also delay field access and can increase soil compaction if fields are worked. Water-logged soils can cause denitrification, the process where soil bacteria convert nitrate to nitrogen gas, thereby decreasing available nitrogen for plants. Regular maintenance of tile drains is an important management practice to ensure agricultural productivity on tile-drained land in Wisconsin.

"Tile drainage systems should be inspected annually, preferably at peak flow times that typically occur during spring melt and after heavy rainfall events."

Maintaining tile Drains

Tile drainage systems should be inspected annually, preferably at peak flow times that typically occur during spring melt and after heavy rainfall events. Inspection should include checking outlet pipes to ensure that rodent guards are in place and working properly **(Figure 1**). Rodent guards prevent nests and debris introduced by rodents from plugging tile outlets. A tile outlet with a rodent guard can be quickly cleaned by sliding your hand inside the pipe under the guard and removing any trapped material. Tile outlets should also be inspected for excessive erosion and broken or crushed pipe. A good indicator of tile drain performance is a change in field moisture conditions, such as when traditionally well-drained areas exhibit prolonged periods of wetness. In this case the tile line should be inspected for a possible mid-field blockage and to verify that an adequate outlet (i.e. conveyance and capacity) exists.

Ongoing maintenance of fields and waterways with tile systems should include visual observations for animal burrows, tile blow-outs or sink holes. These features range in size from a few inches to several feet and can be hard to find. The direct pathways created by these features can result in large amounts of sediment, debris, manure, fertilizer or chemicals entering tiles. Blowouts result from excessively high flow velocity or pressure inside the tile, causing it to crack or burst. Blowouts are common at tile junctions, fittings or weak spots. Blowouts will often create a sink hole when the surrounding material is drawn into the tile and transported down-stream **(Figure 3)**. During high flow periods, water rises and falls within the sink hole. During low and no flow periods, the sink hole is empty. **(Figure 2)**. Blowouts should be repaired promptly by knowledgeable individuals. Improper repairs and quick fixes can result in on-going problems with blockages. Always contact Digger's Hotline, 1-800-242-8511, prior to excavation for tile repairs.

The most essential requirement for any drain system is an unobstructed and properly installed outlet. Drain tiles typically discharge into open ditch systems, which eventually flow into larger bodies of water, such as streams and rivers. The tile outlet to a ditch should be located approximately one foot above the normal ditch water level, allowing water to fall freely into the ditch to prevent erosion of the stream bank. Drainage ditches should be regularly inspected for excessive vegetation growth, erosion and sediment accumulation, and maintenance should be conducted as needed. Maintenance typically includes removal of trees, brush and other debris from the drainage ditch. Other maintenance practices, such as sediment excavation, will occur less frequently. Prior to conducting maintenance of larger drainage ditches, determine if the ditch in question is part of the public drainage system or drainage district (Wis. Stat. Chapter 88). Should this be the case, any maintenance must be approved and may be paid for by the drainage district board. For assistance in determining if a ditch is part of a drainage district, contact the State Drainage Engineer at the WI Department of Agriculture, Trade and Consumer Protection. Due to the potential for tile systems to drain protected wetlands, several regulatory agencies have jurisdiction over drainage projects (tile and ditch maintenance). Agencies to contact prior to construction include your county planning and zoning department, the local WI Department of Natural Resources and the USDA–Natural Resources Conservation Service (NRCS) field offices. Violation of wetland conservation laws can result in enforcement action. In the case of NRCS, violations can result in ineligibility for USDA programs.

Another important issue effecting tile performance is iron ochre growth. Iron ochre is a red, yellow or tan gelatinous material that adheres to drain wall openings or forms around the outside of the buried portion of the drain tile and obstructs flow. Ochre is a filamentous bacterial slime composed of organic masses and iron oxides formed by specific types of bacteria whose growth is supported by the presence of soluble (ferrous) iron in ground water. Iron ochre formation is most common in sandy and organic muck soils (Ford and Harmon, 1993). Alternately wet and dry soils, such as those under irrigation, are also susceptible to ochre formation. Soluble iron forms in soils under anoxic (non-oxygenated) conditions, which can occur

Figure 2: Sinkholes caused by tile blowout.

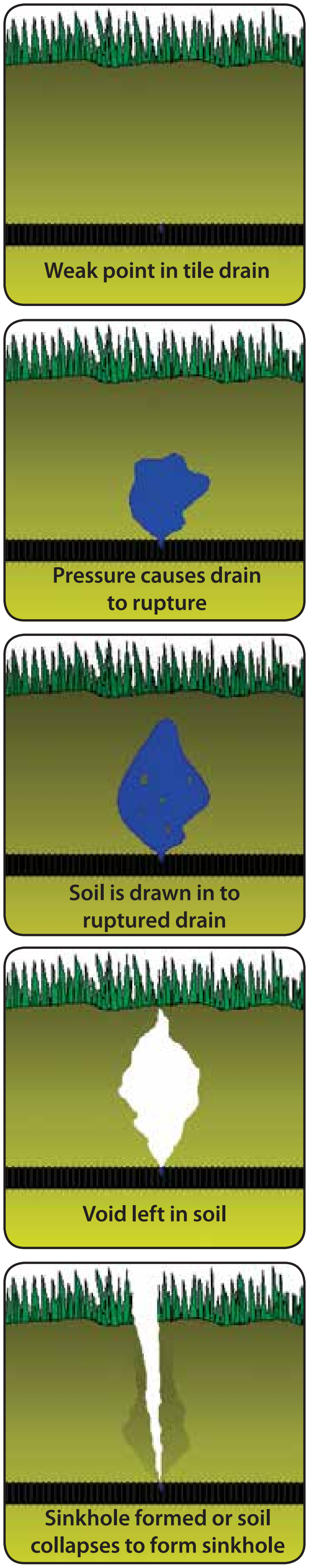

Figure 3: Sequence of steps forming a sinkhole from a tile blowout.

under flooding and high water tables. Since subsurface drain outlets are typically open to the atmosphere, soils around drains are aerobic (contain oxygen) at low levels. As groundwater enters the aerobic zone in and around the drain, solid iron precipitation occurs, creating optimal conditions for ochre growth. Ongoing maintenance is the only economical option for controlling iron ochre formation. If iron ochre has formed on plastic drain tiles, high and low pressure water jet cleaning is the most cost-effective management option. Higher pressure (> 400 psi) can be used with larger drain tile perforations or when drains are enveloped in gravel. Lower pressure (< 400 psi) should be used in sandy soils, when drain tile perforations are small, or when a synthetic sock is used to envelop the tile (Ford and Harmon, 1993).

Figure 5: Tile vent installed at field edge.

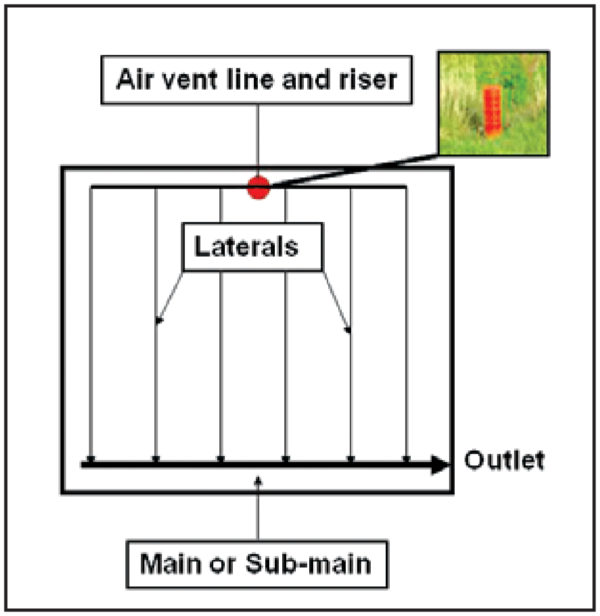

Figure 4: Typical tile drainage system components.

Modifying or installing new tile drainage systems

NRCS standard practices (NRCS Code 606) should be followed when designing, modifying or installing tile drainage systems (NRCS, 2002). A detailed installation plan should be developed addressing specific drainage needs. Preparation of this plan requires assistance from knowledgeable individuals, such as an engineer or experienced tile installer, and should consider crop and soil types as well as site topography. A sub-surface drain system is composed of lateral, sub-main and main line piping. Laterals are the initial collectors of excess water from the soil. Several laterals convey flow to a main or sub-main. A sub-main carries flow to a main line that typically drains to the outlet **(Figure 4)**. When enlarging lines or adding new laterals to existing drainage systems, be certain main lines are adequately sized to accommodate the additional flow, thus avoiding back pressure and blowouts. Air vent installation is recommended to maintain atmospheric pressure through out the system. This allows for maximum flow capacity and relief from back pressure conditions.

Tile system vents are open at the ground surface in order to expose the system to the atmosphere **(Figure 5)**. Vents should protrude above the ground approximately one foot to minimize clogging. They are commonly placed in low traffic areas (e.g. along fence rows), making them difficult to locate. If your system has vents they should be located, mapped, inspected and cleared of obstructions. Some (typically older) tile systems may not have vents. Tile flow rates and water level inspection can be conducted through a vent opening with a flashlight. Also note that because tiles lines located within 80 feet of trees may have flow obstructed by tree roots entering the line, tiled waterways and buffers should be kept clear of trees.

Good record keeping is an essential part of any drainage maintenance program. The location of tile lines, vents, surface inlets and outfalls is critical for troubleshooting and design modifications. Modern GPS technology has become an indispensable tool for mapping tile lines. Tile system mapping should be conducted when new tiles are installed and whenever information becomes available for existing systems (e.g. during routine maintenance). Tile location records should be stored in a safe, readily accessible location.

Summary

Functioning tile drains are essential to crop productivity and water quality in some parts of Wisconsin. Important actions to take when inspecting your tile drain system include:

- ✔ Clear obstructions from tile drain outlets
- ✔ Install rodent guards
- ✔ Monitor drains at times of peak outflow
- ✔ Repair animal burrows, blowouts and sink holes immediately
- ✔ Properly install tile outlets above drainage ditches
- ✔ Properly maintain drainage ditches
- ✔ Inspect tiles for occurrence of iron ochre
- ✔ Follow the rules when modifying tile lines
- ✔ Make sure main lines can handle additional lateral drains
- ✔ Ensure proper functioning of air vents
- ✔ Maintain good records of vent and outlet locations, conditions and performance

Managing Tile-Drained Landscapes to Prevent Nutrient Loss

Tile drainage of agricultural land has the ability to improve yields and reduce surface runoff and erosion losses. However, with a reduction in surface runoff, more water infiltrates the soil and percolates through the soil profile. This is of particular importance to farmers, as this water can also transport essential plant nutrients, specifically nitrogen and phosphorus, out of the root zone. Once nutrients reach the tile drain, they are directly transported to surface waters.

Tile-drained agricultural land must be well-managed to reduce the loss of nutrients to surface waters. Nutrient management practices must be carefully followed to minimize the risk of nutrient loss and to maximize fertilizer use efficiency. Additional considerations need to be taken with manure applications on tile-drained land to both minimize nutrient loss and prevent manure entry into tile drains.

Tile drainage and preferential flow

One of the key factors in nutrient loss to tile drains is preferential flow through the soil profile, which is also referred to as macropore flow. Preferential flow paths are direct conduits from the soil surface to deeper depths in the soil profile. Preferential flow paths are formed by earthworm burrows, decayed root channels, shrinkage cracks, and the structural porosity of the soil. As water percolates through the soil, it travels through preferential flow paths and rapidly transports soluble nutrients below the root zone. As observed with methylene blue dye applied to the surface of the soil in **figure 1**, the dye moved through the soil using a combination of preferential flow paths. Most of the dye entered the soil through shrinkage cracks in the soil surface, then moved laterally along the plow layer and finally moved deeper in the soil profile through earthworm burrows. Water and nutrient transport through the soil matrix is much slower than through macropores. **Figure 1** clearly illustrates that unknown subsurface soil conditions are a main cause of nutrient leaching losses.

The development of preferential flow paths in soil varies significantly with soil type and management. Long-term no-till typically results in increased macropore development as a result of lack of tillage to disrupt preferential flow paths. Soils with higher clay content often develop large shrinkage cracks that occur as soil dries and that can go deep into the soil profile. Nutrients and organic material can be transported rapidly through these shrinkage cracks. For example, plant debris has been observed in well-

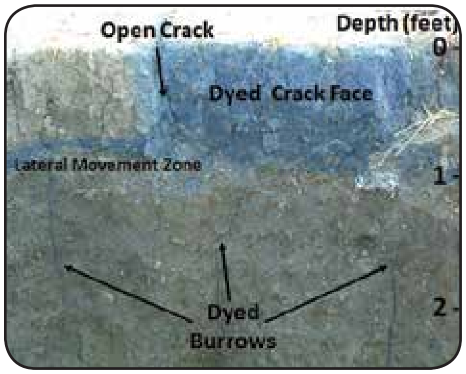

Figure 1. Methylene blue dye flowing through preferential flow paths in the soil (Shipitalo et al., 2004)

developed shrinkage cracks down to 17 feet in Fond du Lac County (Fred Madison, personal communication).

Earthworm activity results in considerable macropore development in soil, and earthworm activity tends to be greater in no-till fields than in fields that are annually tilled. Several studies have shown that earthworm populations in no-till fields were approximately twice that of tilled fields (Kladivko et al., 1997; Kemper et al., 2011). The area over tile drains also creates a prime habitat for earthworms because this area is less frequently saturated. Earthworm populations over tile lines can be double of those between tile lines (Shipitalo et al., 2004). This is important because earthworm burrows that exist within two feet of a tile drain cause direct drainage from the burrow to the tile outlet (Smetler, 2005).

Manure management

When applying manure on tile-drained landscapes, additional pre-

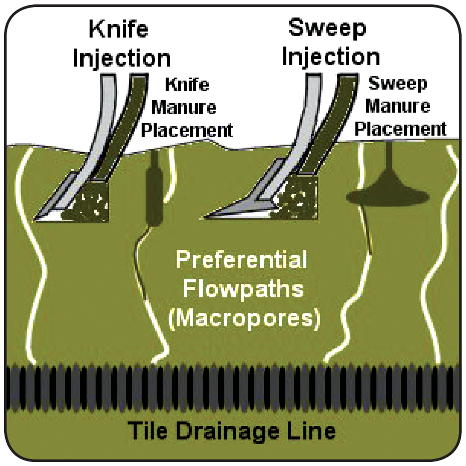

Figure 2. Knife injection and horizontal sweep injection can transmit manure to tile drains if done incorrectly in tile drained landscapes

cautions are needed because of the presence of preferential flow paths which can lead to direct transport of manure to tile drains. The application method, specifically for liquid manure, can have a large effect on the potential to transmit manure to tile drains. The key to preventing applied manure from leaching is to disrupt the macropores around and below the application area.

Although manure transmission can occur with all application methods (e.g., irrigation, surface spreading, and subsurface injections), the two application methods that have the highest potential to lead to leaching of nutrients via preferential flow are knife injection and application using horizontal sweeps. For each of these application methods, there are specific conditions that lead to the high risk of manure leaching. Knife injection can be problematic if sufficient tillage is not performed before application. As shown in **figure 2**, as the knife passes through the soil, it leaves a column of manure behind the knife. If sufficient tillage has not been performed prior to injection, the fluid pressure forces the manure down earthworm burrows, shrinkage cracks, or other preferential flow paths. Tillage and the resulting breakup of macropores decrease the likelihood that the applied manure will leach.

Similarly, horizontal sweep injection can be problematic if sweeps are placed too close together or if the implement is pulled through the soil too rapidly. This results in lifting the soil above the sweep, filling the void with manure. As the weight of the soil comes down on the manure, it may be forced into preferential flow paths and eventually into the tile drains (figure 2). Increasing the spacing distance between knife and sweep injectors increases the loading of manure in a localized area near the injection zone. For example, an 8,000 gallon/acre application made using a horizontal sweep injection toolbar with 10-inch sweeps and 30-inch spacing would result in an effective rate of 24,000 gallon/acre in the area above the sweep **(figure 2)**. The soil loading in the localized application area would be three times larger than a uniformly distributed load. Localized soil loading for knife injection is typically higher than the example used. Emerging technologies for manure injection may disrupt preferential flow pathways and reduce the potential for nutrient leaching.

The consistency and rate of liquid manure applications also factor into the potential for manure transport into tile drains. Manure consisting of greater than 5% solids has enough particulate matter to decrease the probability of preferential flow. Application of manure containing less than 2% solids has a high probability of moving via preferential flow and has been observed in fields (Frank Gibbs, personal communication). The higher the application rate, the greater the volume of water that is added to the soil, thus increasing the potential risk to transmit manure to tile drains. An application of 13,000 gallons of liquid manure per acre has the same amount of water applied to the soil as a half-inch rainfall event.

Soil moisture is an important factor in the potential to transmit manure to tile drains. Both high and low soil moisture can greatly increase this potential. When soils are near saturation, additional water added by liquid manure applications can initiate tile flow, thus facilitating

Figure 3. Cracks in clay soils with high shrink swell capacity.

manure entry into tile drains. In general, liquid manure should not be applied to tile-drained cropland if the drains are flowing. However, the University of Wisconsin Discovery Farms Program has monitored tile outlets that have flowed up to 365 days a year. Tile drains with continual flow indicate that the tile drain is placed below the water table and is actively transporting groundwater. In these situations, there are times when the tile flow is not exporting surface water and surface hydrology is uncoupled from the tile flow. Therefore, it is important for producers to know their tile system characteristics and evaluate soil moisture levels prior to application. Additionally, avoid manure applications when rainfall is predicted, especially when soil moisture levels are elevated because manure transmission to tile drains has occurred days to weeks after application. Research in Ohio identified manure applications to high moisture content soils or heavy rainfall after manure application as the most common factors contributing to manure entry into tile drains (Hoorman and Shipitalo, 2006).

Alternatively, high clay content soils with shrink-swell capacity (figure 3) will have an elevated potential to transmit manure when soil moisture is low. As previously mentioned, these cracks can go deep into the soil during droughty periods. If feasible, pre-tillage (tillage conducted immediately before a manure application) should be performed to disrupt cracks and other macropores. If manure applications are to be made to growing crops or no-till land during low soil moisture conditions, decrease the initial application rate to add moisture to the soil and facilitate closing of the cracks.

"Proper management of crop nutrients on tile drained landscapes is the key to reducing nutrient loss and maximizing nitrogen use efficiency.""

Best management practices on tile-drained agricultural land

There are a variety of best management practices customizable to fit individual cropping systems and various tile-drained landscapes. We have identified twelve key elements that will lead to proper nutrient management on tile-drained land and thus minimize the potential to transmit manure to tile drains.

- ✔ **Understand and locate tile drainage system features:** A working knowledge of tile drainage systems and identification of tile outlets, surface inlets, vents, and other components of tile drainage systems can reduce the potential of inadvertent entry of manure, pesticides, fertilizer, and other soil amendments into the tile. Further information can be found in Tile Drainage in Wisconsin: Understanding and Locating Tile Drainage Systems (Ruark et al., 2009).
- ✔ **Maintain tile drainage systems:** Proper inspection and maintenance of tile drainage systems ensures that the tile system is functioning properly and reduces the potential of inadvertent entry of manure, pesticides, fertilizer, and other soil amendments into tile drainage systems. Annual inspections should be performed to identify tile blowouts and outlet blockages. Further information can be found in Tile Drainage in Wisconsin: Maintaining Tile Drainage Systems (Panuska et al., 2009).
- ✔ **Assess soil conditions prior to liquid manure applications:** Both high and low soil moisture contents can be problematic for liquid manure applications to tile-drained land. Flowing tiles are often a good indicator of high soil moisture conditions and well-developed soil surface cracks are an indicator of low soil moisture conditions in clay soils with high shrink-swell capacity. Manure applications should be avoided during high soil moisture conditions. If manure applications are made during dry soil conditions with surface cracks apparent in the soil, either utilize pre-tillage before application or reduce initial application rate to slowly add moisture to the soil to facilitate closing of the cracks.
- ✔ **Review forecasted weather prior to liquid manure applications:** Avoid applications when rainfall is predicted to occur after application. Soil moisture levels are increased by liquid manure applications, and subsequent rainfall can result in tile flow and release of manure to tile drains. Also avoid applications soon after rainfall events because soil moisture levels are typically elevated.
- ✔ **Monitor tile outlets when applying liquid manure:** Tiles should be monitored before, during, and after liquid manure applications for potential discharge of manure. Tiles flowing before applications are an indication of high soil moisture conditions, in most circumstances, and applications should be avoided. Monitor during applications because water from the liquid manure increases soil moisture content and can result in a flow event. Tile outlets should also be monitored up to a few weeks after application, especially after subsequent precipitation that may cause tile flow.
- ✔ **Restrict tile discharge prior to manure application if able:** If water level control structures are installed in tile systems, insert stoplogs (devices inserted to control water level) to prevent flow from tile drains before application. Subsequent to application, remove stoplogs and check for flow. If flow is present after application, reinsert stoplogs to prevent discharge. Stoplogs should also be reinserted if a large rainfall is predicted to occur within a few weeks of application. Tile plugs can also be used in systems without water level control structures, but they have been shown to fail 50% of the time (Hoorman and Shipitalo, 2006).
- ✔ **Use tillage to break up preferential flow paths prior to or concurrent with application:** Pre-tillage for surface and injected liquid manure applications or application methods that concurrently disrupt preferential flow paths below the manure injection depth should be utilized to prevent manure entry to tile drains. Soils should be tilled at least three inches below the injection depth to adequately disrupt preferential flow paths.
- ✔ **Take precautions when surface applying liquid manure to no-till or perennial crops:** Preferential flow paths are more developed in no-till systems and in later years of perennial crops. Split applications or reduced rates should be considered for liquid manure applications. Additionally, manure can be transported along growing or decayed roots of deep tap root crops like alfalfa.
- ✔ **Ensure precautions are taken for manure and pesticide applications in fields with surface tile inlets:** Surface inlets are commonly used in fields with closed depressions without a surface outlet. Extra precautions need to be taken in proximity of surface tile inlets because they are a direct conduit to tile drainage systems. Check state and local setback requirements for surface tile inlets before applying manure and pesticides.
- ✔ **Use best management practices for fertilizer and manure management:** This includes applying nutrients based on A2809 guidelines (Laboski and Peters, 2012), delaying or splitting nitrogen fertilizer applications, and waiting to apply manure or anhydrous ammonia in the fall until soil temperatures are less than 50°F. If applications are necessary when soil temperatures are above 50°F, use nitrification inhibitors. Research in Indiana has shown that alternating the timing of liquid manure application from fall to spring can reduce nitrate leaching by 30% and that spring application of manure results in nitrate leaching losses similar to spring fertilizer applications (Hernandez-Ramirez et al., 2011).

Figure 4. Water level control structure for tile drains

- ✔ **Utilize conservation management practices such as cover crops, conservation tillage, and planting of grassed waterways:** This also includes any other management practice that increases nitrogen conservation in the soil and reduces erosion. These practices that reduce soil loss also reduce sediment-attached nutrient movement on the soil surface and will also help to reduce the potential of loss to tile drains.
- ✔ **Have an emergency plan in place:** If manure enters tile drains, take immediate steps to stop the flow and prevent discharge to fresh water systems. This can be performed by blocking or diverting the tile outlet, intersecting the tile system, and digging a pit directly downstream of the spill site to collect manure. Contact the Wisconsin DNR Spills Hotline at 1-800-943-0003 to report the spill and get assistance with subsequent remedial actions.

Treatment practices

There are technologies available that can be used to retain water and nutrients in the soil profile. Drainage water management is the practice of controlling water table elevation to desired levels throughout the year. Water level control structures are used to maintain the water level higher in the soil profile after crops are removed to minimize nitrogen loss, predominantly in nitrate form, to surface water **(figure 4)**. The control elevation is then lowered in the spring to remove excess water from the soil profile and to allow the soil to dry out for field access and planting. Once crops are planted, the control elevation is often raised to hold the water level closer to the root zone, especially for crops that are prone to drought stress. Once crops are removed, the control elevation is raised farther to store more water and to prevent nutrient loss until spring. Additional information on drainage water management can be found in *Drainage water management for the Midwest: Questions and answers about drainage water management for the Midwest.*

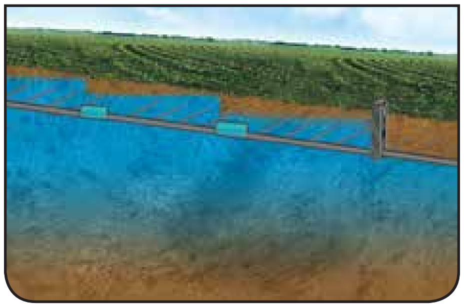

Figure 5. Water Gates™ and Inline Water Level Control Structure "stair-step" water level
(Image courtesy of AgriDrain, Adair, IA)

Water table management in many of Wisconsin's tile-drained landscapes is limited by the slope of the land. Slopes of less than ½% are suitable for drainage control structures to be practical. Slopes greater than ½% will only allow for drainage control on a small portion of the land surface and may result in high fluid head pressures in tile systems and tile blowouts. Many of Wisconsin's tile-drained landscapes have 2–6% slopes. New technologies allow for infield drainage control for lands with higher slopes **(figure 5)**. This type of system has two benefits: It is installed underground so as not to interfere with field operations (including deep tillage), and it can be "stair-stepped" to control drainage on higher sloped land up to 2% **(figure 5)**. The level in each of the structures is controlled by the downstream water control structure located either at a field boundary or tile outlet.

Constructed wetland treatment of tile drainage flow has been shown to be more effective for nitrogen (N) than phosphorus (P) removal, but there are many limitations with this practice (Miller et al., 2002). Constructed wetlands can take large amounts of land out of production for effective treatment sizing. Reported P removal and N concentration reductions vary due to a number of factors, including system design, retention time, and local climatic and physical conditions. Temperature effects on microbial activity may have large influence on N removal capacity, especially in the cold temperature extremes of the northern regions, such as Wisconsin (Jin et al., 2002). The P removal potential of constructed wetlands is limited and highly dependent on the nature of materials used for construction. In fact, during constructed wetland establishment, increases of ammonium N, dissolved reactive P, and total P have been seen in wetland effluent (Tanner et al., 2005).

For tile systems that outlet to drainage ditches, a two-stage drainage ditch can reduce the scouring of ditch banks and increase the removal of sediment, nitrogen and, phosphorus from tile drainage water. The two-stage design, as seen in figure 6, spreads flow over a larger area that decreases water velocity, allowing for sediment to settle out, and increases residence time for biological N removal. During low ditch flow periods, if the drainage ditch is

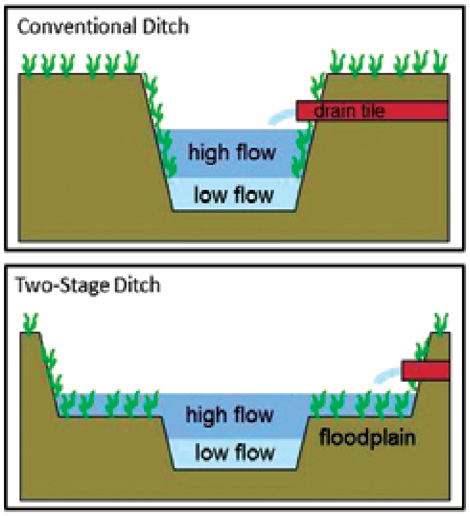

Figure 6. Traditional (top) and two-stage (bottom) drainage ditches
(Image courtesy of Sarah Roley)

constructed properly, tile water will spill onto vegetated benches, allowing for increased removal of sediment and nutrients.

Emerging technologies in drainage water management will likely provide increased options for reducing sediment and nutrient transport from tile drainage systems. Some of these technologies include blind and alternative surface inlets, bioreactors, and saturated buffers.

Contact your local National Resource Conservation Service (NRCS) or Land Conservation Department (LCD) to obtain additional information on management practices to reduce nutrient loss from tile drainage systems and local regulations on manure application requirements and setbacks.

While there are current and emerging technologies to remove nutrients from tile drainage systems, many are limited in effectiveness, are unsuitable for the landscape, or are cost-prohibitive. Overall, the best method to minimize tile drainage release of nutrients to fresh water systems is to utilize management practices that prevent nutrients from reaching tile.

Written by: Matt Ruark, Eric Cooley, John Panuska, and Joe Pagel

http://fyi.uwex.edu/drainage

UW-Discovery Farms Office, PO Box 429, Pigeon Falls, WI 54760, 715-983-5668

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