VERMONT'S

SUBSURFACE TILE DRAINAGE INTERIM REPORT

FEBRUARY 15TH, 2016

VERMONT
AGENCY OF NATURAL RESOURCES

SUBMITTED BY
THE AGENCY OF AGRICULTURE, FOOD AND MARKETS
AND THE AGENCY OF NATURAL RESOURCES

VERMONT
AGENCY OF AGRICULTURE, FOOD & MARKETS

A Letter From **The Secretaries**

The Vermont Agency of Agriculture, Food & Markets (VAAFM) and Vermont Agency of Natural Resources (VANR) are pleased to submit this Subsurface Tile Drainage Interim Report to the Vermont Legislature. This report continues the "all in" collaboration that the two Agencies have delivered over the past five years in order to develop goals and strategies to clean up Lake Champlain and implement the Vermont Clean Water Initiative. Vermont's plan addresses all sectors impacting our waters—roads, wastewater treatment facilities, developed lands, forests and farms—and strategies are in place across all of those sectors to protect Vermont's water resources.

As requested by the Legislature, this Interim Report summarizes currently known assumptions and facts about the use and impact of subsurface tile drainage on Vermont's farms. A literature review of current studies and research around North America, and ongoing studies in Vermont, will inform recommendations for management of tile drains in the final report, due in January, 2017. It is known that there are both economic benefits and environmental costs to the use of tile drains in Vermont. While this report provides an interim assessment of these benefits and costs, the final report will more fully describe current scientific research relating to the environmental management of agricultural tile drainage and how tile drains contribute to nutrient loading of surface waters. The final report will also include recommendations on how to best manage tile drainage to prevent or mitigate the contribution of tile drainage nutrients to Vermont's surface waters. Likewise, that final report will identify knowledge gaps and areas where further study is needed, as well as opportunities for further investment in this field of research.

Moving forward, VAAFM and VANR remain firmly committed to the collaboration required to successfully implement the Phase I Implementation Plan for cleaning up Lake Champlain and the Vermont Clean Water Initiative, to finalize the Required Agricultural Practices, and to address water quality issues around the State. The final tile drain report will be an important step on our path to achieving clean water.

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The Background into **Subsurface Drainage**

As early as the 1830s, subsurface drainage (also known as tile drainage) was installed around the country to remove excess water from the soil profile (or subsurface) through a network of perforated tubes installed at varying depths below the soil surface. These subsurface drainage systems were made of clay tiles and were spaced randomly in fields to target and drain wet spots. For this reason, these systems were called random/target tiling. Today, subsurface drainage is widely used across the United States because it is a practice critical to producing crops and can often be the difference between having a crop and not having one. Current systems are made of corrugated and perforated plastic tubing, and are usually installed in a systematic pattern throughout entire fields. For this reason, they are named pattern/systematic drainage systems.

According to the 2012 agricultural census, 4.8% of Vermont's total acres used for cropland is drained using either random/target or pattern/systematic systems. This practice allows farmers the opportunity to get on their fields earlier, reduce compaction, increase crop yields, decrease susceptibility to disease and pests, and reduce crop risk loss amid climate variability. Due to the agronomic and economic benefits, the United States Department of Agriculture (USDA) encouraged, and provided technical assistance and cost-share payments to farmers for installing subsurface drainage from 1935 into the 1980s.

In the 1970s, the federal government started to realize that subsurface drainage had adverse effects. Wetlands, critical ecosystems that provide water quality protection, flood storage and habitat, had been converted into agricultural fields and development properties with the help of subsurface drainage systems. In fact, half of the wetlands in the United States and 35% of the original wetlands in Vermont have been converted. Research in recent years has also shown that subsurface drainage alters watershed hydrology, and depending on management, nutrient source and soil type, has the potential to export equal or greater amounts of phosphorus and nitrates as surface runoff. Questions remain about many aspects and adverse effects of subsurface drainage and more research needs to be completed, despite the fact that it has been installed in Vermont for almost a century.

Tile Drainage:

Past & Present

Random/Target Tiling	NAME OF SYSTEM	Pattern/Systematic Tiling
1835 - 1940s: Clay Tiles **1940s - 1960s:** Cement Tiles & Bituminized Fiber Pipes 	**MATERIALS**	**1960s - Present:** Corrugated and Perforated, Plastic Tubing 
Fields that were wet or difficult for machinery operation	**TYPE OF FIELD**	All types of fields including apple orchards, vegetable plots, corn and hay fields
Only in wet swales or low areas where water would settle	**PLACEMENT OF TILE**	Grid pattern throughout the entire field
Depth: 2 - 3 feet **Spacing:** No standard spacing; random placement occurred around wet areas.	**DEPTH & SPACING**	**Depth:** 3 - 4.5 feet **Spacing:** Slight variability depending on soil type, but spacing range is between 20-40 feet.
Outlet Diameter: 2 - 36 inches **Location of Outlets:** Most commonly to streams, but some day-lighted to artificial field ditches. **Outlets per acre:** Varied although one outlet was typically used for one tile line.	**OUTLETS**	**Outlet Diameter:** 6 - 15 inches **Location of Outlets:** Unknown, but installers say roughly 50% go to streams and 50% to field ditches. **Outlets per acre:** Varies greatly depending on topography. From 1 outlet per 80 acres (on very flat fields) or 6 outlets on 30 acres (on hilly fields)

From 1935 through the 1980s, the United States Department of Agriculture (USDA) encouraged and provided technical assistance and cost-share payments to farmers for installing subsurface drainage due to the agronomic and economic benefits.

Subsurface Drainage in Vermont:
By the Numbers

According to the 2012 agricultural census, 4.8% of Vermont's agricultural cropland are drained by tile (older random systems and/or more recent pattern systems), however some subwatersheds in the Lake Champlain Basin are estimated to have as much as 70% of the cropland tiled by subsurface drainage.

4.8% **of Vermont's croplands are drained by tile**

According to the 2012 Agricultural Census

According to drainage installation companies and Vermont dairy farmers installing subsurface drainage, the rate of installation is affected by farm income. Since current milk prices are low, tile installation has slowed. Due to the wetter than normal years, grid pattern systems are being installed on mostly clay soils that have less than 20% slope. Some systems are replacing the aging, clay tile systems.

Types of Agriculture that have Installed Tile Drainage in Vermont

Out of 4.8% (23,552 acres) of tiled fields, 80% of those fields are devoted to supporting milk production, as farmers use their land to grow corn as grain or silage, and to grow grass for pasturing and hay.

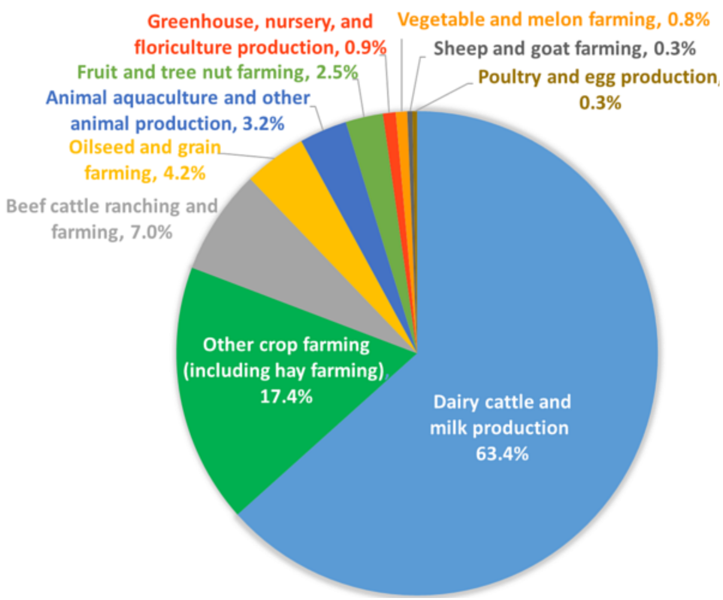


Photo courtesy of Van Wyck Brothers Drainage

According to the 2012 Agricultural Census, an estimated 13% of cropland in the United States could not be in production without subsurface tile drainage. For reference, Illinois has 37% of croplands drained by tile; Indiana has 45%; Ohio has 47%; and Iowa has the lead with 48% of their croplands tiled.

Subsurface Drainage: **The Prospective Benefits**

Due to the removal of excess water in the soil profile that subsurface drainage achieves, it has been demonstrated that there can be agronomic, economic and environmental benefits for farmers to maintain and/or install subsurface drainage.

Agronomic & Economic

- Increases soil aeration which promotes microbial activity and deeper root growth
- Improves soil porosity & tilth
- Enhances soil structure
- Promotes warmer soil temperatures which can lead to earlier spring sowing and germination of seeds, along with a longer growing season
- Improves soil trafficability due to drier soils
- Decreases soil compaction
- Increases adaptation to climate variability
- Decreases susceptibility to disease and pests due to less moisture
- Increases crop yields (up to 5-25% annually)
- Reduces risk of crop loss amid climate variability
- Allows higher value crops to be planted where it would otherwise be too wet
- Reduces labor time and minimizes fossil fuel consumption due to drier soils
- Return on tile drainage investment can range from 1 year to 10 years. depending on weather and cost of installation

Environmental

- May increase soil storage capacity of water due to improved soil structure and less compaction
- Potentially allows more water infiltration which in turn reduces surface runoff (up to 65%) containing sediment, nutrients and pollutants
- Properly functioning subsurface drainage may reduce peak flow volumes up to 50%
- Increased crop yields are assumed to potentially increase uptake of nutrients from the soil

Above: No-till corn planter being used on a cover cropped field. Without subsurface drainage, some fields would not be able to implement no-till planting due to the compaction of the soils.

Right: Field with cover crops. By having subsurface drainage, farmers are able to plant their crops earlier and harvest earlier so they can cover crop in the fall.

The Preliminary Assessment of **Environmental Impacts**

This section reviews the comparisons on tiled and untiled agricultural fields from around the country. Although much is unknown about subsurface drainage and its environmental impacts in Vermont, the final report will reference several partially completed Vermont research studies.

Hydrology Impacts

- Has contributed to the loss of wetlands
- Alters field and watershed hydrology by increasing water yields and stream baseflow
- Although total peak flows decrease when fields are tiled, over 90% of the peak flow has the potential to drain out of tile outlets
- Preferential flow pathways (including macropore flow) in soil profiles can provide a direct conduit to tile for pollutants, and can increase concentration of phosphorus in tile water after a storm event and/or nutrient application

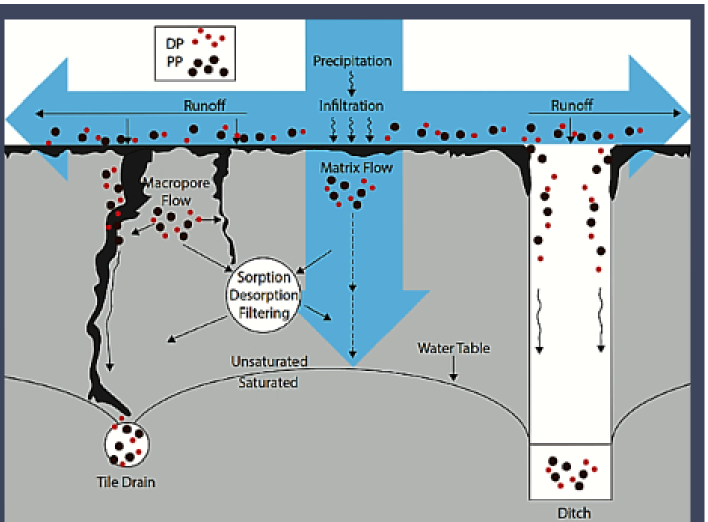


Figure 1. Flow diagram of water and P partitioning between surface runoff and infiltration and the partitioning of infiltration between macropore and matrix flow.
DP, dissolved P; PP, particulate P. (Source: Radcliffe, et al. 2015)

Nutrient Impacts

- Tile outflow has the potential for higher percentages of dissolved phosphorus than surface runoff
- Total phosphorus levels from tile outlets may exceed critical levels necessary for accelerated eutrophication (0.02-0.03 mg L^{-1})
- Elevated phosphorus levels in soils lead to greater and stronger correlation of dissolved phosphorus in subsurface drainage
- Phosphorus levels can be greater on clay loam tiled fields than sandy loam tiled fields
- Depending on management, nutrient source and soil type, flow from outlets can account for 17-41% of total phosphorus and 16-72% of dissolved reactive phosphorus of peak flow
- In some settings, tile may export equal or greater amounts of phosphorus as surface runoff
- Loss of nitrate-nitrogen is greater

Right: Standpipe located at the low point and edge of a field. Standpipes are connected to and routed through existing tile networks.

Standpipes (also known as surface inlets or tile risers) are vertically installed surface pipes placed at the low point of a field that are connected to and routed through an existing tile network. Standpipes allow surface water from a field to flow directly into a tile drainage network and out the outlet. In case of a tile blockage, standpipes can also release water to the surface.

Ongoing Research:
Management Practices on Tiled Fields

Tiled agricultural land must be well-managed on the surface to reduce the loss of nutrients to surface waters. Below are a variety of management practices that can be included in nutrient management plans and improve soil health to mitigate or reduce water quality impacts from tile drainage when used alone or in combination. Literature reviews that are being conducted in 2016 may identify if applications of these management practices might be possible on fields in Vermont.

Current Ongoing Research

Manure and Fertilizer Application Rates and Methods

Phosphorus leaching through tile in clay loam has been shown to be greater than from sandy loam after liquid nutrient application. Dissolved phosphorus levels in tile outlets can be greater with broadcast application compared to incorporation. Higher phosphorus (from manure or fertilizer) application rates can result in higher potential for phosphorus leaching. Nutrient application in relation to soil type, slope, soil test phosphorus (amount of phosphorus identified in a soil test), and type of nutrient incorporation are currently taken into account with the Phosphorus Index (P-Index). The P-Index is a tool developed to assess the potential for phosphorus surface runoff from individual fields based on soil and field characteristics and on management practices. University of Vermont (UVM) Extension has received funding through Natural Resources Conservation Service's (NRCS) Conservation Innovation Grant (CIG) to revise the P-Index to include subsurface drainage flow as a potential risk factor.

Potential Research

Cover Crops

Cover crops are proven to reduce surface erosion of sediment, nutrient, and chemical pollutants, as well as capture residual nutrients in the soil. It has been studied much less frequently to help reduce phosphorus coming from tile outlets.

Cropping rotations

Some tiled fields are continuously in corn, grass, or fruit trees. While crop rotations can be very beneficial for soil health, different crops on tiled fields have also been studied in Sweden and New Zealand as a way to reduce phosphorus concentration in drainage water. Studies would have to be conducted in Vermont to see if alternative crops would give a viable return on investment.

Increase or Reduce Tillage, Till Deeper or No-Till?

Tillage can break-up preferential pathways (or macropores) which could reduce phosphorus levels in tile drainage especially on clay soils. However, no-till planting has been recommended to farmers to reduce surface runoff and improve soil health. Studies in Ontario, Canada, Minnesota, and New York have shown that different tillage methods reduce phosphorus levels from tile outlets. Vermont studies would need to weigh the benefits of tilling on tiled fields versus the benefits of no-till on different sloped fields.

Manure Injection

Manure injection can significantly decrease nutrient surface runoff, but it might also get manure closer to the potential preferential flow paths that have a direct route to subsurface drainage. Minimal, if any, research has been done on manure injection relating to subsurface flow phosphorus concentrations.

Ongoing Research:
Structural Practices on Tiled Fields

Below are a variety of structural practices that may mitigate or reduce water quality impacts from tile outlets when used alone or in combination. Engineering and economic challenges limit these practices. Literature reviews and current research of these practices are still underway.

Past Research

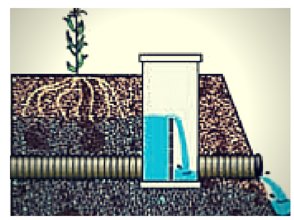
Constructed Wetlands

Constructed wetlands have been used at University of Vermont (UVM) to treat surface runoff but not tile drainage flow. There is reason to believe that they may be effective in reducing phosphorus amounts from outlets over a longer period of time. However, cost and amount of land taken out of production need to be considered to determine cost-effectiveness, along with solutions on how to manage when phosphorus saturation is achieved. The literature review will provide some of this data.

Current Ongoing Research

Drainage Control Structures

Permanent structure placed at a tile drainage conduit allows the operator to regulate drain flow depending on crop growth or field operations. Studies have shown that dissolved phosphorus concentrations from controlled drainage have been both lower and higher than with free flowing drains. Preliminary results at the Miner Institute in New York show that controlled drainage can lower total phosphorus loss by up to 30%. Miner Institute's research will continue to study control structures for an additional 4 years.


Courtesy of the Miner Institute of NY

Phosphorus Removal Systems and Media

Phosphorus removal systems (septic tank-like structures) redirect subsurface tile flow through an adsorption media and contain it for a certain retention time in order to reduce phosphorus concentrations. Vermont's Natural Resources Conservation Service, through their Environmental Quality Incentives Program (EQIP), funded the installation of two systems and the research was funded through a Conservation Innovation Grant (CIG). The project is currently being conducted by the Friends of Northern Lake Champlain with Stone Environmental, Inc. Preliminary results will be available in April of 2016.


Courtesy of Stone Environmental, Inc.

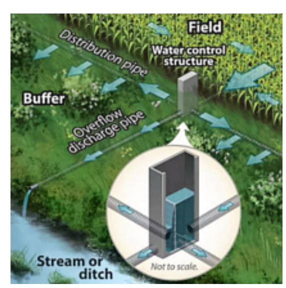
Soil Amendments

Elevated soil test phosphorus levels greatly increase the likelihood of dissolved phosphorus in tile drains, especially in flat clay soils. Soil amendments such as biochar, crushed limestone, gypsum, or water treatment residuals may reduce phosphorus losses from existing tile drains. UVM has completed laboratory research on soil media amendments in the last few years, and the next step is to experiment with these amendments in field studies.

Potential Research

Saturated Buffers

Saturated buffers are “re-plumbed” riparian buffers, where tile water is redirected using a control structure into the buffer as shallow groundwater flow. As the water flows through the buffer, both denitrification and uptake by the perennial plants in the buffer remove nitrates and keep it out of the adjacent stream. UVM has submitted a proposal to United States Department of Agriculture (USDA) to evaluate the potential of saturated buffers to reduce phosphorus.



Courtesy of Iowa State University

Research Needed and **Information Gaps**

Questions remain about many aspects of tile drainage, despite the fact that it has been installed in Vermont for over 80 years. It is important that future recommendations and policies include region-specific information, based on Vermont's soil types, slopes and agricultural management. Some areas where additional information is needed are outlined below. It is also important to note that resources do not currently exist to evaluate these questions.

Research Needed in Vermont

- Cover cropping on tiled fields: Will it reduce phosphorus concentrations in water coming out of tile drains?
- Tilling methods: What methods are effective and ineffective for breaking up preferential pathways and lowering phosphorus concentrations on fields drained by tile?
- Manure injection: Can it increase the connection between manure and preferential pathways? Can manure injection allow for high phosphorus levels in tile outlets?
- Nutrient application rates and timing: Should application rates depend on soil types? Should nutrient application rates be reduced on tiled fields, and by how much? When mild rain events are predicted should nutrient applications be avoided?
- Constructed wetlands and saturated buffers: Can either practice be an effective way in treating the dissolved phosphorus coming from tile outlets?

Information Needed

- Amount of subsurface drainage systems in impaired watersheds
- Amount of standpipes in impaired watersheds
- Concentrations and loading rates of outlet flows specifically in Vermont relating to soil types, cropland practices, crop rotations, existing soil test phosphorus levels, nutrient source of phosphorus (manure, fertilizer or compost) and nutrient application rates/methods, as well as timing of applications in relation to weather conditions
- Net impact of subsurface drainage on phosphorus losses
- Effectiveness of management and structural practices to control and reduce phosphorus loading coming out of outlet systems on varying fields
- Modeling tools designed to predict phosphorus losses from subsurface drainage in combination with a variety of better management practices

Left: Multiple subsurface drainage outlets in one location. Currently, farmers do not have to report to the Agency of Agriculture, Food and Markets or Agency of Natural Resources what fields are tiled, where tile outlets daylight to, or where standpipes are located.

The Next Steps Toward
The Final Report

In the next year, a working group will be created and led by Vermont Agency of Agriculture, Food and Markets (VAAFM) and Vermont Agency of Natural Resources (VANR) to assist in the development of the final report, including recommendations. The final report of subsurface tile drainage will be submitted to the Vermont Legislature in January of 2017, and will include the status of current scientific research relating to the environmental management of subsurface agriculture tile drainage and how subsurface agriculture tile drainage contributes to nutrient loading of surface waters. The final report shall also include recommendations from VAAFM and VANR regarding how best to manage subsurface tile drainage in the State in order to mitigate and prevent the contribution of tile drainage to Vermont's waters. On or by January 18th, 2018, the Required Agricultural Practices (RAPs) will be amended to include requirements for reducing nutrient contribution from subsurface tile drainage to waters of the State.

Some states, counties, towns and water resource districts are permitting tile drainage depending on acreage or intensity of subsurface drainage in a watershed.
Michigan is the only state that includes subsurface drainage requirements in their CAFO General Permit.

Data cited in this report are drawn from:

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Scientific Terms

Described below are terms relating to water quality and soil sampling connected to the agronomic, economic and environmental impacts of subsurface tile drainage.

Eutrophication: The reduction in dissolved oxygen in water bodies caused by an increase of artificial or natural nutrients (mainly phosphates) to an aquatic system. Increase in nutrients can lead to algal blooms and depletion of oxygen in the water that could cause death in fish and other aquatic microorganisms or macroorganisms.
Phosphorus (P): A chemical element that is an essential nutrient used by living organisms for growth.
Phosphate: An inorganic or organic compound that binds phosphorus to oxygen elements. It is needed to replace the phosphorus that plants remove from the soil. Phosphate can be found in livestock manure (in the form of organically bound phosphate), and synthetic fertilizer (in the form of inorganic orthophosphate).
Total Phosphorus (Total P or TP): A measure of all forms of organic and inorganic phosphorus, dissolved and particulate, that are found in a water qualitysample.
Dissolved Phosphorus (DP): Phosphorus that remains in water and is readily available for plant uptake.
Particulate Phosphorus (PP): Phosphorus that is bound to sediment.
Dissolved Reactive Phosphorus (DRP): Orthophosphate that is a chemically active, dissolved form of phosphorus directly available for plant uptake.
Soil Test Phosphorus (Soil Test P or STP): The amount (in parts per million, ppm) of available phosphorus found in a soil test.
Peak Flow: The point at which the stream flow reaches its highest level. Is a combination of surface and subsurface flow.
Subsurface Flow: The flow of water beneath the ground surface.
Preferential Flow Path: The uneven and often rapid movement of water and solutes through direct conduits from the soil surface to deeper depths in the soil. Three types of preferential flow include: macropore flow, funnel flow, and finger flow. These paths can be quite variable depending on soil type and management.
Macropore Flow: The result of subsurface channels or cracks made by roots, worm holes, shrinkage cracks, or subsurface erosion.