



# Final Report

**NEIWPCC Job Code:** 0100-310-002

**Project Code:** L-2016-060

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Stone Environmental, Inc.

## **Assessment of Phosphorus Loads in Tile Drainage in the Jewett Brook Watershed of St. Albans Bay, Lake Champlain: Monitoring Task Report**

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This is a Lake Champlain Basin Program funded project

*Final Report Form v.1.2016 (Revised: 11/3/2016)*

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This project was selected for funding by the Lake Champlain Basin Program (LCBP) Steering Committee and it has been supported directly by an agreement or sub-award issued by the New England Interstate Water Pollution Control Commission (NEIWPCC). NEIWPCC manages LCBP's personnel, contracts, grants, and budget tasks through a partnership with the LCBP Steering Committee.

Although the information in this document may have been funded wholly or in part by the United States Environmental Protection Agency (under agreement CE982720010), the National Park Service, or by the International Great Lakes Fishery Commission, through their respective contracts to NEIWPCC, it has not undergone review by the Agency, Service, or Commission, and no official endorsement of the content of the document should be inferred. The viewpoints expressed here do not necessarily represent those of NEIWPCC, the LCBP, the USEPA, the NPS, or the GLFC, nor does mention of trade names, commercial products, or causes constitute endorsement or recommendation for use.

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## Executive Summary

### Background

Subsurface (tile) drainage is an essential water management practice on many agricultural fields in Vermont, 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. However, tile drainage significantly alters field hydrology, reducing surface runoff but increasing subsurface flow. Reports in the scientific literature suggest that discharge from subsurface drainage systems can be a significant source of phosphorus (P) to surface waters.

In Vermont and across the Lake Champlain Basin, little is known about the potential water quality impacts of agricultural tile drainage systems. To address this knowledge gap, the Project Team monitored representative tile drainage systems in the Jewett Brook watershed (JBW), a tributary to St. Albans Bay of Lake Champlain, estimated P loading from these tile drainage systems, and evaluated the significance of this loading to the overall P export from the JBW

### Objectives and Methods

The study objectives were:

- To synthesize the current state of knowledge concerning the effects of subsurface drainage on hydrology, reported P concentrations and loads in subsurface drainage water, and major factors influencing the loss of P through subsurface drainage, derived from published scientific research;
- To measure total and dissolved P concentrations and flow and calculate P loads from representative tile drainage systems in the JBW;
- To evaluate associations among P concentration and loading and flow with agronomic variables in the study fields; and
- To estimate total and dissolved P loading from the JBW and evaluate the proportion of these loadings contributed by tile drainage systems.

The first objective has been accomplished in a literature review submitted to the Lake Champlain Basin Program in 2016: Literature Review: Tile Drainage and Phosphorus Losses from Agricultural Land (Stone 2016b). Results pursuant to the other objectives are presented in this report.

Twelve tile drain systems were identified for monitoring in the JBW through a comprehensive outreach effort to watershed farmers and agricultural agents. The six participating farmers provided historical and current crop management data on their monitored fields. Nine of the 12 study fields were in silage corn production in 2016. Two of these were planted in soybeans in 2017, while the remaining seven remained in corn. Three fields are in continuous hay production. Five of the corn fields being monitored were seeded with a cover crop of winter rye in 2016. Most of the study fields occur on Massena-Lyons stony loam and Kingsbury-Covington

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clay soils. Manure and fertilizer applications to study fields were highly variable through the study period.

Monitoring stations were constructed in 2016-2017 at each tile drain outlet to allow for year-round continuous flow measurement and automated flow-proportional sampling of tile discharge. Sampling was initiated in April 2017 at all 12 tile outlets and continued through March 2018. Samples were analyzed for total P (TP), total dissolved P (TDP), and total Nitrogen (TN) concentrations at the Vermont Agricultural and Environmental Lab under an approved primary data QAPP. Although the monitoring program experienced occasional interruptions by power outages, outlet submergence, and other problems, data collection efforts were generally successful as planned.

## Results

Flow rates over the course of the monitoring period varied from zero during dry weeks in August and September 2017 to as high as 3,300 L per minute at one station during a rain event in May 2017. All tile drains stopped flowing for periods ranging from days to several weeks in late summer 2017. In general, tile drain flows were sustained in the late winter and spring periods, whereas in summer and early fall the tile drains flowed in response to rain events, with little or no flow between rains. In the JBW, tile drain flow was lowest August – September 2017 and tended to be high May – July 2017 and January – April 2018.

Phosphorus concentrations were variable across the year and across monitored tile systems (Table 1).

*Table 1. Descriptive results, all fields and months combined*

	TP concentration ( $\mu\text{g/L}$ )	TDP concentration ( $\mu\text{g/L}$ )	Flow ( $\text{m}^3/\text{mo.}$ )	TP loading ( $\text{kg}/\text{mo.}$ )	TDP loading ( $\text{kg}/\text{mo.}$ )
Range	18 – 6,977	9 – 4,826	9 – 27,500	0.001 – 5.46	<0.001 – 3.78
Median	150	59	920	0.15	0.06
Mean <sup>1</sup>	140	63	976	0.14	0.06
S.D. <sup>1</sup>	2.4	2.4	5.3	6.2	7.2
n	156	156	156	156	156

*1. Anti-log of log mean, s.d.*

TP concentrations observed in JBW tile drainage were generally comparable to the range observed in other regions reported in the literature. Unlike literature reports, data from the JBW did not show widespread significant associations between high tile flow and high P concentrations. While positive flow-concentration associations were suggested in some cases (more often for TDP than for TP), relationships were generally nonsignificant, sometimes confounded by transient high concentrations such as those observed immediately following manure applications

On average across all monitored tile outlets, about 50% of TP was in the dissolved form (TDP), but the proportion of TDP varied among the monitored tile systems, ranging from a low of ~30% in systems draining fine-textured soils to a high of ~80% in systems draining cornfields in long-term no-till practice. TDP concentrations below 10% and over 90% of TP were reported in individual samples from some tile outlets. These observations tend to confirm the consensus of

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the literature that dissolved P can be an important form of P in tile drainage under some circumstances, but that particulate P sometimes makes up a surprisingly large fraction of TP in drainage water. No distinct seasonal pattern was observed for the proportion of TP made up of TDP.

Annual areal P loading from monitored tile drainage systems in the JBW varied over an order of magnitude (Table 2).

*Table 2. Summary of P loading data for all monitored JBW tile drains*

	Areal TP loading (kg/ha/yr)	Areal TDP loading (kg/ha/yr)
Range	0.122 – 1.124	0.083 – 0.556
Median	0.541	0.199
Mean	0.555	0.272
95% C.I.	0.368 – 0.743	0.166 – 0.378

Monitored P loading in tile drain flow from JBW agricultural fields was in a range comparable to that reported in the literature, both within the Northeast region and other U.S. regions. Annual areal P loads in tile discharge from the monitored JBW tile systems were generally comparable to those reported for P loads in surface runoff from agricultural land across North America,

While the low number of study fields limited the ability to draw significant conclusions on associations between P concentrations or loads and agronomic variables, some suggestive patterns were observed.

- Although the presence of surface inlets in a tile system did not appear to influence P concentrations, the significantly higher tile discharge in those systems resulted in significantly higher P export from tile systems with surface inlets.
- Monitoring data also suggest that P concentrations and export per hectare in tile systems draining row crops tend to be higher than levels observed from hayland.
- There was a tendency for both mean TP and TDP concentrations to be somewhat higher from fields that had received some manure in 2017, compared to fields that were not manured. Moreover, episodic very high P concentrations were observed on occasions when manure application coincided with high wet-weather tile flow.
- While annual tile discharge was clearly positively associated with field size, P concentrations in tile discharge did not vary significantly with field size.
- No significant variations in P concentrations or export were observed that could be attributed to soil characteristics or to the presence of cover crops on corn.

By extrapolating measured annual areal P loads to estimates of tile-drained agricultural land in the JBW provided by VAAFM, we estimate that tile drainage contributed 458 kg TP/yr and 168 – 201kg TDP/yr in the JBW. These contributions appear to represent approximately 15% of TP export and 7% of TDP export from the JBW via Jewett Brook; considering reasonable confidence intervals, tile contributions could be as high as 25% of JBW TP and 15% of TDP.

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In sum, the results of this study confirm the significance of discharge from tile drainage systems in the JBW as a contribution to high P concentrations and loads. Our estimates that tile discharge may contribute up to 24% of watershed TP and up to 15% of TDP loads in Jewett Brook suggest that it will be difficult to accomplish target reductions of agricultural P loads to Lake Champlain without addressing tile drainage.

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## 1. Project Introduction

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). 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 in recent 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 P via agricultural subsurface (tile) drainage systems. For many years, 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. However, recent research outside the LCB 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 in tile drain discharge.

Phosphorus concentrations in tile drainage water reported in the literature frequently exceed the U.S. EPA threshold of 100 µg/L for eutrophication in surface waters (USEPA 1994). In the UK, total phosphorus (TP) concentrations exceeding 1000 µg/L have been observed in tile drainage water, with up to ~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 µg/L in drainage water in Illinois. Kinley et al. (2007) reported mean concentrations of 230 µg/L TP and 80 µg/L soluble P in drainage samples from cropland fields in Nova Scotia. Madison et al. (2014) measured average annual TP concentrations of 21–1300 µg/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,

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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 (e.g., soil cracks and worm holes), 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); excessive accumulations of P in soils (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 and across the LCB, little is known about the extent of tile drainage systems, and the potential impacts of tile drainage systems on water quality have not been adequately assessed. Absent Vermont-specific information regarding P concentrations and loads from tile drainage, resource managers and farmers are likely to continue to make management decisions targeted primarily to reducing P in surface runoff from agricultural fields. Improved management 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 and therefore not addressed by conventional Best Management Practices (BMPs). The paucity of information constrains the ability of the State of Vermont to implement management that properly accounts for P loss via tile drains.

To address this knowledge gap, the Project Team reviewed recent literature on tile drain contributions of P, monitored representative tile drainage systems in the Jewett Brook watershed (JBW) in the Town of St. Albans, Vermont, estimated P loading from these tile drains, and assessed the significance of this loading to the overall P export from the JBW. This study involves the first intensive monitoring of tile drain discharge in Vermont. Stone Environmental (Stone) also analyzed associations between water quality results and land use variables in the tile drained fields. The JBW was selected for this study because of its history of high tributary P concentrations and the prevalence of tile drained agricultural land.

The study objectives were:

- To synthesize the current state of knowledge concerning the effects of subsurface drainage on hydrology, reported P concentrations and loads in subsurface drainage water, and major factors influencing the loss of P through subsurface drainage, derived from published scientific research;
- To evaluate characteristics of the JBW and provide detailed characterization of field areas drained by tile drainage systems selected for monitoring;
- To measure total and dissolved P concentrations and flow and calculate P loads from representative tile drainage systems in the JBW;
- To evaluate association among P concentration and loading and flow with agronomic variables in the study fields;

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- To estimate total and dissolved P loading from the JBW and evaluate the proportion of these loadings contributed by tile drainage systems.

## 2. Tasks Completed

The following tasks were accomplished to meet the study objectives.

**Secondary Data QAPP Preparation.** A secondary data Quality Assurance Project Plan (QAPP) (Stone 2016a) was developed to ensure the quality of environmental data used in preparing a literature review synthesizing the current state of knowledge concerning the effects of subsurface agricultural drainage.

**Literature Review Preparation.** A literature review (Stone 2016b) was prepared synthesizing the current state of knowledge concerning the effects of subsurface drainage on hydrology, reported P concentrations and loads in subsurface drainage water, and major factors influencing the loss of P through subsurface drainage, derived from published scientific research. The review also briefly identifies techniques of drainage management and treatment to reduce P losses.

**Primary Data QAPP Preparation:** A primary data QAPP (Stone 2016c) was developed describing the procedures to be used to ensure the quality of environmental data gathered in the tile drain monitoring portion of the project.

**Characterization of Tile Drainage Systems:** A Tile Drainage System Characterization Report (Stone 2017a) was prepared summarizing the characteristics of tile drainage systems selected for monitoring in the JBW. Methods and results of this characterization task are integrated into the body of this final report.

**Monitoring Station Installation:** A Monitoring Station Installation Report (Stone 2017b) was prepared summarizing the installation of tile drain monitoring systems in the JBW. Methods and results of this monitoring station installation task are integrated into the body of this final report.

**Study Implementation:** Monitoring was performed of selected tile drainage systems in the JBW according to the project workplan and the approved primary data QAPP. The methods and results of this task were presented in monthly monitoring summaries and in a comprehensive Monitoring Task Report (Stone 2018), which is integrated into this final report.

**Data Management, Analysis, and Reporting:** Quarterly reports were prepared, consistent with the project workplan. Continuous flow and nutrient concentration data were reviewed and summarized to calculate P loads at each monitoring station over the sampling period. A great deal of effort was expended generating this continuous dataset. A full presentation of the monitoring data, statistical analyses, and data interpretation are provided in this final report.

## 3. Literature Review Methods (Task 1)

The literature review synthesizes the current state of knowledge concerning the effects of subsurface drainage on hydrology, reported P concentrations and loads in subsurface drainage water, and major factors influencing the loss of P through subsurface drainage, derived from published scientific research. The review also briefly identifies techniques of drainage management and treatment to reduce P losses.

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This review was conducted according to an approved Quality Assurance Project Plan (QAPP) (Stone 2016a). Resources included in the review were identified through extensive searches of online scientific databases, including the *Web of Science*, the National Agricultural Library (AGRICOLA), Elton B. Stephens Co. (EBSCO), and the web search engine *Google Scholar*. Additional resources were obtained through direct communications with researchers in the LCB. References cited by each reviewed source were searched for additional resources. If a review article summarized data from other studies or reports, the original documents were obtained so that all information was taken from original sources.

This review emphasized peer-reviewed sources (published journal articles), but included other references such as approved graduate theses, conference presentations, and agency reports if those sources met the criteria established in the QAPP.

In all, 252 references were identified and obtained for the review. Of these, 86 were not used because they were not applicable (e.g., they did not report P data, or represented a setting not relevant to the LCB). Of the remaining 166 references, 95% were peer-reviewed journal articles. All of the non-peer-reviewed sources represented high-quality information presented by authors published elsewhere in their fields. Work conducted in the LCB was given highest priority; research conducted elsewhere in North America and Europe was also included. The review resulted in 699 individual records reporting P concentration in tile drain flow, and 727 records reporting P loads. Discussion in this literature review first addresses work conducted in or near the LCB, then expands to reports from the U.S. Midwest and eastern Canada, and lastly, to research studies conducted elsewhere in North America and Europe.

Full data on reports of P concentrations or loads are reported in a separate spreadsheet database that includes reported P concentrations/loads and other relevant data such as soils, cropping, fertilization, and monitoring approach. Examples of P concentrations and loads are discussed in the narrative.

Phosphorus is analyzed and reported in a variety of forms. Total P (TP) is considered to represent all P in a sample after chemical digestion that converts all P in the sample to an analyzable form. Within the total, P is frequently reported as “particulate P” (PP, or the P adsorbed to solid matter that will not pass through a filter) or “dissolved P” (synonymous with “soluble P”), based on filtration of the sample to separate the particulate matter from the water. Some researchers analyze “orthophosphate” (any compound containing the  $\text{PO}_4^-$  ion) or “ $\text{PO}_4\text{-P}$ ,” which may be quantified for either filtered or unfiltered samples. Within the dissolved fraction, P is often reported as “reactive” (based on its response to certain analytical methods); less frequently, an “unreactive” form of P will also be reported. Dissolved reactive P (DRP) is sometimes referred to as “soluble reactive P” (SRP). Sometimes total soluble P (TSP) will be reported, based on chemical digestion of a filtered sample. Some researchers have reported “bioavailable P,” usually based on a chemical extraction that is analogous to the P that algae or other plants can readily access; unfortunately, these forms are not always standardized across the field, especially in older work.

To simplify the discussion, this review focuses on the most commonly reported P fractions: total P (TP), soluble reactive P (SRP or DRP), particulate P (PP), and – to a lesser extent – total soluble P (TSP). The designations SRP and DRP are used synonymously and references to “dissolved P” in the text refer to SRP or DRP unless otherwise noted. In a few cases, papers

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report “dissolved inorganic P,” which this review assumes as equivalent to SRP or DRP because where both inorganic and organic dissolved P have been reported, inorganic P is by far the dominant fraction. A problem arises when a publication reports simply “ortho-P” or “PO<sub>4</sub>-P.” These fractions are often poorly defined with respect to dissolved, particulate, or total fraction. Where an examination of the analytical methods reported in a paper could verify that samples were filtered before analysis, reports of ortho-P was designated as soluble P. However, often filtration was not reported and could not be inferred, so these values were reported as they were designated by the author. The P concentrations reported from analysis of unfiltered ortho-P are likely to be intermediate between SRP/DRP and TP. Any non-standard P fractions encountered are reported as used by the author(s).

## 4. Tile Drain Monitoring Methods (Task 2)

### 4.1 Monitoring Site Selection

Through a comprehensive outreach effort to farmers and agricultural agents operating in the JBW in 2016, Stone secured agreements with 6 of the 11 farmers believed to crop tile-drained land in the JBW to allow for monitoring of selected tile drain outlets. Taken together, 18 tile drainage systems were identified across these farmers’ managed lands. Several of these tile drains were clearly not suitable for monitoring. The main reason certain tile drains were determined to be unsuitable is that they drain very small areas (<5 acres) and thus produce relatively little drainflow. Most of these tile drains were dry when visited in the summer of 2016. One other tile drain was eliminated from consideration because it primarily drains barn roof runoff via surface inlets. After excluding these unsuitable tile drains, 15 tile drains that could be monitored were identified, although several of these had obvious drawbacks, including two with known surface inlets (standpipes and/or rock inlets). Given that the number of tile drain outlets available for monitoring was only slightly higher than 12 (the number to be monitored), no formal site selection criteria were established. Farmer cooperation and practical realities necessarily superseded efforts to intentionally represent a range of field conditions (e.g., cropping system, soil type, hydrologic soil group, soil test P, and age, layout, and depth of tile drain system) in the JBW.

### 4.2 Characterization of Study Fields

Data describing the monitored tile-drained fields (Section 5.1) were obtained through field reconnaissance, interviews with participating farmers, review of nutrient management plans, and analysis of the USDA-NRCS SSURGO soils dataset. All six participating farmers provided information about the fields and tile drainage systems investigated.



### 4.3 Monitoring Station Construction

Monitoring station construction began in November 2016. Instrument shelters were moved to the selected monitoring sites or were assembled on site. In December, monitoring manholes were constructed at 11 stations. Manholes were constructed by excavating to a depth two feet below the tile drain line, cutting out a section of the existing pipe, spreading a layer of 1-inch drainage stone in the excavation, attaching a rigid pipe trap on the incoming tile line, and installing a 36-inch diameter, double walled culvert vertically over the pipe trap (Figures 1 and 2). The culvert pipe was notched to fit over the incoming and outgoing pipe (Figure 3). The upper leg of the pipe trap wye was capped. Water flows under full-pipe conditions through the lower leg of the pipe trap wye into the manhole and exits through the existing tile line, which remained at its pre-construction elevation.

Drainage stone and soil were backfilled around the pipe trap and manhole up to grade. A plywood cover was placed over the manhole for safety purposes.



Figure 1. Installation of a pipe trap and manhole at JBT02



Figure 2. Lowering manhole into place over tile drain piping



Figure 3. Cutting notches in manhole for incoming and outgoing pipes

around the pipeline using plywood notched to accommodate the pipe. A hatch was constructed on the top of the weir box for access and installation of monitoring instruments.

Sheet metal strips were screwed to the plywood face of the weir to form a sharp crest. The notch in the weir is approximately 3 inches (8 cm) higher than the invert of the outgoing pipe. Instrument Installation

Due to the large (12-inch) diameter of the JBT06 tile drain outlet, it was not feasible to install a pipe trap for an electromagnetic flowmeter or a manhole over the pipeline. Therefore, a different type of access structure was designed, a large plywood box (8 ft. long x 4 ft. x 4 ft.) containing a 90-degree V weir. The long dimension of the box was installed in-line with the tile drain. A 6-foot long section of the tile drain was cut out and the box was placed over the ends of the pipeline. The ends of the box were capped



Figure 4. 8-inch diameter Waterflux 3000 flowmeter in JBT11 manhole

In late winter 2017, Krohne Waterflux 3000 electromagnetic flowmeters were installed in most of the 11 monitoring manholes, bolted to a flange on the rigid pipe trap (Figure 4). This sensor has outstanding accuracy at high flow rates (less than  $\pm 0.3\%$  in a 6-inch diameter pipe at flows above 300 gallons per minute) and better accuracy at low flows than similar flowmeters (for example, 3% in a 6-inch diameter pipe at 5 gallon per minute). The sensor is



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rated for full submergence and direct burial. At each station, the size of the flowmeter matched the diameter of the tile drain line.

Each Waterflux 3000 flowmeter was cabled to a Krohne IFC-100W signal converter, which processes electrical signals into meaningful flow data. The signal converter was connected to an ISCO 2105ci datalogger/modem for continuous storage and transmission of flow data and to an ISCO 6712 autosampler for collection of flow-paced composite water samples. The wiring and programming of these instruments were highly customized for this monitoring application.

At station JBT06, an ISCO 2110 ultrasonic flowmeter was installed for continuous measurement of water level. The stated accuracy of this instrument is the greater of  $\pm 0.00396$  m or 0.00256 m per foot (0.305 m) from the calibration point. The sensor for this flowmeter was installed on a bracket on the upstream side of the weir, above the water surface. The flowmeter computes flow rate from measured water level using a weir equation. The ISCO 2110 flowmeter was connected to an ISCO 2105ci datalogger/modem for continuous recording and transmission of flow data. The 2105ci modem/logger was also wired to an ISCO 6712 autosampler for collection of flow-paced composite samples.



*Figure 5. Completed monitoring station at JBT11*

In each monitoring shelter (Figure 5), an ISCO 6712 autosampler was mounted on a custom manifold consisting of funnels and hoses to dispense water to a carousel of four 10-liter carboys. The IFC-100W signal converter was programmed to transmit an electrical pulse to the autosampler for every 100 liters that passed through the tile line. At station JBT06, the 2105ci unit sends flow pulses to the autosampler, also at 100-L intervals. The autosampler is programmed to dispense 100-mL aliquots of sample

to the carboys upon receiving a specific number of electrical pulses. The sampling interval was set with the goal of collecting between 5 L and 20 L of sample at each station during a week-long sampling period. The flow-pacing interval was evaluated approximately weekly as tile drain flow changed over the monitoring period.

ISCO 2105ci modems were programmed to transit flow and sampling data to a computer server at Stone's office in Montpelier. Each modem has a static IP address, allowing two-way communication and remote control of the autosampler. These data are checked periodically to assess whether the monitoring program is working as intended.



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Solar panels, charge controllers, and deep cycle batteries provided power at each station.

Table 3 below lists the serial number and calibration constant of the Waterflux 3000 flowmeter and the static IP address of the modem installed at each station.

*Table 3. Reference values for monitoring instruments*

Station	Outfall diam. (in.)	Waterflux 3000 serial number	Waterflux 3000 GKL constant	Modem static IP
JBT01	6	A17080796	1.8229	166.159.121.230
JBT02	4	A17080794	1.3481	166.159.121.183
JBT04	4	A16017315	1.4051	166.159.121.151
JBT05	8	A16033751	1.9112	166.159.121.149
JBT06	12	NA	NA	166.159.121.159
JBT07	4	A16017312	1.4064	166.159.121.231
JBT11	8	A16033752	1.9626	166.239.181.71
JBT13	6	A16017311	1.8055	166.159.121.152
JBT14	8	A16034254	1.8827	166.159.121.154
JBT16	4	A16017314	1.4262	166.239.181.37
JBT18	6	A17080797	1.8022	166.159.121.232
JBT19	6	A16017310	1.8449	166.159.121.160

#### 4.4 Sampling Procedures

Flow monitoring and sample collection were initiated in April 2017 and continued through March 2018 at all 12 tile drain monitoring stations. 48 sampling rounds were performed through March 2018. Samples were retrieved on the same day each week to the extent practicable. At each of the selected tile drains, drainflow was recorded continuously and flow-proportional composite water samples were collected approximately weekly to provide TP, TDP, and TN concentration data representing the preceding period. Field visits to retrieve and process composite water samples (Figure 6) were conducted each week when the monitored tile drain was flowing.

The autosamplers were programmed to withdraw sample aliquots on a flow-proportional basis, according to the frequency of flow pulses received from the flowmeter. Flow-proportional sampling is challenging because discharge rates are highly variable and difficult to predict. If sample aliquot collection is too infrequent (e.g., in small runoff events), insufficient sample volume may be collected to perform the intended analyses. If sample aliquots are collected too frequently (e.g., in an unexpectedly large runoff event), the bulk sample container may not have the capacity to contain samples over the entire event, resulting in a non-representative sample. To minimize the occurrence of under-sampling and overfilling, a two-part program was used whereby the autosampler pumped sample aliquots to two sets of containers at different intervals of accumulated discharge. Each bottle set consisted of two 10-L polyethylene carboys. The first bottle set (Set A) was intended to capture a representative sample at low flow rates and the second bottle set (Set B) was intended to capture a representative sample at high flow rates. Set B was filled at approximately one tenth the frequency of Set A. The second bottle in each

set was filled only after the first was full, at the same frequency as the first. Adjustments to the autosampler programs to increase or decrease the sampling frequency were made either by direct connection or via remote access. Failure of the system to collect at least three sample aliquots in bottle Set A during a weekly period resulted in rejection of the sample as non-representative.



*Figure 6. Processing a composite water sample*

Collection of flow-paced composite samples was generally successful until the week of November 14, 2017, when all the composite sample carboys were frozen. As of November 14<sup>th</sup>, automated composite sampling was suspended due to below freezing conditions. The monitoring manholes were insulated to protect the flowmeters against freezing. Grab samples were collected from November 14, 2017 through March 2018, approximately once per week. In addition to scheduled sample collection, we attempted to sample high flow events during the winter and early spring period to represent the range of observed flow conditions.

Collected water samples were transported on ice to the Vermont Agriculture and Environmental Lab (VAEL) in Burlington, VT within the stated holding times for each analyte. Samples were tracked using a Chain of Custody form that was completed by the sampler and accompanied all water samples delivered to VAEL. 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 were accepted by VAEL, they were subject to the lab's internal tracking system.

#### **4.5 Testing and Measurement Protocols**

All water samples were analyzed according to VAEL's standard methods. These methods and relevant data quality objectives, assessment procedures, and reporting limits are described in VAEL's Quality Systems Manual, Revision 23, dated December 18, 2015. Methods of analysis are summarized in Table 4. Approved analytical data are presented in Appendix A.

Table 4. Water analysis methods

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

Due to difficulty with the field preservation procedure, acidified TN samples were acidified following delivery to the VAEL Laboratory on five sampling dates: 12/4/2017, 12/15/2017, 12/19/2017, 01/16/2018, and 2/1/2018. All TN samples were preserved with acid within 24 hours of collection.

#### 4.6 Phosphorus Loading Computations

Collection of flow-proportional samples ensures that the resulting composite sample is a true representation of the variability in P concentrations over the sampling period. For each sampling period (typically 6-8 days), weekly loads were calculated simply as the product of the weekly total discharge and the composite sample concentrations of TP and for TDP. The TP and TDP loads for the approximately weekly sampling periods were summed to compute TP and TDP loads by month and for the entire period during which composite samples were collected.

For the period between November 14, 2017 and the end of April 2018, autosamplers were shut down due to freezing conditions. During this period, grab samples were collected approximately weekly, while also targeting specific high flow events for sampling. The flow rate (in L/15-minute) corresponding to the time of grab sample collection was multiplied by the sample concentrations to compute instantaneous TP and TDP loads. Note that use of the term “instantaneous” is not entirely accurate, as the flowmeters record the total flow volume over a 15-minute period. Also, at very low flow rates when the cumulative volume was less than 100 L/15-minutes, flow rates of zero were frequently recorded. In these instances, the flow volume was summed over a two-hour period spanning the sampling time and divided by the number of 15-minute readings to produce an average 15-minute flow volume, which was then used in the “instantaneous” load calculation. The 15-minute flow volumes and TP and TDP loads were log transformed to meet the assumptions of parametric statistics. Simple linear regression was then used to relate the TP and TDP loads to the corresponding 15-minute flow volumes. Regressions were statistically significant ( $P < 0.01$ ) at all sites (Table 5). The resulting regression equations were then applied to the continuous 15-minute flow record to obtain a corresponding continuous record of TP and TDP loads. These loads were then summed by month. Finally, the flow volumes and TP and TDP loads for the winter months calculated using regression were combined with the flow volumes and loads calculated during for the April – November 2017 flow-paced sampling period to provide annual flow and TP and TDP loading estimates for each station.

Table 5. Results *P* loading regression analyses for winter grab sampling period

Station	Number of grab samples collected	Adjusted R <sup>2</sup> TP load vs. volume	Adjusted R <sup>2</sup> TDP load vs. volume
JBT01	16	0. 94*	0. 98*
JBT02	12	0. 92*	0. 95*
JBT04	15	0. 92*	0. 96*
JBT05	16	0. 91*	0. 91*
JBT06	15	0. 97*	0. 97*
JBT07	12	0. 95*	0. 95*
JBT11	12	0. 95*	0. 96*
JBT13	14	0. 86*	0. 92*
JBT14	11	0. 92*	0. 94*
JBT16	15	0. 83*	0. 94*
JBT18	12	0. 95*	0. 93*
JBT19	4 <sup>a</sup>	0. 98*	0. 98*

\*Significant at  $P < 0.01$

<sup>a</sup> Multiple winter grab samples collected at JBT19 were invalid

Shortly after a mid-winter thaw on January 11th and 12th, sediment buried the autosampler intake line at station JBT19. Consequently, sample results from January 12 through March 31, 2018 were invalid at this site due to high sediment content.

## 5. Quality Assurance Tasks Completed

Sample analyses by VAEL were conducted according to the laboratory's established procedures, which are described in VAEL's Quality Systems Manual, Revision 23, dated December 18, 2015. This manual identifies the analytical methods and relevant data quality objectives, assessment procedures, and reporting limits applied. Field quality assurance measures included adherence to the study Quality Assurance Project Plan and the Study-Specific Sampling Procedure included as an appendix to the QAPP.



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## 6. Results

### 6.1 Tile Drainage System Construction and Agronomic Data



Figure 7. JBT06 outfall (12-inch diameter)



Figure 8. JBT02 outlet discharging directly to Jewett Brook

All 12 tile drainage systems selected for monitoring are constructed of standard, perforated, corrugated drain pipe. Tile drains were installed in most of the study fields within the last decade. The outfalls of these systems range in diameter from 4–12 inches; there are four 4-inch, four 6-inch, three 8-inch, and one 12-inch diameter outfalls (Figure 7). Nine of the 12 tile drains discharge to drainage ditches, generally close to the bottom of the ditch such that submergence is common. The remaining three—JBT01, JBT02 (Figure 8), and JBT04—drain contiguous fields and discharge directly to Jewett Brook. The depths of the tile drains generally range from 3–5 feet below ground surface, with most in the 3–4 foot range. There do not appear to be any exceptionally shallow or deep tile drains. All but one of the study fields has patterned tile drainage. Only JBT16 has a dendritic (branching) system. Drain spacing among the patterned tile drain systems is in the typical range of 25–40 feet, except for JBT18 and JBT19, which have 80-foot spacing that is unusually wide. Data summarizing the construction of the selected tile drainage systems are presented in Table 6.

Table 6: Construction of the selected tile drainage systems

Site	Year installed	Outfall diam. (in.)	Outfall position	Depth (ft)	Nominal spacing (feet)	Surface inlet type	Comment
JBT01	~2012	6	surcharges	3-5	25	None known	
JBT02	~2012	4	underwater	3-5	25	None known	
JBT04	~2012	4	surcharges	3-5	25	None known	
JBT05	2011	8	surcharges	3-4	35	None known	Majority of field outside JBW
JBT06	Unknown	12	surcharges	unknown	unknown	3 standpipes	Significant erosion (gully)
JBT07	2011	4	may surcharge	3-4	40	None known	Tile exposed ~6'
JBT11	2010	8	surcharges	3-4	40	None known	Existing structure raises level of outlet
JBT13	2013	6	surcharges	3	40	None known	
JBT14	2013	8	surcharges	3	40	2 inlet pipes in ditches (one clogged)	
JBT16	~2004	4	may surcharge	3-4	dendritic	1 surface inlet at northern property boundary, 100 yards into field from road	Cropped to edge of bank
JBT18	2006	6	surcharges	3	80	None known	
JBT19	2006	6	surcharges	3	80	None known	

#### 6.1.1 Surface Inlets to Tile Drains

There are no known surface inlets into 9 of the 12 tile drainage systems selected for this study. In field JBT06, there is a cluster of three standpipes in a wet area that are connected to the underlying tile lines. Field JBT16 has one surface inlet, which receives runoff from an adjacent residential property and overflow from a pond. It is located along the property boundary on the north side of the field, approximately 300 feet into the field from the road. There are also two connected standpipes in ditches bordering the JBT14 field. One appears to receive little, if any, runoff from field areas. The second standpipe appears to receive runoff from cropped areas, but it was plugged.

#### 6.1.2 Crop Production in Study Fields

Nine of the 12 study fields were in silage corn production in 2016. Two of these—JBT01 and JBT02—were planted in soybeans in 2017, while the remaining seven remained in corn. Three fields—JBT11, JBT18, and JBT19—are in continuous hay production. JBT11 was seeded in 2015 in alfalfa hay and JBT18 and JBT19 were seeded in 2016 for clover hay production. Five of the corn fields being monitored were seeded with a cover crop of winter rye in 2016.

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### 6.1.3 *Study Field Soil Types*

Two soil complexes comprise most of the area of the study fields. These complexes are the Massena-Lyons stony loams and Kingsbury-Covington clays. Kingsbury-Covington clays are the principal soils in 7 of the 12 study fields. Massena-Lyon stony loams are the principal soils in four fields. The remaining field, JBT19, has a roughly equal acreage in both soil complexes.

Massena-Lyons soils are deep, level to gently sloping, somewhat poorly drained and poorly drained, loamy soils in depressional areas (Flynn and Joslin 1979). These soils formed in glacial till. The Massena soils are at a slightly higher position in the landscape than the Lyons soils. Both soils have a seasonal high water table. Without drainage, crop production on Massena-Lyons soils may be limited by wetness and a high water table.

Clays in the Kingsbury-Covington complex are deep and somewhat poorly drained to poorly drained (Flynn and Joslin 1979). They formed in water laid deposits of clay on old lake plains. Kingsbury soils are at a higher position in the landscape than Covington soils. Both soils have a seasonal high water table. Without drainage, crop production on Kingsbury-Covington soils may be limited by wetness due to their slow permeability.

Georgia stony loam is also a significant soil in several of the study fields. Georgia stony loam comprises 31 percent of field JBT11, 17 percent of JBT18, and 10 percent of JBT05. Georgia stony loams are deep and moderately well drained, in contrast to the other dominant soils among the study fields (Flynn and Joslin 1979). They are stony or extremely stony and they formed in glaciated uplands in western Franklin County.

### 6.1.4 *Manure and Fertilizer Applications in Study Fields*

In 2016, the manure and fertilizer application methods of the six participating farmers on the study fields differed dramatically. Manure application methods on the cornfields included spring application at planting on JBT13 and JBT14, fall surface application on JBT07, fall incorporation on JBT16, and fall injection on JBT05 and JBT06. A small amount of “pop-up” or starter fertilizer containing P was applied at planting on all the cornfields except JBT13 and JBT14.

On the three hay fields, no commercial fertilizer containing P was applied. Manure was applied to the two clover hay fields, JBT18 and JBT19, in mid-May 2016. Field JBT11 apparently received no P in any form.

In 2017, manure application methods included spring application at planting again on JBT13 and JBT14, fall incorporation again on JBT16, fall injection again on JBT05 and JBT06, and late fall surface application on JBT01 and JBT02. A small amount of “pop-up” or starter fertilizer containing P was applied at planting on all row cropland (corn and soybean) except JBT13 and JBT14. As in 2016, field JBT11 received no P in any form.

Agronomic data for the study fields are presented in Table 7.

Table 7. Agronomic data for the study fields

Site	Area (A)	Crop	Soil Survey Data % area, type, slope, hydro group	Soil Test P (ppm)	Fertilizer Application	Manure Application	Cover Crop	2017 Dates
JBT01	25	2016: Silage corn 2017: Soybean	82%: Kingsbury clay, 0 to 3%, D 10%: Massena stony loam, 0 to 3%, C/D 8%: Kingsbury clay, 3 to 8%, D	7.2	2016: starter at plant; urea in June or July 2017: starter at plant	2016: None Fall 2017: spread	2016: None 2017: None	SB harvested ~10/3 Plowed ~ 10/24 Manure spread ~11/15
JBT02	4.7	2016: Silage corn 2017: Soybean	69%: Kingsbury clay, 3 to 8%, D 31%: Kingsbury clay, 0 to 3%, D	9.3	2016: starter at plant; urea in June or July 2017: starter at plant	2016: None Fall 2017: spread	2016: None 2017: None	SB harvested ~10/3 Plowed ~ 10/24 Manure spread ~11/15
JBT04	5.7	2016: Silage corn 2017: Silage corn	100%: Kingsbury clay, 0 to 3%, D	4.5	2016: starter at plant 2017: starter at plant	2016: None 2017: None	2016: None 2017: None	Corn chopped, field plowed ~11/20
JBT05	94	2016: Silage corn 2017: Silage corn	30%: Kingsbury clay, 0 to 3%, D 30%: Massena stony loam, 0 to 3%, C/D 29%: Covington clay, D 10%: Georgia stony loam, 3 to 8%, C	?	2016: pop-up at plant 2017: pop-up at plant	Fall 2016: inject Fall 2017: inject	2016: Winter rye 2017: Winter rye	Corn harvested ~10/10 Manure spread ~10/10 Manure injected on part of field ~10/24
JBT06	91	2016: Silage corn 2017: Silage corn	51%: Covington clay, D 36%: Massena stony loam, 0 to 3%, C/D 7%: Kingsbury clay, 0 to 3%, D 6%: Georgia stony loam, 3 to 8%, C	?	2016: pop-up at plant 2017: pop-up at plant	Fall 2016: inject Fall 2017: inject	2016: Winter rye 2017: Winter rye	Corn harvested ~10/10 Manure injected ~10/24
JBT07	28	Continuous silage corn	53%: Covington clay, D 37%: Kingsbury clay, 0 to 3%, D 10%: Massena stony loam, 0 to 3%, C/D	12	2016: 5 gal/A pop-up at plant 2017: 5 gal/A pop-up at plant	Fall 2016: 6,000 gal/A Fall 2017: None	2016: None 2017: None	Corn harvested ~10/17 Manure injected ~10/24 Plowed ~ 11/20
JBT11	51	Continuous alfalfa hay	58%: Massena stony loam, 0 to 3%, C/D 16%: Georgia stony loam, 3 to 8%, C 15%: Georgia stony loam, 0 to 3%, C 11%: Covington clay, D	4	2016: No P 2017: No P	2016: None 2017: None	2016: NA 2017: NA	Hay cut ~7/5 Hay cut ~8/30 Hay cut ~10/24
JBT13	22	Continuous silage corn	52%: Massena stony loam, 0 to 3%, C/D 47%: Kingsbury clay, 0 to 3%, D	?	2016: No P 2017: No P	2016: 6,000 gal/A at plant 2017: 6,000 gal/A (5/10-11) at plant	2016: Winter rye 2017: Winter rye	Manure 5/10-11, approx. 6000 gal/A Corn harvested ~10/11
JBT14	33	Continuous silage corn	97%: Massena stony loam, 0 to 3%, C/D 3%: Binghamville silt loam, C/D	?	2016: No P 2017: No P	2016: 6,000 gal/A at plant 2017: 6,000 gal/A (5/10-11) at plant	2016: Winter rye 2017: Winter rye	Manure applied 5/10-11, approx. 6000 gal/A Corn harvested ~10/11
JBT16	7.0	Continuous silage corn	76%: Massena stony loam, 0 to 3%, C/D 10%: Lyons stony loam, C/D 6%: Covington clay, D 4%: St. Albans slaty loam, 3 to 8%, A 3%: Georgia stony loam, 0 to 3%, C	?	2016: pop-up at plant 2017: pop-up at plant	Fall 2016: incorporated Fall 2017: incorporated	2016: Winter rye 2017: Winter rye	Plowed ~5/30 Harvested corn ~9/26 Manure spread between 9/27 and 10/1
JBT18	11	2016: Hay (clover) 2017: Hay (clover)	43%: Kingsbury clay, 0 to 3%, D 25%: Massena stony loam, 0 to 3%, C/D 17%: Georgia stony loam, 0 to 3%, C 15%: Covington clay, D	?	2016: No P 2017: No P	2016: 12 ton/A in mid-May 2017: None	2016: NA 2017: NA	Hay cut ~8/30 Hay cut ~10/24
JBT19	10	2016: Hay (clover) 2017: Hay (clover)	48%: Kingsbury clay, 0 to 3%, D 43%: Lyons stony loam, C/D 7%: Massena stony loam, 0 to 3%, C/D	?	2016: No P 2017: No P	2016: 12 ton/A in mid-May 2017: None	2016: NA 2017: NA	Hay cut ~8/30 Hay cut ~10/24



## 6.2 Tile Drain Monitoring Data

Table 8 presents the dates flow monitoring and autosampling began at each monitoring station. Approved analytical results are included as Appendix A.

Table 8: Start dates for monitoring activities at each station

Station	Start flow monitoring	Start autosampling
JBT01	3/23/17	4/5/17
JBT02	3/23/17	4/5/17
JBT04	4/3/17	4/5/17
JBT05	4/20/17	4/20/17
JBT06	4/5/17	4/5/17
JBT07	3/30/17	4/5/17
JBT11	4/5/17	4/5/17
JBT13	4/3/17	4/11/17
JBT14	4/5/17	4/5/17
JBT16	3/30/17	4/5/17
JBT18	4/22/17	4/22/17
JBT19	4/22/17	4/22/17

Flow rates over the course of the monitoring period varied from zero during dry weeks in August and September 2017 to as high as 3,300 L per minute at station JBT06 (which drains a 100-acre field) during a rain event on May 2, 2017. All tile drains stopped flowing for periods ranging from days to several weeks in late summer 2017. The large quantity of flow data precludes presenting these data in tables. Figure 9 below displays the flow rate data at station JBT01 over the monitoring period to provide a sense of the variation and seasonal pattern in flow rates. Tile drain flows were sustained in the late winter and spring periods, whereas in summer and early fall the tile drains flowed in response to rain events, with little or no flow between rains.

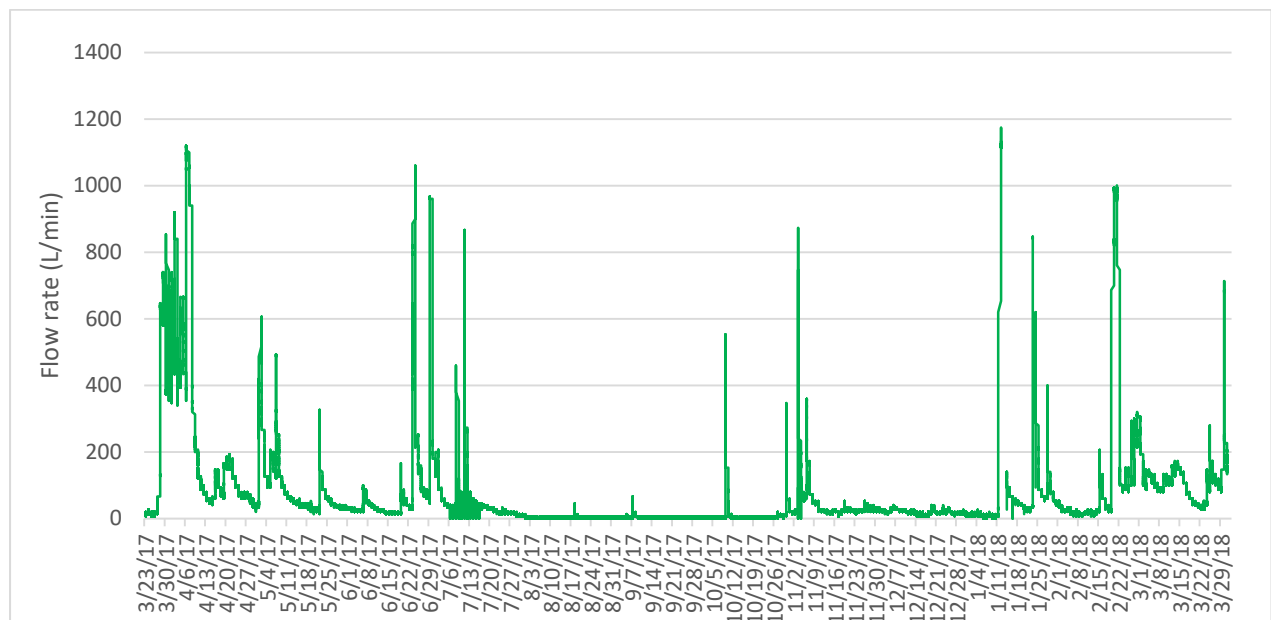


Figure 9. Flow rate at the JBT01 tile drain monitoring station

### 6.2.1 Descriptive Statistics for Monitored Tile Drains

Table 9 presents summary statistics for all the tile drain monitoring data, combining all stations and months.

Table 9. Descriptive results, all fields and months combined

	TP concentration (µg/L)	TDP concentration (µg/L)	Flow (m <sup>3</sup> /mo.)	TP loading (kg/mo.)	TDP loading (kg/mo.)
Range	18 – 6,977	9 – 4,826	9 – 27,500	0.001 – 5.46	<0.001 – 3.78
Median	150	59	920	0.15	0.06
Mean <sup>1</sup>	140	63	976	0.14	0.06
S.D. <sup>1</sup>	2.4	2.4	5.3	6.2	7.2
n	156	156	156	156	156

1. Anti-log of log mean, s.d.

Table 10 presents summary statistics for the individual monitored tile drains.

Table 10. Descriptive results by field (all data)

	TP concentration (µg/L)	TDP concentration (µg/L)	Flow (m <sup>3</sup> /mo.)	TP loading (kg/mo.)	TDP loading (kg/mo.)
<b>JBT01</b>					
Range	30 – 424	17 – 81	49 – 6,015	0.002 - 1.32	0.001 - 0.37
Median	135	45	2,216	0.45	0.11
Mean <sup>1</sup>	137	41	1,500	0.20	0.06
S.D. <sup>1</sup>	2.1	1.6	5.0	7.5	6.6
n	13	13	13	13	13
<b>JBT02</b>					
Range	129 – 936	56 – 92	15 – 836	0.002 - 0.36	0.001 - 0.15
Median	362	102	264	0.13	0.05
Mean <sup>1</sup>	362	123	195	0.07	0.02
S.D. <sup>1</sup>	1.8	1.8	3.7	4.5	4.6
n	13	13	13	13	13
<b>JBT04</b>					
Range	45 – 675	23 – 108	56 – 1,230	0.007 - 0.23	0.003 - 0.07
Median	215	51	403	0.12	0.03
Mean <sup>1</sup>	211	52	398	0.08	0.02
S.D. <sup>1</sup>	1.6	1.5	2.6	2.8	2.8
n	13	13	13	13	13
<b>JBT05</b>					
Range	60 – 454	40 – 299	778 – 11,078	0.08 – 2.4	0.04 – 2.0
Median	193	138	6,153	1.18	0.78
Mean <sup>1</sup>	168	116	4,150	0.70	0.48
S.D. <sup>1</sup>	1.7	1.9	2.6	3.4	3.9
n	13	13	13	13	13
<b>JBT06</b>					
Range	61 – 650	39 – 528	44 – 27,520	0.004 - 5.4	0.002 - 3.8
Median	153	110	10,813	2.10	1.30
Mean <sup>1</sup>	106	105	4,350	0.70	0.46
S.D. <sup>1</sup>	1.8	2.0	8.3	11.7	13.5
n	13	13	13	13	13

	TP concentration (µg/L)	TDP concentration (µg/L)	Flow (m <sup>3</sup> /mo.)	TP loading (kg/mo.)	TDP loading (kg/mo.)
<b>JBT07</b>					
Range	26 – 388	22 – 162	50 – 3,568	0.006 - 0.67	0.003 - 0.40
Median	137	88	1,122	0.22	0.09
Mean <sup>1</sup>	145	75	916	0.13	0.07
S.D. <sup>1</sup>	2.0	1.8	3.2	4.2	4.1
n	13	13	13	13	13
<b>JBT11</b>					
Range	18 – 386	14 – 374	9 – 10,847	<0.001-0.57	<0.001-0.40
Median	46	28	3,823	0.16	0.08
Mean <sup>1</sup>	53	33	1,913	0.10	0.06
S.D. <sup>1</sup>	2.1	2.4	7.5	5.9	6.4
n	13	13	13	13	13
<b>JBT13</b>					
Range	53 – 6,977	28 – 4,826	40 – 782	0.009 - 5.46	0.005 - 3.78
Median	440	62	440	0.07	0.03
Mean <sup>1</sup>	240	104	328	0.08	0.03
S.D. <sup>1</sup>	3.3	3.7	2.4	4.9	5.5
n	13	13	13	13	13
<b>JBT14</b>					
Range	52 – 961	34 – 366	181 – 9,149	0.06 – 5.42	0.04 – 2.07
Median	181	93	3,548	0.55	0.28
Mean <sup>1</sup>	194	100	2,921	0.56	0.29
S.D. <sup>1</sup>	2.0	1.8	3.1	3.8	3.5
n	13	13	13	13	13
<b>JBT16</b>					
Range	22 – 414	9 – 269	50 – 3,567	0.004 - 0.19	0.002 - 0.07
Median	45	26	874	0.09	0.04
Mean <sup>1</sup>	62	30	839	0.05	0.02
S.D. <sup>1</sup>	2.3	2.3	4.1	3.3	3.1
n	13	13	13	13	13
<b>JBT18</b>					
Range	61 – 266	28 – 114	29 – 2,305	0.002 - 0.52	0.001 - 0.25
Median	150	73	517	0.06	0.03
Mean <sup>1</sup>	140	64	488	0.07	0.03
S.D. <sup>1</sup>	1.3	1.6	3.5	4.6	4.8
n	13	13	13	13	13
<b>JBT19</b>					
Range	34 – 110	14 – 48	22 – 2,417	0.001 - 0.25	<0.001 - 0.09
Median	62	26	760	0.03	0.02
Mean <sup>1</sup>	66	26	540	0.04	0.01
S.D. <sup>1</sup>	1.4	1.5	4.1	4.6	5.5
n	13	13	13	13	13

<sup>1</sup> Anti-log of log mean, s.d.

Figures 10 and 11 present the percentage of TP present in a dissolved form (%TDP) across the tile drains (Figure 10) and over the 12-month monitoring period (Figure 11). The percentage of P present in a particulate form is the inverse of %TDP (100% - %TDP). The %TDP results

generally varied by site characteristics. For example, tile drains JBT01, JBT02, and JBT04, which drain adjacent field areas with very fine textured soils, typically had a relatively low percentage of P in the dissolved form (and high particulate P). The tile drains draining the two cornfields in long-term no-till (JBT05 and JBT06) tended to have among the highest percentages of P in the dissolved form.

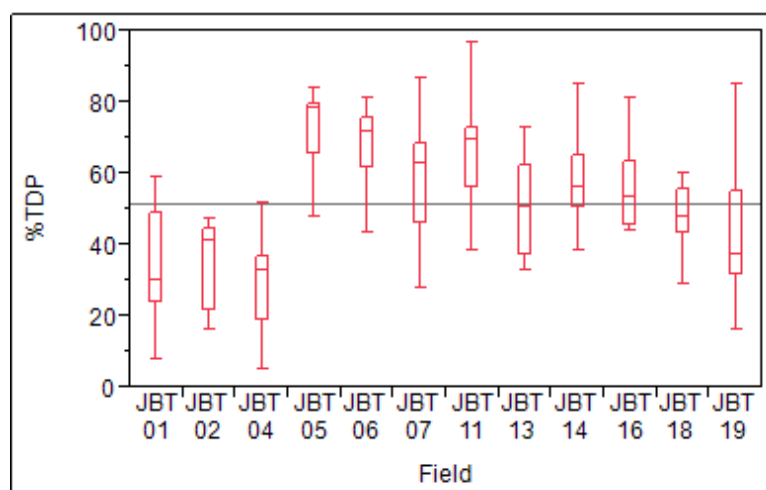


Figure 10. Percent of P in dissolved form, by field (excludes April 2017)

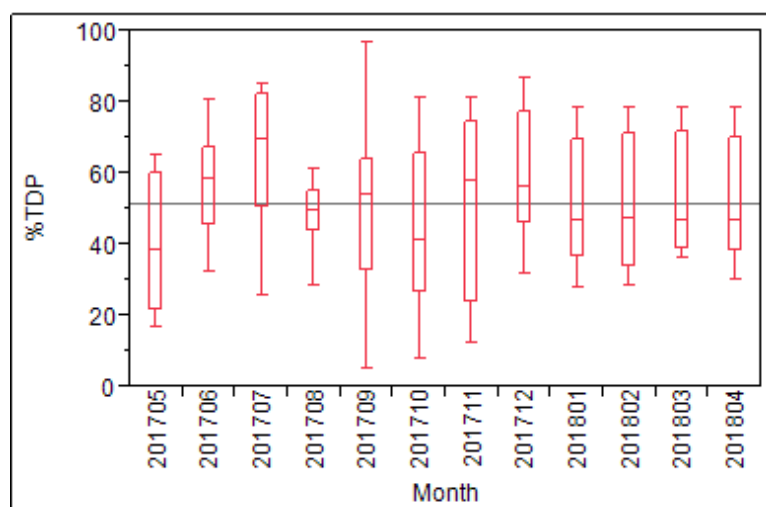


Figure 11. Percent of P in dissolved form, by month (excludes April 2017)

Figures 12 and 13 illustrate the distributions of TP and TDP concentrations and loads and flow by study field (Figure 12) and by month (Figure 13). Although seasonal patterns of P concentration in tile drain flow have been reported in the literature (although inconsistently), there was no distinct seasonal pattern observed for either TP or TDP concentrations in tile drainage from JBT fields (Figure 13). Although lowest concentrations tended to occur in December and highest concentrations in October, both high and low P concentrations were observed in all months over the monitoring period.

Figure 12. Tile drain monitoring data by field<sup>1</sup>

1. Incomplete month of April 2017 and high P outlier at JBT13 excluded

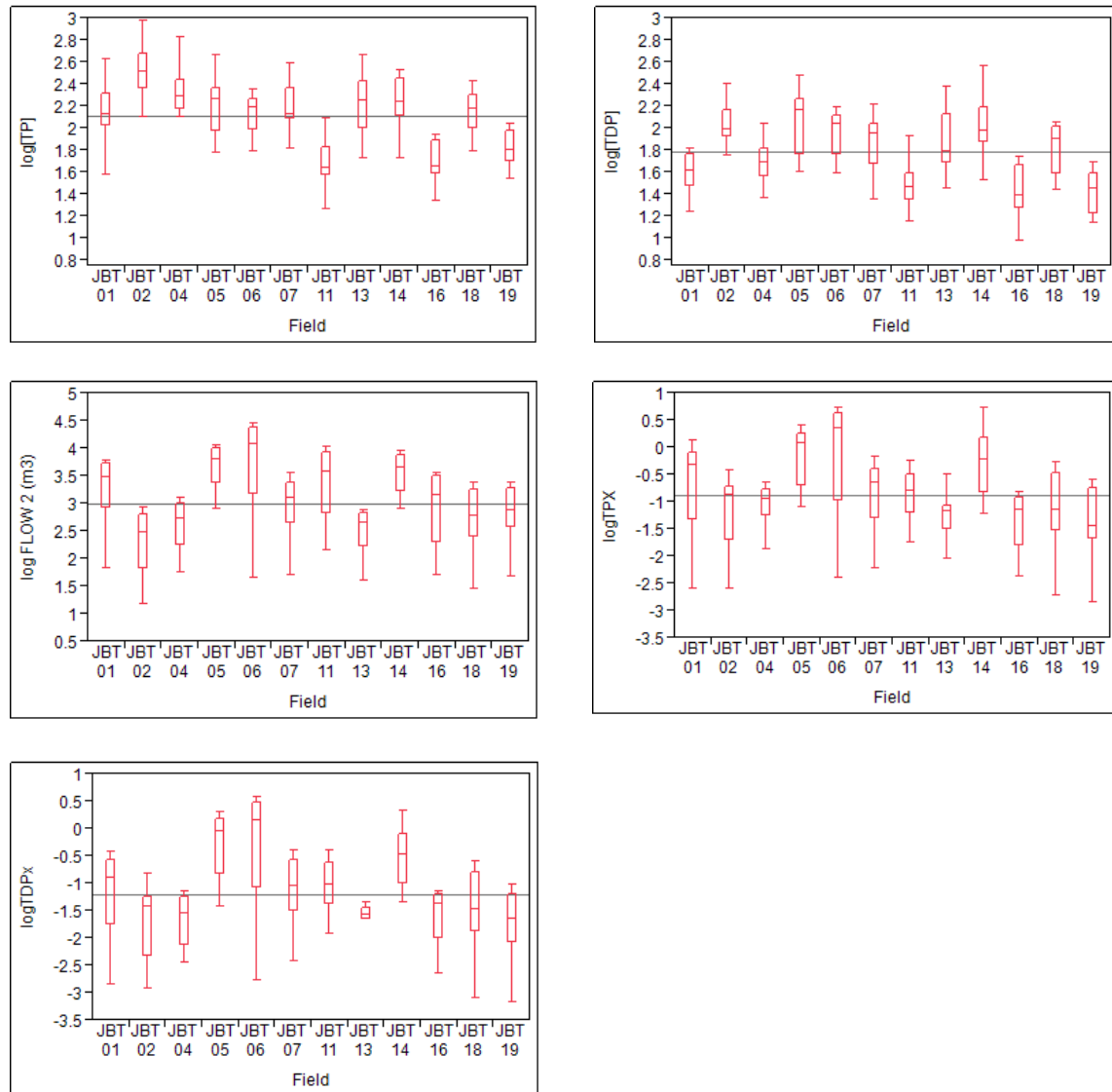


Table 11. Analysis of Variance for tile drain monitoring data by field<sup>1</sup>

	JBT01	JBT02	JBT04	JBT05	JBT06	JBT07	JBT11	JBT13	JBT14	JBT16	JBT18	JBT19
[TP] (µg/L)	127 c	339 a	196 b	164 bc	152 bc	137 bc	54 d	164 bc	186 bc	55 d	138 bc	67 d
[TDP] (µg/L)	39 ef	110 ab	50 de	117 a	101 ab	76 bc	35 ef	80 abc	105 ab	30 f	66 cd	26 f
Flow (m <sup>3</sup> /mo.)	1532 bc	201 f	414 def	4383 a	4334 a	958 cd	1836 abc	320 ef	3081 ab	848 cde	504 def	538 de
TP load (kg/mo.)	0.195 bc	0.068 cde	0.081 cde	0.720 a	0.660 a	0.132 cd	0.099 cde	0.052 de	0.572 ab	0.047 de	0.070 cde	0.037 e
TDP load (kg/mo.)	0.060 bcd	0.022 cde	0.021 de	0.511 a	0.438 a	0.073 b	0.065 bc	0.026 bcde	0.323 a	0.026 bcde	0.034 bcde	0.015 e

1. Incomplete month of April 2017 and high P outlier at JBT13 excluded

2. Within rows, means followed by same letter(s) do not differ significantly,  $P \leq 0.10$

NOTE: values are anti-log of log means. These values DO NOT correspond to means reported in descriptive statistics because one extreme high outlier and the incomplete month of April 2017 are excluded.

Figure 13. Tile drain monitoring data by month<sup>1</sup>

1. Incomplete month of April 2017 and high P outlier at JBT13 excluded

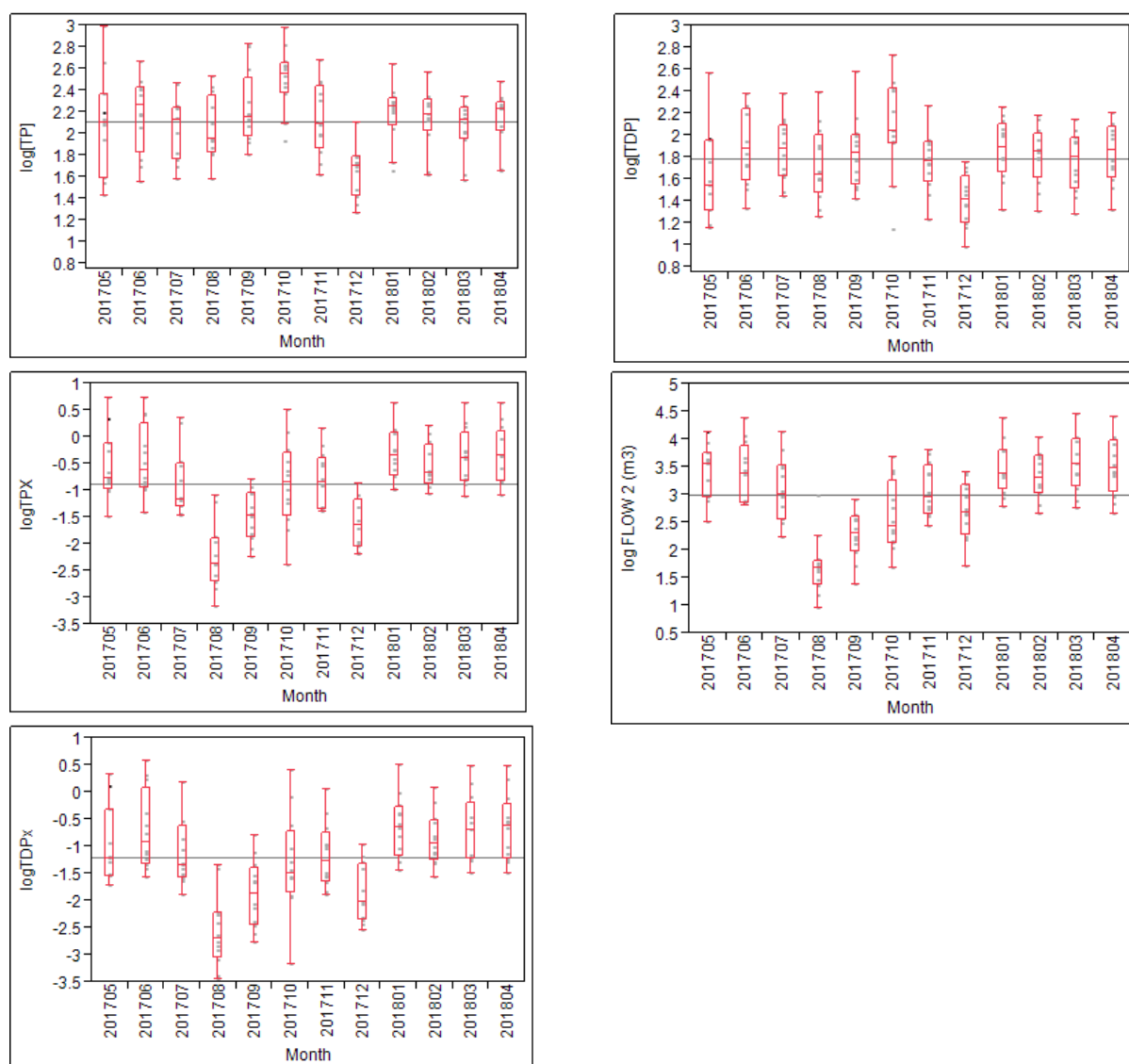


Table 12. Analysis of Variance for tile drain monitoring data by month<sup>1</sup>

	May 2017	June 2017	July 2017	Aug. 2017	Sep. 2017	Oct. 2017	Nov. 2017	Dec. 2017	Jan. 2018	Feb. 2018	Mar. 2018	Apr. 2018
[TP] ( $\mu\text{g/L}$ )	122 <b>b</b>	148 <b>b</b>	114 <b>b</b>	111 <b>b</b>	169 <b>b</b>	320 <b>a</b>	135 <b>b</b>	44 <b>c</b>	154 <b>b</b>	135 <b>b</b>	112 <b>b</b>	138 <b>b</b>
[TDP] ( $\mu\text{g/L}$ )	43 <b>c</b>	80 <b>ab</b>	72 <b>ab</b>	54 <b>bc</b>	69 <b>bc</b>	117 <b>a</b>	57 <b>bc</b>	25 <b>d</b>	74 <b>ab</b>	65 <b>bc</b>	57 <b>bc</b>	68 <b>bc</b>
Flow ( $\text{m}^3/\text{mo.}$ )	2352 <b>ab</b>	2427 <b>ab</b>	1176 <b>b</b>	50 <b>e</b>	190 <b>d</b>	403 <b>cd</b>	1183 <b>b</b>	517 <b>c</b>	3071 <b>a</b>	2107 <b>ab</b>	3598 <b>a</b>	3242 <b>a</b>
TP load ( $\text{kg}/\text{mo.}$ )	0.288 <b>abc</b>	0.359 <b>ab</b>	0.135 <b>c</b>	0.006 <b>e</b>	0.032 <b>d</b>	0.129 <b>c</b>	0.160 <b>bc</b>	0.023 <b>d</b>	0.473 <b>a</b>	0.284 <b>abc</b>	0.404 <b>a</b>	0.447 <b>a</b>
TDP load ( $\text{kg}/\text{mo.}$ )	0.102 <b>abc</b>	0.194 <b>a</b>	0.084 <b>abc</b>	0.003 <b>e</b>	0.013 <b>d</b>	0.047 <b>c</b>	0.067 <b>bc</b>	0.013 <b>d</b>	0.227 <b>a</b>	0.137 <b>ab</b>	0.206 <b>a</b>	0.220 <b>a</b>

1. Incomplete month of April 2017 and high P outlier at JBT13 excluded

2. Within rows, means followed by same letter(s) do not differ significantly,  $P \leq 0.10$

NOTE: values are anti-log of log means. These values DO NOT correspond to means reported in descriptive statistics because one extreme high outlier and the incomplete month of April 2017 are excluded.

### 6.2.2 Discussion of P Concentrations in JBW Tile Drains

Table 13 summarizes all the tile drain P concentrations observed in the JBW, except for a single exceedingly high TP concentration recorded at station JBT13 on May 16, 2017, where it appeared manure entered the tile drain following a surface application and a rain event.

Table 13. Tile drain P concentrations observed in the JBW<sup>1</sup>

	TP concentration (µg/L)	TDP concentration (µg/L)
Range	18 – 6,977	9 – 4,826
Median	150	59
Mean <sup>2</sup>	140	63
S.D. <sup>2</sup>	2.4	2.4
n	156	156

1. Excludes high TP outlier at JBT13 on 5/16/17

2. Anti-log of log mean, s.d.

Phosphorus concentrations in JBW tile drainage (Table 13) were substantially higher than those previously reported from similar land uses in the LCB region (Stone 2016b). From studies that examined seasonal or multi-event tile drainage, Benoit (1973) reported all tile drainage samples from corn silage and hay plots in Franklin, VT contained less than 20 µg/L TP, the detection limit. More recently, Young (2015) reported TP concentrations of 23 – 175 µg/L (mean 98 µg/L) and SRP concentrations of 9 – 41 µg/L (mean 11 µg/L) in tile drainage water on five farms in Clinton and St. Lawrence Counties, NY. In the same region, Klaiber (2015) reported mean TP concentration in tile drainage of 29 µg/L and mean SRP concentration of 12 µg/L in tile drainage from seven events over a year. Note that all these data were reported from seasonal or multi-event data, not from samples collected throughout the year. Given the tremendous variability observed among individual samples of tile drain flow, it is more appropriate to compare these JBW data with data reported from annual studies (see Table 14).

Table 14. Selected annual P concentrations observed in New York and Quebec

Location	Land Use	TP concentration <sup>1</sup> (µg/L)	SRP concentration <sup>1</sup> (µg/L)	Reference
NY	Corn	110 – 9,800		Goehring et al. 2001
NY	Corn		9 – 441	Hergert et al. 1981
Que	Corn-soybeans	10 – 130	10 – 30	Beauchemin et al. 1998
Que		60 – 370		Enright and Madramootoo 2004
Que	Corn	200	40	Simard 2005
Que	Corn	11 – 53	1 – 12	Simard 2005
Que	Corn, grains, grass	<1 – 2,726		Goulet et al. 2006

1. Single values represent means; otherwise range is reported. Note that SRP is not equivalent to TDP measured in JBW

TP concentrations observed in JBW tile drainage were more comparable to the range observed in Ontario (20 – 9,700 µg/L), Ohio (110 – 300 µg/L), and in Wisconsin (80 – 1,780 µg/L) than to the few LCB studies available (Benoit 1973, Young 2015, and Klaiber 2015).

Unlike the tendency for high P concentrations in tile discharge to be associated with stormflow or other high flow periods, data from the JBW did not show widespread significant associations between high tile flow and high P concentrations. While positive flow-concentration associations were suggested in some cases (more often for TDP than for TP), relationships were generally nonsignificant, sometimes confounded by transient high concentrations such as those observed immediately following manure applications. Another explanation for this result is that by collecting composite samples over the course of approximately seven days, higher particulate P concentration water we would expect to measure during peak flows was diluted by lower particulate P concentration water sampled during lower flow periods prior to and after an event.

### 6.2.3 Discussion of Flow in JBW Tile Drains

The spring and early summer of 2017 were wetter than normal, which caused sustained tile drain flow later into the summer than is typical. June 2017 was exceptionally wet, with total rainfall recorded at the Burlington National Weather Service Station (43 km from the JBW) of 7.17 in. (18.2 cm), nearly double the 30-year average (Table 15). Monthly rainfall totals were below average for the remainder of 2017.

*Table 15. Monthly precipitation totals and 30-yr normals in Burlington, VT*

Years	Normal Monthly Precipitation (1981-2010) (in.)	Total Monthly Precipitation 2017/2018 (in.)
Apr	2.82	3.83
May	3.45	4.91
Jun	3.69	7.17
Jul	4.16	3.45
Aug	3.91	2.40
Sep	3.64	2.79
Oct	3.60	3.55
Nov	3.13	1.68
Dec	2.38	2.18
Jan	2.06	2.54
Feb	1.76	1.40
Mar	2.22	2.63
Apr	2.82	4.84

Source: NOAA NWS, Burlington, VT (NOAA 2019)

Literature reports suggest that the volume of tile flow tends to follow strong seasonal patterns. Although tile drain flow can respond to large precipitation or snowmelt events at any time of year, the largest drainage volumes tend to occur from fall through spring, with tile drain flow becoming very small or entirely absent during the summer growing season.

In the JBW, tile drain flow was lowest August – September 2017 and tended to be high May – July 2017 and January – April 2018 (Figure 14). Note that the monitoring period covered just one annual cycle.



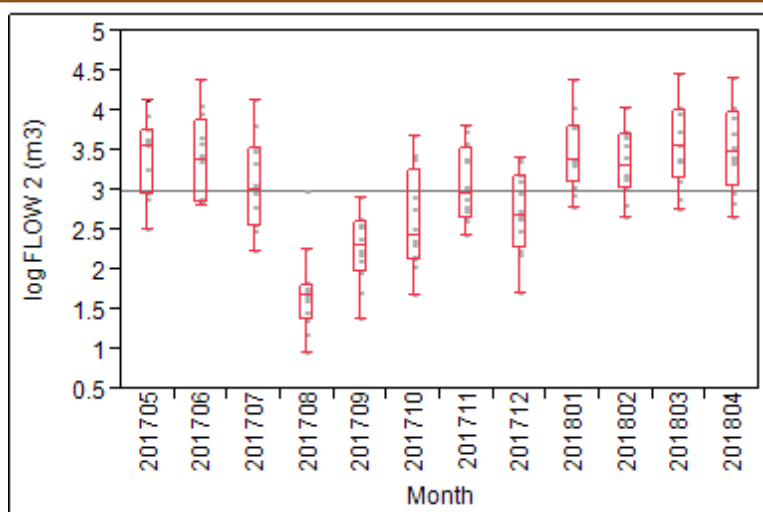


Figure 14. Distribution of tile drain flow rates

#### 6.2.4 Discussion of P Loading in JBW Tile Drains

Table 16 summarizes all the tile drain P loading data calculated for monitored tile drains in the JBW. The exceedingly high TP concentration and loading recorded at station JBT13 on May 16, 2017 was not included in these computations.

Table 16. Summary of P loading data for all monitored JBW tile drains

	Areal TP loading (kg/ha/yr)	Areal TDP loading (kg/ha/yr)
Range	0.122 – 1.124	0.083 – 0.556
Median	0.541	0.199
Mean	0.555	0.272
95% C.I.	0.368 – 0.743	0.166 – 0.378

Just as with P concentration, reported P loads attributed to tile drain flow have been highly variable. With the exception of TP loads in New York (within the LCB) reported by Klaiber (2015) (0.13 kg/ha/yr and SRP of 0.05 kg/ha/yr in tile drainage from grass plots), monitored P loading in tile drain flow from JBW agricultural fields was in a range comparable to that reported in the literature (Stone 2016b, Table 4). Miller (1979) reported TP losses of 0.28 kg/ha/yr and PO<sub>4</sub>-P losses of 0.08 kg/ha/yr from Ontario crop fields. In the Quebec portion of the LCB, Jamieson et al. (2003) reported an estimated TP load in subsurface drainage from a corn field during snowmelt of 0.1 kg/ha, representing 37% of the total snowmelt P load from the field. Simard (2005) measured mean P loads exported from corn fields in the Missisquoi Bay watershed averaging 0.61 kg/ha/yr. Annual TP loads in tile drainage from one field varied from 0.69 to 1.23 kg/ha/yr. In northern Quebec, Goulet et al. (2006) reported average loads from plots of: 0.51 kg/ha/yr TP, 0.08 kg/ha/yr TSP, and 0.44 kg/ha/yr PP; annual TP loads from individual plots greater than 1.0 kg/ha were observed. These TP loads in drain flow represented 95% of all TP export from the plots.

JBW areal TP loads in tile drainage were also comparable to loads reported from Iowa, Ohio, and other Midwest states. For example, King et al. (2014) reported annual TP loads of 0.28 – 0.92 kg/ha from Ohio corn/soybean fields.

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### 6.3 Associations Between Water Quality and Agronomic Variables

Statistical analyses were performed to identify associations between water quality variables (measured P concentrations, P loads, and flow) and agronomic variables in the study fields. The agronomic variables considered were presence/absence of surface inlets, 2017 crop type, 2017 manure applications, presence/absence of cover crops, soil types, and field size. Associations were documented by t-Test or Analysis of Variance and/or correlation and simple linear regression, depending on the factor groups being evaluated. The relatively low number of study fields limited our ability to draw statistically significant conclusions in some cases.

The following independent variables were evaluated:

- Presence of surface inlet: Yes or No
- 2017 crop: soybeans (SB), corn silage (C), hay (H), and alfalfa (ALF) and corn (C) vs. other (O)
- 2017 manure: Y or N (manure application data not detailed enough to use rate or method)
- 2017 cover crop: Y or N (corn cropland only)
- Soil: clay (Cl) or loam (Lo) based on majority of field soil
- Size: tile-drained field area (ha)

The dependent variables evaluated were:

- [TP]: mean TP concentration ( $\mu\text{g/L}$ ), anti-log of logmean of monthly concentrations
- [TDP]: mean TDP concentration ( $\mu\text{g/L}$ ), anti-log of logmean of monthly concentrations
- Q: total flow volume (sum of monthly discharge) ( $\text{m}^3$ )
- TPx: total TP loading over monitoring period (kg)
- TDPx: total TDP loading over monitoring period (kg)
- Areal TPx: total TP loading/field area (kg/ha)
- Areal TDPx: total TDP loading/field area (kg/ha)
- %TDP: percentage of TPx as TDPx, based on total annual TP and TDP export

### 6.3.1 Presence of Surface Inlet(s)

Mean TP and TDP concentrations were not significantly associated with the presence of surface inlet(s),  $P < 0.10$ . There appeared to be a slight tendency for higher P concentrations in tile drainage from fields without surface inlet(s) (Figure 15). A possible explanation for this finding is that on two of the three study fields with surface inlets (JBT14 and JBT16), inlets primarily function to convey runoff from neighboring (non-crop) areas which may dilute P concentrations in tile discharge.

Figure 15. Associations between TP and TDP concentrations and surface inlets

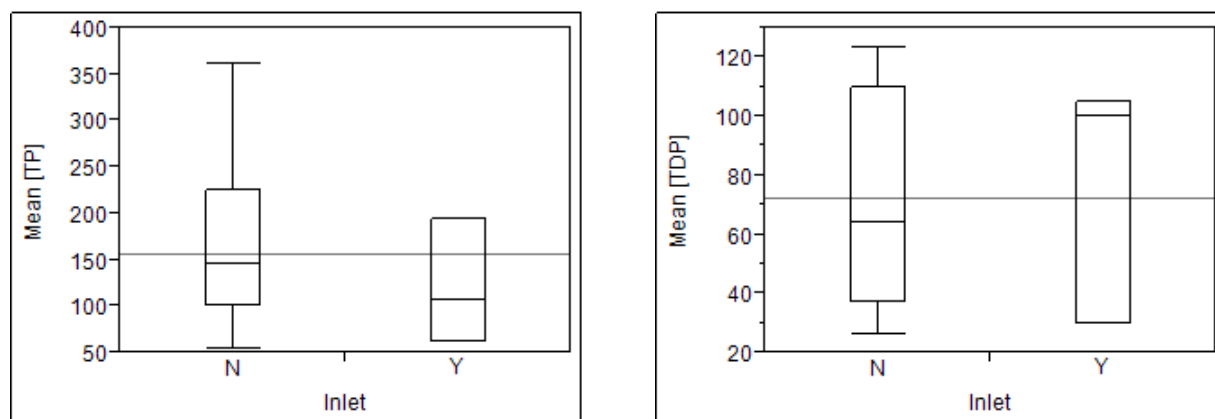
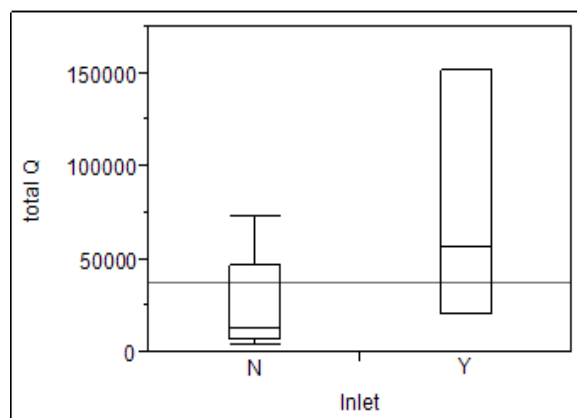


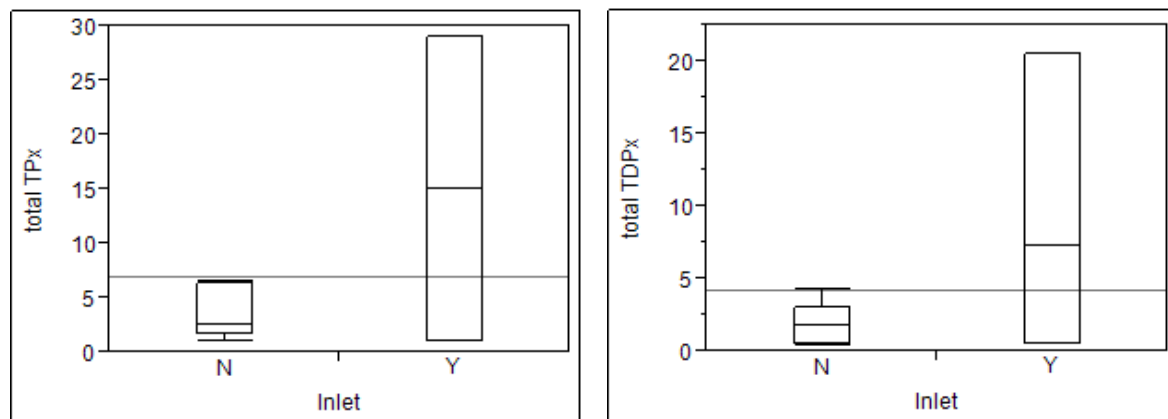
Figure 16. Association between flow and surface inlets



Total tile discharge was significantly higher from fields with surface inlet(s),  $P=0.067$  (Figure 16). Again, a possible explanation for this finding is that surface inlets at JBT14 and JBT16 convey runoff from neighboring (non-crop) areas.

Driven by the flow differences, both TPx and TDPx were significantly higher from fields with surface inlet(s),  $P=0.053$  and  $P=0.089$ , respectively (Figure 17).

Figure 17. Associations between TP and TDP loading and surface inlets



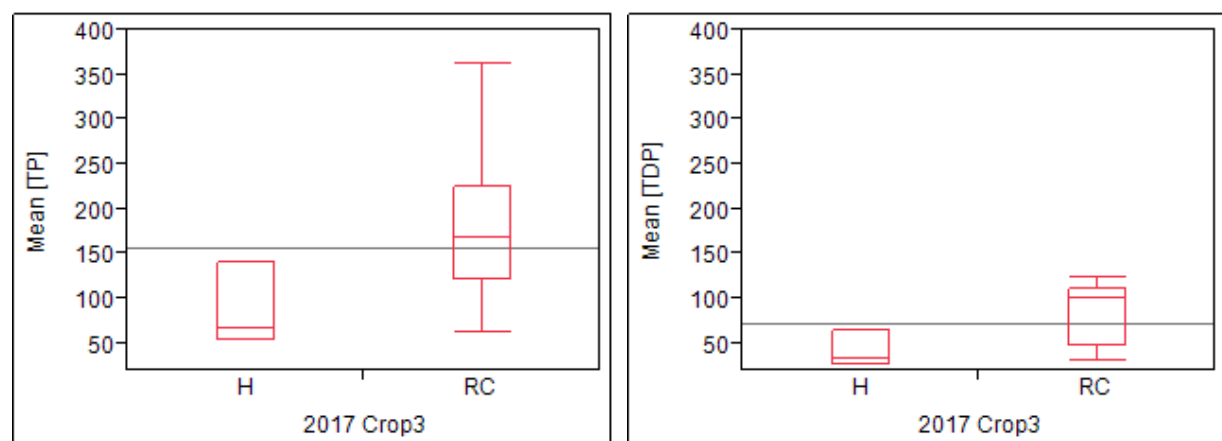
A similar pattern was shown for areal TPx and TDPx, although the difference was nonsignificant for TPx. There was no significant difference in mean %TDP between fields with and without surface inlets.

### 6.3.2 2017 Crop

The influence of crop type and cropping activities on tile drain flow P concentrations has been variable in published research. In the JBW, no significant associations were observed between specific 2017 crop types and P concentration, flow, or P load in tile drain flow. This is not surprising, as the number of fields in clover hay (n=2), soybeans (n=2), and alfalfa (n=1) was too small for reliable statistical inference.

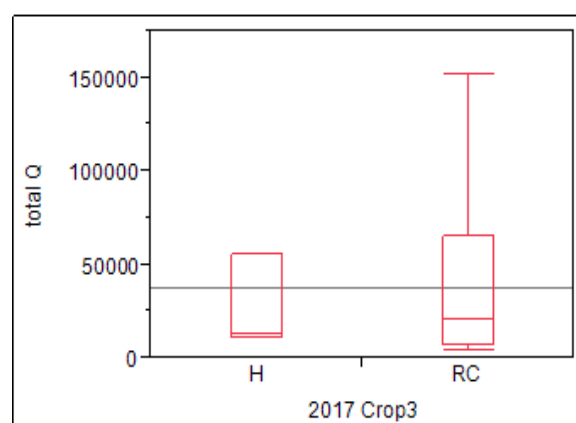
However, when crop types were aggregated into two categories, Row Crop (corn and soybeans) and Hay (clover and alfalfa), there was some evidence that P concentrations and areal P loads tended to be higher from row cropland compared to hayland. These Row Crop (RC) and Hay (H) groups were not confounded by field size – there was no significant difference ( $P = 0.64$ ) between Row Crop (RC) and Hay (H) fields with respect to size. Mean TP and TDP concentrations tended to be higher from RC fields, although the difference was significant only for TDP ( $P = 0.08$ ) (Figure 18).

Figure 18. Associations between TP and TDP concentrations and crop type



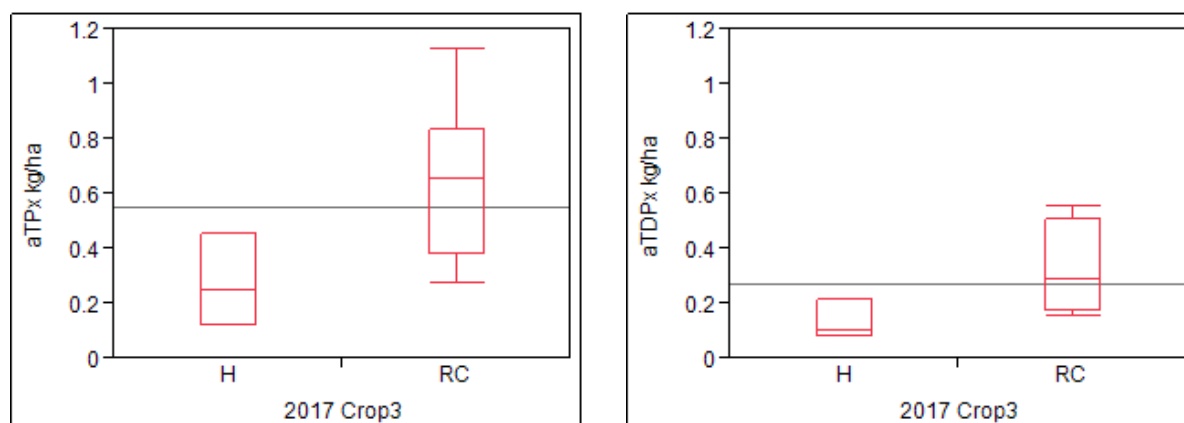
There was no significant difference between RC and H for annual tile discharge, although discharge tended to be somewhat higher and more variable from RC land (Figure 19).

Figure 19. Associations between flow and crop type



Although differences in annual total TP and TDP loads between H and RC crop groups were not statistically significant, differences with respect to areal P loads were significant. Row cropland contributed significantly more TP and TDP per hectare than hay fields (Figure 20). No significant difference in %TDP between RC and H crop types were observed ( $P = 0.89$ ).

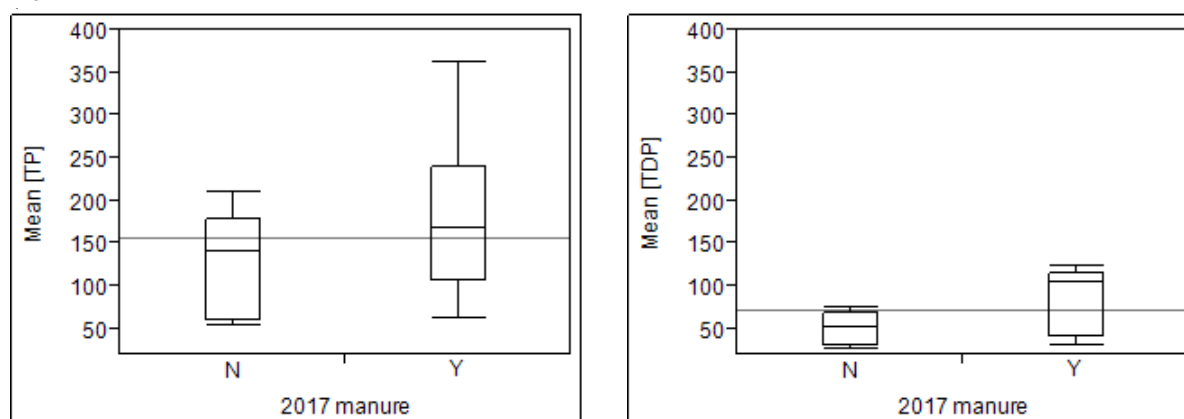
Figure 20. Associations between areal TP and TDP loadings and crop type



### 6.3.3 2017 Manure

No significant associations were observed between 2017 manure application and P concentrations in tile drain flow over the monitoring year, although there was a tendency for both mean TP and TDP concentrations to be somewhat higher from fields that had received some manure in 2017, compared to fields that were not manured (Figure 21). Unfortunately, data from the JBW are insufficiently detailed to confirm literature reports of high P concentrations in drain flow associated with long-term manure applications or excessive soil test P levels.

Figure 21. Associations between TP and TDP concentrations and 2017 manure application



Published research has sometimes reported significant P loss in tile drain flow associated with manure applications (Stone 2016b). For example, in New York, Scott et al. (1998) reported soluble P concentrations in tile drain flow that peaked at 1,170  $\mu\text{g/L}$ . At nearly every JBW site where manure was applied in 2017, we observed dramatic, short-term increases in TP and TDP

concentrations in composite samples collected during the week of application (Figures 22 and 23). The exception was manure application to adjacent fields JBT01 and JBT02 in mid-November; manure appeared to have frozen on the ground and the composite sampling program was suspended in the same week. On two occasions—JBT13 on May 16, 2017 and JBT06 on November 1, 2017—the presence of manure in the tile drain flow was visually obvious and was further demonstrated by high P concentrations in the composite samples collected during the week of the application. At JBT13, TP concentrations declined from the exceedingly high concentration of 35,295 µg/L the week of manure application to the more typical value of 525 µg/L over the course of six weeks. At the other sites, TP concentrations were markedly higher in samples collected the week of the application and fell to more typical concentrations within 1-2 weeks.

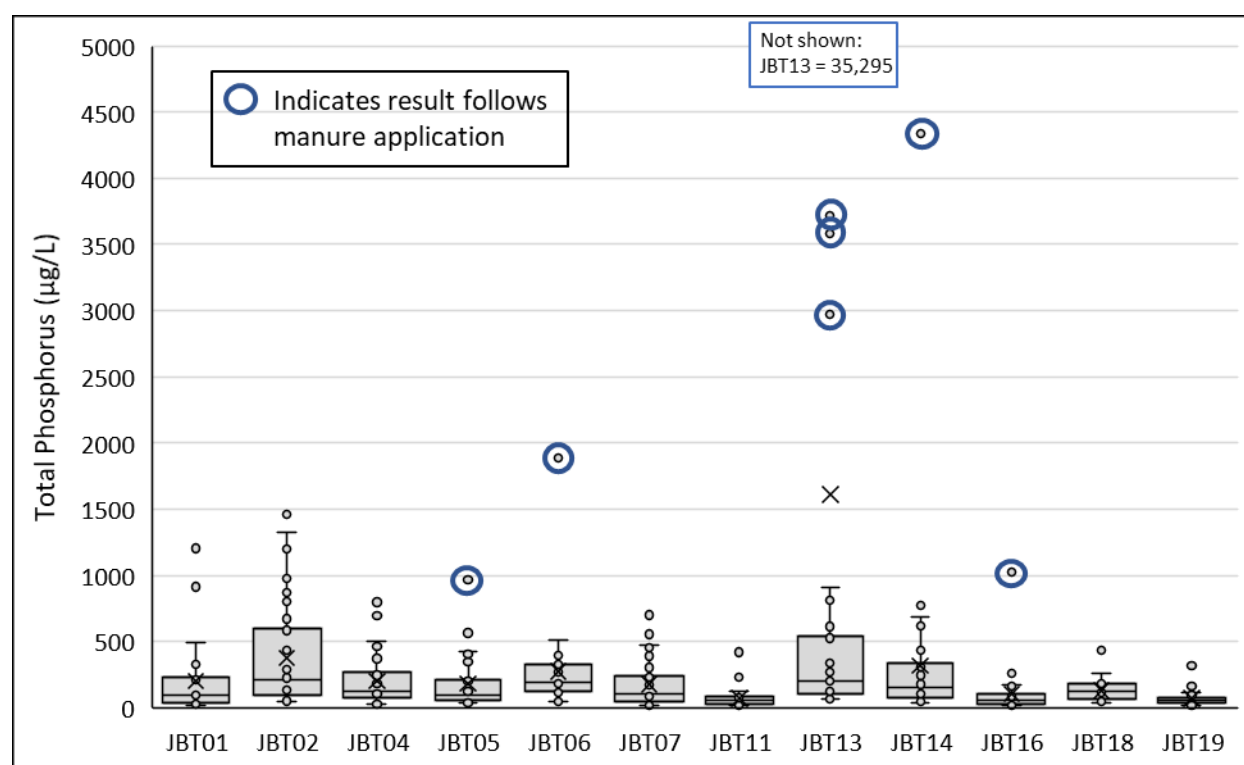


Figure 22. TP concentration distribution during the composite sampling period (April – Nov. 2017)

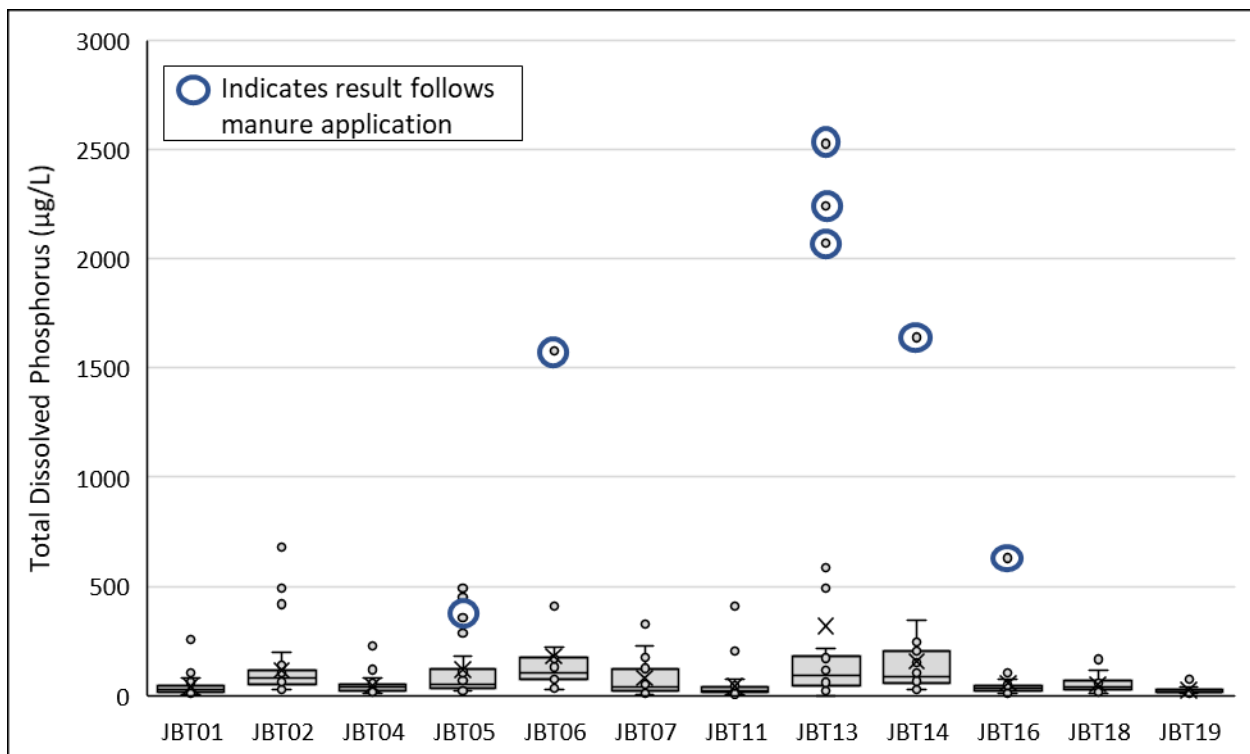
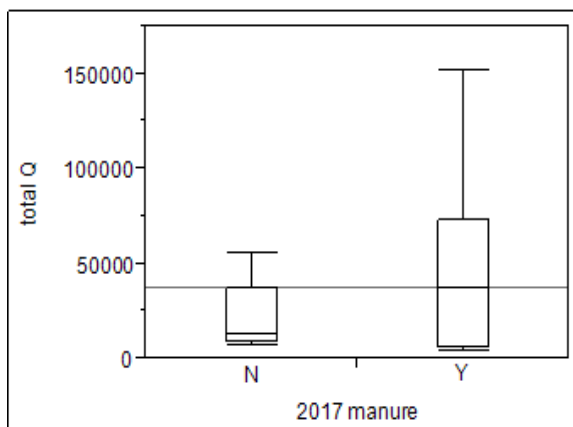


Figure 23. TDP concentration distribution during the composite sampling period (April – Nov. 2017)

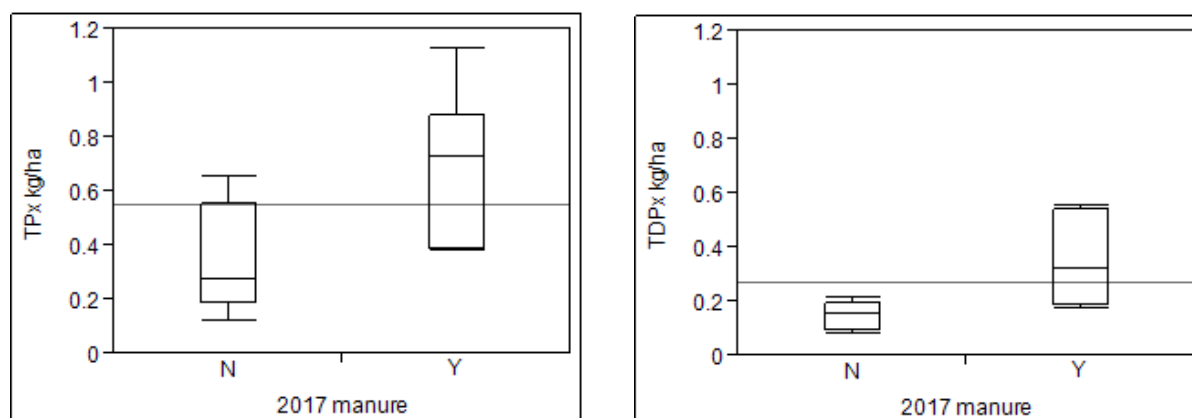
There was a nonsignificant tendency for annual tile discharge to be higher from fields that received manure in 2017 (Figure 24); this pattern drove a similar tendency for P export to be higher from fields that received manure.

Figure 24. Associations between flow and 2017 manure applications



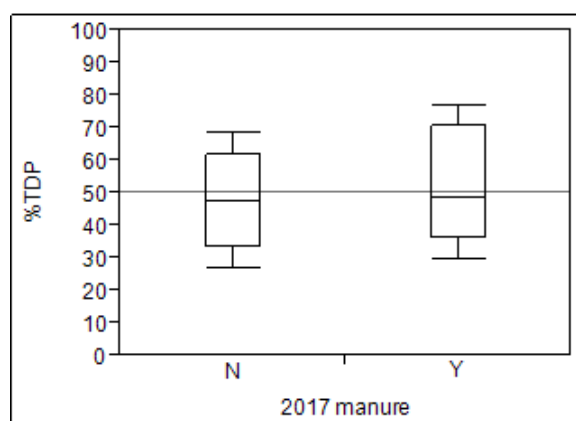
However, because it seems unlikely that manure application alone would lead to increased tile discharge on an annual basis, the higher tile flow is more likely due to the fact that manure application favored larger fields, and fields in corn; both of these characteristics tended to show higher tile flow than did smaller fields in other crops. The higher tile flows also drove significantly higher P export (both absolute and areal) from manured fields (Figure 25); but this result must be viewed with some skepticism because of the confounding effects of field size and crop.

Figure 25. Associations between areal TP and TDP loadings and 2017 manure applications



There was no significant difference in %TDP between fields that did and did not receive manure in 2017 (Figure 26).

Figure 26. Associations between %TDP and 2017 manure applications



#### 6.3.4 Cover Crop on Corn

Because cover crop is applied only to corn silage in this case, only the six fields in corn were included in this analysis. The presence of a cover crop did not appear to have a significant effect on P concentrations or loads from the monitored fields. There was a slight tendency for cover cropped corn fields to exhibit higher and more variable TP and TDP concentrations and loads, but this was confounded by the observed tendency for cover crops to be applied on the larger corn fields. Also, the inclusion of only two corn fields without cover crops did not support rigorous statistical inference.

#### 6.3.5 Soils

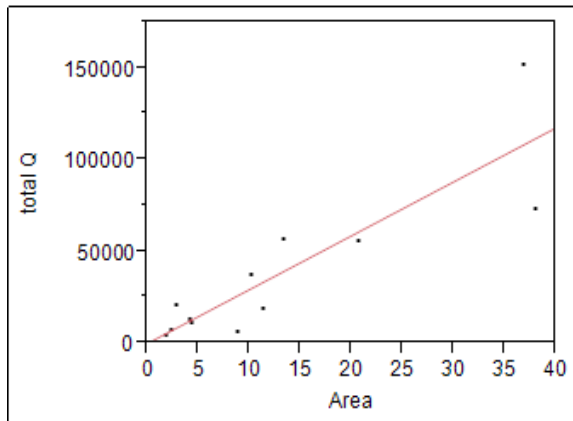
There were no significant (or even suggestive) differences in P concentration, tile discharge, or P export from fields with predominantly clay soils compared to fields with a majority of loam soils.

#### 6.3.6 Field Size

Mean P concentration in tile discharge did not vary significantly with field size. However, annual tile discharge did appear to be partially a function of field size ( $P < 0.001$ ,  $r^2=0.77$ ) (Figure 27).

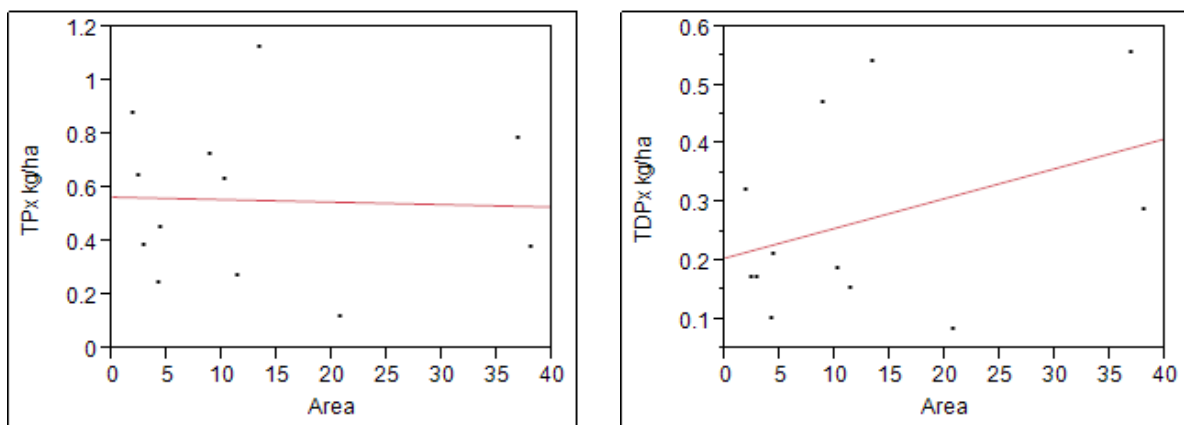


Figure 27. Annual tile drain discharge vs. field size



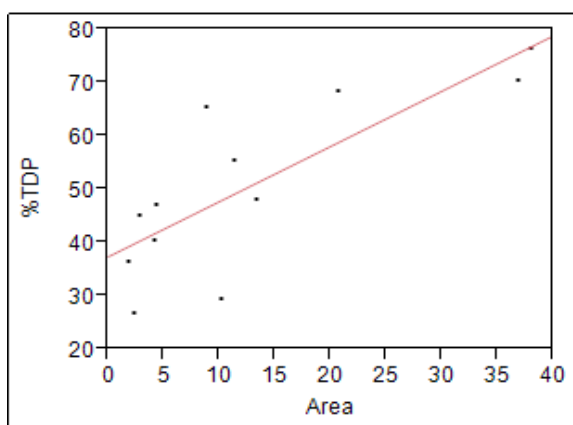
Because of this strong relationship between field size and tile discharge, there was also a strong positive association between field size and annual TP and TDP loading. However, this relationship was not evident when P export was expressed on an areal basis (Figure 28).

Figure 28. Annual areal TP and TDP loading vs. field size



There appeared to be a positive association between field size and %TDP in tile discharge (Figure 29). The reason for such a relationship is unclear, but it may be related to longer travel time in tile lines in larger fields offering greater opportunities for tile flow to pick up soluble P.

Figure 29. %TDP vs. field size



Finally, it is worth noting that the relationship between field size and annual tile discharge is strong but not perfect; size explains only 77% of the variability in annual tile discharge. This suggests two important things. First, the uncertainty of the association may reflect differences between field boundaries and tile system drainage area, i.e., the field area may not exactly correspond to the drainage area. This uncertainty may add additional uncertainty to subsequent P loading estimates. Second, there are likely other factors in addition to size that influence tile system discharge, e.g., tile drain spacing, crop type, the magnitude of preferential (macropore) flow, actual soil porosity, etc.

#### 6.4 Estimation of P Load from Tile Drains in the JBW

We estimated P loads from all tile drain discharge in the JBW using measured P loads from monitored fields JBT01 – JBT19. Monitored absolute loads (kg/yr) were converted to areal loads (kg/ha/yr) based on the assumption that the tile drainage area was equal to the surface area of each drained field. The areal loads appeared to conform to a normal distribution; no transformations were required for subsequent analysis. We chose median and 95% confidence interval annual areal TP and TDP loads from the group of monitored fields to provide representative areal loads to apply across the JBW. Finally, we used VAAFM data on “presence of tile” for the entire JBW (2096 ha) with fields clipped to watershed boundaries, amounting to 845.5 ha.

We used two methods in computing estimates. Method 1 combined all monitoring data to apply median and 95% C.I. values to all tile drained fields in the JBW. Because previous analysis suggested significant difference in P loads from row crop (corn, soybeans) vs. hay (hay, alfalfa), Method 2 applied different median and 95% C.I. values to row crop and hayland areas, then summed for the entire JBW tile-drained area.

Areal load values used in Method 1 are shown in Table 17 below.

*Table 17. Method 1 – Areal P load from tile-drained land in the JBW (all data combined)*

	<b>Areal TP load (kg/ha/yr)</b>	<b>Areal TDP load (kg/ha/yr)</b>
Range	0.122 – 1.124	0.083 – 0.556
Median	0.541	0.199
Mean	0.555	0.272
95% C.I.	0.368 – 0.743	0.166 – 0.378

Assuming the total JBW tile drained area is 845.5 ha, estimated P loads from combined tiled agricultural land in the JBW are in Table 18 below.

*Table 18. Method 1 – P load from all tile-drained land in the JBW (all data combined)*

	<b>Median P load (kg/yr)</b>	<b>95% C.I. (kg/yr)</b>
TP	458	311 - 638
TDP	168	140 - 320

Areal load values used in Method 2 (row crop and hay estimated separately) are shown in Table 19 below.

Table 19. Method 2 – Areal P load from tile-drained land in the JBW (Row Crop and Hay estimated separately)

	Row Crop (RC)		Hay (H)	
	Areal TP load (kg/ha/yr)	Areal TDP load (kg/ha/yr)	Areal TP load (kg/ha/yr)	Areal TDP load (kg/ha/yr)
Range	0.276 – 1.124	0.153 – 0.556	0.122 – 0.451	0.083 – 0.212
Median	0.650	0.289	0.249	0.101
Mean	0.649	0.318	0.274	0.132
95% C.I.	0.441 – 0.857	0.191 – 0.445	0.138 – 0.686	0.042 – 0.306

To account for land reported by VAAFM as in corn/hay rotation, we assumed a 50-50 split in an average year, resulting in an estimated total of 614 ha of tile-drained row cropland and 232 ha of tile-drained hayland in the JBW.

Estimated P loads from tile-drained agricultural land in the JBW when row crop and hayland are separated are in Table 20 below.

Table 20. Method 2 – P load from all tile-drained land in the JBW (Row Crop and Hay estimated separately)

	TP (kg/yr)		TDP (kg/yr)	
	Median	95% C.I.	Median	95% C.I.
Row crop	399	270.8 – 526.2	177	117.3 – 273.2
Hay	58	32.0 – 158.8	23	9.7 – 70.8
TOTAL	458	302.8 – 685.0	201	127.0 – 344.0

Estimates of TP export in tile drainage agree between the two approaches. Treating row crop and hayland separately yield a higher estimate of TDP export.

### 6.5 Jewett Brook P Loading Analysis

We estimated annual and monthly mean P loading rates from Jewett Brook for the period May 2017 to April 2018 from stream discharge and P concentration measurements obtained during the period January 2017 to September 2018. We chose this date range to provide an adequate P concentration sample size to support the development of loading regression models while limiting the data to recent months best representing agricultural management and other watershed features present during the tile drain monitoring period.

We obtained discharge measurements for use in estimating phosphorus loading in Jewett Brook from the U.S. Geological Survey (USGS) stream flow gauge on Jewett Brook at Lower Newton Road (USGS Reference No. 0429810, 3.74 mi<sup>2</sup> [969 ha] drainage area). Average daily flow rates in cubic feet per second (cfs) for the period of 1/1/2017 to 9/30/2018 were downloaded for this site on October 1, 2018 from the USGS National Water System website ([https://waterdata.usgs.gov/vt/nwis/uv?site\\_no=04292810](https://waterdata.usgs.gov/vt/nwis/uv?site_no=04292810)). Average daily flow values after October 11, 2017 were identified as provisional by the USGS. No flow values were reported on a total of 35 winter days between December 28, 2017 and February 21, 2018 due to intermittent ice effects at the gauge site. These missing values due to ice effects were replaced for this analysis with flow rates representing the mean value from the two nearest adjoining dates for which flow data were available. Zero discharge rates were reported on 74 days during the dry summer months of 2018. These zero values were replaced for this analysis with values of 0.001 cfs in order to permit logarithmic transformation of the data.

We obtained TP and TDP concentrations measured in samples from Jewett Brook from the Vermont DEC, Lake Champlain Long-Term Monitoring website (<https://anrweb.vermont.gov/dec/dec/LongTermMonitoringTributary.aspx>). We used results from a total of 29 TP samples and 21 TDP samples obtained under a range of flow conditions from February 24, 2017 to September 11, 2018 for this analysis.

We used the USGS program *LOADEST* (Runkel et al. 2004) to calculate phosphorus loading rates in Jewett Brook from the stream flow and P concentration data, and the utility program *LoadRunner* (Raymond et al. 2011) to automate runs of *LOADEST*.

*LOADEST* supports the development of regression models to calculate daily, monthly, and annual mean loads (with error estimates) from constituent concentration data and a time series of daily stream flow measurements. Several predefined regression model options are provided in *LOADEST* to predict loads from various combinations of stream flow and decimal time. For this analysis, *LOADEST* was allowed to automatically select the optimum regression model from the predefined list for both TP and TDP load estimation, based on a minimum value of the Akaike Information Criterion statistic.

Regression coefficients were fit by *LOADEST* using Maximum Likelihood Estimation, appropriate for uncensored data (no results below detection limits) and where regression residuals are normally distributed. Regression diagnostic procedures described in Runkel et al. (2004) were used to confirm that model residuals were independent, homoscedastic, and normally distributed.

Application of the *LOADEST* program to the Jewett Brook data resulted in the selection of *LOADEST* regression model 2, described in equation 1, for both TP and TDP load estimation.

$$\ln(L) = a_0 + a_1 \ln(Q) + a_2 \ln(Q)^2 \quad (1)$$

where,  $\ln(L)$  = natural log of the daily loading rate

$\ln(Q)$  =  $\ln(\text{daily stream flow rate}) - \text{center of } \ln(\text{daily stream flow rate})$

$a_0, a_1, a_2$  are calibrated regression coefficients

Regression models calibrated from discharge and P concentration data obtained during the date range of January 1, 2017 to September 30, 2018 were used to estimate monthly and annual TP and TDP loading rates for the period of May 2017 to April 2018, which closely approximates the tile drain monitoring period. Loading estimates and their 95% confidence limits calculated by the *LOADEST* program are shown in Tables 21 and 22 for TP and TDP, respectively. These loading estimates apply at the location of the USGS stream gage station on Jewett Brook. No adjustments were made to account for the additional downstream watershed area.

Table 21. Monthly mean TP loading rates and 95% confidence limits in Jewett Brook.

Month	Year	N Days	Mean Flow (cfs)	Mean TP Load (kg/day)	Lower 95% Limit (kg/day)	Upper 95% Limit (kg/day)
May	2017	31	5.69	5.24	4.06	6.66
June	2017	30	5.62	5.40	3.89	7.31
July	2017	31	3.91	3.56	2.70	4.61
Aug.	2017	31	0.52	0.46	0.34	0.62
Sep.	2017	30	0.93	0.83	0.58	1.14
Oct.	2017	31	0.64	0.56	0.40	0.76

Month	Year	N Days	Mean Flow (cfs)	Mean TP Load (kg/day)	Lower 95% Limit (kg/day)	Upper 95% Limit (kg/day)
Nov.	2017	30	2.92	2.58	2.00	3.27
Dec.	2017	31	1.13	0.98	0.75	1.26
Jan.	2018	31	9.04	8.67	6.60	11.18
Feb.	2018	28	12.25	11.32	9.23	13.74
Mar.	2018	31	9.52	8.98	6.97	11.38
Apr.	2018	30	15.23	14.99	11.59	19.07
Period Total		365	5.55	5.24	4.46	6.12

Thus, we estimate that the TP load from the monitored portion of the JBW over the entire period was 1,913 kg/yr (1,628 – 2,234 kg/yr).

Table 22. Monthly mean TDP loading rates and 95% confidence limits in Jewett Brook.

Month	Year	N Days	Mean Flow (cfs)	Mean TDP Load (kg/day)	Lower 95% Limit (kg/day)	Upper 95% Limit (kg/day)
May	2017	31	5.69	3.90	2.79	5.30
June	2017	30	5.62	3.91	2.58	5.68
July	2017	31	3.91	2.70	1.88	3.74
Aug.	2017	31	0.52	0.39	0.26	0.56
Sep.	2017	30	0.93	0.66	0.42	0.98
Oct.	2017	31	0.64	0.46	0.30	0.68
Nov.	2017	30	2.92	2.02	1.44	2.75
Dec.	2017	31	1.13	0.81	0.56	1.13
Jan.	2018	31	9.04	6.23	4.38	8.60
Feb.	2018	28	12.25	8.31	6.29	10.78
Mar.	2018	31	9.52	6.53	4.71	8.83
Apr.	2018	30	15.23	10.57	7.54	14.42
Period Total		365	5.55	3.83	3.05	4.75

We estimate that the TDP load from the monitored portion of the JBW over the entire period was 1,398 kg/yr (1,278 – 1,734 kg/yr).

## 6.6 Percentage of Jewett Brook P Load from Tile Drains

Because P loads in Jewett Brook were computed at a station representing only a portion of the JBW, we took two approaches to estimate the contribution of tile discharge to JBW P loads. For both approaches, we used the areal P loads from tile discharge estimated by Method 1 (Section 6.4), wherein all tile drained land is combined.

**Approach 1.** In this approach, we recomputed estimates for annual P loads from tile discharge for the tile drained cropland within the 969 ha captured at the USGS station on Lower Newton Road (Table 23). This allows direct comparison between annual P loads in Jewett Brook with estimated annual P loads in tile discharge from the same area, although not from the entire JBW.

Table 23. Monitored P loads at USGS station on Lower Newton Rd (drainage area = 1180 ha)

	Mean annual load (kg/yr)	95% C.I. (kg/yr)
TP	1,913	1,628 – 2,234
TDP	1,398	1,278 – 1,734

We recalculated estimated P loads in tile discharge for the 517 ha of tiled area cited in the VAAFM data for JBW, representing the area of drained fields clipped to the “above” watershed boundary (Table 24). Annual estimated tile loads were calculated as median tile P load x estimated tiled area using a single P loading rate because no assumptions of breakdown of row crop/hayland was required.

Table 24. Estimated P loads in tile discharge above USGS station (tiled area = 517 ha)

	Mean annual load (kg/yr)	95% CI (kg/yr)
TP	280	190 – 384
TDP	103	86 - 195

We summarize the proportion of total JBW P loads contributed by tile discharge as follows. Mean tile P load % of total is computed as the estimated median P load from tile discharge divided by the monitored Jewett Brook P load. An error range for this estimate was computed as the [low 95% C.I. of tile load]/[high 95% C.I. of monitored load] and the [high 95% C.I. of tile load]/[low 95% C.I. of monitored load]. These estimates are shown Table 25 below.

Table 25. Proportion of total JBW P loads above USGS station contributed by tile drains

	Tile load % of total	Range
TP	15%	8.5 – 24%
TDP	7%	5 – 15%

**Approach 2.** In this approach, we compared estimates of annual P loads from tile discharge for the 845.5 ha of tiled cropland within the entire JBW from the VAAFM inventory against annual P loads in Jewett Brook extrapolated from the USGS monitored area (1,180 ha) to the entire watershed (2,096 ha) by a simple area ratio of 1.78. These results are in Tables 26 and 27.

Table 26. Jewett Brook P loads extrapolated to entire JBW (drainage area = 1180 ha)

	Mean annual load (kg/yr)	95% C.I. (kg/yr)
TP	3,404	2,898 – 3,976
TDP	2,488	2,275 – 3,086

Table 27. Estimated P loads in tile discharge for entire JBW (tiled area = 846 ha)

	Mean annual load (kg/yr)	95% CI (kg/yr)
TP	458	311 – 638
TDP	168	140 - 320

Finally, we summarize the proportion of the total JBW P loads represented by tile discharge extrapolated for the entire watershed by the same methods as in Approach 1. These estimates are shown in Table 28 below.



Table 28. Proportion of total JBW P loads contributed by tile drains

	Tile load % of total	Range
TP	13%	8 – 22%
TDP	7%	4.5 – 14%

Data from this study in the Jewett Brook Watershed confirm that tile drain discharge can be a major pathway for P export from agricultural land. Areal P loads in tile discharge from the JBW were comparable to those reported for P loads in surface runoff from cropland from across North America, as reported by Harmel et al. (2006), as shown in Table 29 below.

Table 29. Median annual P load values in surface runoff from cropland (Harmel et al. 2006).

Land Use	Total P (kg/ha/yr)	Dissolved P (kg/ha/yr)	Particulate P (kg/ha/yr)
Corn	1.29	0.22	0.85
Soybeans	1.18	-	-
Oats/wheat	2.20	0.3	3.45
Fallow cultivated	1.08	0.48	0.45
Pasture/range	0.24	0.15	0.00
Various rotations	0.59	0.80	0.60

Our estimates of the proportion of total JBW P loads contributed by tile drainage (Tables 25 and 28 above) are lower than some values reported elsewhere. For example, in the LCB region, Jamieson et al. (2003) reported an estimated TP load in subsurface drainage from a Quebec corn field during snowmelt of 0.1 kg/ha, representing 37% of the total snowmelt P load from the field. Simard (2005) measured mean P loads exported from corn fields in the Missisquoi Bay watershed averaging 0.61 kg/ha/yr (compared to 1.21 kg/ha/yr in surface runoff). Annual TP loads in tile drainage from one field varied from 0.69 to 1.23 kg/ha/yr. In northern Quebec, Goulet et al. (2006) reported average loads from plots of: 0.51 kg/ha/yr TP, 0.08 kg/ha/yr TSP, and 0.44 kg/ha/yr PP; annual TP loads from individual plots >1.0 kg/ha were observed. These TP loads in drainflow represented 95% of all TP export from the plots. Note that data from plot studies is difficult to extrapolate to a watershed scale.

Nevertheless, our estimates that tile discharge may contribute up to 24% of watershed TP and up to 15% of TDP loads in Jewett Brook suggest that it will be difficult to accomplish target reductions of agricultural P loads to Lake Champlain without addressing tile drainage.

## 7. Deliverables Completed

The results of this study have been reported in a series of reports and presentations.

Project reports relevant to the literature review (Task 1) are:

- Literature Review of Published Research Examining Tile Drainage Systems, Quality Assurance Project Plan, Version 1.0 (Stone 2016a)
- Literature Review: Tile Drainage and Phosphorus Losses from Agricultural Land (Stone 2016b)

Project reports relevant to the monitoring phase (Task 2) are:

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- Quality Assurance Project Plan, Version 1.0, Amendment 1 (Stone 2016c)
  - Characterization of Tile Drainage Systems in the Jewett Brook Watershed (dated Stone 2017a)
  - Assessment of Tile Drainage Systems in the Jewett Brook Watershed: Monitoring Station Installation (Stone 2017b)
  - Quarterly Progress Reports (10 reports: 2016 Q4 – 2018 Q1)
  - Monthly Monitoring Summaries (12 reports: April 2017 – March 2018)
  - Assessment of Phosphorus Loads in Tile Drainage in the Jewett Brook Watershed of St. Albans Bay, Lake Champlain: Monitoring Task Report (Stone 2018).

This final report presents the results of the Task 3 analyses.

This study has been presented at the following events:

- Meeting of the Vermont Agency of Agriculture, Food, and Markets' Tile Drain Advisory Group, December 21, 2017
- New England Interstate Water Pollution Control Commission annual conference, Glens Falls, NY, April 25, 2018
- Lake Champlain Basin Program Technical Advisory Committee meeting on May 2, 2018
- Vermont Environmental Consortium's annual conference, Randolph, VT, June 6, 2018

## 8. Conclusions

Monitored tile drains in the JBW flowed continuously in the late winter and spring periods, whereas in summer and early fall, the tile drains flowed only in response to rain events, with little or no flow between rains. This pattern is consistent with tile lines capturing and conveying excess soil water during times of high water table and inputs from precipitation or snowmelt, versus the growing season when evapotranspiration from growing crops draws much of the available soil water. This seasonal flow pattern is commonly reported in the literature, although monitored drains did not show as strong a seasonal flow pattern as is sometimes observed elsewhere.

Tile discharge exhibited variable and sometimes high P concentrations, averaging 140 µg/LTP and 63 µg/L TDP, but containing as much as 6,977 µg/L TP and 4,826 µg/L TDP at times. These P concentrations frequently exceeded the U.S. EPA threshold of 100 µg/L for eutrophication in surface waters (USEPA 1994). No clear seasonal patterns in TP or TDP concentrations in tile discharge were observed, nor were strong positive correlations between P concentrations and tile discharge. Average P concentrations in JBW tile drainage were in a comparable range to values reported in the literature; peak P concentrations in JBW tended to be higher than values reported elsewhere. Most researchers have reported P concentrations in tile discharge substantially lower than those observed in surface runoff from cropland. However, average P levels in JBW tile discharge in this study were similar to in-stream concentrations reported in surface waters draining small agricultural watersheds in the St. Albans Bay watershed in the 1980s (VT RCWP CC 1991), and in northeast Franklin County, VT in the 1990s (Meals 2001). While average P levels in JBW tile discharge measured in this study were generally lower than those observed in Jewett Brook itself from 1990 – 2017 by the VT DEC Lake Champlain Long-

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Term Monitoring Program, peak P concentrations in tile discharge in this study sometimes exceeded those reported concentrations. Thus, it can be concluded that tile discharge in this portion of the LCB can carry significant levels of P directly to surface waters.

On average across all monitored tile outlets, about 50% of TP was in the dissolved form (TDP). The proportion of TDP, however, varied among the monitored tile systems, ranging from a low of ~30% in systems draining fine-textured soils to a high of ~80% in systems draining cornfields in long-term no-till practice. TDP concentrations below 10% and over 90% of TP were reported in individual samples from some tile outlets. These observations tend to confirm the consensus of the literature that dissolved P can be an important form of P in tile drainage under some circumstances, but that particulate P sometimes makes up a surprisingly large fraction of TP in drainage water. No distinct seasonal pattern was observed for the proportion of TP made up of TDP.

P loads from monitored tile systems in the JBW averaged 0.555 kg/ha/yr and 0.272 kg/ha/yr for TP and TDP, respectively. Areal P loads varied by an order of magnitude among the monitored systems. Monitored P loading in tile drain flow from JBW agricultural fields was in a range comparable to that reported in the literature. Median annual P loads from JBW tile systems were somewhat lower than median P loads reported in surface runoff from row crop land across the U.S. but were higher than loads reported from pasture and general cultivated land (Harmel et al. 2006). Again, this result confirms the potential significance of P loads in tile drainage contributions to surface waters in the LCB.

While the low number of study fields limited the ability to draw significant conclusions on associations between P concentrations or loads and agronomic variables, some suggestive patterns were observed. Although the presence of surface inlets in a tile system did not appear to influence P concentrations, the significantly higher tile discharge in those systems resulted in significantly higher P export from tile systems with surface inlets. Monitoring data also suggest that P concentrations and export per hectare in tile systems draining row crops tend to be higher than levels observed from hayland. There was a tendency for both mean TP and TDP concentrations to be somewhat higher from fields that had received some manure in 2017, compared to fields that were not manured. Moreover, episodic very high P concentrations were observed on occasions when manure application coincided with high wet-weather tile flow. While annual tile discharge was clearly positively associated with field size, P concentrations in tile discharge did not vary significantly with field size. No significant variations in P concentrations or export were observed that could be attributed to soil characteristics or to the presence of cover crops on corn. Based on these observations, monitoring data from JBW tile systems suggest that tile systems with surface inlets draining large fields in row crops that receive manure at times of high tile flow are likely to be the systems of highest concern for P loading to surface water.

Tile drainage in the JBW was estimated to contribute ~458 kg TP/yr and ~168-200 kg TDP/yr to the annual 1,913 kg TP/yr and 1,398 kg TDP/yr loads from the watershed to Lake Champlain. While the apparent contribution of tile drainage of an average of 15% of the annual TP load and 7% of the TDP load is somewhat lower than values reported in the literature, these contributions represent a significant proportion of the annual watershed P load. It is interesting to note that while TDP comprised only ~40% of the TP load in tile drainage, TDP made up over 70% of the TP load in Jewett Brook. This result may reflect high levels of dissolved P in other sources contributing to Jewett Brook or in-stream processes promoting transformation of dissolved P from particulate forms, or both.

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In sum, the results of this study confirm the significance of discharge from tile drainage systems in the JBW as a contribution to high P concentrations and loads. Our estimates that tile discharge may contribute up to 24% of watershed TP and up to 15% of TDP loads in Jewett Brook suggest that it will be difficult to accomplish target reductions of agricultural P loads to Lake Champlain without addressing tile drainage.

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## Appendix A: TP, TDP, and TN Concentration Data

*TP, TDP, and TN concentrations in samples collected through March 9, 2018*

LAB ID	Site	Sampling Date	Carboy	TP (μg/L)	TDP (μg/L)	TN (mg/L)	Comment
JBT01-04112017-1	JBT01	4/11/2017	1	491	258	4.81	TDP vial cloudy
JBT01-04182017-1	JBT01	4/18/2017	1	55.1	21.1	4.77	
JBT01-04252017-1	JBT01	4/25/2017	1	77.3	17.6	5.24	
JBT01-05022017-1	JBT01	5/2/2017	1	333	81.2	5.63	
JBT01-05092017-1	JBT01	5/9/2017	1	208	44.5	5.29	
JBT01-05092017-2+3	JBT01	5/9/2017	2+3	236	40.8	5.17	
JBT01-05162017-1	JBT01	5/16/2017	1	26.7	15.4	4.96	
JBT01-05232017-1	JBT01	5/23/2017	1	127	26.7	5.27	
JBT01-05302017-1	JBT01	5/30/2017	1	19.3	13.0	5.13	
JBT01-06072017-1	JBT01	6/7/2017	1	23.5	7.6	5.32	VAEL remark: TDP biased low
JBT01-06132017-1	JBT01	6/13/2017	1	23.9	13.9	5.29	
JBT01-06222017-1	JBT01	6/22/2017	1	28.6	16.1	6.48	
JBT01-06272017-1	JBT01	6/27/2017	1	108	64.4	22.19	
JBT01-06272017-2	JBT01	6/27/2017	2	111	72.2	15.57	
JBT01-06272017-3	JBT01	6/27/2017	3	63.8	44.1	8.47	
JBT01-07052017-1	JBT01	7/5/2017	1	256	77.9	8.05	
JBT01-07052017-2+3	JBT01	7/5/2017	2+3	94.6	46.7	6.27	
JBT01-07112017-1+2	JBT01	7/11/2017	1+2	223	106	6.63	
JBT01-07182017-1+2	JBT01	7/18/2017	1+2	98.0	47.5	5.31	
JBT01-07262017-1	JBT01	7/26/2017	1	31.6	21.7	4.40	Reversed TP and TDP result
JBT01-08012017-1	JBT01	8/1/2017	1	23.8	20.9	3.69	
JBT01-08082017-1	JBT01	8/8/2017	1	33.3	20.1	NS	
JBT01-08222017-1	JBT01	8/22/2017	1	55.5	26.6	3.10	
JBT01-090517-1	JBT01	9/5/2017	1	37.0	13.6	3.81	
JBT01-091217-1	JBT01	9/12/2017	1	114	34.0	NS	
JBT01-091917-1	JBT01	9/19/2017	1	116	73.0	2.40	
JBT01-092617-1	JBT01	9/26/2017	1	119	18.3	NS	
JBT01-100317-1	JBT01	10/3/2017	1	49.3	14.8	3.53	
JBT01-101017-1	JBT01	10/10/2017	1	1250	45.3	NS	TDP filtered at VAEL on 10/12/17
JBT01-101017-2	JBT01	10/10/2017	2	1204	35.0	NS	TDP filtered at VAEL on 10/12/17
JBT01-101017-3+4	JBT01	10/10/2017	3+4	914	37.9	NS	TDP filtered at VAEL on 10/12/17
JBT01-102417-1	JBT01	10/24/2017	1	44.2	13.4	NS	
JBT01-110117-3	JBT01	11/1/2017	3	360	NS	NS	TDP sample invalid (diluted w/ distilled
JBT01-110717-3	JBT01	11/7/2017	3	329	60.6	NS	
JBT01-111417-1	JBT01	11/14/2017	1	40.2	33.9	NS	Carboy partially frozen--liquid sampled
JBT01-112017-1	JBT01	11/20/2017	1	33.8	17.6	NS	Carboy frozen--processed in office
JBT01-120417-GR	JBT01	12/4/2017	GR	30.7	18.2	4.02	TN acidified 24 hrs. later, kept cold
JBT01-121517-GR	JBT01	12/15/2017	GR	30.9	11.6	3.49	
JBT01-121917-GR	JBT01	12/19/2017	GR	22.7	15.6	3.48	
JBT01-122717-GR	JBT01	12/27/2017	GR	19.2	15.9	NS	
JBT01-010918-GR	JBT01	1/9/2018	GR	25.9	16	NS	
JBT01-011218-GR	JBT01	1/12/2018	GR	377	NS	5.63	
JBT01-011618-GR	JBT01	1/16/2018	GR	27.8	21.4	4.91	
JBT01-012418-GR	JBT01	1/24/2018	GR	154	67.5	NS	
JBT01-020118-GR	JBT01	2/1/2018	GR	18.9	18.9	2.84	
JBT01-020518-GR	JBT01	2/5/2018	GR	21.6	19.2	NS	
JBT01-022118-GR	JBT01	2/21/2018	GR	260.5	82.5	6.04	
JBT01-030918-GR	JBT01	3/9/2018	GR	33.3	17.4	5.11	

LAB ID	Site	Sampling Date	Carboy	TP (µg/L)	TDP (µg/L)	TN (mg/L)	Comment
JBT02-04112017-1	JBT02	4/11/2017	1	976	678	7.19	TDP vial cloudy
JBT02-04182017-1	JBT02	4/18/2017	1	242	93.6	8.52	
JBT02-04252017-1	JBT02	4/25/2017	1	491	142	8.68	
JBT02-05022017-1	JBT02	5/2/2017	1	805	492	8.58	
JBT02-05092017-1	JBT02	5/9/2017	1	585	120	8.52	
JBT02-05092017-2	JBT02	5/9/2017	2	868	122	7.88	
JBT02-05092017-3	JBT02	5/9/2017	3	868	156	8.00	
JBT02-05162017-1	JBT02	5/16/2017	1	109	37.6	8.26	
JBT02-05302017-1	JBT02	5/30/2017	1	78.5	30.3	8.83	
JBT02-06072017-1	JBT02	6/7/2017	1	67.3	28.2	11.78	
JBT02-06132017-1	JBT02	6/13/2017	1	48.0	28.5	11.69	
JBT02-06222017-1	JBT02	6/22/2017	1	90.9	42.3	12.86	
JBT02-06262017-1	JBT02	6/26/2017	1	137	61.9	25.34	
JBT02-06262017-2	JBT02	6/26/2017	2	189	82.2	29.34	
JBT02-06262017-3	JBT02	6/26/2017	3	160	94.0	27.34	
JBT02-06262017-4	JBT02	6/26/2017	4	315	106	22.93	
JBT02-07052017-1+2	JBT02	7/5/2017	1+2	102	60.5	9.85	
JBT02-07112017-1	JBT02	7/11/2017	1	303	118	8.68	
JBT02-07112017-2	JBT02	7/11/2017	2	434	196	7.19	
JBT02-07182017-1	JBT02	7/18/2017	1	187	118	7.27	
JBT02-07262017-1	JBT02	7/26/2017	1	73.1	70.4	8.03	
JBT02-08012017-1	JBT02	8/1/2017	1	63.9	40.0	8.41	
JBT02-08082017-1	JBT02	8/8/2017	1	50.5	37.0	NS	
JBT02-08152017-1	JBT02	8/15/2017	1	52.0	41.3	7.29	
JBT02-08222017-1	JBT02	8/22/2017	1	308	141	5.81	
JBT02-08302017-1	JBT02	8/30/2017	1	142	63.2	NS	
JBT02-090517-1	JBT02	9/5/2017	1	137	53.4	5.09	
JBT02-091217-1	JBT02	9/12/2017	1	674	106	NS	
JBT02-091917-1	JBT02	9/19/2017	1	138	85.6	6.36	
JBT02-092617-1	JBT02	9/26/2017	1	102	65.2	NS	
JBT02-100317-1	JBT02	10/3/2017	1	81.3	43.3	4.93	
JBT02-101017-1	JBT02	10/10/2017	1	1464	69.7	NS	TDP filtered at VAEL on 10/12/17
JBT02-101017-2	JBT02	10/10/2017	2	1322	77.5	NS	TDP filtered at VAEL on 10/12/17
JBT02-101017-3+4	JBT02	10/10/2017	3+4	1202	91.7	NS	TDP filtered at VAEL on 10/12/17
JBT02-101717-1	JBT02	10/17/2017	1	252	86.7	9.22	
JBT02-102417-1	JBT02	10/24/2017	1	86.2	48.0	NS	
JBT02-110117-3	JBT02	11/1/2017	3	672	419	NS	
JBT02-110717-3	JBT02	11/7/2017	3	599	82.2	NS	
JBT02-111417-1	JBT02	11/14/2017	1	226	103	NS	Carboy partially frozen--liquid sampled
JBT02-112017-1	JBT02	11/20/2017	1	292	113	NS	Carboy frozen--processed in office
JBT02-112917-GR	JBT02	11/29/2017	GR	277.8	125	NS	
JBT02-120417-GR	JBT02	12/4/2017	GR	64.5	31.1	8.72	TN acidified 24 hrs. later, kept cold
JBT02-121517-GR	JBT02	12/15/2017	GR	60.3	16.5	9.44	
JBT02-121917-GR	JBT02	12/19/2017	GR	33.9	20.9	7.62	
JBT02-122717-GR	JBT02	12/27/2017	GR	46.4	27.7	NS	
JBT02-010918-GR	JBT02	1/9/2018	GR	32.5	18.8	NS	
JBT02-011218-GR	JBT02	1/12/2018	GR	449	NS	4.71	
JBT02-022118-GR	JBT02	2/21/2018	GR	253.5	135	5.08	
JBT02-030918-GR	JBT02	3/9/2018	GR	227.5	65.5	8.25	

LAB ID	Site	Sampling Date	Carboy	TP (µg/L)	TDP (µg/L)	TN (mg/L)	Comment
JBT04-04112017-1	JBT04	4/11/2017	1	798	120	4.89	TDP vial cloudy
JBT04-04182017-1	JBT04	4/18/2017	1	115	38.6	4.33	
JBT04-04252017-1	JBT04	4/25/2017	1	133	45.4	4.86	
JBT04-05022017-1	JBT04	5/2/2017	1	500	79.2	5.43	
JBT04-05092017-1	JBT04	5/9/2017	1	303	52.9	4.19	
JBT04-05092017-2+3	JBT04	5/9/2017	2+3	404	58.8	4.23	
JBT04-05162017-1	JBT04	5/16/2017	1	68.8	22.2	3.80	
JBT04-05232017-1	JBT04	5/23/2017	1	109	23.6	4.35	
JBT04-05302017-1	JBT04	5/30/2017	1	90.2	18.1	4.37	
JBT04-06072017-1	JBT04	6/7/2017	1	114	10.7	5.65	VAEL remark: TDP biased low
JBT04-06132017-1	JBT04	6/13/2017	1	42.9	19.6	5.19	
JBT04-06222017-1	JBT04	6/22/2017	1	108	49.5	5.39	
JBT04-06272017-1	JBT04	6/27/2017	1	184	52.4	29.19	
JBT04-06272017-2	JBT04	6/27/2017	2	135	49.6	27.59	
JBT04-06272017-3	JBT04	6/27/2017	3	115	65.3	16.71	
JBT04-06272017-4	JBT04	6/27/2017	4	73.6	50.1	11.85	
JBT04-07052017-1	JBT04	7/5/2017	1	271	53.0	13.07	
JBT04-07052017-2+3	JBT04	7/5/2017	2+3	132	52.6	7.29	
JBT04-07112017-1+2	JBT04	7/11/2017	1+2	262	51.5	8.25	
JBT04-07182017-1	JBT04	7/18/2017	1	126	38.4	5.79	
JBT04-07262017-1	JBT04	7/26/2017	1	50.4	39.5	4.36	Reversed TP and TDP result
JBT04-08012017-1	JBT04	8/1/2017	1	30.5	24.1	3.81	
JBT04-08082017-1	JBT04	8/8/2017	1	35.2	20.6	NS	
JBT04-08152017-1	JBT04	8/15/2017	1	29.8	22.6	2.92	
JBT04-08222017-1	JBT04	8/22/2017	1	465	228	5.89	
JBT04-08302017-1	JBT04	8/30/2017	1	71.0	23.5	NS	
JBT04-090517-1	JBT04	9/5/2017	1	152	21.5	3.19	
JBT04-091217-1+2	JBT04	9/12/2017	1+2	698	32.4	NS	0.5 L left in carboy 2
JBT04-091917-1	JBT04	9/19/2017	1	64.8	22.5	1.29	
JBT04-092617-1	JBT04	9/26/2017	1	67.6	32.0	NS	
JBT04-100317-1	JBT04	10/3/2017	1	78.3	31.0	1.05	
JBT04-101017-1	JBT04	10/10/2017	1	500	33.5	NS	TDP filtered at VAEL on 10/12/17
JBT04-101017-2	JBT04	10/10/2017	2	256	34.7	NS	TDP filtered at VAEL on 10/12/17
JBT04-101017-3+4	JBT04	10/10/2017	3+4	244	39.3	NS	TDP filtered at VAEL on 10/12/17
JBT04-101717-1	JBT04	10/17/2017	1	102	23.9	1.38	
JBT04-102417-1	JBT04	10/24/2017	1	110	17.5	NS	
JBT04-110117-3	JBT04	11/1/2017	3	372	135	NS	
JBT04-110717-3	JBT04	11/7/2017	3	384	36.6	NS	
JBT04-111417-1	JBT04	11/14/2017	1	183	51.0	NS	Carboy partially frozen--liquid sampled
JBT04-112017-1	JBT04	11/20/2017	1	53.2	27.6	NS	Carboy frozen--processed in office
JBT04-112917-GR	JBT04	11/29/2017	GR	54.3	21.8	NS	
JBT04-120417-GR	JBT04	12/4/2017	GR	54.6	17.1	2.22	TN acidified 24 hrs. later, kept cold
JBT04-121517-GR	JBT04	12/15/2017	GR	43.4	21.7	2.2	
JBT04-121917-GR	JBT04	12/19/2017	GR	24.2	17.6	2.2	
JBT04-122717-GR	JBT04	12/27/2017	GR	18.4	15.9	NS	
JBT04-011218-GR	JBT04	1/12/2018	GR	367	NS	3.61	
JBT04-011618-GR	JBT04	1/16/2018	GR	49.9	24.2	3.99	
JBT04-012418-GR	JBT04	1/24/2018	GR	158	52.8	NS	
JBT04-020118-GR	JBT04	2/1/2018	GR	21.2	23.1	3.04	
JBT04-020518-GR	JBT04	2/5/2018	GR	32.2	16.9	NS	
JBT04-022118-GR	JBT04	2/21/2018	GR	240	108	3.96	
JBT04-030918-GR	JBT04	3/9/2018	GR	98.9	34	3.35	

LAB ID	Site	Sampling Date	Carboy	TP (µg/L)	TDP (µg/L)	TN (mg/L)	Comment
JBT05-04252017-1	JBT05	4/25/2017	1	68.7	53.7	24.78	
JBT05-05022017-1	JBT05	5/2/2017	1	226	108	20.60	
JBT05-05092017-1	JBT05	5/9/2017	1	132	82.9	23.56	
JBT05-05162017-1	JBT05	5/16/2017	1	33.6	26.6	21.68	
JBT05-05232017-1	JBT05	5/23/2017	1	60.0	38.4	14.84	
JBT05-05302017-1	JBT05	5/30/2017	1	38.4	37.0	10.52	
JBT05-06062017-1+2	JBT05	6/6/2017	1+2	34.1	21.4	8.10	
JBT05-06132017-1+3	JBT05	6/13/2017	1+3	67.6	49.6	12.68	
JBT05-06222017-1	JBT05	6/22/2017	1	61.2	40.6	14.48	
JBT05-06272017-1+2	JBT05	6/27/2017	1+2	345	285	34.73	
JBT05-06272017-3+4	JBT05	6/27/2017	3+4	408	357	27.73	
JBT05-06302017-1	JBT05	6/30/2017	1	79.7	57.2	24.83	
JBT05-06302017-2	JBT05	6/30/2017	2	595	452	21.23	
JBT05-06302017-3	JBT05	6/30/2017	3	210	181	23.63	
JBT05-07052017-1	JBT05	7/5/2017	1	134	100	24.58	
JBT05-07112017-1+2	JBT05	7/11/2017	1+2	565	493	23.70	
JBT05-07182017-1	JBT05	7/18/2017	1	138	104	29.55	
JBT05-07262017-1	JBT05	7/26/2017	1	85.8	51.5	23.80	Reversed TP and TDP result
JBT05-08012017-1	JBT05	8/1/2017	1	42.8	37.6	21.61	
JBT05-08082017-1+2	JBT05	8/8/2017	1+2	51.1	46.6	NS	Reversed TP and TDP result
JBT05-08152017-1	JBT05	8/15/2017	1	32.2	26.1	10.63	
JBT05-08222017-1	JBT05	8/22/2017	1	125	44.4	15.31	
JBT05-08302017-1	JBT05	8/30/2017	1	91.1	28.6	NS	
JBT05-090517-1	JBT05	9/5/2017	1	204	51.3	10.41	
JBT05-091217-1	JBT05	9/12/2017	1	133	67.6	NS	
JBT05-091917-1	JBT05	9/19/2017	1	65.2	30.6	11.76	
JBT05-092617-1	JBT05	9/26/2017	1	39.0	22.3	NS	
JBT05-100317-1	JBT05	10/3/2017	1	43.7	22.4	7.82	
JBT05-101017-1	JBT05	10/10/2017	1	966	383	18.54	
JBT05-101717-1	JBT05	10/17/2017	1	167	122	12.63	
JBT05-102417-1	JBT05	10/24/2017	1	84.0	33.7	NS	
JBT05-110117-3	JBT05	11/1/2017	3	420	321	NS	
JBT05-110717-3	JBT05	11/7/2017	3	368	300	NS	
JBT05-111417-3	JBT05	11/14/2017	3	131	98.2	NS	Carboy partially frozen--liquid sampled
JBT05-112017-1	JBT05	11/20/2017	1	75.0	51.1	NS	Carboy frozen--processed in office
JBT05-112917-GR	JBT05	11/29/2017	GR	54.4	32.5	NS	
JBT05-120417-GR	JBT05	12/4/2017	GR	37.6	31.0	17.83	TN acidified 24 hrs. later, kept cold
JBT05-121517-GR	JBT05	12/15/2017	GR	43.1	35.1	16.95	
JBT05-121917-GR	JBT05	12/19/2017	GR	33.9	27.4	16.5	
JBT05-122717-GR	JBT05	12/27/2017	GR	45.6	36.3	NS	
JBT05-010918-GR	JBT05	1/9/2018	GR	40.3	26.4	NS	
JBT05-011618-GR	JBT05	1/16/2018	GR	56.2	39.7	22.34	
JBT05-012418-GR	JBT05	1/24/2018	GR	453	422	NS	
JBT05-020118-GR	JBT05	2/1/2018	GR	60.3	48.9	16.42	
JBT05-020518-GR	JBT05	2/5/2018	GR	49	38.7	NS	
JBT05-022118-GR	JBT05	2/21/2018	GR	619	526.2	11.1	
JBT05-030918-GR	JBT05	3/9/2018	GR	47.3	36.2	16.55	



LAB ID	Site	Sampling Date	Carboy	TP (µg/L)	TDP (µg/L)	TN (mg/L)	Comment
JBT06-04112017-1	JBT06	4/11/2017	1	195	131	33.47	
JBT06-04182017-1	JBT06	4/18/2017	1	192	76.3	20.71	
JBT06-04252017-1+2	JBT06	4/25/2017	1+2	117	70.1	24.03	
JBT06-05022017-1	JBT06	5/2/2017	1	321	164	25.20	
JBT06-05092017-1	JBT06	5/9/2017	1	150	100	28.20	
JBT06-05092017-2	JBT06	5/9/2017	2	135	98.1	13.54	
JBT06-05162017-1	JBT06	5/16/2017	1	180	96.2	26.04	
JBT06-05232017-1	JBT06	5/23/2017	1	327	65.2	21.04	
JBT06-05302017-1	JBT06	5/30/2017	1	67.7	37.8	22.52	
JBT06-06072017-1	JBT06	6/7/2017	1	138	88.9	25.87	
JBT06-06132017-1	JBT06	6/13/2017	1	47.4	36.4	25.95	
JBT06-06222017-1	JBT06	6/22/2017	1	45.9	27.3	23.12	
JBT06-06272017-1	JBT06	6/27/2017	1	412	192	42.67	
JBT06-06272017-2	JBT06	6/27/2017	2	210	157	48.27	
JBT06-06272017-3	JBT06	6/27/2017	3	416	222	46.63	
JBT06-06272017-4	JBT06	6/27/2017	4	234	183	49.83	
JBT06-06302017-	JBT06	6/30/2017	1+2+3	266	174	33.83	
JBT06-07052017-1	JBT06	7/5/2017	1	134	109	34.82	
JBT06-07112017-1+2	JBT06	7/11/2017	1+2	228	137	26.50	
JBT06-07182017-1	JBT06	7/18/2017	1	128	106	32.55	
JBT06-07262017-1	JBT06	7/26/2017	1	90.2	39.1	27.40	Reversed TP and TDP result
JBT06-101017-1	JBT06	10/10/2017	1	393	171	NS	
JBT06-110117-3	JBT06	11/1/2017	3	1884	1576	NS	
JBT06-110717-3	JBT06	11/7/2017	3	510	412	NS	
JBT06-111417-1	JBT06	11/14/2017	1	123	88.1	NS	Carboy partially frozen--liquid sampled
JBT06-112017-1	JBT06	11/20/2017	1	234	186	NS	Carboy frozen--processed in office
JBT06-112917-GR	JBT06	11/29/2017	GR	88.9	66	NS	
JBT06-120417-GR	JBT06	12/4/2017	GR	53.3	36	18.13	TN acidified 24 hrs. later, kept cold
JBT06-121517-GR	JBT06	12/15/2017	GR	32.5	31.9	16.94	
JBT06-121917-GR	JBT06	12/19/2017	GR	38.6	23.4	17.56	
JBT06-011218-GR	JBT06	1/12/2018	GR	335	NS	13.77	
JBT06-011618-GR	JBT06	1/16/2018	GR	52.6	51.5	24.54	
JBT06-012418-GR	JBT06	1/24/2018	GR	244	225	NS	
JBT06-020118-GR	JBT06	2/1/2018	GR	44.3	45.5	22.36	
JBT06-020518-GR	JBT06	2/5/2018	GR	41.9	37.2	NS	
JBT06-022118-GR	JBT06	2/21/2018	GR	303	252	10.77	
JBT06-030918-GR	JBT06	3/9/2018	GR	64.8	55.5	14.59	

LAB ID	Site	Sampling Date	Carboy	TP (µg/L)	TDP (µg/L)	TN (mg/L)	Comment
JBT07-04112017-1+2	JBT07	4/11/2017	1+2	708	159	7.52	
JBT07-04182017-1	JBT07	4/18/2017	1	45.0	14.1	4.81	
JBT07-04252017-1	JBT07	4/25/2017	1	103	27.4	5.79	
JBT07-05022017-1	JBT07	5/2/2017	1	280	58.0	6.72	
JBT07-05092017-1	JBT07	5/9/2017	1	126	41.4	6.17	
JBT07-05092017-2+3	JBT07	5/9/2017	2+3	230	54.2	6.59	
JBT07-05162017-1	JBT07	5/16/2017	1	19.7	12.9	5.21	
JBT07-05232017-1	JBT07	5/23/2017	1	24.4	11.9	5.08	
JBT07-05302017-1	JBT07	5/30/2017	1	21.1	14.2	5.29	
JBT07-06072017-1	JBT07	6/7/2017	1	17.0	7.0	5.57	
JBT07-06132017-1	JBT07	6/13/2017	1	NS	13.1	5.35	VAEL remark: TDP biased low
JBT07-06222017-1	JBT07	6/22/2017	1	39.3	17.1	8.16	
JBT07-06262017-1	JBT07	6/26/2017	1	242	177	45.18	
JBT07-06262017-2	JBT07	6/26/2017	2	555	357	45.18	
JBT07-06262017-3	JBT07	6/26/2017	3	204	182	31.59	
JBT07-06262017-4	JBT07	6/26/2017	4	389	230	23.59	
JBT07-06302017-1	JBT07	6/30/2017	1	79.7	60.8	12.67	
JBT07-06302017-2+3	JBT07	6/30/2017	2+3	700	327	18.55	
JBT07-07052017-1	JBT07	7/5/2017	1	119	88.6	11.62	
JBT07-07112017-1	JBT07	7/11/2017	1	47.3	21.0	11.05	
JBT07-07182017-1	JBT07	7/18/2017	1	69.9	54.9	15.37	
JBT07-07262017-1	JBT07	7/26/2017	1	82.5	37.3	9.14	
JBT07-08012017-1	JBT07	8/1/2017	1	29.4	25.1	6.96	
JBT07-08222017-1	JBT07	8/22/2017	1	226	136	3.37	
JBT07-08302017-1	JBT07	8/30/2017	1	52.0	32.6	NS	
JBT07-091217-1	JBT07	9/12/2017	1	169	89.5	NS	
JBT07-091217-2+3	JBT07	9/12/2017	2+3	106	77.3	NS	
JBT07-091917-1	JBT07	9/19/2017	1	51.8	19.1	3.06	
JBT07-092617-1	JBT07	9/26/2017	1	101	32.3	NS	
JBT07-101017-1	JBT07	10/10/2017	1	304	125	NS	
JBT07-101717-1	JBT07	10/17/2017	1	39.6	21.4	2.04	
JBT07-102417-1	JBT07	10/24/2017	1	44.0	20.6	NS	
JBT07-110117-3	JBT07	11/1/2017	3	471	197	NS	
JBT07-110717-3	JBT07	11/7/2017	3	450	125	NS	
JBT07-111417-1	JBT07	11/14/2017	1	116	44.3	NS	Carboy partially frozen--liquid sampled
JBT07-112017-1	JBT07	11/20/2017	1	104	38.2	NS	Carboy frozen--processed in office
JBT07-112917-GR	JBT07	11/29/2017	GR	31.7	24.8	NS	
JBT07-120417-GR	JBT07	12/4/2017	GR	28.2	22	3.2	TN acidified 24 hrs. later, kept cold
JBT07-121917-GR	JBT07	12/19/2017	GR	25.7	19.4	2.96	
JBT07-011218-GR	JBT07	1/12/2018	GR	433	361.5	13.47	Reversed TP and TDP result
JBT07-012518-GR	JBT07	1/25/2018	GR	53.2	49.2	NS	
JBT07-020118-GR	JBT07	2/1/2018	GR	23.4	23.5	4.24	
JBT07-020518-GR	JBT07	2/5/2018	GR	22.2	19.8	NS	
JBT07-022118-GR	JBT07	2/21/2018	GR	271.5	194.2	14.9	
JBT07-030918-GR	JBT07	3/9/2018	GR	42.2	34.6	5.87	

LAB ID	Site	Sampling Date	Carboy	TP (µg/L)	TDP (µg/L)	TN (mg/L)	Comment
JBT11-04112017-1	JBT11	4/11/2017	1	57.80	39.50	3.35	Reversed TP and TDP result
JBT11-04182017-1	JBT11	4/18/2017	1	16.20	11.50	2.59	Reversed TP and TDP result
JBT11-04252017-1	JBT11	4/25/2017	1	14.7	9.7	2.45	
JBT11-05022017-1	JBT11	5/2/2017	1	46.5	16.1	2.04	
JBT11-05092017-1	JBT11	5/9/2017	1	28.8	12.0	1.63	
JBT11-05092017-2	JBT11	5/9/2017	2	39.0	12.9	1.53	
JBT11-05162017-1	JBT11	5/16/2017	1	31.2	23.1	1.24	
JBT11-05232017-1	JBT11	5/23/2017	1	234	28.8	1.24	
JBT11-05302017-1	JBT11	5/30/2017	1	18.1	9.6	0.81	
JBT11-06072017-1	JBT11	6/7/2017	1	18.6	6.5	0.91	VAEL remark: TDP biased low
JBT11-06132017-1	JBT11	6/13/2017	1	49.7	17.2	1.29	
JBT11-06222017-1	JBT11	6/22/2017	1	68.8	26.4	0.77	
JBT11-06272017-1	JBT11	6/27/2017	1	61.5	29.2	1.48	
JBT11-06272017-2	JBT11	6/27/2017	2	89.8	48.0	1.59	
JBT11-06272017-3	JBT11	6/27/2017	3	77.1	51.4	1.54	
JBT11-06272017-4	JBT11	6/27/2017	4	81.4	44.0	1.51	
JBT11-06302017-1	JBT11	6/30/2017	1	30.3	17.9	1.11	
JBT11-06302017-2	JBT11	6/30/2017	2	24.8	17.9	1.01	
JBT11-06302017-3	JBT11	6/30/2017	3	24.0	16.8	1.05	
JBT11-06302017-4	JBT11	6/30/2017	4	23.3	16.0	1.06	
JBT11-07052017-1	JBT11	7/5/2017	1	21.2	16.8	1.16	
JBT11-07112017-1	JBT11	7/11/2017	1	28.1	19.5	1.30	
JBT11-07182017-1+2	JBT11	7/18/2017	1+2	64.4	33.5	1.22	Reversed TP and TDP result
JBT11-07262017-1	JBT11	7/26/2017	1	26.0	15.4	0.96	Reversed TP and TDP result
JBT11-08012017-1	JBT11	8/1/2017	1	59.1	35.2	1.23	
JBT11-090517-1	JBT11	9/5/2017	1	92.6	45.2	1.13	
JBT11-091217-1+2	JBT11	9/12/2017	1+2	420	411	NS	
JBT11-091917-1	JBT11	9/19/2017	1	77.9	38.1	1.20	
JBT11-092617-1	JBT11	9/26/2017	1	127	34.9	NS	
JBT11-100317-1	JBT11	10/3/2017	1	26.0	14.1	0.19	
JBT11-101117-1	JBT11	10/11/2017	1	256	203	NS	
JBT11-101717-1	JBT11	10/17/2017	1	92.5	77.8	0.81	
JBT11-102417-1	JBT11	10/24/2017	1	66.7	25.0	NS	
JBT11-110117-1	JBT11	11/1/2017	1	79.3	44.0	NS	
JBT11-110717-3	JBT11	11/7/2017	3	84.3	58.3	NS	
JBT11-112017-3	JBT11	11/20/2017	3	15.9	8.4	NS	Carboy frozen-processed in office; VAEL remark: TDP biased
JBT11-112917-GR	JBT11	11/29/2017	GR	20.1	12.5	NS	
JBT11-120417-GR	JBT11	12/4/2017	GR	16.2	12.2	1.31	TN acidified 24 hrs. later, kept cold
JBT11-121517-GR	JBT11	12/15/2017	GR	14.3	11.9	1.55	
JBT11-121917-GR	JBT11	12/19/2017	GR	14	12	1.49	
JBT11-012418-GR	JBT11	1/24/2018	GR	44.9	36.6	NS	
JBT11-020118-GR	JBT11	2/1/2018	GR	25.8	12.2	1.42	
JBT11-020518-GR	JBT11	2/5/2018	GR	19.1	16.7	NS	
JBT11-022118-GR	JBT11	2/21/2018	GR	140.8	105	2.13	
JBT11-030918-GR	JBT11	3/9/2018	GR	11.7	11.3	1.76	

LAB ID	Site	Sampling Date	Carboy	TP (µg/L)	TDP (µg/L)	TN (mg/L)	Comment
JBT13-04182017-1	JBT13	4/18/2017	1	63.8	23.2	6.12	
JBT13-04252017-1	JBT13	4/25/2017	1	113	26.1	6.44	
JBT13-05022017-1	JBT13	5/2/2017	1	560	41.1	5.25	
JBT13-05092017-1+2	JBT13	5/9/2017	1+2	120	35.7	6.10	
JBT13-05162017-1	JBT13	5/16/2017	1	35,295	NS	217.21	TDP vial lost in transit; samples dark brown
JBT13-05232017-1	JBT13	5/23/2017	1	3,720	2,525	17.20	
JBT13-05302017-1	JBT13	5/30/2017	1	2,975	2,070	14.08	Sample is cloudy; lots of sediment
JBT13-06072017-1	JBT13	6/7/2017	1	3,585	2,240	19.08	Sample is cloudy; lots of sediment
JBT13-06132017-1	JBT13	6/13/2017	1	815	490	7.97	
JBT13-06222017-1	JBT13	6/22/2017	1	912	585	8.94	
JBT13-06272017-1	JBT13	6/27/2017	1	525	218	21.83	
JBT13-06272017-2	JBT13	6/27/2017	2	385	137	12.71	
JBT13-07052017-1	JBT13	7/5/2017	1	312	143	28.87	
JBT13-07052017-2	JBT13	7/5/2017	2	87.1	70.5	14.03	
JBT13-07112017-1	JBT13	7/11/2017	1	350	191	12.15	
JBT13-07182017-1	JBT13	7/18/2017	1	95.3	94.8	16.97	
JBT13-07262017-1	JBT13	7/26/2017	1	127	118	10.20	
JBT13-08082017-1	JBT13	8/8/2017	1	248	148	NS	
JBT13-08152017-1	JBT13	8/15/2017	1	336	196	5.29	
JBT13-08222017-1	JBT13	8/22/2017	1	275	139	7.74	
JBT13-08302017-1	JBT13	8/30/2017	1	272	94.1	NS	
JBT13-090517-1	JBT13	9/5/2017	1	139	70.8	2.87	
JBT13-091217-1+2	JBT13	9/12/2017	1+2	202	149	NS	
JBT13-091917-1	JBT13	9/19/2017	1	105	57.7	5.94	
JBT13-092617-1	JBT13	9/26/2017	1	86.8	46.4	NS	
JBT13-100317-1	JBT13	10/3/2017	1	99.1	61.5	1.86	
JBT13-101117-1	JBT13	10/11/2017	1	612	172	NS	TDP filtered at VAEL on 10/12/17
JBT13-101717-1	JBT13	10/17/2017	1	178	115	NS	
JBT13-102417-1	JBT13	10/24/2017	1	63.2	36.5	NS	
JBT13-110117-1+2	JBT13	11/1/2017	1+2	172	77.6	NS	
JBT13-110717-3	JBT13	11/7/2017	3	141	85.6	NS	
JBT13-111417-1	JBT13	11/14/2017	1	66.4	49.8	NS	Carboy partially frozen--liquid sampled
JBT13-112017-1	JBT13	11/20/2017	1	64.1	42.8	NS	Carboy frozen--processed in office
JBT13-112917-GR	JBT13	11/29/2017	GR	35.8	24.5	NS	
JBT13-120417-GR	JBT13	12/4/2017	GR	36.8	26	5.72	TN acidified 24 hrs. later, kept cold
JBT13-121517-GR	JBT13	12/15/2017	GR	182	24	6.65	
JBT13-121917-GR	JBT13	12/19/2017	GR	38.9	24.5	6.12	
JBT13-010918-GR	JBT13	1/9/2018	GR	36.8	27.1	NS	
JBT13-011618-GR	JBT13	1/16/2018	GR	79.8	24	6.47	
JBT13-012418-GR	JBT13	1/24/2018	GR	129	74.2	NS	
JBT13-020118-GR	JBT13	2/1/2018	GR	31.9	25.4	2.51	
JBT13-022118-GR	JBT13	2/21/2018	GR	188	108	3.75	
JBT13-030918-GR	JBT13	3/9/2018	GR	51.1	21.9	5.17	

LAB ID	Site	Sampling Date	Carboy	TP (µg/L)	TDP (µg/L)	TN (mg/L)	Comment
JBT14-04112017-1	JBT14	4/11/2017	1	248	66.5	7.43	
JBT14-04182017-1	JBT14	4/18/2017	1	70.5	33.2	8.25	
JBT14-04252017-1	JBT14	4/25/2017	1	145	51.5	7.62	
JBT14-04252017-2	JBT14	4/25/2017	2	46.3	35.2	8.22	
JBT14-05022017-1	JBT14	5/2/2017	1	342	59.3	7.20	
JBT14-05092017-1+2	JBT14	5/9/2017	1+2	177	51.1	7.12	
JBT14-05162017-1	JBT14	5/16/2017	1	4335	1640	51.21	Samples dark brown; TDP filtered at VAE
JBT14-05232017-1	JBT14	5/23/2017	1	690	183	9.66	
JBT14-05302017-1	JBT14	5/30/2017	1	78.2	75.7	7.72	
JBT14-06072017-1	JBT14	6/7/2017	1	138	143	19.95	
JBT14-06132017-1+2	JBT14	6/13/2017	1+2	73.6	60.1	9.89	
JBT14-06222017-1	JBT14	6/22/2017	1	189	132	11.88	
JBT14-06272017-1	JBT14	6/27/2017	1	482	208	31.95	
JBT14-06272017-2	JBT14	6/27/2017	2	618	345	22.75	
JBT14-06272017-3	JBT14	6/27/2017	3	246	216	19.91	
JBT14-06302017-1	JBT14	6/30/2017	1	436	210	56.87	
JBT14-06302017-2	JBT14	6/30/2017	2	220	162	34.23	
JBT14-07052017-1	JBT14	7/5/2017	1	95.9	86.4	16.81	
JBT14-07052017-2	JBT14	7/5/2017	2	90.4	74.1	14.07	
JBT14-07112017-1	JBT14	7/11/2017	1	103	87.4	13.35	
JBT14-07182017-1+2	JBT14	7/18/2017	1+2	102	88.3	14.87	Reversed TP and TDP result
JBT14-07262017-1	JBT14	7/26/2017	1	79.3	69.4	12.90	Reversed TP and TDP result
JBT14-08012017-1	JBT14	8/1/2017	1	73.6	59.7	11.80	Reversed TP and TDP result
JBT14-08302017-1	JBT14	8/30/2017	1	350	239	NS	
JBT14-090517-1	JBT14	9/5/2017	1	309	251	4.97	
JBT14-091217-1+2	JBT14	9/12/2017	1+2	162	107	NS	
JBT14-091917-1	JBT14	9/19/2017	1	52.9	26.1	7.84	
JBT14-092617-1	JBT14	9/26/2017	1	37.5	29.0	NS	
JBT14-100317-1	JBT14	10/3/2017	1	82.0	67.7	4.95	
JBT14-101117-1	JBT14	10/11/2017	1	776	150	NS	
JBT14-101117-3	JBT14	10/11/2017	3	341	184	NS	
JBT14-101117-4	JBT14	10/11/2017	4	134	91.0	NS	
JBT14-101717-1	JBT14	10/17/2017	1	67.3	49.5	NS	
JBT14-102417-1	JBT14	10/24/2017	1	54.4	39.0	NS	
JBT14-110117-3	JBT14	11/1/2017	3	152	71.7	NS	
JBT14-110717-3+4	JBT14	11/7/2017	3+4	161	98.4	NS	
JBT14-111417-1	JBT14	11/14/2017	1	107	42.7	NS	Carboy partially frozen--liquid sampled
JBT14-112017-1	JBT14	11/20/2017	1	55.1	43.1	NS	Carboy frozen--processed in office
JBT14-112917-GR	JBT14	11/29/2017	GR	38	28.3	NS	
JBT14-120417-GR	JBT14	12/4/2017	GR	73.7	27.7	8.28	TN acidified 24 hrs. later, kept cold
JBT14-121517-GR	JBT14	12/15/2017	GR	56.7	17.2	8.1	
JBT14-121917-GR	JBT14	12/19/2017	GR	25	23.6	8.22	
JBT14-020518-GR	JBT14	2/5/2018	GR	46	37.8	NS	
JBT14-022118-GR	JBT14	2/21/2018	GR	288	204	4.28	
JBT14-030918-GR	JBT14	3/9/2018	GR	34.8	28.5	7.55	

LAB ID	Site	Sampling Date	Carboy	TP (µg/L)	TDP (µg/L)	TN (mg/L)	Comment
JBT16-04112017-1+2	JBT16	4/11/2017	1+2	105	72.7	5.77	
JBT16-04182017-1	JBT16	4/18/2017	1	28.2	22.4	5.12	
JBT16-04252017-1	JBT16	4/25/2017	1	28.5	21.5	4.48	
JBT16-05022017-1	JBT16	5/2/2017	1	256	25.5	3.89	
JBT16-05092017-1+2	JBT16	5/9/2017	1+2	31.3	13.7	2.79	
JBT16-05162017-1	JBT16	5/16/2017	1	19.4	13.3	2.89	
JBT16-05232017-1	JBT16	5/23/2017	1	26.2	17.0	2.96	
JBT16-05302017-1	JBT16	5/30/2017	1	26.7	17.7	2.62	
JBT16-06072017-1	JBT16	6/7/2017	1	25.9	9.6	3.68	VAEL remark: TDP biased low
JBT16-06132017-1	JBT16	6/13/2017	1	29.4	17.4	3.44	
JBT16-06222017-1	JBT16	6/22/2017	1	85.9	32.9	5.81	
JBT16-06262017-1+2	JBT16	6/26/2017	1+2	89.2	44.1	21.99	
JBT16-07052017-1	JBT16	7/5/2017	1	41.0	28.9	14.85	
JBT16-07052017-2+3	JBT16	7/5/2017	2+3	34.3	27.6	12.43	
JBT16-07112017-1	JBT16	7/11/2017	1	32.8	29.8	9.75	
JBT16-07182017-1	JBT16	7/18/2017	1	35.4	22.3	8.40	
JBT16-07262017-1	JBT16	7/26/2017	1	51.7	45.9	8.87	
JBT16-08012017-1	JBT16	8/1/2017	1	54.7	39.1	8.52	
JBT16-08152017-1	JBT16	8/15/2017	1	159	32.6	6.41	
JBT16-08222017-1	JBT16	8/22/2017	1	81.9	59.9	6.67	
JBT16-08302017-1	JBT16	8/30/2017	1	59.6	36.8	NS	
JBT16-091217-1+2	JBT16	9/12/2017	1+2	84.1	48.5	NS	
JBT16-091917-1	JBT16	9/19/2017	1	63.5	35.3	5.66	
JBT16-101017-1	JBT16	10/10/2017	1	1025	630	NS	TDP filtered at VAEL on 10/12/17
JBT16-101717-1	JBT16	10/17/2017	1	169	133	7.09	
JBT16-110117-1	JBT16	11/1/2017	1	161	115	NS	
JBT16-110717-3	JBT16	11/7/2017	3	120	106	NS	
JBT16-111417-1	JBT16	11/14/2017	1	44.5	31.5	NS	Carboy partially frozen--liquid sampled
JBT16-112017-1	JBT16	11/20/2017	1	18.0	10.5	NS	Carboy frozen--processed in office
JBT16-112917-GR	JBT16	11/29/2017	GR	53.7	10.7	NS	
JBT16-120417-GR	JBT16	12/4/2017	GR	40.5	9.6	6.96	TN acidified 24 hrs. later, kept cold
JBT16-121517-GR	JBT16	12/15/2017	GR	12.0	9.9	6.5	
JBT16-121917-GR	JBT16	12/19/2017	GR	24.6	19.3	3.03	
JBT16-122717-GR	JBT16	12/27/2017	GR	26.4	12.1	NS	
JBT16-010918-GR	JBT16	1/9/2018	GR	71.2	12.1	NS	
JBT16-011618-GR	JBT16	1/16/2018	GR	30.7	12.0	8.24	
JBT16-012518-GR	JBT16	1/25/2018	GR	20.3	15.3	NS	
JBT16-020118-GR	JBT16	2/1/2018	GR	18.0	11.7	3.39	
JBT16-020518-GR	JBT16	2/5/2018	GR	16.7	11	NS	
JBT16-022118-GR	JBT16	2/21/2018	GR	100	59.6	4.6	
JBT16-030918-GR	JBT16	3/9/2018	GR	82.7	11.9	5.59	



LAB ID	Site	Sampling Date	Carboy	TP (µg/L)	TDP (µg/L)	TN (mg/L)	Comment
JBT18-04252017-1	JBT18	4/25/2017	1	87.4	46.1	1.16	
JBT18-05022017-1	JBT18	5/2/2017	1	170	42.3	1.26	
JBT18-05092017-1	JBT18	5/9/2017	1	140	40.1	1.13	
JBT18-05092017-2	JBT18	5/9/2017	2	77.5	37.5	0.99	
JBT18-05092017-3	JBT18	5/9/2017	3	159	32.5	1.06	
JBT18-05092017-4	JBT18	5/9/2017	4	199	38.6	1.10	
JBT18-05162017-1	JBT18	5/16/2017	1	80.8	35.9	0.71	
JBT18-05232017-1	JBT18	5/23/2017	1	49.7	16.0	0.78	
JBT18-05302017-1	JBT18	5/30/2017	1	89.1	23.0	0.95	
JBT18-06062017-1	JBT18	6/6/2017	1	46.5	8.6	0.79	VAEL remark: TDP biased low
JBT18-06132017-1	JBT18	6/13/2017	1	160	31.1	1.25	
JBT18-06222017-1	JBT18	6/22/2017	1	71.2	NS	1.33	Lab broke TDP sample vial
JBT18-06302017-1	JBT18	6/30/2017	1	261	57.2	2.04	
JBT18-06302017-2	JBT18	6/30/2017	2	234	71.5	1.90	
JBT18-06302017-3	JBT18	6/30/2017	3	206	58.9	1.61	
JBT18-06302017-4	JBT18	6/30/2017	4	142	57.9	1.38	
JBT18-07052017-1+2+3+4	JBT18	7/5/2017	1+2+3+4	143	74.4	0.98	
JBT18-07112017-1	JBT18	7/11/2017	1	135	59.5	1.06	
JBT18-07182017-1	JBT18	7/18/2017	1	183	166	1.15	Reversed TP and TDP result
JBT18-07262017-1	JBT18	7/26/2017	1	66.5	40.0	1.10	
JBT18-08012017-1	JBT18	8/1/2017	1	43.3	28.2	0.83	
JBT18-08082017-1	JBT18	8/8/2017	1	34.5	16.1	NS	
JBT18-08222017-1	JBT18	8/22/2017	1	75.9	33.1	2.18	
JBT18-08302017-1	JBT18	8/30/2017	1	46.2	26.6	NS	
JBT18-090517-1	JBT18	9/5/2017	1	75.9	28.3	3.15	
JBT18-091217-1	JBT18	9/12/2017	1	186	114	NS	
JBT18-091217-2	JBT18	9/12/2017	2	117	71.2	NS	
JBT18-091917-1	JBT18	9/19/2017	1	64.6	26.9	0.84	
JBT18-092617-1	JBT18	9/26/2017	1	180	28.6	NS	
JBT18-101017-1	JBT18	10/10/2017	1	223	80.9	NS	
JBT18-101717-1	JBT18	10/17/2017	1	195	47.9	1.58	
JBT18-102417-1	JBT18	10/24/2017	1	97.0	68.5	NS	
JBT18-110117-1	JBT18	11/1/2017	1	432	194	NS	
JBT18-110717-3	JBT18	11/7/2017	3	130	73.2	NS	
JBT18-111417-1	JBT18	11/14/2017	1	46.0	33.5	NS	Carboy partially frozen--liquid sampled
JBT18-112017-1	JBT18	11/20/2017	1	61.5	43.4	NS	Carboy frozen--processed in office
JBT18-112917-GR	JBT18	11/29/2017	GR	59.7	19.5	NS	
JBT18-120417-GR	JBT18	12/4/2017	GR	35.4	15.3	0.51	TN acidified 24 hrs. later, kept cold
JBT18-121917-GR	JBT18	12/19/2017	GR	33.4	19.9	0.35	
JBT18-010918-GR	JBT18	1/9/2018	GR	23.5	12.8	NS	
JBT18-011218-GR	JBT18	1/12/2018	GR	264.5	219.3	1.24	Reversed TP and TDP result
JBT18-012518-GR	JBT18	1/25/2018	GR	61	42.4	NS	
JBT18-022118-GR	JBT18	2/21/2018	GR	317.5	240	2.09	
JBT18-030918-GR	JBT18	3/9/2018	GR	134	76.2	1.16	

LAB ID	Site	Sampling Date	Carboy	TP (µg/L)	TDP (µg/L)	TN (mg/L)	Comment
JBT19-04252017-1	JBT19	4/25/2017	1	31.7	27.2	1.00	Reversed TP and TDP result
JBT19-05022017-1	JBT19	5/2/2017	1	56.0	21.1	1.10	
JBT19-05092017-1	JBT19	5/9/2017	1	40.1	29.1	0.76	
JBT19-05092017-2	JBT19	5/9/2017	2	20.9	12.2	0.61	
JBT19-05092017-3+4	JBT19	5/9/2017	3+4	55.2	20.4	0.82	
JBT19-05162017-1	JBT19	5/16/2017	1	17.6	12.6	0.45	
JBT19-05232017-1	JBT19	5/23/2017	1	54.6	22.1	1.00	
JBT19-05302017-1	JBT19	5/30/2017	1	21.8	10.4	0.49	
JBT19-06132017-1	JBT19	6/13/2017	1	81.1	23.1	0.91	
JBT19-06222017-1	JBT19	6/22/2017	1	151	NS	1.24	Lab broke TDP sample vial
JBT19-06302017-1	JBT19	6/30/2017	1	163	73.7	2.04	
JBT19-06302017-2	JBT19	6/30/2017	2	52.2	39.4	0.88	
JBT19-06302017-3+4	JBT19	6/30/2017	3+4	51.8	40.9	0.94	
JBT19-07052017-1+2+3+4	JBT19	7/5/2017	1+2+3+4	41.4	31.3	0.71	
JBT19-07112017-1	JBT19	7/11/2017	1	45.3	21.8	0.57	
JBT19-07182017-1+2	JBT19	7/18/2017	1+2	79.3	74.2	1.05	
JBT19-07262017-1	JBT19	7/26/2017	1	29.3	27.5	0.73	
JBT19-08012017-1	JBT19	8/1/2017	1	32.8	18.7	0.58	
JBT19-08082017-1	JBT19	8/8/2017	1	111	22.6	NS	
JBT19-08302017-1	JBT19	8/30/2017	1	29.1	13.8	NS	
JBT19-090517-1	JBT19	9/5/2017	1	55.5	17.4	1.92	
JBT19-091217-1+2	JBT19	9/12/2017	1+2	62.4	28.9	NS	
JBT19-091917-1	JBT19	9/19/2017	1	62.1	12.5	0.75	
JBT19-101717-1	JBT19	10/17/2017	1	209	16.4	1.46	
JBT19-102417-1	JBT19	10/24/2017	1	318	15.0	NS	
JBT19-110117-1	JBT19	11/1/2017	1	95.9	14.8	NS	
JBT19-110717-3	JBT19	11/7/2017	3	63.8	16.0	NS	
JBT19-111417-1	JBT19	11/14/2017	1	35.7	18.5	NS	Carboy partially frozen--liquid
JBT19-112017-1	JBT19	11/20/2017	1	27.5	11.4	NS	Carboy frozen--processed in office
JBT19-112917-GR	JBT19	11/29/2017	GR	50.6	12.7	NS	
JBT19-120417-GR	JBT19	12/4/2017	GR	54.9	10.5	0.39	TN acidified 24 hrs. later, kept cold
JBT19-121917-GR	JBT19	12/19/2017	GR	29.5	16.5	0.41	