Spatial and Temporal Patterns in Water Quality along Nine Tributaries of Lake Carmi during 2018

Prepared for the

Franklin Watershed Committee

by

Fritz Gerhardt, Ph.D.

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Beck Pond LLC

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Cover. *The beauty of Lake Carmi, as viewed from North Beach along Lake Road in Franklin, Vermont on 21 August 2015, belies the water quality problems that are harming the aesthetic and recreational enjoyment of the lake and its tributaries.*

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Acknowledgments

This project would not have been possible without the support and assistance of many individuals and organizations. Emily Porter-Goff (Franklin Watershed Committee) spearheaded the development of and obtained funding for this project and provided valuable insights into Lake Carmi and the water quality sampling program there. Staff and volunteers from the Franklin Watershed Committee collected all of the water samples, and an Analytical Services Partnership with the Vermont Department of Environmental Conservation enabled the water samples to be analyzed at the Vermont Agriculture and Environmental Laboratory. The Franklin Watershed Committee supported this project financially. The assistance and support of these individuals and organizations are greatly appreciated.

Executive Summary

1. Over the past two decades, there has been increasing concern about water quality conditions in Lake Carmi, especially the alarming increase in phosphorus levels and the more frequent occurrences of algal and cyanobacterial (blue-green algal) blooms. Since 2004, the Franklin Watershed Committee and Vermont Department of Environmental Conservation have assessed water quality conditions throughout the Lake Carmi watershed, including all of the major tributaries flowing into the lake, to identify and assess possible sources of water quality problems.
2. During 2018, staff and volunteers from the Franklin Watershed Committee collected water quality data on twelve dates at 19 sites along nine tributaries of Lake Carmi. Using these data, we analyzed spatial patterns in water quality conditions along these tributaries, compared these data and results with those obtained during 2008-2017, and developed recommendations for future monitoring and assessment efforts.
3. Total phosphorus concentrations were generally high to very high at many sites along these tributaries. In particular, total phosphorus concentrations were very high (mean >100 µg/l) at several sites along Marsh Brook and Sandy Bay Brook and moderately high (mean = 65-100 µg/l) at other sites along these two tributaries, Dicky's Brook, and Kane's Brook. In contrast, total phosphorus concentrations were low or moderate (mean <65 µg/l) along five other tributaries.
4. During 2008-2018, total phosphorus concentrations decreased significantly at four sites along three tributaries, including Sandy Bay Brook, Dicky's Brook (two sites), and Dewing Brook. In contrast, total phosphorus concentrations tended to increase at one site along Hammond Brook North.
5. Possible sources of the high phosphorus levels have previously been identified along several tributaries of Lake Carmi, including Dewing Brook, Marsh Brook, and Sandy Bay Brook. Restoration and protection projects have already been undertaken or are being planned along these tributaries. In addition, protection and restoration projects may be needed in shoreline areas that drain directly into the lake, as these areas represent some of the most highly developed lands in the basin but were not sampled as part of this study.
6. Collectively, these data increased our knowledge about water quality problems and their sources in the Lake Carmi watershed. Future monitoring efforts should include: 1) continued monitoring of total phosphorus along all major reaches and branches of these nine tributaries and 2) the addition of new sample sites in areas where water quality problems were identified but are not fully understood (e.g. Kane's Brook and Hammond Brook North). With these data, it will be easier to identify, develop, and evaluate the success of protection and restoration projects that most effectively reduce nutrient and sediment exports from these watersheds into Lake Carmi.

1.0 Introduction

Lake Carmi and its tributaries are highly-valued resources that support a wide array of recreational activities, economic benefits, and ecological functions to residents of and visitors to northern Vermont. Water bodies in the Lake Carmi watershed are used extensively for boating, swimming, fishing, hunting, nature-viewing, and other recreational activities. The floodplains and the many wetlands around the lake and its tributaries serve important flood control and water filtration functions. In addition, the surface waters and associated habitats support a number of rare plant and animal species and significant natural communities, which contribute greatly to regional biodiversity.

Over the past two decades, there has been increasing interest in protecting and improving water quality in Lake Carmi and its tributaries. This interest has been spurred by concerns that water quality in Lake Carmi has been deteriorating and is now threatened by excessively high nutrient levels, more frequent and widespread algal blooms, and accelerated eutrophication. This concern has been further exacerbated by the increasing occurrence of cyanobacterial (blue-green algal) blooms, especially during the past several years. Lake Carmi is listed as impaired and is the subject of a pollution control plan (Total Maximum Daily Load or TMDL) due to elevated phosphorus levels and algae blooms (State of Vermont 2008; Part D, State of Vermont 2018). Despite numerous efforts to improve water quality, the data collected over the past 25 years indicate that water quality conditions, including total phosphorus concentrations and chlorophyll-*a* levels, in Lake Carmi continue to deteriorate (Figure 1).

2.0 Study Goals

In order to assist efforts to protect and improve water quality in Lake Carmi, we analyzed the water quality data collected by the Franklin Watershed Committee from the tributaries of Lake Carmi in 2018. Previous studies had indicated that several of these tributaries exhibited very high phosphorus levels and were likely significant sources of the nutrients and sediment flowing into Lake Carmi (Howe et al. 2011, Stone Environmental 2011, Gerhardt 2015, Gerhardt 2018). In earlier studies, we analyzed and reported on the total phosphorus concentrations measured by the Franklin Watershed Committee (FWC) during 2008-2017 (Gerhardt 2015, 2018). In the present study, we analyze and report on the most recent year of water quality data to update and inform water quality management along these tributaries of Lake Carmi. Specifically, the goals of this study were threefold: 1) to identify spatial patterns in water quality conditions in these tributary watersheds, 2) to compare the water quality data collected during 2018 with those collected during 2008-2017, and 3) to provide recommendations for future water quality monitoring efforts and on-the-ground assessments of possible nutrient and sediment sources.

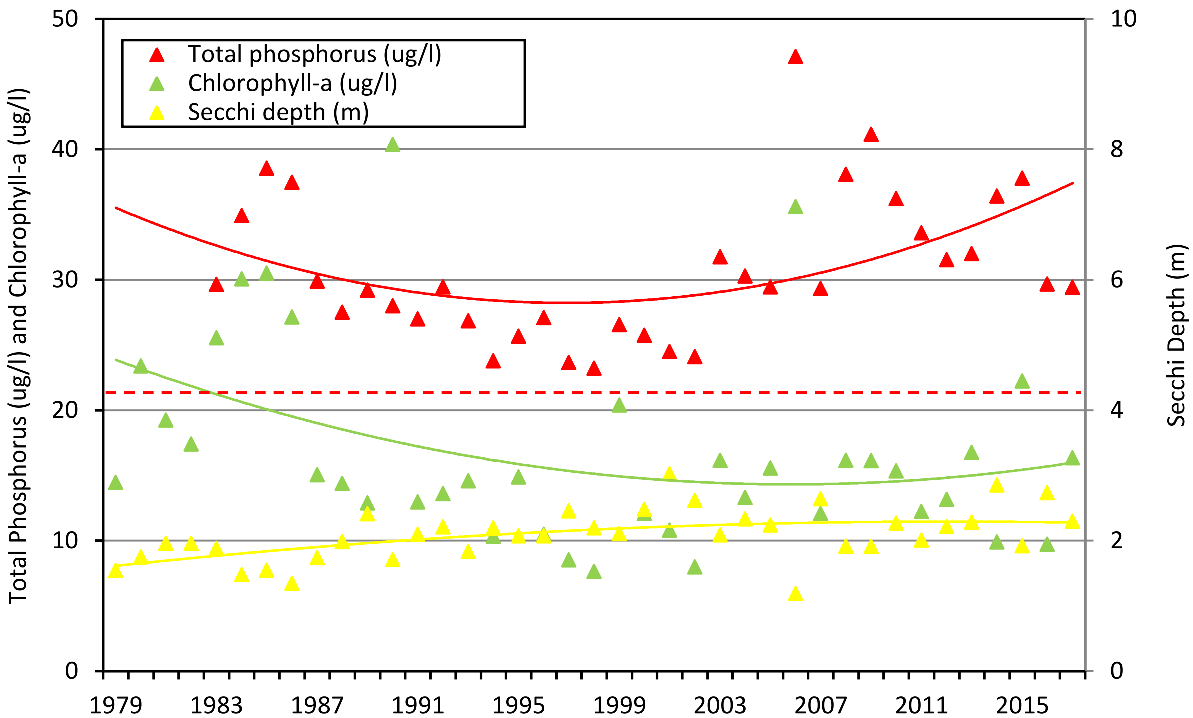

Figure 1. *Water quality conditions in Lake Carmi during 1979-2017. These data were collected through the Lay Monitoring Program coordinated by the Vermont Department of Environmental Conservation. The red dashed line indicates the maximum total phosphorus concentration targeted by the TMDL.*

3.0 Description of Watershed

Lake Carmi (Waterbody ID VT05-02L01) drains the upper watershed of the Pike River in the towns of Franklin and Berkshire in Franklin County, Vermont (Figure 2). Lake Carmi is the fourth largest natural lake in Vermont, covers an area of 567 ha (1,402 acres), averages 6.1 m (13 ft) in depth, and has a maximum depth of 10 m (33 ft). The watershed draining into the lake encompasses a gently rolling area of approximately 3,120 ha (7,710 acres) ranging in elevation from 133 m (436 ft) at the lake's surface to 276 m (905 ft) along the eastern edge of the watershed. The dominant bedrock types are fine-grained, calcium-rich phyllite, quartzite, and schist and igneous greenstone. Surficial geology is dominated by glacial till but areas of bedrock exposures and wetland deposits also occur. Soils are mostly fine sandy loams. Approximately 44% of the land in the Lake Carmi watershed is used for agriculture, and another 45% is forested or covered by wetlands. Approximately 300 camps line the shores of Lake Carmi, and Lake Carmi State Park offers camping facilities at the southern end of the lake. Lake Carmi is listed as impaired and has a completed and approved TMDL due to elevated phosphorus levels and algae blooms (State of Vermont 2008; Part D, State of Vermont 2016). In addition, the Pike River, including the entire Lake Carmi watershed, was identified as a Critical Source Area and an important source of phosphorus loading into Missisquoi Bay (Stone Environmental 2011). Lake

Carmi has also been altered by aquatic invasive species and is subject to an ongoing management plan, including mechanical harvesting, due to locally abundant Eurasian watermilfoil (*Myriophyllum spicatum*)(Part E, State of Vermont 2018).

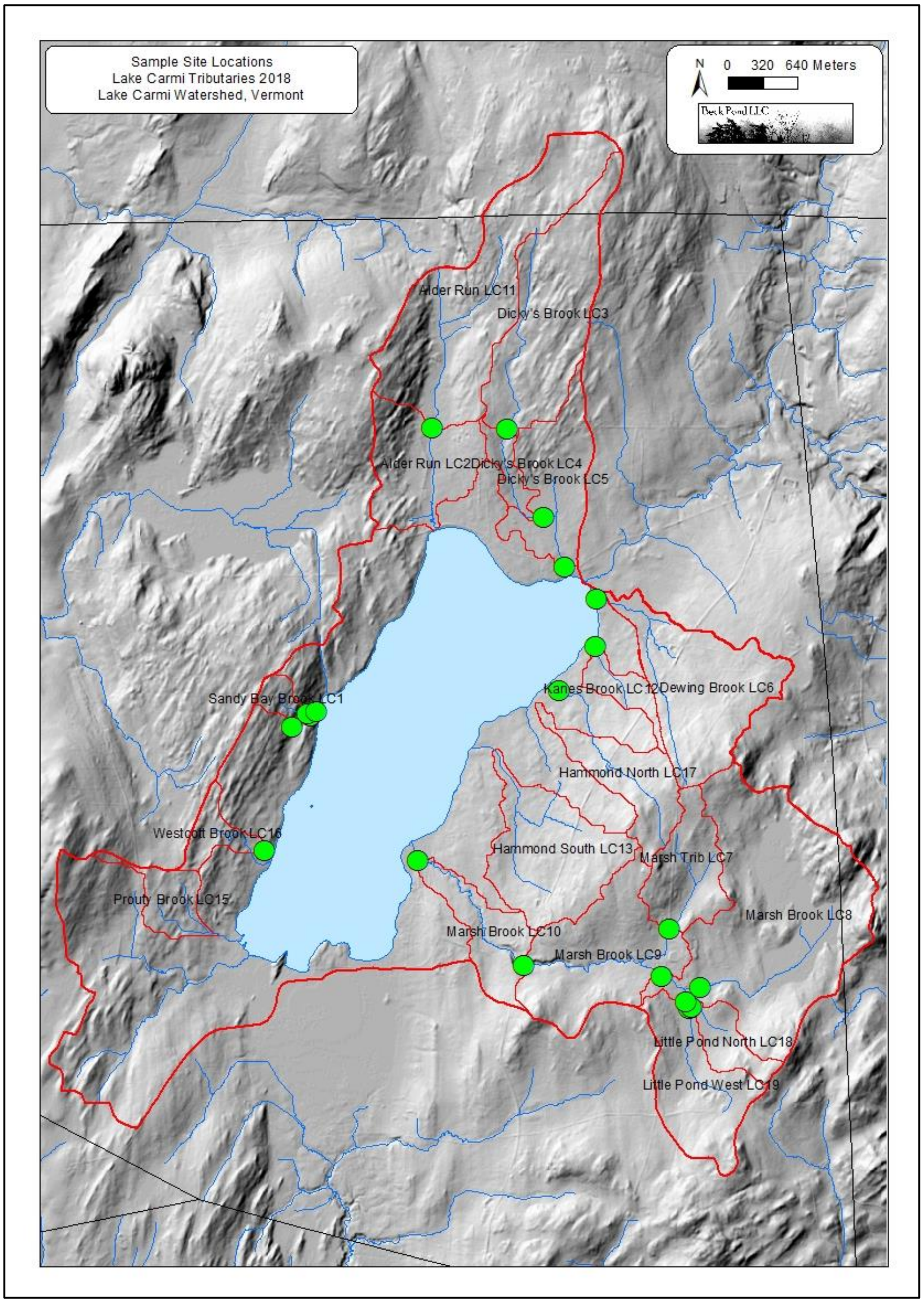

Figure 2. *Locations of 19 sites sampled by the Franklin Watershed Committee in the Lake Carmi watershed during 2018.*

4.0 Methods

During 2005-2018, the Franklin Watershed Committee collected water samples in order to assess three measures of water quality: total phosphorus, total nitrogen, and turbidity.

Total phosphorus measures the concentration of all forms of phosphorus in the water column, including dissolved phosphorus, phosphorus attached to suspended sediments, and phosphorus incorporated into organic matter. Phosphorus is typically the limiting nutrient and regulates the amount of aquatic life in northern freshwater ecosystems. Consequently, elevated phosphorus concentrations can lead to eutrophication, in which excessive algal and plant growth lead to oxygen depletion and increased mortality of aquatic life. In Vermont, most phosphorus originates from soil erosion, wastewater, and agricultural runoff.

Total nitrogen measures the concentration of all forms of nitrogen in the water column, including nitrogen gas (N_2), nitrite (NO_2), nitrate (NO_3), ammonia (NH_3), ammonium (NH_4), and particulate nitrogen (N). Although typically not the limiting nutrient in northern freshwater ecosystems, nitrogen is an essential plant nutrient, and high levels of nitrogen can impact both in-lake and in-stream water quality and can exacerbate algal blooms and eutrophication and lead to more frequent and more toxic cyanobacterial blooms. In Vermont, most nitrogen in surface waters originates from wastewater, stormwater, agricultural runoff, and atmospheric deposition.

Turbidity, which is measured in Nephelometric Turbidity Units (NTU), measures the light-scattering properties of all dissolved and suspended materials in the water column. Turbidity greatly affects the health of aquatic ecosystems, as more turbid waters allow less light to penetrate into the water column and transport more pollutants, nutrients, and sediment. In addition, sediment and other suspended materials can settle out of the water column and smother aquatic biota and their habitats. Much of the dissolved and suspended material in the water originates from stormwater and surface runoff associated with agriculture, forestry, urban and suburban development, and stream channel erosion. However, turbidity is also affected by natural biological and chemical processes and chemical pollutants.

In this study, we analyzed the water quality data collected during 2018 at 19 sites along nine tributaries of Lake Carmi. First, we downloaded the water quality data collected by the Franklin Watershed Committee from the State of Vermont's volunteer monitoring data portal (https://anrweb.vt.gov/DEC/DEC/VolunteerMonitoring.aspx). Second, we downloaded the relevant stream flow data from the U.S. Geological Survey (USGS) maintained stream gage located along the Pike River at East Franklin near Enosburg Falls, Vermont (USGS station 04294300). Once downloaded, all of the data were screened to identify any errors or outlying data points, and the quality assurance (QA) data were analyzed to verify that water samples were collected in a repeatable manner and with no contamination. We then calculated the median, mean, 25% and 75% quartiles, and range for each parameter for each sample site. We used the geographic coordinates to map all of the sample sites in a Geographic Information System (ArcGIS 10, ESRI, Redlands, California), and we used the USGS StreamStats program (https://water.usgs.gov/osw/streamstats/) to delineate the subwatersheds drained by each sample site. These shapefiles and summarized data allowed us to map the sample sites and associated subwatersheds according to their nutrient and sediment levels. We then compared these data summaries and maps with those created previously using the data collected during 2008-2017 (Gerhardt 2015, 2018). Finally, we developed recommendations for revising the sampling network, including identifying new sites that would better pinpoint and assess possible nutrient and sediment sources. We also developed preliminary recommendations for on-the-ground surveys to further investigate possible nutrient and sediment sources.

All data were compiled in Microsoft Excel (Microsoft Home and Office 2010, Microsoft, Redmond, Washington). All data and analyses were archived by the author, and electronic copies were provided to the Franklin Watershed Committee.

4.1 Statistical Analyses

To compare the water quality data collected during 2018 with those collected during 2008-2017, we used linear regressions to analyze changes in water quality conditions over time. A linear regression models the relationship between two numerical variables (in this study, the sample dates and total phosphorus concentrations) to determine whether or not there is a statistically-significant relationship. For each statistical test, a *P*-value less than the established level of significance (0.05) indicated that the linear relationship was statistically significant. A *P*-value greater than 0.05 indicated that the linear relationship was not statistically significant or that the available data were insufficient to detect a significant relationship. The latter was particularly relevant for this study, because phosphorus levels can be extremely variable, and this variability and the strong relationship between phosphorus levels and stream flows combined with small sample sizes often make it difficult to detect significant differences, even when there are relatively large changes in mean or median values.

5.0 Results and Discussion

5.1 Quality Assurance

All of the water quality data were collected in accordance with a Quality Assurance Project Plan (QAPP) developed in conjunction with the Vermont Department of Environmental Conservation (DEC). As part of this plan, FWC staff and volunteers collected one field blank and one field duplicate on most sample dates during 2018. Blank sample containers were rinsed and filled with de-ionized (DI) water only and, if done properly, should result in values below the detection limit for each parameter. Field duplicates required collecting a second sample at the same time and place as the original sample. When done properly, the values for the two pairs of samples should differ on average by less than the prescribed Relative Percent Difference (RPD).

In general, the quality assurance data collected by the Franklin Watershed Committee were more problematic than in previous years (quality assurance data are presented in Appendix A). The field blanks, which indicate possible contamination during sampling, were the most problematic. None of the seven field blanks for total nitrogen exceeded the detection limit (0.1 mg/l), and only one of the seven field blanks for turbidity slightly exceeded the detection limit (0.2 NTU). In contrast, three of the nine field blanks for total phosphorus exceeded the detection limit (5 μg/l). All three of these were relatively minor deviations (range = 7.12-10.2 μg/l), and all three occurred on the first three sample dates in 2018. Given the timing, it seems possible that the same container of DI water was used on all three dates and that the problems with the field blanks were caused by contaminated DI water, rather than improper sample collection and processing. It should also be noted that a number of other watershed groups in Vermont had similar problems with their field blanks in 2018.

The mean Relative Percent Differences between duplicate samples were also well below the prescribed differences for two of the three parameters [total phosphorus = 8% (prescribed difference <30%) and total nitrogen = 6% (prescribed difference <20%)]. Only one of the eight pairs of total phosphorus samples and one of the seven pairs of total nitrogen samples exceeded the prescribed differences. In contrast, the mean Relative Percent Difference between the duplicate turbidity samples exceeded the prescribed difference [turbidity = 30% (prescribed difference <15%)], and three of the four pairs of turbidity samples differed by >15% (range = 23-54%). The good results for total phosphorus and total nitrogen and the relatively poor results for turbidity parallel the results obtained by other water quality monitoring programs (e.g. White, Mad, and Missisquoi Rivers and Lake Memphremagog) and suggest some systemic cause not specific to this sampling program.

5.2 Stream Flow

Stream flow measures the volume of water passing a given location per unit of time and is calculated by multiplying the area of the stream cross-section by water velocity. Stream flow affects both water quality and the quality of aquatic and riparian habitats. For example, fast-moving streams are more turbulent and better aerated than slow-moving streams. High flows also dilute dissolved and suspended pollutants but, at the same time, typically carry more surface runoff and associated sediment and nutrients. Stream flow is extremely dynamic and changes frequently in response to changes in temperature, precipitation, and season.

To approximate stream flows at the sample sites examined in this study, we used the daily stream flows measured for the Pike River at East Franklin near Enosburg Falls, Vermont (USGS station 04294300). The 2018 sampling season was characterized by modestly high but prolonged peak spring flows throughout April and the first half of May (Figure 5). Subsequently, flows decreased steadily during May and were extremely low throughout the summer and fall (June - October) before rising again in early November following repeated rains. Unlike prior years, there were also two prolonged periods of high flows during the winter and no moderate or high flows during the summer, as often occurs following heavy rains and thunderstorms.

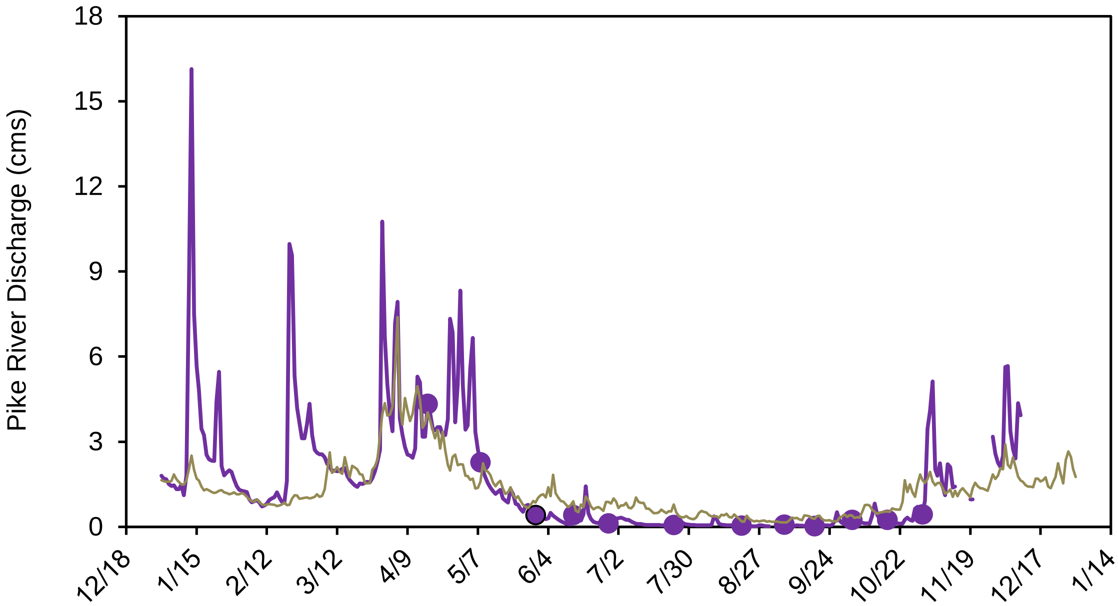

Figure 3. *Stream flows along the Pike River at East Franklin near Enosburg Falls, Vermont during 2018. Stream flows were measured by the U.S. Geological Survey (USGS station 04294300). The twelve dates on which water samples were collected are indicated by filled circles. The gray line indicates the median flows measured on each date during 2007-2018.*

The water quality sampling conducted by the Franklin Watershed Committee largely reflected the limited variation in and relatively low stream flows that occurred during the summer of 2018 (Figure 4). The twelve sample dates included two high-flows in the spring (16 April and 8 May), no moderate flows, and ten low flows during the remainder of the spring, summer, and fall. Thus, 83% of the water samples were collected at low flows, which are defined as those flows representing the least 25% of all flows; and 17% of the samples were collected during high flows, which represent the greatest 25% of all flows. Thus, the water quality sampling conducted by the Franklin Watershed Committee in 2018 was severely biased towards sampling low flows and against sampling moderate flows, which should represent the middle 50% of all flows. Collecting water samples across this limited range of stream flows likely diminished our ability to identify and assess water quality problems, especially those affected by stream flow. Low flows are most informative for identifying and assessing nutrient and sediment inputs originating from point and groundwater sources. In contrast, moderate and high flows, especially during rain events, are more informative for identifying and assessing nutrient and sediment inputs originating from surface runoff and other nonpoint sources, which typically generate the majority of the nutrient and sediment loads exported from these watersheds.

5.3 Overall Patterns of Water Quality

Water quality data were collected by the Franklin Watershed Committee at 19 sites along nine tributaries and the outlet of Lake Carmi during 2018 (Table 2, Figure 2). All but one of these 19 sites had been sampled prior to 2018. The 19 sites were sampled on 1-10 dates during 2018 (no sites were sampled on all twelve dates).

Table 2. Nineteen sites where water quality was sampled by the Franklin Watershed Committee in the Lake Carmi watershed during 2018. The names of many of the streams sampled are not official U.S. Geological Survey place names but rather are the names given by local residents and water quality samplers.

Location ID	Site Name	Site Code	# Dates Sampled	Years Sampled
501136	Alder Run at Middle Road	LC11	7	2009-2018
501141	Dewing Brook at Dewing Road	LC6	6	2008-2018
501140	Dicky's Brook at Lake Road	LC5	10	2008-2018
501138	Dicky's Brook at Middle Road	LC3	7	2008-2018
501139	Dicky's Brook at Rainville Field	LC4	2	2008-2018
505527	Hammond Brook North	LC17	5	2011-2018
502649	Kane's Brook	LC12	9	2010-2018
502651	Little Pond Road Culvert	LC14	6	2010-2018
501135	Marsh Brook at Lake Carmi State Park	LC10	9	2008-2018
501144	Marsh Brook at State Park Road	LC9	6	2008-2018
501142	Marsh Brook at Towle Neighborhood North	LC7	4	2008-2018
501143	Marsh Brook at Towle Neighborhood South	LC8	7	2008-2018
507911	Marsh Brook Drain Tile	LC20	5	2013-2018
-	Mill Pond Outlet (Pike River)	-	8	2018
501134	Sandy Bay Brook at Black Woods Road	LC1	8	2008-2018
510254	Sandy Bay Brook at Black Woods Road 2	LC21	2	2014-2018
510255	Sandy Bay Brook at Black Woods Road 3	LC22	4	2014-2018
515456	Sandy Bay Brook at Black Woods Road 4	LC23	1	2015, 2017-2018
502652	Westcott Brook	LC16	6	2010-2018

During 2018, total phosphorus concentrations at the 19 sites ranged between 10.9-840 µg/l. Total phosphorus concentrations differed dramatically among the different sites and different tributaries of Lake Carmi (Figure 5-6). Both median and mean total phosphorus concentrations were very high along Sandy Bay Brook and Marsh Brook; moderately high along Kane's Brook; and low to moderate along the remaining tributaries (Alder Run, Dewing Brook, Dicky's Brook, Hammond Brook North, Westcott Brook, and the Pike River).

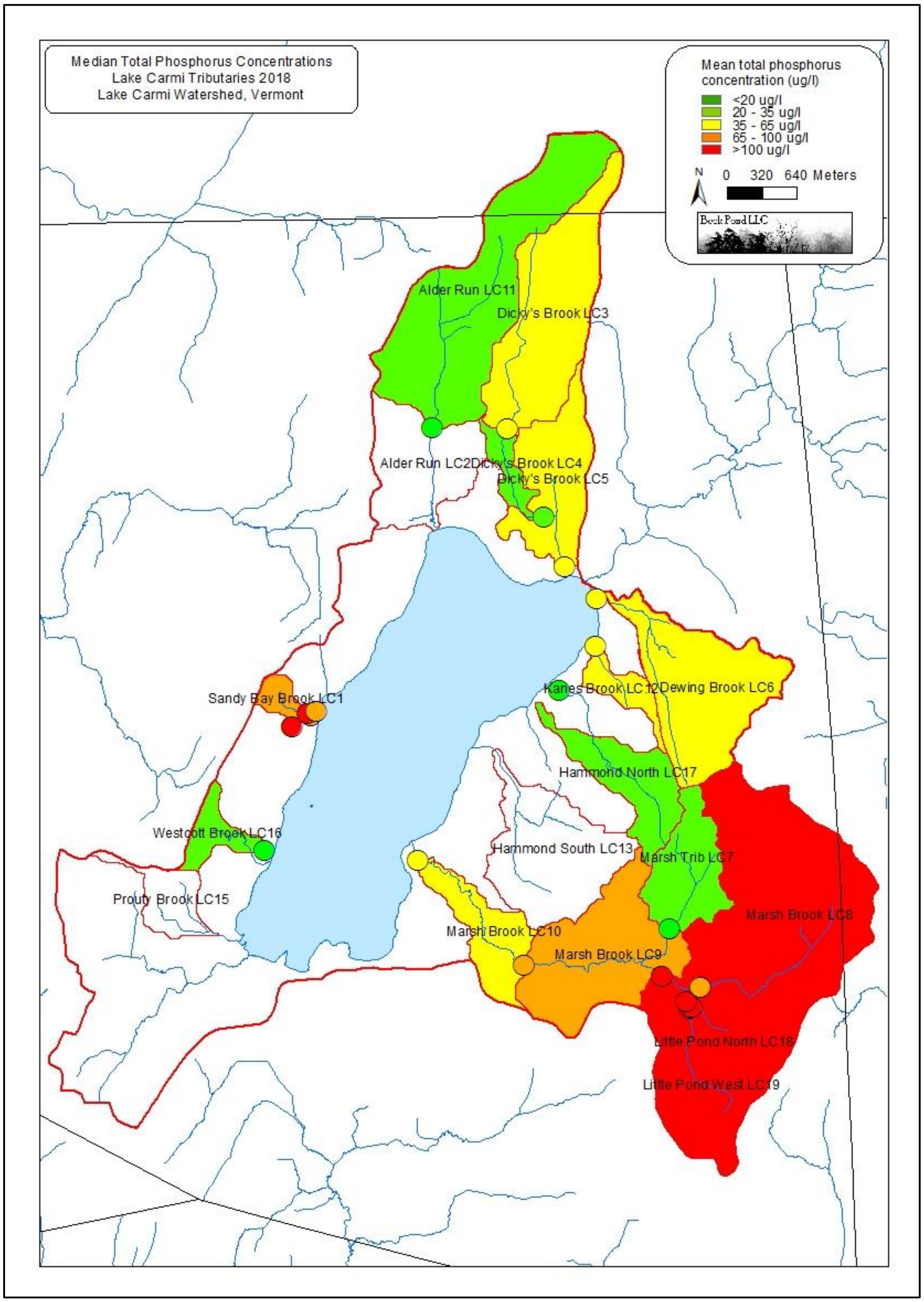

Figure 5. *Median total phosphorus concentrations at 19 sites along the tributaries of Lake Carmi during 2018. The sample site symbols and the subwatersheds drained by each sample site are color-coded according to the median total phosphorus concentrations measured at each site.*

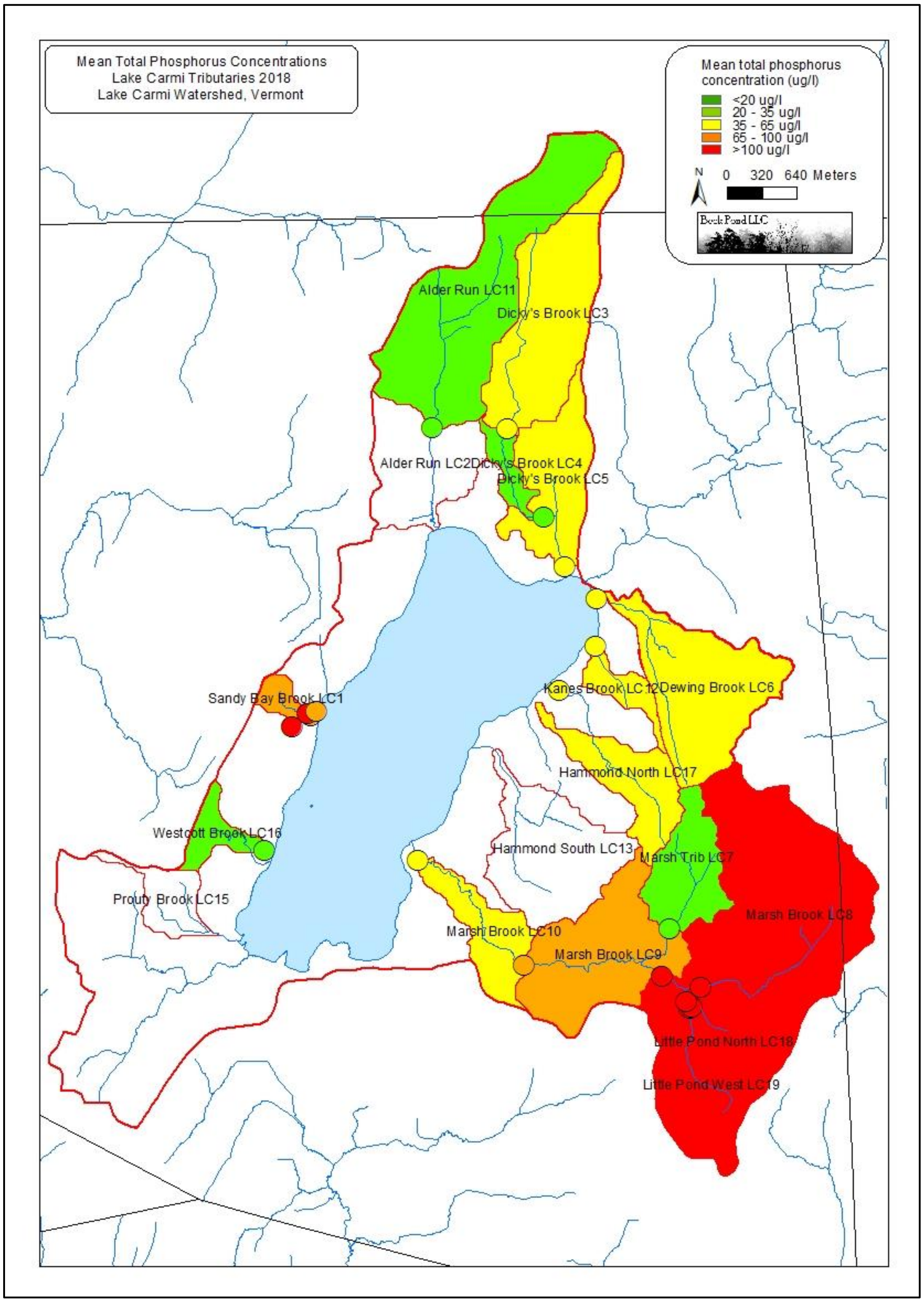

Figure 6. *Mean total phosphorus concentrations at 19 sites along the tributaries of Lake Carmi during 2018. The sample site symbols and the subwatersheds drained by each sample site are color-coded according to the mean total phosphorus concentrations measured at each site.*

In comparing these results (2018) to those obtained from the earlier data (2008-2017), it was clear that water quality has improved at some sites but not at other sites. However, across all sites, there appears to be a general improvement in both mean and median total phosphorus concentrations (Figure 7-8). The specific changes are described more fully in the sections describing the results for individual tributaries.

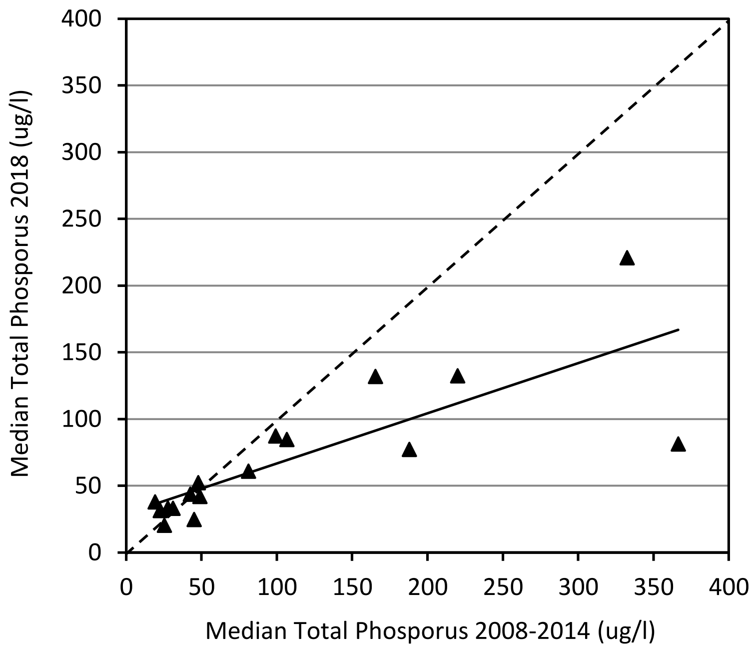

Figure 7. *Median total phosphorus concentrations during 2008-2014 and during 2018 at 17 sites along nine tributaries of Lake Carmi. The dashed line indicates the linear relationship that would exist if there were no change in median values, and the solid line indicates the actual linear relationship between the 2007-2014 and 2018 median values. Sites located in the lower right quadrant of the graph showed improvement; those in the upper left quadrant showed deterioration.*

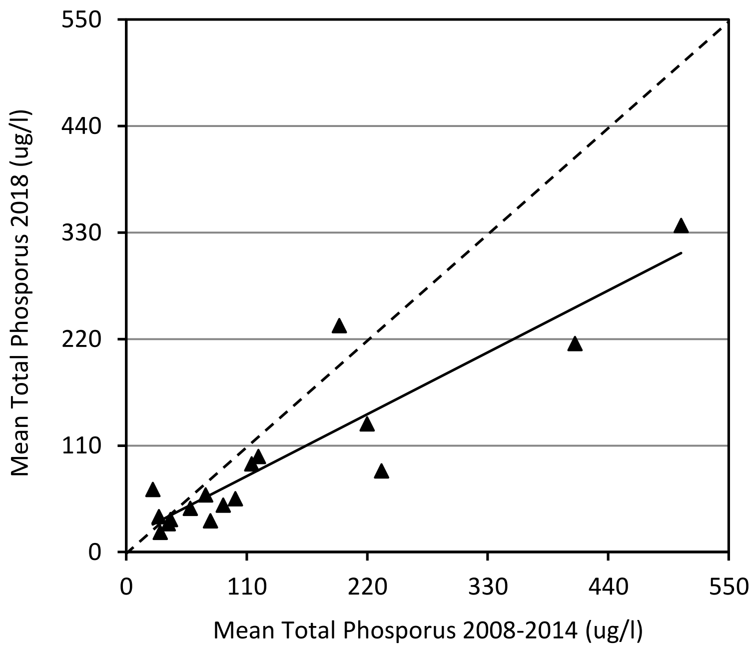

Figure 8. *Mean total phosphorus concentrations during 2008-2014 and during 2018 at 17 sites along nine tributaries of Lake Carmi. The dashed line indicates the linear relationship that would exist if there were no change in mean values, and the solid line indicates the actual linear relationship between the 2007-2014 and 2018 mean values. Sites located in the lower right quadrant of the graph showed improvement; those in the upper left quadrant showed deterioration.*

5.4 Water Quality along Select Tributaries

5.4.1 Sandy Bay Brook

The water quality data indicated that there continued to be serious water quality problems in Sandy Bay Brook. All four sites sampled during 2018 exhibited high to very high total phosphorus concentrations (Table 3, Figure 9). Although high in both branches of this tributary, total phosphorus concentrations were highest at the site (LC21) on the northern branch of Sandy Bay Brook (Figure 10). During 2008-2018, total phosphorus concentrations at the downstream-most site (LC1) decreased significantly (Figure 11; F=15.884, df=1,99, P<0.001). Thus, although total phosphorus concentrations remained high at all four sites, water quality conditions continue to show improvement along this tributary of Lake Carmi.

Table 3. Summary of total phosphorus concentrations at four sites along Sandy Bay Brook in the Lake Carmi watershed during 2018.

Site Name	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
Sandy Bay Brook at Black Woods Road	8	77.3	83.8	47.5-177
Sandy Bay Brook at Black Woods Road 2	2	132.4	132.4	60.8-204
Sandy Bay Brook at Black Woods Road 3	4	84.8	98.7	50.3-175
Sandy Bay Brook at Black Woods Road 4	1	138.0	138.0	138

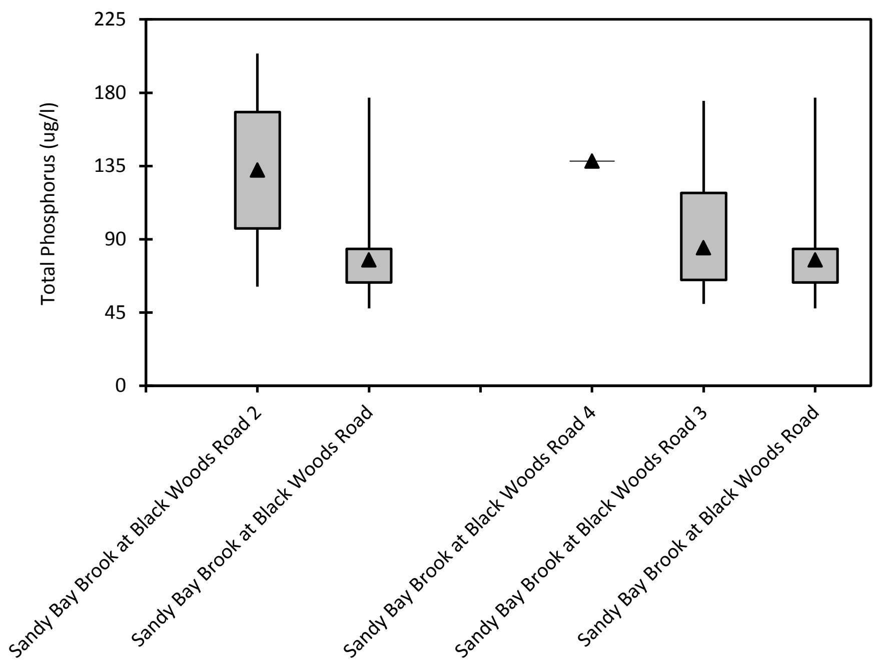

Figure 9. *Total phosphorus concentrations at four sites along the northern branch (left) and southern branch (right) of Sandy Bay Brook during 2018. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line). Note that the downstream-most site (Sandy Bay Brook at Black Woods Road) is included twice, once for each branch.*

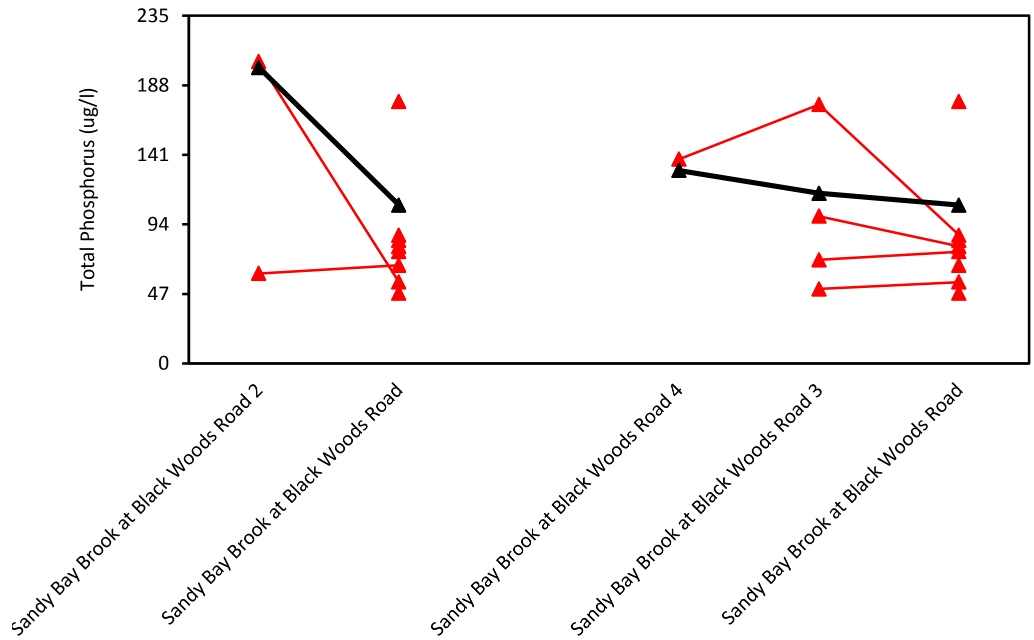

Figure 10. *Total phosphorus "profile" from upstream to downstream along the northern branch (Sandy Bay Brook at Black Woods Road 2) and southern branch (Sandy Bay Brook at Black Woods Road 3 and 4) of Sandy Bay Brook during 2018. The black line represents the median for each site during 2015-2018. Note that the downstream-most site (Sandy Bay Brook at Black Woods Road) is included twice, once for each branch of this tributary.*

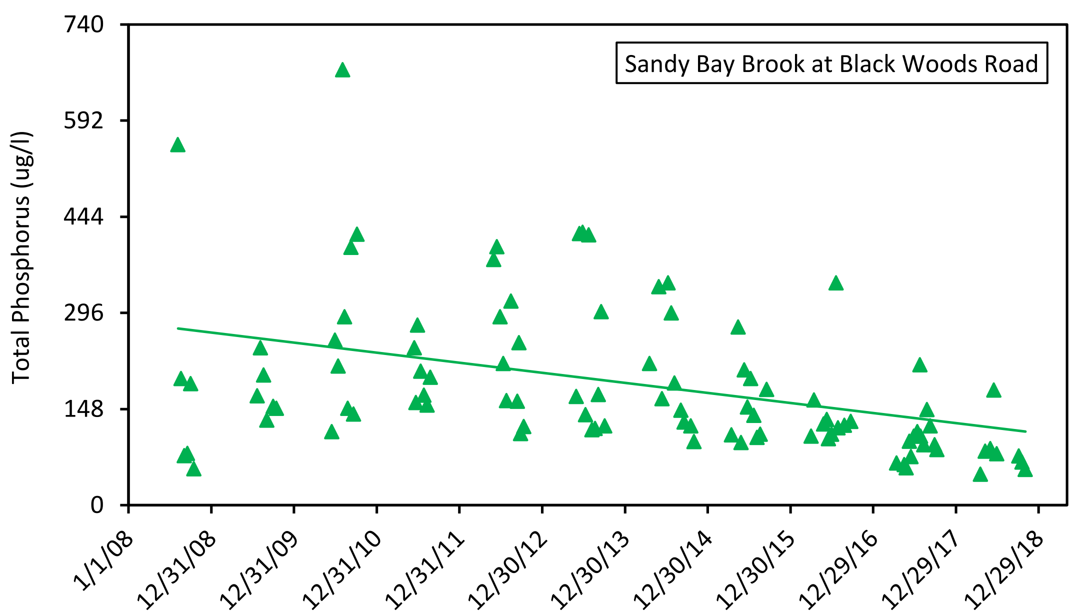

Figure 11. *Total phosphorus concentrations in relation to sample date at the downstream-most site (Sandy Bay Brook at Black Woods Road) during 2008-2018.*

5.4.2 Marsh Brook

The water quality data also indicated that there continued to be serious water quality problems in parts of the Marsh Brook watershed. Five of the six sites sampled during 2018 exhibited moderately high to very high total phosphorus concentrations, and this was especially true for two of the sites located in the upper watershed (Table 4, Figure 12). Furthermore, total phosphorus concentrations generally decreased from the upstream to downstream sites along the main stem of Marsh Brook (Figure 13). During 2008-2018, total phosphorus concentrations did not show statistically-significant changes at any of the sites along the main stem or tributaries of Marsh Brook. Thus, additional efforts need to be undertaken to improve water quality conditions in this largest tributary of Lake Carmi.

Table 4. Summary of total phosphorus concentrations at six sites along Marsh Brook in the Lake Carmi watershed during 2018.

Site Name	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
Marsh Brook at Lake Carmi State Park	9	60.9	55.1	25.2-86.1
Marsh Brook at State Park Road	6	87.5	91.2	23.2-171
Marsh Brook at Towle Neighborhood South	7	132.0	233.9	52.8-840
Marsh Brook at Towle Neighborhood North	4	24.7	32.3	17.4-62.5
Little Pond Road Culvert	6	221.0	215.6	55.2-371.2
Marsh Brook Drain Tile	5	81.4	337.4	64.5-745

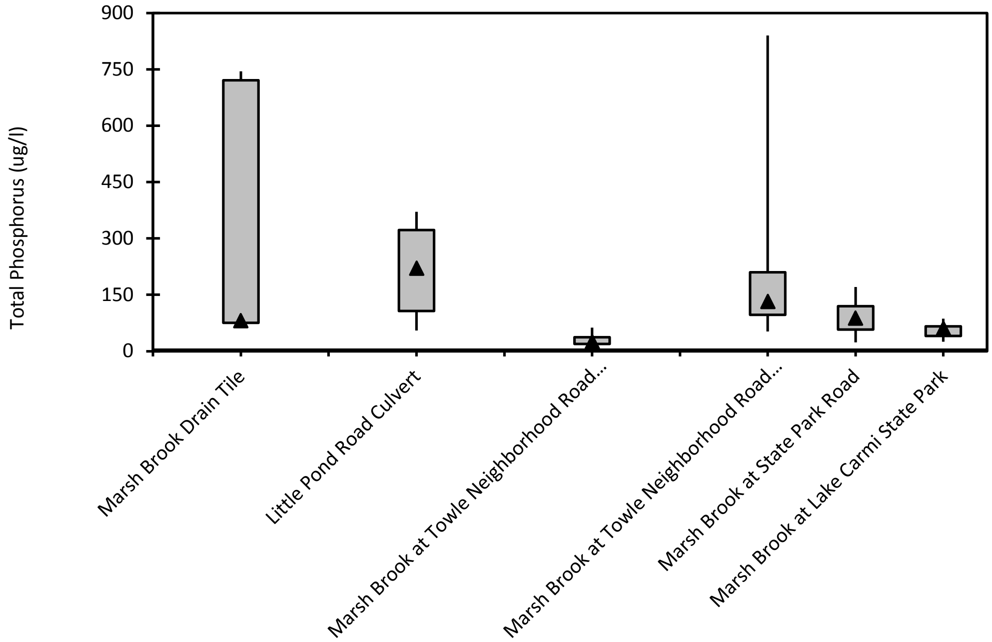

Figure 12. *Total phosphorus concentrations at six sites along Marsh Brook during 2018. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line).*

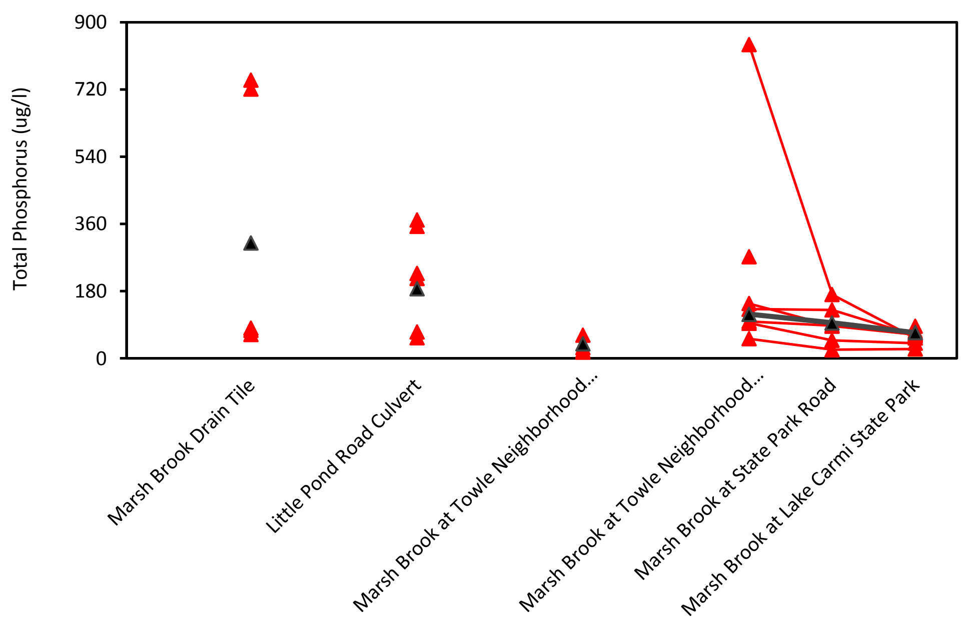

Figure 13. *Total phosphorus "profile" along the main stem and tributaries of Marsh Brook from Marsh Brook Drain Tile downstream to Marsh Brook at Lake Carmi State Park during 2018. The black line and triangles represent the median for each site during 2015-2018.*

5.4.3 Dicky's Brook

Compared to Sandy Bay Brook and Marsh Brook, water quality conditions were considerably better in Dicky's Brook. All three sites sampled during 2018 exhibited moderate total phosphorus concentrations, although they remained slightly higher at the downstream-most site (Table 5, Figure 15-16). During 2008-2018, total phosphorus concentrations decreased significantly at both the downstream-most site (Figure 17; F=19.819, df=1,107, P<0.001) and the upstream-most site (F=5.756, df=1,92, P=0.018). Thus, total phosphorus concentrations remained somewhat elevated but have improved considerably over the past few years in this tributary of Lake Carmi.

Table 5. Summary of total phosphorus concentrations at three sites along Dicky's Brook in the Lake Carmi watershed during 2018.

Site Name	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
Dicky's Brook at Lake Road	10	42.0	45.1	14.1-82.1
Dicky's Brook at Rainville Field	2	20.4	20.4	17.7-23.1
Dicky's Brook at Middle Road	7	37.9	64.7	12.5-232

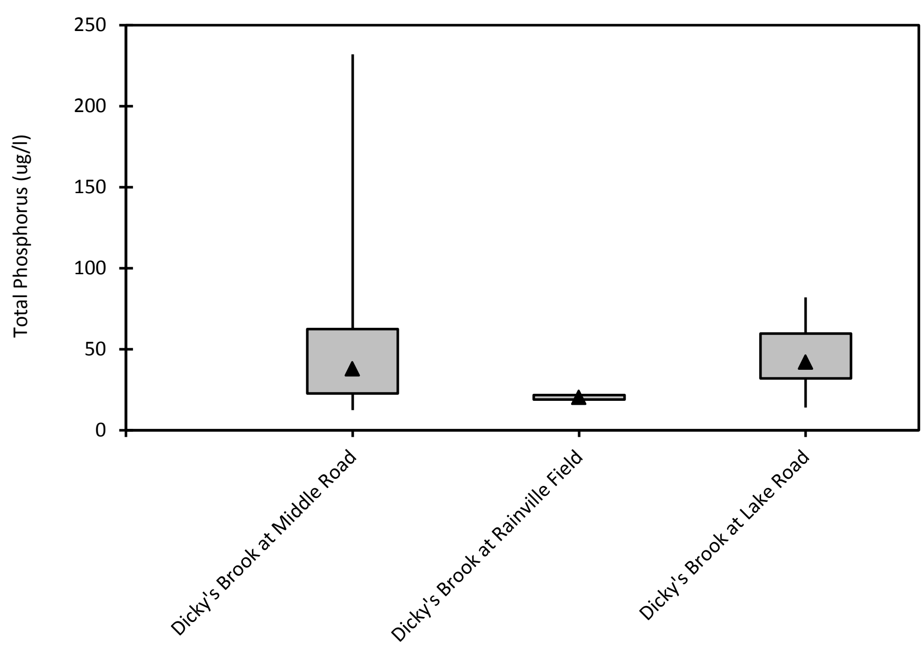

Figure 15. *Total phosphorus concentrations at three sites along Dicky's Brook during 2018. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line).*

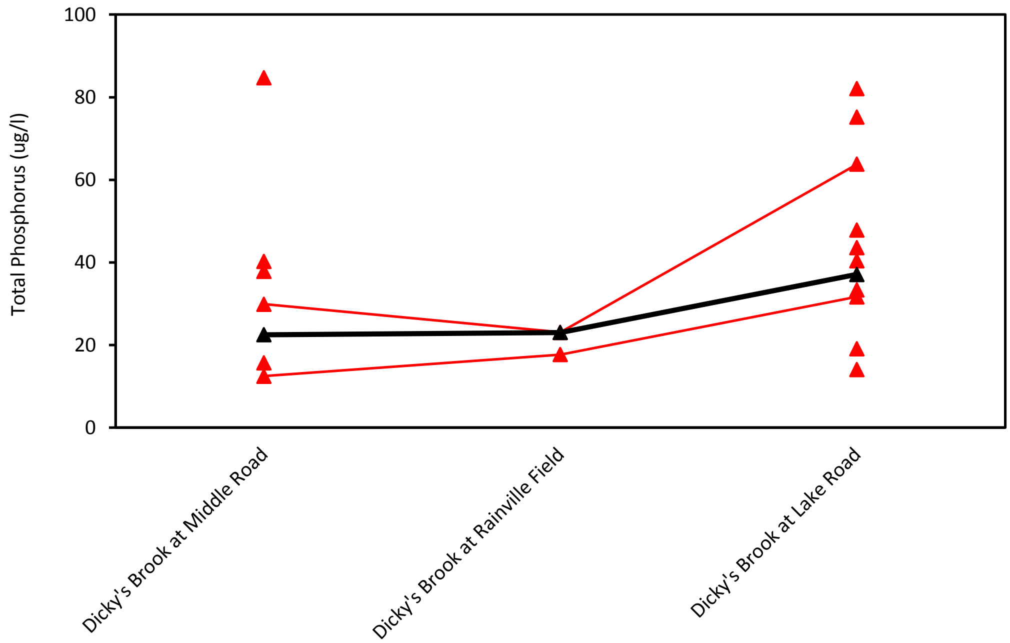

Figure 16. *Total phosphorus "profile" along Dicky's Brook from Dicky's Brook at Middle Road downstream to Dicky's Brook at Lake Road during 2018. The black line represents the median for each site during 2015-2018.*

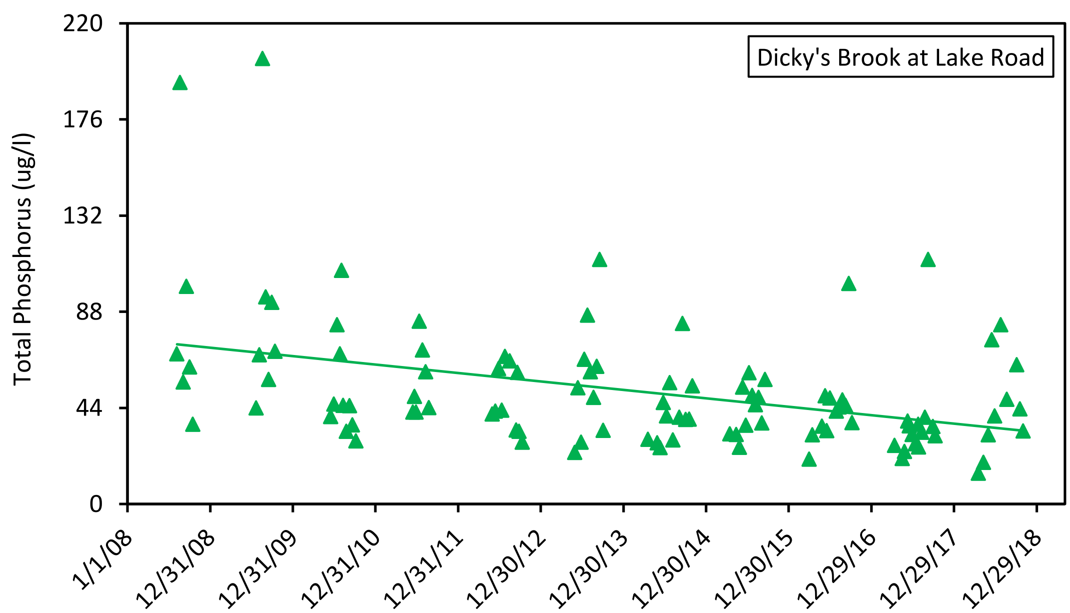

Figure 17. *Total phosphorus concentrations in relation to sample date at the downstream-most site on Dicky's Brook during 2008-2018.*

5.4.4 Other Tributaries

Total phosphorus concentrations were generally low to moderate in four other tributaries and were moderately high in one other tributary of Lake Carmi. Specifically, total phosphorus concentrations were moderately high in Kane's Brook; moderate in Dewing Brook; and moderately low in Alder Run, Hammond Brook North, and Westcott Brook (Table 6, Figure 18). During 2008-2018, total phosphorus concentrations changed significantly at one of these five sites: Total phosphorus concentrations decreased significantly at Dewing Brook (Figure 19; F=5.448, df=1,91, P=0.022). In addition, total phosphorus concentrations showed a marked but not statistically significant increase at Hammond Brook North (Figure 20; F=3.549, df=1,66, P=0.064).

Table 6. Summary of total phosphorus concentrations at five sites along five tributaries of Lake Carmi during 2018.

Site Name	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
Alder Run at Middle Road	7	33.5	29.5	13.4-46.2
Dewing Brook at Dewing Road	6	43.6	48.7	23.9-91.9
Hammond Brook North	5	31.5	36.7	17-57.4
Kane's Brook	9	52.4	59.0	30.9-144
Westcott Brook	6	33.1	33.6	10.9-66.1

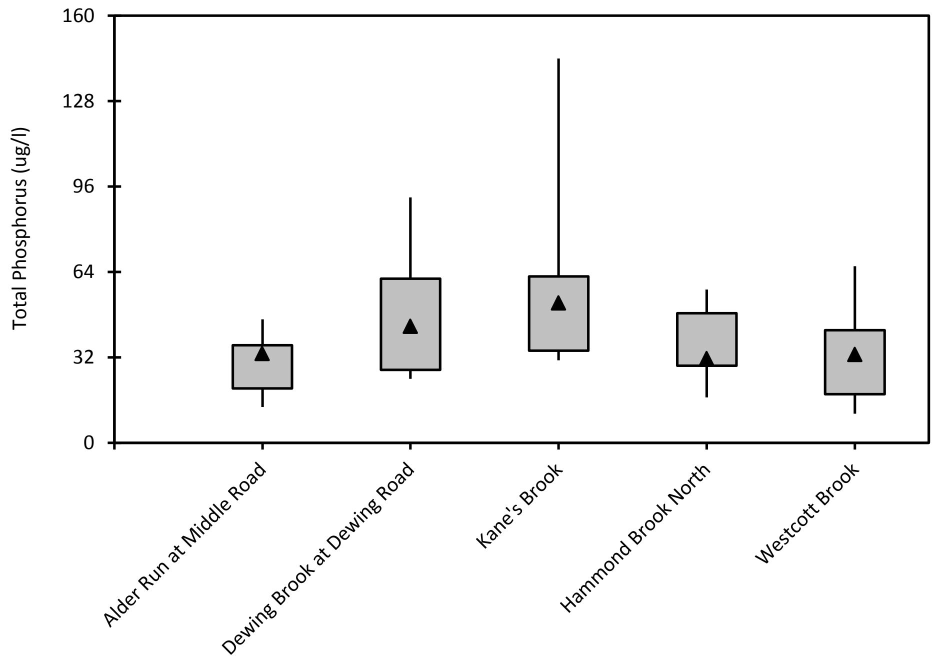

Figure 18. *Total phosphorus concentrations at five sites along five tributaries of Lake Carmi during 2018. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line).*

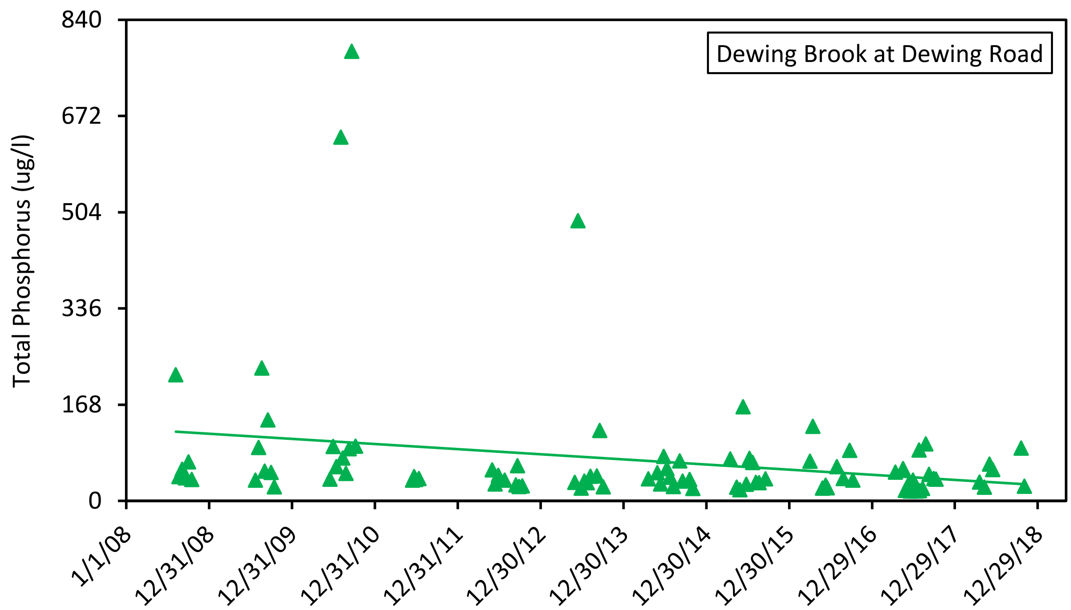

Figure 19. *Total phosphorus concentrations in relation to sample date at Dewing Brook at Dewing Road during 2008-2018.*

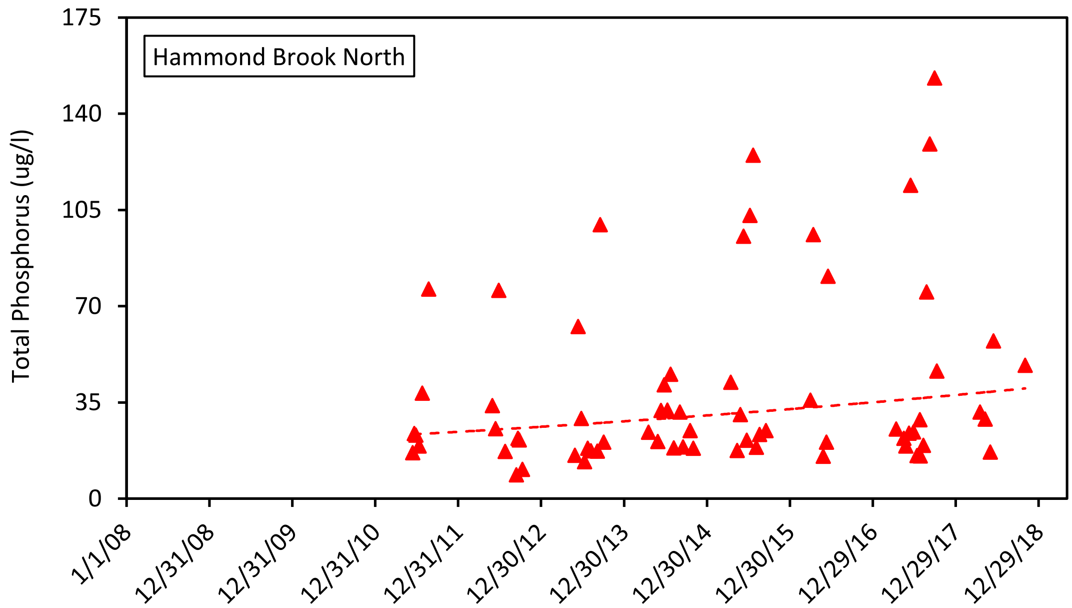

Figure 20. *Total phosphorus concentrations in relation to sample date at Hammond Brook North during 2010-2018.*

6.0 Recommendations

Many of the tributaries of Lake Carmi continued to exhibit moderately high to high phosphorus levels, and phosphorus levels and algal and cyanobacterial blooms remain problematic in Lake Carmi itself. Thus, we recommend continuing to monitor water quality conditions in the tributaries of Lake Carmi, and we make the following specific recommendations:

1. Retain most or all of the 19 sites sampled in the Lake Carmi watershed during 2018, as these sites provide an outstanding record of water quality conditions across this watershed over time (most of these sites have been sampled since 2010 or earlier).
2. If resources are lacking, the sites on Alder Run, the upstream one or two sites on Dicky's Brook, and/or Westcott Brook could be dropped, as these tributaries generally exhibited lower phosphorus levels than the other tributaries. In addition, the value of the new site at Mill Pond Outlet is not entirely clear, as it largely sampled the water flowing out of Lake Carmi, which would be better sampled in the lake itself.
3. Retaining the current sites and adding new sites might help to further pinpoint and assess possible nutrient and sediment sources along Marsh Brook and Sandy Bay Brook. Along Sandy Bay Brook, two sites could be added to sample the water flowing out of the two culverts under Riley Road. Along Marsh Brook, one site could be added further upstream from Little Pond Road to bracket possible nutrient and sediment sources

between a small farm and the wetlands below the farm, and another site could be added just upstream of the outflow from the Marsh Brook Drain Tile to separate the phosphorus flowing from the tile drain and that flowing from areas further upstream.

4. As water quality improvement projects and practices are completed, continued sampling of many of these same sites, especially along Sandy Bay Brook, Marsh Brook, and Dewing Brook, will be invaluable for evaluating the success of these and the need for additional projects and practices.
5. Given the moderately high phosphorus levels measured there, the site on Kane's Brook should continue to be monitored; and, given the trend towards increasing phosphorus levels measured there, the site on Hammond Brook North should continue to be monitored as well.

Based on the additional data collected during 2018, we were able to confirm that certain areas should continue to be targeted for on-the-ground investigations of possible nutrient and sediment sources. In particular, these areas included the watersheds of Sandy Bay Brook, Kane's Brook, and Hammond Brook North and much of the watershed of Marsh Brook, especially the upstream areas. A number of projects and practices have already been implemented in these areas, including improved field practices along Dewing Brook and excavation of a nutrient-laden swale along Sandy Bay Brook. In addition, a number of other projects and practices are being advanced along Marsh Brook, and we hope that the many agencies and organizations active in this watershed will continue to support these efforts. Finally, water quality improvement projects and practices may also be needed in the shoreline areas that drain directly into the lake. These areas represent some of the most highly developed lands in the basin but were not sampled by the sites analyzed in this study.

7.0 Conclusions

In this study, we updated our earlier analyses of the spatial and temporal patterns in water quality conditions along the tributaries of Lake Carmi. The goals of this effort were threefold: 1) to identify spatial patterns in water quality conditions in 2018 in these tributary watersheds, 2) to compare the water quality data collected during 2018 with those collected during 2008-2017, and 3) to provide recommendations for future water quality monitoring efforts and on-the-ground assessments of possible nutrient and sediment sources. To accomplish these goals, we analyzed the water quality data collected by the Franklin Watershed Committee at 19 sites along nine tributaries of Lake Carmi during 2018.

The water quality data collected during 2018 proved invaluable for updating our understanding of water quality conditions and for identifying and assessing possible sources of nutrients and sediment along these tributaries of Lake Carmi. In general, phosphorus levels were moderately high to very high at many sites throughout the Lake Carmi watershed. Total phosphorus concentrations remained very high but decreased significantly at the downstream-most site along Sandy Bay Brook but remained high at five of the six sites along Marsh Brook.

In addition, total phosphorus concentrations were moderately high along Kane's Brook and were moderate but tending to increase along Hammond Brook North. Total phosphorus concentrations also remained moderately high but decreased significantly at two sites along Dicky's Brook. Finally, total phosphorus concentrations were moderately low along four other tributaries of Lake Carmi, including Dewing Brook, where they decreased significantly during 2008-2018. Thus, the results of these analyses generally paralleled those reported in earlier studies that found that phosphorus concentrations and loadings were highest in many of these same tributaries (Howe et al. 2011, Stone Environmental 2011, Gerhardt 2015, Gerhardt 2018).

Based on these analyses, we recommend that staff from the appropriate agencies and organizations (e.g. Vermont Agency of Agriculture, Food & Markets; Vermont DEC; USDA Natural Resources Conservation Service; and Franklin County Natural Resources Conservation District) conduct on-the-ground assessments to further investigate possible nutrient and sediment sources and to identify, develop, implement, and evaluate projects and practices that most effectively protect and improve water quality in these tributaries of Lake Carmi. Possible projects and practices include green water infrastructure, road stormwater projects, nutrient management plans, cover cropping, no-till cropping, increased cropping setbacks on saturated or frequently-flooded fields, livestock exclusion fencing, filter strips and/or riparian buffer plantings, gully stabilization, treatment of tile drainage effluent, wetlands protection and restoration, and river corridor protection projects.

8.0 Bibliography

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Appendix A. Quality assurance data, including field blanks and field duplicates, collected at 19 sites along nine tributaries of Lake Carmi during 2018. Bold values indicate field blanks that exceeded detection limits (0.1 mg/l for total nitrogen, 5 µg/l for total phosphorus, and 0.2 NTU for turbidity) or field duplicates that differed by >20% for total nitrogen, >30% for total phosphorus, and >15% for turbidity.

Field Blanks

Site	**Date**	**Total Nitrogen (mg/l)**	**Total Phosphorus (µg/l)**	**Turbidity (NTU)**
Marsh Brook at Lake Carmi State Park	4/16/2018	-	**9.14**	<0.2
Marsh Brook at Lake Carmi State Park	5/8/2018	<0.1	**7.12**	<0.2
Marsh Brook at Lake Carmi State Park	5/30/2018	<0.1	**10.2**	<0.2
Marsh Brook at Lake Carmi State Park	6/14/2018	<0.1	<5	-
Marsh Brook at Lake Carmi State Park	6/27/2018	-	<5	<0.2
Marsh Brook at Lake Carmi State Park	8/20/2018	<0.1	<5	<0.2
Sandy Bay Brook at Black Woods Road	10/3/2018	<0.1	<5	-
Sandy Bay Brook at Black Woods Road 2	10/17/2018	<0.1	<5	**0.31**
Hammond Brook North	10/31/2018	<0.1	<5	<0.2

Field Duplicates: Total Nitrogen

Site	**Date**	**1st Total Nitrogen (mg/l)**	**2nd Total Nitrogen (mg/l)**	**Relative % Difference**
Marsh Brook at Lake Carmi State Park	5/8/18	1.00	0.95	5
Marsh Brook at Lake Carmi State Park	5/30/18	1.00	0.93	7
Marsh Brook at Lake Carmi State Park	6/14/18	0.73	0.76	4
Marsh Brook at Lake Carmi State Park	8/20/18	0.53	0.51	4
Sandy Bay Brook at Black Woods Road	10/3/18	0.56	0.56	0
Sandy Bay Brook at Black Woods Rd 2	**10/17/18**	**0.49**	**0.60**	**20**
Hammond Brook North	10/31/18	0.55	0.54	2
Mean				**6**

Field Duplicates: Total Phosphorus

Site	**Date**	**1st Total Phosphorus (µg/l)**	**2nd Total Phosphorus (µg/l)**	**Relative % Difference**
Marsh Brook at Lake Carmi State Park	4/16/18	26.5	25.9	2
Marsh Brook at Lake Carmi State Park	5/8/18	70	72.9	4
Marsh Brook at Lake Carmi State Park	5/30/18	66.7	65.9	1
Marsh Brook at Lake Carmi State Park	6/14/18	83.6	86.1	3
Marsh Brook at Lake Carmi State Park	8/20/18	54.6	54.7	0
Sandy Bay Brook at Black Woods Road	10/3/18	75.5	73.3	3
Sandy Bay Brook at Black Woods Road 2	10/17/18	63	60.8	4
Hammond Brook North	**10/31/18**	**29.8**	**48.5**	**48**
Mean				**8**

Field Duplicates: Turbidity

Site	**Date**	**1st Turbidity (NTU)**	**2nd Turbidity (NTU)**	**Relative % Difference**
Marsh Brook at Lake Carmi State Park	4/16/18	1.45	1.67	14
Marsh Brook at Lake Carmi State Park	**5/8/18**	**2.44**	**4.24**	**54**
Marsh Brook at Lake Carmi State Park	**5/30/18**	**0.46**	**0.58**	**23**
Marsh Brook at Lake Carmi State Park	**8/20/18**	**4.67**	**3.49**	**29**
Mean				**30**

Beck Pond LLC

394 Beck Pond Road

Newark, VT 05871

beckpond@gmail.com