FINAL REPORT

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DEVELOPMENT OF A TREATMENT TRAIN TO REMOVE PHOSPHORUS FROM STREAMFLOW IN THE ST. ALBANS BAY WATERSHED–PHASE 2: TECHNICAL FEASIBILITY EVALUATION

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This project has been funded wholly or in part by the United States Environmental Protection Agency under an assistance agreement to NEIWPCC in partnership with the Lake Champlain Basin Program (LCBP). NEIWPCC manages LCBP's personnel, contract, grant, and budget tasks and provides input on the program's activities through a partnership with the LCBP Steering Committee.

Executive Summary

Development of a treatment train facility to remove phosphorus from Jewett Brook prior to discharge to St. Albans Bay has the potential to accelerate water quality improvements in St. Albans Bay. Jewett Brook has chronically elevated concentrations of phosphorus. Implementing a treatment train facility on Jewett Brook would involve withdrawing, treating, and releasing a portion of the streamflow. This facility could extend ongoing agency nutrient reduction programs focused on implementation of agricultural conservation practices in the St. Albans Bay watershed and bring the St. Albans Bay phosphorus targets within reach.

In the first phase of this project, representatives of local, state, and federal government bodies were convened to evaluate the regulatory feasibility of developing a treatment facility on Jewett Brook. The evaluation served to clarify which resource concerns were paramount as well as potential ways to avoid or minimize impacts to these resources. The resource concerns that emerged as most challenging were 1) entrainment of fish (specifically larvae) in intake pumps; 2) potential impacts to aquatic organisms due to warming of the stream at the discharge location; and 3) potential impacts to fish species recruitment due to alteration of the natural flow regime in Jewett Brook and the Black Creek Wildlife Management Area.

Stone performed a comprehensive review of potential sites in the lower Jewett Brook watershed for development of a treatment train facility. Two sites on the Dunsmore Farm on Dunsmore Road emerged as most viable. Each site has advantages and disadvantages. A conceptual treatment facility design is presented for each site. At this juncture, we believe the Dunsmore 2 site is the best option, because it is more proximate to Jewett Brook and its soil, slope, tree shading, and access conditions are more favorable. The primary resource concerns could be addressed in the design and operation of a treatment facility located at the Dunsmore 2 site. Operating the facility only when flow conditions are suitable will minimize impacts on aquatic biota.

Assuming seasonal operation (spring and fall), Stone estimates a median total phosphorus removal rate of 286 kg per year (631 lb./yr) for the proposed Dunsmore 2 Treatment Train. Using ballpark cost estimates, we predict the cost of P removal at this facility will be about $800 per kilogram.

Jewett Brook Treatment Train: Technical Feasibility Evaluation

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1. Introduction

For many years, a top priority of lake managers and the agricultural sector in Vermont has been reducing phosphorus (P) runoff from farmland through the implementation of agricultural conservation practices. These practices, however, may not be sufficient to address the problem in Lake Champlain's eutrophic St. Albans Bay. The Lake Champlain TMDL Phase 1 Implementation Plan states that higher nutrient loading from agricultural runoff in a handful of subwatersheds, including St. Albans Bay, will require implementation of creative solutions and innovative restoration techniques to achieve the goals of the Lake Champlain TMDL (Vermont Agency of Natural Resources, 2016).

Phosphorus inputs to St. Albans Bay are dominated by loading from three tributaries, the Mill River, Stevens Brook, and Jewett Brook. The tributary with the highest median total phosphorus (TP) concentration – approximately 400 µg/L in the 2009-2020 period – is Jewett Brook (Vermont Agency of Natural Resources, 2022). Median concentrations of both TP and total dissolved phosphorus (TDP) in Jewett Brook greatly exceed all other monitored Lake Champlain tributaries (Figures 1 and 2). Note that in Figures 1 and 2 the period of record for Jewett Brook, 2008 – 2020, is shorter than for the other tributaries.

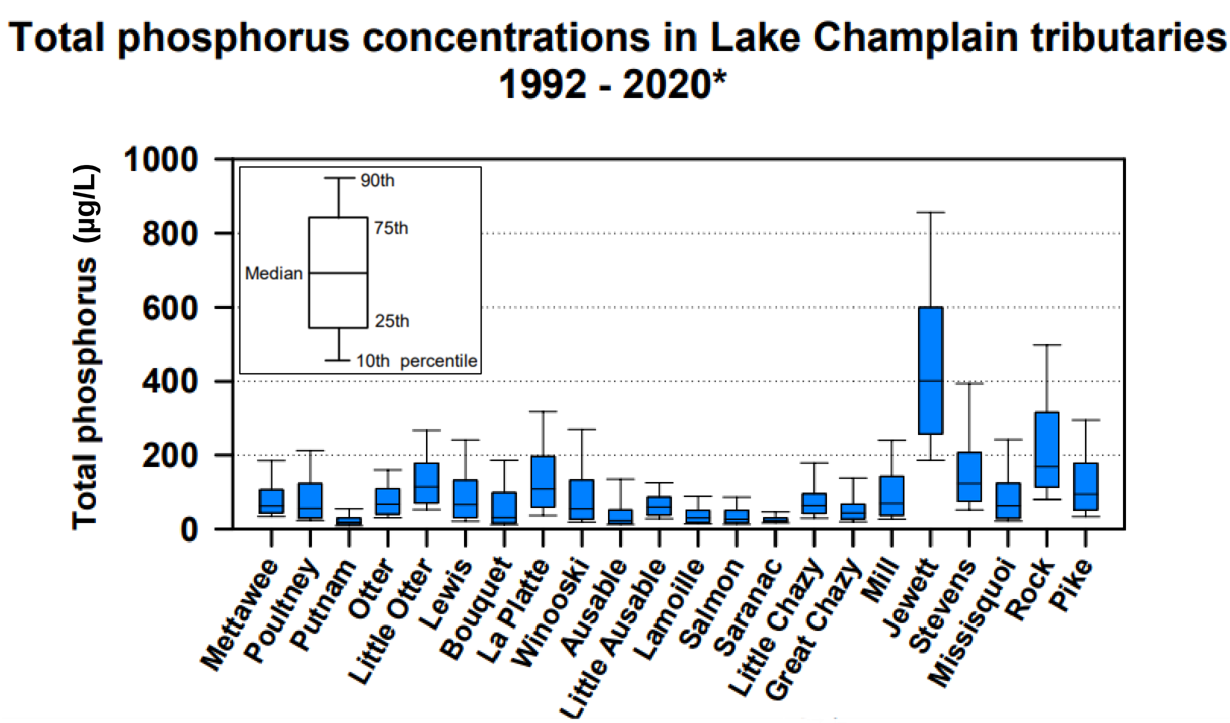

Figure 1. TP concentrations in Lake Champlain tributaries

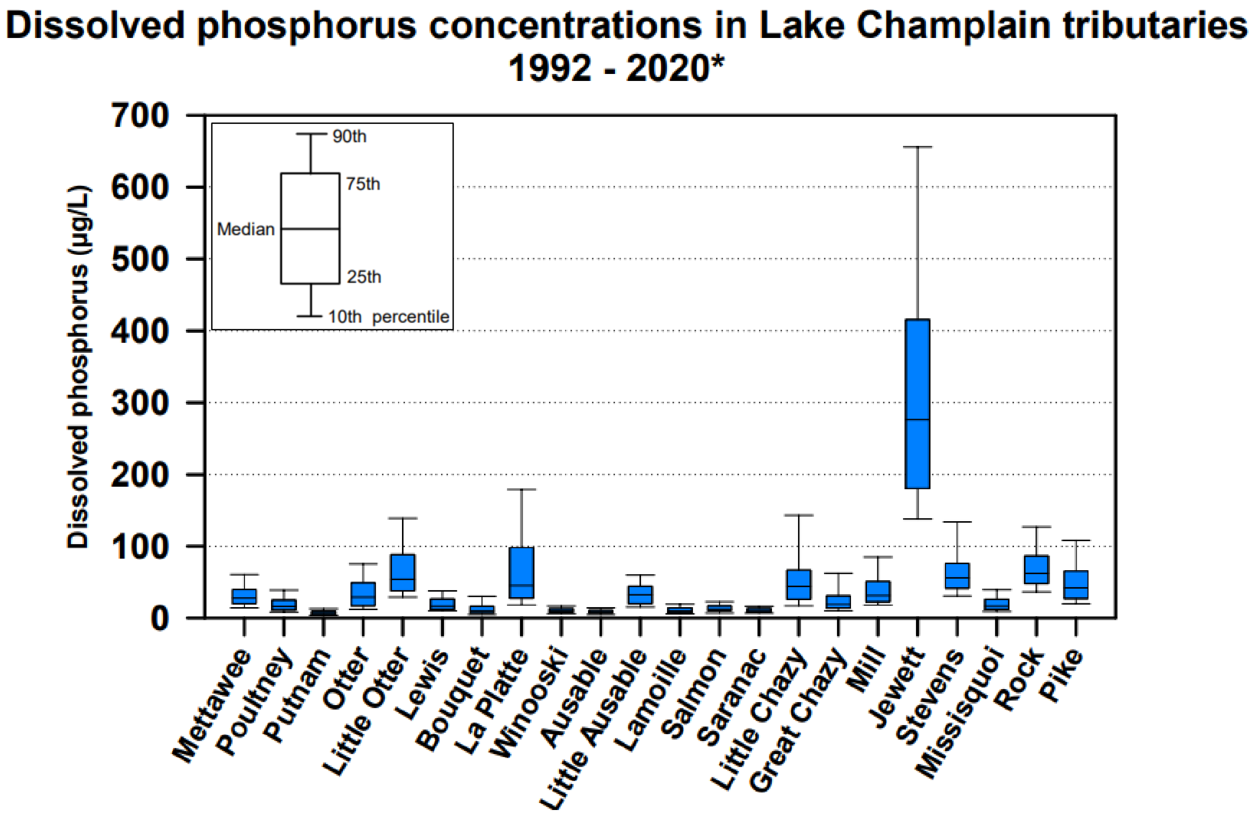

Figure 2. TDP concentrations in Lake Champlain tributaries

Internal flux of P from the sediment in St. Albans Bay to the water column represents a second substantial P input (Druschel et al. 2005). Chemical treatment options to control sediment P release in St. Albans Bay have been considered, but not pursued, largely because high tributary P loadings are predicted to negate the effectiveness of in-lake treatments over a relatively short period of time (ENSR 2007).

Many of the phosphorus interventions contemplated in the TMDL Phase 1 Implementation Plan rely on the completion of substantial but dispersed, watershed-based nutrient reduction actions. The cumulative effects of these practices will take time – decades – to produce significant, measured improvements in Lake Champlain's water quality. It is clear there are areas of the lake, including St. Albans Bay, in need of more immediate relief, and thus requiring more aggressive intervention.

One innovative P reduction approach that is gaining attention in Vermont is the development of treatment systems to remove P from streamflow before it reaches Lake Champlain. In theory, treating streamflow in certain priority watersheds could complement existing conservation programs and achieve more certain, near-term P reductions. Though practices capable of removing significant quantities of P from surface waters are in their infancy, there have been successful applications of these systems on tributaries of Grand Lake St. Marys (GLSM) in Ohio. The largest of three treatment train systems at GLSM draws up to 2.5 million gallons per day (MGD) from Coldwater Creek.

This project examined the feasibility of implementing a treatment train facility in the Jewett Brook watershed. This facility would withdraw and treat a portion of the streamflow. The first treatment step would consist of one or more settling basins with chemicals added to promote coagulation, flocculation, and settling of phosphorus and suspended sediment. The water would then pass by gravity through constructed wetlands that would settle additional sediment and particulate P and assimilate dissolved nutrients through plant uptake, before returning to Jewett Brook.

Operation of a facility that would remove phosphorus from streamflow prior to discharge to Lake Champlain holds certain advantages not available at the scale of individual farms or developments. Treatment technologies could be applied that are not feasible at smaller scales. Such a facility would have electric power to run pumps, chemical feeds, and mixers. It would have reliable, year-round access, which can be a challenge with on-farm practices. It would be staffed by trained operators, who would follow standard operating procedures, maintain equipment, and monitor system performance. Treatment performance could be optimized through the year by adjusting the pumping rate, the chemical addition rate, and the water level in the constructed wetlands, considering the stream stage, flow rate, and temperature. In contrast to field practices designed to treat runoff, the facility would remove phosphorus continuously, except in the winter or during low flow periods when it would not operate.

Given the potential for stream treatment facilities to remove significant quantities of P, resource managers should consider this option where required nonpoint source P load reductions may be difficult to achieve through BMP implementation alone. The Lake Champlain P TMDL requires a 24.5% reduction in the total P load to St. Albans Bay and a 34.5% reduction in the agricultural portion of this load. Implementing a treatment train system could extend and enhance ongoing agency programs focused on BMPs and nutrient management and bring the St. Albans Bay P targets within reach.

Development of a treatment train facility in the St. Albans Bay watershed is a multiyear effort. In 2017-2018, Stone conducted a project for LCBP to evaluate the regulatory feasibility of developing a treatment train facility to remove phosphorous from Jewett Brook. We concluded that while regulatory challenges exist, particularly concerns regarding thermal impacts to certain fish populations, potential resource impacts could be minimized on a favorable site through accommodations in facility design and operation.

In this Phase 2 Technical Feasibility Evaluation, Stone evaluated potential facility sites, conducted an analysis of available flow and water quality data for Jewett Brook, considered sizing of treatment components and developed treatment train conceptual designs, estimated achievable P load reductions, and prepared a preliminary assessment of costs. Stone modeled the design of the Jewett Brook treatment train after the Coldwater Creek treatment train at GLSM, which is discussed in detail in Section 2.

1.1. Project Objective

The overarching goal of this effort is to advance development of a treatment train facility to provide cost-effective removal of phosphorus that would otherwise flow to St. Albans Bay of Lake Champlain. This goal is consistent with Opportunities for Action Objective 1.C; it will also demonstrate a practice to reduce nutrient loading to Lake Champlain.

The objective of this Phase 2 project is to evaluate the technical feasibility and costs of developing a treatment train facility to remove phosphorus from Jewett Brook before it flows into St. Albans Bay.

2. Treatment Trains at GLSM

Conditions in the Grand Lake St. Marys watershed are similar in many respects to those in the Lake Champlain Basin. Intensive agricultural production and increased development over the last century have adversely impacted lake water quality (Overcash and Pfeiffer, 2014). Like St. Albans Bay, GLSM has regularly experienced algal blooms due to excessive nutrient loading. In 2010, algal blooms were of such magnitude and duration that the Ohio Department of Natural Resources (ODNR) was forced to close the lake to all recreational activity.

In 2012, the ODNR began working with the GLSM Restoration Commission to implement treatment trains—systems consisting of a series of engineered (settling pond), biotechnical (constructed wetlands), and natural (restored wetlands) treatment practices—to improve the quality of water flowing to GLSM. The approach being used in GLSM involves withdrawing water from a tributary stream and pumping it to a settling pond, from which it flows by gravity through a series of constructed wetlands that assimilate additional P. Outflow from the constructed wetlands flows into a restored, littoral wetland for further nutrient attenuation before dispersal into GLSM. The first GLSM treatment train is located near the mouth of Prairie Creek (Figure 3). It began operating in June 2013. Prairie Creek has a watershed of 6 mi^2 (16 km^2) of which approximately 95% is in agriculture use. The Prairie Creek treatment train treats 0.75

Figure 3. Locations of the Prairie Creek and Coldwater Creek Treatment Trains

MGD (Overcash and Pfeiffer, 2014). While alum was initially used at the Prairie Creek facility to improve P removal, this was discontinued due to its high cost. As a result of the success of the Prairie Creek treatment train, a second treatment train facility was constructed at Coldwater Creek in 2015. The Coldwater Creek treatment train has a treatment capacity of 2.5 MGD, greater than the Prairie Creek facility. Coldwater Creek drains a 19-mi^2 (50-km^2) agricultural watershed.

The Coldwater Creek site is owned by the Mercer County Board of Commissioners. The facility is viewed as a significant improvement over the earlier Prairie Creek facility. It is also more comparable in scale to Stone's conceptual model for a treatment facility in the Jewett Brook watershed. Therefore, certain aspects of the construction and operation of this facility are described in this section.

2.1. Details of Coldwater Creek Facility

Information regarding the construction and operation of the Coldwater Creek treatment train facility was collected by George Valentine, Water Resources Technician with Stone Environmental, during a tour of the facility led by Dr. Stephen Jacquemin, Wright State University and Theresa Dirksen, PE, Mercer County Community & Economic Development on September 18, 2020. Dave Braun collected additional information in communications with ODNR, Ohio EPA, Theresa Dirksen, and Dr. Jacquemin.

2.1.1. Construction

The facility consists of an intake on Coldwater Creek, a pump station, a settling pond, and approximately 20 acres of constructed wetlands, primarily shallow marsh with emergent vegetations (Figure 4). Water is pumped from a segment of Coldwater Creek that is backwatered by Grand Lake St. Marys. Due to the backwatered condition at the intake, the water stage in Coldwater Creek does not fluctuate with pumping and the pumping rate is not limited by streamflow, which enables continuous operation. Under low streamflow conditions the water withdrawn from Coldwater Creek is a mixture of streamflow and lake water. Treatment of lake water is not viewed as a problem. It is advantageous because wetland vegetation can be maintained through dry periods.

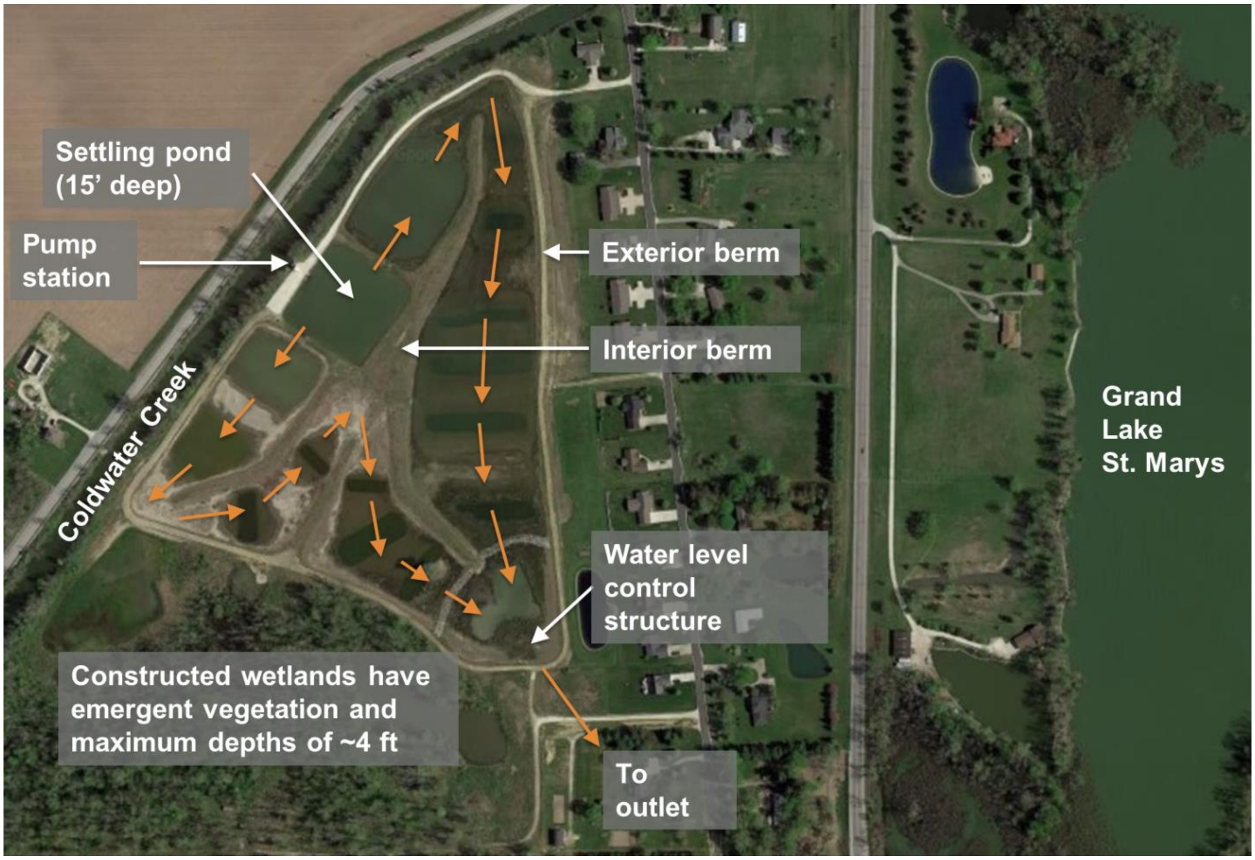

Figure 4. Coldwater Creek Treatment Train

The intake is a round concrete vault built into the bank of Coldwater Creek (Figure 5). Floating booms in front of the intake exclude floating objects. There is an opening in the side of the vault facing the stream allowing water to flow into the vault. In the opening, vertical steel bars spaced 3 inches apart screen out large debris (Figure 6). The vault is 10 ft. in diameter. The normal water depth in the vault is 6-8 ft. The top of the vault is approximately 8 feet above the normal water surface and the floor of the vault is raised slightly above the channel bed to minimize sediment flow into the intake. There is an instrument in the vault to continuously measure the water level.

Figure 5. Intake location on Coldwater Creek

Figure 6. Intake grate

Two 8-inch diameter suction pipes extend vertically approximately 6 feet below the water surface (Figure 7). The pipes are connected to pumps located in the adjacent pump station (Figure 8).

Figure 7. Suction pipes within intake vault

Figure 8. Suction pipe connection to vault

The pump station is located on the gravel road between Coldwater Creek and the settling pond (Figure 9). Inside the pump station (Figure 10) there are two 8-inch Gorman-Rupp T Series Self-Priming Centrifugal Pumps (Model No. T8A3S-B/WW). The pumps are paired with flow meters for continuous flow measurement. The two pumps can pump a combined maximum of 4 MGD. This compares with an average daily

Figure 9. Pump station

flow in Coldwater Creek of 12 MGD. The pumping rate can be varied and remotely controlled.

According to Theresa Dirksen and Stephen Jacquemin, chemical treatment was not implemented at the Coldwater Creek treatment train because the system installed at Prairie Creek was expensive to operate and proved unnecessary. Managers concluded that the constructed wetlands provided adequate treatment without the addition of alum or other chemical coagulant/flocculent. Theresa Dirksen and Stephen Jacquemin recommended against installing an alum injection system at the Jewett Brook facility. Note that there may be some disagreement on this point. A Lake Facilities Authority representatives stated that if they could afford to use alum, the residence time could be lowered without compromising treatment performance, enabling treatment of a greater proportion of streamflow.

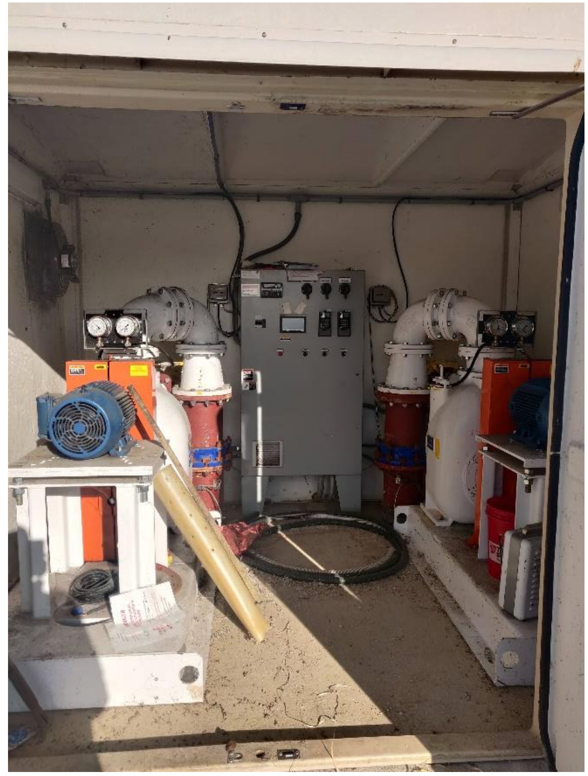

Figure 10. Interior of pump station

Flow is pumped to an initial settling pond that is square and approximately 1.3 acres (0.54 ha) in area (Figures 11 and 12). The pond is not lined, because it was excavated in clay soil. It was excavated 16 feet deep and has accumulated about 2 feet of sediment. It has not had to be cleaned yet. At the Prairie Creek facility, the settling pond may be undersized. It required cleaning after only five years in operation. The excavated sediment was sold as good quality fill. Theresa Dirksen and Stephen Jacquemin recommended constructing the settling pond as deep as possible. They advised against planting wetland vegetation in the pond because the water would be too deep.

Figure 11. Outlet pipes to the settling pond

The outflow from the settling pond is divided between two series of constructed wetland cells (Figure 4). These shallow marshes comprise 70% of the site area. Within the shallow wetland cells there are multiple narrow pools, 6-12 inches deeper than the surrounding marsh, which create a diversity of habitats and growing conditions.

The whole site (wetland cells and berms) was seeded with a commercially available mix of wetland seeds (Wetland Mix #1 from J.F. Cardno). The wetland cells are dominated by cattails, arrowhead, sedges, and bulrush. Water lost to evapotranspiration and seepage is negligible in spring, 10-15% in summer, and ~5% in fall.

Figure 12. Settling pond looking into constructed wetland cell

The berms enclosing the wetland cells were built to be driven on, to facilitate maintenance. The interior berms are low and flat, and they have been colonized by woody, upland plants from the seed mixture, which help stabilize them. The exterior berms are taller (by approximately 3 feet) and enclose the entire system. This design permits flooding the entire system, although this has never been done. The exterior berms are grassy and mowed (Figure 13), creating a recreation path. The operators believe grass cover on the berms is preferable to crushed stone; stone is difficult to keep clean.

Figure 13. First wetland cell downstream of settling pond

Flow from the final constructed wetland (Figure 14) enters an outlet consisting of two 24-inch wide Agri-Drain water level control structures (Figure 15). The water level control structures contain plastic stoplogs that slide in vertical tracks. The water level is raised and lowered by manually inserting or removing stoplogs (or substituting taller or shorter stoplogs).

Water passing through the water level control structures joins in a concrete junction box before flowing through a 0.25-mile long (0.4 km), buried pipe to a wetland area bordering GLSM. This 250-acre (101-ha) littoral wetland was expanded by construction of a rock berm that encloses a shallow portion of the lake. Dredged material is still being added to raise it to 6-12” depth. This littoral wetland is thought to increase nutrient removal.

2.1.2. Operations and maintenance

The constructed wetlands are designed for a maximum water depth of 4 feet. Typically, the water depth is maintained between 6 inches and 3 feet, depending on the time of year. In the spring when wetland plants are short, the water depth is maintained near 6 inches to avoid submerging the plants. In the fall when the vegetation is at its maximum height, water depths are maintained close to 3 feet. Water depths greater than 3 feet are too high for emergent wetland vegetation. The system is shut down in the winter.

Figure 14. Terminal constructed wetland cell

Operators routinely vary the pumping rate to achieve optimum hydraulic residence time in the constructed wetlands. A lower pumping rate will increase residence time, which theoretically should result in improved P removal. The pumping rate is reduced if the P removal rate declines. A 3-day residence time is typical in the summer when primary productivity is highest. In the spring the pumping rate is set lower to maintain low water levels in the cells as the emergent wetland vegetation begins growing. In the fall, as the treatment efficiency falls, pumping rates are reduced to increase the residence time to 4-5 days.

Figure 15. Adjusting stoplogs in water level control structure

Operators at the GLSM treatment trains have not considered timing water withdrawals for high streamflow periods to optimize P removal because they are always pumping the maximum amount the system can effectively treat. Stephen Jacquemin and Theresa Dirksen suggested that attempting timed withdrawals would overcomplicate operation of the system and possibly impair its long-term performance.

Operations are not adjusted to minimize impingement or entrainment of aquatic organisms at the intake (for example, during critical spawning periods). Stream biota in the lower reach of Coldwater Creek are of little concern relative to water quality in GLSM. Coldwater Creek has low biodiversity and no macroinvertebrate or fish species of concern. Stephen Jacquemin confirmed that the pumps suck carp, sucker, creek chub, Pimephales minnows, shiners, crappies (spp.), bluegills, pumpkinseeds, and bullhead and channel catfish up to 6-inches long into the system. Some fish are killed by the impellers, but many survive and live in the ponds.

Similarly, no adjustments are made in pumping rates or timing, water residence times, or treated water release rates or timing to reduce potential thermal impacts at the discharge location.

Routine maintenance at the Coldwater Creek facility requires about 3-4 hours per week of staff time. Staff from ODNR Division of Wildlife mow the berms regularly and clear the intake vault, booms, and grate every 2-3 weeks. Additional staff time is required at certain times of year to adjust pumping rates.

Most of the sediment is removed in the settling pond. Operators have not had to excavate the settling pond or the wetland cells to remove sediment and do not anticipate having to do so. Nor have operators had to cut back wetland vegetation to maintain acceptable treatment performance. Invasive exotic plants have not been a problem thus far.

Muskrats have been a problem because they make burrows in the banks and berms, destabilizing them. Operators have encouraged local trappers to trap out the muskrat.

The biggest maintenance problem has been with carp entrained at the intake, which become resident in the wetlands. The carp have eaten much of the wetland vegetation, reducing the system's treatment performance. For example, the terminal wetland shown in Figure 14 is meant to be fully vegetated; the carp have opened a large area of open water. Rotenone was used in 2020 to kill the carp. Operators anticipate having to treat the wetlands with rotenone every ~3 years. Previously they experimented with drawing down the water in winter to freeze the carp, however, the carp persisted in the deep settling pond, and reinvaded the wetlands.

2.1.3. Performance

Routine water quality monitoring is conducted to inform operations and provide performance data. Monitoring is conducted by Stephen Jacquemin's students at Wright State University and is paid for by the Lake Restoration Commission, a volunteer organization funded by private donors. Samples are collected weekly at the inflow and the outflow for TP, dissolved reactive phosphorous (DRP), nitrate, and total suspended solids (TSS).

Dr. Jacquemin and others summarize performance data for the Coldwater Creek treatment train in annual updates. The 2019 update is available at https://lakeimprovement.com/knowledge-base/. Other updates have been requested directly of Dr. Jacquemin. Reductions in TP, DRP, nitrate, and TSS concentrations and loading from inflow to outflow are summarized for 2019-2020 by season in Table 1. TP load reductions totaled 356 kg in 2019 and 324 kg in 2020. TP and DRP load reductions were greatest during the spring and summer. A ~90% decrease in DRP concentrations was measured in the spring in both years. TP concentration reductions were substantial (43-56%) in spring and summer seasons in both years. The fall data are very inconsistent, with poor TP removal and good DRP removal in 2019 and the opposite result in 2020. In fall 2019, the DRP load reduction (41 kg) exceeded the TP load reduction (27 kg). This result is difficult to interpret since DRP is a component of TP, although there could be several explanations, such as timing differences in TP and TDP grab sample collection.

Table 1. Coldwater Creek treatment train concentration and load reductions, 2019-2020

		Concentration reduction (%)				Load reduction (kg)			
Year	**Season**	**TP**	**DRP**	**Nitrate**	**TSS**	**TP**	**DRP**	**Nitrate**	**TSS**
2019	Winter	0	0	0	0	0	0	0	0
2019	Spring	49	90	47	2	79	59	1,814	18,144
2019	Summer	51	64	46	54	249	136	2,041	40,823
2019	Fall	5	63	0	0	27	41	0	0
2019 Annual						356	236	3,856	58,967
2020	Winter	0	0	0	0	0	0	0	0
2020	Spring	56	91	48	74	141	36	919	24,948
2020	Summer	43	29	19	60	152	54	193	24,948
2020	Fall	47	0	1	88	32	0	240	9,072
2020 Annual						324	91	1,352	58,967

According to Dr. Jacquemin, water temperature was measured occasionally in the first year of operation. He found that passage through the treatment train did not significantly affect water temperature in the spring, winter, or fall, but that water temperature increased by as much as 5°F (2.8°C) in the summer.

2.1.4. Cost

Table 2 presents approximate costs for construction and operation of the Coldwater Creek treatment train. This information was provided by Theresa Dirksen and Stephen Jacquemin.

Table 2. Approximate costs of the Coldwater Creek Treatment Train

Component	Cost
Land acquisition	NA
Construction of intake, pump station, pump equipment, and appurtenances	$300,000
Wetland construction	$400,000
Outlet pipe construction	$100,000
Annual electricity cost (for pumps)	$60,000
Routine maintenance by ODNR staff	3-4 hr/week

3. Jewett Brook Flow and Water Quality

The Jewett Brook watershed is 9.2 square miles (2,389 ha). There is a USGS stream gauging station (#04292810) located at the Lower Newton Road crossing, the same location where water quality samples are collected (site JEWE02) by Vermont DEC through its Lake Champlain Long-Term Water Quality and Biological Monitoring Program (LTMP). The Jewett Brook watershed upstream of Lower Newton Road is 5.7 square miles (1,474 ha). Certain calculations in this section assume linear extrapolation based on drainage area from the stream gauge to the watershed outlet (multiplied by 1.62).

3.1. Water Quality

Stone reviewed water quality data collected from 2011 through 2020 in VTDEC's LTMP to describe current water quality conditions in Jewett Brook and inform design of the proposed treatment train facility. The water quality parameters we reviewed are alkalinity, aluminum, chloride, conductivity, dissolved organic carbon (DOC), TDP, pH, temperature, TP, and TSS. Descriptive statistics were calculated for these parameters over the entire period reviewed, using base R functions (Table 3).

Table 3. Jewett Brook water quality, 2011-2020

Parameter	No. samples	Min	Max	Mean	Median	St. dev.	25th percentile	75th percentile	IQR[1]
TP (µg/L)	153	87.4	1750.0	470.5	408.0	296.5	263.1	575.0	311.9
TDP (µg/L)	94	52.9	1417.0	333.9	254.0	224.2	183.5	412.4	228.9
Alkalinity (mg/L)	19	60.5	230.0	129.0	116.0	53.4	90.0	164.8	74.8
pH	85	6.4	9.4	7.5	7.5	0.5	7.2	7.8	0.6
Aluminum (µg/L)[2]	11	134.1	4730.0	1363.9	336.9	1607.3	169.3	2491.0	2321.7
Chloride (mg/L)	95	2.5	74.1	27.9	24.6	15.7	16.0	38.5	22.5
Cond. (µS/cm)	77	8.0	1425.0	498.6	476.0	242.1	320.0	668.0	348.0
DOC (mg/L)	10	12.9	28.7	17.3	16.7	4.4	15.4	18.0	2.6
Temp. (deg C)	85	0.7	26.6	12.8	12.7	7.9	5.4	20.1	14.7
TSS (mg/L)	92	1.6	708.0	44.7	14.8	85.2	7.8	47.2	39.4

1. IQR = Interquartile range
2. The 2022 draft Vermont Water Quality Standards include toxicity criteria for aluminum based on EPA's 2018 Final Aquatic Life Ambient Water Quality Criteria for Aluminum (https://www.epa.gov/sites/default/files/2018-12/documents/aluminum-final-national-recommended-awqc.pdf). Using median pH and DOC values for Jewett Brook and the default range for hardness, the chronic criterion equals 820 -1,000 µg/L total Al

Water temperature in Jewett Brook ranged from freezing to a high of 26.6°C (79.9°F) on July 21, 2011. All water temperature observations above the 75th percentile, 20.1°C (68.2°F), occurred during the months of June, July, August, or September. These water temperature data are considered further in Section 8.3 in the context of permissible in-stream temperature changes.

Alkalinity refers to the capacity of a waterbody to neutralize acids and bases. The alkalinity of Jewett Brook ranged from 60.5 to 230 mg/L, with a median of 116 mg/L and an IQR of 74.8 mg/L. The pH of Jewett Brook ranged from 6.4 to 9.4, with a median of 7.5. Alkalinity and pH are considered further in Section 7.1 in the context of P inactivation by aluminum sulfate.

Trends in TP and TDP concentrations in Jewett Brook from 2011 to 2020 were analyzed in R Studio using the Kendall and mblm packages and functions, following methods outlined in Helsel et al. (2020). The non-parametric Mann-Kendall test with α level=0.05 was used to determine whether TP and TDP tended to decrease or increase from 2011 through 2020. There was no significant trend ($P = 0.233$) in TP concentration during this period, but a positive trend ($P < 0.05$) in TDP concentration. The Theil-Sen estimator (or Theil-Sen robust line) was also calculated for each parameter and is shown in Figure 16 and Figure 17.

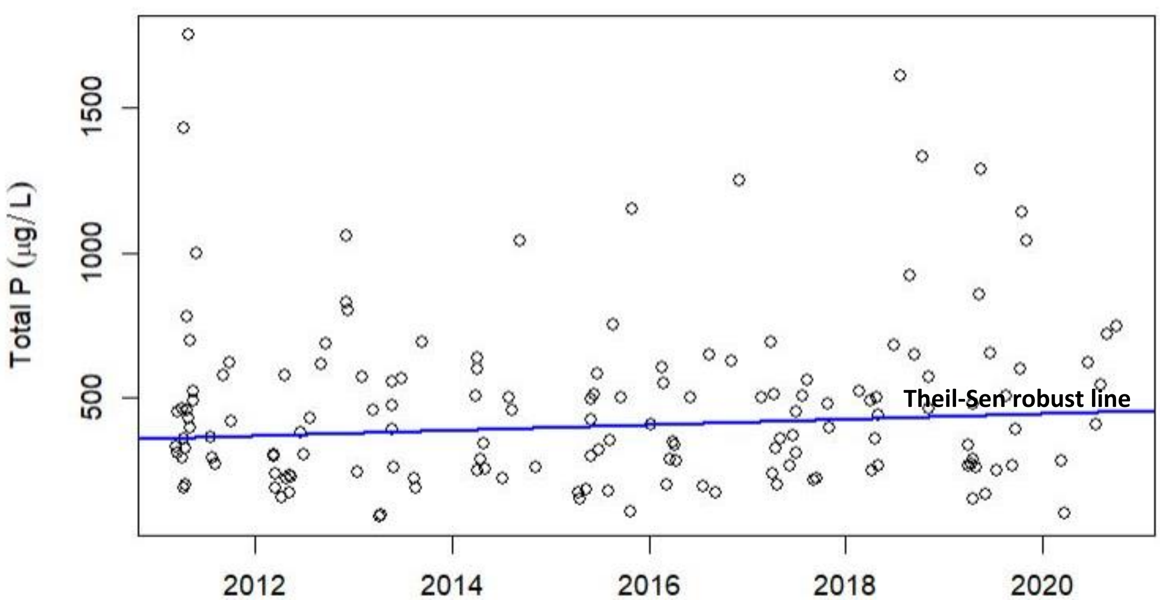

Figure 16. TP concentrations in Jewett Brook, 2011-2020

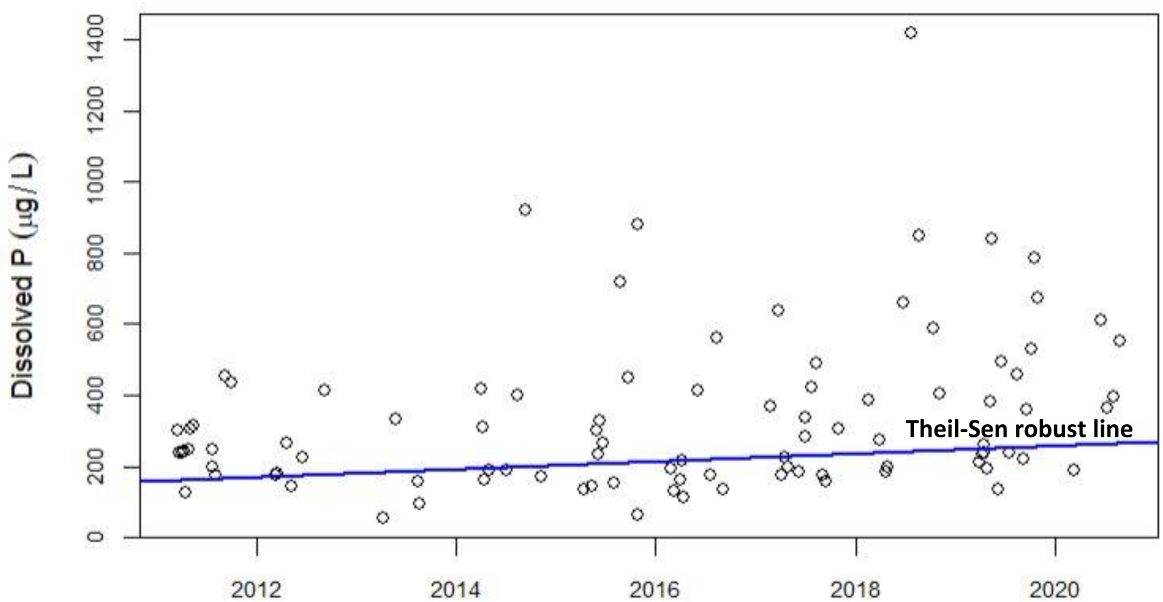

Figure 17. TDP concentrations in Jewett Brook, 2011-2020

The TP and TDP concentration trend analyses indicate that any P concentration reductions anticipated because of implementation of agricultural conservation practices over the last decade have yet to manifest.

3.2. Flow and P Loading

Mean daily flows at the Lower Newton Road gauge were reviewed for the 12-year period, January 1, 2009 through December 31, 2020 (Figure 18). As one would expect, flow rates are typically highest between March and May, decline through the summer months, often interrupted by short duration storm flows, and rise again in October through December. The highest instantaneous discharge during this period was 416 cfs, which occurred on April 28, 2011. The lowest flow rates are typically recorded in August. In five years (2012, 2014, 2018, 2019, and 2020) the stream at Lower Newton Road dried up for all or multiple days in July and August. In 2020 there was no flow in Jewett Brook from June 5 through October 19 except for two days in early August. 2012 was also very dry, with no flow recorded from June 15 through September 4 except for one week in late July.

Daily time series of measured discharges and estimated TP and TDP concentrations and loads were computed for Jewett Brook by Dr. Matthew Vaughan (2022) using the Weighted Regressions on Time, Discharge, and Season (WRTDS) statistical model. Daily flow totals from the USGS were paired with contemporaneous P concentration data from VTDEC's LTMP. In estimating daily mean concentrations and loads, Vaughan used methods like those described in Vaughan (2019) and applied a new technique, Kalman filtering (Zhang and Hirsch, 2019), which accounts for autocorrelation in the time series data to improve estimates. The flux bias statistic for the model predicting TDP is +0.096, which is just on the cusp of general acceptability (the cutoff is usually +/- 0.1). This means that the model is likely over-predicting the TDP load. The flux bias statistic for total phosphorus is -0.0008, indicating a better model and lower bias.

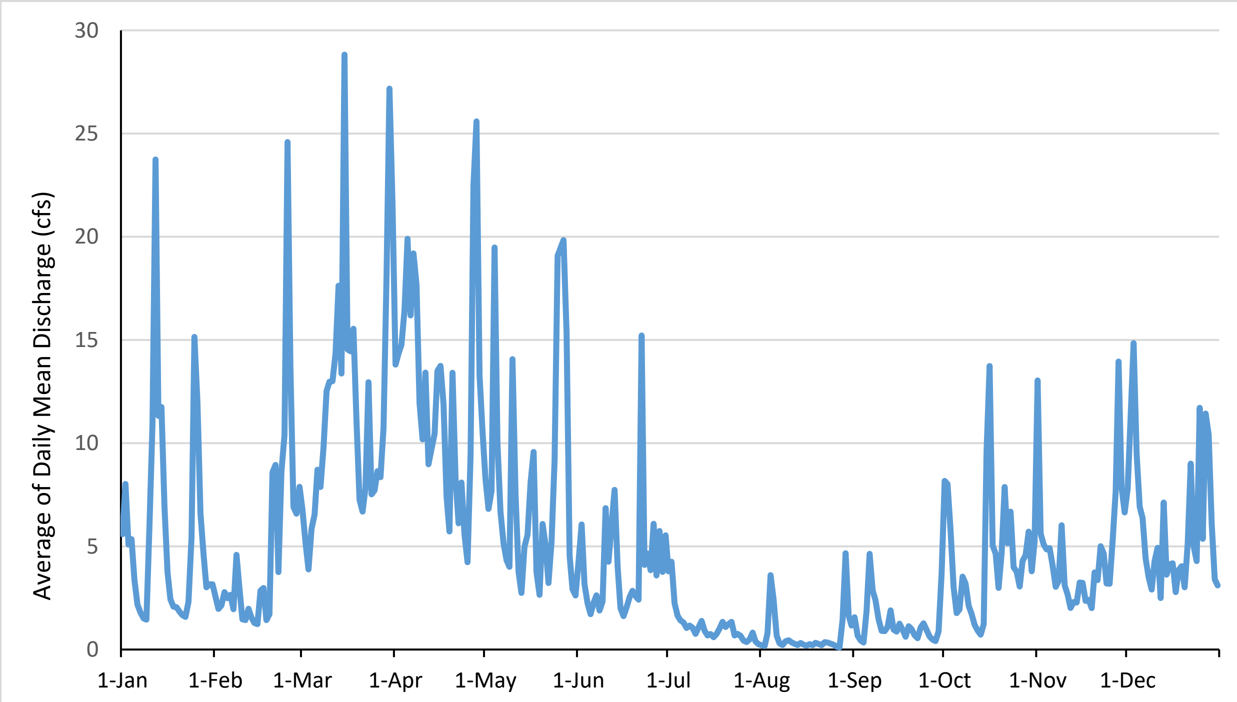

Figure 18. Average daily mean discharge by day for the period 2009-2020

The P loading estimates developed by Vaughan compare reasonably well with an earlier analysis by Eric Schmeltzer (unpublished data) using the USGS model LOADEST for May 2017-April 2018. Total loads calculated by Vaughan are 13% lower for TP and 11% lower for TDP than the LOADEST estimates for the equivalent period. Since the WRTDS estimates are derived from a longer and more current dataset, Vaughan's estimates are used in place of Schmeltzer's earlier estimates.

Table 4 presents the total estimated TP and TDP loads for each year at the Lower Newton Road stream gauge. Summary statistics for the 12-year period are also presented. The "watershed" loads are simple linear extrapolations (multiplying by 1.62) of the estimated loads to account for the unmonitored, lower portion of the Jewett Brook watershed. The median TP load was 2,217 kg/yr at the gauge and 3,446 kg/yr for the whole watershed. The median TDP load was 1,359 kg/yr at the gauge and 2,201 kg/yr for the whole watershed. Over this 12-year period, TDP was 61% of TP. Particulate P accounts for the remaining 39%.

Table 4. TP and TDP loads estimated at the gauge and extrapolated to the whole watershed

Year	Estimated TP Load (kg/yr)	Estimated TDP Load (kg/yr)	Watershed TP Load (kg/yr)	Watershed TDP Load (kg/yr)
2009	1248	764	2021	1238
2010	3266	1806	5291	2926
2011	5513	2827	8931	4580
2012	1195	716	1936	1160
2013	2171	1422	3517	2304
2014	1851	1178	2999	1909
2015	1700	1104	2754	1789
2016	2147	1295	3479	2098
2017	2107	1500	3413	2430
2018	2194	1467	3555	2377
2019	3763	2447	6096	3964
2020	1182	835	1915	1353
Average	2361	1447	3826	2344
25th percentile	1587	1037	2571	1680
Median	2127	1359	3446	2201
75th percentile	2462	1576	3989	2554
12-year totals	28,649	17,556	46,412	28,441

Table 5 summarizes the total and dissolved P annual loading data.

Table 5. Summary of annual Jewett Brook TP and TDP loading

		Lower Newton Rd. gauge	Whole watershed
TP Load (kg/yr)	Median	2,127	3,446
	Range	1,182-5,513	1,915-8,931
TDP Load (kg/yr)	Median	1,359	2,201
	Range	716-2,827	1,160-4,580

Table 6 presents the average daily mean flows and average daily estimated TP and TDP concentrations and loads by month at the Lower Newton Road gauge. The preponderance of P loading occurs in the spring and late fall. While P concentrations are high between July and September, especially for TDP, very little of the annual loading (5% or TP and 6% of TDP) occurs during this 3-month period because streamflows are so low.

Table 6. Average daily mean flow and P concentrations and loads at the gauge by month

	Average of daily mean flow (cfs)	Average of est. daily mean TP concentration (mg/L)	Average of est. daily mean TP load (kg/day)	Average of est. daily mean TDP concentration (mg/L)	Average of est. daily mean TDP load (kg/day)
January	5.67	0.252	7.05	0.186	4.14
February	4.81	0.174	4.44	0.145	2.84
March	11.86	0.215	10.10	0.180	6.88
April	12.54	0.220	12.13	0.172	6.54
May	7.99	0.266	10.31	0.229	6.06
June	4.14	0.364	4.24	0.319	2.95
July	1.15	0.463	1.14	0.385	0.89
August	0.72	0.542	1.08	0.441	0.85
September	1.28	0.577	1.71	0.408	1.18
October	4.69	0.589	7.56	0.375	4.87
November	4.88	0.494	8.07	0.315	4.64
December	6.03	0.421	9.60	0.255	4.91

3.3. Influence of Lake Champlain

VTDEC Rivers Program staff have made it clear that any water withdrawal that lowers the stage of Jewett Brook significantly, reducing the stream's wetted perimeter, would not be acceptable. Potential impacts to aquatic organisms would be minimized if water were withdrawn from the backwater zone in which the stage in Jewett Brook is influenced by the elevation of Lake Champlain. Water withdrawal from the backwatered channel will not cause water level fluctuation, minimizing impacts on aquatic organisms.

Given the importance of avoiding any fluctuation in the water level in Jewett Brook, the preferred location for a water intake and treatment facility will be in the lower Jewett Brook watershed, near the Dunsmore Road bridge or further downstream. Therefore, the resource review and site evaluation described in Sections 4 and 5 are limited to the lower portion of the Jewett Brook watershed.

Figure 19 presents daily mean Lake Champlain water levels at Burlington (USGS gauge 04294500) over the last 20 years (October 1, 2001-September 30, 2021). The high water elevation in Lake Champlain typically occurs in late April or early May. The daily median (50^{th} percentile) high water elevation in late April is 98.5 ft. amsl (NGVD29). At 98.5 ft., the lake's backwater effect extends upstream of the Dunsmore Road bridge. At an exceptionally high lake level of 102 ft., the backwatered zone extends ~2,500 ft. (~760 m) upstream of the Dunsmore Road bridge.

To evaluate the threshold lake level below which Jewett Brook at Dunsmore Road ceases to be backwatered, depth measurements were made from the Dunsmore Road bridge downstream to the Boissoneault farm bridge. This depth survey was performed on May 22, 2020, at about 3:30 PM. On this date/time, the Lake Champlain level at Burlington was 97.11 ft. amsl (NGVD29) and the flow rate recorded at the Jewett Brook gauge was 0.23 cfs (149,000 GPD).

In the pool immediately downstream of the Dunsmore Road bridge, the water depth varied between 2 and 3 feet. The downstream edge of this pool is defined by a bed of reed canary grass completely spanning the channel. The deepest continuous path through the reed canary grass bed was 1.5 ft. Downstream of this flow restriction the channel deepens; it was consistently over 2.0 feet deep down to the bridge on the Boissoneault Farm, below which the channel becomes deeper and wider through the Black Creek Wetland. Therefore, we conclude that Jewett Brook should be backwatered at the Dunsmore Road bridge until the level in Lake Champlain falls below ~95.6 ft. amsl (NGVD29) (i.e., 97.1 ft.–1.5 ft.).

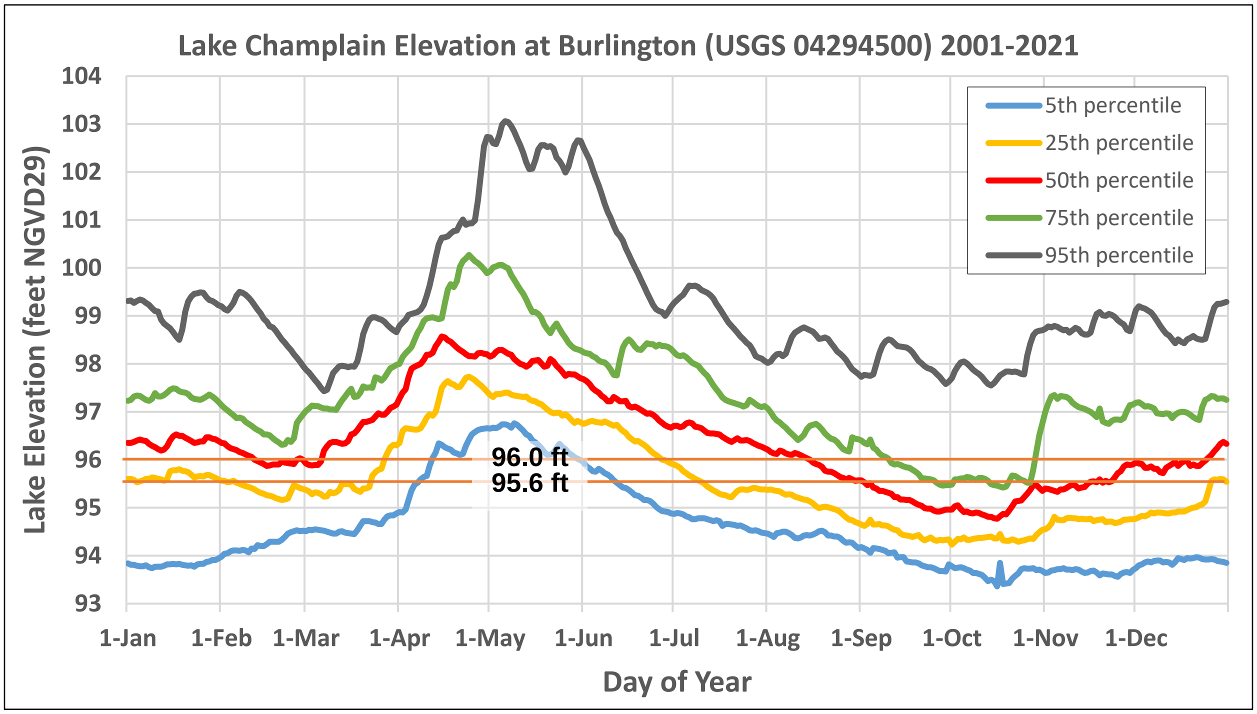

Figure 19. Daily mean water level of Lake Champlain at Burlington, 2001-2021

In a median year, Lake Champlain falls below 95.6 ft. from early September through mid-November (Figure 19). In a dry year (25th percentile), Lake Champlain falls below this threshold from early-July through the end of the year. In a wet year (75th percentile), Lake Champlain falls below 95.6 ft. only in October, and then only slightly.

In planning facility operations, it may be advisable to assume a somewhat higher lake level cutoff than 95.6 ft. to account for wind effects at the Lake Champlain gauges and to provide a margin of safety. Vermont Fisheries Biologist Bernie Pientka suggested establishing 96.0 ft. amsl (NGVD) as an operating condition below which water will not be withdrawn. Subsequent calculations of treatment performance assume this conservative 96.0 ft. cutoff. Using the 96.0 ft. cutoff, a facility withdrawing water at the Dunsmore Road bridge could operate between ~mid-March and mid-August in a typical (50% percentile) year, plus potentially a couple weeks in December (5+ months). The facility might only operate between late March and late June (3 months) in a dry year (25% percentile). In a wet year (75% percentile), the facility could operate for approximately eight months, mid-March to mid-September plus November-December.

While Lake Champlain will influence the water stage in lower Jewett Brook under most conditions, there is no corresponding effect on water quality. The lake backwater zone extends further up the Jewett Brook channel than water mixing should occur. Therefore, assuming Jewett Brook is flowing, and the lake level is greater than 96.0 ft., it should be possible to withdraw streamflow with high P concentrations from the backwater zone without affecting the water level in the stream.

4. Resource Concerns in the Lower Jewett Brook Watershed

4.1. Prime Agricultural Soils

The State of Vermont defines Primary Agricultural Soils as soils that are mapped by NRCS as “prime” and/or “statewide” agricultural soils (10 V.S.A. § 6001). Prime soils have been determined to have the best physical and chemical characteristics for growing food and fiber. Statewide soils are soils that fail to meet one of the requirements for prime soils, but which are considered important to the State of Vermont for agricultural production.

Soils in the lower Jewett Brook watershed include a mix of prime and statewide soils. Outside of the Black Creek Wetland most of the soils in the area are identified as either prime or statewide important (Figure 20).

One objective in siting a treatment train facility is to minimize impacts to prime agricultural soils.

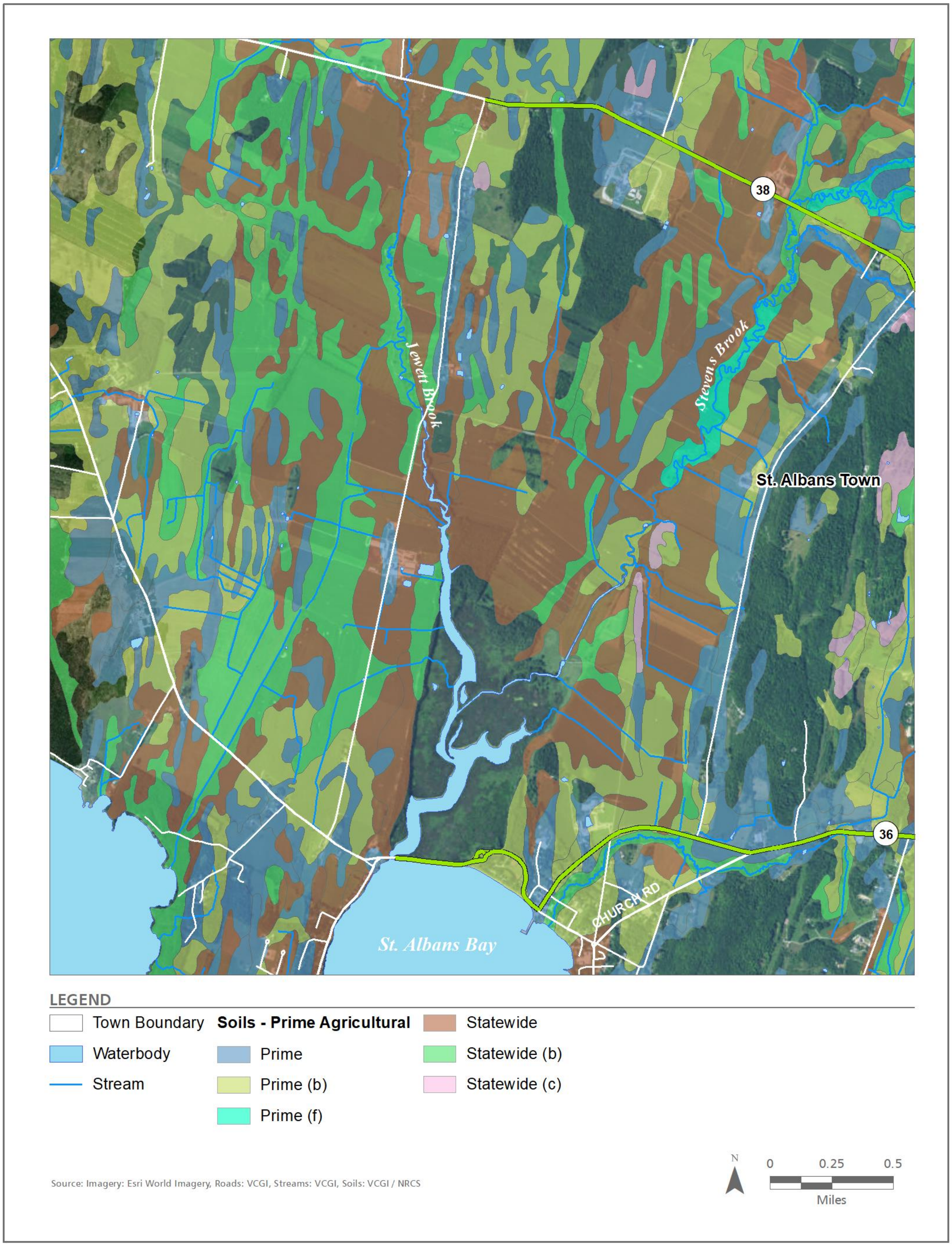

Figure 20. Important agricultural soils (colored areas are of prime or statewide importance)

4.2. Wetlands

The Black Creek Wetland is a Vermont Wildlife Management Area (WMA) with significant fisheries and wildlife values (Figure 21). The WMA encompasses the entire eastern side of lower Jewett Brook. On its western side, the WMA boundary extends to the centerline of Jewett Brook.

The entire Black Creek WMA is mapped as a Class II wetland, as are contiguous wetland areas around the WMA (Figure 22). These mapped wetlands (Vermont Significant Wetland Inventory) extend a considerable distance north, east, and southwest of lower Jewett Brook. On the northwestern side there is only a narrow strip of mapped wetland between Jewett Brook and the adjacent farmland.

Wetlands that are subject to regulation include areas that meet defined wetland criteria; they are not restricted to those areas appearing on the VSWI map layer. Potential wetland areas can be identified using in-office tools such as hydric soils maps and aerial photography that shows wet ground conditions. Mapped soils in the lower Jewett Brook watershed are dominated by heavy clay soils such as Covington (Cv) and Kingsbury (Kb). These soils have low permeability and high natural fertility, and are classified as hydrologic soil group D. Within and immediately adjacent to the Black Creek Wetland, there are also areas of deep organic soils such as Carlisle Muck (Ce) and Terric Medisaprists (Tm). The Covington clay and Terric Medisaprists are identified as hydric soils that occur in wet areas and typically support hydrophytic vegetation. Kingsbury soils also have a high clay content, but this soil series is not classified as hydric. Mapped hydric soils extend beyond the VSWI mapped wetlands on the north and west sides of the WMA into fields that are used for hay and corn production (Figure 23). Hydric soil inclusions and pockets of wetland could occur beyond these mapped hydric soils, especially in the areas mapped as Kingsbury soil.

The 2013 Vermont Orthophotos were flown in the spring of the year and are particularly useful in showing wet ground conditions. These are seen as darker areas in the photography. There are obvious wet areas adjacent to the WMA to the east, north and west (Figure 24). Only small pockets of wet areas are visible in the agricultural fields between Jewett Brook and Dunsmore Road.

Based on available map data there appear to be significant areas of wetland to the east and north of lower Jewett Brook. On the western side of Jewett Brook, the adjacent wetland appears to narrow towards the northern end of this area. Wetlands may extend westward into the agricultural fields along Dunsmore Road.

Any treatment facility on the east side of Jewett Brook east of the WMA would directly impact the WMA to some degree.

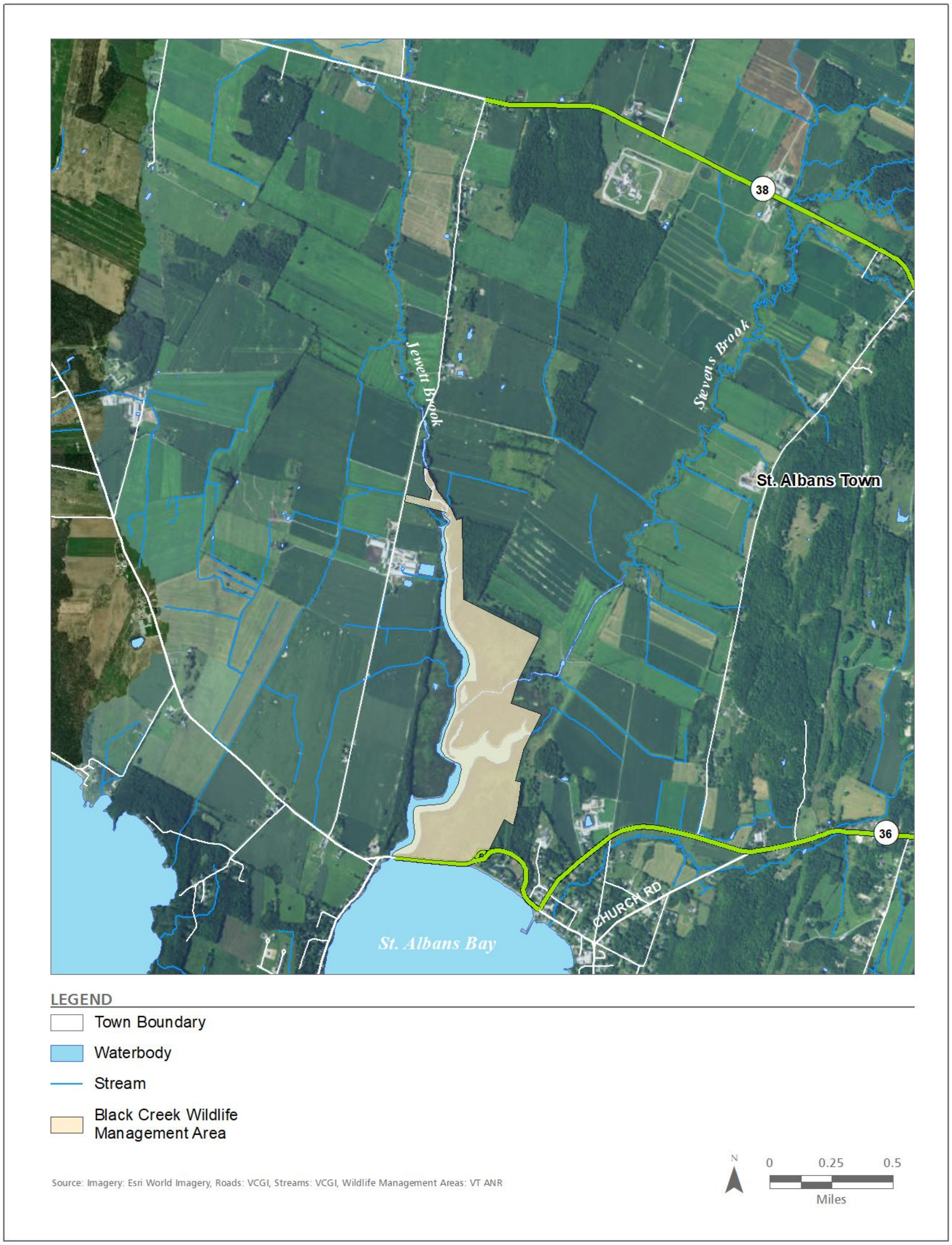

Figure 21. Black Creek Wildlife Management Area

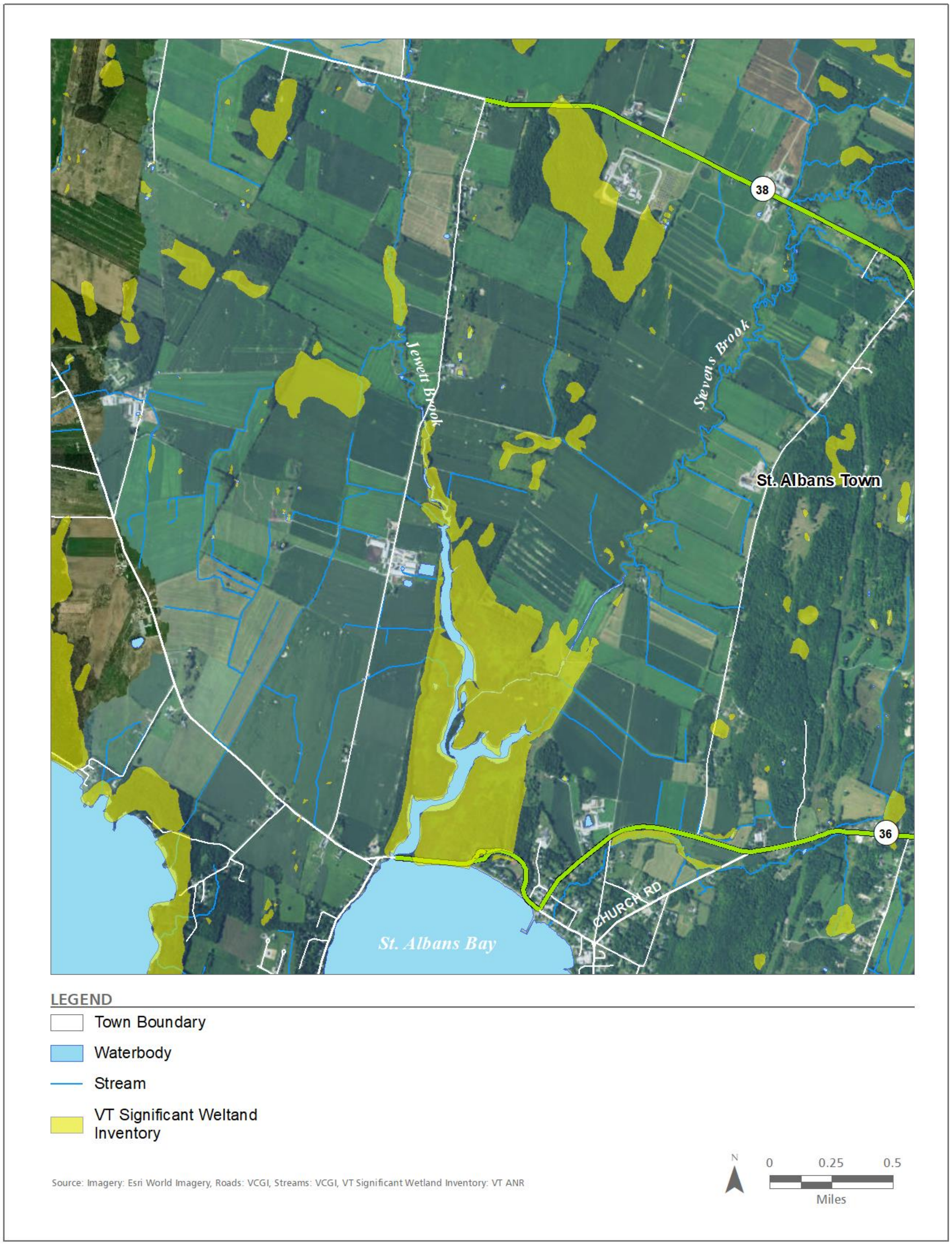

Figure 22. Vermont Significant Wetland Inventory map

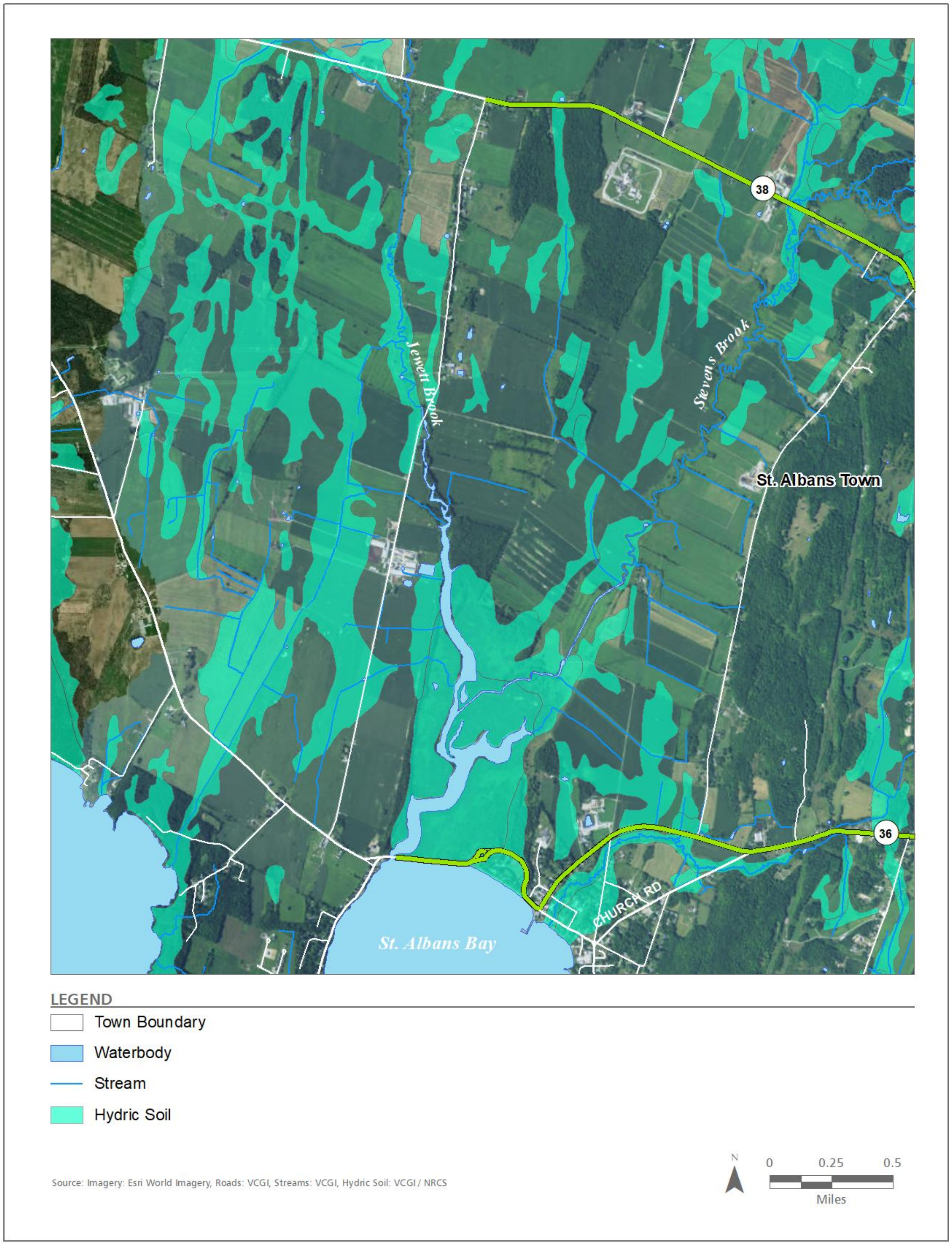

Figure 23. Hydric soils

Figure 24. Vermont 2013 orthophoto

The State of Vermont regulates wetlands under the Vermont Wetland Rules (Vt. Code R. 12 004 056, updated January 21, 2020). The State regulates impacts to 1) all wetlands on the VSWI maps, 2) other wetlands determined to have significant functions and values, and 3) the 50-ft. buffer zone adjacent to these wetlands. Under the Vermont Wetland Rules, general permits are available for some activities in wetlands, but these would not apply to the project under consideration. As part of the individual permit process, it must be shown that all reasonable efforts have been made to avoid impacts to wetlands. The functions and values of the wetlands must be assessed, and it must be demonstrated that there will be no undue, adverse impact to these functions and values. It is also recommended that a decommissioning plan for the treatment train be included in any wetland permit application. An impact fee is assessed on any impacted wetlands according to the area of impact.

The U.S. Army Corps of Engineers under Section 404 of the Clean Water Act has jurisdiction over all Waters of the U.S., including wetlands. Under this regulatory program it must be demonstrated that all reasonable alternatives have been considered to avoid and minimize impacts to jurisdictional wetlands. Upon notification to the Corps, a State Program General Permit might be available if the area of wetland impact is less than 10,000 ft^2. Individual permits are required for larger or more significant wetland impacts and would require an acceptable wetland mitigation plan or payment of an in-lieu fee. Under Section 404, the Corps also requires a State 401 Water Quality Certification (WQC) and an archaeological assessment of any areas proposed for ground disturbance. The 401 WQC would also be reviewed under Section 10 of the U.S. Rivers and Harbors Act. This Act places restrictions on structures (length and height of structure) being built in navigable waterways.

In siting the treatment train facility, avoidance or minimization of wetlands impacts will be demonstrated.

4.3. Floodplains

In Vermont, municipalities administer the review and permitting of development in floodplains according to locally adopted Hazard Area Bylaws. Under Vermont Statue (24 V.S.A. §4424) the State reserves the right to review all floodplain applications. For certain types of activities, VTDEC administers the permit review.

The effective Flood Insurance Rate Map covering the lower Jewett Brook watershed in the Town of St. Albans is panel 500219 0005A (FEMA, 1988). This map shows a Zone AE flood hazard area with a base flood elevation (BFE) of 102 ft., the same flood elevation as for St. Albans Bay, extending up Jewett Brook approximately 1900 linear feet beyond the Dunsmore Road bridge. Upstream of this point there is a Zone A flood hazard area (no BFE established) extending almost to Lower Newton Road.

No encroachments will be made within established flood hazard areas.

4.4. Farmland Conservation Easements

The Vermont Housing and Conservation Board (VHCB) administers and coordinates a farmland conservation program in Vermont. In Franklin County there are large blocks of conserved agricultural land. These easements restrict the use of the land for development or other nonagricultural uses. Approval is required from VHCB for any use of the land that is prohibited under a conservation easement.

In the lower Jewett Brook watershed, there is conserved agricultural land west of Dunsmore Road and north of the Black Creek WMA (Figure 25). The farmland immediately adjacent to the Black Creek WMA to the west and east is not conserved.

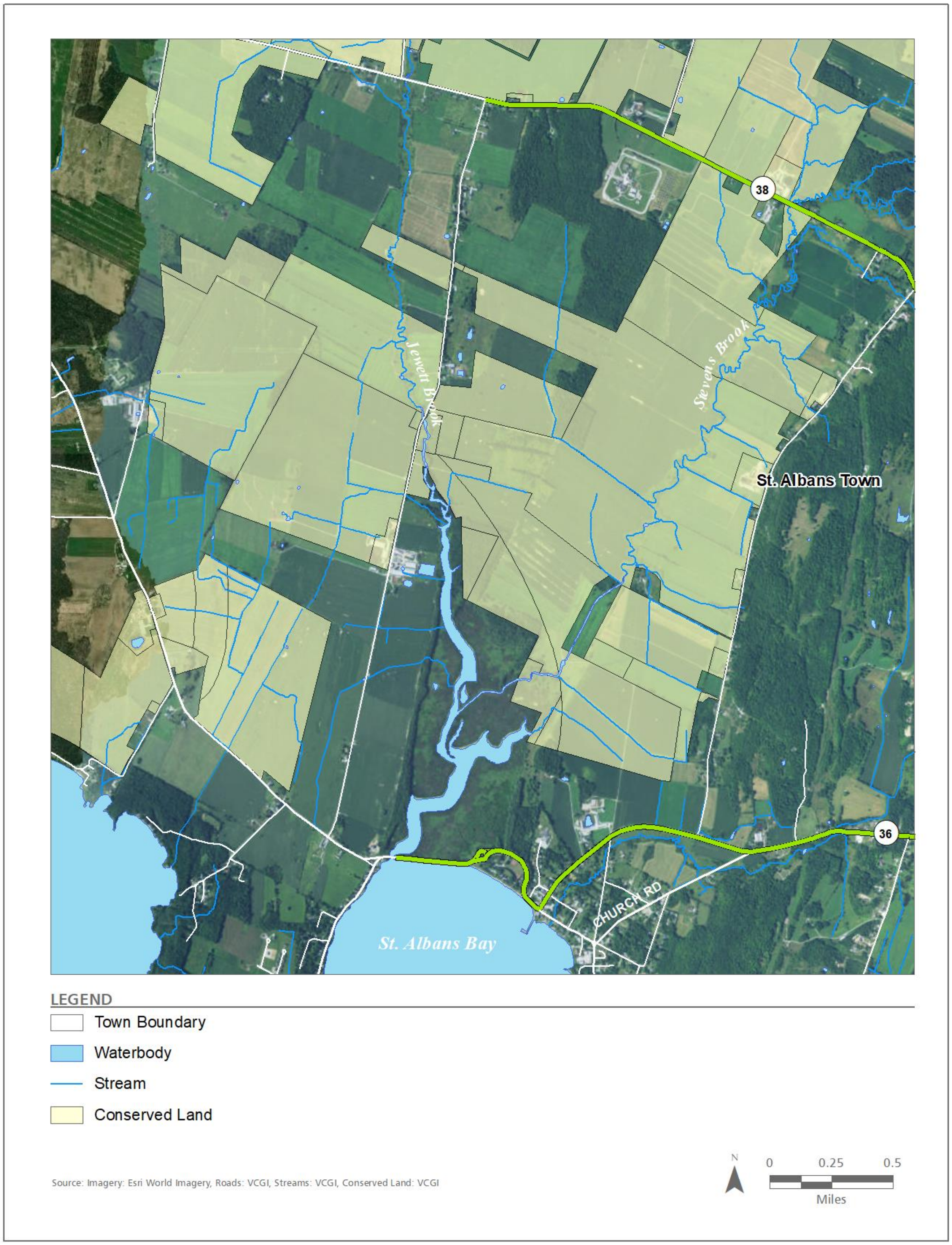

Figure 25. Conserved farmland

4.5. Cultural Resources

Vermont's historic cultural resources include buildings, structures, landscapes, and archeological sites. If a project is supported with federal or state funds, or licenses or permits, it must be reviewed by the State Historic Preservation Office (SHPO) for potential impacts to Historic Resources. Any district, site, building, structure, or object meeting the National Register Criteria for Evaluation must be reviewed and assessed under this procedure.

The Vermont Division of Historic Preservation maintains a confidential list and map of known historic and archeologic sites. The Vermont Archaeological Inventory (VAI) contains over 6,000 known sites and is maintained as a confidential database. Most ground disturbing projects require a trained archeologist to evaluate the site for historic or archeological resources. Potential impacts to historic or cultural resources must be avoided and/or minimized to the extent possible. The area around the Black Creek Wetland may contain archeological sites due to its proximity to water and significant sources of food.

5. Site Evaluation

Stone evaluated potential treatment train facility locations on open land close to Jewett Brook, above the base flood elevation, and outside the designated river corridor. Potential locations were identified and evaluated qualitatively using a GIS-based approach. We anticipated that the site could include prior converted wetlands in agricultural use. Certain wetland functions could be restored on such a site.

We considered the following primary criteria in reviewing potential sites:

- Location: Open land adjacent to backwatered segment of Jewett Brook
- Size: Approximately 20 acres
- Slope: 0-4%
- Floodplain: Above base flood elevation and outside fluvial erosion hazard areas
- Wetlands: Minimal impacts
- Archaeology: Avoid recognized cultural resources
- Require verbal agreement to consider sale or lease of the property to the State of Vermont (or to an entity operating on its behalf)

No suitable sites were identified east of Jewett Brook downstream of the Dunsmore Road bridge. Access to this area is poor and there are likely (unspecified) cultural resources conflicts.

A preferred site of adequate size, good access to Jewett Brook, and appropriate soils and slopes was identified in a farm field west of Jewett Brook and east of Dunsmore Road. Stone and State of Vermont representatives pursued negotiations with the property owner over an extended period; however, these were not ultimately productive.

Finally, two sites were identified on the Dunsmore Farm, referred to as Dunsmore 1 and Dunsmore 2 (Figure 26). The property owner, Carol Dunsmore, has shown a sustained interest in working with Stone and the State of Vermont on this project.

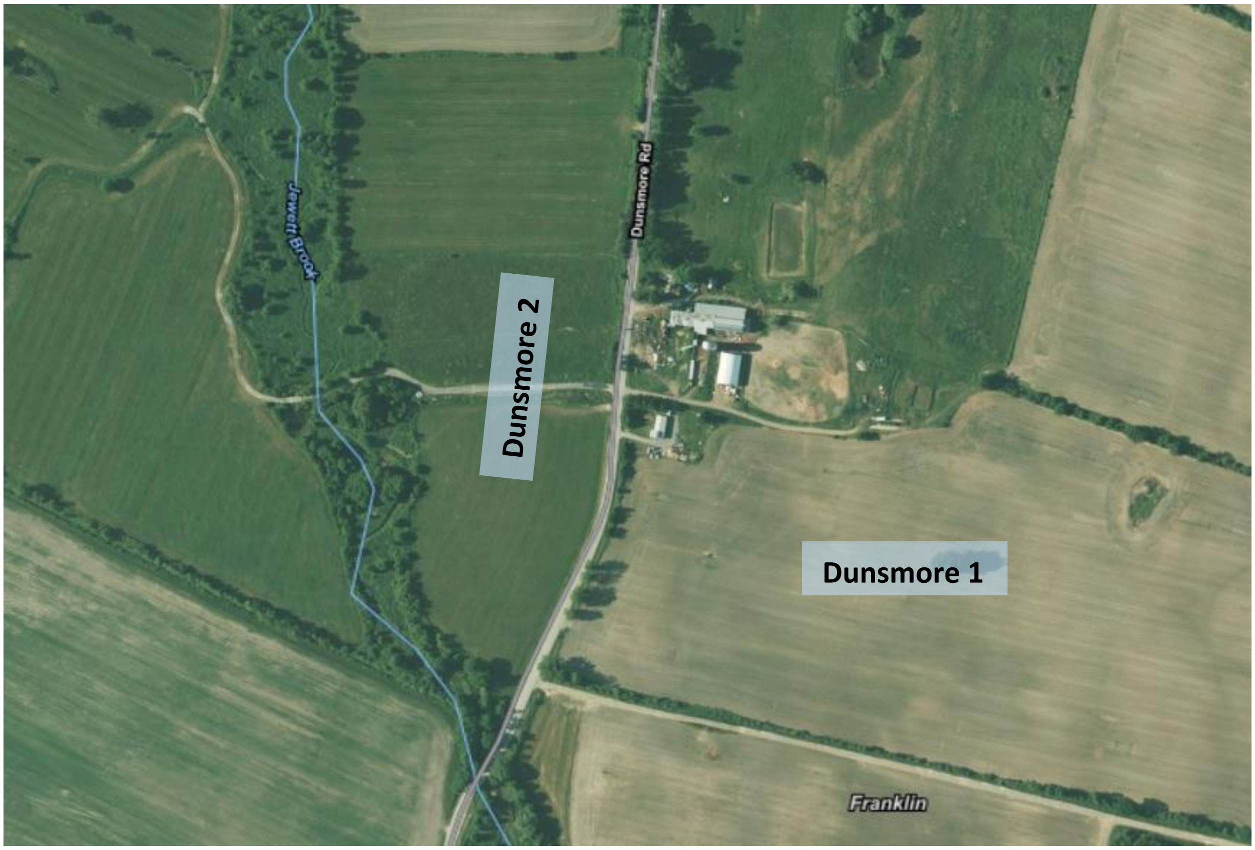

Figure 26. Dunsmore sites

5.1. Dunsmore 1 Site

The Dunsmore 1 site is located north of Jewett Brook on the east side of Dunsmore Road (Figure 26). Figure 27 is a photograph taken from the farm road looking down across the site toward Jewett Brook.

Figure 27. Dunsmore 1 site

The basic characteristics of the Dunsmore 1 site are:

- Ownership: Parcel owned by Carol Dunsmore and conserved with the Vermont Land Trust.
- Site area: 26 acres
- Access: Would require substantial improvement of the farm road to access the site.
- Hydrology: Upslope runoff of minimal concern. The swale/ditch on the north side of the field conveys runoff around the site. Two or three tile drain lines run down the slope, discharging either on the adjoining parcel or beyond this to Jewett Brook. Tile lines would need to be removed.
- Slope: 1-2%. Elevation change top to bottom is ~20 ft. Would require stair-stepping wetland cells down the slope.
- Aspect: Southerly aspect with almost no shading.
- Soil texture: 1) Massena and Georgia stony loam; 2) Kingsbury clay; 3) Scantic silt loam. At 44 50.31428 / 73 8.74069, augured to 3.5 ft.: gravelly sandy loam grading to moist loam. Georgia stony loam is moderately well drained and Kingsbury clay is somewhat poorly drained.
- Soil depth: Shallow bedrock is a concern, particularly with respect to siting a deep settling basin. Bedrock outcrops are visible north of the grass swale on the north side of the property.
- Prime agricultural soils: Statewide, Statewide (b), and Prime (b).
- Wetlands: The small (<0.1 acre) VSWI mapped class 2 wetland (and a 50-ft. buffer around it) east of the proposed settling basin would be avoided. While the extent of prior converted wetlands is unknown, 4.2 acres has a wetland restoration potential score of 1.2.
- Floodplain and river corridor encroachment: The facility is well outside of both the Zone AE special flood hazard area designated by FEMA and the river corridor designated by VTDEC.
- Cultural resources: Unknown (though likely considering proximity to stream).

5.2. Dunsmore 2 Site

The Dunsmore 2 site is located on the west side of Dunsmore Road, opposite Dunsmore 1. Figure 28 is a photograph taken at the north end of the proposed site, looking south toward Jewett Brook.

Figure 28. Dunsmore 2 site

The basic characteristics of the Dunsmore 2 site are:

- Ownership: Parcel owned by Carol Dunsmore and conserved with the Vermont Land Trust.
- Site area: 20 acres
- Access: Adjacent to Dunsmore Road, which is paved. The short farm road bisecting the site would need improvement.
- Hydrology: Stormwater would need to be routed immediately east of the constructed wetland area via a grass swale along Dunsmore Road to an outlet at Jewett Brook. Would require a new culvert under the (improved) farm/access road.
- Slope: 0-1%. Elevation change top to bottom is ~5 ft., conducive to gradual elevation decrease through facility. Field is slightly bedded, with very shallow ditches running east to west.
- Aspect: Low, westerly aspect. Wooded river corridor provides some shading.
- Soil texture: 1) Covington and Kingsbury clay (88%); 2) Stony and slaty loams.
- Soil depth: Augured 15 feet in central location and found clay to depth, groundwater at ~2 ft.
- Prime agricultural soils: Statewide and Statewide (b), no Prime
- Wetlands: No VSWI mapped wetlands. While the extent of prior converted wetlands has not been assessed, 4 acres has a wetland restoration potential score of 3.4. Given the clay soils (Covington is a hydric soil), low slope, and observed shallow groundwater, we anticipate a significant portion of this site could be classified as wetland.
- Floodplain and river corridor encroachment: The western side of the facility is close to but appears outside of both the Zone AE special flood hazard area designated by FEMA and the river corridor designated by VTDEC.
- Cultural resources: Unknown (though likely considering proximity to stream).

6. Conceptual Design

6.1. Overview

The functional design of the treatment train system will be the same regardless of the site chosen. The following description follows the flow of water from the intake to the discharge.

1. During periods when Jewett Brook is backwatered by Lake Champlain, water will be withdrawn at an intake near the Dunsmore Road bridge.
2. A large (~18- or 24-inch diameter) pipe will extend below ground from the stream channel to a vault/pump station in the field (>150 feet from the stream). The pipe opening will have a vertical grill with bars spaced ~2 inches apart to exclude wildlife. A floating boom will exclude floating debris. The intake pipe will be configured to allow backflushing.
3. In the pump vault, a rack of finer screens will be installed to exclude smaller fish. To minimize impingement of fish, the effective velocity at the surface of the screen should not exceed 0.3 ft/s.
4. A duplex pump station (two pumps) will be needed to achieve the maximum flow rate (2.5 MGD) and to allow operational flexibility. A programmable logic controller will control the pumping rate, with inputs for stream stage and flow rate.
5. Water will be pumped from the vault through an 8-inch diameter force main. The piping and vents will be configured to allow draining of the force main.
6. A coagulant, or a mixture of coagulants (aluminum sulfate, sodium aluminate, polyaluminum chloride, and/or a non-ionic polymer) will be metered into a mixing tank or injected directly into the force main.
7. Water will be discharged at one end of the settling basin. Suspended sediments and particulate P will be removed in the basin via chemically assisted settling. Amorphous aluminum compounds will react with ortho-P to form fine P precipitates, which will coagulate into larger flocs and settle. At the maximum pumping rate, the residence time in the settling basin will be about 2.5 days for the original Dunsmore 1 and Dunsmore 2 site plans. Note that the alternate Dunsmore 2 site plan described in Section 6.5 includes two settling basins each with a residence time of 1.5 days at the maximum pumping rate (1.25 MGD per basin).
8. Treated water will flow from the settling basin over a weir into the first constructed wetland. Water will flow horizontally through each wetland. Additional fine particles and particulate P will settle in the wetlands. During the growing season, the plants will take up dissolved P and N.
9. The water level in the wetlands will be controlled using water level control structures built into the berm separating each wetland. Levels will be kept low (~6 inches) in the spring to prevent submerging growing plants. Water levels will be raised over the growing season, achieving a maximum of ~3 feet. Note that the alternate Dunsmore 2 site plan described in Section 6.5 includes only one constructed wetland.

10. At the terminus of the final constructed wetland, water will flow into a pipe and back to Jewett Brook.

A powerline will be run to the pump station.

Excavated soil will be used to level the floor of each wetland and build wide (top width ~10-feet) berms around the settling basin and each wetland. The berms will be compacted and suitable for driving on.

The constructed wetlands will be seeded with a wetland plant seed mix. Emergent wetland vegetation will become established in the constructed wetlands. Woody shrubs will be encouraged on the sloping sides of the berms. Perennial grasses will be planted on the tops of the berms. Around the periphery of the site native trees will be planted wherever appropriate to provide as much shading of the wetlands as possible. Invasive plants will be controlled.

The following sections present aspects of the conceptual designs specific to each site.

6.2. Dunsmore 1 Site

Figure 29 is a plan view of the facility designed for the Dunsmore 1 site. Flow will pass from the settling basin to wetland 1, wetland 2, and so on before discharging through a final control

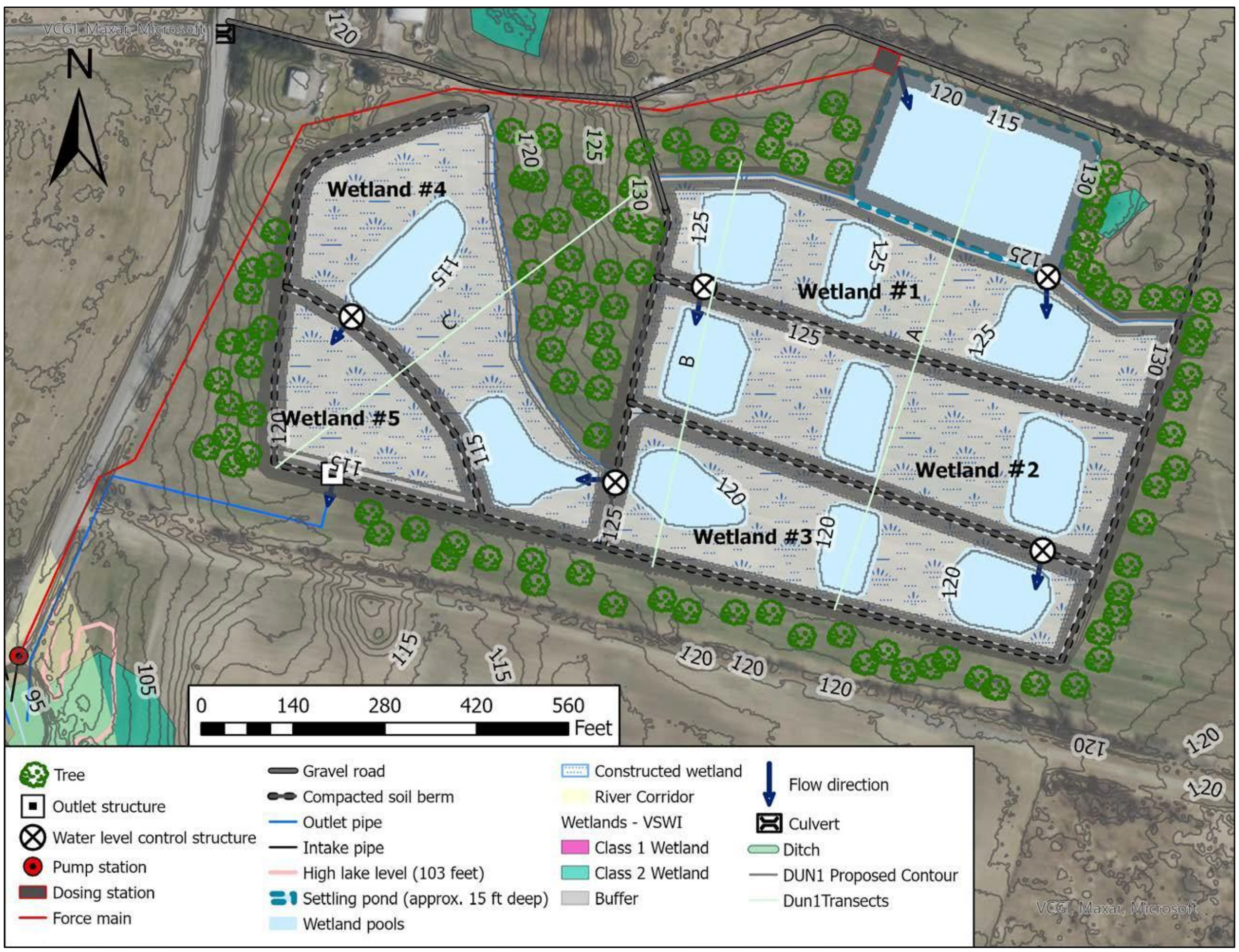

Figure 29. Dunsmore 1 site treatment train facility

structure at the terminus of wetland 5. The settling basin is 15 feet deep and approximately 2.2 acres. The combined area of the five constructed wetlands is 14.1 acres. The settling basin and berms have 1:2 side slopes (rise:run). The water surface elevation in the settling basin is approximately 131 ft. The maximum water surface elevation in wetland 5 is 117 feet.

The structures shown in Figure 29 are consistent with the objective of balancing cut and fill in the earthwork. A total volume of 1,176,000 cubic feet of soil will be excavated (cut) and placed to create the berms and raise portions of the constructed wetland to level them. Figure 30 is a diagram of where these cuts (blue) and fills (red) will be made.

Figure 30. Cut and fill diagram for the Dunsmore 1 site facility

Figure 31 shows ground surface elevations along the transects shown in Figure 29. Note that the floor elevations of the wetlands decrease substantially from upstream to downstream through the facility.

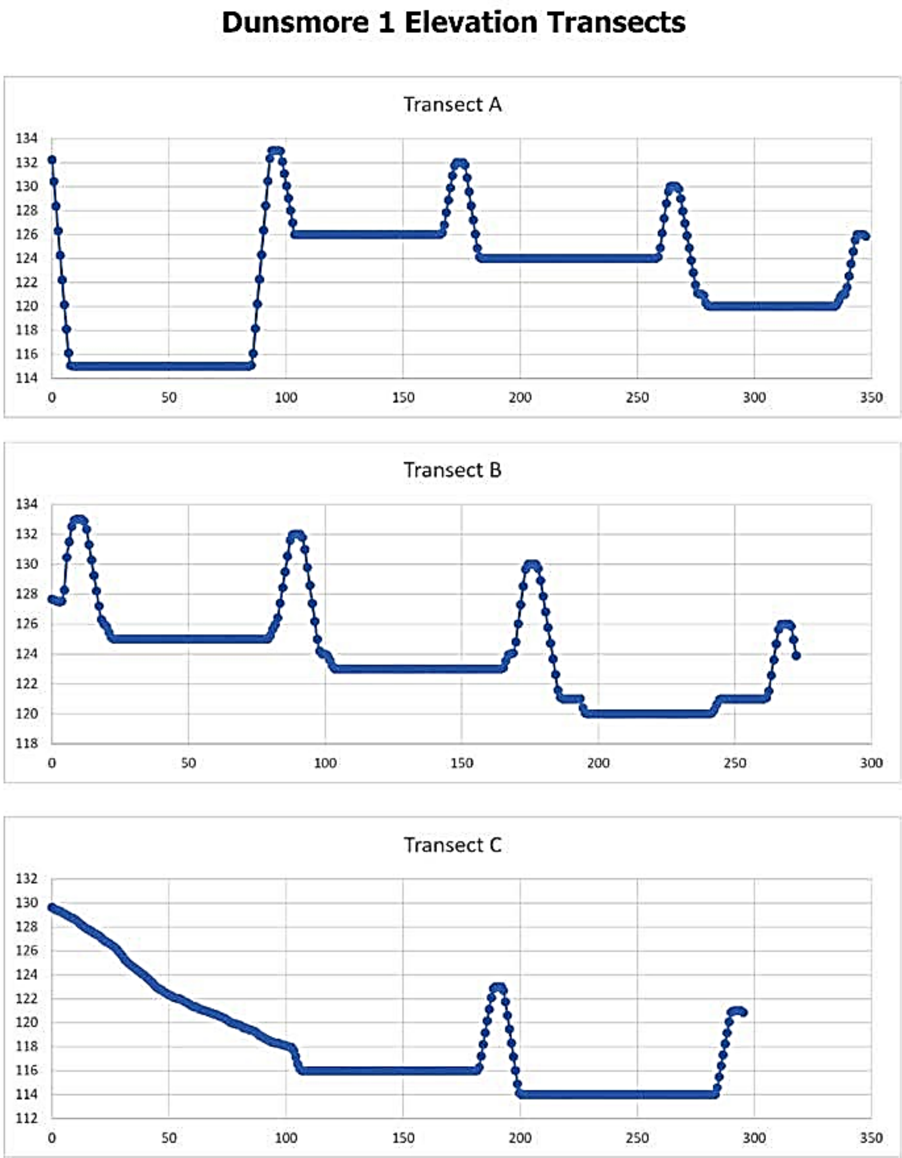

Figure 31. Proposed ground surface along transects at Dunsmore 1 (ft. amsl)

6.3. Dunsmore 2 Site

Figure 32 is a plan view of the facility designed for the Dunsmore 2 site. The total site area is 20 acres. Flow will pass from the settling basin to wetland 1 and wetland 2 before discharging through a final water level control structure at the terminus of wetland 3. The settling basin is 15 feet deep and approximately 1.3 acres. The combined area of the three constructed wetlands is 10.3 acres. The settling basin and berms have 1:2 side slopes (rise:run). The water surface elevation in the settling basin is approximately 110 feet. The maximum water surface elevation in wetland 3 will be 109 feet.

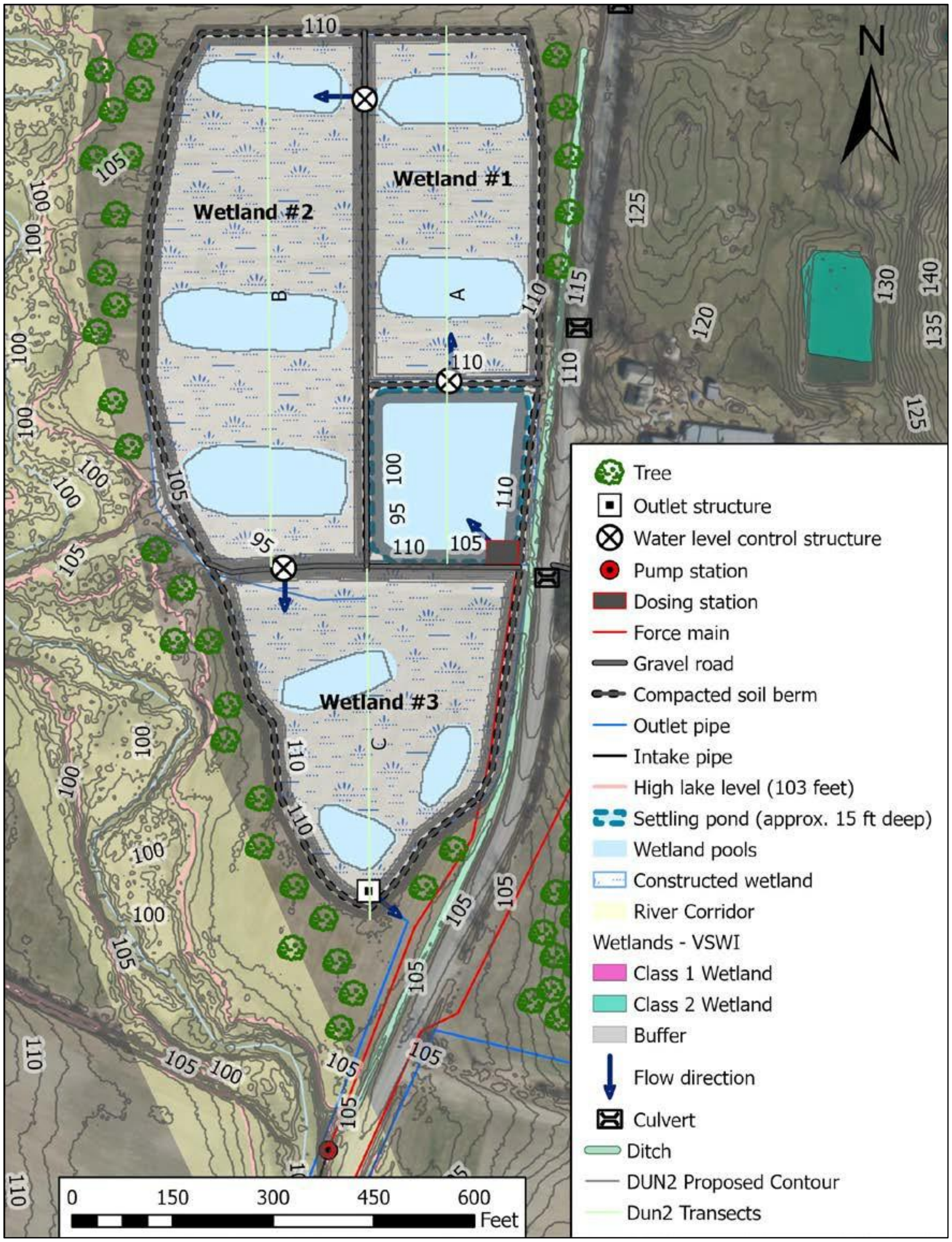

Figure 32. Dunsmore 2 site treatment train facility

The structures shown in Figure 32 are consistent with the objective of balancing cut and fill in the earthwork. A total volume of 812,000 cubic feet of soil will be excavated (cut) and placed to create the berms and raise portions of the constructed wetland to level them. Figure 33 is a diagram of where these cuts (blue) and fills (red) will be made.

Figure 33. Cut and fill diagram for the Dunsmore 2 site facility

Figure 34 shows ground surface elevations along the transects shown in Figure 32. Note that the floor elevations of the wetlands decrease slightly from upstream to downstream through the facility.

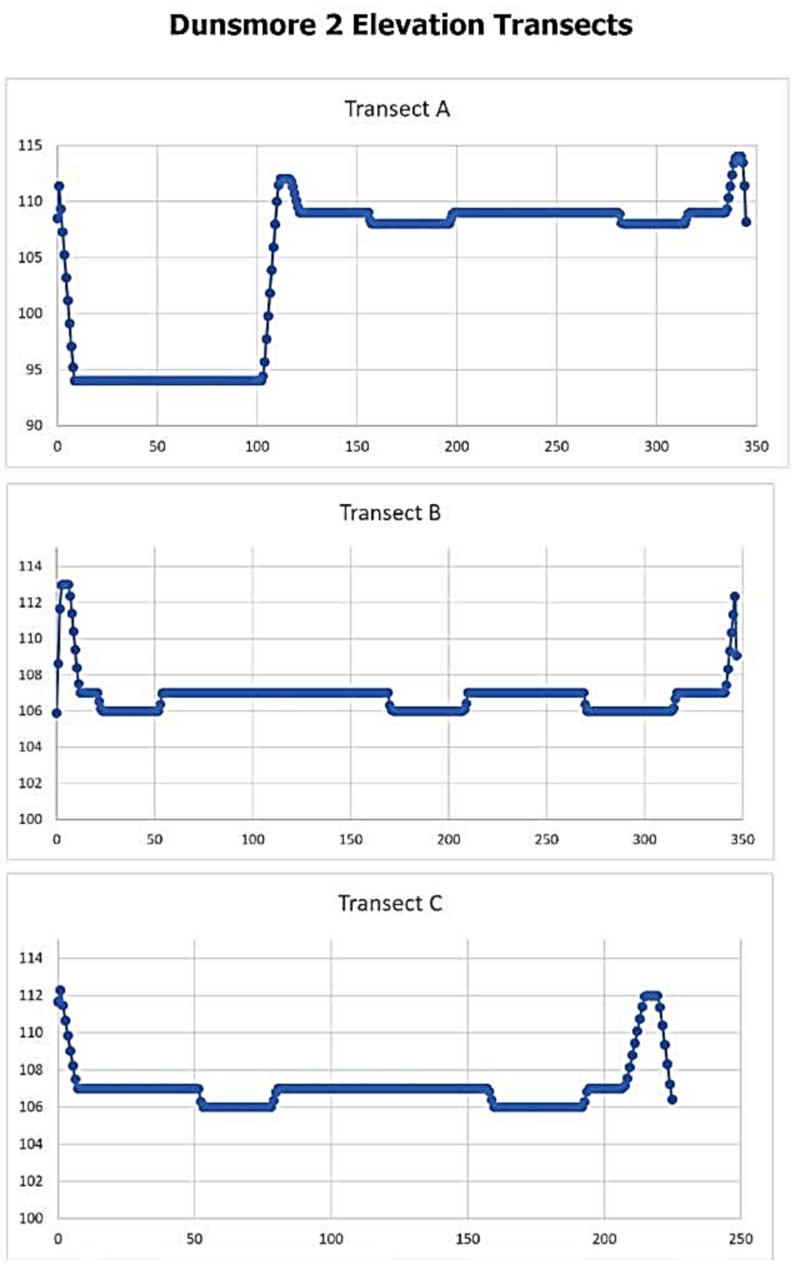

Figure 34. Proposed ground surface along transects at Dunsmore 2 (feet amsl)

The Dunsmore 2 site lies close to the river corridor determined by VTDEC (Figure 32) and the Zone AE special flood hazard area designated by FEMA (Figure 35); however, no excavation or placement of fill should occur in these zones. Constructing the intake near the Dunsmore Road bridge will encroach on the river corridor; however, the intake will not impact the hydraulic conveyance capacity at the bridge.

Figure 35. Regulatory floodplain on Jewett Brook near the Dunsmore Road bridge

6.4. Site Comparison

The Dunsmore 2 site has several definite advantages over the Dunsmore 1 site. The soils are primarily clay (Figure 36), and they are deep. At Dunsmore 1 the settling basin and some of the constructed wetlands would probably need to be lined with an impermeable barrier to prevent excessive seepage losses. Excessive seepage on the Dunsmore 1 site could affect shallow groundwater levels on the downgradient cropped field, which is not part of the Dunsmore Farm, creating undesirable field conditions. Constructed wetlands in the eastern portion of the site (Figure 29; wetlands 1, 2, and 3) would probably also need to be lined to avoid excessive seepage losses and drying out of the wetland cells during dry periods. The clay soils at the Dunsmore 2 site should minimize seepage losses and better support wetland vegetation without need for a liner, especially since groundwater levels on this parcel are shallow. Furthermore, we are confident that shallow bedrock is not a problem on the Dunsmore 2 site, whereas bedrock could interfere with excavation of the deep settling basin at the Dunsmore 1 site, given the bedrock outcrops evident in the fields north and south of the Dunsmore 1 field.

The slope of the Dunsmore 2 site is also more conducive to construction of constructed wetlands than the slope of Dunsmore 1. At Dunsmore 2 water levels could be managed in the constructed wetlands with a maximum drop of 2 feet between upslope and downslope wetlands. At the Dunsmore 1 site the maximum drop in the water surface elevation between wetland cells is substantially greater, approximately 5 feet (between wetland 3 and wetland 4). These larger

Figure 36. Clay soil at the Dunsmore 2 site

drops at Dunsmore 1 will result in greater hydrostatic forces against the constructed wetland berms, increasing the risk of failure, and complicate management of the system.

The greater elevation of the settling basin and dosing station at Dunsmore 1 (132 ft. amsl) than Dunsmore 2 (113 ft. amsl) will place greater demands on the pump and increase electricity costs to operate the pump. Assuming a typical water surface elevation in Jewett Brook at the Dunsmore Road bridge of 98 ft., the vertical lift required at Dunsmore 1 is more than twice that at Dunsmore 2 (34 ft. versus 15 ft.).

The farm road accessing the Dunsmore 1 site is longer and steeper and more rutted in parts than the farm road at Dunsmore 2. The Dunsmore 1 access would be more expensive to rebuild and maintain than the Dunsmore 2 access, which is shorter, straighter, and nearly level.

The primary advantages of the Dunsmore 1 site over Dunsmore 2 are that the area of constructed wetlands could be larger and the construction of an intake and forcemain on the east side of Dunsmore Road could be more straightforward than on the west side of the road. However, given the several advantages of Dunsmore 2 we recommend proceeding with this site.

At both the Dunsmore 1 and the Dunsmore 2 sites we anticipate unavoidable impacts to prior converted wetlands (which are now cropped fields). Hydric soils are present in portions of both sites: Scantic silt loam at Dunsmore 1 and Covington clay at Dunsmore 2. While Stone has not delineated wetlands on either site, the slopes and soils and our observations on site suggest that wetlands impacts would be potentially more extensive on the Dunsmore 2 site. Absent the bedded surface of Dunsmore 2 (bedding is done to improve drainage and increase crop yield) and current agricultural management, significant portions of the Dunsmore 2 site would likely support wetland vegetation.

6.5. Dunsmore 2 Site: Alternate plan

Several factors led us to develop an alternate plan for the Dunsmore 2 site. These include:

- The long force main needed to convey water to the settling basin in the original Dunsmore 2 plan (Figure 32) would be exceedingly expensive (~$400,000).
- The property is changing hands and the new owner appears more amenable to completing the project if it has a smaller footprint.
- The greatest opportunities for removing phosphorus from Jewett Brook exist when streamflow is substantial (>2.5 MGD) and the channel is backwatered by Lake Champlain (see Section 3.3). These conditions typically occur in spring and in late fall/early winter. Unfortunately, constructed wetlands are most efficient at removing P when the plants are growing rapidly in late spring and summer. Due to this temporal mismatch constructed wetlands should not be relied upon to perform substantial P treatment at this site. To efficiently remove P, nearly all P removal must occur in the settling basins. Since wetlands are less important for P removal, they can be smaller.

Figure 37 shows an alternate plan for the Dunsmore 2 site, incorporating two parallel, 480 ft long settling basins that discharge to a single wetland wrapping around the northern and western sides of the site. The berms and access roads have 1:2.5 side slopes (rise:run). The intake pipe is much shorter, reducing the cost.

The total project area is 9.2 acres (3.7 ha), considerably more compact than the original design. This is the area proposed for rental and it is outlined with a red dashed line in Figure 37. The area enclosed by berms and roads is 7.4 acres (3.0 ha) and incidental field areas comprise the remaining 1.8 acres (0.7 ha). These field areas would be planted in trees if acceptable to the landowner, particularly the sliver of land in the VTDEC-designated river corridor. The incidental field

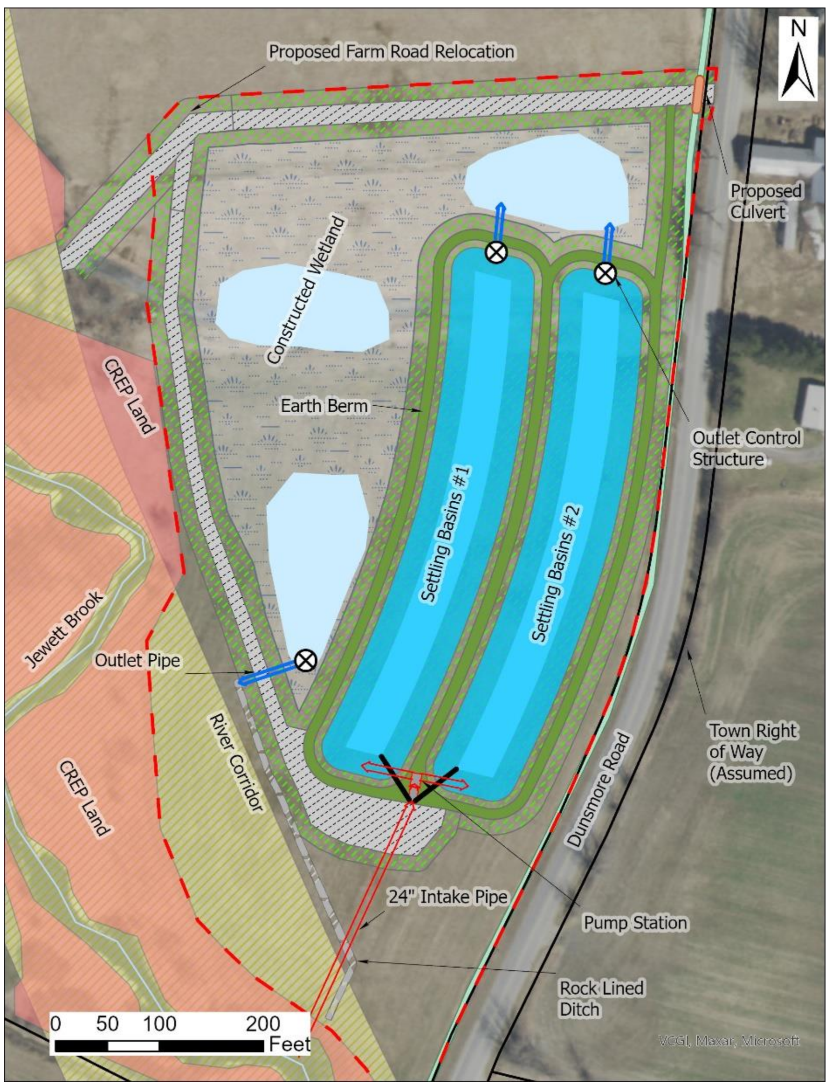

Figure 37. Alternate Dunsmore 2 site plan

areas are included in the project area because it may not be economical to access and crop them.

Along the western side the facility abuts land enrolled in the Conservation Reserve Enhancement Program (CREP). CREP land is not included in the project area.

This alternate plan prioritizes chemically assisted settling of P in settling basins, which can be effective in the months with highest streamflow and P loading. The long and narrow settling basins will promote more uniform mixing and reduce the likelihood of flow short-circuiting, as compared with the nearly square settling basin in Figure 32. At ~10 ft. deep, the basins are also shallower than in the original plan. Reducing the depth to 10 ft. should not impact P removal significantly. Constructing shallower basins will reduce the likelihood of low dissolved oxygen conditions at the sediment-water interface and the cost and complexity of the earthwork. One disadvantage is that cleanout of deposited sediments will need to be more frequent to maintain adequate capacity in the basins. Having two linear basins will allow one to remain operational while the second is drained and cleaned.

One negative aspect of the smaller facility area may be reduced uptake of N by plants due to shorter residence time in the substantially reduced wetlands.

7. Estimate of Achievable P Removal

We used the Dunsmore 2 site conceptual design (original and alternate plans) as the basis for these phosphorus removal estimates because we believe Dunsmore 2 is the better site. For the purposes of these estimates, we assume the original and alternate Dunsmore 2 plans would provide essentially equivalent phosphorus removal.

7.1. Treatment Efficiency

The deep settling basin in the original Dunsmore 2 conceptual plan (Figure 32) has a volume of 849,420 ft^3 (6,354,103 gallons; 24,052,896 L). The residence time in this settling basin will vary between 2.5 days at the maximum flow rate of 2.5 MGD to almost 13 days at 0.50 MGD. The combined volume of the two linear settling basins in the Dunsmore 2 alternate plan is lower, 505,440 cubic feet (3,780,954 gallons; 14,312,467 L). The residence time in these settling basins will vary between 36 hours at the maximum flow rate of 2.5 MGD to about 8 days at 0.50 MGD. In both cases, the residence times should be sufficient to achieve high rates of P removal using aluminum sulfate ("alum") to coagulate and flocculate P in the settling basins.

The water quality of Jewett Brook appears conducive to using aluminum sulfate to remove P. The relatively high P concentrations in Jewett Brook (median 408.0 µg/L; Table 3) will enable efficient P removal in the settling basin, approximately 90%. An accepted rule of thumb in planning P inactivation treatments in lakes is to apply aluminum at a 10 Al:1 P molar ratio, considering the mass of P requiring inactivation. Project advisor Dr. Ken Wagner (personal communication, May 17, 2022) indicated that this same treatment ratio is appropriate for P removal in a settling basin. A slightly higher application ratio than 10 Al:1 P may be needed to maintain 90% P removal when influent P concentrations are near the lower end of the measured 87–1750 µg/L range. The constructed wetlands will serve to polish the water after chemical treatment and settling in the settling basin, further reducing sediment, aluminum, and P, while also achieving substantial nitrogen reductions during the growing season.

The alkalinity (median 116 mg/L, range 60.5-230 mg/L; Table 3) is sufficiently high that addition of aluminum sulfate should not significantly depress the pH. In the unlikely event the pH is depressed, polyaluminum chloride may be substituted for aluminum sulfate. Polyaluminum chloride has negligible impact on pH, but it is more expensive than aluminum sulfate per unit of aluminum.

7.2. Achievable P Removal

We calculated the mass of P entering the Dunsmore 2 treatment train (original or alternate) from daily flows and P loading estimates using the following assumptions:

Condition 1: The system will not be operated in the winter (mid-December to mid-March).

Condition 2: At all times, the pumping rate will not exceed the streamflow rate.

Condition 3: Except for #1 and #2, the maximum flow rate will be 2.5 MGD (3.87 cfs)

Condition 4: Water will only be withdrawn when the level of Lake Champlain exceeds 96.0 ft. amsl (NGVD29) to ensure the channel is backwatered by the lake. This cutoff includes a margin of safety. See Section 3.3 for details regarding this condition.

Daily mean Lake Champlain water level data (USGS gauge 04294500 in Burlington) were associated with corresponding daily Jewett Brook flows and P loading estimates provided by Dr. Matthew Vaughan (see Section 3.2) after these estimates were multiplied by a factor of 1.62 to account for the unmonitored portion of the watershed. Operating Conditions 1 through 4 were then applied to the daily P loading estimates to constrain withdrawal. For example, water withdrawal and P loading to the facility were assumed to be zero on winter days (Condition 1) and days when the lake level was below 96.0 ft. amsl (Condition 4). When Conditions 1 and 4 were met, the withdrawal rate was assumed to be the lesser of the Jewett Brook flow rate (Condition 2) or 2.5 MGD (Condition 3).

Given daily P loading estimates, operating conditions 1 through 4, and an assumed average P removal rate of 90%, predicted annual P removals for the Dunsmore 2 facility were calculated for 2009–2020 (Table 7).

Table 7. Estimated TP removal by Dunsmore 2 treatment train assuming operating conditions

Year	Jewett Brook TP load[1] (kg/yr)	TP load to Dunsmore 2 facility (kg/yr)	TP removed by Dunsmore 2 facility (kg/yr)
2009	2,021	322	290
2010	5,291	557	501
2011	8,931	761	684
2012	1,936	117	105
2013	3,517	306	275
2014	2,999	205	184
2015	2,754	216	194
2016	3,479	104	94
2017	3,413	328	295
2018	3,555	243	219
2019	6,096	591	532
2020	1,915	66	60
Mean	**3,826**	**318**	**286 (7.5% JB load)**

1. Multiplied by 1.62 from estimated TP loads at Lower Newton Road gauge

We did not further reduce the assumed water withdrawal rates to account for minimizing temperature impacts at the discharge point (see Section 8.3.2). P loading is generally low during the conditions we are most concerned with--low stream flows and warm ambient stream temperatures. Curtailing operations under these conditions would not greatly affect the overall P removal rates, especially as these conditions frequently coincide with low lake levels during which Condition 4 would prevail.

8. Potential Impacts on Stream Biota

Based on input from resource managers during the regulatory feasibility phase of this project regarding potential impacts of the facility on fish and other aquatic organisms, we considered the following concerns in greater depth:

- Potential changes in the flow regime of Jewett Brook and the Black Creek Wetland
- Fish impingement and entrainment at the system intake
- Changes in water temperature at the discharge point

8.1. Changes in the Flow Regime

If the intake and the discharge are both located near the Dunsmore Road bridge, as anticipated, applying Conditions 2 and 4 (see Section 7.2) should limit any alterations of the flow regime to minor and very localized effects. No water level fluctuations or reverse flow would occur in Jewett Brook and the Black Creek Wetland would not be affected. The only likely effect is some local circulation between the discharge point and the intake. This would be negligible at moderate and high flows when only a fraction of the streamflow can be treated. However, as the streamflow rate declines and approaches the pumping rate, a portion of the treatment train outflow would likely flow to the intake. This effect will be minimized to the degree possible by locating the discharge point a short distance (<100 feet) downstream of the intake.

8.2. Impingement and Entrainment of Fish Larvae

Impingement and entrainment of larval fish can be minimized through accommodations in the facility design. Strategies to reduce the potential for larval fish impingement and entrainment include sizing the intake pipe to reduce water velocity and installing screens.

For a given flow rate, increasing the intake pipe size will result in lower water velocities at the intake. Table 8 provides the effective water velocities at round intakes of varying diameter, assuming a maximum pumping rate of 2.5 MGD (3.9 cfs).

Table 8. Water velocity at opening of intake pipes of varying diameters

Inflow rate (MGD)	Inflow rate (cfs)	Intake diameter (in.)	Intake area (ft^2)	Water velocity (ft/s)
2.5	3.9	8	0.35	11.1
2.5	3.9	10	0.55	7.1
2.5	3.9	12	0.79	4.9
2.5	3.9	15	1.23	3.2
2.5	3.9	18	1.77	2.2
2.5	3.9	24	3.14	1.2

In lower Jewett Brook and the Black Creek Wetland, two fish species of particular concern are northern pike and walleye. Table 9 presents reported swimming velocities of larval pike and walleye.

Table 9. Larval fish swimming speeds

Species	Mean maximum swimming velocity of larva (ft/s)	Source
northern pike (*Esox lucius*)	13.03	Harper and Blake, 1990
walleye (*Sander vitreus*)	9.84	Houde, 1969

Comparing the swimming speeds of larval northern pike and walleye with water velocities in the intake pipe (Table 8), we expect that a 12-inch diameter intake pipe would not present an undue risk to fish. Walleye larva, the slower of the two species, can swim at speeds about double the water velocity at the intake. A larger intake cross-section, such as an 18-inch diameter pipe or two 12-inch diameter pipes, would minimize the risk entrainment.

The US Bureau of Reclamation provides an excellent manual (USBR, 2014) outlining the basics of screening for fish and screen design. We have considered the principles and the types of screens presented and propose the following general concept for screening aquatic organisms to minimize impingement and entrainment at the intake:

1. A floating boom like that shown in Figure 5 will block large, floating debris from nearing the intake.
2. A large (~18- or 24-inch diameter) pipe will extend below ground from the stream channel to a pump vault in the field (>150 feet from the stream). The pipe opening will have a vertical grill with bars spaced ~2 inches apart to exclude wildlife.
3. The pump vault will be approximately 8 ft. wide by 10 ft. long, and the floor of the vault will be set at the elevation of the channel bottom. A rack of sliding vertical screens will span the width of the vault, bisecting it into screened and unscreened halves. The screens will be constructed of stainless-steel wedge wire. Screen openings will be small enough to exclude juvenile fish.
4. A pump suction pipe will extend vertically into the screened half of the vault, opposite the intake pipe. The suction pipe will extend to a point about 1 ft. above the vault floor.

The rationale for this design is that water velocities will be sufficiently low through the large diameter intake pipe and pump vault that fish that enter the intake can escape. Within the vault, the large surface area of the ~8-foot-wide screen should result in low effective velocities (<=0.3 ft/s) at the face of the screen, which should minimize impingement of fish.

8.3. Temperature Impacts

Jewett Brook is classified as warm water fish habitat (VTANR, 2017). The applicable temperature standards for Jewett Brook are presented in Table 10. Compliance with these standards is assessed at the upstream and downstream boundaries of a 200-ft. long mixing zone about the discharge point.

Table 10. Temperature change standards for Jewett Brook

Stream temperature (ºF)	Allowable temperature change at mixing zone boundary (ºF)
>66	1
63 - 66	2
59 - 62	3
55 - 58	4
<55	5

Thermal impacts on Jewett Brook by the proposed treatment train facility are of greatest concern during summer months when stream temperatures are already elevated and solar radiation and air temperatures are highest. At the Coldwater Creek treatment train facility in Ohio, temperatures increased a maximum of 5°F between the intake and the outlet in the summer months (Dr. Stephen Jacquemin, 2020, *pers. comm)*.

We were not able to make accurate predictions regarding the effect the treatment train facility would have on stream temperatures in Jewett Brook. We worked with a simple spreadsheet model, the Response Temperature model or RTemp (Greg Pelletier, Washington State Department of Ecology), to simulate water temperature changes in the Dunsmore 1 site treatment train. This model produces a time series of water temperature estimates given groundwater and meteorological inputs. While the lack of adequate input data necessitated worst case assumptions for some parameters, the model proved insensitive to variables other than air temperature. Despite considerable efforts, we conclude that the RTemp model predictions presented in this section (which are included to demonstrate these efforts) are probably not worthwhile.

8.3.1. Temperature modeling with RTemp (Version 27)

Thermal modeling of the Dunsmore 1 site treatment train was severely handicapped by the lack of continuous temperature measurements for Jewett Brook. To assess the potential thermal impacts of the proposed treatment train, we must first approximate the existing conditions. Since continuous temperature measurements do not exist for Jewett Brook (or most Vermont streams), we attempted to estimate these using best available data, including:

- Interactive Catchment Explorer (ICE) predictions. The ICE tool is available at: http://ice.ecosheds.org/. For the Jewett Brook watershed, this tool predicted an average summer temperature of 18.7°C (65.7°F). Daily average stream temperatures exceeding 18.0°C (64.4°F) were predicted on 68 days of the year and temperatures exceeding 22°C (71.6°F) were predicted on 3 days of the year.
- The LTMP dataset includes occasional measurements of stream temperature at the Jewett Brook gauge on Lower Newton Road. The average summer stream temperature for the 2009-2010 period was 20.4°C (68.8°F).
- The Stevens Brook watershed lies immediately east of the Jewett Brook watershed. Stevens Brook drains downtown St. Albans and surrounding suburban areas. While the

watersheds are dissimilar, there are some continuous temperature data for Stevens Brook that may provide a useful reference. Stone's stream gauging program on behalf of the City and Town of St. Albans and the municipalities in Chittenden County developed continuous, unreported stream temperature data for Stevens Brook between 2017 and 2021. These temperature data were reviewed for the summer months of 2019 and 2020 to derive the average summer water temperature, which was 19.3°C (66.8°F).

Three trials were performed using the RTemp model, the results of which are described here.

Trial 1: The first trial was set up to evaluate the model. The bathymetry of the treatment train was estimated using areas from the proposed Dunsmore 1 site plan and depths from the Coldwater Creek facility. The initial, estimated water response temperature was derived using the ICE tool. Sediment conductivity and exchange were estimated for the type of clay soils present at the Dunsmore 1 site. Hourly meteorological data were sourced from the NOAA station at the Burlington International Airport (National Climate Data Center local climatological data) and combined with hourly solar radiation data (diffuse modeled solar radiation from the National Solar Radiation Database). These data were interpolated in R to achieve the sub-hourly resolution required in the RTemp model. Since the most recent data available from the National Solar Radiation Database were from 2005, climatological data were input for the same year.

The results showed a marked increase in water temperature from the initial temperature (Figure 37). Predicted water temperature closely followed air temperature for the rest of the period. Note that the "observed water temperature" line indicated in Figures 37, 38, and 39 is simply the assumed water temperature at the initial time step.

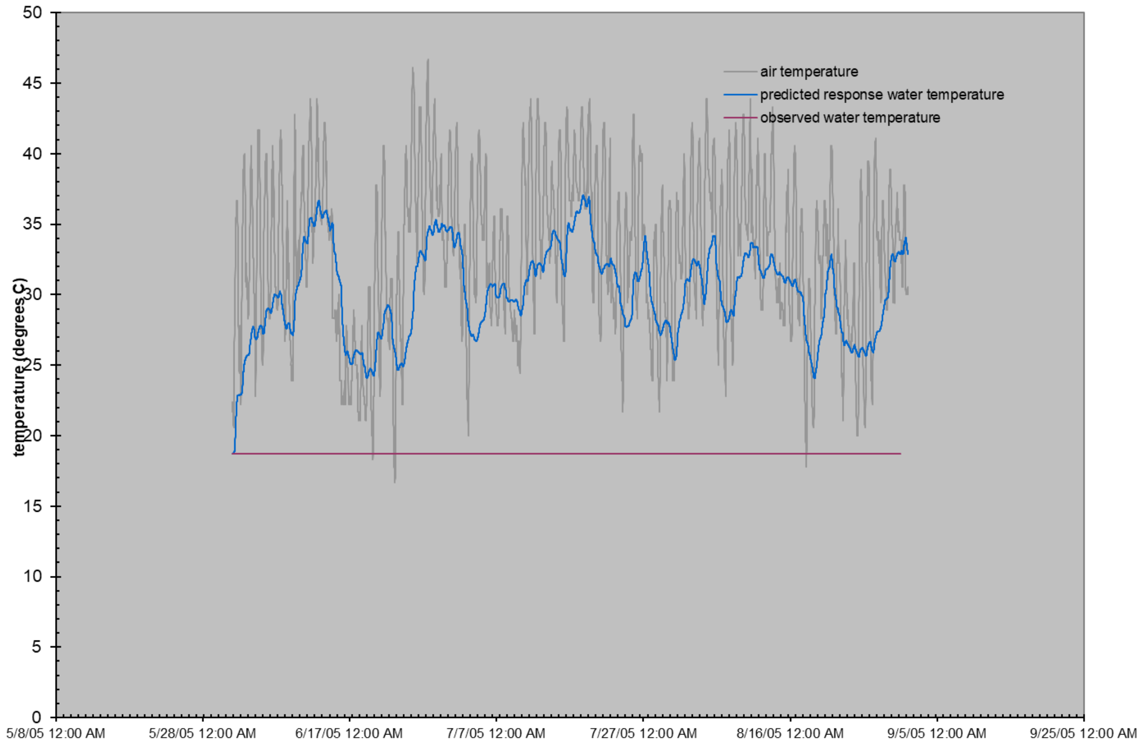

Figure 38. Trial 1 temperature time series plot

Trial 2: The purpose of the second trial was to represent conditions in Jewett Brook more accurately than in Trial 1. Since RTemp cannot account for surface water inflow to the system, groundwater inflow was used as a proxy. An inflow of 4 MGD was entered as groundwater inflow (note that 4 MGD exceeds the 2.5 MGD maximum pumping rate currently assumed). Shading was increased to represent wetland vegetation and a possible shaded cooling cell at the end of the system. The model predictions continued to show a marked temperature increase and water temperatures that closely tracked air temperatures (Figure 38).

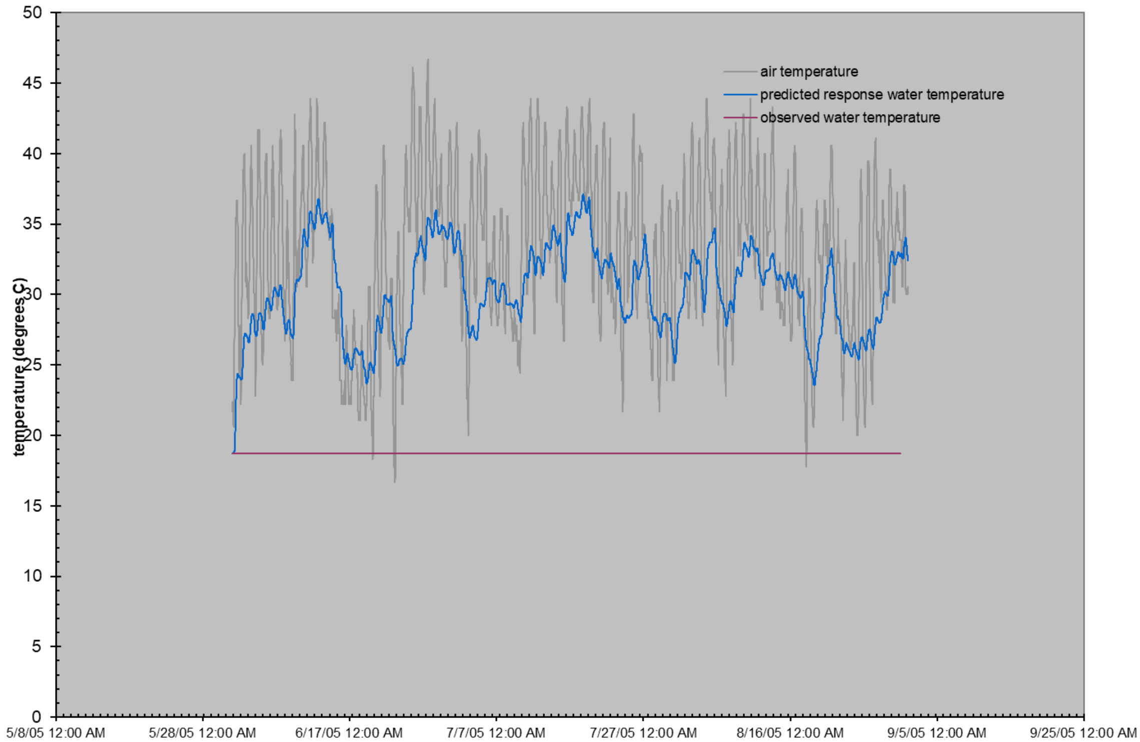

Figure 39. Trial 2 temperature time series plot

Trial 3: The purpose of the third trial was to drastically change certain inputs to see if any combination of inputs could result in a more stable temperature regime. The input changes and their effects are shown in Table 11. Again, predicted water temperatures closely tracked air temperatures (Figure 39). Compared with Trial 2, Trial 3 dampened diurnal temperature fluctuations, but produced a similar overall pattern.

Table 11. Input changes and results for Trial 3

Change	Result
Set solar radiation as default (-999)	No change. Water temp still reaches >35°C
Set cloud cover as 1 (100%) for entire input period	No change. Water temp still reaches >35°C
Set initial water response temp to 10°C	No change. Water temp still reaches >35°C
Set shading to 1 (100%)	No change. Water temp still reaches >35°C
Set water depth to 4.87 m (16 ft. for deep cell)	No change. Water temp still reaches >35°C
Set Brutsaert model parameter to 1.3	No change. Water temp still reaches >35°C

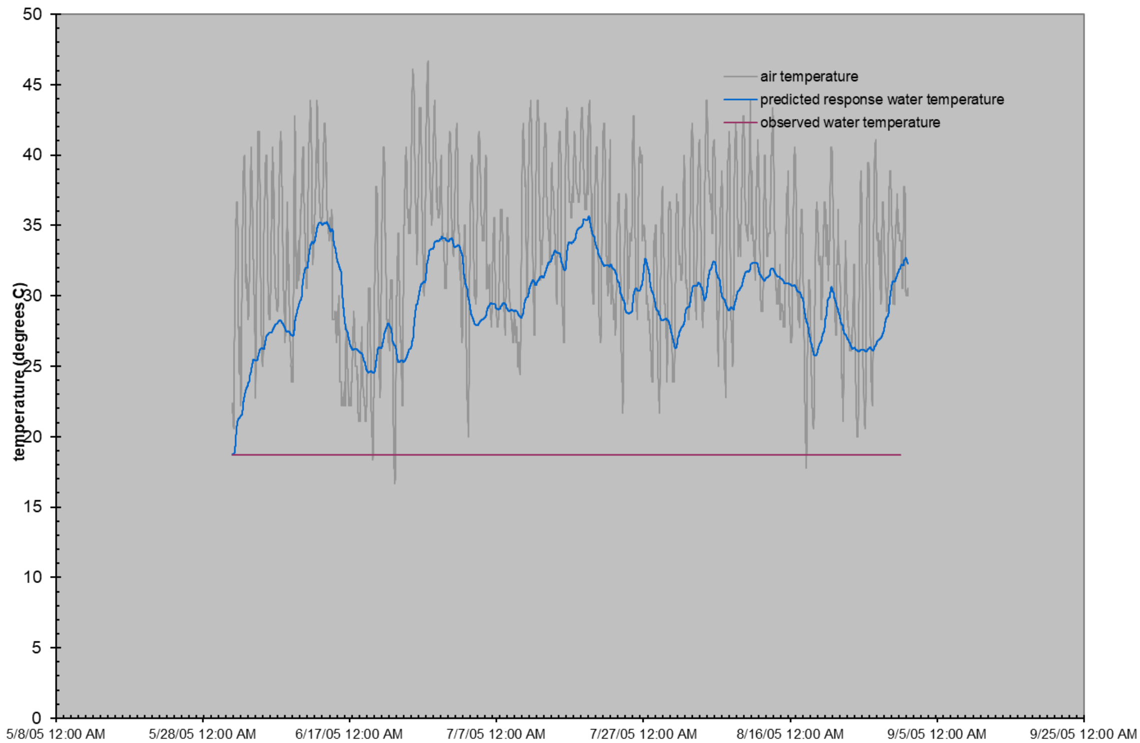

Figure 40. Trial 3 temperature time series plot

Although the proposed Jewett Brook treatment train facility may indeed raise water temperatures, sustained temperatures >30°C do not appear realistic. In all simulations, water temperatures closely followed air temperatures. This may occur since the model does not account for the volume of water it is simulating. It may be simulating temperature response in 1 cubic meter or many thousands of cubic meters. In conclusion, based on both its output and what we can understand about its computations, we have little confidence in these RTemp model predictions for this application.

The lack of adequate input datasets and the substantial time required to implement a more sophisticated (and ideally more realistic) model precluded further modeling efforts. Before making this determination, we evaluated several models, including HEC-RAS (USACE), SNTEMP (USGS), AEM3D (HydroNumerics), CE-QUAL-W2 (USACE), SWMM (USEPA), and MINUHET, to assess their applicability and input requirements.

8.3.2. Strategies to minimize water temperature impacts

Shading of the wetlands will be critical to minimizing water temperature increases during residence in the treatment train. The Dunsmore 1 site is an agricultural field with a southerly aspect and negligible canopy shading. The Dunsmore 2 site is lower and has a westerly aspect, with trees in the river corridor providing some shading of the field. In the conceptual designs prepared for both sites, trees are planned wherever possible around the periphery of the facility.

At the Dunsmore 2 site, trees will be planted in the entire area between the outside berm and the forested river corridor.

Shading by the emergent vegetation in the constructed wetlands will also be critical to minimizing temperature impacts. As discussed in Section 6.1, the entire area of the constructed wetlands will be planted in emergent wetland plants and water levels will be controlled so as not to submerge growing vegetation. Both living and dead wetland vegetation will provide a high degree of shading after the plants become established. We found little relevant literature on shading effects of emergent wetland vegetation. Most studies focus instead on riparian shading or the shade *tolerance* of wetland plant species.

The second strategy to avoid water temperature impacts will be to limit water withdrawal and treated water discharge when streamflow rates are low and ambient stream temperatures are highest. These conditions usually coincide with low lake levels, during water withdrawal would be prohibited under Condition 4.

We do not have enough information at this stage to propose strict operating conditions with respect to stream temperature; however, we are confident these could be worked through with Vermont Fish and Wildlife Department staff as plans for the project develop further. Without question temperature sensors could be used at the intake and discharge points to inform operations and potentially to adjust pumping rates automatically, in concert with flow data. The following are a few examples of how these data could be used:

> **Example 1:** The water temperature at the intake is 65°F and the current discharge rate is 50% of the streamflow rate. The temperature at the outflow is <=69°F; therefore, the applicable in-stream temperature criterion (Table 10) should be met in the mixing zone through simple dilution.
>
> **Example 2:** The water temperature at the intake is 70°F and the current discharge rate is 100% of the streamflow rate. The temperature at the outflow is <=71°F, therefore, the applicable in-stream temperature criterion (Table 10) should be met in the mixing zone.
>
> **Example 3:** The water temperature at the intake is 70°F and the current pumping rate is 100% of the streamflow rate. The temperature at the outflow is 72°F; therefore, the discharge rate would be decreased to <=50% of the streamflow rate to meet the applicable in-stream temperature criterion (Table 10).

9. Analysis of Costs

Stone obtained cost information from sources including Hoyle, Tanner & Associates, Inc., Ben Gabos of VAAFM, Ken Wagner of Water Resources Services, Alan Mashtare of the Town of St. Albans, and Steven Jacquemin and Theresa Dirksen, our primary contacts regarding the Coldwater Creek treatment train. In most cases original estimates were from other projects the sources were involved with and we adjusted them in Table 12 to reflect the original plan of the Dunsmore 2 treatment train.

Table 12. Preliminary (ballpark) cost estimates for the Dunsmore 2 Treatment Train

	Capital costs	Annual costs	Source
Land lease[1]	NA	~$21,000	Ben Gabos (adjusted)
Construction			
Earthwork	$400,000		Jacquemin/Dirksen (adjusted)
Intake pipe (150’ of 18” diam.)	$50,000		Hoyle Tanner
2.5 MGD duplex pump station	$700,000		Hoyle Tanner
Force main (1,150’ of 16” diam.)	$400,000		Hoyle Tanner
Dosing station	$100,000		Hoyle Tanner
Electrical and controls	$50,000		Hoyle Tanner
Tree planting	$6,000		Michele Braun
Operating			
Site maintenance		$20,000	Dave Braun
Chemicals		$5,000	Ken Wagner (adjusted)
Electricity		$50,000	Jacquemin/Dirksen (adjusted)
Sludge removal		$5,000[2]	Dave Braun / Ken Wagner
Performance monitoring		$16,000	Dave Braun
Totals	~$1,700,000	~$117,000	

1. Assumes 14 acres at $1,500/acre
2. Annualized cost

While many components of the treatment train facility (such as the constructed wetlands, settling basin, pump vault, and pipelines) could have a very long life, other components (particularly the pump and pump controls, dosing and mixing equipment, and water level control structures) have a shorter expected life. For the purposes of this cost analysis, we assumed that the capital cost of the Dunsmore 2 treatment train ($1,700,000) will be depreciated over a 15-

year design life, for an annualized capital cost of ~$113,000. In this case, the total annualized cost of the treatment train will be approximately $230,000 ($113,000 in capital cost depreciation and $117,000 in operating expenses).

Using this $230,000 annualized cost and the mean annual P removal estimate of 286 kg P/yr (Table 7), we estimate that the Dunsmore 2 treatment train will remove phosphorus at a cost of approximately $800 per kilogram.

The alternate plan proposed for the Dunsmore 2 site should achieve similar P reductions at lower cost. While we have not prepared a full accounting of these cost savings, the items that would cost substantially less with the alternate design are the earthwork, the force main, and the land lease. By very rough approximation, we expect a facility based on the alternate Dunsmore 2 plan would have an annualized cost of ~$200,000, for a P removal cost of $700 per kilogram.

10. Analysis of Alternatives

10.1. Agricultural Practices

To place the P removal efficiency of the proposed Dunsmore 2 treatment facility into context, we evaluated alternative practices that could potentially achieve similar P reductions.

From previous work, we estimated the areas of agricultural land uses in the Jewett Brook watershed as 480 ha in continuous corn, 404 ha in corn-hay rotation, 92 ha in permanent hay, and 25 ha in pasture.

We estimated P losses from these acreages using the BMP Scenario Tool developed by TetraTech (2015). The Tool predicted a P load from all cropland in the Jewett Brook watershed of 2,794 kg/yr. This predicted cropland P loading was reduced by 1,638 kg/yr following implementation of 1) cover crops, conservation tillage, and manure injection on all continuous corn hectares; 2) cover crops on all land in corn-hay rotation; 3) manure injection on hay hectares; and 4) livestock exclusion and buffers on all pastureland.

We then estimated P reductions corresponding to a few common annual practices (cover crop - CC, conservation tillage - CT, manure injection - MI, and change in rotation - CR) and limited the land use categories to continuous corn and corn-hay rotation. Further, we limited the implementation of practices to clay soils only since these soils comprise most of the cropland area. Table 13 provides the resulting P reductions estimated for different combinations of land use and annual conservation practices.

Table 13. Estimated P reductions for different agricultural land use and practice combinations

Land use	Practice	Area applied (ha)	P reduction (kg/yr)
Continuous corn	No-till–Cover crops–Manure injection	46	139
Corn-hay rotation	No-till–Cover crops–Manure injection	45	33
Continuous corn	Cover crops	49	69
Corn-hay rotation	Cover crops	46	15
Continuous corn	Change in rotation	30	35
		Total=216	Total=291

These results suggest that implementation of conservation tillage, cover crops, and manure injection on 46 ha of continuous corn could reduce P loading by 139 kg/yr, a greater impact than other conservation practices. Implementing cover crops on 46 hectares of continuous corn could reduce P by 69 kg/yr. Implementing this suite of practices on a total of 216 hectares results in a phosphorus load reduction of 291 kg/yr, which is nearly equivalent to the proposed treatment train project.

Costs of implementing these conservation practices can be estimated from the Vermont NRCS EQIP Cost Tables (VT NRCS 2022). Table 14 shows the estimated costs per hectare to implement the practices.

Table 14. Estimated costs of conservation practices

Practice	Cost/ha	Area applied (ha)	Annual cost
No-till (CC)	$56.19	46	$2,574
No-till (3CC,3Hay)	$28.01*	45	$1,275
Cover crops (CC)	$171.84	49	$7,874
Cover crops (3CC, 3Hay)	$85.92*	46	$3,911
Change in rotation	$10.71	30	$317
			Total=$15,951

*Assume only half of acreage in any given year would be corn, planted with no-till and to cover crops

Implementing conservation practices to achieve an estimated P reduction of 291 kg/yr would cost approximately $15,951 per year. Total costs of implementing these practices over the life of a 20-year project would be approximately $319,020, without including the effects of inflation.

Table 15 presents P reduction costs for conservation practices on a dollar per kg P basis.

Table 15. Cost efficiency of agricultural conservation practices in reducing P loading

Practice	Area applied (ha)	Annual cost	P reduction (kg/yr)	Cost per kg P
CT–CC–MI (CC)	46	$2,574	139	$18
CT–CC–MI (3CC,3Hay)	45	$1,275	33	$39
Cover crops (CC)	49	$7,874	69	$114
Cover crops (3CC,3Hay)	46	$3,911	15	$260
Change in rotation	30	$317	35	$9
Totals	216	$15,951	291	Average=$55

*Assume only half of acreage in any given year would be corn, planted with no-till and to cover crops

Estimated costs of P loading reductions vary widely among practices and between different cropping systems. Implementing a system of conservation practices (no-till, cover crops, and manure injection) on continuous corn is predicted to be highly cost effective. Implementing a rotation of corn and hay on land currently in continuous corn production is even more so, but this does not account for any costs or offsets related to decreased corn production for the farm operation.

The estimated overall cost of reducing phosphorus loading using a suite of conservation practices on farmland in the Jewett Brook watershed is approximately $55 per kg of P.

10.2. Developed Lands Stormwater Practices

10.2.1. Subsurface Flow Wetland

A technical fact sheet developed by USEPA (2000) provides typical P loading rates and removal efficiencies for a hypothetical subsurface flow wetland. The subsurface wetland example had an inflow rate of 378,000 L per day. The total phosphorus concentration in the inflow was 4 mg/L, while the outflow contained 2 mg/L. Based on these values the total inflow of TP was 551 kg/yr. With a removal rate of 50%, the project removed 225 kg/yr of TP. This is only slightly lower than the 290 kg P/yr reduction for the proposed treatment train project.

The EPA factsheet also provides cost estimates for this hypothetical subsurface flow wetland, based on typical material and construction costs for the year 2000. The total cost, including maintenance, over 20 years was $530,000.

10.2.2. Stormwater Detention Basin

A publication by Weiss et al. (2005) provides estimates of stormwater practice costs and P removal efficiencies. One of the practices considered was a wet detention basin. The authors assumed a P removal rate of 52% for wet detention basins. Using their charts and data a wet detention basin with an annual P removal rate of 653 lbs/yr (290 kg/yr) would have a flow rate of 300,000 cu/ft. per year. A wet detention basin sized for this flow rate would cost over $407,000, including maintenance costs, but not land costs. This estimate is based on material and labor costs in 2005.

11. Conclusion

Based on the forgoing analyses, site assessments, and planning, we conclude that it should be technically feasible to develop a treatment train facility at the Dunsmore 2 site to remove phosphorus from Jewett Brook. We estimate a median P reduction of 286 kg per year should be achievable with such a facility. This P loading reduction estimate accounts for (is constrained by) four operating conditions, two of which are intended to minimize impacts of the facility on aquatic biota: water will be withdrawn only when the intake on Jewett Brook is backwatered by Lake Champlain and never at a rate exceeding the streamflow rate. Other resource concerns will be addressed through the siting and design of the facility, including shading to reduce thermal impacts, and upsizing the intake pipe and installing screens in the pump vault to reduce fish impingement and entrainment.

After careful consideration, we recommend the Dunsmore 2 site as the best choice for this project. We recommend further developing the alternate Dunsmore 2 facility plan, which is smaller and closer to a suitable intake location on Jewett Brook than earlier plans. This alternate facility would also be less expensive to construct.

While the proposed Jewett Brook treatment train facility appears technically feasible, it would not be inexpensive to construct and operate. The estimated cost is approximately $800 per kilogram of P removed. This cost is many times higher than agricultural conservation practices and many stormwater practices predicted to achieve similar reductions. Based on a straight cost comparison, we understand that the project could be judged as not viable. A counter argument is that reductions achievable though the treatment train facility would be certain, irreversible, and relatively easy to measure accurately.

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