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Agricultural Drainage

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Drainage refers to the process and practices used to remove excess water from the soil surface and from the soil profile. This bulletin briefly describes the history, need, types and extent of Michigan drainage as well as the pros and cons, and environmental impact related to drainage.

1. Drainage History

The U.S. Swamp Land Acts of 1849 and 1850 provided federal funding to encourage drainage to make the swamp areas in the Midwest more habitable, and thereby encourage economic development. Through this program, many miles of streams were deepened and channelized to create drainage outlets with the result that large parts of the Corn Belt were drained. Once drained, these areas became recognized as having among the most fertile soils in the world. Early medical professionals had suggested drainage in the Midwest as they found that it reduced malaria, although they did not know malaria was spread by mosquitos at that time (Huffman et al., 2013). With the increase in drainage in 1860, the human death toll due to malaria started to decline in the upper Mississippi River Valley.

2. Why Drainage?

Agriculture is one of Michigan's leading industries with over 300 commodities. Corn and soybean are the state's two leading crops with a combined planted area of 4.47 million acres, and a production value of $1.1 billion for grain corn and $983 million for soybean in 2016 (USDA-NASS, 2016). As the world population grows, providing food security at a global scale will require increased production per acre. Without drainage, crop production would not be able to meet the growing food demand (Figure 1).

3. Drainage Types

The two general types of drainage practices are surface and subsurface. Surface drainage is the removal of excess water from the soil surface. Subsurface drainage is the removal of water from the soil profile.

3.1. Surface Drainage

For the purpose of preventing surface water ponding and controlling runoff without causing erosion, surface drainage is the cheapest and easiest option in some cases. In this system, excess water from the soil surface is removed by flowing over the naturally or artificially sloping ground toward surface inlets, shallow ditches and grassed waterways.

3.2. Subsurface Drainage

Surface drainage may not be sufficient or practical in poorly drained soils where the water table is naturally near the ground surface. In these cases, perforated

Figure 1. An example of crop damage due to excess water during the early growth stage of soybean.

plastic pipes are buried in the ground to remove the excess water and lower the water table. This practice is referred to as subsurface (tile) drainage (Figure 2). In this system, perforated drainpipes (laterals) can be installed in a random or parallel (pattern) layout (Figure 3) with the latter being the more common of the two in recent years. The herringbone layout is a subset of the parallel layout. A random layout is common in rolling landscapes where surface drainage provides enough drainage for field operations on most of the field except in isolated depression areas where removal of excess water is needed for uniform field operations (Huffman et al., 2013). In some cases, surface inlets (open inlets) are connected to the subsurface drainage system in sections of the field where there is a need for quicker removal of water from the soil surface.

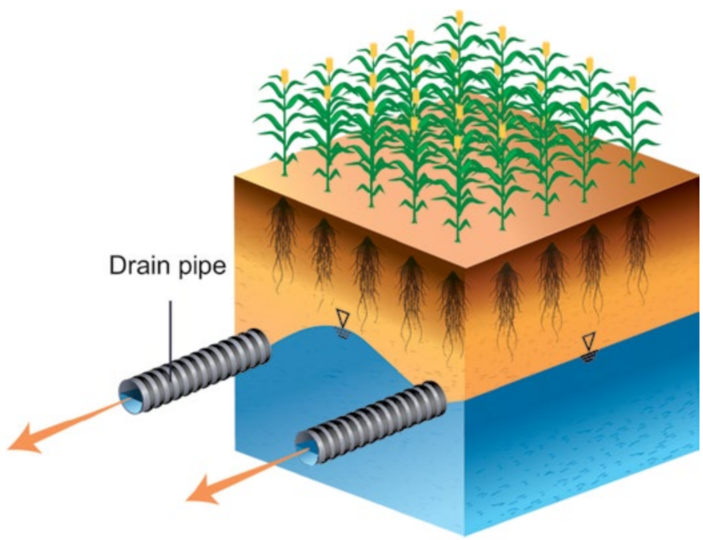


Figure 2. Diagram of a soil profile with subsurface (tile) drainage. Not to scale.

3.2.1. Mole Drains

In some clay soils where surface drainage is not sufficient and installing subsurface drainage is uneconomical, mole drains can be used as a short-term and inexpensive means to drain the excess water from the field. This practice is common in Ireland, U.K., Australia and New Zealand. Mole drains are unlined channels in the clay subsoil formed by a mole plow, which is composed of a shank (leg) attached to a cylindrical foot followed by a cylindrical expander (for channel wall compaction) (Hopkins, 2002). Mole drains can discharge into the drainage ditch or an interceptor drain. The major benefit of this system is the low cost; the disadvantage is the limited lifetime of 1 to 5 years. However, if mole drains are installed properly in suitable soil (minimum 35% nonswelling clay content), they can last beyond 5 years. For more information, see Hopkins (2002).

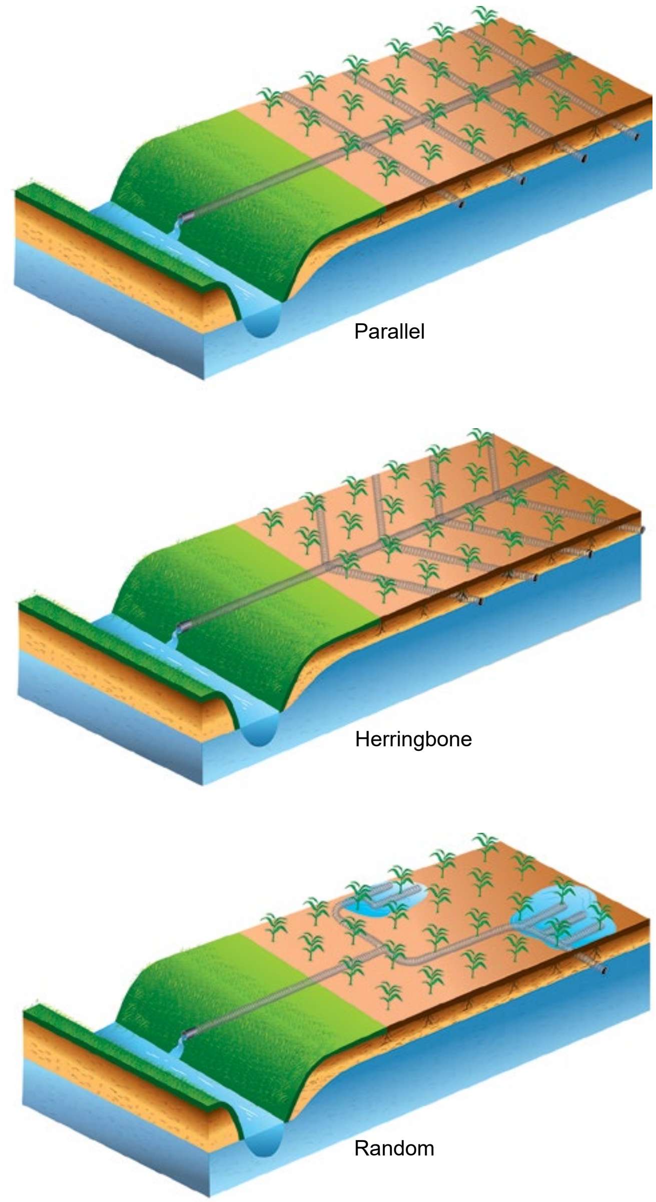


Figure 3. Drainage system layouts. The herringbone layout is a subset of a parallel (pattern) layout. Not to scale.

4. Drainage Water Cycle Components

To better understand subsurface drainage, we need to understand the water cycle components at the field scale (Figure 4). The water cycle components in a field with subsurface drainage are composed of precipitation, evaporation, transpiration, infiltration, surface runoff, lateral seepage, deep percolation, capillary rise, storage (on the surface and within the profile) and drainage discharge. Precipitation is the primary source of water for crop use. As precipitation falls on the soil and crops, some of it evaporates and some of it infiltrates the soil to build a water table in the soil profile. Some of the water is held in the soil as soil water storage. The water in the soil profile can pass through the restrictive layer slowly in the process

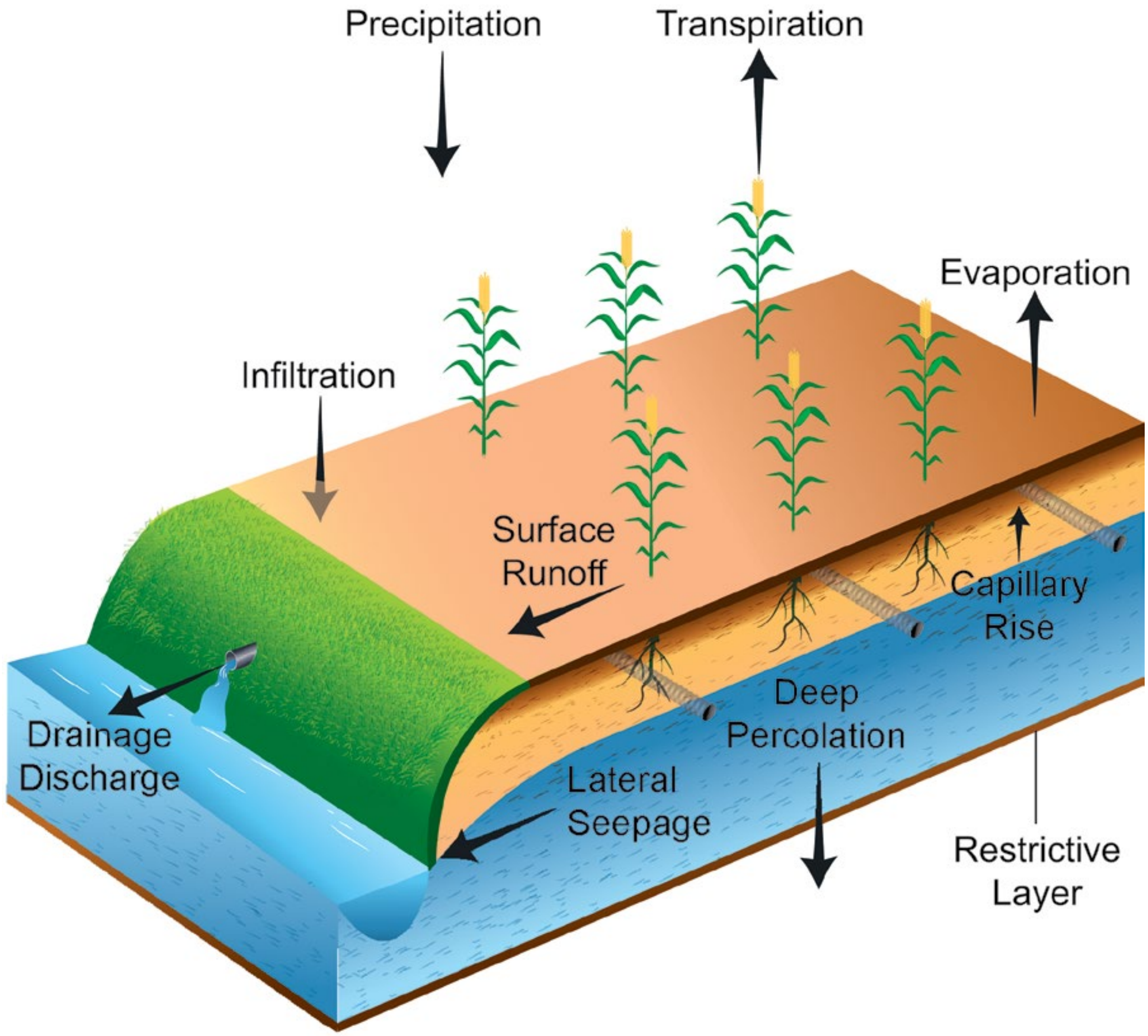


Figure 4. The water cycle on a field with subsurface (tile) drainage. Not to scale.

of deep percolation. Water can rise above the water table in the process of capillary rise that provides water for plant roots above the water table. Plants uptake water and release it in the process of transpiration. The combination of evaporation and transpiration is called *evapotranspiration*. When precipitation rate exceeds the infiltration capacity of the soil, water starts to accumulate on the surface, and with a sloping field, surface runoff will be generated. Water in the soil profile moves toward the ditch through lateral seepage. The subsurface drainage system moves the water from the soil profile to the drainage ditch or receiving stream.

The water balance in the drainage system is described as

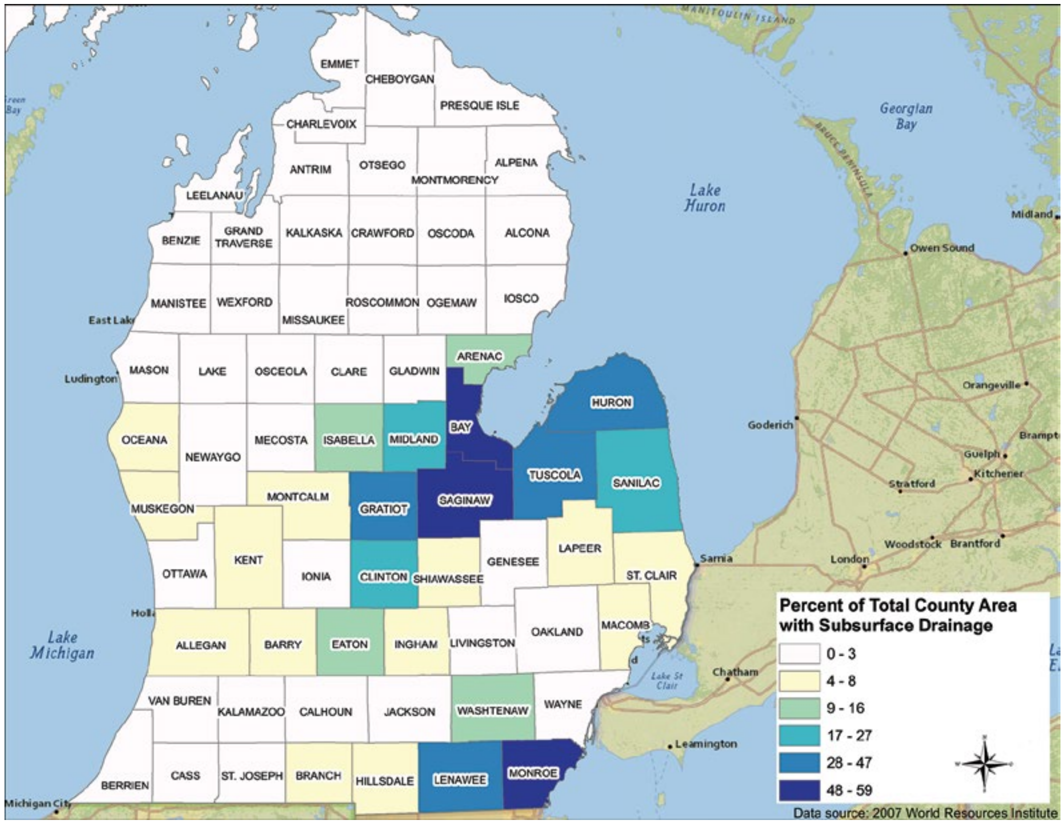
Drainage discharge = Precipitation - Evapotranspiration - Surface runoff - Lateral seepage - Deep percolation - Soil water storage

5. Michigan Drainage

In Michigan, laterals are typically installed at a depth of 2.5 to 3 feet. Lateral spacing ranges from 20 to 50 feet for a new installation with the lower range for fine textured soils (clay, clay loams and loams) and the higher range for coarse textured soils (sands and sandy loams). Overall, there has been a recent trend for narrower lateral spacing, which allows for a quicker water removal from the field.

Currently, much of the subsurface drainage of the U.S. is concentrated in the Midwest. In Michigan's Lower Peninsula, subsurface drainage is more concentrated in the southeast and east (that is, the Thumb region) where the dominant natural drainage classes are very poorly, poorly and somewhat poorly drained with the very poorly drained creating more surface runoff and the somewhat poorly drained creating more seepage under natural conditions

Figure 5. Map of Michigan's Lower Peninsula with the percent of total county area with subsurface drainage (Data Source: Sugg, 2007).



(Figure 5). Drainage class identifies the natural drainage condition of the soil, which refers to the frequency and duration of wet periods under natural conditions.

It is difficult to know exactly how much land is subsurface drained in Michigan, but the 2007 estimate was 2.3 million acres (Sugg, 2007). In 2012 and 2013, higher crop demand led to higher crop prices, which led to more drainage installation with narrower lateral spacing to achieve higher crop yield. In recent years, farm size has continued to grow and producers have been incorporating larger equipment with more technology such as auto-steer, yield monitors, grid soil sampling and variable rate application capability to help them manage these additional acres efficiently. Using yield monitor maps and soil maps, producers can observe low-yield areas within a field and identify needs for corrective measures to achieve uniform high crop yield and field trafficability. Achieving uniform high crop yield and uniform field trafficability, investing in land for positive return and mitigating the crop damage risk due to heavy rainfall events are some of the reasons that have prompted many producers to install additional subsurface drainage with narrower lateral spacing.

6. Some Points About Subsurface Drainage

The location of the outlet of a drainage system is important to the proper water-removal function of the system. Choose the outlet with care to allow free flow (unsubmerged) most of the time. Typically, water that flows into the laterals connects to submains and a main that conveys the water toward the system outlet. Then the water from the outlet can flow into a stream, drainage ditch (Figure 6a), an existing main or a sump. When the system outlet connects to an existing main, check the capacity of the main to make sure it can handle the water volume.

At times, the field is nearly level with not enough grade to allow gravity flow of the drainage water toward an outlet, or the drainage ditch is not deep enough to allow the outlet to flow into it. In these cases, a pumped outlet is needed where the main conveys drainage water into a sump from which it is pumped out to remove the excess water (Figure 6b).

Overall, the subsurface drainage system should be designed to lower the water table from the upper parts of the effective root zone (top 6 to 12 inches) no later than 24 hours after becoming saturated. Significant crop yield loss will generally occur after 24 hours of saturation (Evans and Fausey, 1999). Therefore, proper subsurface drainage is vital to prevent crop damage due to excess water.

Figure 6. (a)(left) Subsurface drainage outlet flowing into a drainage ditch, and (b)(right) a nearly level field with not enough grade to allow gravity flow of the drainage water into a shallow drainage ditch, so the drainage water flows into a sump from which it is pumped out to the ditch.

7. Subsurface Drainage Pros and Cons

Draining the excess water from the soil profile provides the necessary aeration needed for proper crop root development (Figure 7). In other words, drainage promotes deep root development and prevents the crop roots from drowning in too much water. As a result, there is less risk of crop damage due to too much water, and the well-developed roots will have access to the deeper water in the soil. In contrast, in an undrained soil, prolonged waterlogging conditions reduce biological activity, and thereby can destroy soil structure and reduce soil aeration. Also, the shallow-rooted crops under undrained conditions will have access to less water during summer when there is a low water table compared to the drained condition (Figure 7). With drainage, soil warms faster in spring, and with good aeration, biological activity is increased. The increased biological activity enhances soil structure by increasing soil aggregation and it helps provide nutrients to the crop.

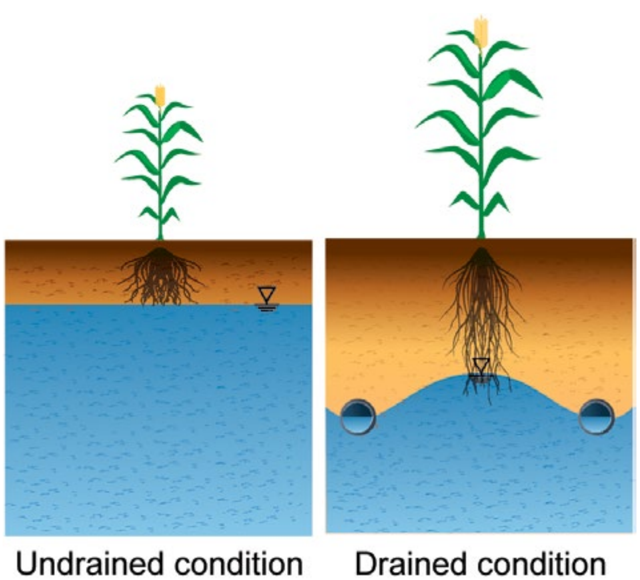


Figure 7. Crop root development for undrained and drained conditions. Not to scale.

Drainage also helps the soil dry sooner, which provides timely field operations (planting, harvesting and other processes) and trafficability. Earlier drying of the soil provides earlier seed germination due to warmer soil temperatures. In contrast, late planting due to wet soils makes the crop more susceptible to frost damage, water stress, and weed and insect issues later in the season (Huffman et al., 2013).

Also, wet undrained soils are more susceptible to soil compaction. Reduced soil erosion is another important outcome of having subsurface drainage as it allows water to infiltrate the soil and flow into the perforated drain pipes rather than flowing over the ground surface. Research has also shown that crop yield is less variable from year to year with subsurface drainage (Brown et al.,1998). The overall impact of subsurface drainage is a healthier, more productive soil with more stable crop yields (Table 1).

A disadvantage of drainage is that it provides less opportunity for groundwater recharge due to less deep percolation, which may be important in locations where the aquifer is in decline. Furthermore, when soil aeration is increased with water removal by drainage, oxidation of soil organic matter increases, and thereby loss of soil organic matter is accelerated.

Table 1. Pros and Cons of Subsurface Drainage in Humid Regions.

Pros	Cons
Increases crop yield	Excess phosphorus transport
Less variability in yearly crop yield	Excess nitrate transport
Increases soil aeration	Less groundwater recharge
Improves soil structure	Accelerates loss of soil organic matter
Decreases surface runoff	
Provides timely field operations and trafficability	

8. Environmental Impact

The two major pathways for nutrient transport from an agricultural field include surface runoff and subsurface drainage flow. In the last decade, the environmental impact of subsurface drainage has heightened concern. While farmers need subsurface drainage for economical crop production, it can also transport nutrients to surface water from organic matter mineralization as well as from commercial fertilizers and manure used to produce crops (Table 1). In other words, subsurface drainage has been recognized as a considerable pathway for phosphorus (P) loss (especially the dissolved form) from the field to surface water bodies (King et al., 2015). As excess nutrients get into surface water bodies, they can cause hypoxia (low oxygen levels) and harmful algal blooms (USEPA, 2013). In 2014, algal blooms produced toxins that contaminated the drinking water supply for thousands of people in southeastern Michigan and northwestern Ohio. Algal blooms occurred again the following year of 2015 and affected the water quality in that region.

For fresh water bodies, P is the limiting nutrient for algae growth meaning that as P concentration increases, it stimulates an increase in algae growth. However, increases in nitrate concentration have been shown to increase algae toxin production in fresh water (Horst et al., 2014). As the fresh water bodies of the Great Lakes surround Michigan, P is the primary nutrient of concern. It is notable that Western Lake Erie and the Saginaw Bay are the two most vulnerable water bodies surrounding Michigan due to their shallower water depth that provides warmer temperatures for algae (Figure 8). The western basin of Lake Erie has an average water depth of only 24 feet (up to 32 feet deep), whereas the average water depth of the eastern basin of Lake Erie is 80 feet (up to 200 feet deep) (NOAA). This explains the warmer water temperature in Lake Erie's western basin. The inner bay of Saginaw Bay has an average water depth of 15 feet (up to 45 feet deep) (McCormick and Schwab, 2008) that allows water to warm up faster and provide temperatures suitable for algal blooms.

Figure 8. Satellite image of algal bloom in Western Lake Erie on September 25, 2017 (NASA WORLDWIDE).

Golden Rule of Drainage:

Drain only the amount of water that is necessary for crop production and not a drop more.

9. Conclusion

Subsurface drainage has many benefits. It is needed to sustain agricultural production in many areas, but it can exacerbate nutrient loss. Solutions to address water quality issues are needed to reduce the transport of P and nitrogen to surface water bodies. Best management practices such as nutrient management, cover crops, conservation tillage, controlled drainage, saturated buffers, wetland, denitrification beds (woodchip bioreactors) and two-stage ditches are available to help address this water quality issue. Furthermore, other technologies such as P-filters with P-adsorbing media are being investigated as a solution.

For more information about these practices and drainage tools, visit www.egr.msu.edu/bae/water/.

Reviewed by Michael Cook (Secretary and Treasurer of Michigan Land Improvement Contractors Association), Norman Fausey (retired, USDA-Agricultural Research Service), Tim Harrigan (MSU) and Steve Miller (MSU)

Photos and diagrams credit: Ehsan Ghane, Michigan State University.

References

Brown, L.C., Schmitz, B.M., Batte, M.T., Eppley, C., Schwab, G.O., Reeder, R.C., Eckert, D.J., 1998. Historic drainage, tillage, crop rotation, and yield studies on clay soils in Ohio. Proc. 7th Int. Drain. Symp. 456–464.

Evans, R.O., Fausey, N.R., 1999. Effects of inadequate drainage on crop growth and yield. Agric. Drainage. Agron. Monogr. 38. ASA, CSSA, SSSA.

Hopkins, D., 2002. Managing wet soils : mole drainage. State of Victoria, Department of Primary Industries, Australia.

Horst, G.P., Sarnelle, O., White, J.D., Hamilton, S.K., Kaul, R.B., Bressie, J.D., 2014. Nitrogen availability increases the toxin quota of a harmful cyanobacterium, Microcystis aeruginosa. Water Res. 54, 188–198. https://doi.org/10.1016/j.watres.2014.01.063

Huffman, R.L., Fangmeier, D.D., Elliot, W.J., Workman, S.R., 2013. Soil and Water Conservation Engineering, 7th ed. American Society of Agricultural and Biological Engineers.

King, K.W., Williams, M.R., Macrae, M.L., Fausey, N.R., Frankenberger, J., Smith, D.R., Kleinman, P.J.A., Brown, L.C., 2015. Phosphorus Transport in Agricultural Subsurface Drainage : A Review. J. Environ. Qual. 44, 467–485. https://doi.org/10.2134/jeq2014.04.0163

McCormick, M.J., Schwab, D.J., 2008. Observations of currents in Saginaw Bay, Lake Huron. Aquat. Ecosyst. Health Manag. 11, 182–189. http://www.tandfonline.com/doi/abs/10.1080/14634980802092997

NASA WORLDWIDE. NASA Worldview application operated by the NASA/Goddard Space Flight Center Earth Science Data and Information System (ESDIS) project. URL https://worldview.earthdata.nasa.gov (accessed 1.30.2018).

NOAA, Great Lakes Data Rescue Project - Lake Erie and Lake Saint Clair Bathymetry [WWW Document]. URL https://www.ngdc.noaa.gov/mgg/greatlakes/lakeerie_cdrom/html/e_gmorph.htm (accessed 6.22.17).

Sugg, Z., 2007. Assessing U.S. Farm Drainage: Can GIS Lead to Better Estimates of Subsurface Drainage Extent?, World Resource Institute. World Resource Institute. Washington, DC.

USDA-NASS, 2016. Quick Stats-Michigan.

USEPA, 2013. Reassessment 2013: Assessing progress made since 2008. Mississippi River Gulf of Mexico Watershed Nutrient Task Force. United States Environmental Protection Agency, Washington, DC, USA.