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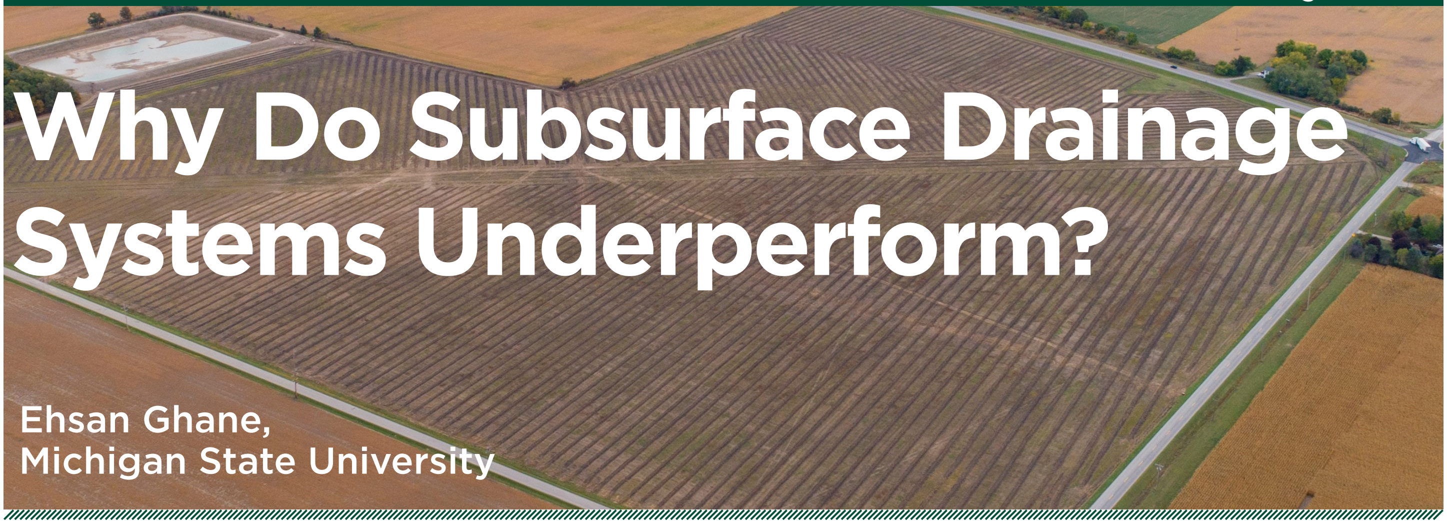

Why Do Subsurface Drainage Systems Underperform?

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1. Overview of drainage under-performance

Subsurface (tile) drainage removes excess water from the soil to create good fieldwork and crop growth conditions on poorly drained soils. When properly designed, installed, and maintained, subsurface drainage systems can perform well for decades (Sands, 2023). However, many design, installation, and management considerations can lead to the underperformance of subsurface drainage systems.

One measure of drainage system performance is that the system should be able to lower the water table from the soil surface to 1-ft depth in less than 48 hours following a heavy rainfall. Additionally, the drainage system should be able to maintain the water table below 2-ft depth over at least 90% of the drained area during at least 90% of the growing season. If the performance of the drainage system falls below these criteria, it is likely to be underperforming and may subsequently reduce profitability.

In this bulletin, three common causes for the under-performance of subsurface drainage systems are described (Section 2). Then, the impacts of these common causes of under-performance are presented (sections 3-5).

2. Causes of under-performance

This section describes design, installation, and maintenance issues as common causes for the under-performance of drainage systems.

2.1. Design issues

Design issues may cause the drainage system to underperform. Most design issues are avoidable by increasing knowledge through education and training opportunities. Drainage system users are also encouraged to use the Drain Spacing Tool to maximize system performance and profit. To learn about the Drain Spacing Tool, see Ghane (2022c).

Common design issues include pipe grade less than the minimum requirement (Section 3.2.3), installation in a very poorly permeable deep soil layer (Section 2.1.2), installation in sand layers without a protective measure (Section 3.2.3), and installation in high-risk iron ochre areas without special design considerations (Section 3.3).

2.1.1. Under-design issue

Under-design occurs when a drainage coefficient less than the drainage intensity is chosen to size the main pipe (see glossary). This means that the main pipe is too small, thereby water enters the main pipe faster than the main can carry it away. The solution is upsizing the main pipe, so the drainage coefficient is equal to or greater than the drainage intensity.

Under-design may occur when installing additional lateral drains in between the original wider laterals (known as splitting spacing) while not checking whether upsizing of the main pipe is necessary. If you do not upsize the main pipe in a condition where upsizing is necessary, the newly installed narrower drain spacings will not drain water as quickly as intended. This is because water removal will be limited by the under-sized main pipe.

2.1.2. Drain depth issues

The drain depth issue occurs when installing the pipe in the deeper, poorly permeable soil layer. Instead, install the drain pipe in the shallower, more permeable soil layer while maintaining minimum pipe cover. This is because drain pipes work best when installed in the more permeable soil. Shallow drains have a higher initial cost than deep drains, but they are worth considering because of their benefits. For more information about the benefits of shallow drains, see Ghane (2022d).

Draining a muck soil is a challenge because the soil subsides when the organic matter oxidizes in the absence of water. In this case, install deeper lateral drain pipes (4 to 6 ft depth) to keep the required pipe cover after subsidence.

Most commercial tile plows have enough power to install deep drains without difficulty. However, a pull-behind plow is more susceptible to difficulty pulling the plow at deeper drain depths, and it may require a second tractor, especially in heavy clay soil with stones.

2.1.3. Compromised outlet

The comprised outlet issue occurs when the outlet pipe is off the ditch bottom by less than 1 ft and the ditch water level frequently rises high enough to submerge the outlet and reduce flow (Figure 1). In this situation, either clean and deepen the ditch, raise the outlet to allow normal free flow, or use a pump station.

2.1.4. Lack of breathers

Lack of breathers in the system is another example of a common design issue. Breathers allow air to enter the drain pipe to vent the pipe. Breathers are usually installed when going from a relatively flat minimum grade to a steep grade, thereby preventing piping of the soil into the drain pipe. Also, if there is no breather and the water table is above the top of the lateral drain pipe, flow may be restricted when going from a relatively flat minimum grade to a steep grade.

Inadequate venting can cause piping of the soil into the pipe when a steep grade results in high water velocity (low pressure) in the pipe. Inadequate venting can cause blowouts when a sudden change of grade from steep to relatively flat minimum grade results in high pressure in the pipe (Cooley & Herron, 2015). Tile blowouts are also caused by blockage of the system outlet, or a broken or cut drain pipe (Cooke, 2023).

Figure 1- Top: The outlet is submerged because it is too close to the ditch bottom. Bottom: The same ditch during the process of being cleaned and deepened to allow free flow from the outlet (photo credit: Jason R. Piwarski).

2.2. Installation problems

Poor installation may cause the drainage system to underperform. Installation quality should be assured using proper machinery, using suitable methods, following correct specifications and standards, and generally providing good quality control during installation. Installation problems are avoidable by increasing knowledge and gaining experience.

2.2.1. Wet conditions

Avoid installation or any other fieldwork during wet soil surface conditions because it leads to soil compaction, which is one of the causes of impeded infiltration and percolation (Section 4.1).

When the water table is above the drain installation depth, there is a higher risk of smearing the soil adjacent to the drain pipe, especially in heavy clay soil. When the water table is near the drain installation depth, capillary rise can still create wet conditions for the soil at the drain depth, thereby increasing the risk of smearing. Smearing slows down water entry into the drain pipes, so the system will not work well at first. It may take up to 3 years for the drainage system to work efficiently as the ground goes through cycles of drying, wetting, and frost to break up the compaction.

The ideal installation conditions are when the ground is driest and the water table is deepest, usually during summer. Typically, there is limited control over this because the condition may be less than ideal when the drainage contractor is available to work during normal installation windows (before and after planting). To reduce the risk of under-performance due to installation under wet conditions, one option is growing crops with an early harvest (wheat, barley, oats, rye, and corn silage) during the year planned for installation to provide ideal installation conditions after harvest. Another option is installing through a standing crop when the ground is driest.

2.2.2. Examples of installation problems

Examples of avoidable installation problems include installing perforated drain pipes through trees or shrubs (Section 3.1.1), improper connections causing root clogging (Section 3.1.1), sediment clogging of the drain pipe (Section 3.2.1), off-grade dips or humps in the drain pipe causing root clogging (Section 3.1.1), improper installation speed, improper use of pull-behind or mounted plows, mishandling of pipes, and lack of outlet protection.

Improper installation speed can cause off-grade outcomes. Flatter grades require a slower installation speed than steeper grades.

An inexperienced operator using a pull-behind plow may cause poor installation because it is harder to maintain a consistent grade. These machines can cause installation challenges when encountering dead furrows, fence lines, ridges, swales, and rocks. Thus, experience is essential with pull-behind plows.

Two examples of pipe mishandling are exposing the pipe (with or without sock) to the sun for too long and over-stretching the pipe when not using a power feeder. Exposing black sand-slot pipes to the sun for too long may cause the narrow perforation widths to stretch during installation and become wider perforations, which allow fine sand or silt to enter the pipe, causing sediment-clogged pipes (Section 3.2).

When installing lateral drains in the downslope direction, water can enter the laterals. Then, laterals may need to be connected to the main pipe under water, leading to a poor connection.

In some situations, air-locking can occur when there is a severe negative grade in a section of the drain pipe and the water table is above the top of the pipe. In this case, air generally cannot exit the pipe and it restricts drain flow.

2.3. Inadequate maintenance

Drainage systems need maintenance to keep them in good working condition. When proper maintenance is lacking, the system will not work as designed.

For example, the drainage system should be regularly maintained to prevent blockage of the outlet. The field should be checked for blowouts and wet spots. If a hole appears over a drain pipe due to a pipe blowout, soil could enter the drain pipe and clog the drainage system. In that case, replace the pipe in the blowout area as soon as possible. If a wet spot appears in the field under normal rainfall that was not there before, there may be a drain pipe clogging issue (Section 3) or impeded infiltration issue (Section 4). Overall, inadequate maintenance can result in under-performance of the drainage system.

3. Drain clogging due to design, installation, and maintenance issues

Drain clogging occurs due to design, installation, and maintenance issues, causing slower water removal from the field than needed. Use a camera to inspect the inside of the drain pipe to identify what is blocking the pipe. Drain pipes can clog by roots, sediment, iron ochre, and calcium carbonate.

3.1. Root clogging

3.1.1. Root clogging occurrence

Roots of annual crops do not pose a risk of drain clogging when pipes are installed properly between 2.5- and 4-ft depth. Some smaller younger roots enter the drain pipes, but they die after plant harvest and slowly decay, and their remains wash away.

When poor installation of drain pipes results in an off-grade dip or hump in the pipe, water will stand in the pipe, thereby promoting increased root growth in and around the pipe. Also, improper connections can increase the chance of root clogging. For example, when tap-tees are not correctly inserted, they can lead to an obstruction that can catch the younger roots flowing with water in the pipe. Then, the roots can accumulate and clog the pipe, or significantly reduce the flow (Figure 2). Use fittings that have minimal parts sticking into the pipe.

Figure 2- Roots formed a thick bundle that clogged a perforated drain pipe (photo credit: Paul F. Gross).

If radish cover crops grow too much, they may cause drain clogging with their long roots. Avoid planting radish cover crops too early to prevent their roots from getting too long. Early planting such as with prevented planting, may lead to radish roots reaching and clogging the drains. Radishes planted in late August or early September should not pose a risk of drain clogging for drainage systems in good condition.

Perennial crops may cause root clogging depending on the type of vegetation. For example, when drain pipes need to go through trees or shrubs, use a nonperforated pipe to prevent root entrance.

3.1.2. Root clogging mitigation methods

For addressing root clogging, flushing the younger weaker crop roots with a high-pressure jet nozzle (also known as jetting) helps remove some of the crop roots. With stronger roots or tree roots, jetting may need to be combined with rodding to break up the roots. Consider that, generally, rodding takes more time than jetting and is useful to remove clogging closer to the outlet. If these solutions do not work, new drain pipes may need to be installed. Contact a local sewer or plumbing cleaning company for jetting (Figure 3).

3.1.3. Root clogging preventive measures

A good installation reduces the chance of root clogging by preventing off-grade dip or hump in the pipe (Section 3.1.1). Use proper pipe connections to reduce obstruction. Use a non-perforated pipe in the vicinity of trees or shrubs. Avoid letting the radish cover crop grow too much.

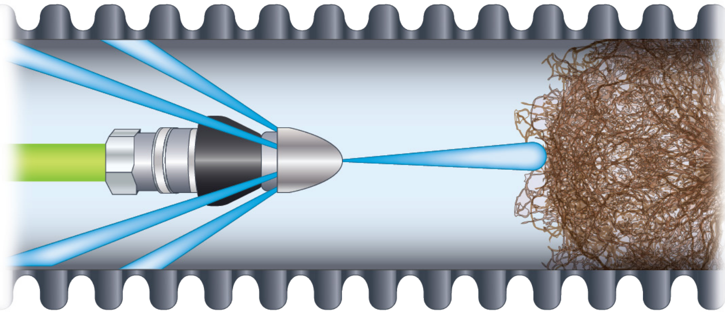

Figure 3- Diagram of water jets coming out of the sprayer nozzle for flushing the weaker roots.

The area in the vicinity of the outlet pipe should be kept clear from brush growth because brush roots can follow the wall of the outlet pipe in the upstream direction. Then, they can enter the pipe through the first connection and clog the pipe. A good practice is to mark the area in the vicinity of the outlet pipe so that the site can be easily found and the brush removed.

3.2. Sediment clogging

3.2.1. Sediment clogging occurrence

Pipes may become partially or fully clogged by sediment if proper pipe material is not used. When fine sand or silt particles enter the pipe, they can remain near the pipe entry point, build up over time, and cause clogging of the pipe. At typical pipe grades of 0.1% to 0.2%, sand will not be carried with water to the outlet. When clay particles enter the pipe, they wash away and do not cause a problem.

Sediment clogging of the pipe can be a problem in soil with low clay and organic matter. Example soils that can be a problem are sand, loamy sand, sandy loam, loam, silt loam, and silt (Stuyt et al., 2005) (Figure 4). Soil with high clay provides cohesion (sticking of particles together) to keep the soil in place and prevent it from entering the pipe. To determine if drain sedimentation is a problem for your pipes, see Ghane (2022b).

Improper connections can cause drain clogging. Avoid connecting lateral pipes to the bottom half of the main to reduce the chance of sediment clogging the drain pipe. When poor installation results in an off-grade dip or hump, or improper connection (Section 3.1.1), it creates an obstruction where fine sediment can accumulate and clog the pipe.

Figure 4- A 6-inch main, installed in 2013. The pipe was 2/3 filled with sand in 2020. The use of regular-perforated pipe in sandy loam soil was the cause of the drain sedimentation (photo credit: William Word).

3.2.2. Sediment clogging mitigation method

In the early period after installation, fine sediment may enter the pipe, where it is carried by water to the system outlet, causing turbid water (Vlotman et al., 2020). If severe sediment issues exist beyond two years, occasionally clean the pipes with high-pressure jetting to flush the sediment. If sediment is not flushed, it can harden and make the jetting more difficult. If this solution does not work, new drain pipes may be needed.

3.2.3. Sediment clogging preventive measures

A good installation will reduce the chance of drain sedimentation (Section 3.2.1). If drain sedimentation is a problem, use either a sock-wrapped or sand-slot pipe. A sand-slot pipe has a narrow slot width to keep sediment out of the pipe. For more information about sock-wrapped and sand-slot pipes, see Ghane (2023b).

It is important to meet the minimum pipe grade requirement to maintain minimum water velocity, so water can carry the sediment to the system outlet.

3.3. Iron ochre clogging

Iron ochre occurs when soluble iron enters the drain pipe. Then, bacteria oxidize soluble iron to insoluble iron and create ochre. Iron ochre can cause clogging of drain perforations, valleys of corrugations, and inside of the pipe. This results in under-performance or failure of the drainage system. For information about iron ochre potential, identification, and mitigation, see Ghane (2023c).

3.4. Calcium carbonate clogging

Calcium carbonate clogging of drain pipes can occur in soil with high pH and dissolved Ca^{+2} concentration at high temperatures (Ghobadi Nia et al., 2020).

A calcareous soil has high calcium carbonate, which increases dissolved Ca^{+2} concentration in water. As the calcium-rich water enters the pipe, pressure drops because water moves from a saturated soil into a partially open pipe. The pressure drop releases carbon dioxide (CO_2) gas from the water, thereby increasing the pH of water. At the same time, high temperatures during the summer decrease the solubility of calcium carbonate in water, which leads to the formation of an insoluble calcium carbonate (Stuyt et al., 2005).

Calcium carbonate can cause perforation clogging, or in rare cases, blockage of the pipe. Figure 5 shows a sample of a hard-pan layer of calcium carbonate that deposited on the bottom of a 12-inch main pipe in southwest Minnesota. That location was a few miles from a calcareous fen. Calcareous fens are wetlands with a steady supply of calcium-rich groundwater, which provide one of the ingredients for calcium carbonate clogging.

Calcium carbonate clogging has been observed in southwest Minnesota mostly in drain pipes with a steep grade. A pipe with a steep grade (without a breather) can increase the chance of calcium carbonate clogging. This is because the pressure drop is greater when water enters a pipe with a steeper grade (without a breather) than a flatter grade.

Figure 5- A hard-pan layer of calcium carbonate that deposited on the bottom of a 12-inch corrugated main pipe. The sample is from southwest Minnesota (near Canby, MN), a few miles from a calcareous fen (sample was provided by Stu Frazeur).

4. Impeded infiltration and percolation due to soil and installation problems

Impeded infiltration and percolation occur due to soil management and installation problems, causing slower water removal from the field than needed. Thus, the performance of the drainage system is reduced. Also, this problem could lead to increased surface runoff. One sign of this problem is when surface ponding lasts for extended periods with little to no drainage discharge, indicating that water cannot reach the drain pipes.

In impeded infiltration, water cannot infiltrate the soil surface fast enough because of surface sealing or compacted surface layer, and ponding usually occurs on the surface. In the case of impeded percolation, water in the soil cannot move downward to the drain pipes and causes a perched water table due to a plow-pan or compacted layer below the surface. In both cases, soil auguring and consultation with a soil scientist can identify this problem.

4.1. Impeded infiltration and percolation caused by compaction

The most common cause of impeded infiltration and percolation is field operations (planting, spraying, harvesting, and drain pipe installation) during wet soil surface conditions that lead to soil compaction. Tillage can also create a compacted layer just below the tillage depth that limits percolation.
The following are some guidelines to address the compaction issue:

- If a plow-pan or compacted layer is the problem, break it up with subsoiling or moling. Mole drains result in soil cracks, leading to increased infiltration. For more information about mole drains, see Ghane (2023d). Caution is advised when subsoiling or moling under wet surface conditions as these can worsen the compaction issue.
- Improve soil health with reduced tillage, cover crops, manure or compost, and diverse rotations, thereby improving infiltration and percolation.
- If the impeded infiltration is in a depressional area, a blind inlet can be installed to increase infiltration. For more information about blind inlets, see Ghane (2022a).
- Surface drainage can be used to prevent surface ponding. For more information about surface drainage, see Ghane (2023a).

Improve soil health with reduced tillage, cover crops, manure or compost, and diverse rotations, thereby improving infiltration and percolation.

4.2. Impeded infiltration caused by soil dispersion

Another reason for impeded infiltration is soil dispersion on the soil surface, which causes soil structure degradation, sealing of the soil surface, reduced infiltration, and increased surface runoff. Soil dispersion can be caused by mineral imbalance and raindrop impact.

4.2.1. Mineral imbalance causes soil dispersion

Generally, soils are more susceptible to dispersion when the mineral concentration of the soil solution is low (Vlotman et al., 2020). One method of increasing the soil mineral concentration is to add calcium to enhance the soil's physical properties and improve infiltration. Soil dispersion can also occur when the ratio of soil calcium to magnesium is too low, that is low calcium and high magnesium (Qadir et al., 2018). Soil dispersion can also occur if the soil has high sodium and low calcium (sodic soil). The high sodium causes clay particles to disperse and seal the soil surface, thereby reducing infiltration. In Michigan, most soils are rich with calcium, so the risk of impeded infiltration due to excess magnesium or sodium is generally low. Nevertheless, soil test and consult a soil scientist to identify soil dispersion.

In parts of the Red River Valley in the Upper Midwest U.S.A., sodic or saline-sodic soil may cause under-performance of the drainage system due to soil dispersion on the surface. Before installing subsurface drain pipes in those soils, evaluate the suitability for subsurface drainage as described in the Extension bulletin by Cihacek et al. (2012).

Mineral imbalance can cause soil dispersion on the soil surface and around drain pipes. Soil test and consult a soil scientist to identify soil dispersion.

4.2.2. Raindrop impact causes soil dispersion

The impact force of raindrops on bare soil can break soil aggregates, disperse soil particles, and reduce infiltration (Figure 6). To reduce soil dispersion, protect the soil from raindrops with cover crops, crop residue, or mulch. The cover absorbs the raindrop impact force and reduces soil dispersion.

Figure 6- Top: A soil surface with a failed germination. Bottom: A close-up of the same soil surface showing soil dispersion and crusting caused by mineral imbalance and raindrop impact (photo credit: Zouheir Massri).

5. Water quality decline due to under-performance

When design, installation, or maintenance issues cause under-performance, the system does not remove water as designed and surface runoff increases. As a result, more soil-attached phosphorus moves with surface runoff. A properly functioning drainage system reduces issues from surface runoff, but it increases the transport of nitrate and phosphorus through subsurface drainage discharge. The excess phosphorus in downstream water bodies causes adverse economic, social, and environmental impacts. Also, excess waterlogged conditions resulting from drain clogging or impeded infiltration harms the soil structure and reduces crop yield. The poor soil structure decreases infiltration, causing an increase in surface runoff and nutrient loss.

Generally, improving soil health enhances the performance of drainage systems, but nitrogen and phosphorus losses to surface water are still an issue. Therefore, use conservation drainage practices to reduce nutrient loss while maintaining crop productivity. See Christianson et al. (2016) for more information about conservation drainage practices.

> An under-performing drainage system can increase surface runoff, increase sediment loss, and reduce crop yield.

6. Conclusions and recommendations

If there is a drainage system failure, it usually occurs during the first two years after installation. Subsequently, the system should function properly if adequately maintained. Most under-performance problems can be avoided with proper design, installation, and maintenance. However, unforeseen situations can lead to under-performance. Increasing knowledge about design and installation is key to avoiding most under-performance issues. Drainage system users are encouraged to attend educational drainage workshops as a means of increasing knowledge.

The under-performance of a drainage system can lead to yield decline due to slower water removal and lead to poor water quality due to increased surface runoff. The solution for an under-performance issue depends on local conditions. If the under-performance issue is severe, consult a drainage contractor and soil scientist to identify the problem, and address it early to avoid adverse crop and environmental outcomes. Generally, improving soil health improves the performance of drainage systems, but nutrient loss is still an issue. Therefore, use conservation drainage practices to reduce nutrient loss while maintaining crop productivity.

Glossary

Drainage coefficient	The rate of water movement through the drainage pipe network (inches per day).
Saturated hydraulic conductivity	A measure of the soils ability to transmit water (inches per hour).
Drainage intensity	A measure of the rate of water movement through the soil into the drain pipes (inches per day).

Expert Reviewed

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