

End-of-Tile Phosphorous Removal System Project

Final Report



STONE
ENVIRONMENTAL



**Filter B: Limestone
"bedding sand"**

**Filter A: Drinking water
treatment residuals**

PROJECT NO.

14-084

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- Kip Potter, USDA-NRCS
- Laura Dipietro, Vermont Agency of Agriculture, Food, and Markets
- Dr. Don Ross, University of Vermont, Department of Plant and Soil Science
- Dr. Chad Penn, USDA-ARS (formerly of Oklahoma State University)

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Executive Summary

Phosphorus removal systems installed at the outlets of agricultural tile drains have the potential to significantly reduce phosphorus (P) loads to drainage ditches and receiving waters. Stone Environmental and the Friends of Northern Lake Champlain designed, constructed, and tested two media filters to remove P from tile drainage water on a farm in Franklin, VT. The objectives of the project were:

1. To design and construct a treatment system to remove P from tile drainage water.
2. To compare the P removal efficiencies of two types of filter media.

Although the investigators faced numerous technical and logistical challenges, these study objectives were met. Two media filters were constructed at a cost of \$5,000 per filter. Both filters removed substantial percentages of total and dissolved P and total suspended solids over the 11-month monitoring period. The inflow P concentrations were highly variable, 93 – 2,520 $\mu\text{g/L}$, with a median event mean concentration of 345 $\mu\text{g/L}$. The filter containing drinking water treatment residuals performed consistently better than the filter containing crushed limestone. The filter containing drinking water treatment residuals removed 69% of total P and 72% of total dissolved P, while the filter containing crushed limestone removed 54% of total P and 51% of total dissolved P. The P removal efficiency of both filters improved with increasing inflow P concentration. Neither filter effectively removed nitrogen.

The greatest challenge encountered in this study was premature clogging of both filters with sediment. The filtration rates of both filters decreased by over 90% over the monitoring period, which resulted in a high proportion of water bypassing the filters. Due primarily to lower than anticipated filtration rates, the inflow P load and the mass of P retained in the filters were lower than expected.

The design of media filters to treat tile drainage water from cropland must accommodate substantial sediment loads. In addition to selecting media with substantially higher hydraulic conductivity (preferably >0.3 cm/s) than those used in this study, we recommend filters be designed with a sedimentation chamber upstream and a means to backflush the filter of accumulated sediments. Further, we recommend testing an up-flow filter configuration constructed in a trench, rather than the down-flow design and concrete media tanks used in this study. We expect such a filter system would be less costly to construct and easier to maintain. These are two keys to more widespread adoption of this conservation practice.

End-of-Tile Phosphorous Removal System Project

Filters filled with phosphorus sorbing media, prior to installation of the tank lids

Contents

Acknowledgements	2
Executive Summary	3
1. Introduction	6
1.1. Project Overview	7
2. Objectives	8
3. Study Site Description	9
4. Description of Tasks	10
4.1. Prepare Quality Assurance Plan	10
4.2. Design and Construction of Phosphorus Treatment Systems	10
4.2.1. Filter Media Selection.....	10
4.2.2. Filter Design	11
4.2.3. Filter Construction	12
4.3. Flow and Water Quality Monitoring.....	16
4.3.1. Installation of Monitoring Systems	16
4.3.2. Sample Processing	17
4.3.3. Analysis of Water Samples.....	17
4.4. Data Analysis.....	17
4.5. Business or Academic Relationships that Facilitated the Project	17
5. Review of Methods	18
5.1. Innovations	18
5.2. Accommodations	18
5.3. Schedule of Events.....	18
5.4. Challenges Encountered.....	19
5.5. Design Alternative to Reduce Filter Clogging	20
6. Quality Assurance	22
6.1. Calibration	22
7. Findings	23
7.1. Comparison of Inflow and Outflow Concentrations	23
7.2. Filtration Rate.....	27
7.3. Phosphorus Mass Removed.....	28
8. Conclusions and Recommendations	29
9. Presentations	30
10. References	31
Appendix A: Quality Assurance Plan	33
Appendix B: Testing Arsenic Contribution of Saturated Water Treatment Residuals	59

Table of Figures

Figure 1: Study field	9
Figure 2: Treatment system schematic (plan view).....	11
Figure 3: View of the P filters without lids and soil cover	12
Figure 4: Media (left) and Flout (right) chambers prior to placing lid on Filter A.....	13
Figure 5: Placing septic tank in excavation for Filter A	13
Figure 6: Constructing outflow and drain pipes.....	14
Figure 7: Filter outflow and drain pipes.....	14
Figure 8: Agri-Drain water level control structure installed on tile drain.....	15
Figure 9: Interior of distribution box.....	15
Figure 10: Autosamplers for Filter A (left) and Filter B (right) outflows	16
Figure 11: Repair made to tile drain due to a muskrat hole.....	20
Figure 12: TP concentrations in composite samples of inflow and filter outflows	23
Figure 13: TDP concentrations in composite samples of inflow and filter outflows.....	24
Figure 14: TP concentrations in paired composite samples of inflow and outflow	25
Figure 15: TDP concentrations in paired composite samples of inflow and outflow.....	25
Figure 16: TSS concentrations in paired composite samples of inflow and outflow	26
Figure 17: Percent TP removal relative to TP concentration in filter inflow	26
Figure 18: Percent TDP removal relative to TDP concentration in filter inflow	27

Table of Tables

Table 1: Schedule of events.....	19
Table 2: Summary of analyte concentrations in inflow and filter outflows.....	24
Table 3: Percent removal of TP, TDP, TN, and TSS by Filter A and Filter B	27

1. Introduction

Lake Champlain (Vermont – New York – Quebec) continues to suffer from the effects of excessive P loading from sources in the Lake Champlain Basin (LCB). Nonpoint source P derived from agricultural land is a substantial component of the lake’s annual P load (Troy et al. 2007). Vermont farmers have shown strong interest in implementing best management practices (BMPs), such as conservation tillage, manure and nutrient management, and cover crops over the past decades to address losses of P, sediment, and other pollutants to surface waters. However, despite unprecedented investments by farmers and federal and state programs, these efforts have not yet yielded the desired water quality results.

One factor that may contribute to the slow pace of progress in attaining these water quality goals is the loss of dissolved P via agricultural tile drainage systems. For many years, relatively scant attention was given to potential tile drainage contributions of P to receiving waters due to the prevailing view that, because soils have an affinity for P, losses of P via subsurface drainage should be minimal. However, recent research has revealed that tile drainage systems in agricultural fields can discharge significant quantities of P under a wide range of soil characteristics and management practices. Vadas et al. (2007), Sims et al. (1998), Kleinman et al. (2003), Beauchemin et al. (2003), and King et al. (2014) all demonstrated that a considerable amount of P can be transported beneath the surface in tile-drained fields.

Phosphorus concentrations in tile drainage water reported in the literature frequently exceed the U.S. EPA threshold of 100 $\mu\text{g/L}$ for eutrophication in surface waters (USEPA 1994). In the UK, total phosphorus (TP) concentrations exceeding 1000 $\mu\text{g/L}$ have been observed in tile drainage water, with up to roughly 90% in dissolved form (Heckrath et al. 1995, Gardner et al. 2002). Algoazany et al. (2007) reported annual mean soluble P concentrations of 86–194 $\mu\text{g/L}$ in drainage water in Illinois. Kinley et al. (2007) reported mean concentrations of 230 $\mu\text{g/L}$ TP and 80 $\mu\text{g/L}$ soluble P in drainage samples from cropland fields in Nova Scotia. Madison et al. (2014) measured average annual TP concentrations of 21–1,300 $\mu\text{g/L}$ in tile drainage from Wisconsin field sites.

Phosphorus exported from agricultural fields in drainage water can represent a significant component of overall nonpoint source P loads. In southern Quebec, Eastman (2008, 2010) reported TP loss in drainage water of 1.2 to 4.0 kg/ha, the same order of magnitude reported in surface runoff from agricultural fields. King et al. (2014) reported that tile drainage from an Ohio watershed contributed 0.48 kg/ha of TP, compared to an average annual watershed TP export of 0.98 kg/ha. Drainage water accounted for 47% of the dissolved P and 40% of the TP exported from the watershed. In Wisconsin, Madison et al. (2014) reported annual TP loads in tile drainage of 0.24–2.73 kg/ha, contributing 17 to 41% of all TP loss and up to 72% of dissolved P loss. Smith et al. (2015) documented that 49% of soluble P and 48% of TP losses from Indiana research fields occurred via tile discharge.

Subsurface drainage is an essential water management practice on many agricultural fields, allowing timely equipment access, reduced soil compaction, and increased crop yields in fields otherwise too wet to efficiently farm. Tile drainage can provide significant environmental benefits, from reduced soil erosion to more efficient nutrient uptake by crops to enabling more timely application of conservation measures, because producers

face fewer delays due to wet field conditions. By drawing down the water table and providing rapid conveyance of subsurface water to an outlet, tile drainage can significantly change the hydrologic behavior of a field, reducing surface runoff by enhancing infiltration and ground water transmission. We now know that, management remaining equal, the net result of reduced surface runoff P losses and increased subsurface P losses may be positive or negative, depending on the field and the year.

Although research is not yet conclusive on the factors driving P export via tile drains, characteristics that appear to enhance P loss include: the presence of macropores, especially on clay soils (Beauchemin et al. 1998, Kleinman et al. 2003, Eastman 2010); high drainage flows associated with precipitation or snowmelt events (Gentry et al. 2007); high soil test P and/or soil P saturation (Beauchemin et al. 2003, Kinley et al. 2007, Toor and Sims 2015); and high nutrient inputs, especially manure applications to soils with high or excessive soil test P (Sims et al. 1998, Kinley et al. 2007).

In Vermont, as in much of the nation, the pace of tile drain installation has accelerated in recent years. However, as the area of systematically drained cropland rises, concern regarding nutrient losses and other water quality impacts related to tile drainage has increased.

Beginning in the 1930's, the USDA Soil Conservation Service, now the Natural Resources Conservation Service (NRCS), began developing conservation practices to reduce soil erosion and nutrient losses from cropland. Today we have a long list of conservation practice standards concerning everything from manure and silage leachate management in barnyards to erosion prevention and sediment and nutrient control on cropland. Practices targeting surface runoff, however, may not be sufficient to meet water quality targets if a substantial portion of the P loading from tile-drained agricultural land is delivered through subsurface drainage. Currently, there is no national NRCS practice standard addressing phosphorus losses via tile drainage. To our knowledge, Vermont is the only state with a standard, an interim conservation practice standard (Phosphorus Removal System, Code 782) adopted by Vermont NRCS in 2013.

Phosphorus removal systems installed at the outlets of tile drains that direct flow through filtering media have the potential to significantly reduce phosphorus loads to drainage ditches and receiving waters (McDowell et al. 2008, Penn et al. 2012, Bryant et al. 2012). There is a significant need for the development of standardized approaches to reduce tile drain P contributions.

1.1. Project Overview

Beginning in 2015, the Friends of Northern Lake Champlain (FNLC) and Stone collaborated on the first implementation of Vermont's *Phosphorus Removal System* interim practice standard (Code 782), constructing two media filters on a farm in Franklin County, Vermont to remove P from tile drainage water. The filters were designed to remove dissolved phosphorus from tile drainage water using P sorbing media available locally at low or no cost. Types of media considered included various mine tailings, industrial by-products, and water treatment residuals. We hypothesized that an appropriate filter containing P sorbing media could remove a significant proportion of phosphorus from the tile drainage water over an extended period.

The filter systems were installed between October 20 and November 5, 2015. Continuous flow measurement and routine collection of composite samples from the inflow and the outflow of the filter systems began immediately following installation and continued for 11 months. Concentrations and loads of total phosphorus (TP), total dissolved phosphorus (TDP), total nitrogen (TN), and total suspended solids (TSS) were determined at the inflow and at the outflows of each filter over the monitoring period, at approximately one-week intervals. Phosphorus and nitrogen removal by the filter systems were quantified to evaluate performance of the filters over time.

2. Objectives

The main objectives of this project were to:

1. Design and construct a treatment system to remove P from tile drainage water, and
2. Compare the P removal efficiencies of two types of filter media.

3. Study Site Description

The tile drainage system selected for monitoring and treatment drains a 14-ha (35-acre) field on a commercial dairy farm in Franklin, Vermont (Figure 1). The farm milks approximately 120 cows. The field is cropped with alternating strips of hay and silage corn or soybean. The tile drainage system is dendritic, with a main line extending from east to west across the field, along a low lying path, to the discharge point in a drainage ditch. A grassed waterway overlies the main tile drain in the downslope portion of the field. There are two 10-cm (4-inch) diameter laterals branching off the main line, one extending to the south and one to the north. The tile drain is constructed of perforated, corrugated, single wall, polyethylene pipe. The main line is 15 cm (6 inch) in diameter and the laterals are 10 cm (4 inch) in diameter.



Figure 1: Study field

4. Description of Tasks

4.1. Prepare Quality Assurance Plan

A Quality Assurance Plan was prepared to guide data collection activities. This plan is included as Appendix A. The plan describes the “above and below” study design and data collection procedures used to evaluate the performance of the filtration systems.

4.2. Design and Construction of Phosphorus Treatment Systems

There are two fundamental components of any media filter: the treatment media and the physical structures which contain the media and distribute water through it. The characteristics of the selected media are of paramount importance in the filter design, particularly the hydraulic conductivity as this determines the filtration rate and hence the sizing of the filter.

4.2.1. Filter Media Selection

In selecting two types of media to compare in this study, Stone considered the availability, predicted P sorption capacity, hydraulic conductivity, and reuse potential of the following materials:

- Alum-based drinking water treatment residuals (DWTR);
- Slag materials from steel manufacturing; and
- Crushed rock and mine tailings (gypsum, locally sourced crushed marble and limestone, and wollastonite tailings from Willsboro, New York).

Samples of potential filter materials were delivered to laboratories at the University of Vermont and Oklahoma State University for testing of their P sorption capacity. Under the direction of Dr. Don Ross, University of Vermont students performed a series of experiments to quantify the P sorption potential of several materials. The UVM students performed experiments in which solutions of known P concentration were added to saturated columns packed with media. Influent and effluent concentrations and volumes were compared to estimate the reduction in P concentration and the cumulative mass of P removed through the column. These experiments demonstrated high rates of P removal by both DWTR and crushed limestone. However, the experiments were not representative of anticipated field conditions; in comparison to field conditions, the P concentrations in the inflow were substantially higher and ratios of added P mass to media mass were very low. Therefore, while encouraging, the results were of limited utility in designing the filters.

The experiments conducted by Dr. Chad Penn’s laboratory at Oklahoma State University were flow-through sorption experiments. Water containing P was cycled through a trough containing granular media. These experiments demonstrated moderately high P retention by DWTR and surprisingly good retention by crushed limestone. Other materials performed less well. Wollastonite tailings from a mine in Willsboro, New York, performed poorly. A very fine marble tailings product provided by OMYA in Florence, Vermont demonstrated the highest P sorption of any of the materials tested; however, this material was rejected due to its very poor hydraulic conductivity.

Ultimately, weighing the estimated P sorption capacity, hydraulic conductivity, reuse potential, and availability of various media choices, the two media selected for comparison in this study were DWTR from the Chaplain Water District in South Burlington, Vermont and “bedding” grade crushed limestone from Swanton Lime in Swanton, Vermont.

4.2.2. Filter Design

Stone designed media filters for the selected tile drain based upon the characteristics of the chosen media, site conditions, predicted phosphorus loads, and estimated flows. The design of the filters is consistent with Vermont NRCS’s *Phosphorus Removal System* Interim Conservation Practice Standard, Code 782. A schematic representation of the treatment system layout is shown in Figure 2.

During the design process, Stone assisted Vermont NRCS in performing a cultural resources review at the preferred installation site. Stone provided the maps and data necessary for the NRCS archeologist to conduct this review.

Two major considerations in the design were the horizontal cross sectional area of the filter bed and the hydraulic head available to cause water to flow through the media. Because P sorption involves chemical reactions on particle surfaces, finer grades of material tend to have higher P sorption capacity than coarser grades. However, coarser grade materials have better hydraulic conductivity than finer grades. The apparently inexorable tradeoff between P sorption capacity and hydraulic conductivity is perhaps the most challenging aspect in designing a media filter for P removal.

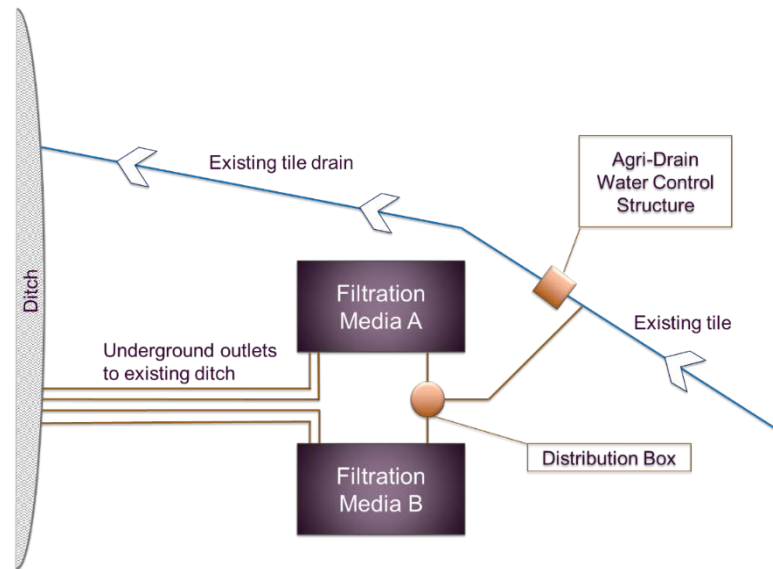


Figure 2: Treatment system schematic (plan view)

In addition to the P sorption studies performed by the cooperating universities, Stone obtained five types of data to inform the design of the filters:

1. Flow data at the tile drain outlet: Stone installed an ISCO 2150 flowmeter at the outlet of the selected tile drain in November, 2014. One month of continuous flow data was collected between November 4 and December 3, 2014. These data were summarized to calculate peak flow rates and total flow volumes for the period.
2. Grab samples were collected at the tile drain outlet on four dates. The total phosphorus concentration of these samples ranged from 104 $\mu\text{g/L}$ to 450 $\mu\text{g/L}$, with a median concentration of 286 $\mu\text{g/L}$.
3. Hydraulic conductivity of the media: Stone measured the hydraulic conductivity of the selected media by timing the infiltration rate of water added to 5-gallon buckets containing a depth of approximately 25 cm of media. The bottom of the bucket was removed and filter fabric was placed over the open bottom to contain the media. The media was first saturated, then water was quickly added to achieve a ponded depth of 5 cm. The time required for the water to infiltrate to the media surface was then recorded, and expressed as depth per unit time (cm/s).
4. The potential for DWTR to release arsenic was tested at the request of the Vermont DEC. A report on this study is presented in Appendix B. Three buckets each containing approximately 18 L of

DWTR from the Champlain Water District were saturated with 7.5 L of water collected from the same tile drain to be treated. Under these saturated test conditions, a small amount of arsenic was released from the DWTR. The total dissolved arsenic concentration of drainage water increased from $<1 \mu\text{g/L}$ to approximately $2.2 \mu\text{g/L}$. This increase occurred within the first hour of the test and longer periods of saturation (up to 30 hours) did not further increase total dissolved arsenic concentrations in solution. The maximum observed concentration of total dissolved arsenic was $2.59 \mu\text{g/L}$, substantially below the maximum contaminant level in Vermont's Water Supply Rule of $10 \mu\text{g/L}$ (VT ANR 2010). Therefore, this experiment demonstrated that DWTR can be used safely in filter systems designed to remove dissolved phosphorus from drainage water.

5. Elevation survey. A careful survey was performed of the elevations of tile drain line, receiving drainage ditch, and the ground surface. The tile drain was approximately 3.5 feet below grade. There was essentially no difference in elevation along the final 100-200 feet of the drain above the outlet (no slope). The invert of the outlet pipe was only slightly higher than the ditch line elevation, such that lowering the outlet pipe as a means to increase the available hydraulic head to the filter was not an option.

Incorporating the above data sources, calculations were made to design and size the filters to allow adequate flow rates and retention times. Engineering plans were created in AutoCAD, including a plan view and typical cross sections of the P removal system and associated components. The basic elements of the design are described in the following section.

4.2.3. Filter Construction

Stone oversaw construction of the P filters by a hired contractor between October 20 and November 5, 2015. Structures were installed per the engineering plans, at predetermined elevations. Materials were assembled on site.

Figure 3 shows the layout of the filter tanks prior to installing their concrete lids and mounding soil over them. Low profile ("ledge"), 1000 gallon concrete septic tanks were customized for use as P filters. The tanks contain two chambers: a larger chamber for media separated by a concrete divider from a smaller chamber containing a Flout® device (Figure 4). The internal dimensions of the media and Flout® chambers are 3.08 m x 1.81 m (10.1 ft. x 5.95 ft.) and 0.46 m x 1.81 m (1.52 ft. x 5.95 ft.), respectively.



Figure 3: View of the P filters without lids and soil cover



Figure 4: Media (left) and Flout (right) chambers prior to placing lid on Filter A

Three 5-cm (2-inch) diameter pipes were cast into the base of the divider wall to convey drainage water from the media chamber to the Flout® chamber. The concrete divider wall is about 5 cm (2 inches) shorter than the side walls of the tank.



Figure 5: Placing septic tank in excavation for Filter A

The filter tanks were lowered into excavations using a boom truck (Figure 5). The tanks were set on levelled beds of crushed stone.

A Flout® with a 4-inch diameter outlet was installed in each filter to alternately saturate and drain the connected media chamber. A Flout® is a mechanical device manufactured by Rissy Plastics (Torrington, CT) that allows the tank to fill and then rapidly flush when the water level reaches the level of the Flout® intake. This cycling of the water level in the filter was

intended to provide adequate contact time and disperse the drainage water evenly through the media as the water level rises and then promote oxygen transfer into the media bed as the chamber flushes.

After the tanks were in place, a main outlet and a drain pipe were connected to each tank and laid through a common trench (Figure 6). The outlet pipe is a 10-cm (4-inch) diameter schedule 40 PVC pipe connected to the Flout® device. There is a backflow preventer valve on the pipe inside the tank and a muskrat guard at the outfall end (Figure 7). The drain pipe is a 5-cm (2-inch) diameter schedule 40 PVC pipe installed from each tank to the drainage ditch. This pipe was set at a slightly lower elevation than the main outlet to enable complete drainage of the filter. The end of the drain line inside the Flout® chamber is capped.



Figure 6: Constructing outflow and drain pipes

After installing the tank and outlet piping, a drainage layer was constructed at the bottom of the media chamber. This layer consists of three perforated, 5-cm (2-inch) diameter schedule 40 PVC pipes bedded in 13 cm (5-inches) of 2.5 cm (1-inch) diameter crushed limestone. Non-woven geotextile was placed over the top of the stone to prevent the media from migrating into the drainage layer. Filter media was then layered on top of the fabric. Approximately 2.5-2.6 m³ (3.3 cubic yards) of media was added to each filter, creating beds 46 cm (18 inches) deep. A second layer of geotextile was installed over the media. Water is distributed over the top of the media bed using a coil of 10-cm (4-inch) diameter, perforated drainage tile held in place with sand bags containing media (Figure 4). Concrete lids were placed on the tanks and native soil was mounded over them to prevent freezing and entry of surface runoff.

Drainage water flows to the filters through a wye installed in the 15-cm (6-inch) diameter tile drain line. An Agri-Drain water level control structure (Figure 8) installed immediately downstream of the wye raises the



Figure 7: Filter outflow and drain pipes

water level in the line above the elevation of the filter inlets. A length of 15-cm (6-inch) diameter, non-perforated, corrugated plastic pipe conveys water from the wye to a distribution box (Figure 9) located between the two filters. 10-cm (4-inch) diameter rigid pipe connects the distribution box to an inlet pipe stub on each filter tank.



Figure 8. Agri-Drain water level control structure installed on tile drain

By adjusting riser plates in the Agri-Drain water level control structure, the amount of water diverted to the filters from tile drain line can be controlled. Any flow not diverted to the filters will bypass over the top plate into the existing tile drain. After a period of experimentation, the elevation of the top of the top plate was set at 2.0 cm (0.79 in.) above the elevation of the filter inlet pipe inverts.

Within the distribution box, plastic caps with orifices drilled into them were placed on the ends of the filter inlet pipes to further control the amount of water flowing to each filter. As the filters clogged, these orifices were made progressively smaller, although events still occurred during which water overtopped the divider wall between the media chamber and the Flout® chamber.

The final, installed cost of the filters was approximately \$5,000 per filter. This cost included labor and all material costs (tanks, Flout® devices, Agri-Drain water level control structure, distribution box, and all associated piping, valves, and couplers). This cost does not include the cost of design.



Figure 9. Interior of distribution box

4.3. Flow and Water Quality Monitoring

4.3.1. Installation of Monitoring Systems

Three ISCO 6712 automatic samplers were used to collect composite samples of the tile drainage water inflow and of the outflows from Filters A and B. The autosamplers were programmed to withdraw sample aliquots on a flow-proportional basis. At the upstream (inflow) station, this was achieved by computing discharge continuously from the water level measured in the Agri-Drain structure, using a formula for a rectangular weir. Aliquots of water were withdrawn from the Agri-Drain structure at a frequency proportionate to the calculated flow rate. At the filter outflows, measurement of flow and flow-proportional sample pacing were achieved through a unique method involving the cycling of the Flout® device. ISCO 2110 flowmeters were installed to measure the water level in each Flout® chamber, using an ultrasonic sensor mounted above the high water level. Every time the water level in the chamber dropped rapidly due to the Flout® flushing, the flowmeter was programmed to send a pulse to the autosampler, initiating collection of a small volume aliquot from the Flout® chamber. Sample collection was therefore strictly proportionate to the flow rate through the filter. Each cycling of the Flout® discharges a reasonably constant volume, 293 L for Filter A and 233 L for Filter B; therefore, the total outflow from each filter was computed by multiplying the number of flow pulses by the constant volume per cycle.

The autosamplers sequentially filled four, 10-L polyethylene carboys (Figure 10). When the first carboy was filled, the autosamplers dispensed sample aliquots to the second carboy, and so on until either the fourth carboy was filled or the sampling program was stopped. The volume of the aliquots was adjusted seasonally to minimize the risk of over-sampling (carboy capacity exceeded) or under-sampling (insufficient sample collected for analysis).



Figure 10: Autosamplers for Filter A (left) and Filter B (right) outflows

Each autosampler and flowmeter was connected to an ISCO 2105ci Interface

Module (a combination datalogger and modem). These modules recorded the time every sample aliquot was collected. Every 30 minutes, they transmitted the sampling, flow, and other data to a computer server located at Stone's office in Montpelier, at which point the data were directly viewable on a customized website. The ability to view station status and monitoring data in near-real time, on any computer, enhanced the scientific quality of the data by enabling early detection of instrument malfunctions and remote changes in instrument programming. We were able to reprogram the instruments from our offices, which was particularly useful in adjusting autosampler settings based on forecasted weather.

Composite samples of the inflow and filter outflows were retrieved and processed approximately weekly when the monitored tile drain was flowing. The exact timing of sampling activities was influenced by weather and agronomic considerations. Stations remained operational through dry periods, although samples were obviously not collected if tile outlets ceased flowing. During the winter, the flow monitoring systems remained operational; however, autosamplers were turned off to avoid damaging them.

Monitoring instruments were powered by a Kyocera KD135GX 135-Watt solar panel and a 12-V deep cycle battery. The autosamplers, flow meters, interface modules, charge controllers, batteries, and a churn splitter were housed in a secure instrument shelter (Figure 10).

4.3.2. Sample Processing

Bulk composite samples were split in the field using a churn splitter to obtain samples for chemical analysis. The last carboy filled was combined in the churn splitter with the previous carboy if the combined volume of the two carboys was less than 14 L, the capacity of the churn splitter; otherwise, a separate set of splits was collected from each sample carboy. Splits were prepared for TP, TDP, TN, and TSS analysis. Sample processing and preservation is described in the project QAP (Appendix A).

A sample retrieval form was used to document sample collection. Completed forms are maintained on file in Stone's office in Montpelier, VT. Samples were transported to the Vermont Agricultural and Environmental Laboratory (VAEL) within the holding times stated for each analyte. Each step in the sample handling process was documented to ensure traceability of samples from generation to analysis.

4.3.3. Analysis of Water Samples

VAEL used their approved methods and QA/QC procedures in performing the requested analyses, at no cost to FNLC or Stone. The laboratory's Quality Systems Manual (2016) and the methods it references were approved by EPA Region 1.

4.4. Data Analysis

Event mean concentrations (EMCs) and mass loads were calculated from flow data and approved analytical results for each 6-8 day sampling period. Inflow and outflow EMCs were compared to quantify the P reduction by each filter, as a percentage of the inflow EMC. The P removal efficiency of the tile drain filters over the 11-month monitoring period was then calculated as the average of the percent reductions for each sampling period. Because the filter inflows must equal the outflows, the average percent reduction in constituent EMCs also approximates the percent reduction in the TP, TDP, TN, and TSS loads.

4.5. Business or Academic Relationships that Facilitated the Project

The University of Vermont and Oklahoma State University assisted the project investigators by testing the P sorption capacity of various materials. Dr. Don Ross of the University of Vermont Plant and Soil Science Department led students in performing a series of experiments to quantify the P sorption potential of several materials using saturated columns packed with media. Dr. Chad Penn's laboratory at Oklahoma State University conducted flow-through P sorption experiments on several materials. The services of these laboratories were accounted for as in-kind support.

The Champlain Water District in South Burlington, Vermont provided drinking water treatment residuals free of charge for use in one of the media filters.

No direct support was received or provided to UVM, OSU, or the Champlain Water District.

5. Review of Methods

A Quality Assurance Plan (QAP) is included as Appendix A. This QAP was developed for use by the project team, to document the field and analytical methods employed during the monitoring phase of the study. As the project was not subject to EPA review, the QAP was not submitted for review and approval.

5.1. Innovations

While simple in concept, there have been few attempts to treat P in tile drainage water. This project is the first application of Vermont NRCS' interim practice standard for phosphorus removal systems.

One of the unique design elements was the use of a Flout[®] device to increase the contact time of the drainage water in the media, ensure that the whole volume of media was in contact with drainage water, and enable alternating saturated and unsaturated conditions.

The method of pacing the autosamplers installed at the filter outflows was also original, to our knowledge. By initiating collection of a small aliquot of treated drainage water with every Flout[®] cycle, the composite samples produced were in strict conformance with the flow-proportional sampling method.

5.2. Accommodations

The producer had to remove plates from the Agri-Drain water level control structure a few days prior to planting and harvest, to reduce the potential for machinery to become mired in soft soil. The producer also had to create a stabilized rock outlet for the grassed waterway, because the bank of the receiving ditch eroded due to prolonged saturation.

5.3. Schedule of Events

Table 1 provides the schedule of the major phases and events in the study. The filters were operational on November 5, 2015 and monitoring commenced on November 17, 2015. The filters remained operational through the winter months. The tile drain continued to flow and temperatures in the Flout[®] chambers remained above freezing all winter. Because the monitoring shelters were not heated, the autosamplers were shut down for the winter months. Sampling activities were resumed at all three monitoring stations on May 7, 2016 after the risk of freezing had decreased.

On May 11, 2016 three sections of drain tile were dug up with an excavator and replaced. These sections had been gnawed through by muskrats in years past, leading to sinkholes which introduced surface runoff and sediment into the tile drain (Figure 11).

The tile drain ceased flowing during periods in July and August, 2016. However, summer storms generated sufficient tile drain flow for collection of flow proportional composite samples in certain weeks.

The monitoring program was terminated on October 19, 2016, a month earlier than expected, due to a misunderstanding with the participating farmer.

Table 1: Schedule of events

	Start Date	End Date
Tile drain flow characterization (for design)	November 4, 2014	December 3, 2014
Treatment system design	December 3, 2014	October 5, 2015
Media testing for P sorption	January 1, 2015	September 7, 2015
Testing DWTR for arsenic leaching	July 8, 2015	July 16, 2015
Installed tanks and media	October 20, 2015	November 5, 2015
Installed monitoring systems	October 20, 2015	November 17, 2015
Filter system flow monitoring	November 17, 2015	October 19, 2016
Filter system water quality monitoring		
Period I	November 17, 2015	December 16, 2016
Period II (winter thaw)	January 26, 2016	January 27, 2016
Period III	May 7, 2016	October 19, 2016
Manure application on corn strips (5,000 gal./A)		April 28, 2016
Tile drain repairs		May 11, 2016
Fertilizer application on corn strips (200 lb./A of 10-20-28)		May 11, 2016
Manure application to hay strips (5,000 gal./A)		June 17, 2016
Manure application to hay strips (2,000 gal./A)		July 17, 2016
Monitoring station decommissioning		October 19, 2016

In addition to the manure and fertilizer applications listed in Table 1, the participating farmer made five urea applications to the hay strips and one urea application to the corn strips between May and August, 2016.

5.4. Challenges Encountered

This project was intended as a first attempt in Vermont to design, construct, and measure the performance of a system to remove phosphorus from tile drainage water. Problems were to be expected, especially considering the modest size of the grant and the technical challenges inherent in treating large volumes of subsurface drainage water without the benefit of electrically powered devices (pumps, chemical feeds, mixers, etc.) or even modest hydraulic head from the drain tile invert to the receiving ditch. The main problems encountered were as follows:

- Engineering for the system was more far more involved and expensive than anticipated, in large part because there was almost no change in elevation from the area where the practice was installed to the tile drain outlet. In addition, VTDEC required unanticipated testing and permitting of the DWTR media before they approved its use, which delayed construction of the filters.
- Both filters were unable to “keep up” during high flow events, resulting in bypass flow over the Agri-Drain plates and within each filter, when the water in the media chamber rose above the level of the divider wall, spilling into the Flout® chamber. This occurred for two reasons: 1) the peak flow rates measured during high flow periods of the study were substantially higher than the peak flow rates

assumed in the design (1.0 L/s); and 2) progressive clogging of the filter media greatly reduced the filtration rate of both filters. The design flow for each filter was based on peak flows measured during the month-long flow characterization monitoring (November, 2014). Four rainstorms produced peak flows in the 2.0 to 4.5 L/s range. For comparison, peak flow rates measured since construction of the filters were in excess of 22 L/s, five times greater than any flows recorded in the November 2014 period. As the filtration rate declined due to clogging, both the elevation of the top plate in the Agri-Drain and the diameter of the orifice on the inflow line to each filter were adjusted to reduce flow to the filters.

- Large quantities of sediment were introduced into the tile drain due to sinkholes that formed over old muskrat holes. Muskrats habitually crawl up tile lines and burrow out when they cannot turn around. The muskrat holes are believed to predate the study, prior to the cooperating farmer installing a muskrat guard at the outfall. The additional hydraulic pressure resulting from operation of the water



Figure 11: Repair made to tile drain due to a muskrat hole

level control structure is believed to have caused old holes in the drain to blow out, creating sinkholes. This resulted in accumulation of sediment on the top of the filters, which reduced their flow rate and increased the proportion of drainage water bypassing the filters. The holes in the drain line were patched on May 11, 2015, as soon as an excavator could access the area. Unfortunately, the filtration rate of both filters had decreased substantially by this time.

5.5. Design Alternative to Reduce Filter Clogging

At the outset of the design phase, a decision was made to develop a down-flow type of filter. An up-flow type of filter was considered, but was rejected due to concerns that such a filter could be difficult to clean if it became clogged. As it happened, the down-flow filters installed became clogged and we were not able to clean them within the timeframe and budget of this project. The soil backfill over the tanks and the 6,000 lb. concrete lid on each tank were major impediments to maintenance of the filters.

Stone is presently considering alternate designs to improve the performance and operation of the P filter. In retrospect, an up-flow type filter with an upstream sedimentation chamber and flashboard riser would probably have been a better design. A sedimentation chamber should have been used upstream of the filters. This same chamber could have served the multiple purposes of settling solids, providing a high flow bypass, permitting installation of flow metering instruments, and enabling filter backflushing. Backflushing of the

filter could be accomplished by removing plates on a flashboard riser within the chamber, causing rapid drainage of the filter and flushing of sediments trapped in the water distribution pipe and gravel layer. An up-flow filter would have allowed water distribution and contact time with the media equal to or better than the down-flow filter and Flout® arrangement.

Two alternate designs for the media chamber were considered in the early stages of the design phase: buried concrete tanks and lined excavations. 1000 gallon, low profile septic tanks were used for this project primarily because the Flout® was a critical component, and this device requires a rigid, water-filled chamber to function properly. Tanks were also selected because media replacement was thought to be easier in a tank than in a lined excavation. The tanks also provided nearly identical test systems to compare the performance of the different media. However, in retrospect, placing the media in a lined excavation may have been a better, more practical design. The filter tanks proved undersized; whereas a lined excavation could have been made substantially larger, with more media volume to filter drainage water and adsorb P. 1000 gallon tanks were the practical upper size limit with respect to cost and installation requirements. Higher filtration rates could have been achieved using a long (40-60 ft.) lined excavation. A filter in a lined excavation with an upstream sedimentation chamber could also have been constructed at lower cost than the installed filters. Constructing an up-flow filter in a lined excavation would eliminate need for a Flout®.

6. Quality Assurance

The Quality Assurance Plan included as Appendix A describes the monitoring procedures and quality assurance measures applied in this study.

Since due to an oversight the QAP does not cover calibration of the level sensors, this procedure is described as follows.

6.1. Calibration

Level readings of the ISCO 720 vented pressure transducer installed in the Agri-Drain and the ultrasonic sensors installed in Flout® chambers of Filter A and B were checked against manual measurements made approximately monthly. The sensor readings were adjusted, as necessary.

7. Findings

Although the project investigators encountered several technical and logistical challenges, our findings demonstrate that this study met both of its stated objectives. The project investigators succeeded in 1) designing and installing a treatment system that removed P from tile drainage water, and 2) demonstrating which of two media performed better than the other. DWTR clearly outperformed crushed limestone “bedding sand”. The following sections highlight the major study findings.

7.1. Comparison of Inflow and Outflow Concentrations

Figures 12 and 13 compare the TP and TDP concentrations of composite samples collected approximately weekly of the tile drain inflow and the outflows of Filters A and B. Figure 12 demonstrates that outflow from both filters had consistently lower TP concentrations than the untreated inflow, and that with few exceptions the outflow from Filter A had lower TP concentrations than Filter B. The pattern in TDP concentrations (Figure 13) was similar.

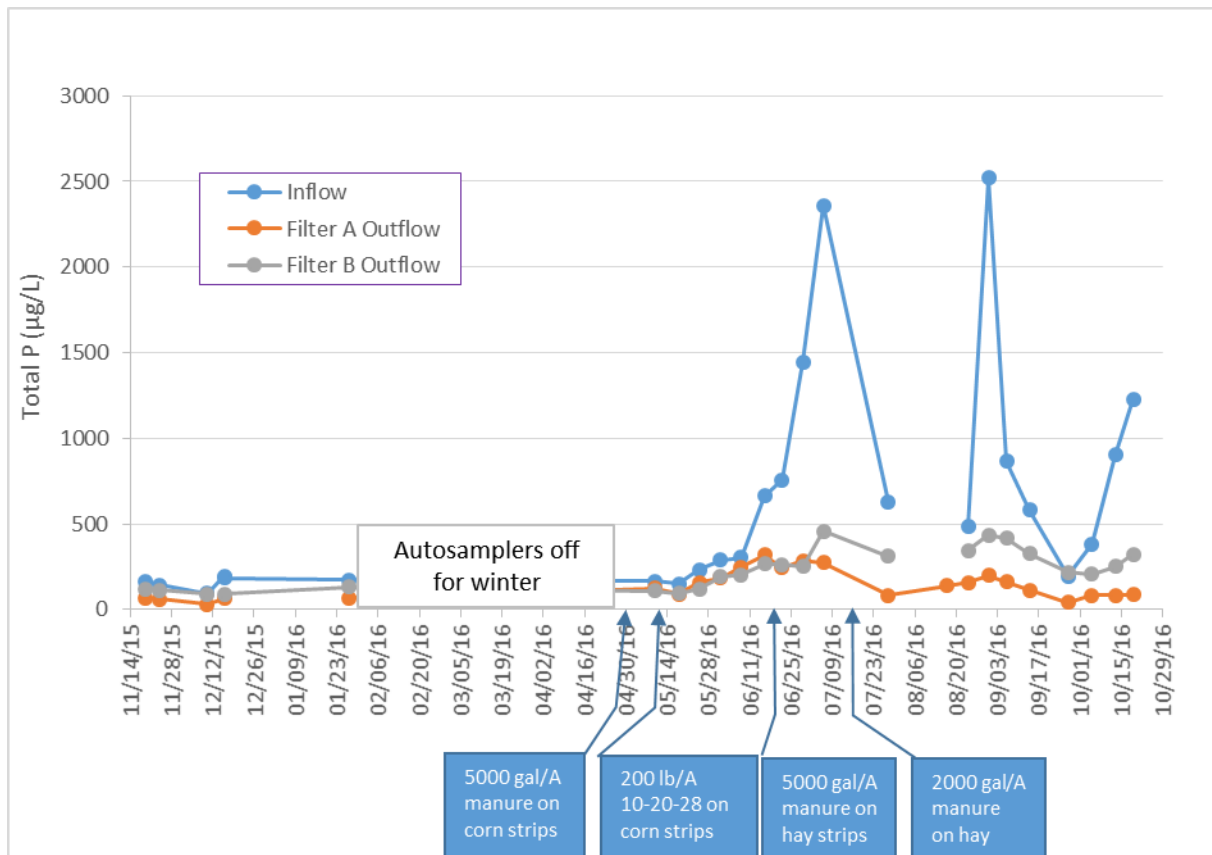


Figure 12. TP concentrations in composite samples of inflow and filter outflows

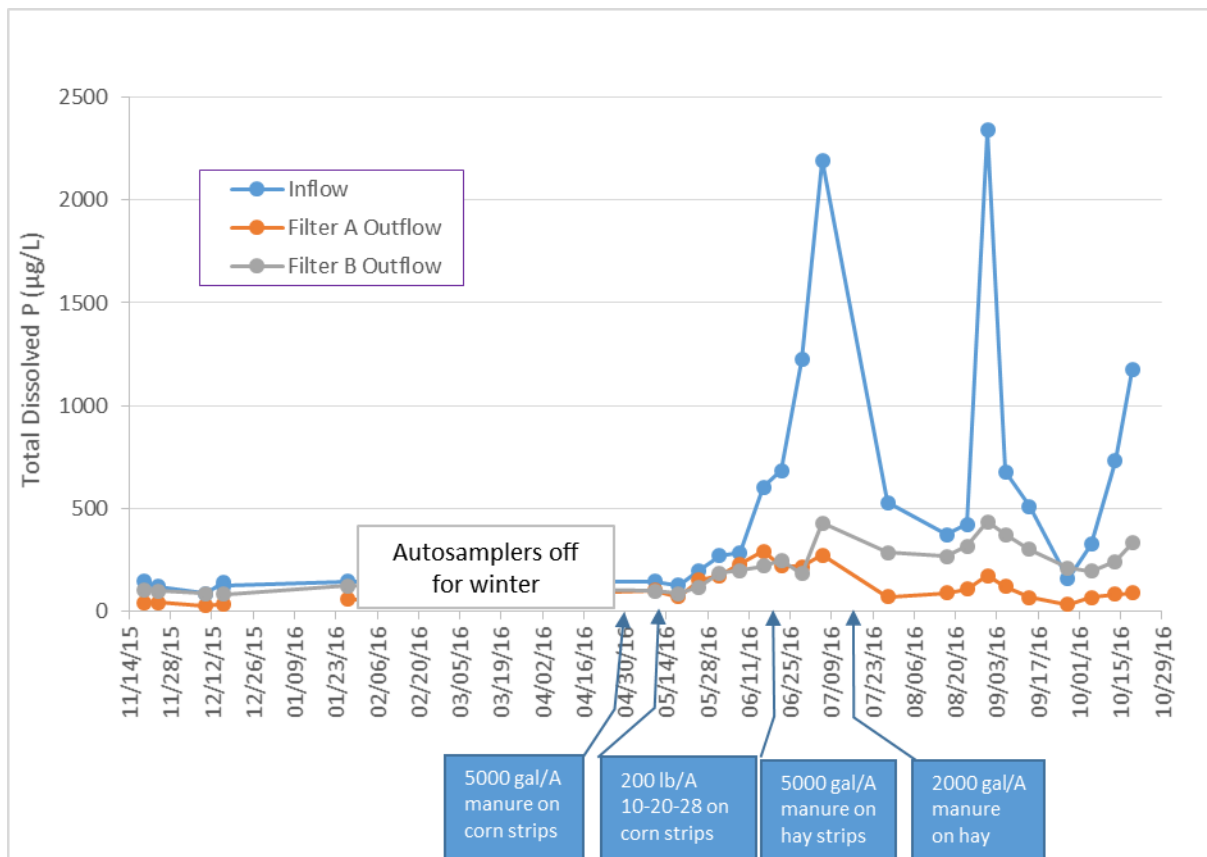


Figure 13. TDP concentrations in composite samples of inflow and filter outflows

Table 2 presents the ranges and medians of event mean concentrations of TP, TDP, TN, and TSS in the inflow and filter outflows over the 11-month monitoring period. The range in the inflow TP concentrations was large, from 93 to 2,520 $\mu\text{g/L}$. The median TP EMC in the Filter A outflow (118 $\mu\text{g/L}$) was considerably lower than the TP EMC in the Filter B outflow (220 $\mu\text{g/L}$), and both filters produced water with substantially lower median TP concentrations than the inflow (345 $\mu\text{g/L}$). On average, 86 percent of the P in the filter inflow was in the dissolved form.

Table 2: Summary of analyte concentrations in inflow and filter outflows

Analyte	Inflow EMCs (range; median)	Filter A (DWTR) Outflow EMCs (range; median)	Filter B (limestone) Outflow EMCs (range; median)
Total P ($\mu\text{g/L}$) (n=24)	93 – 2,520; 345	31 – 321; 118	90 – 457; 220
Total Dissolved P ($\mu\text{g/L}$) (n=25)	84 – 2,340; 325	26 – 292; 89	83 – 435; 205
Total N (mg/L) (n=25)	3.7 – 21.2; 9.1	4.7 – 14.9; 8.8	6.8 – 13.2; 8.3
TSS (mg/L) (n=24)	1.4 – 49.5; 6.1	1.0 – 17.9; 3.9	1.0 – 15.8; 2.0

Figures 14 and 15 compare event mean TP and TDP concentrations in the inflow to the filter outflows. With few exceptions, outflow from Filter A had lower TP and TDP concentrations than the outflow from Filter B.

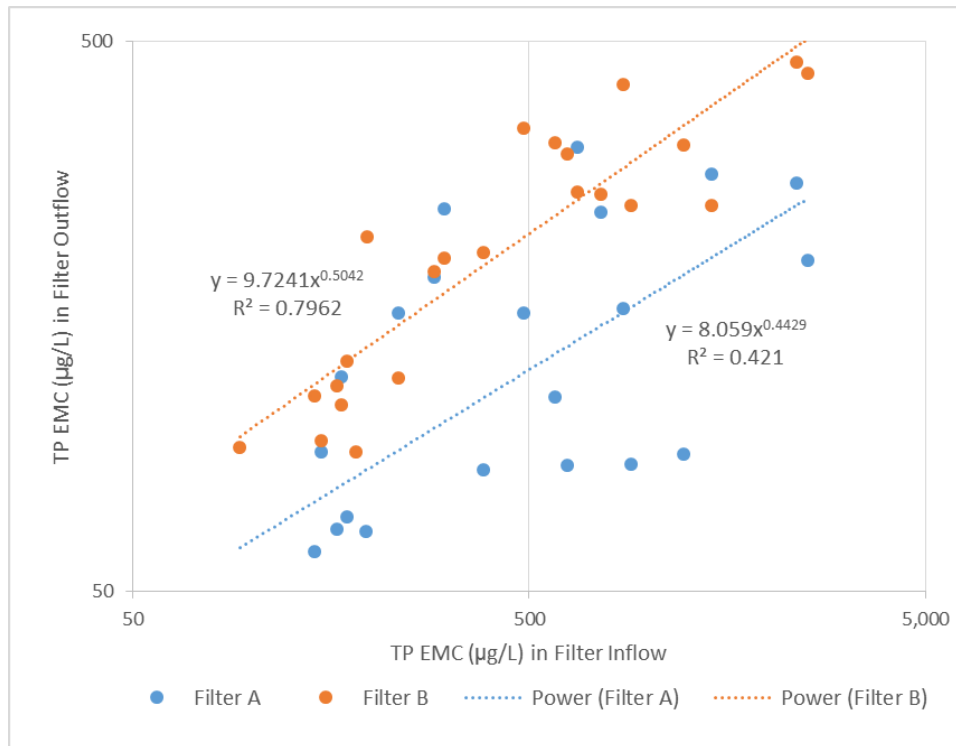


Figure 14: TP concentrations in paired composite samples of inflow and outflow

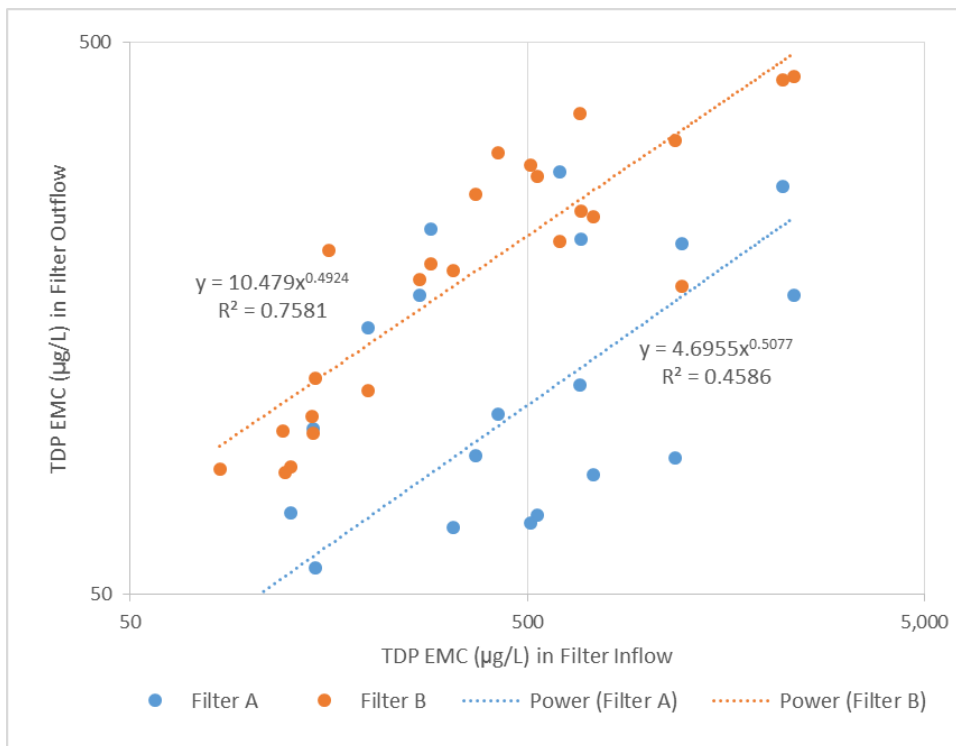


Figure 15: TDP concentrations in paired composite samples of inflow and outflow

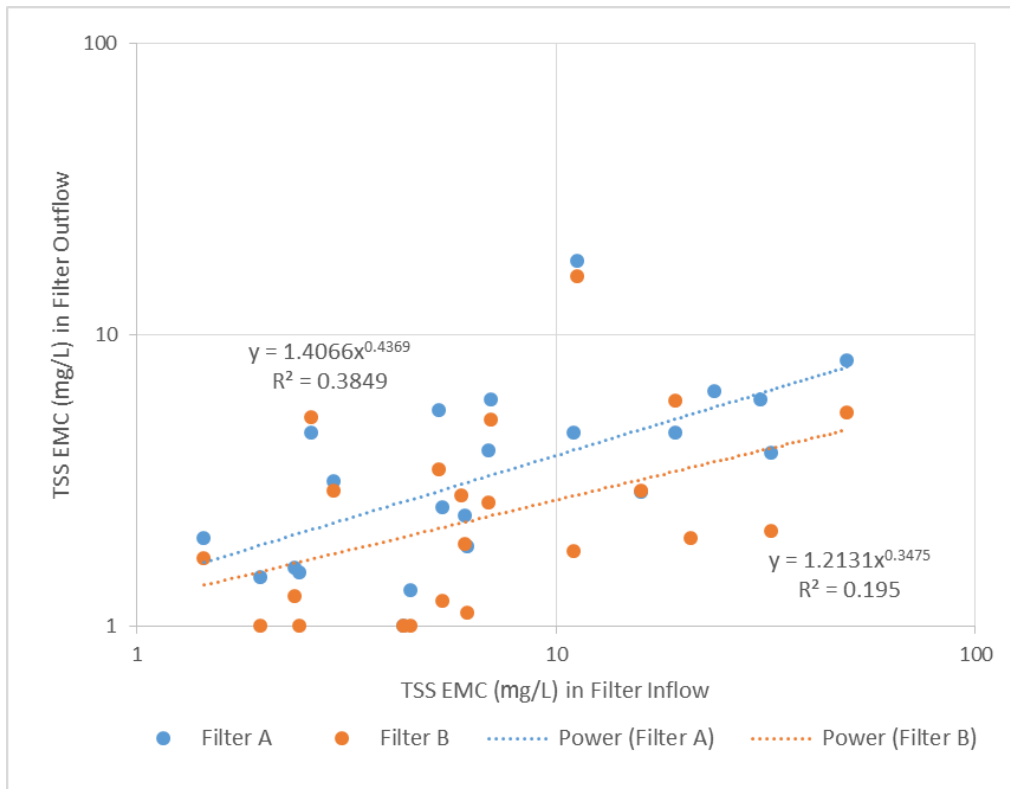
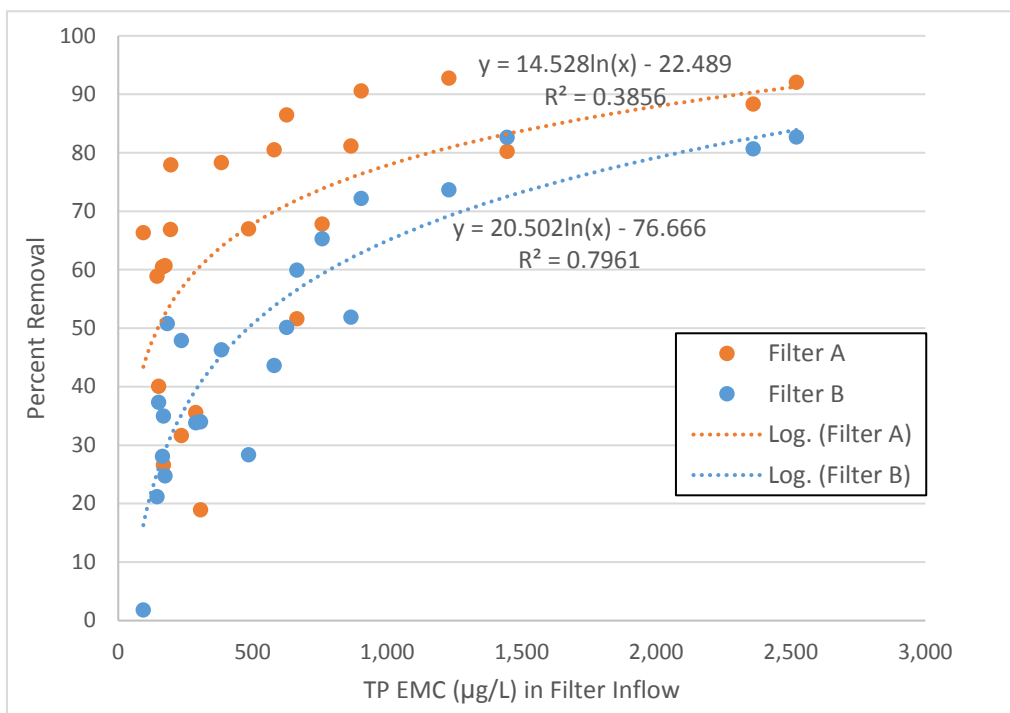


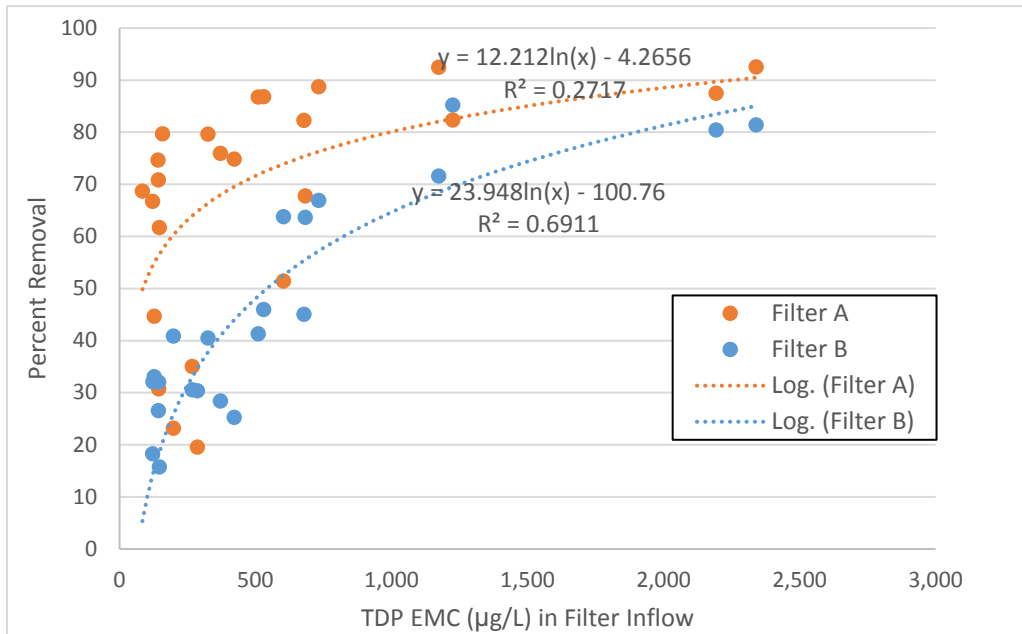
Figure 16 shows TSS EMCs in the inflow and filter outflows. Outflow from both filters contained lower TSS concentrations than the inflow, with marginally better TSS removal by Filter B.

Figure 16: TSS concentrations in paired composite samples of inflow and outflow



Percent removals of TP and TDP through the filters are presented in Figures 17 and 18. These figures demonstrate two important points: 1) Both filters reduced P more efficiently as the inflow P concentration increased, and 2) DWTR removed a higher percentage of P than crushed limestone across the entire range of observed

Figure 17: Percent TP removal relative to TP concentration in filter inflow



inflow P concentrations. Both filters had consistently high (>40%) P removal rates by when inflow concentrations were above 500 µg/L. In the two weeks when inflow P concentrations exceeded 2,000 µg/L, P removal increased to ~90% in Filter A and ~80% in Filter B. At the lowest inflow P

Figure 18: Percent TDP removal relative to TDP concentration in filter inflow

concentrations, the limestone media was markedly less efficient than the DWTR. There was little difference in these patterns between TP and TDP, only perhaps slightly greater removal of TDP.

Table 3 summarizes the removal efficiencies of Filter A and B for each monitored constituent. These results demonstrate that over the monitoring period, both Filter A and Filter B removed substantial percentages of total and dissolved P and TSS. Neither filter effectively removed TN, though Filter B was somewhat more efficient than Filter A in this respect.

Table 3. Percent removal of TP, TDP, TN, and TSS by Filter A and Filter B

	Percent Reduction ¹	
	Filter A (DWTR)	Filter B (limestone)
Total P	69%	54%
Total Dissolved P	72%	51%
Total	7%	15%
TSS	58%	63%

1. Calculated as mean percent difference between paired inflow and outflow samples

7.2. Filtration Rate

During the 11-month monitoring period, Filter A (DWTR) treated approximately 2,123,000 L (561,000 gal.) of drainage water. Filter B treated a slightly greater volume, approximately: 2,339,000 L (618,000 gal.). For comparison, the design flow per filter was 9,000,000 L per year. Both filters became clogged with sediment. Over 11 months, the maximum filtration rates of both filters declined from approximately 48 L (13 gal.) per

minute to 3.7 L (0.97 gal.) per minute, a 92 percent decrease. Due to clogging, the volume of water treated by the filters was less than the design assumption. A greater proportion bypassed the filters.

7.3. Phosphorus Mass Removed

Over the course of the 11-month monitoring period, Filter A removed approximately 310 g (0.68 lb.) of P, or 0.16 mg P per kilogram of DWTR. Filter B removed approximately 200 g (0.45 lb.). Therefore, while Filter A treated 9% less water than Filter B, it retained 50% more P.

The DWTR filter design calculations assumed an average of 2.6 kg of P would be removed by the DWTR filter each year, over a 10-year design life. The total amount of P removed by the systems was lower than expected primarily because the majority of the flow through the system was bypassed. Also, while impressive P removal efficiencies were observed when inflow P concentrations were high during the summer months, the flows through the summer were lower; P removal was less efficient during the winter and spring period when flows tended to be higher and inflow P concentration were lower.

There was no indication that either media was reaching the point of P saturation at the time monitoring ended. The amount of P that had been retained by the DWTR in Filter A was a small fraction, approximately 4%, of the predicted sorption capacity of this material.

8. Conclusions and Recommendations

Stone and FNLC designed, constructed, and tested two filters to remove P from tile drainage water on a farm in Franklin, VT. A great deal of effort was spent designing the filters. The University of Vermont Plant and Soil Science Department and the University of Oklahoma characterized the P sorption capacity of several locally sourced candidate media, using different test methods. In October, 2016, two custom designed filter tanks were installed near the outlet of a 15-cm (6-inch) diameter tile drain. The tile drain is dendritic in layout, but consists of modern (1970's era) perforated, corrugated plastic drain tile. A water level control structure and a distribution box were used to raise the water level in the drain and distribute it evenly to each filter. Monitoring stations were constructed with instruments to measure flow and withdraw samples on a flow proportional basis from the inflow and the filter outflows. These data were summarized to obtain estimates of reductions in concentrations of total and dissolved phosphorus, total nitrogen, and total suspended solids through the filters, as well as the mass of P removed by each filter.

The results demonstrate that both Filter A and Filter B removed substantial percentages of total and dissolved P and TSS over the 11-month monitoring period. The inflow P concentrations were highly variable, 93 – 2,520 $\mu\text{g/L}$, with a median event mean concentration of 345 $\mu\text{g/L}$. Filter A removed 69% of TP and 72% of TDP, while Filter B removed 54% of TP and 51% of TDP. The P removal efficiency of both media improved with increasing inflow P concentration. Neither filter effectively removed TN, though Filter B was somewhat more efficient than Filter A in this respect. Over the 11-month period, the maximum filtration rates of both filters declined due to clogging from approximately 48 L (13 gal.) per minute to 3.7 L (0.97 gal.) per minute, a 92 percent decrease, which resulted in a high proportion of water bypassing the filters. Due primarily to lower than anticipated filtration rates, the inflow P load and the mass of P retained in the filters were lower than expected.

There is a challenging conflict inherent in the design of media filters for P removal: finer particles provide greater surface area for chemisorption processes, therefore more efficient P removal; however fine media are prone to rapid clogging. This study and another effort Stone is currently engaged in in the Jewett Brook watershed have demonstrated that tile drains can transport large amounts of suspended sediments at high flow rates, even without sinkholes or intentional surface inlets. Design of media filters to treat tile drainage water from cropland must therefore accommodate substantial sediment loads. In addition to selecting media with substantially higher hydraulic conductivity (>0.3 cm/s; in the range of gravel) than those used in this study, we recommend filters be designed with a sedimentation chamber upstream and a means to backflush the filter of accumulated sediments.

9. Presentations

On June 8, 2016, Julie Moore (co-principal investigator) presented an overview of the project and the results to date at the Vermont Environmental Consortium's annual Water Quality Conference in Randolph, Vermont.

On August 1, 2016, Christine Gingras of Stone presented an overview of the project and the results to date at the Northeast Agricultural and Biological Engineering Conference (NABEC) in Orono, Maine.

On February 24, 2017, Dave Braun of Stone presented an overview of the project and the preliminary results at the Winter Farmer Meeting in St. Albans, Vermont, an annual event coordinated by FNLC and the University of Vermont Extension Program.

On May 23, 2017, Christine Gingras of Stone presented the study findings at the 2017 EWRI World Environmental & Water Resources Congress, held in Sacramento, CA.

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Appendix A: Quality Assurance Plan

QUALITY ASSURANCE PROJECT PLAN

Phosphorus Removal from Tile Drainage Systems
Using In-Ground Filter Systems

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Table of Contents

SECTION 1.0 – Project Overview and Objectives.....	3
SECTION 2.0 – Project Organization and Management.....	6
SECTION 3.0 – Monitoring Approach.....	8
SECTION 4.0 – Sampling Procedures.....	11
SECTION 5.0 – Testing and Measurement Protocols (analytical methods)	14
SECTION 6.0 – Quality Assurance / Quality Control QA/QC).....	15
SECTION 7.0 – Data Handling Procedures	19
REFERENCES	21

Appendices

- Appendix A Sample Retrieval Form
- Appendix B Chain of Custody Form for Water Samples

Quality Assurance Project Plan (QAPP)

SECTION 1.0 PROJECT OVERVIEW AND OBJECTIVES

Lake Champlain (Vermont – New York – Quebec) continues to suffer from the effects of excessive phosphorus (P) loading from sources in the Lake Champlain Basin (LCB). It is estimated that more than 90% of the lake's current annual P load is derived from nonpoint sources (VANR 2008). Nonpoint source P derived from agricultural land is a significant component of the lake's annual P load (Troy et al. 2007). Vermont farmers have shown strong interest in implementing best management practices (BMPs) such as conservation tillage, manure and nutrient management, and cover crops over the past decades to address losses of P, sediment, and other pollutants from agricultural operations in the LCB. However, despite unprecedented investments by farmers and federal and state programs, these efforts have not yet yielded the desired water quality results.

One factor that may contribute to the slowness of progress toward attainment of water quality goals is losses of dissolved phosphorus via agricultural tile drainage systems. For many years relatively scant attention was given to potential tile drainage contributions of P to local receiving waters due to the prevailing view that, because soils have an affinity for P, losses of P via subsurface drainage should be minimal. More recently, Sharpley et al. (2004), Vadas et al. (2007), and King et al. (2014) all demonstrated that a considerable amount of P can be transported beneath the surface in tile-drained systems. King et al. (2014) demonstrated that tile drainage accounted for approximately 47 percent of the discharge and 48 percent of dissolved phosphorus losses over an eight-year period in a small agricultural watershed in central Ohio. Tile drainage can dramatically alter field hydrology and the transport of nutrients from agricultural lands to surface waters. Historically, it was believed that increased subsurface losses were more than offset by reduced surface runoff losses, as the drains lower the water table, reducing the frequency and magnitude of saturated overland flow events. We now know that, management remaining equal, the net result of reduced surface runoff losses and increased subsurface losses may be positive or negative, depending on the field and the year.

In Vermont, as in much of the nation, the pace of tile drain installation has accelerated in recent years. In addition to its many widely recognized agronomic benefits, tile drainage can provide significant environmental benefits, from reduced soil erosion and compaction to more efficient nutrient uptake by crops to enabling more timely application of conservation measures, because producers face fewer delays due to wet field conditions. However, concern regarding nutrient losses and other water quality impacts related to tile drainage has increased as the area of systematically drained cropland rises

Beginning in the 1930's, the USDA Soil Conservation Service, now the Natural Resources Conservation Service (NRCS), began developing conservation practices to reduce soil erosion and nutrient losses from cropland. Today we have a long list of conservation practice standards concerning everything from manure and silage leachate management in barnyards to erosion prevention and sediment and nutrient control on cropland. However, there is currently no national NRCS practice standard addressing phosphorus losses via tile drainage. To our

knowledge, Vermont is the only state with a practice standard, an interim standard adopted by Vermont NRCS in 2013. Given that tile drainage has been found to be a substantial source of P in certain watersheds, the need for standardized approaches to reducing tile drain P contributions is great.

Phosphorus filtration technology has been successfully employed in treating water in drainage ditches and surface water runoff from agricultural and residential land uses (Penn et al., 2007, 2012, and 2014). In fact, the Maryland Department of Agriculture is currently cost-sharing the construction of phosphorus removal structures in drainage ditches. However, there is a great need to adapt this technology to tile drain systems. Phosphorus removal systems installed at the outlets of tile drains that direct flow through filtering media have the potential to significantly reduce phosphorus loads to drainage ditches, and thus to streams and rivers in the watershed (McDowell et al. 2008, Penn et al. 2012, Bryant et al. 2012).

In this study, filters will be designed to remove dissolved phosphorus from tile drain water using sorptive media available locally or within the region at low or no cost. Types of media being considered include various mine tailings, industrial by-products, and treatment residuals. Filter designs will be developed that are appropriate for Vermont's landscape, soils, and climate. Two packed bed media filters will be installed on a single tile drain by splitting the flow between the adjacent filtration structures.

The main objective of this study is to evaluate and document the efficacy of phosphorus removal systems installed at the end of an agricultural tile drainage system. Specific components include:

- Continuously monitoring inflows and outflows through the phosphorus treatment systems;
- Quantifying phosphorus reductions in the treatment systems by comparing total phosphorus and total dissolved phosphorus concentrations and loads in inflow and outflows;
- During critical periods such as start-up and following manure and fertilizer applications, quantifying changes in nitrogen and total suspended solids concentrations and loads by comparing inflow and outflows.

The phosphorus removal systems were constructed on a commercial dairy farm in Franklin, Vermont in the Lake Champlain Basin. The project consists of nine major tasks:

1. QAPP development
2. Filter media selection
3. Design of phosphorus removal systems
4. Design of monitoring systems
5. Construction of phosphorus removal systems
6. Installation of monitoring systems
7. Discharge and water quality monitoring
8. Station decommissioning
9. Data management and analysis (to evaluate system performance)

Construction of the phosphorus removal systems and installation of associated monitoring systems was completed in October and November 2015. Discharge measurements and routine collection of composite samples from the inflow and the outflows of the treatment systems began on November 17 and will continue through the 2016 field season, assuming the filters continue to remove P. These flow and water quality data will allow for evaluation of the performance of the treatment systems and a full scale comparison of the efficiency of the two types of media selected.

SECTION 2.0 PROJECT ORGANIZATION AND MANAGEMENT

2.1 Project contacts

Contact information for all involved parties is presented in Table 2.1.

Table 2.1. Project contact information

Name	Title	Phone	Email
USDA-NRCS			
356 Mountain View Dr., Suite 105, Colchester, VT 05446			
Fletcher (Kip) Potter	VT State Resources Conservationist	(802) 951-6796	kip.potter@vt.usda.gov
Rob Allen	State Conservationist Engineer	(802) 951-6796	rob.allen@vt.usda.gov
State of Vermont			
Laura DiPietro, VAAFM	Deputy Director, Division of Agricultural Res. Management	(802) 828-1289	laura.dipietro@state.vt.us
Michael J. Middleman VAAFM	Water Quality Partner Liaison	(802) 828-5362	Michael.Middleman@state.vt.us
Dan Needham VDEC	Laboratory Director	(802) 585-9808	dan.needham@state.vt.us
Eric Smeltzer VDEC	Environmental Scientist	(802) 338-4830	eric.smeltzer@state.vt.us
Friends of Northern Lake Champlain			
Denise Smith	Executive Director	(802) 951-6796	denisefnlc@gmail.com
Stone Environmental, Inc.			
535 Stone Cutters Way, Montpelier, VT 05602			
Julie Moore, PE	Project Manager	(802) 229-1881	jmoore@stone-env.com
David C. Braun	Water Quality Scientist	(802) 229-4541	dbraun@stone-env.com
Allison Jerram	Water Quality Scientist	(802) 778-3001	ajerram@stone-env.com
Chris Stone	President	(802) 229-6433	cstone@stone-env.com
University of Vermont			
Dr. Don Ross Department of Plant and Soil Science	Research Professor	(802) 656-0138	dross@uvm.edu
Oklahoma State University			
Dr. Chad Penn, Department of Plant and Soil Sciences	Associate Professor, Soil and Environmental Chemistry	(405) 744-2746	Chad.penn@okstate.edu

2.2 Project participants and responsibilities

The roles and responsibilities of the principal project participants are listed in Table 2.2.

Table 2.2. Project roles and responsibilities

Individual(s) assigned	Responsible for:
Fletcher (Kip) Potter	Project oversight Review media and treatment system design
Rob Allen	Technical review of treatment system design
Dan Needham	Sample analysis
Denise Smith	Project administration Coordination with farm cooperator Routine sample collection and station maintenance
Julie Moore, PE	QAPP review Project management Technical review of treatment system design Report preparation Presentation
David C. Braun	QAPP preparation Treatment and monitoring system design Treatment system construction oversight Monitoring system installation Non-routine monitoring station maintenance Station decommissioning Report preparation
Allison Jerram	QAPP preparation Assist with treatment system design Data management and analysis Report preparation
Don Ross	Filter media analysis
Chad Penn	Filter media analysis Review treatment system design

2.3 Special Training Requirements/Certifications

Personnel with considerable expertise and experience in performing the project tasks will conduct sampling and analysis for the project. Consistency in sampling and maintenance routines will be aided by the use of standard checklists and forms for station maintenance and sample retrieval. Stone Environmental maintains training records for all staff that document relevant training and SOP review. Laboratory analysis will occur at the Vermont DEC laboratory under the direction of the Laboratory Director. No additional specialized training or certifications are necessary for personnel to conduct the project tasks.

SECTION 3.0 MONITORING APPROACH

3.1 Monitoring design

The project team will design, construct, and test innovative in-ground phosphorus removal systems. The systems will be integrated directly into the tile drainage system to assess nutrient removal potential from the tile drain flow prior to discharge into a field ditch. Total phosphorus (TP) and total dissolved phosphorus (TDP) concentrations and loads will be determined at inflows and outflows of two treatment systems over the monitoring period, at approximately one-week intervals. Phosphorus removal by the treatment systems will be quantified to evaluate performance of the systems over time. During certain critical periods (startup, after manure and fertilizer applications, et cetera), total suspended solids and total nitrogen concentrations and loads will also be quantified.

Installation of monitoring facilities was completed in November 2015. Monitoring will be conducted from November 2015 – December 2016 with the exception of January – March 2016 when monitoring may be suspended due to freezing conditions.

3.2 Study location

The phosphorus removal systems were constructed at the approximate location indicated in Figure A.1. The systems were installed near the end of an existing tile drainage system which reportedly drains 35 acres of cropped field (personal communication with A. Rainville, January 28, 2015). The exact siting was determined after detailed topographic survey was performed. Stone performed an elevation survey using a GeoMax Zoom30 total station. The elevation of the tile outlet relative to the ground surface and the receiving ditch was measured. The elevation of the buried tile line was determined after digging to expose the line.

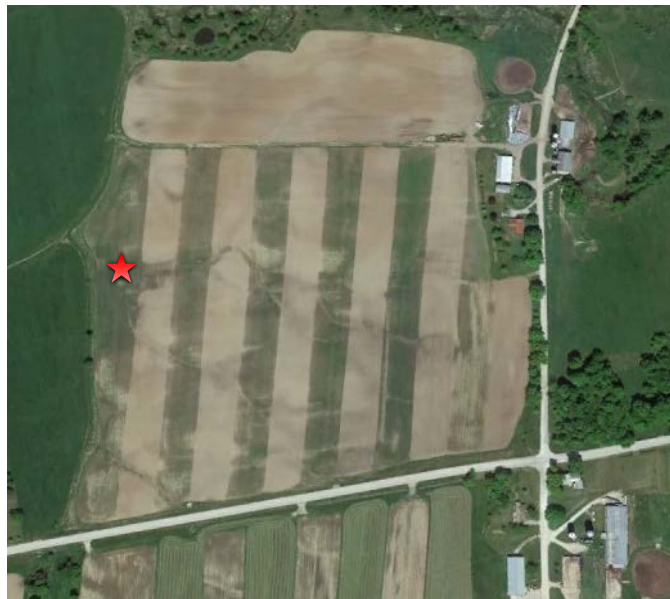


Figure A.1. Approximate location proposed for the phosphorus removal system

3.3 Monitoring duration and frequency

Weekly collection of flow-proportional composite water samples will provide constituent concentration data on events occurring during the preceding week. Weekly discharge, concentration, and loading data will be aggregated to calculate flow volume, distributions of TP and TDP concentrations, and cumulative TP and TDP loads in treatment system inflows and outflows by season and over the entire monitoring period. Field visits to collect and process composite water samples will be conducted each week when the monitored tile drain is flowing. Samples will be collected on the same day each week whenever possible.

The sampling program may be influenced by weather, agronomic considerations, and treatment efficiency. We expect the following general schedule of monitoring activities:

1. Monitoring systems installation occurred in November 2015.
2. System operation, sample collection, and sample analysis will continue from June 2015 to December 2016 with the exception of January – March 2016 when monitoring may be suspended due to freezing conditions.

In the event the phosphorus removal performance of one or both filters is judged to be poor, or becomes poor within the intended monitoring period, monitoring of the filter(s) may be discontinued.

3.4 Major pollutants of concern

The principal pollutants of concern are phosphorus (P), nitrogen (N), and suspended sediment. In addition to the potential impacts of nutrients and sediments on immediate receiving waters, P is the primary cause of eutrophication-related impairments in Lake Champlain. Sediment and nutrient losses are also of agronomic concern.

3.5 Irrigation source water quality

The cropland on the study site is not irrigated, so source water quality is not an issue.

3.6 Constituents to be monitored

Using a churn splitter, the flow-paced composite water samples will be processed into sample splits for TP and TDP analyses approximately weekly. During certain critical periods, sample splits will also be prepared for total suspended solids (TSS) and total nitrogen (TN) analyses. These critical periods will include the start-up period (November-December 2015), following manure and fertilizer applications, and following tillage, when appropriate.

3.7 Practices being monitored

The study team will design, construct, monitor, and evaluate the effectiveness of two variations of the same general practice: a phosphorus removal system to be installed near the outflow of an agricultural tile drain. The flow from a single tile line will be split within a distribution box between two concrete tanks containing different filtration media with capacity to remove dissolved P. This design allows for comparison of the efficacy of two different media. In each filter, the flow will percolate through the media and exit via underdrains. A peak flow bypass will be incorporated in the design to avoid damage to the filters or surcharging of the tile line under extreme flow conditions.

Since phosphorus removal systems have previously been shown to be very effective at low- to moderate-flow conditions (McDowell et al., 2007; Bryant et al., 2012; Penn et al., 2012), we hypothesize a P removal system with appropriate filter media will remove a significant proportion of phosphorus from the tile drainage water.

3.8 Adoption and application of monitored practice

Few data are currently available regarding typical phosphorus concentrations in agricultural tile drainage water in Vermont. USDA NRCS in Vermont and the Vermont Agency of Agriculture, Food and Markets (VAAFAM) are leading efforts to acquire these data in the near term, to characterize the extent and magnitude of tile drain P losses in the Lake Champlain Basin. This will enable managers to determine appropriate allocations of resources to the problem. If the problem is considered significant and the treatment systems developed for this project are effective, we expect there to be substantial interest in the Lake Champlain Basin in applying phosphorus removal systems to treat tile drain water. Cost share available for this practice from NRCS would incentivize its widespread implementation.

3.9 Other monitoring efforts

There are two edge-of-field runoff monitoring stations located on the farm immediately south of the study field. These stations are part of a cooperative field research program involving VAAFAM, USDA NRCS, the University of Vermont, and the Lake Champlain Basin Program. Stone Environmental, Inc. designed, constructed, and maintains the stations. The closer station (“FRA1”) is approximately 460 meters to the south. The farther station (“FRA2”) is approximately 620 meters to the south. These stations will be monitored through 2015, but are scheduled to be decommissioned in the spring of 2016. During 2015, the runoff volumes and constituent concentrations will provide a useful point of comparison to the subsurface tile drainage losses measured in this study.

SECTION 4.0 SAMPLING PROCEDURES

Monitoring and sampling methods will be consistent for the duration of the study period. Trained personnel will be responsible for satisfactory sampling operations, maintenance of monitoring stations, and processing of field data. Field personnel will be responsible for recording failures of sampling systems and taking corrective actions.

4.1 Estimated number of samples to be submitted for analysis

Table 4.1 summarizes the number and type of samples that are anticipated in this study. The numbers of samples intended for TP and TDP analysis are based on collection of one composite sample per week at each of three monitoring points (Inflow, Filter A outflow, Filter B outflow) over the 18-month monitoring period. The number of samples for TN and TSS analysis assumes collection of these splits on 12 occasions over the 18-month monitoring period. A minimum of 10% additional QC samples are included in the sample counts.

Table 4.1. Sample numbers and types to be collected

Sample Matrix	Analytical Parameters	Sample Container	Number of Samples	Sample Preservation	Hold Time (days)
Water	TP ¹	Polyethylene bottle (composite) / 60-mL glass vial (aliquot for lab)	260	None	28
Water	TDP ¹	Polyethylene bottle (composite) / 60-mL glass vial (aliquot for lab)	260	Filtered (0.45 µm) in field	28
Water	TN	Polyethylene bottle (composite) / 50-mL plastic centrifuge tube, blue cap (aliquot for lab)	40	Cool (<6°C), 0.1 mL H ₂ SO ₄	28
Water	TSS	Polyethylene bottle (composite) / 500-mL plastic bottle (aliquot for lab)	40	Cool (<6°C)	7

¹ VDEC employs an EPA-approved variant of standard methods wherein samples for phosphorus analysis are digested in the same glass storage vial in which they are collected. No acidification is necessary.

4.2 Discharge measurement

Discharge will be monitored at three points: within the Agri-drain water control structure and at the Filter A and Filter B outflows. The inflow will be monitored using a pressure transducer installed in the water control structure. Total discharge at the inflow will be the sum of inflow to Filter A, inflow to Filter B, and bypass flow over the top plate in the water control structure. Each of these flow components will be calculated using the stage data from the pressure transducer in conjunction with orifice and weir equations specific to each filter inlet and to the water control structure.

Water passing through the filter media will be flow via a system of underdrains into an open chamber in the same tank. The internal dimensions of this chamber are: 6.0 ft long, 1.5 ft wide, and 2.5 feet high. A 4-inch (10 cm) diameter Flout® manufactured by Rissy Plastics will be installed in this chamber to periodically flush water from the chamber. A downward facing ultrasonic sensor installed in the Flout® chamber of each filter will record continuous stage data. Each discharge cycle of the Flout® will be recorded as a rapid decrease in the water level in the chamber. The outflow rate from each filter will be calculated by multiplying the number of Flout® cycles in a given period of time by the average volume of each cycle.

4.3 Runoff sampling instrumentation

All water samples will be collected using ISCO 6712 autosamplers. The autosamplers will be programmed to pump sample aliquots on a flow-proportional basis, sequentially filling four 10-L polyethylene carboys. When the first carboy is filled, the autosampler will begin dispensing sample aliquots to the second carboy, and so on until either the fourth carboy is filled or the sampling program is stopped. The bulk composite samples will be split in the field using a 14-L polyethylene churn splitter to obtain aliquots for chemical analysis. Each filled or partially filled carboy will be processed into sample splits, unless it contains insufficient sample, in which case the sample may be combined in the churn splitter with the volume of the previous carboy.

Each autosampler will be connected to an ISCO 2105ci Interface Modules (a combination datalogger and modem). These modules will record the time every sample aliquot is collected and will transmit the sampling, stage, discharge, and other data to a computer server located at Stone's office in Montpelier, Vermont.

Untreated tile drainage water will be sampled via an intake line submerged within the Agri-drain water control structure. This autosampler will be paced based on accumulated flow, calculating flow rate using the water stage in the water control structure in conjunction with an orifice equation for the filter inlet. Samples withdrawn from the water control structure should be representative of the inflow to each filter and of the bypass flow through the water control structure.

The outflow from each filter will be sampled via an intake line secured within the Flout® chamber. Each discharge cycle of the Flout® will be recorded as a rapid decrease in the water level in the chamber. The 2105ci module will trigger the autosampler to pump a sample aliquot to the sample carboys every time this rapid decrease in water level is detected (that is, when the Flout® flushes the chamber). The sampling rate will depend on the rate at which the Flout® device cycles, hence collection of the filter outflow samples will be flow proportional.

12-VDC deep cycle batteries charged by solar panels will be used to power the monitoring equipment.

4.4 Automated runoff sampling protocols

Approximately weekly, field technicians will process the bulk composite sample(s) into appropriate splits for delivery to the VDEC laboratory. Sample will be poured into a 14-L polyethylene churn splitter, a device that consistently agitates the water to deliver representative subsamples from a spigot. A dedicated churn splitter will be stored at the site and will be cleaned with distilled water after each use. Subsamples will be collected from the churn splitter in containers provided by the VDEC laboratory. Sample splits for TDP analyses will be filtered in the field by dispensing sample from the churn splitter directly into a filtration apparatus containing a Durapore® 0.45 µm acetate membrane filter supplied by the laboratory. The filtrate will be dispensed directly into the appropriate sample container, identified in Table 4.1.

Following the sample retrieval process, the polyethylene sample carboys, the churn splitter, and the filtration apparatus will be triple rinsed with distilled water. The containers will be reinstalled and the station reset for the next monitoring interval.

Each step in the sample handling and custody process will be documented to ensure traceability of samples from generation to analysis. For each sampling event, a sample retrieval form (Appendix A) will document sample ID, sample type, source, and volume; completed forms will be maintained on file in the Stone Environmental office for the duration of the project. The analytes for which splits are prepared will be recorded. Samples will be transported to the laboratory within the stated holding times for each analyte.

Collected water samples will be transported on ice to the Vermont Department of Environmental Conservation Laboratory in Burlington, VT, approximately 20 km/25 min from the monitoring sites. Samples will be tracked using a Chain of Custody form (Appendix B) that will be completed by the sampler and will accompany all water quality samples delivered to the lab for analysis. The Chain of Custody form includes sample IDs, number of containers of each sample being sent to the lab, and the analyses requested. Once the water samples are accepted by the lab, they will be subject to the lab's internal tracking system.

4.5 Meteorological data

A simple meteorological station installed at a neighboring farm will be used for the continuous monitoring of rainfall and air temperature. Air temperature will be recorded as hourly and daily, minimum, maximum and average values throughout the study period. The temperature sensor will be housed in an appropriate solar radiation shield. A tipping bucket rain gage will be installed above the maximum crop canopy level. Every tip, marking accumulation of 0.01 in. (0.254 mm) of rainfall, will be recorded in memory with a time stamp. These precipitation data will enable evaluation of the amount of incipient rainfall expressed as tile drain flow.

SECTION 5.0 TESTING AND MEASUREMENT PROTOCOLS

All water samples will be analyzed by the standard methods of the VDEC Laboratory. These methods and relevant data quality objectives, assessment procedures, and reporting limits are described in the laboratory's Quality Assurance Plan, Revision 21, dated January 2013 (VDEC 2013). Methods of analysis are summarized in Table 5.1.

Table 5.1. Analytical methods

Sample Matrix	Analytical Parameter	Lab	Method
Water	TP	VT DEC	4500-P H
Water	TDP	VT DEC	4500-P H
Water	TN	VT DEC	4500-N C-modified
Water	TSS	VT DEC	2540-D
References: Standard Methods for the Examination of Water and Wastewater; 21st Ed. 2005.			

SECTION 6.0 QUALITY ASSURANCE / QUALITY CONTROL (QA/QC)

6.1 Quality objectives and criteria for measurement data

The project data-quality objective is to collect, provide, maintain, analyze, display, and document valid water quantity and quality data. The monitoring information that will be collected to support project objectives will meet the quality assurance objectives outlined in this section. Data quality will be measured in terms of accuracy and precision, completeness, representativeness, comparability, completeness, and traceability.

Table 6.1 summarizes data quality requirements associated with the sampling program and the accuracy and precision levels reported by the analytical laboratory for each parameter. The analytical laboratory for the water samples is the Vermont Department of Environmental Conservation (VDEC) Laboratory, which is currently located on the University of Vermont campus in Burlington. The VDEC laboratory is accredited by the National Environmental Laboratory Accreditation Conference Institute (TNI) for the specified water quality parameters. Meteorological monitoring will produce data to characterize ambient temperature and rainfall conditions during the study. Discharge measurement will document the rate and total quantity of drain flow over the course of the study. Analysis of flow-proportional water samples will provide mean concentrations of each monitored constituent. Mass of each monitored constituent will be computed from interval and total discharge volumes and constituent concentrations. To ensure data quality objectives are met, all sampling activities will be well-documented and will occur in accordance with the specifications presented in this QAPP.

6.1.1 Accuracy. Accuracy is defined as a measure of how close a result is to the true value. For physical/chemical parameters, accuracy is generally assessed through the analysis of spiked samples, with results expressed as percent recovery. The Vermont DEC Laboratories Quality Assurance Plan (VDEC 2013) provides acceptance criteria for spiked sample results for each analyte tested, with the exception of TSS which cannot be spiked. Calibration procedures, blank samples, and sample handling protocols provide additional information used to evaluate the accuracy of each analytical procedure.

6.1.2 Precision. Precision is defined as a measure of the reproducibility of individual measurements of the same property under a given set of conditions. Precision is generally assessed through field and laboratory duplicate analyses. In this case, duplicate analysis will be conducted on splits of field-collected composite samples (see Section 6.2). The most commonly used measure of precision is the relative percent difference (RPD). The formula for calculating the Relative Percent Difference is:

$$RPD = 100 * \text{Absolute Value}(X_1 - X_2) / ((X_1 + X_2) / 2)$$

where X_1 and X_2 are the two measurements being compared.

The method RPD is provided for the key analytical parameters in Table 6.1. Field duplicates will be prepared and delivered to the laboratory at a minimum rate of 10%.

6.1.3 Representativeness. In the context of this study, representativeness expresses the degree to which the data gathered by the project accurately and precisely represent field conditions. By continuously measuring discharge and collecting flow-proportional samples for chemical

analysis, the data gathered will accurately represent water and pollutant export under true field conditions.

Data representativeness for primary source data for this project will be accomplished through implementing standard sampling procedures and analytical methods which are appropriate for the intended data uses.

6.1.4 Comparability. Comparability expresses the confidence with which one data set can be compared to another. Comparability of the field measurements is ensured by adhering to consistent standard sampling techniques and protocols. Such consistency will be reinforced by training and supervision of field staff (see Section 2.0). Comparability of laboratory measurements is ensured through following the Vermont DEC Laboratory Quality Assurance Plan, Revision 21, dated January 2013, and the respective SOP for a given analyte.

6.1.5 Completeness. Completeness is a measure of the percentage of planned samples collected or the percentage of usable data points per measurement, with a usable result defined as one that meets criteria for accuracy, precision, and representativeness. Project specific completeness goals account for all aspects of sample handling, from collection through reporting. The minimum completeness objective for the key parameters measured in field/watershed runoff is determined to be 95 percent.

$$\% \text{ Completeness} = \# \text{ of Usable Points} / \text{Total \# of Data Points Collected} \times 100$$

A usable result is defined as a result that meets all criteria for accuracy, precision, and representativeness.

6.1.6 Traceability. Traceability is defined as the ability to trace the generation of each analytical result from sample collection through analysis and reporting. To accomplish this, all activities must be fully documented. Specific requirements will be met for documenting operation and maintenance of field instrumentation, sample tracking, analytical methodology including NIST traceable standards, record-keeping, data reduction procedures, and data presentation; these requirements are described elsewhere in this document. The data quality objective for traceability with respect to all primary data analyses for all samples is 100 percent.

6.2 Quality control requirements

All data acquired or generated will be fully documented as to original source, quality, and history.

Field quality control sampling will consist of the following:

- At least 10% of composite sample splits will be duplicated in the field by collecting a second aliquot from the churn splitter for delivery to the lab.
- No travel blanks will be collected because the parameters are not susceptible to cross contamination during shipment.

Data from field duplicates will be accepted if the RPD is less than or equal to 20%; in such cases, the mean of accepted field duplicates will be used to represent data from the sample involved. In

cases where the RPD of field duplicates exceeds 20%, the data may be deemed unusable. Sampling QC excursions are evaluated by the Project Manager. Field duplicate sample results are used to assess the entire sampling process, including environmental variability; therefore the arbitrary rejection of results based on predetermined limits is not practical. The professional judgment of the Project Manager or her designee will be relied upon in evaluating results. Rejecting sample results based on wide variability is a possibility. Notations of field duplicate excursions and blank contamination will be noted in the final report.

Table 6.1. Data quality requirements and assessments

Matrix	Parameter	Units	PQL ¹	Accuracy ²	Accuracy protocol	Precision Lab/Field ³	Precision protocol	Method Range
Water	Total P	µg/L	5 µg/L	85-115%	Spike recovery	15/20	Field duplicate	5 – 200 µg/L
Water	Total Dissolved P	µg/L	5 µg/L	85-115%	Spike recovery	15/20	Field duplicate	5 – 200 µg/L
Water	Total N	mg/L	0.1 mg/L	85-115%	Spike recovery	10/20	Lab duplicate	0.05 to 2.0 mg/L as N
Water	Total Suspended Solids	mg/L	1 mg/L	80-120%	N/A	15 ⁴ /20	Lab duplicate	1 – 2000 mg/L
Air	Temperature	°C	N/A	± 0.47°C at 25°C	N/A	N/A	N/A	-20° to 70°C
Space	Precipitation	mm	N/A	±1.0% (up to 20 mm/hr)	N/A	N/A	N/A	0 to 12.7 cm/hr

1. Practical Quantitation Limits (PQL) is the lower limit of quantitation (reporting).

2. Accuracy for analytical parameters is expressed as Percent Recovery of Sample Matrix Spike. Analyte Percent Recovery acceptance criteria are method specified limits or generated from historical laboratory data. Recoveries are matrix/sample dependent.

3. Laboratory Analytical Duplicate Relative Percent Difference (RPD) acceptance criteria/Field Duplicate RPD acceptance criteria.

6.3 Instrument/equipment calibration and frequency

Field analytical equipment that may be used in this project includes instruments for measuring water stage, rainfall, and air temperature. Calibration procedures for the equipment will follow manufacturer instructions. The tipping bucket rain gage will be calibrated annually.

Instrument and equipment calibration for water analysis will be routinely carried out by the VDEC laboratory under their EPA approved Quality Assurance Plan, Revision 21, dated January 2013.

6.4 Data acquisition requirements for non-direct measurements

Sources of supplementary data considered in this project may include weather data obtained from a local NWS cooperating station. Such data may be used to supplement on-site meteorological data during monitored events or to compare contemporary weather conditions against long-term averages or normals. These data will be accepted as valid if officially published by the NWS. Second, historical soil and manure test data from the farm’s nutrient management plan (if available) may be reviewed to help characterize site soils and agronomic management. Soil and manure samples for this purpose are typically collected by certified crop management consultants and analyses are performed through the UVM Agricultural and

Environmental Testing Laboratory. The data reported in this manner will be accepted as valid if it is contained in a nutrient management plan recognized by the AAFM. Farm records maintained by the participating farmers will be reviewed for information regarding management of the study fields. Collection of these data by the farmer meets record keeping requirements of Vermont AAFM. Additional supplemental data sources used include published topographic data and soils mapping based on the USDA-NRCS county soil surveys.

The supplementary data will not contribute directly to project decision-making, with the exception of field agronomic practices data recorded by the participating farmer.

6.5 Data summarizations

Summary data tables will be prepared for each station using the procedures described in Section 7.2. These tables will include total event discharge, accumulated precipitation, mass export, and mean concentrations of all monitored constituents. Using these summary data tables, descriptive statistics (range, mean, median, standard deviation, coefficient of variation) will be calculated by station. These summary data tables and statistical summaries will be stored electronically on Stone Environmental's servers, which are backed up daily to a Unitrends backup appliance. Once per week the most recent backup will be written to a drive which is taken to a storage vault offsite.

SECTION 7.0 DATA HANDLING PROCEDURES

7.1 Methods for data acquisition and storage

To protect PII in any publications or public discussions of project results, the study site will be identified by town name (Franklin) only, with the monitoring stations identified as “FRT2 inflow”, “Filter A outflow”, and “Filter B outflow”. Once data are reported to Vermont NRCS, they will be subject to standard measures required to protect participants’ PII.

The Stone Environmental Project Manager or her designee will be responsible for organization and oversight of data generation, disbursement, processing and storage so that the data will be documented, accessible and secure for the foreseeable time period of its use. The VDEC director has the same responsibility for the laboratory data and information s/he generates.

Standard sample retrieval forms (Appendix A) will be used to document sample location, station and field conditions, date and time of collection, and personnel responsible for collection for all samples collected in the field. A Chain of Custody form (Appendix B) will be used by the laboratories to confirm sample delivery. The VDEC laboratory will complete log-in sheets to document sample receipt and condition. Copies of all field sheets will be maintained in the project file at the offices of Stone Environmental.

Analytical data from the VDEC lab will be transmitted in electronic format to the Project Manager or her designee after all internal review has been completed.

Data from the flowmeter, autosampler, and tipping bucket rain gauge will be automatically pushed to Stone’s computer server every 30 minutes. These raw electronic data will be maintained on the server for the duration of the project and will be viewable in near real-time through a web user interface. These data will be extracted into Access databases, Excel workbooks, and R for manipulation and preparation of data summaries.

All electronic files on Stone’s servers, including raw data pushed from monitoring stations, will be backed up daily to a Unitrends backup appliance. Once per week the most recent backup will be written to a drive which is taken to a storage vault offsite. Paper and electronic files will be archived for a minimum of five years at Stone Environmental following completion of the project.

7.2 Methods of analyses

The ISCO 2105ci interface module at each station will record instantaneous discharge rates measured by the flowmeters at five minute intervals. Discharge and sample event mark data (as well as meteorological data and battery voltage) will be transmitted automatically to a computer server located at Stone Environmental’s offices in Montpelier, VT.

An Access database has been created to import and process analytical data from electronic tables transmitted by the VDEC laboratory, import and aggregate corresponding event discharge data from the SQL server, import and aggregate corresponding precipitation data, and calculate total discharge, precipitation, constituent mean concentrations, and mass export. This data processing

will be performed using a series of database queries that will accomplish the following data manipulations:

1. Analytical results of duplicate samples will be averaged
2. Analytical results will be linked to specific sampling events on a common ID (LabID)
3. The total discharge that is effectively sampled (SQ) will be calculated
4. The constituent mass corresponding to the collection period of each composite sample (concentration multiplied by associated discharge total) will be calculated
5. Where multiple composite samples are subsampled for analysis (for example, carboys B3 and B4), the partial event constituent masses from #4 will be summed to derive total export for the interval.

The data set used for the primary statistical analyses will include total event discharge (m^3), mean concentration over some time interval ($\mu\text{g/L}$), and total export (kg) for each monitored constituent for each station (inflow and two outflows). In the course of data analysis, the assumptions for the general linear model of independence, constancy of variance, and normality of distribution will be tested and appropriate transformations will be made on discharge, concentration, and mass export data to assure the validity of use of parametric statistical analysis. All statistical analyses will be done using version 3.1.3 of *R*. Basic descriptive statistics and exploratory data analysis will be conducted on this data set prior to analysis for treatment effects.

The principal hypothesis to be tested is the null hypothesis, that there will be no significant change in event discharge, pollutant concentration, or pollutant export from the phosphorus removal system.

The magnitude of treatment effect (e.g., the percent reduction of TP export due to the treatment systems) will be assessed by comparing the inflow and outflow constituent concentrations and loads at various discharge conditions and over the duration of the monitoring period.

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Sample retrieval and routine maintenance form

Collected by: _____ Date: _____

Weather: _____

	Filter A	Filter B	Inlet
Station condition	<input type="checkbox"/> OK Other _____	<input type="checkbox"/> OK Other _____	<input type="checkbox"/> OK Other _____
Stage above orifice or top plate	Read: _____ cm	Read: _____ cm	Read: _____ cm
Field/crop condition			
AUTOSAMPLER			
Sampler display	_____, _____ bottle	_____, _____ bottle	_____, _____ bottle
Comments			
SAMPLE COLLECTION			
Time you stopped the autosampler	_____ AM or PM	_____ AM or PM	_____ AM or PM
Carboy volume (L)	1: 2: 3: 4:	1: 2: 3: 4:	1: 2: 3: 4:
Sample ID assigned	Filter A – A1 – _____ (Station) - (carboy) - (mmddyy)	Filter B – B1 – _____ (Station) - (carboy) - (mmddyy)	Filter IN - IN1 – _____ (Station) - (carboy) - (mmddyy)
	Filter A – A2 – _____ (Station) - (carboy) - (mmddyy)	Filter B – B2 – _____ (Station) - (carboy) - (mmddyy)	Filter IN – IN2 – _____ (Station) - (carboy) - (mmddyy)
	Filter A – A3 – _____ (Station) - (carboy) - (mmddyy)	Filter B – B3 – _____ (Station) - (carboy) - (mmddyy)	Filter IN – IN3 – _____ (Station) - (carboy) - (mmddyy)
	Filter A – A4 – _____ (Station) - (carboy) - (mmddyy)	Filter B – B4 – _____ (Station) - (carboy) - (mmddyy)	Filter IN – IN4 – _____ (Station) - (carboy) - (mmddyy)
Splits collected (circle)	TP TDP TN TSS	TP TDP TN TSS	TP TDP TN TSS
Duplicates collected?	TP TDP TN TSS	TP TDP TN TSS	TP TDP TN TSS
Carboy _____	Carboy _____	Carboy _____	Carboy _____
TN splits acidified?	Yes No	Yes No	Yes No

Sample retrieval/Post-event maintenance by sampler form – PAGE 2

RESETTING STATIONS									
STOP then Re-RUN SAMPLING PROGRAM	<input type="checkbox"/> Sampler ACTIVE, DISABLED			<input type="checkbox"/> Sampler ACTIVE, DISABLED			<input type="checkbox"/> Sampler ACTIVE, DISABLED		
Carboys and churn splitter triple rinsed?	Yes	No	NA	Yes	No	NA	Yes	No	NA
Desiccant good?	Yes	Changed		Yes	Changed		Yes	Changed	
Carboys installed properly?	Yes	No		Yes	No		Yes	No	
Additional comments:									

v. 1

Chain of Custody Form for Water Samples

Stone Project ID: 14-084
Lab Program #: 137-60

Stone Contact: Dave Braun, 802-272-8819, dbraun@stone-env.com

Collection Date	Sample ID	Total # of Containers	Analyses Requested (circle those collected)
			TP TN TSS TDP
			TP TN TSS TDP
			TP TN TSS TDP
			TP TN TSS TDP
			TP TN TSS TDP
			TP TN TSS TDP
			TP TN TSS TDP
			TP TN TSS TDP
			TP TN TSS TDP
			TP TN TSS TDP
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			TP TN TSS TDP
			TP TN TSS TDP
			TP TN TSS TDP
			TP TN TSS TDP

Sampled by: _____
 print name signature

Appendix B: Testing Arsenic Contribution of Saturated Water Treatment Residuals

Testing Arsenic Contribution of Saturated Water Treatment Residuals

August 12, 2015

Prepared for:	Prepared by:
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Table of Contents

1.	INTRODUCTION.....	4
2.	METHODS.....	4
	2.1 Experimental set up.....	4
	2.2 Sampling procedure.....	6
	2.3 Water analysis methods	7
3.	RESULTS	7
4.	CONCLUSIONS.....	8
5.	REFERENCES.....	8
	APPENDIX A : ANALYTICAL REPORT	9

List of Tables

Table 1. Volumes of WTR and drainage water added	6
Table 2. Rationale for selected residence times	6
Table 3. Total dissolved arsenic and phosphorus concentrations in saturated WTR	7
Table 4. Average total dissolved arsenic concentrations among test buckets	8

1. INTRODUCTION

Drinking water treatment residuals (DWTR) produced by the Champlain Water District (CWD) appear to be an effective media for use in filtration systems to remove dissolved phosphorus from water. DWTRs - also properly termed “backwash residuals” – are the materials that are coagulated and then filtered from the raw source water which, in the case of CWD, is drawn from Lake Champlain. The CWD uses alum as the coagulant. The filters are periodically backwashed and the residuals (e.g., flocs of coagulated material from the raw water) are sent to a holding basin for settling. Each summer/fall the settled backwash residuals are pumped into a sand-bottom drying bed, where they are allowed to freeze over the winter and then thaw in the spring; this breaks the bonds of hydration and allows the particulate materials to separate from the clear water which drains away through the sand, resulting in a residual that is more than 90% solids. These residuals contain a high concentration of aluminum and iron.

The Friends of Northern Lake Champlain (FNLC) and Stone Environmental are currently designing a packed bed media filter containing CWD’s water treatment residuals to remove phosphorus from agricultural tile drainage water prior to discharge. The filter will be constructed on a commercial dairy farm in Franklin, Vermont. The Vermont Department of Environmental Conservation (DEC) has raised a concern regarding potential for the treatment process to mobilize arsenic from the DWTR, allowing it to be released into the environment. The arsenic present in CWD’s water treatment residuals is the result of naturally occurring concentrations in the waters of Lake Champlain. DEC recently issued Stone an Insignificant Waste Management Event Approval (IWMEA) for use of water treatment residuals in a tile drainage water filter; a condition of this permit is successful benchtop testing to evaluate any change in the concentration of arsenic in the tile drainage water resulting from contact with the water treatment residuals.

The objective of this testing was to assess arsenic contributions from DWTR under conditions representative of those expected in the proposed treatment system. A variable of particular interest is residence time of drainage water within the filter bed of water treatment residuals. Residence time is a function of filter design and the flow rate through the filter, which we expect to vary between zero (dry) and approximately 1.25 liters per second (after splitting the tile drain flow between two filters and providing bypass for the highest flows). Four representative residence times were simulated to cover the range of expected flows.

This brief report provides the methods and results of the requested testing.

2. METHODS

2.1 Experimental set up

Three 5-gallon buckets filled with DWTR were prepared. Each bucket was equipped with a 1-inch (2.54 cm) diameter PVC tube in the center to serve as a sampling well, allowing samples to be retrieved while limiting disturbance of the water treatment residuals. The bottom 15 cm of the tube was perforated

with a series of 0.25-inch (0.64 cm) diameter holes and wrapped in filter fabric to allow water to enter from the saturated treatment residuals (Figure 1).



Figure 1. Perforated sample collected tube installed in each bucket



Figure 2. Bucket with saturated WTR and sampling apparatus

Each bucket was filled with DWTR to within 5 cm of the rim. 7.5 L of tile drainage water was added to each bucket to saturate the DWTR and raise the level to a depth of 1-2 cm over the surface of the DWTR. A fourth bucket without DWTR was filled with 7.5 L of tile drainage water to serve as the control. The source of the tile drainage water added to all four buckets was the tile drain (“FRT2”) in Franklin we intend to treat as part of this pilot project. Bulk water samples were collected at the outlet on July 8, 2015 and refrigerated prior to use.

Table 1. Volumes of DWTR and drainage water added

Bucket	Volume of DWTR (L)	Drainage water (L)
1	18.2	7.5
2	17.9	7.5
3	18.7	7.5
4 (control)	0	7.5

Because the filter will be vented, the buckets were not covered. The buckets were stored at room temperature.

2.2 Sampling procedure

Samples were prepared by drawing water from the sampling well in each bucket using a peristaltic pump and silicone tubing (Figure 2). The sampling well was purged prior to sampling by drawing water from the well and discharging it to the surface of the residuals, cycling the water through the residuals for one minute. The amount of water purged in one minute slightly exceeds the volume of the sampling well. A 0.45- μm cartridge filter (Geotech dispos-a-filter™) was then affixed to the discharge end of the tubing and sample was run through the filter for one minute to flush it before sample was dispensed into clean, 250-mL HDPE bottles.

Drainage water was added to the buckets at approximately 17:00 on July 15, 2015. The sampling procedure was performed at 1 hour, 3.5 hours, 15, and 30 hours after filling the buckets. The rationale for these sampling times is based on our preliminary design and expected flow rates and is described in Table 2.

Table 2. Rationale for selected residence times

Sampling time (hour)	Rationale
1.0	Represents expected residence time at flow rate of 0.36 liters per second, which is typical of high flow events. Flow monitoring data from November 2014 indicates that 47 percent of the total volume from the tile drain discharged at a rate greater than 0.36 L/s. At the peak filter design flow (~1.25 L/s), the minimum residence time will be approximately 17 minutes
3.5	Represents residence time when the filter is operating at a flow rate typical of fall/spring low flows (~0.1 L/s), representing the “tail” of an event which often extends for several days after rain events.
15	A sampling time intermediate between 3.5 hours and 30 hours. At this residence time, there will be a trickle of flow from the tile drain and the flow rate from the filter will be divided almost equally between the siphoning outlet pipe and the small diameter tube draining the filter.
30	Represents the longest expected residence time in the filter. This residence time will be achieved only after the tile drain stops flowing and only a small diameter tube draining the filter is flowing.

2.3 Water analysis methods

The Vermont State Agricultural and Environmental Laboratory performed the total dissolved arsenic analysis of samples submitted by Stone. Samples were acidified with concentrated nitric acid upon receipt by the laboratory. Samples were prepared according to method SW 6020A and were analyzed by ICP.

3. RESULTS

Concentrations of total dissolved arsenic in the drainage water control (Bucket 4) were below the limit of quantitation (1.0 µg/L) throughout the experiment (Table 3). The DWTR contributed small amounts of arsenic to the drainage water, resulting in total dissolved arsenic concentrations ranging between 1.78 and 2.59 µg/L. The average concentrations among the test buckets in each treatment duration category (1 h, 3.5 h, 15 h, and 30 h) ranged from 2.13 µg/L to 2.27 µg/L (Table 4). Between the first sampling at 1 hour and the last sampling at 30 hours, there was very little change in the arsenic concentration.

Table 3. Total dissolved arsenic and phosphorus concentrations in saturated WTR

Bucket	Treatment duration (hours)	Total dissolved arsenic (µg/L)	Total dissolved phosphorus (µg/L)
1	1	2.51	-
2	1	2.14	-
3	1	1.90	113
4	1	<1	114
1	3.5	2.40	-
2	3.5	2.31	-
3	3.5	1.89	82
4	3.5	<1	-
1	15	2.30	-
2	15	2.32	-
3	15	1.78	83
4	15	<1	-
1	30	2.36	-
2	30	2.59	-
3	30	1.86	86
4	30	<1	111

Table 4. Average total dissolved arsenic concentrations among test buckets

Treatment duration (hours)	Total dissolved arsenic (µg/L)
1	2.18
3.5	2.20
15	2.13
30	2.27
Mean	2.20

4. CONCLUSIONS

Under saturated test conditions, a small amount of arsenic was released from CWD’s drinking water treatment residuals. The total dissolved arsenic concentration of drainage water used to saturate the DWTR increased from <1 µg/L to approximately 2.2 µg/L. This increase occurred within the first hour of the test and longer periods of saturation (up to 30 hours) did not further increase total dissolved arsenic concentrations in solution. The maximum observed concentration of total dissolved arsenic was 2.59 µg/L, substantially below the maximum contaminant level in Vermont’s Water Supply Rule of 10 µg/L (VT ANR 2010). Therefore, this experiment demonstrated that DWTR can be used safely in filter systems designed to remove dissolved phosphorus from drainage water.

5. REFERENCES

VT ANR. 2010. Environmental Protection Rules, Chapter 21, Water Supply Rule. Revised December 1, 2010.

APPENDIX A: ANALYTICAL REPORT



Analytical Report

Order ID 150832
Customer Name 193 FNLC CIG Tile Drain Study
 Project ID 1
 Date/Time Recv'd 7/16/2015

Matrix	Sample ID	Cust. Samp ID
Water	150832-01	Bucket1-1h
	150832-02	Bucket2-1h
	150832-03	Bucket3-1h
	150832-04	Bucket4-1H
	150832-05	Bucket1-3.5h
	150832-06	Bucket2-3.5h
	150832-07	Bucket3-3.5h
	150832-08	Bucket4-3.5h
	150832-09	Bucket1-15h
	150832-10	Bucket2-15h
	150832-11	Bucket2-15h-D
	150832-12	Bucket3-15h
	150832-13	Bucket4-15h
	150832-14	Equipment Blank
	150832-15	Bucket1-30h
	150832-16	Bucket2-30h
	150832-17	Bucket3-30h
	150832-18	Bucket4-30h

Sample ID 150832-01
Cust. Samp ID Bucket1-1h
Date Collected 7/15/2016
Site
Matrix Water
Collector

Test Method

Param	CAS	Status	Desc.	Num. Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
Metals, All-Dissolved SW 6020A									
Arsenic - Dissolve	440-38-2	Approved		2.507	2.51	ug/l	1		1

Sample ID 150832-02
Cust. Samp ID Bucket2-1h
Date Collected 7/15/2016
Site
Matrix Water
Collector

Test Method

Param	CAS	Status	Desc.	Num. Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
Metals, All-Dissolved SW 6020A									
Arsenic - Dissolve	440-38-2	Approved		2.144	2.14	ug/l	1		1

Sample ID 150832-03 **Site**
Cust. Samp ID Bucket3-1h **Matrix** Water
Date Collected 7/15/2016 **Collector**

Test Method

Param	CAS	Status	Desc.	Num. Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
Metals, All-Dissolved SW 6020A									
Arsenic - Dissolve	7440-38-2	Approved		1.903	1.9	ug/l	1		1
Phosphorus - Filtered/Digested SM 4500-P H									
Phosphorus		Approved		113	113	ug P/L	5		

Sample ID 150832-04 **Site**
Cust. Samp ID Bucket4-1H **Matrix** Water
Date Collected 7/15/2016 **Collector**

Test Method

Param	CAS	Status	Desc.	Num. Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
Metals, All-Dissolved SW 6020A									
Arsenic - Dissolve	7440-38-2	Approved		0.286	<1	ug/l	1		1
Phosphorus - Filtered/Digested SM 4500-P H									
Phosphorus		Approved		114	114	ug P/L	5		

Sample ID 150832-05 **Site**
Cust. Samp ID Bucket1-3.5h **Matrix** Water
Date Collected 7/15/2016 **Collector**

Test Method

Param	CAS	Status	Desc.	Num. Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
Metals, All-Dissolved SW 6020A									
Arsenic - Dissolve	7440-38-2	Approved		2.396	2.4	ug/l	1		1

Sample ID 150832-06 **Site**
Cust. Samp ID Bucket2-3.5h **Matrix** Water
Date Collected 7/15/2016 **Collector**

Test Method

Param	CAS	Status	Desc.	Num. Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
Metals, All-Dissolved SW 6020A									
Arsenic - Dissolve	7440-38-2	Approved		2.307	2.31	ug/l	1		1

Sample ID 150832-07 **Site**

Cust. Samp ID Bucket3-3.5h Matrix Water
Date Collected 7/15/2016 Collector

Test Method

Param	CAS	Status	Desc.	Num. Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
Metals, All-Dissolved SW 6020A									
Arsenic - Dissolve	440-38-2	Approved		1.892	1.89	ug/l	1		1
Phosphorus - Filtered/Digested SM 4500-P H									
Phosphorus		Approved		81.9	82	ug P/L	5		

Sample ID 150832-08 Site
Cust. Samp ID Bucket4-3.5h Matrix Water
Date Collected 7/15/2016 Collector

Test Method

Param	CAS	Status	Desc.	Num. Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
Metals, All-Dissolved SW 6020A									
Arsenic - Dissolve	440-38-2	Approved		0.267	<1	ug/l	1		1

Sample ID 150832-09 Site
Cust. Samp ID Bucket1-15h Matrix Water
Date Collected 7/16/2016 Collector

Test Method

Param	CAS	Status	Desc.	Num. Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
Metals, All-Dissolved SW 6020A									
Arsenic - Dissolve	440-38-2	Approved		2.3	2.3	ug/l	1		1

Sample ID 150832-10 Site
Cust. Samp ID Bucket2-15h Matrix Water
Date Collected 7/16/2015 Collector

Test Method

Param	CAS	Status	Desc.	Num. Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
Metals, All-Dissolved SW 6020A									
Arsenic - Dissolve	440-38-2	Approved		2.267	2.27	ug/l	1		1

Sample ID 150832-11 Site
Cust. Samp ID Bucket2-15h-D Matrix Water
Date Collected 7/16/2015 Collector

Test Method

Param	CAS	Status	Desc.	Num. Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
Metals, All-Dissolved SW 6020A									

Arsenic - Dissolved 440-38-2 Approved 2.376 2.38 ug/l 1 1

Sample ID 150832-12 **Site**
Cust. Samp ID Bucket3-15h **Matrix** Water
Date Collected 7/16/2015 **Collector**

Test Method

Param	CAS	Status	Desc.	Num.	Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
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Metals, All-Dissolved SW 6020A

Arsenic - Dissolved	440-38-2	Approved		1.775	1.78	ug/l		1		1
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Phosphorus - Filtered/Digested SM 4500-P H

Phosphorus		Approved		82.7	83	ug P/L		5		
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Sample ID 150832-13 **Site**
Cust. Samp ID Bucket4-15h **Matrix** Water
Date Collected 7/16/2015 **Collector**

Test Method

Param	CAS	Status	Desc.	Num.	Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
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Metals, All-Dissolved SW 6020A

Arsenic - Dissolved	440-38-2	Approved		0.297	<1	ug/l		1		1
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Sample ID 150832-14 **Site**
Cust. Samp ID Equipment Blank **Matrix** Water
Date Collected 7/15/2016 **Collector**

Test Method

Param	CAS	Status	Desc.	Num.	Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
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Metals, All-Dissolved SW 6020A

Arsenic - Dissolved	440-38-2	Approved		0.015	<1	ug/l		1		1
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Sample ID 150832-15 **Site**
Cust. Samp ID Bucket1-30h **Matrix** Water
Date Collected 7/16/2015 **Collector**

Test Method

Param	CAS	Status	Desc.	Num.	Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
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Metals, All-Dissolved SW 6020A

Arsenic - Dissolved	440-38-2	Approved		2.361	2.36	ug/l		1		1
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Sample ID 150832-16 **Site**
Cust. Samp ID Bucket2-30h **Matrix** Water

Date Collected 7/16/2015 Collector

Test Method

Param	CAS	Status	Desc.Num.	Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
Metals, All-Dissolved SW 6020A									
Arsenic - Dissolve	440-38-2	Approved	2.588	2.59	ug/l		1	1	

Sample ID 150832-17 Site
 Cust. Samp ID Bucket3-30h Matrix Water
 Date Collected 7/16/2015 Collector

Test Method

Param	CAS	Status	Desc.Num.	Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
Metals, All-Dissolved SW 6020A									
Arsenic - Dissolve	440-38-2	Approved	1.859	1.86	ug/l		1	1	
Phosphorus - Filtered/Digested SM 4500-P H									
Phosphorus		Approved	86.2	86	ug P/L		5		

Sample ID 150832-18 Site
 Cust. Samp ID Bucket4-30h Matrix Water
 Date Collected 7/16/2015 Collector

Test Method

Param	CAS	Status	Desc.Num.	Result	Result	ReportingUnits	Rep. Limit	LowerLimit	Upper Limit
Metals, All-Dissolved SW 6020A									
Arsenic - Dissolve	440-38-2	Approved	0.274	<1	ug/l		1	1	
Phosphorus - Filtered/Digested SM 4500-P H									
Phosphorus		Approved	111	111	ug P/L		5		

Report Key:

- Sample Data Style applied to the parameter if the Result falls outside of the Parameter Limit, and if the Result has been Approved.
- Sample Data Style applied to the parameter if the Result falls outside of the Parameter Limit, and if the Result has **not** been Approved.
- MDL** (Method Detection Limit) Defined as the minimum concentration of a substance that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero and is determined from analysis of a sample in a given matrix containing the analyte.
- PQL** (Practical Quantification Limit) The lowest level that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions.
- MCL** (Maximum Concentration Limit) The regulatory limit for various constituents, usually organics and inorganics; there are different levels for different media, such as air, soil, and water. The MCL cannot be exceeded
- CAS** Acronym for Chemical Abstract Services. The CAS number is a means by which chemists categorize chemicals. Each chemical has a unique CAS number by which may be used to look up chemicals and their properties.
- ND** Not Detected. Laboratory analysis indicates that the substance is not present.