PATRICK LEAHY
Lake Champlain
Basin Program

TECHNICAL REPORT NO. 109

Tile Drain Base-flow Phosphorus Removal Using St. George Black

June 2025

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For:
The Lake Champlain Basin Program and NEIWPCC

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TILE DRAIN BASE-FLOW PHOSPHORUS REMOVAL USING ST. GEORGE BLACK

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1. EXECUTIVE SUMMARY

Tile drain effluent is a fairly new research topic, but potentially significant source of phosphorus (P) loading into Lake Champlain. End-of-tile treatments require specific approaches based on the changing flow conditions in a particular setting. The Vermont Tile Drain Advisory Group deemed “treatment technologies” as an effective tile drain intervention in combination with broader education and management strategies. While it is understood that particulate P export is highest during high tile flows, P export in baseflow conditions is equally important to consider for treatment.

Watershed Consulting, with support from Friends of Northern Lake Champlain and the University of Vermont College of Agriculture and UVM Extension conducted a three-year long experiment (August 2018-November 2021) evaluating the performance of an adsorptive filter material as a tile drain treatment technology. The primary objective of this study was to evaluate the efficacy of a locally sourced shale material, St. George Black (SGB), as an adsorptive phosphorus filter exclusively in low-flow conditions on tiled agricultural fields. The study took place in St. Albans, VT on private agricultural land with permission from the landowner. The treatment site was located on tile-drained fields in the Jewett Brook-St. Albans Bay watershed.

In October 2018, a Quality Assurance Project Plan (QAPP) was developed to establish quality assurance procedures that upheld project performance. This document was approved on November 20th, 2018. A model filter unit was sized based on flow and water quality conditions at the site. This also helped determine media coarseness that would provide the appropriate hydraulic conductivity within the filter. Existing site conditions were evaluated, and filter design drawings were created. The filter was constructed according to the design specifications and installed at the site along with monitoring equipment at inlet and outlet locations. From May to September 2019, it was anticipated that twelve sets of water quality samples would be collected and tested from the influent and effluent of the filter unit. However, due to lack of baseflow and equipment malfunctions, this task was not accomplished and was extended for an additional year. Samples were successfully collected between May and November 2020. Research was extended an additional year with sampling occurring between June and November of 2021.

Eighteen sets of samples were processed by the Vermont Agriculture and Environmental Lab. Data demonstrates overall reductions in total phosphorus (TP; 46.3%), total dissolved phosphorus (TDP; 50.1%), and soluble reactive phosphorus concentrations (SRP; 57.1%) for both monitoring years combined. A two-tailed, paired t-test was performed on each dataset to determine if there was a statistically significant difference between the influent and effluent’s phosphorus concentrations.

Quarterly reports were submitted from October 2018 to October 2021 to elaborate on task progress, issues encountered, and corrective actions to improve project performance.

The consistency in phosphorus reductions over the two six-month sampling periods indicates that SGB filter configuration is an effective end-of-tile treatment technology in baseflow conditions and can contribute to larger integrated nutrient management plans in tiled, agricultural settings.

2. CONTENTS

3. PROJECT SYNOPSIS

Agronomic benefits of tile drains are clear and are evidenced by the increasing rate of installation in the Lake Champlain Basin (i.e., greater yield potential, increased trafficability, lower compaction potential, extended growing season). However, tile drainage can facilitate nutrient transport to surface waters in some settings (Skaggs, Breve, & Gilliam, 1994; Tebbetts & Moore, 2017). Tile drainage increases hydrologic connectivity of landscapes and alters hydrologic flow pathways within watersheds, providing rapid transport of subsurface water over longer distances compared to surface water runoff, increasing dispersal of nutrient loads (Schilling and Helmers, 2008). Loss of phosphorus (P) through tile drainage fluxes has historically received less attention than nitrogen loss since most P loss is thought to primarily be from surface runoff and erosion pathways (Sims, Simard, & Joern, 1998). However, recent research suggests that P can also be transported in tile drainage discharge, particularly where soil preferential flow pathways exist in combination with a labile P source (i.e., manure or excessive soil test P). Recent studies in the Midwest US have shown that a substantial proportion of total P loss from fields can be due to P lost in tile drainage discharge (King et al., 2015). King et al. (2015b) monitored eight tile outlets in central Ohio over an eight-year period, and nearly half of the dissolved P and 40% of the total P load measured at the watershed outlet was attributed to runoff delivered by tile drains. More locally, a very recent study in the Jewett Brook catchment of the St. Albans Bay watershed in Vermont recorded elevated P concentrations in event and non-event tile flow (Braun, 2017a). As a result, Watershed Consulting has chosen to focus our research efforts in this area.

Conservation management options will play a role in managing both surface and subsurface runoff from agricultural operations. But end-of-tile treatments are simultaneously important elements to create a holistic strategy for controlling deleterious effects of tile drain effluent. The Vermont Tile Drain Advisory Group (TDAG) recommended “treatment technologies” as the highest ranked based on feasibility, preference, and impact after a suite of education and management interventions.

A number of tile drainage interventions of have been tested around the country. The Watershed Consulting team has focused its tile drainage research efforts on high flows (i.e., ‘smart valves’ for closing outlets during storm events), in an effort to control P export during times when particulate loads are expected to be highest due to cracking soils and preferential flow. However, the data from the Jewett Brook indicate that base flows deserve equal attention, especially in the St. Albans Bay watershed, where this study site was located. An end-of-tile filter project released in November 2017 (Braun, 2017b) confirms the challenge in addressing both high and low flows with the same approach. During high flows, liberated particulate matter readily clogs filter units and the volume overwhelms the capacity of a flow-through system that relies on contact time for adsorptive removal mechanism activation. Premature clogging during high flows ultimately prevents performance during low flows due to reduced hydraulic conductivity.

Many approaches to tile best management practices (BMPs) (i.e., end-of-pipe treatment) have been stymied by high flows, but it was hypothesized that an in-ditch treatment approach for base flows, paired with storm-event valving, will address both types of P export. **This project demonstrated proof of concept of the in-ditch treatment approach as an effective BMP for P in base flow; with further potential to then pair it with an event-valving mechanism as an effective treatment system that spans the range of tile flow rates.**

FILTER MATERIAL SPECIFICATIONS AND HOUSING

Dr. Don Ross, a team member on this project, has been investigating adsorptive filter materials for P removal on the lab scale at the University of Vermont (UVM) for well over a decade. His lab has focused testing on materials ranging from biochar and eggshells to drinking water treatment residuals and bauxite. Working with Stone Environmental and the Friends of Northern Lake Champlain, students in Dr. Ross' service-learning classes tested and recommended the limestone and drinking water treatment residuals used in the end-of-tile system described by Braun (2017b). Recently, Dr. Ross' lab results demonstrated removal of soluble reactive phosphorus using a locally mined shale called "St. George Black" at a rate much greater than other media identified as super adsorbents – including drinking water treatment residuals. In testing to date, this shale has consistently produced the lowest effluent concentrations of soluble phosphorus from both synthetic and natural P-containing solutions.

St. George Black (SGB) is a shale material consisting chiefly of silicon dioxide as well as aluminum, calcium, and iron oxides. The oxide materials in the SGB are well known as chemical adsorbers of phosphate – the positive surface charge on the SGB material is attracted to the negatively charged phosphate anion. SGB is a natural stone product that is locally sourced and can be ground to achieve the hydraulic conductivity specified by the project site base flow conditions and necessary contact time based on concentration (a calculation was determined in the lab prior to field installation.)

The filter unit that contained the St. George Black for this field trial was a low profile, in-ditch, flow-through unit - as recommended by the 2017 report on end-of-tile phosphorus removal system (Braun, 2017b). The filter unit was specifically designed to accept influent only during low flow events via an overhang above the inlet that prohibited entrance in high energy flows while low flow (base flows) entered via surface tension. This design eliminated clogging risk by prohibiting turbid, high-energy flow from entering the unit (another noted recommendation of the recently released end of tile report from the Lake Champlain Basin Program, Braun (2017b)).

CHEMICAL ANALYSIS

Total and dissolved phosphorus (TP and TDP) as well as soluble reactive phosphorus (SRP) species were measured at the study site. The difference between TP and TDP establishes the fraction of P in particulate form versus dissolved form and informs water quality. For instance, if there were high concentrations of particulate P during base flows, a direct connection from the surface of the field to the tile was investigated. The project team found it important to further differentiate between TDP and SRP. SRP is the inorganic portion of the soluble fraction of phosphorus in the tile, the rest is in an organic and less biologically available form. The Watershed Consulting team expected that in a fertilized farm field, the bulk of TDP exiting the tiles would be in SRP form. Further, SRP is the form of P most suitable for removal in adsorptive media filters like the one evaluated here and in other studies. Confirming the portion of P in tile drain flow that is SRP is important for determining end-of-tile treatment mechanisms most likely to be impactful on total loading.

STUDY SITE

Project partners Kent Henderson (Chairman of the Board of the Friends of Northern Lake Champlain) and Joshua Faulkner (UVM Extension Professor) met with a farmer and landowner with tile drained fields in the Jewett Brook/ St. Albans Bay watershed who was open to serving as a study site for this investigation. The configuration of new, 6-inch, corrugated HDPE tiles, that outlet to a central ditch and culvert provided a convenient location for flow measurement with monitoring devices.

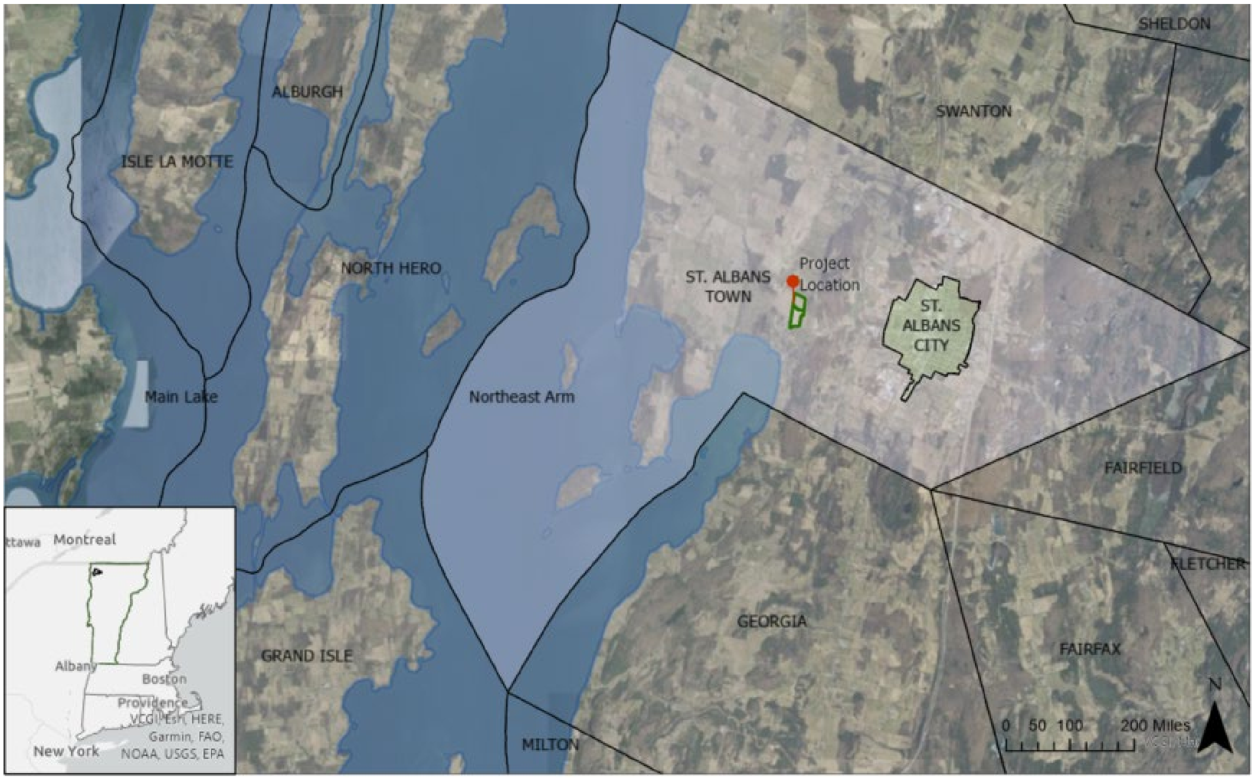

Figure 1. Overview map of the project location, marked with a red pin. The tiled fields that flow into this system are outlined in green.

FILTER DESIGN

The filter unit was designed adjacent to the ditch flowing between two tile-drained fields, collecting effluent from the tile using a solar powered pump. This filtered the water through the chambers filled with filter media and discharged back into the ditch. The pump was activated following storm flow within 24 hours to allow only low (base) flows to enter a closed chamber filled with SGB material. Filter sizing was determined by measured base flow rate at the field site. Material coarseness (grind) was specified to allow contact time necessary for SRP adsorption (optimal contact time determined by lab column studies in Dr. Ross' lab). Filter box material and joints were watertight to avoid short circuiting.

4. TASKS COMPLETED

TASK 1 – DEVELOP QAPP

The Quality Assurance Project Plan (QAPP) was developed in close communication with the LCBP project officer as well as field and lab staff. Details of sampling, transport, and analysis techniques were developed to maximize data quality. Field safety procedures were also detailed in the QAPP. Standard procedures for equipment and sampling containers were developed by Watershed Consulting staff with reference to scientifically robust standards. Watershed Consulting staff developed and maintained standard recording sheets to facilitate consistent record keeping by all partners. Digital data management ensured efficient and secure access to collaborators throughout the data collection period.

TASK 2 – MODEL FILTER PERFORMANCE AND SIZE UNIT

Flow monitoring equipment was installed in the field ditch to determine tile flow rates in base flow conditions over a two-week range in the Spring of 2018. Using a low-profile weir placed in the culvert separating the two fields and a level/flow meter, flow was monitored continuously with attention on non-storm event flows. This information informed parameters for filter sizing. At all times when the research team was on site, boots and waders were cleaned and rinsed with tap water before and after visitation. Findings from a column study in Drs. Ross and Faulkner's UVM classes provided data on the hydrologic conductivity and removal rates with the material. (Work performed by UVM faculty was funded by sources other than LCBP). Watershed Consulting team members accounted for the field conditions and column study results in the HydroCAD model to appropriately size the filters.

TASK 3 – CREATE DESIGN DETAILS

The Watershed Consulting field team determined contours of the field and ditch, including tile drain elevations to facilitate filter placement for flow capture and control. The project team combined filter sizing and field conditions to create a design detail of the filter housing and its effective placement in the ditch. The project team coordinated with a project advisory committee made up of interested members of the LCBP TAC to complete a final design that includes their experienced suggestions. Watershed Consulting met with the committee once to review project design before installation and once at the completion of the first year of data collection to review preliminary results prior to a second field season. Construction details and materials were specified in addition to the low flow capture mechanism that prohibited high flow events from entering the media. The filter unit was modified to incorporate sampling ports for collection of influent and effluent within the filter box, but outside of the filter media. This prevented potential contamination in the ditch itself as well as provided a more accurate flow measure of the water that entered the filter and did not bypass. The site survey results illustrated exceedingly flat conditions with insufficient head to force water through a media filter located within the ditch (as originally envisioned). However, installation of a low flow solar pump could lift water at a steady rate into an up-flow media filter to allow for field trialing of the media.

TASK 4 – BUILD AND INSTALL TREATMENT UNIT AND MONITORING EQUIPMENT

The filter box unit, and integrated sampling ports to facilitate influent and effluent sampling were built following the design specifications. SGB filter material was ordered at a specified coarseness and tested for hydraulic conductivity to meet design expectations. The project team coordinated with the landowner to establish timing for installation of the unit on site with use of farm equipment to properly bed the filter units. As with previous field components, disinfection procedures were followed to reduce spread of invasive species.

ISCO automated sampling devices were installed for sampling flow into and out of the filter bed upon programmed initiation. Watershed Consulting technical staff programmed the ISCO units for a time-based composite sampling regime and trained Friends of Northern Lake Champlain staff on programming protocols and troubleshooting as well as sample collection, unit cleaning, and set up between rain events.

TASK 5 – MEASURE P REMOVAL EFFICIENCY OF FILTER IN LOW FLOW CONDITIONS (YEAR 1)

The field team completed 12 composite sampling events, each taken over a 24-hour period in base flow conditions, between May and November 2020. This timeframe represented a range of base flow conditions. The sampling events were coordinated to avoid storm event flows as these events bypassed the filter unit to follow design specifications. The composited samples were collected from the unit within 12 hours and stored on ice for immediate transport to the lab for processing.

The Vermont Agricultural and Environmental Laboratory (VAEL) analyzed all samples for TP, TDP, and SRP. This portion of the project was funded by VTAAFM. For all sampling events, chain of custody paperwork was documented for all samples and signed by lab staff to indicate date and time of receipt. TDP and SRP samples were field filtered. SRP samples were analyzed within their 2-day hold time (12 hours of receipt using molybdenum blue complex and a flow-injection colorimeter). TP and TDP samples were analyzed within a week with TDP samples filtered before storage on ice. These samples underwent persulfate digestion.

Task 6 – Filter Performance Analysis (Year 1)

Influent and treated effluent were compared for their TP, TDP, and SRP concentrations. Seasonal conditions were considered when deciding when to sample the units as they can influence the influent quality and filter performance. Filter performance was graphed and statistically analyzed to determine the role of St. George Black filter material on phosphorus removal in base flow conditions.

Task 7 – Quarterly Reporting

The project team consolidated data for progress update reports to LCBP grant managers on a quarterly basis. Reports were submitted electronically via email and reports were formatted using an LCBP-formatted quarterly report template. Any design details, graph generation, photographs, and data collected in the reporting period were specified in the progress reporting documents. Data was recorded in MS Excel spreadsheet format and provided digitally. Any unexpected problems and corrective actions were detailed in the reports.

Task 8 - Interim Report

An interim report was completed at the end of the 2020 sampling season, summarizing the tasks completed to date including analysis of the year 1 results. Recommendations were made for the second year of sampling to further investigate the longevity of the SGB performance.

Task 9 - Measure P removal efficiency of filter (year 2)

Watershed Consulting staff attempted 13 sampling events to collect the necessary samples for this year. Six complete datasets were achieved. Sampling began in May and was completed in November. The tile ceased to run for several months as a historically dry season and unexpectedly low water tables plagued the region. Growing crops and drought conditions made the tile-drain and ditch very dry, preventing the sampling equipment from detecting sufficient flow to sample from. In the Fall, sufficient baseflow was present, and two more sampling events were completed later in the season after the corn crop was harvested.

Task 10 – Filter performance analysis (year 2)

Influent and treated effluent were compared for their TP, TDP, and SRP concentrations. Filter performance was graphed and statistically analyzed to determine the role of St. George Black filter material on phosphorus removal in base flow conditions.

5. METHODOLOGY

BUILD AND INSTALL TREATMENT UNIT AND MONITORING EQUIPMENT

From April 1 to June 30, 2019, filter housing units were identified, purchased, delivered, thoroughly cleaned, and installed in the field. The filter housing units were originally food-grade bulk transport totes that once carried vinegar and soy sauce before being recycled for this project. ISCO sampler units, solar panel and battery, pump, level logger and all hosing were implemented on site. Two cubic yards of SGB material were ground to ¾" x ¼" pieces, washed, and packaged by the producer into bulk sacks. A third-party delivery service moved the material from the quarry to the field location in St. Albans. The material was then transferred to the filter totes by hand by the project team. A small sump was installed at the end of the tile drain in the ditch to allow the submersible pump to move water from the tile drain into the up-flow filter units while limited ditch flow influence.

MEASURE P REMOVAL EFFICIENCY OF FILTER IN LOW FLOW CONDITIONS (YEARS 1+2)

A sampling event was planned at least 24 hours after a storm event to ensure composite samples were taken in baseflow conditions. A SunPump uses high pressure to pump tile flow collected in the sump into the filter housing units. Two 12-volt Marine Deep Cycle batteries powered the SunPump to operate for eight hours which allowed the units to completely fill up with influent and allow sufficient contact time with the SGB media.

6712 ISCO full size portable samplers were located at the inlet and outlet of the filter units. Each ISCO was packed with ice surrounding the sample container and this container was triple rinsed with deionized water. The ISCO was programmed by Watershed Consulting staff to take a 100 mL sample every 15 minutes over a 24-hour period (triggered to start sampling after the eight-hour contact period). This acquired 9.6 L of composited sample.

Samples were collected within 12 hours to prevent SRP transformations before lab processing. TDP and SRP samples were field filtered with 0.45 µm syringe filters. Samples were labeled using pre-printed waterproof labels and filled in with ink pen or sharpie with the date, time, sampler name, and analyte as well as indication of field filtration and/or acidification. Nitrile gloves were worn by field staff when handling sample containers or suction tubing attached to the ISCO samplers. Samples were stored and transported in certified clean glass 60-mL vessels in the dark at 4 °C.

Duplicates were taken twice in 2020 and three times in 2021. A field blank for each analyte was taken in 2020 and TP and SRP blanks in 2021. 18 sets of samples were analyzed at the lab for TP and TDP and 16 for SRP, as two sets were not able to be run for this analyte. In the first monitoring year, some samples were not processed due to temporary laboratory closures under COVID-19 restrictions and glass sample vials breaking in transit after being frozen once the lab resumed sample submissions. In 2021, the duplicate regime was on track to complete all of the set duplicates. However, given the drought conditions, the complete sampling events for this year were not obtained.

A YSI ProDSS multiparameter probe was placed in the sump to measure temperature, dissolved oxygen (DO), pH, and conductivity levels of pre-treated water. Field conditions, date, time of sample collection, and ditch flow conditions were recorded in the Fulcrum application. This information can be viewed in Appendix A.

For all sampling events, chain of custody (CoC) paperwork accompanied samples and were signed by lab staff to indicate date and time of receipt. CoC paperwork included the sampler's name, date and time of sample collection, date and time of receipt at lab, temperature of samples when received, and signature of sampler and lab receiver.

FILTER PERFORMANCE ANALYSIS (YEARS 1+2)

TP, TDP, and SRP concentration data from the lab were recorded and analyzed in Excel. Percent TP, TDP, and SRP reduction was calculated for each sampling event. A two-tailed, paired t-test was performed on the three datasets to determine if there was a statistically significant relationship between influent and effluent concentrations in each monitoring year.

The percent composition of SRP and TDP that makes up TP was calculated to confirm if the filter was effectively adsorbing the inorganic, biologically available (i.e., most readily available) phosphorus.

6. QUALITY ASSURANCE TASKS COMPLETED

PROJECT MANAGEMENT

Criteria for Measurement Data

Data quality was measured in terms of accuracy and precision, completeness, representativeness, comparability, and the required detection limits for the analytical methods.

Data acceptance was based on adherence to field sampling, recording, transport, and lab analytical procedures and the use of field and lab blanks and duplicates. Corrective action, if necessary, included repeated field sampling and/or analysis and repeated staff training on procedures.

Field measurements and laboratory analytical data was periodically reviewed by the Project Quality Assurance Officer. In 2020, duplicate samples did not produce a relative percent difference (RPD) of 10% or greater, therefore no data was withheld based on RPD values. In 2021, one set of SRP outlet duplicates did not conform to the accuracy standards based on duplicate comparability of 10% RPD and was not used in analysis. No field blank produced a measurement above the reporting limit of the corresponding testing method for either year, therefore no data was withheld from analysis based on reporting limit values.

Sensitivity was assessed with field blanks. Staff prepared blanks in the field by filling vials directly with distilled water. Blanks were then handled and transported to the laboratory in the same manner as the rest of the samples. Field blank results were expected to be below the parameter specific Method Detection Limits (MDLs) or Reporting Limits (RLs). Reporting limits for TP is 5 µg/L, TDP is 5 µg/L, and SRP is 5 µg/L.

Bias was minimized by following the procedures documented within the QAPP. In addition, all field staff received training by the Project Manager and Project QA Officer to ensure consistent methods prior to any sample collection, handling, or transport.

Soluble reactive phosphorus (SRP) values are known to change rapidly in the environment and are significantly influenced by temperature and sunlight. The sampling methods minimized rapid SRP cycling by containing samples in dark, cool coolers. SRP and TDP samples were filtered in the field prior to lab transport to halt biogeochemical alteration.

Special Training Requirements/Certifications

Staff engaged in sample collection were fully trained by the Project Manager and QA Officer in proper field sampling and sample handling techniques, field documentation, and data management prior to any sampling activities. Samples were collected following EPA standard protocols for the sampling of surface waters (from Standard Methods for the Examination of Water and Wastewater, 23rd Edition). No untrained staff person was permitted to collect or process samples at any point in the project. Samples were sent to the Vermont Agricultural and Environmental Laboratory, accredited by the U.S. Food and Drug Administration and the U.S. Department of Agriculture. When staffing conditions changed, additional training opportunities were made available. Regular review staff doing project tasks were completed by the Project Manager and QA Officer after each sample collection and processing point.

Documentation and Records

Field data, including conditions, date, time of sample collection, and photo documentation of the site were collected using the Fulcrum application for smart phones. Files were stored both in the Fulcrum application software (under a license held by Watershed Consulting) and in exported format on the Watershed Consulting file network (using Box Drive). Watershed Consulting's complete file database is backed up daily to an on-site hard drive. Lab report data was sent to the project manager via email. Those data were entered into the Fulcrum log for the appropriate date. Digital data will be saved for a minimum of five years following the project end date. This data can be viewed in Appendix A.

MEASUREMENT/ DATA ACQUISITION

Samples were taken from the influent and effluent points of the ditch filter box at the approximate latitude and longitude: 44.818208, -73.132996 (Figure 2).

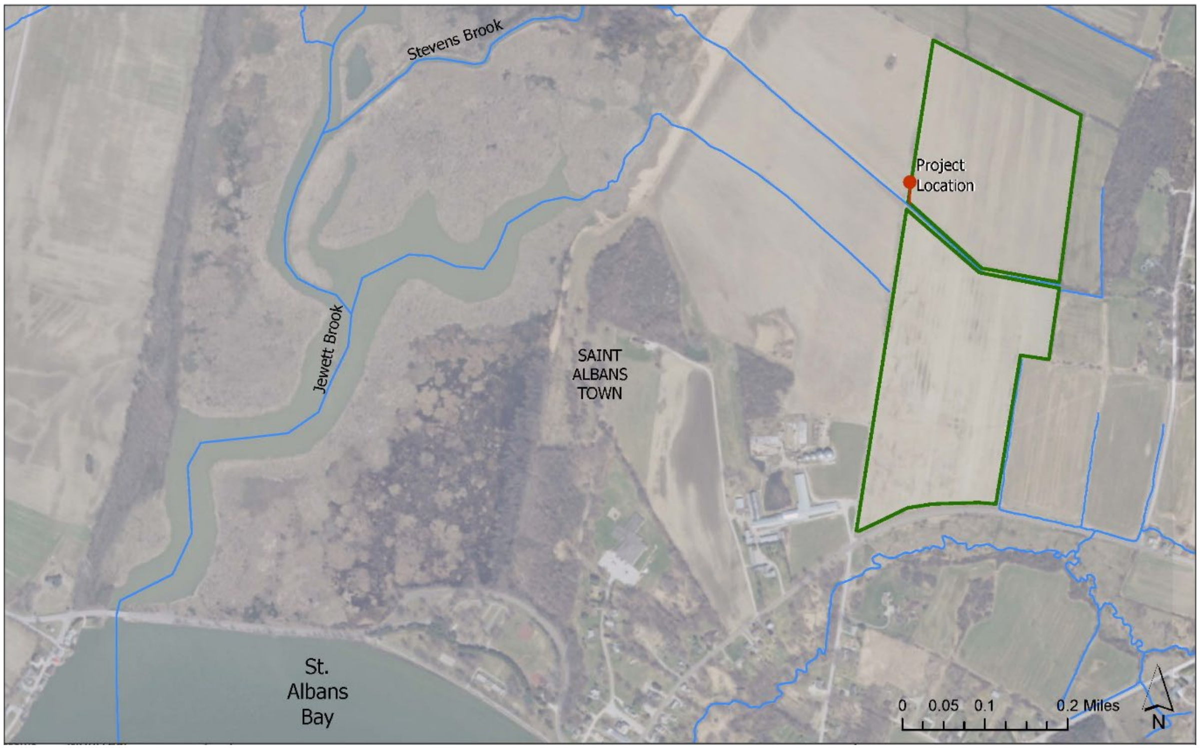

Figure 2. Project sampling location. Ditch collecting tile drain effluent from adjacent fields (outlined in green) where filter will be installed, marked with the red pin.

Sampling and Data Acquisition Methods

The following details are relevant to Task 5 – Measure P removal efficiency of filter in low flow conditions.

Samples were collected following EPA standard protocols for the sampling of surface waters (from Standard Methods for the Examination of Water and Wastewater, 23rd Edition) (Table 1).

Table 1. Parameters for analysis.

Parameter	Method/SOP	# Total Samples	# Field QC samples	Volume	Container	Preservation	Hold Time
TP	HNO_3, H_2SO_4 digestion and colorimetry (APHA-AWNA/WPCF Method 4500-P)	18	2	60 mL	Glass vial	Stored on ice (4 °C)	28 days
TDP	Filtration, HNO_3, H_2SO_4 digestion and colorimetry (APHA-AWNA/WPCF Method 4500-P)	18	1	60 mL	Glass vial	Field filtration (0.45 µm) Stored on ice (4 °C)	28 days
SRP	Filtration and direct colorimetry (no digestion) (APHAAWNA/WPCF Method 4500-P)	15	2	60 mL	Glass vial	Field filtration (0.45 µm) Stored on ice (4 °C)	48 hours

When problems occurred, field and lab staff recorded the issue and communicated with the Project Manager. Removal of data points and resampling or analysis were necessary to restore data points of poor quality. Data points that were removed from analysis due to sampling or analytical error were documented in project reporting tables and communicated with LCBP Project Officer in quarterly reports.

Analytical Methods

Field collection methods followed standards detailed by the US EPA in Surface Water Sampling Operating Procedure and the USGS National Field Manual for the Collection of water quality data. Laboratory processing procedures followed standard methods for phosphorus examination in *Standard Methods for the Examination of Water and Wastewater, 20th Ed. 1999*. APHA-AWNA/WPCF Method 4500-P Phosphorus.

Quality Control Requirements

All data acquired or generated was fully documented as to original source, quality, and history. A field duplicate was collected at both the filter inlet and outlet once every fourth sample. Precision for duplicates was expressed as a relative percent difference (%RPD). Duplicate pairs needed to be within 10% RPD. RPD was calculated using the formula:

$$RPD = \frac{|value1 - value2|}{(value1 + value2)/2} * 100$$

Field blank results were below the parameter specific Method Detection Limits (MDLs) or Reporting Limits (RLs). Reporting limits for TP, TDP, and SRP were each 5 µg/L.

Corrective action required having to repeat sampling due to damaged glass sample vials due to keeping them frozen for an extended period when the lab was closed due to COVID-19 restrictions.

Instrument/Equipment Calibration and Frequency

Field analytical equipment (Yellow Springs Instruments, ProDSS multiparameter probe) that was used in this project included instruments for measuring water temperature, DO, pH, and conductivity. Calibration procedures for the equipment followed manufacturer instructions. To maintain field precision and accuracy, the water quality instruments were calibrated to known standards. Laboratory instrument calibration followed manufacturer instructions and accepted procedures associated with the selected analytical methods and Standard Operating Procedures (SOP)s.

Inspection Acceptance of Supplies and Consumables

All supplies and consumables for field and laboratory activities were inspected for compliance with the acceptance criteria by qualified laboratory staff prior to use. Any equipment determined to be in an unacceptable condition was replaced. Supplies and consumables have been stored in accordance with identified storage requirements of each item.

Data Acquisition Requirements for Non-Direct Measurements

No data was acquired from outside sources for this project.

Data Management

Instrumentation used to generate, process, and store data was configured, maintained, and operated in accordance with manufacturer recommendations and accepted industry standards. Generated raw data was stored in formats compatible with the method or instrument of generation. Processed data was stored in MS Excel workbooks. Electronic data was stored in project directories on a Watershed Consulting computer network server compatible with this software and that was backed up daily. Only electronic records were kept for this project. All electronic files were backed up on a regular basis.

DATA VALIDATION AND USABILITY

Data Review, Validation, and Verification Requirements

The data quality was reviewed for logical consistency and coding errors as identified in appropriate standards. The Project QA Officer was responsible for overall validation and final approval of the data in accordance with project purpose and use of the data.

Validation and Verification Methods

The QA Officer provided review and approval of the data before closure of the project. Datasets lacking appropriate metadata were not used in any analysis or delivered to outside agencies. Documentation of provisional datasets were reviewed to verify references to the use and limitations of the data.

The Project Manager reviewed QC reports as applicable to ensure they were acceptable. The QA Manager compared final datasets with original source information for consistency.

Reconciliation with User Requirements

The QA Officer and Project Manager reviewed data results to verify that it was within acceptable limits per user requirements. No base data or attribute data demonstrated limitations or inconsistencies; therefore, no action was taken to identify or obtain more accurate datasets.

7. DELIVERABLES COMPLETED

Task #	Task Title	Objective	Deliverable or Output	Timeline
1	Develop a QAPP	Describe quality assurance procedures that will maintain project performance.	QAPP Approval	August 2018
2	Model filter performance and size unit	Monitor flow and water quality conditions at site to determine appropriate sizing and hydraulic conductivity of media	Filter unit sizing and media coarse details	September 2018
3	Create design details	Evaluate and detail existing conditions and create filter design drawings.	Site survey and filter design drawings	December 2018
4	Build and install filter unit	Build filter to design specs, install filter unit and monitoring equipment	Photo documentation of installed equipment	April 2019
5	Measure P removal efficiency of filter (year 1)	Collect and test water quality samples from the influent and effluent of the filter unit	Water quality sampling dates and results	May-November 2020

Task #	Task Title	Objective	Deliverable or Output	Timeline
6	Filter performance analysis (year 1)	Compare water quality of filter's influent and effluent to determine efficacy.	Results of data analysis	Nov-Dec 2020
7	Quarterly Reporting	Write and submit progress reports	Quarterly reports	Due 10 days after the end of each calendar quarter
8	Year 1 interim report	Compile and report all information from year 1 of study	Interim Report	December 31, 2020
9	Measure P removal efficiency of filter (year 2)	Collect and test water quality samples from the influent and effluent of the filter unit	Water quality sampling dates and results	May – Nov 2021
10	Filter performance analysis (year 2)	Compare water quality of filter's influent and effluent to determine efficacy.	Results of data analysis	Nov - Dec 2021
11	Final report	Summarize project findings and make recommendations to Lake Champlain stakeholders	Approved Final report	December 31, 2021
	Contract End Date		None	June 30, 2022

TASK 1 DELIVERABLE: APPROVED QAPP

The Quality Assurance Project Plan was written to establish quality assurance procedures related to project management, measurement & data acquisition, assessment & oversight, and data validation & usability.

The project data-quality objective was to collect, provide, analyze, and document valid data. The monitoring information that was collected to support the performance capacity of St. George Black to remove phosphorus from solution met the defined quality assurance objectives.

TASK 2 DELIVERABLE: FILTER MEDIA SIZING AND MEDIA COARSE DETAILS

The average high flow in base flow conditions was found to be 0.5-0.75 cubic feet per second (cfs). Based on this range, the filter was designed to accept ≤1 cfs of flow.

The SGB media was optimized to have a coarseness size of ¾" x ¼". This material was thoroughly washed to remove all fines that could potentially clog the treatment system. Based on this coarseness, the hydraulic conductivity of SGB appropriate for the filter was 0.86 cm/min (0.01 cm/sec). Two cubic yards of SGB was required to completely fill the filter units (Figure 3).

Figure 3. St. George Black media within the filter housing unit.

TASK 3 DELIVERABLE: SITE SURVEY AND FILTER DESIGN DRAWINGS

The project team sampled tile effluent at the study site to determine average soluble reactive phosphorus content and measured flow in the ditch to which the tiles drained to determine average flow conditions at the site to inform filter sizing. SRP data taken during existing conditions had a range of 22-50 µg/L in ditch flow. In the spring of 2018, the project team also surveyed the field and ditch to record accurate elevation information of surface features and key infrastructural components (Figure 4).

The survey results illustrated exceedingly flat conditions with insufficient head to force water through a media filter located within the ditch (as originally envisioned). However, installation of a low flow solar pump could lift water at a steady rate into an up-flow media filter to allow for field trialing of the media.

A tile drain filter study funded by LCBP in 2016/2017 resulted in recommendations for improvement that this filter design is taking advantage of. Notably, the 2017 report recommended high saturated hydraulic conductivity (>0.3 cm/s) and an up-flow filter design to avoid clogging (Braun, 2017b). The previous investigation also noted the challenge of housing the filter media in a closed, buried, concrete tank which lacked accessibility. The construction of such a system was costly and impractical on a working farm. In response to these recommendations, the proposed filter in this study had an up-flow filter design with a highly conductive material in a sufficiently large housing unit to allow optimal contact time with the media (Figure 7). The filter housing was specified to be a prefabricated plastic tub commonly used on farms and easily purchased from local farm stores. This also gave the added benefit of ease of installation and removal at the end of the study period or potential replacement with a different media to test alternatives in a future study. Figure 5 through Figure 8 illustrate the existing conditions on the study site and the proposed location of the filter and sampling equipment.

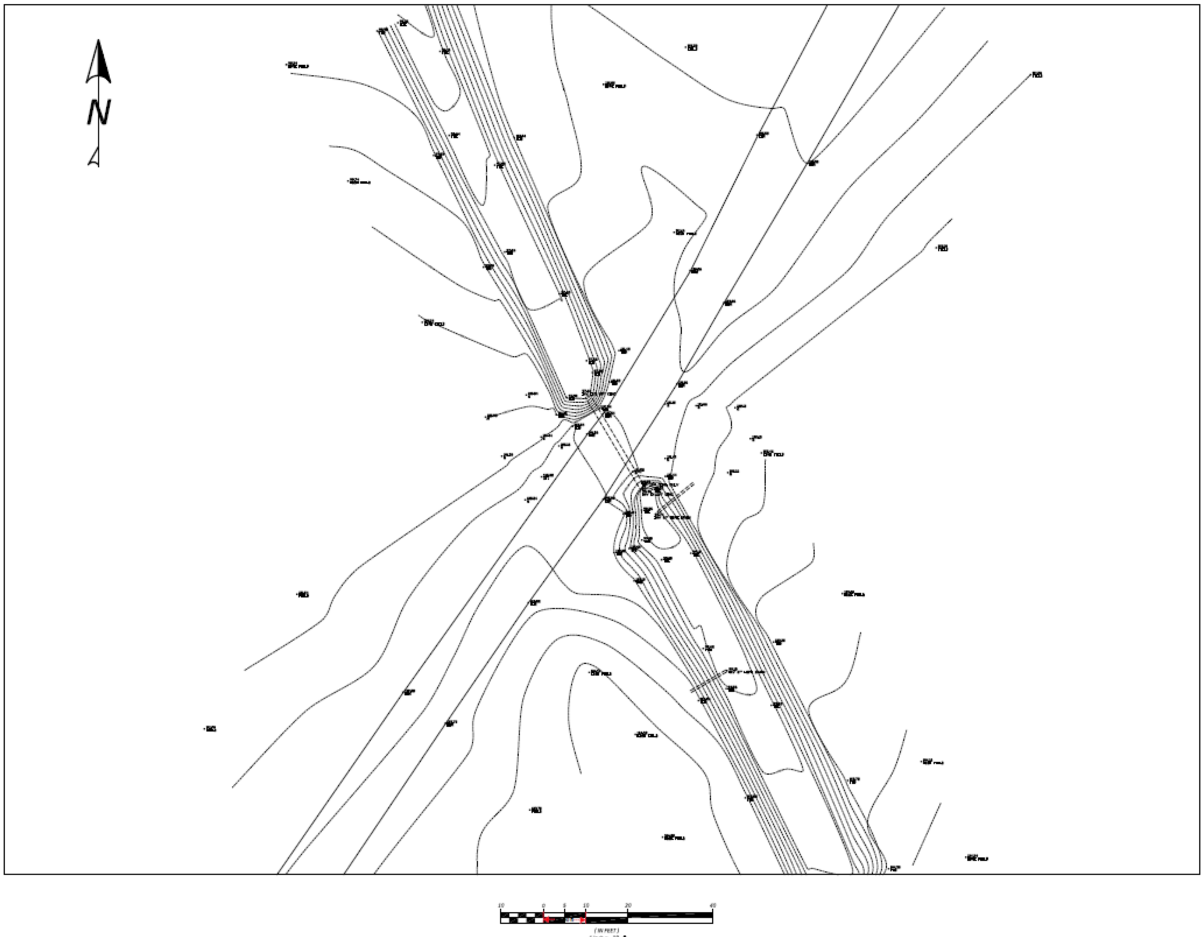

Figure 4. Surveyed conditions at study site. Note two tile inlets to a central ditch connected by a culvert under an access road.

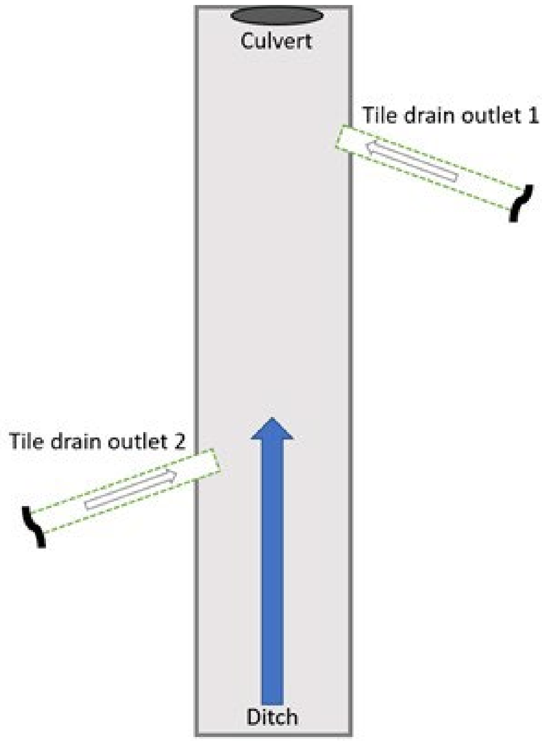

Figure 5. Plan view of the existing conditions at the study site. Two tile outlets discharged into a central ditch.

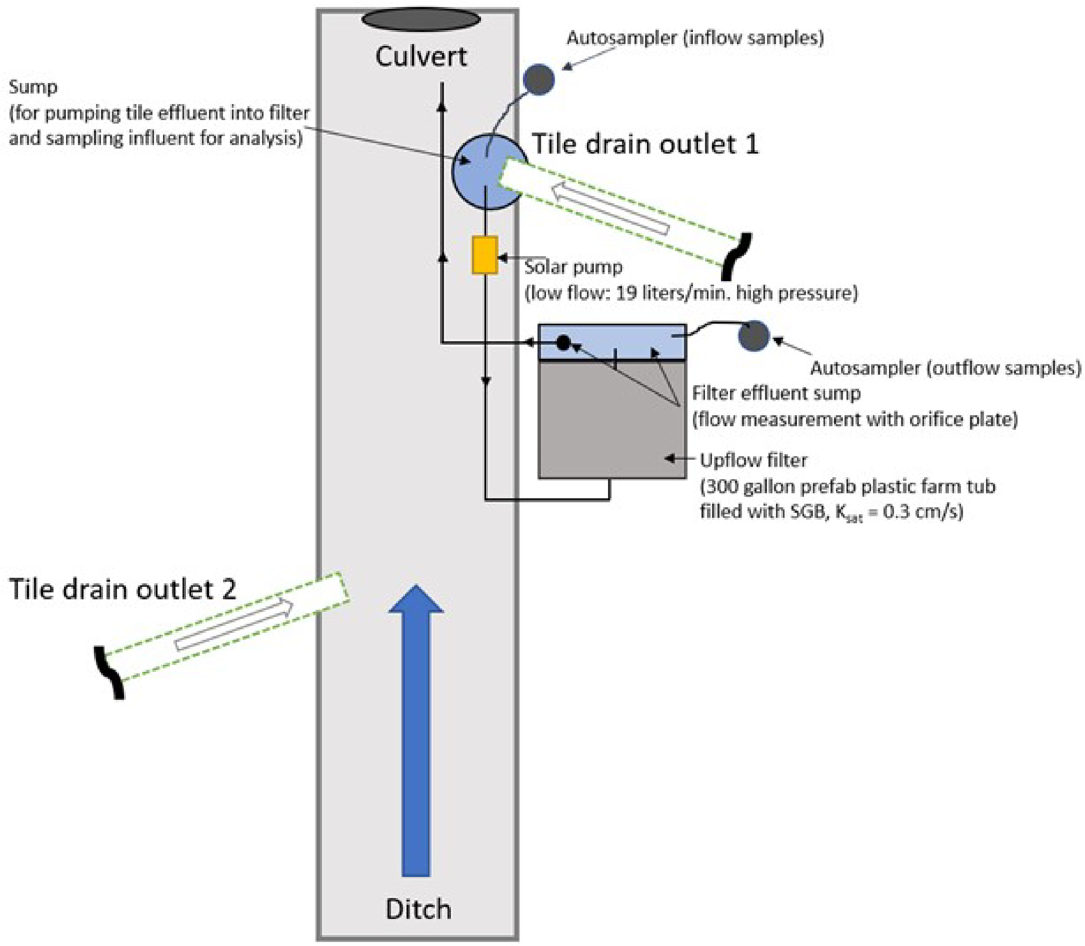

Figure 6. Plan view of the proposed conditions. The SGB filter received flow while tiles were discharging in the range of typical low flow contributions from the tile.

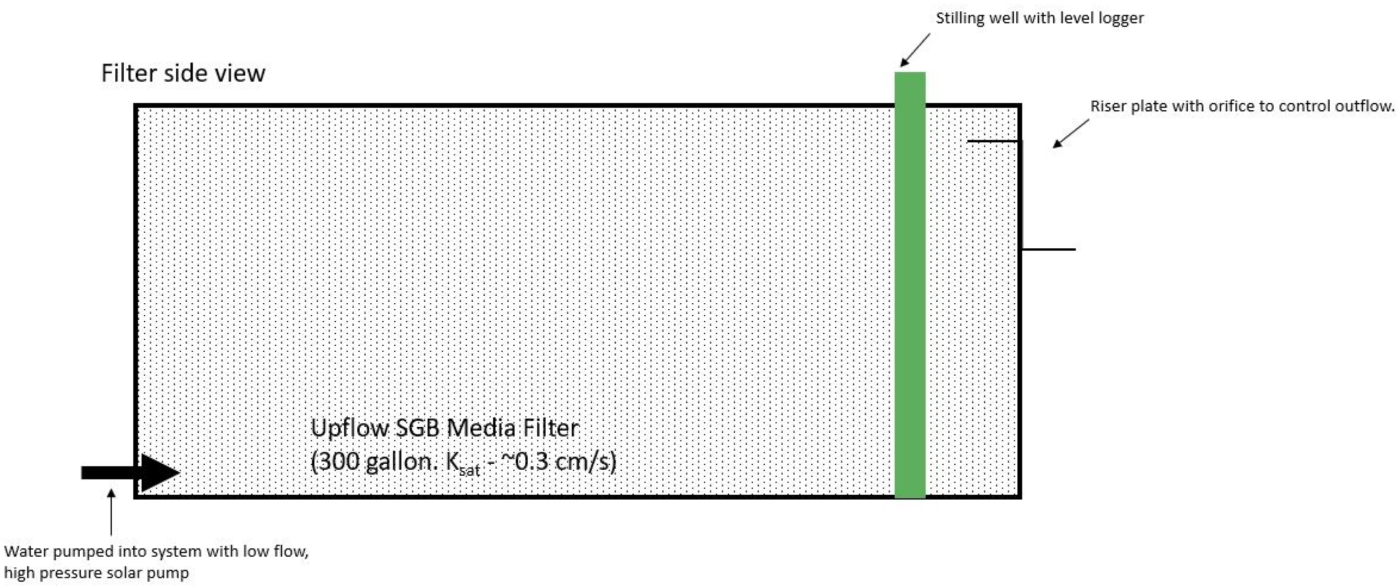

Figure 7. Side view of the proposed filter.

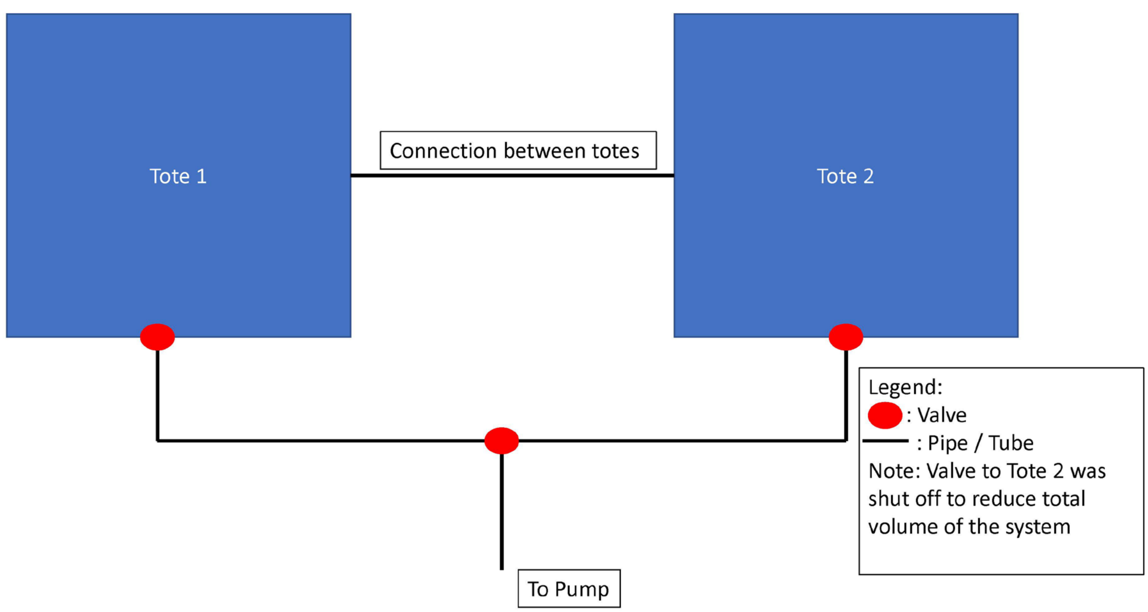

Figure 8. A schematic of the two filter housing units connected to each other and the pump.

TASK 4 DELIVERABLE: PHOTO DOCUMENTATION OF INSTALLED EQUIPMENT

The Spring 2019 conditions in the field were very wet, delaying the delivery date of the SGB and pushing back the first sampling events. Some challenges with pump activity were also encountered as the solar pump failed to operate when linked only to the 12-volt batteries. Additional electrical connectors were ordered to fix this issue. The filter units themselves were installed in the field to process tile water. The experimental design setup was finalized by May 2019 (Figure 9-Figure 12).

Figure 9. The original experimental design setup with the filter units, ISCO samplers, solar panel, batteries, sump, and the Sunpump.

Figure 10. ISCO Sampler setup.

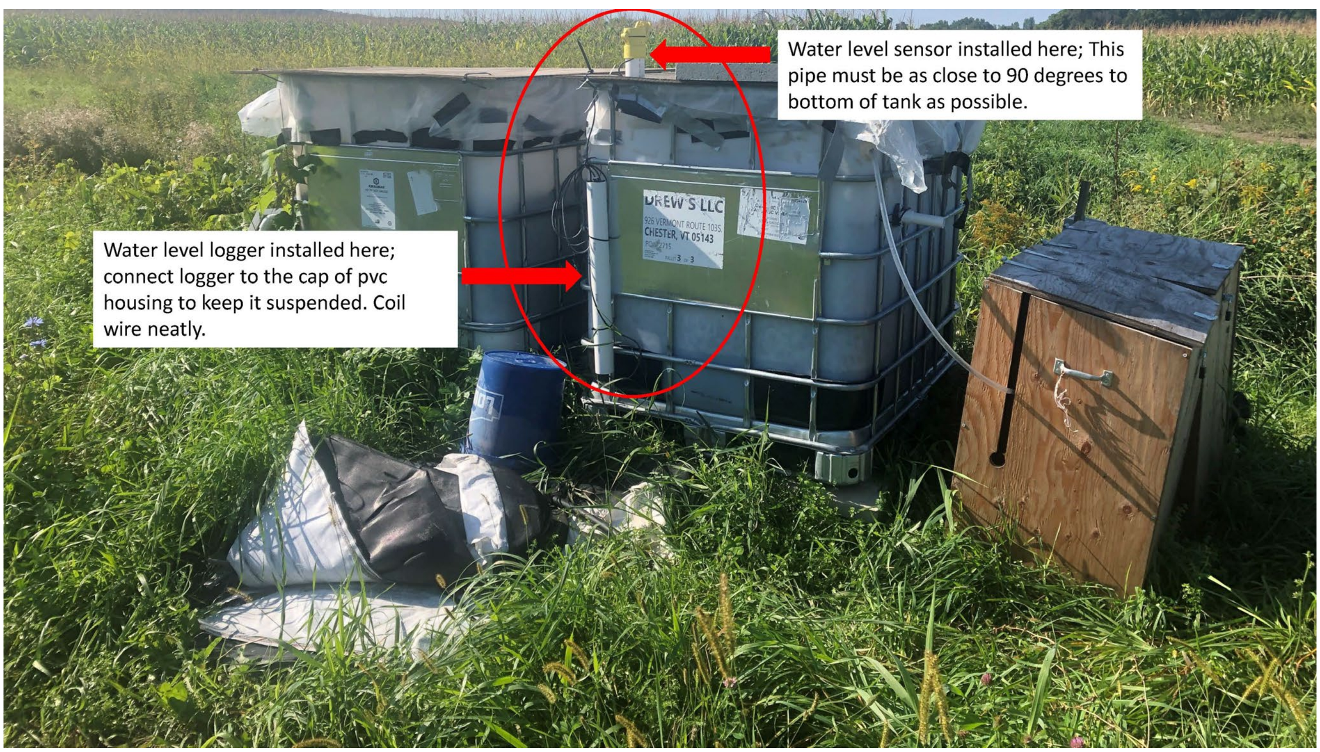

Figure 11. Water level logger and sensor setup.

Figure 12. Close-up of sump collecting ditch flow.

The Summer 2019 conditions in the farm field were very dry, resulting in a very slow process to fill the filter units. The flow splitter installed to share flow from the tile between two filter units was closed to reduce the overall volume needed to fill the filter. Even with the reduced volume, the lack of water from the tiles resulted in only a partially filled unit that did not generate effluent to allow testing of filter performance. At the end of September 2019, following the harvest of the corn crop, the tiles began to run again. At that time, the filters were able to be filled with water from the pump and began generating effluent. Upon the first viable sampling date, the float switch that controlled the pump was found to be malfunctioning. A complete rewiring of the unit did not fix the problem. A new float switch was ordered and installed in October 2019. No samples were collected in 2019 field season.

Due to the lack of baseflow and equipment malfunctions encountered in 2019, the project contract was extended to December 30, 2020, to collect twelve sets of water quality samples.

TASK 5 DELIVERABLE: WATER QUALITY SAMPLING DATES AND RESULTS (YEAR 1)

Thirteen sets of inlet and outlet samples were submitted to the lab for TP, TDP, and SRP analysis between May and November 2020. Twelve sets were analyzed for TP and TDP due to one set of vials breaking during lab processing (Table 2 and Table 3). Ten sets were analyzed for SRP due to one set of vials breaking during lab processing and one set being below the detection limit (Table 4).

Table 2. TP concentration data collected at the inlet and outlet from May to November 2020. Relative percent difference was collected for 2 sets of duplicates. The outlet sample vial collected on May 19th, 2020, broke.

Sample Collection Date	Blank (ug P/L)	Inlet	Outlet	TP Reduction (%)
5/8/2020		68.4	46.9	31.4
5/22/2020		66.3	41	38.2
5/27/2020		23.4	13.3	43.2
6/4/2020		19.8	12.7	35.9
10/2/2020	<5.0	95.3	77.1	19.2
10/9/2020		39.1	29.8	23.8
10/15/2020		29.5	11.1	62.4
10/19/2020		27.8	9.2	66.9
10/22/2020		39.5	30.3	23.3
10/28/2020		31.2	30.5	2.2
11/3/2020		48.6	28.7	40.9
11/5/2020		47.5	25.4	46.5
5/19/2020		69.6	Broken outlet sample	No result

Duplicate Collection Date	RPD (Inlet replicates)	RPD (Outlet replicates)
10/2/2020	4.83	3.50
10/22/2020	2.79	6.28

Avg Reduction (%)	T Test (P value)
36.2	2.3683E-05

Table 3. TDP concentration data collected at the inlet and outlet from May to November 2020. Relative percent difference was collected for 2 sets of duplicates. The inlet sample vial collected on May 8th, 2020, broke.

Sample Collection Date	Blank (ug P/L)	Inlet	Outlet	TDP Reduction (%)
5/19/2020		57.3	38.5	32.8
5/22/2020		56.4	33.2	41.1
5/27/2020		19.0	8.8	53.7
6/4/2020		19.1	8.7	54.5
10/2/2020		75.1	59.4	20.9
10/9/2020		36.1	29.2	19.1
10/15/2020		26.3	8	69.6
10/19/2020	<5.0	26.4	6.2	76.5
10/22/2020		31.7	21.5	32.3
10/28/2020		29.3	27.9	4.8
11/3/2020		42.4	26.9	36.6
11/5/2020		45.0	24.6	45.3
5/8/2020		Broken inlet sample	43.2	No result

Duplicate Collection Date	RPD (Inlet replicates)	RPD (Outlet replicates)
10/2/2020	0.13	1.18
10/22/2020	1.89	3.26

Avg Reduction (%)	T Test (P value)
40.6	1.00824E-05

Table 4. SRP concentration data collected at the inlet and outlet from May to November 2020. Relative percent difference was collected for 2 sets of duplicates. The inlet sample vial collected on May 27th, 2020, broke. The results from 5/19/2020 were determined to be erroneous due to sampling after the hold times due to COVID-19 restrictions and was excluded from the analysis.

Sample Collection Date	Blank (ug P/L)	Inlet	Outlet	SRP Reduction (%)
5/8/2020		14.3	7.3	49.0
5/22/2020		7.6	5.0	34.2
10/2/2020		55.6	40.2	27.7
10/9/2020		27.5	19.1	30.5
10/15/2020		22.0	5.0	77.3
10/19/2020		18.7	5.0	73.3
10/22/2020		22.3	10.9	51.1
10/28/2020		23.0	21.5	6.5
11/3/2020	<5.0	36.1	19.9	44.9
11/5/2020		38.9	18.4	52.7
5/27/2020		Broken inlet sample	Below detection limit	No result
6/4/2020		Below detection limit	Below detection limit	No result

				SRP Increase (%)
5/19/2020		11.5	54.7	376

Duplicate Collection Date	RPD (Inlet replicates)	RPD (Outlet replicates)
10/2/2020	1.26	0.75
10/22/2020	1.79	0.00

Avg Reduction (%)	T Test (P value)
44.7	0.000306924

In Spring 2020, the Vermont Agricultural and Environmental Lab (VAEL) was temporarily not accepting samples due to essential work restrictions at the beginning of the field season due to the COVID-19 Pandemic. In response to this, the sampling protocol was altered to specify that samples could be frozen to extend preservation. However, the freezing method may have caused the breakage of the three sample glass vials during lab processing. To prevent this from happening in the remaining sampling events, the samples were not frozen and instead were delivered to the VAEL within 24 hours of collection.

TASK 6 DELIVERABLE: RESULTS OF YEAR 1 DATA ANALYSIS

Inlet and treated outlet samples were analyzed for TP, TDP, and SRP at the VAEL. The raw data presented the concentration (µg/L) of each sample as well as additional comments specifying if samples were below the detection limit of 5 µg/L or damaged during lab processing.

All twelve sampling events analyzed for TP demonstrated reductions in treated outlet samples (Figure 13). The average TP reduction was 36.2%. All twelve sampling events analyzed for TDP demonstrated reductions in treated outlet samples (Figure 14). The average TDP reduction was 40.6%. The ten sampling events analyzed for SRP all demonstrated reductions in the outlet samples (Figure 15). The average SRP reduction was 44.7%.

The second sampling event on May 19th, 2020, was the only event that showed an increase in SRP concentration in the treated outlet sample (Table 4). An increase of 376% relative to the average 44.7% SRP reduction presented concern about sample quality. Due to COVID-19 restrictions, VAEL was temporarily unable to accept samples due to COVID-19 essential worker restrictions and unable to process samples when this event was collected. In response, SRP samples were stored in a chest freezer until the lab reopened and could accept them for analysis. This extended storage period was well beyond the two-day hold time for SRP analysis which indicates that the results from this sampling event are erroneous and not representative of the SRP levels during sample collection. The Watershed Consulting QA Officer verified that this sample set was erroneous and could be excluded from data analysis.

A two-tailed, paired distribution t-test was performed on the TP, TDP, and SRP datasets to produce a P-value for each dataset. Results of this analysis show that outlet concentrations were significantly lower than inlet concentrations during events for TP ($p<0.05$), TDP ($p<0.05$) and SRP ($p<0.05$).

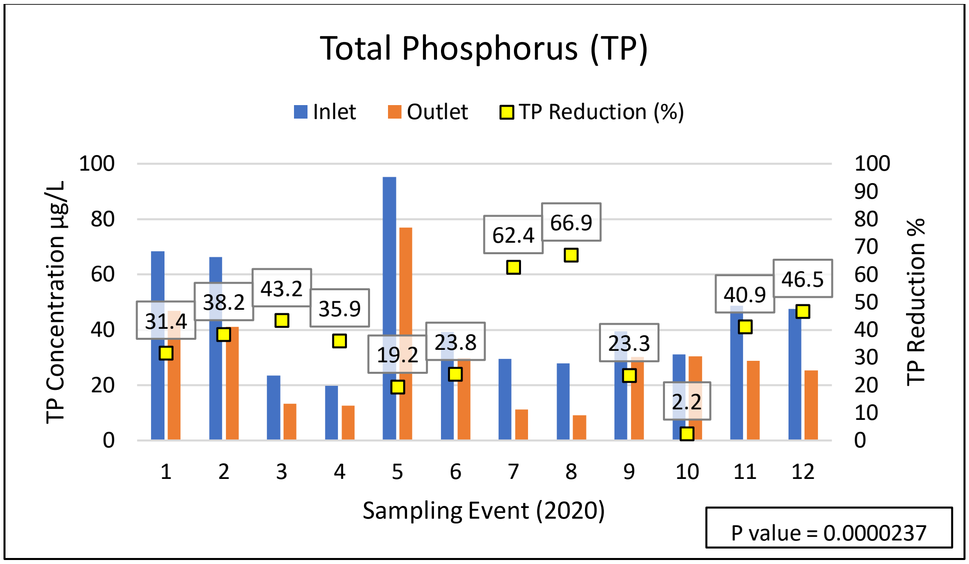

Figure 13. Total Phosphorus concentrations are shown for the inlet and outlet over 12 sampling events. A paired, normal distribution t-test was performed to determine significance. TP reduction is statistically significant as shown by the P-value. Note that vertical axis scale differs between the 2020 and 2021 plots.

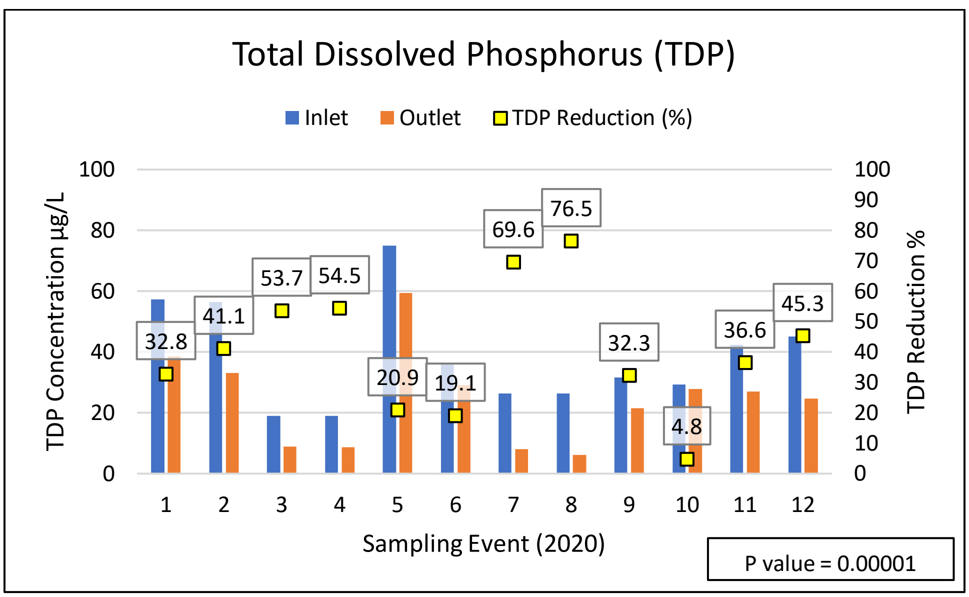

Figure 14. Total Dissolved Phosphorus concentrations are shown for the inlet and outlet over 12 sampling events. A paired, normal distribution t-test was performed to determine significance. TDP reduction is statistically significant as shown by the P-value. Note that vertical axis scale differs between the 2020 and 2021 plots.

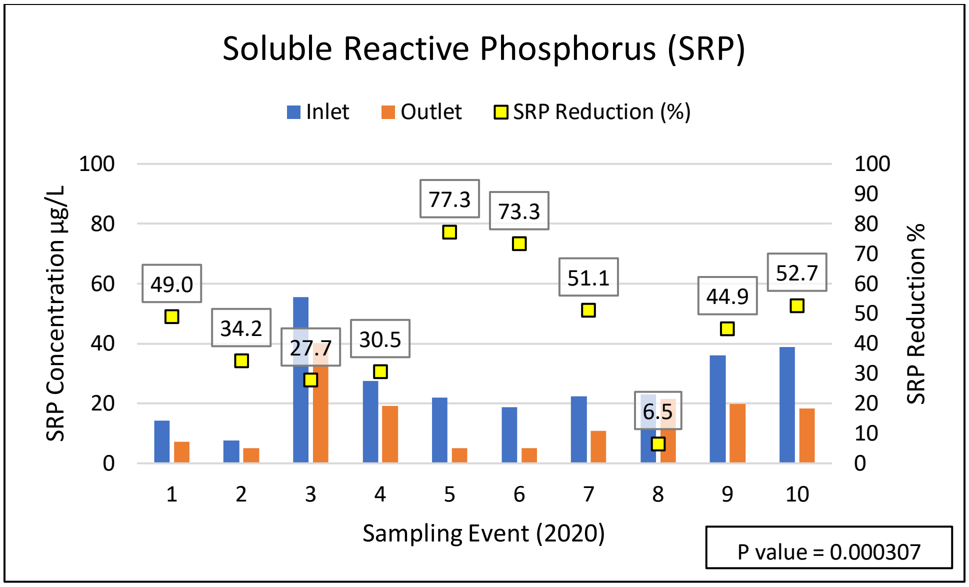

Figure 15. Soluble Reactive Phosphorus concentrations are shown for the inlet and outlet over 10 sampling events. A paired, normally distributed t-test was performed to determine significance. SRP reduction is statistically significant as shown by the P-value. Note that vertical axis scale differs between the 2020 and 2021 plots.

TASK 7 DELIVERABLE: QUARTERLY REPORTS (YEARS 1 + 2)

Thirteen quarterly reports were submitted from October 2018 to December 2021. Due to the extension of the contract that was approved in 2019, additional quarterly reports were submitted in 2020 to provide progress updates on Tasks 5 and 6.

TASK 8 DELIVERABLE: YEAR 1 INTERIM REPORT

Year 1 analysis observed consistent TP, TDP, and SRP reductions over the six-month long monitoring period, showing how St. George Black is an effective, adsorptive phosphorus filter material for agricultural tile drains in base flow conditions. This treatment technology is effective at removing TDP, particularly SRP that is prevalent in baseflow more so than particulate P. In conjunction with the filter, the event-valving system's ability to control the tile flow rate that can enter the treatment filter creates opportunities to apply this system in settings with a range of tile flow rates.

However, at the end of the previous sampling season, it was determined that six months is not a sufficient or adequate amount of time to answer all of the questions on SGB performance. The longevity of SGB would be continued to be studied in the 2021 sampling season as this could provide further insight on the phosphorus-capturing capacity of the material and how it performs over several years of seasonal and landuse changes. Within a single season, fluctuating temperatures and weather conditions can alter phosphorus composition within incoming baseflow and treated water in the filter unit. It was determined that studying TP, TDP, and SRP over a longer-monitoring period could provide more data on how these components affect phosphorus concentration on a small and large temporal scale.

TASK 9 DELIVERABLE: WATER QUALITY SAMPLING DATES AND RESULTS (YEAR 2)

Six sets of inlet and outlet samples were submitted to the lab for TP, TDP, and SRP analysis between June and November 2021. A complete list of all the sampling attempts can be seen in the dataset from Fulcrum, included in Appendix A.

Table 5. Total Phosphorus concentrations collected at the inlet and outlet from June to November 2021. Relative percent difference was collected for 3 sets of duplicates sampling dates and concentrations.

Sample Collection Date	Blank (ug P/L)	Inlet	Outlet	TP Reduction (%)
6/17/2021	<5.0	48.55	24.3	49.95
7/8/2021		288	12.7	95.59
7/12/2021		539	10.9	97.98
8/5/2021		3655	12.65	99.65
11/3/2021		27.4	17.9	34.67
11/17/2021		22.15	17.35	21.67

Duplicate Collection Date	RPD (Inlet replicates)	RPD (Outlet replicates)
6/17/2021	0.21	1.65
8/5/2021	0.82	5.53
11/17/2021	2.05	2.04

Avg Reduction (%)	T Test (P value)
66.6	0.257578674

Table 6. Total Dissolved Phosphorus concentrations collected at the inlet and outlet from June to November 2021. Relative percent difference was collected for 3 sets of duplicates.

Sample Collection Date	Blank (ug P/L)	Inlet	Outlet	TDP Reduction (%)
6/17/2021		42.1	16.95	59.74
7/8/2021		254	6.9	97.28
7/12/2021		487	10.1	97.93
8/5/2021		3205	9	99.72
11/3/2021		23	15.6	32.17
11/17/2021		19.35	13.85	28.42

Duplicate Collection Date	RPD (Inlet replicates)	RPD (Outlet replicates)
6/17/2021	1.43	1.77
8/5/2021	0.31	8.89
11/17/2021	0.78	0.36

Avg Reduction (%)	T Test (P value)
69.21	0.25473649

Table 7. Soluble Reactive Phosphorus concentrations collected at the inlet and outlet from June to November 2021. Relative percent difference was collected for 3 sets of duplicates. The duplicate analysis for the outlet done on August 5th, does not conform to accuracy standards based on duplicate comparability of 10% RPD. Concentrations from this event were not analyzed as part of the average percent reduction in SRP concentrations.

Sample Collection Date	Blank (ug P/L)	Inlet	Outlet	SRP Reduction (%)
6/17/2021		32.85	9.15	72.1
7/8/2021		242	5	97.9
7/12/2021	<5	472	5	98.9
8/5/2021		3005	18.3	99.4
11/3/2021		17.6	7.3	58.5
11/17/2021		14.95	9.05	39.5
Duplicate Collection Date		**RPD (Inlet replicates)**	**RPD (Outlet replicates)**	
6/17/2021		1.52	1.09	
8/5/2021		3.00	145.36	
11/17/2021		2.37	5.10	
Avg Reduction (%)	**T Test (P value)**			
73.40	0.176020585			

TASK 10 DELIVERABLE: RESULTS OF YEAR 2 DATA ANALYSIS

Inlet and treated outlet samples were analyzed for TP, TDP, and SRP at the VAEL. Six sample sets were collected during this sampling season, with seven other attempts made to sample in 2021. The average TP reduction was 66.6% (Table 5). All six sampling events analyzed for TDP demonstrated reductions in treated outlet samples. The percent reduction for each sampling event is displayed in Figure 13. The average TDP reduction was 69.21% (Table 6 and Figure 14). The five sampling events analyzed for SRP all demonstrated reductions in the outlet samples, as seen in Figure 15. The average SRP reduction was 73.4% (Table 7).

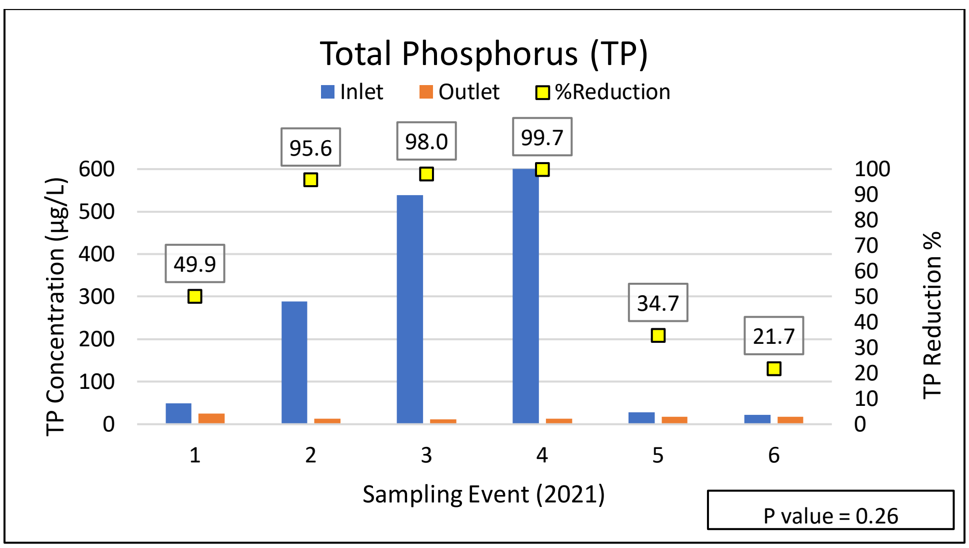

Figure 16. Total phosphorus concentrations at the inlet and outlet of the treatment practice. Percent TP reduction is also displayed. Sampling event 4 has a high inlet concentration (3655 µg/L), which is not fully represented at this scale of the graph. Note that vertical axis scale differs between the 2020 and 2021 plots.

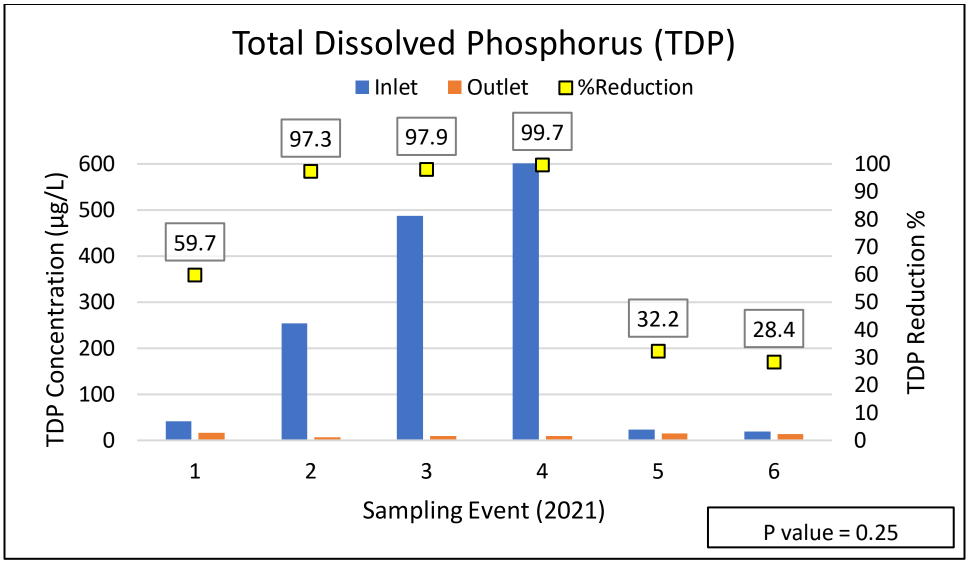

Figure 17. TDP concentrations for the inlet and outlet of the treatment practice. Sampling event 4 had a high inlet concentration (3205 µg/L) and is not fully represented in the scale of this graph. Note that vertical axis scale differs between the 2020 and 2021 plots.

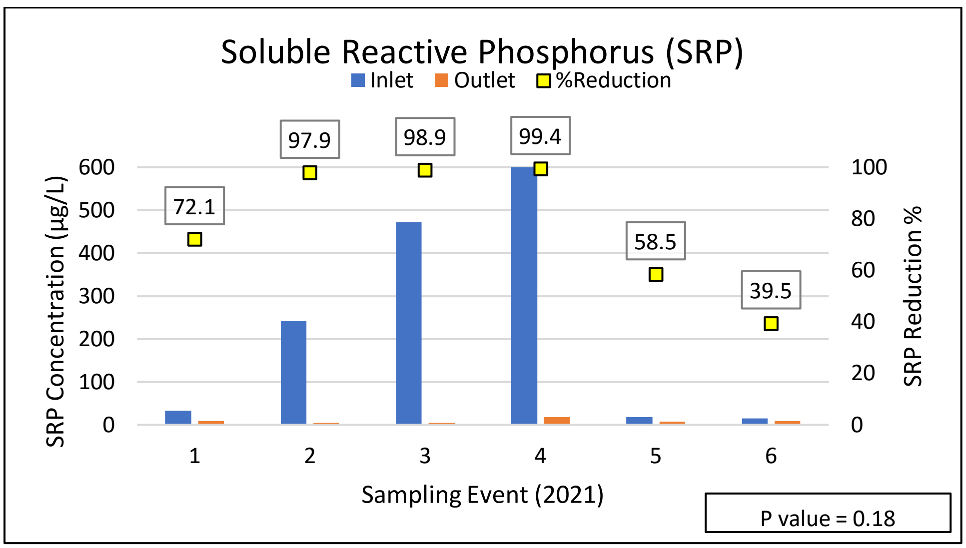

Figure 18. SRP concentrations for the inlet and outlet of the treatment practice. Sampling event 4 had a high inlet concentration (3005 ug/L) and is not fully represented in the scale of this graph. Sampling event 4 was on August 5th, where the relative percent difference analysis for the outlet replicates did not conform to accuracy startards of being within 10% of each other. This sampling event was not analyzed as part of the t-test, so the p value is from sampling events 1-4 and 6. Note that vertical axis scale differs between the 2020 and 2021 plots.

RPD analysis was done on the three sampling events that duplicate sampling occurred on. For the duplicates on August 5th, the outlet replicates did not pass the accuracy standards based on duplicate comparability of 10% RPD for SRP concentrations. This information can be seen in Table 7. Because of this, this sampling event was not used in analysis. The raw data is still presented in Appendix A.

All field blanks, collected on June 17th and July 12th, are below the reporting limit for their respective parameter, each being below 5 µg/L.

A two-tailed, paired distribution t-test was performed on the TP, TDP, and SRP datasets to produce a P-value for each dataset. However, with such a small sample size (n=5), the p value was above the significant test statistic of 0.05 for each of the datasets. So, while the 2021 data, constituting five sampling events, did not have a statistically significant relationship between the concentrations of each form of phosphorus in the inlet and outlet samples, the percent reductions were still meaningful.

Analysis was also done using concentration data from both monitoring years. The overall average reduction for each form of phosphorus was determined. These results are shown in Table 8.

Table 8. Overall average percent reduction for each of the phosphorus species for the two sampling seasons, 2020 and 2021.

Phosphorus Form	Overall Avg Reduction (%)
TP	46.3
TDP	50.1
SRP	57.1

Analysis of the average SRP percent composition of TP and TDP and the average TDP composition of TP was completed. Inlet results are shown in Table 9. Outlet results are shown in Table 10.

Table 8. Average percent components of SRP in TP and TDP for the inlet samples in 2020, 2021, and between both years.

	2020	2021	Overall
Avg SRP Comp of Inlet TP	58.9	75.5	65.2
Avg TDP Comp of Inlet TP	88.6	87.4	88.1
Avg SRP Comp of Inlet TDP	71.0	86.3	77.1

Table 9. Average percent components of SRP in TP and TDP for the outlet samples in 2020, 2021, and between both years.

	2020	2021	Overall
Avg SRP Comp of Outlet TP	49.2	43.2	47.2
Avg TDP Comp of Outlet TP	80.3	75.8	78.7
Avg SRP Comp of Outlet TDP	63.1	81.9	61.1

In 2021, the inlet samples had a greater percentage of SRP in TP than inlet samples in 2020. SRP is the inorganic portion of the soluble fraction of phosphorus in the tile – the remaining soluble portion is in an organic and less biologically available form. This is important as SRP is the form of phosphorus that the SGB media is most effective at adsorbing. SRP also made up a greater composition of TDP in 2021 inlet samples than in 2020 inlet samples. These results demonstrate that a large fraction of the phosphorus from fertilized, tiled farm fields is in the inorganic form of SRP. This finding further confirms the portion of phosphorus in tile drain flow that is SRP is important for determining end-of-tile treatment mechanisms most likely to be impactful on total loading.

The SRP fraction of TP for all outlet samples were lower than the SRP fraction of TP in the inlet samples for both monitoring years. In 2020, the SRP composition of TP was 10% lower, while in 2021 the SRP composition of TP in the outlet was 32.3% lower. Across both years, there are lower SRP concentrations in the outlet samples, demonstrating that this biologically available form of phosphorus is effectively adsorbing to the surface of the SGB media.

ESTIMATED REMOVAL RATE CALCULATIONS

Members of the TAC requested that Watershed Consulting complete additional calculations to determine the phosphorus mass removal load in grams per day. It was assumed that the outflow rate was also the same as the inflow (pumping) rate at 19 L/min. Subtracting the Outlet concentration in micrograms per liter from the Inlet concentrations for each phosphorus constituent gave the change in concentration in micrograms per liter. This was multiplied by the pumping rate of 19 liters per minute to determine the load rate in micrograms per minute. Units were then converted to determine the loading rate assuming the constant pumping rate in grams per day. This calculation is the removal load for each P form in mass per day. The averages by sampling season can be seen below in Table 16. The overall average between the two sampling seasons can be seen in the table under “All”.

Table 10. The average load estimate in grams per day for each P form. The overall average removal load between the two years can be seen in the "All" calculations.

	Average Removal Load (grams / day)		
	TP	TDP	SRP
2020	0.41	0.39	0.31
2021	3.84	3.47	3.39
All	1.65	1.50	1.56

The average loading rate for each sampling event can be seen in the graphs below. The sampling events in 2021 has a wider range of loading rate, as displayed in a different scale as the graph for 2020. The loading rate for 2020 can be seen in Figure 19. The loading rates for each of the sampling events in 2021 can be seen in Figure 20.

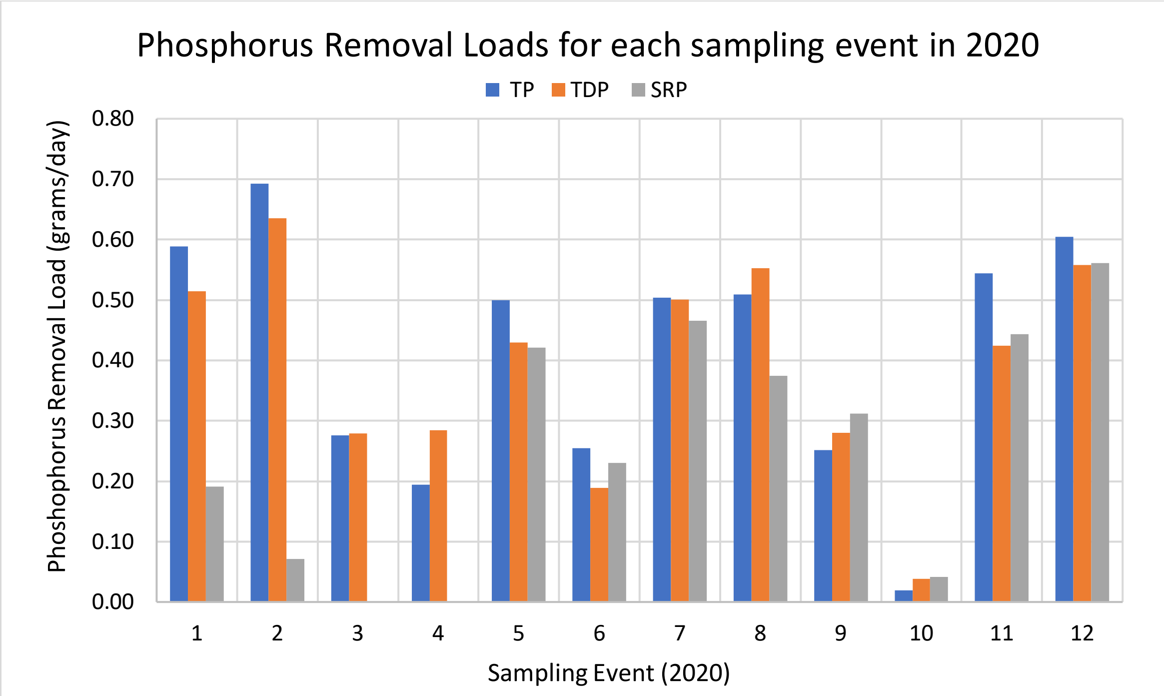

Figure 19. Phosphorus removal loads for each of the P forms for each sampling event in 2020. Note that each P form is displayed in its own-colored bar. Also note that the scale for the load in grams per day is different than the scale for the sampling events in 2021.

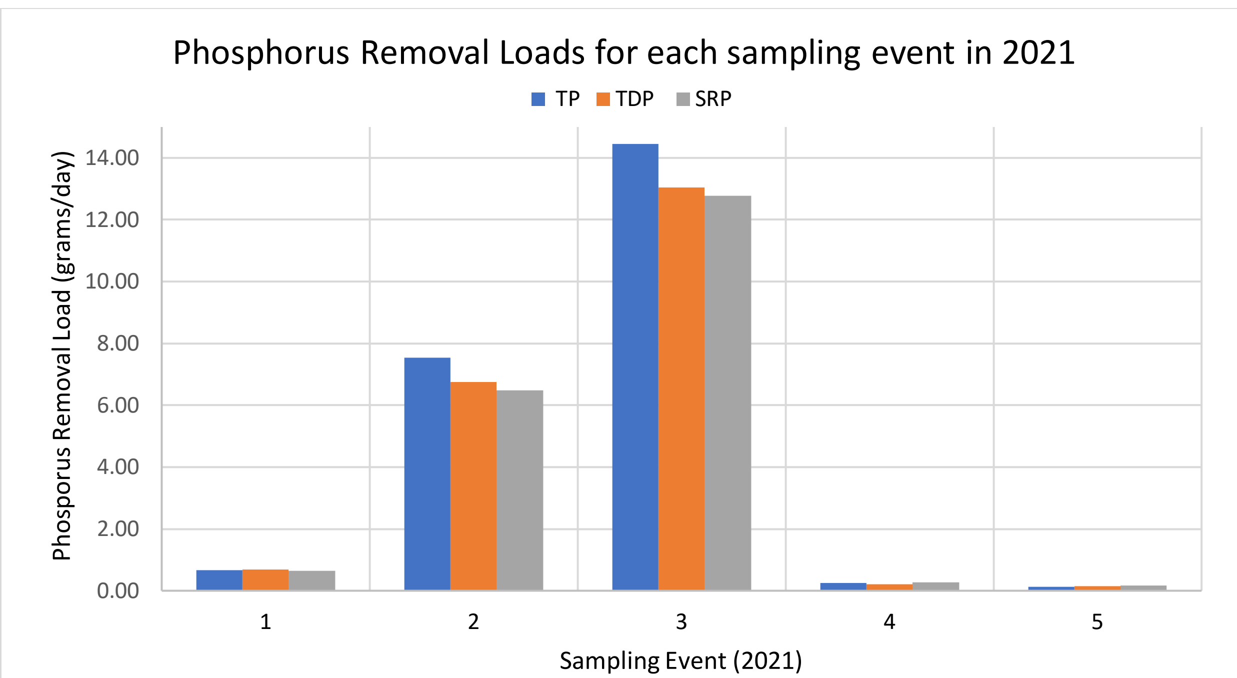

Figure 20. Phosphorus removal loads for each of the P forms for each sampling event in 2021. Note that each P form is displayed in its own-colored bar. Also note that the scale for the load in grams per day is different than the scale for the sampling events in 2020.

Additionally, the TAC posed the question of what the future removals and load estimates would be based on different design scales. Watershed Consulting determined that too many assumptions would be required to estimate for future scenarios. The load estimates done for the current project assumed a constant volume in the tote based off the set pumping rate of the SunPump at 19 Liters per minute. The following factors would need to be considered when estimating for various design configurations:

- Utilizing a different pumping rate would change the amount of water flowing through the system and affect the contact time with the SGB filter media.
- Scaling up the size of the tote would change the storage capacity
- Changing the amount of contact time with the SGB, may subsequently affect the ability for the SGB to adsorb phosphorus.
- Changing the storage capacity or pumping rate may require a different size grind of the SGB material, which may affect the void space and Ksat value of the filter media.

However, these specific factors were not studied in this project. Future studies could effectively address the various design factors of upscaled treatment systems and their respective phosphorus load retentions between the influent and effluent.

8. CONCLUSIONS

This project was a three-year, two-season long endeavor, accomplishing 18 sampling events, examining the influent and effluent of agricultural runoff of from two tile drained fields and filtered through the use of St. George Black shale, a material well-tested for adsorbing particulate phosphorus from water. The longevity of the filter material was studied, and the percent reduction of phosphorus was consistent from the last sample in November 2021 to the first sample in May 2020. Data demonstrates overall reductions in total phosphorus (TP; 46.3%), total dissolved phosphorus (TDP; 50.1%), and soluble reactive phosphorus concentrations (SRP; 57.1%) for both years combined.

This project, located in the Jewett Brook watershed, draining to St. Albans Bay of Lake Champlain, experienced drought in both years of sampling, with 2021 being the tenth driest year in the past 127 years (NDMC, USDA, and NOAA, 2021). This is similar to the conditions of 12 tile drained fields monitored in 2017 and 2018 in the Jewett Brook Watershed, where tile drainage was lowest in August through September (Braun, Meals and Smeltzer, 2019). Despite these difficult sampling conditions, the St. George Black was an effective filtering media for base flow conditions from tile drained farm fields. While these results were specific to the sampling conditions of this project, it can be inferred that this media is suitable for other wide scale application. Watershed Consulting performed minimal maintenance on the SGB, making this material well-suited for use on agricultural farms where landowners have limited capacity to maintain the practice.

This type of practice can be scaled up to be paired with a system treating higher flows, where higher flows are diverted into a basin with an outlet control to meter particulates. This would allow the filter system to be utilized in a controlled fashion. Additionally, rather than using a pump to pull flow from the ditch up into the media-filled totes, this can be gravity fed instead. A stormflow basin with an outlet control could collect water, and flow into a second basin with the St. George Black media. Further research on passive configurations will be important for realworld applications of SGB as a media filter for tile drained fields. Watershed Consulting's limited research showed the SGB's effectiveness for two years. The longevity of the media beyond the research period is still unknown. Proper disposal, whether as an on-field soil amendment or otherwise is still to be determined. Watershed Consulting will determine the optimal solution for disposal of the SGB material with further collaboration with the landowner and LCBP project manager in the Spring of 2022.

These data may be used to inform additional studies or to supplement management decisions regarding best management practices associated with tile drains in agricultural land. These data can reasonably be estimated to represent likely tile drain concentrations in other areas with similar soil and crop types, fertilization methods, climatic conditions, and a similar tile drain network (age, material, depth).

Because these conditions vary widely from field to field even throughout the Champlain Valley, these data should not be thought to be valid if extrapolated to other locations without extreme care. Comparison to other studies should also be done with care as it relates to tile drain nutrient and solids concentrations because the goals of this study were focused on the performance of a filter unit in low flow conditions. As a result, the representativeness and comparability of the study's data are limited by the complexity of the environmental system in which the tile drains are embedded as well as the specificity of the foci of this study's goals. Care should be taken when extrapolating to other times and locations.

If further studies or applications attempt to apply this type of practice outside of Vermont, locally sourced shale with similar adsorptive properties should be located if this practice is outside of Vermont. St. George Black is composed chiefly of silicon dioxide as well as aluminum, calcium, and iron oxides. The oxide materials in the SGB are well known as chemical adsorbers of phosphate. Another similar shale material with these components may be researched for similar use.

The study addressed water quality concerns through collaboration. Qualified water quality professionals, like Watershed Consulting, and farmers can work together to implement projects similar to the SGB filter application on tile-drained fields in order to reduce phosphorus into waterways. This study and future adaptations support the NEIWPCC's work on Connections and the overall goal of advancing water quality.

This treatment application is an example of a best management practice that can provide protection in reducing the amount of nutrient runoff on agricultural fields and entering Lake Champlain. This reduction in nutrient loading can help individual municipalities meet the TMDL goals for the lake.

This project was completed with support from student interns from the University of Vermont and recently graduated water resources scientists to conduct field work and sampling. These scientists oversaw analysis and deduced conclusions based on the data. This supports NEIPCC's workforce development objectives, in attracting and retaining a diverse and talented group of water quality professionals to the field.

This research endeavor achieved funding partnerships as this project was the result of collaboration between the NEWIPCC, LCBP and the USEPA. Collaboration with the University of Vermont, and a local non-profit group, Friends of Northern Lake Champlain, expanded the partnership as well. Future studies can achieve similar collaboration and partnerships between local universities, environmental consulting firms and non-profit groups all interested in achieving water quality improvements.

Further studies can support the NEIWPCC's Strategic Plan. Additional applications can utilize the SGB media for treatment of urban stormwater using passive stormwater design such as rain gardens, all for the purpose of improving water quality. This can help achieve the objective to engage in scientific research that can be translated into environmental applications, supporting NEIWPCC's vision of clean water managed sustainably throughout the Northeast.

9. REFERENCES

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10. APPENDICES

Appended Documents:

Appendix A: Project Data

Appendix B: Phosphorus Graphs

Appendix C: Photos

Appendix D: CWP Agricultural Symposium Presentation

REFERENCED SOPS

EPA Surface Water Sampling Methods: https://www.epa.gov/sites/production/files/2015-06/documents/Surfacewater-Sampling.pdf

U.S. Geological Survey, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations: http://pubs.water.usgs.gov/twri9A.

P analysis methods from Standard Methods of Water and Wastewater (this includes methods for both SRP and TP. SRP is simply a filtered sample that is run without digestion while TP is unfiltered and digested): http://edgeanalytical.com/wp-content/uploads/Inorganic_SM4500-P.pdf

YSI Pro DSS Calibration Guide: https://www.ysi.com/File%20Library/Documents/Guides/W89_YSI_ProDSS_Calibration_Guide.pdf

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