TECHNOLOGIES IN TILE DRAINAGE WATER TREATMENT

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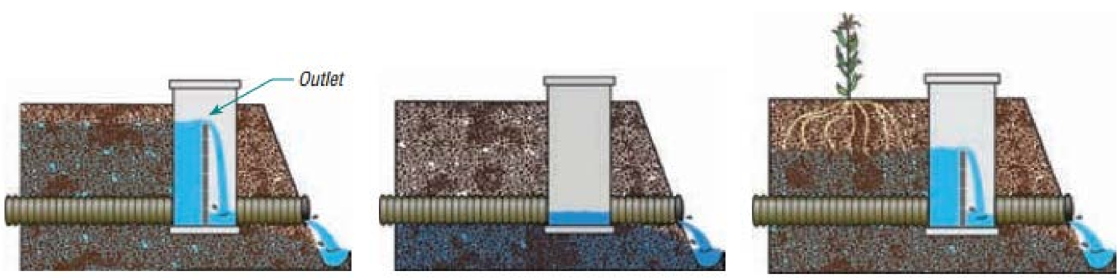
Tile-drained agricultural land must be well-managed to reduce the loss of nutrients to surface waters. Nutrient management practices must be carefully followed to minimize the risk of nutrient loss and to maximize fertilizer use efficiency. This is of particular importance to farmers, as this water can also transport essential plant nutrients, specifically nitrogen and phosphorus, out of the root zone. Once nutrients reach the tile drain, they have a direct conduit to surface waters.

Emerging technologies in drainage water treatment can mitigate nutrient transport from tile drainage systems. Some of these technologies include drainage water management, constructed wetlands, bioreactors, and saturated buffers. The information provided will briefly assess the cost and effectiveness of nitrogen and phosphorus removal of these tile drainage treatment options.

Drainage Water Management

Drainage water management is the practice of controlling water table elevation to desired levels throughout the year to retain water and nutrients in the soil profile (Fig. 1). 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. 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 (a practice known as subsurface irrigation), 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*.



The outlet is raised after harvest to reduce nitrate delivery.

The outlet is lowered a few weeks before planting and harvest to allow the field to drain more fully.

The outlet is raised after planting to potentially store water for crops.

Figure 1. Drainage water management controlling water table elevation (Frankenberger et al., 2006).

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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 to 6% slopes. New technologies allow for infield drainage control for lands with higher slopes (AgriDrain - Water Gates™). 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% (Fig. 2). The level in each of the structures is controlled by the downstream water control structure located either at a field boundary or tile outlet.

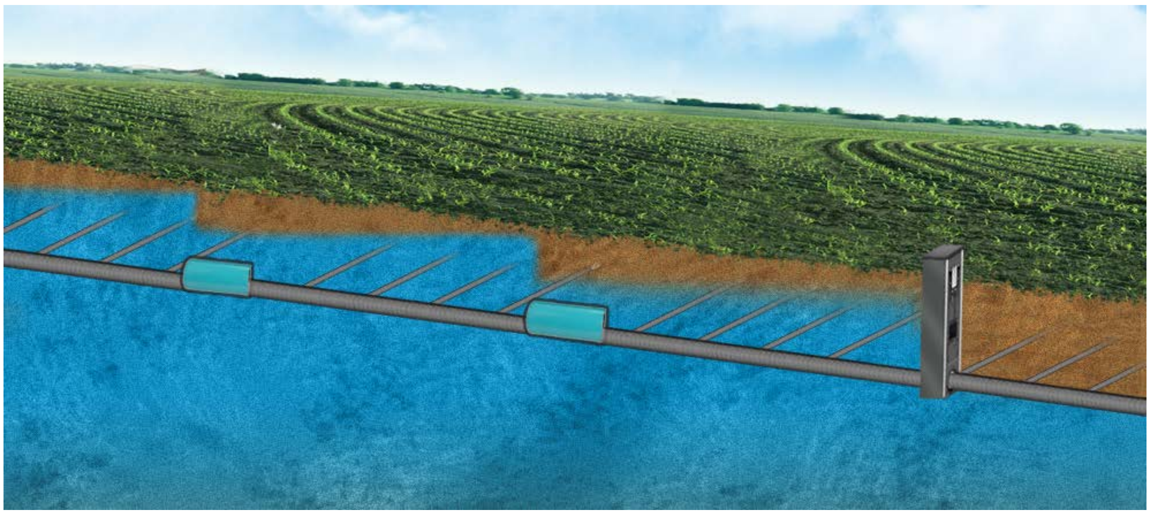

Figure 2. AgriDrain - Water Gates™ "stair-stepped" controlled drainage (Image courtesy of AgriDrain, Adair, IA).

Constructed Wetlands

Constructed wetland treatment of tile drainage flow has been shown to be effective for nitrogen and phosphorus removal (Fisher and Acreman, 2004; Jin et al., 2002), but there are many limitations with this practice (Miller et al., 2002). Constructed wetlands have also been shown to reduce biochemical oxygen demand (BOD) that can contribute to decreased dissolved oxygen levels, which can be detrimental to aquatic life (Jin et al., 2002; Lee et al., 2004). Additionally, total coliform and E. Coli bacteria concentrations have undergone significant reductions, over 90% concentration reduction, with constructed wetland treatment (Jin et al., 2002).

Reported phosphorus removal and nitrogen 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 nitrogen removal capacity, especially in the cold temperature extremes of the northern regions, such as Wisconsin (Jin et al., 2002). The total phosphorus 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 nitrogen, dissolved reactive phosphorus, and total phosphorus have been seen in wetland effluent (Tanner et al., 2005).

Constructed wetlands are engineered to develop optimal physical, biological, and chemical conditions to mimic treatment properties of natural wetland systems. The aerobic water portion and upper layers of sediment carry out the formation of insoluble P-metal precipitates and allow for nitrification. The anaerobic, underlying layers of sediment support denitrification and ammonification. It has been shown that constructed wetlands will often have less diverse vegetation, large deviations in water chemistry, and will likely respond differently to environmental stresses such as drought which can affect nutrient removal capabilities (Hunt, 2001). Vegetation is important to constructed wetland systems by encouraging sedimentation, providing a carbon source for denitrification, and controlling sediment oxygen.

Wetland shape has a large effect on residence time, thus treatment efficiency (Worman and Kronnas, 2005). Additionally, vegetation and bottom roughness are additional factors in residence times. It is important to design wetlands to prohibit channeling of flow. Wide wetlands tend to form a central channel that dominates residence times. In one study, a narrow wetland was three times more effective of nitrogen removal as a wide wetland (Worman and Kronnas, 2005). Wetlands can be designed using several parallel ponds or using several inlets and outlets on a single pond to maximize residence times and treatment efficiency of nitrogen.

Conversely for particulate matter and phosphorus, wetland efficiency increases with surface area and increased hydraulic load or sediment input, with exception of extreme episodes (Braskerud et al., 2000). The depth of settling ponds may have little to no influence on sedimentation and shallow wetlands have small settling distance and best efficiency. Relative surface area of constructed sedimentation wetlands for one study on silty clay loam soils was 0.03 to 0.07% of the watershed with detention times of 2 to 10 hours and retention of particles of 8 to 23% respectively (Braskerud et al., 2000).

Phosphorus reductions in constructed wetlands can be initially high, but as concentration build in wetland sediments, higher effluent concentrations can occur especially under low influent phosphorus concentrations (Dunne et al., 2005). High initial removal of phosphorus can also be attributed to microbial vegetation uptake, but both processes are exhausted quickly (Jaimeson et al., 2002). Sharp declines in phosphorus removal efficiency can be observed after 2 to 5 years (Drizo et al., 1999; Kadlec and Knight, 1996) with total phosphorus saturation at 8 years (Jaimeson et al., 2002). Sedimentation of constructed wetlands can severely limit nutrient removal and can occur in 8 to 20 years of installation (Braskerud et al., 2000).

Phosphorus sorption capacity of constructed wetlands varied considerably for different substrates (Xu et al., 2006). Chemical composition as well as grain size effect phosphorus sorption capacity. Fine grain sizes have increased surface areas thus enhanced phosphorus sorption. Organic matter accumulation decreased phosphorus sorption capacity as substrate pores are clogged by the organic matter. Shallow reservoirs with calcareous clay loam substrate have shown to effectively remove soluble phosphorus from overlying floodwaters (Reddy and Graetz, 1981). Water flowing through peat land has removed orthophosphate and total phosphorus up to 100% (Kellog and Bridgeham, 2003). Phosphorus can be precipitated and adsorbed by reactions with calcium, aluminum and iron (Jaimeson et al., 2002; Zhu et al., 1997). A possible source of calcium is milk house waste.

Denitrification, a form of anaerobic bacterial respiration, produces nitrous oxide which is a greenhouse gas. Anaerobic respiration tends to preclude and inhibit methanogenesis due to the competitive superiority of denitrifiers and sulfate reducers (Conrad, 1996). It is possible that nitrate removal is not only due to respiratory denitrification, but conversion to ammonium (Whitmire and Hamilton, 2005). Reported nitrate removal rates were observed in 5 to 20 hours and were rate dependent on concentration (Whitmire and Hamilton, 2005).

A main consideration for constructed wetland treatment is the removal of large amounts of land out of production that may be required for effective treatment sizing.

Bioreactors

The following italicized text is an excerpt from Conservation Drainage for the Midwest web site: https://engineering.purdue.edu/watersheds/conservationdrainage/bioreactors.html

Bioreactors are essentially subsurface trenches filled with a carbon source, mainly wood chips, through which water is allowed to flow just before leaving the drain to enter a surface water body. The carbon source in the trench serves as a substrate for bacteria that break down the nitrate through denitrification or other biochemical processes. Bioreactors provide many advantages:

- *They use proven technology*
- *They require no modification of current practices*
- *No land needs to be taken out of production*
- *There is no decrease in drainage effectiveness*
- *They require little or no maintenance*
- *They last for up to 20 years*

How do bioreactors work? Organisms from the soil colonize the woodchips. Some of them break down the woodchips into smaller organic particles. Others "eat" the carbon produced by the woodchips, and "breathe" the nitrate from the water. Just as humans breathe in oxygen and breathe out carbon dioxide, these microorganisms breathe in nitrate and breathe out nitrogen gas, which exits the bioreactor into the atmosphere. Through this mechanism, nitrate is removed from the tile water before it can enter surface waters.

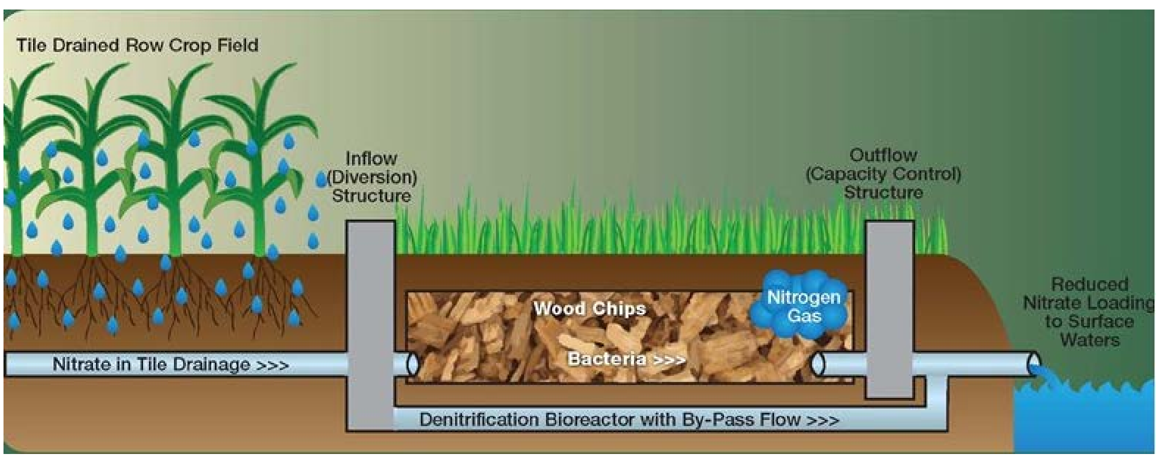

Figure 3. Nitrate in tile drainage water is converted to nitrogen gas by bacteria in the bioreactor. The wood chips provide habitation and food source for bacteria (Laura Christianson, Iowa State University Ph.D. candidate, 2012).

Multiple studies indicate ranges of effectiveness of bioreactors between 15 - 80 percent of the annual nitrate load (Christianson, L. and M. Helmers. 2011; Janes et al., 2009). A bioreactor design program has been developed by R. Cooke and N.L. Bell at University of Illinois, and is available at: http://www.wq.illinois.edu/dg/

Saturated Buffers

Saturated buffers are an option for utilizing existing riparian buffers to treat tile drainage water in addition to surface runoff. Traditionally, tile mains transfer water directly from the field edge to a stream or drainage ditch, thus bypassing the riparian buffer (Fig. 4). Saturated buffers utilize the riparian buffer to treat some or all of the drainage water that would otherwise flow untreated through the buffer. To accomplish this, a diverter box or control structure is installed on the tile main line at the boundary between the field edge and the buffer to divert water from the tile main into a subsurface distribution pipe running parallel to the boundary between the field edge and the riparian buffer. The distribution pipe is common perforated drainage pipe utilized infield to collect drainage water. The diverted water can then seep out of the distribution pipe, though the soil in the riparian buffer, and finally to the stream or drainage ditch (Fig. 4).

The nitrate in the drainage water is removed by the buffer through denitrification, plant uptake and bacterial immobilization. Initial research results have shown a high efficiency of removal for both nitrate and ortho-phosphorus from water diverted to saturated buffers, although only 55% of the total water was redirected to the saturated buffer (Jaynes and Isenhart, 2014). An overflow discharge pipe allows for bypass of the distribution pipe to the saturated buffer during times of high drainage flow rates, to prevent back up of water in the tile main. The overflow discharge pipe discharges directly to the stream or drainage ditch (Fig. 4).

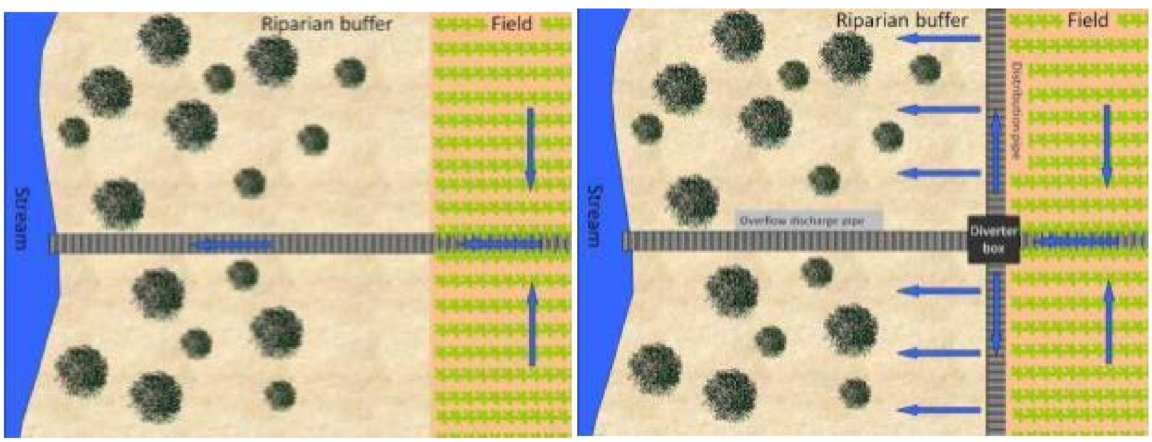

Figure 4. Subsurface drainage leaving the field and bypassing the existing vegetated riparian buffer (left), and a saturated buffer system where the tile water is diverted to flow through the buffer (right). (Jaynes and Isenhart, 2011)

Contact your local National Resource Conservation Service or Land Conservation Department 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.

A series of three fact sheets on tile drainage are available for download at Discover Farms and The Learning Store websites.

Tile drainage in Wisconsin:

1. Understanding and locating tile drainage systems (Ruark et al., 2009)
2. Maintaining tile drainage systems (Panuska et al., 2009)
3. Managing Tile-Drained Landscapes to Prevent Nutrient Loss (Cooley et al., 2013)

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