Spatial Patterns in Water Quality along Nine Tributaries of Lake Carmi during 2015-2017

Prepared for the

Franklin Watershed Committee

and

Vermont Department of Environmental Conservation

by

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Cover. *The beauty of the Lake Carmi watershed, as viewed from North Sheldon Road in Franklin, Vermont on 31 March 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. Neil Kamman (Vermont Department of Environmental Conservation) spearheaded the development of, obtained funding for, and provided valuable advice throughout this project. Ben Copans (Vermont Department of Environmental Conservation) provided valuable advice throughout this project, created the flow duration curve template, and helped administer this project. Perry Thomas (Vermont Department of Environmental Conservation) facilitated the allocation of additional funds to expand the scope of the analyses presented in this report. Emily Porter-Goff (Franklin Watershed Committee) and Karen Bates (Vermont Department of Environmental Conservation) provided valuable insights into Lake Carmi and the water quality sampling program there. Kristen Underwood (South Mountain Research & Consulting) created the template that was used to guide the presentation in this report. David Pasco (Vermont Department of Environmental Conservation) administered this project. The Vermont Agency of Natural Resources supported this project financially (contract #33072). The assistance and support of all 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 total phosphorus concentrations and 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 2015-2017, staff and volunteers from the Franklin Watershed Committee continued to collect water quality data 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 earlier years, 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) along Marsh Brook and Sandy Bay Brook and moderately high (mean 65-100 µg/l) along Kane's Brook. In contrast, total phosphorus concentrations were low or moderate (mean <65 µg/l) along six other tributaries.
4. During 2008-2017, total phosphorus concentrations decreased significantly at four sites along four tributaries, including Marsh Brook, Sandy Bay Brook, Dicky's Brook, and Dewing Brook. In contrast, total phosphorus concentrations increased significantly 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 are already underway or are being planned along many of 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 greatly 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 tributaries; 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); and 3) monitoring of total nitrogen, especially in areas where water quality problems may have agricultural sources. With these data, it will be easier to identify, develop, and evaluate the success of protection and restoration projects that most effectively reduce phosphorus 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 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 (Part D, State of Vermont 2016). The Environmental Protection Agency (EPA) approved a TMDL for phosphorus for Lake Carmi in 2009 (State of Vermont 2008). 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 during 2015-2017. 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). In an earlier study, we analyzed and reported on the total phosphorus concentrations measured by the Franklin Watershed Committee (FWC) during 2008-2014 (Gerhardt 2015). In the present study, we analyze and report on the three most recent years 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 2015-2017 with those collected during 2008-2014, and 3) to provide recommendations for future water quality monitoring efforts and on-the-ground assessments of possible nutrient and sediment sources.

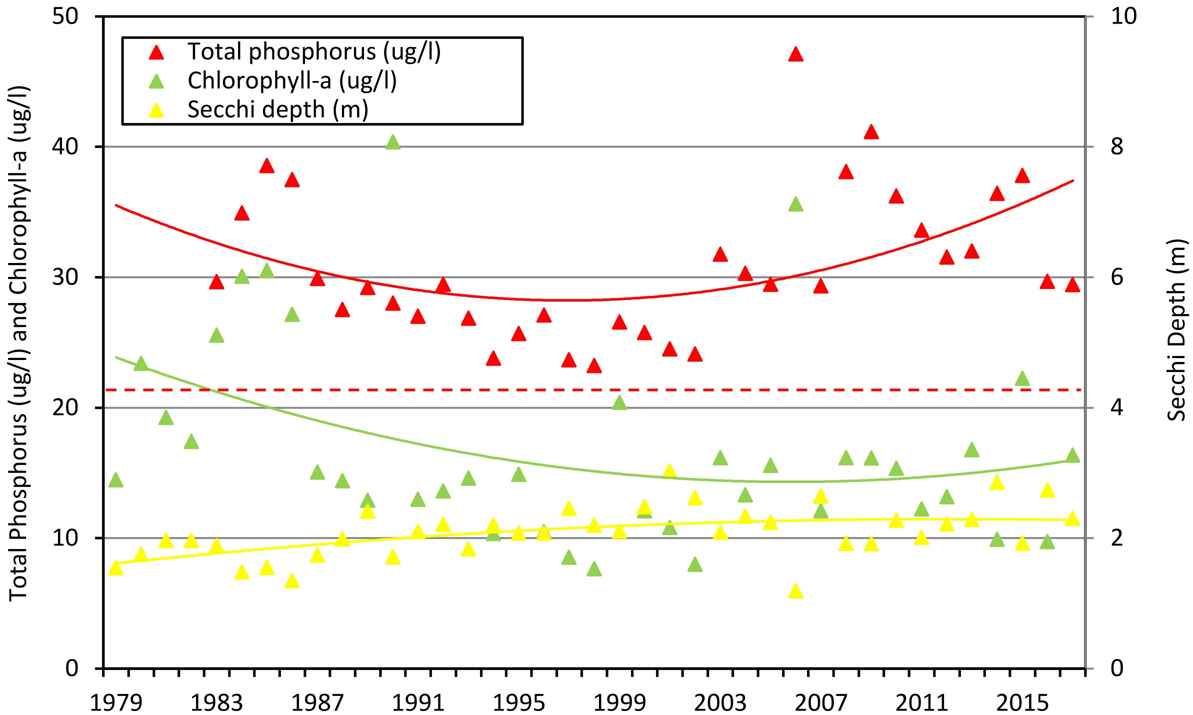

Figure 1. *Water quality conditions in Lake Carmi during 1979-2017. These data were collected through the Lay Monitoring Program administered by the Vermont Department of Environmental Conservation. The red dashed line indicates the maximum total phosphorus concentration targeted by the TMDL.*

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 shorelines 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 (Part D, State of Vermont 2016). 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).

4.0 Methods

During 2015-2017, the Franklin Watershed Committee continued to collect water samples for assessing two measures of water quality: total phosphorus 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, manure, and synthetic fertilizers.

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 sediments. 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 column 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.

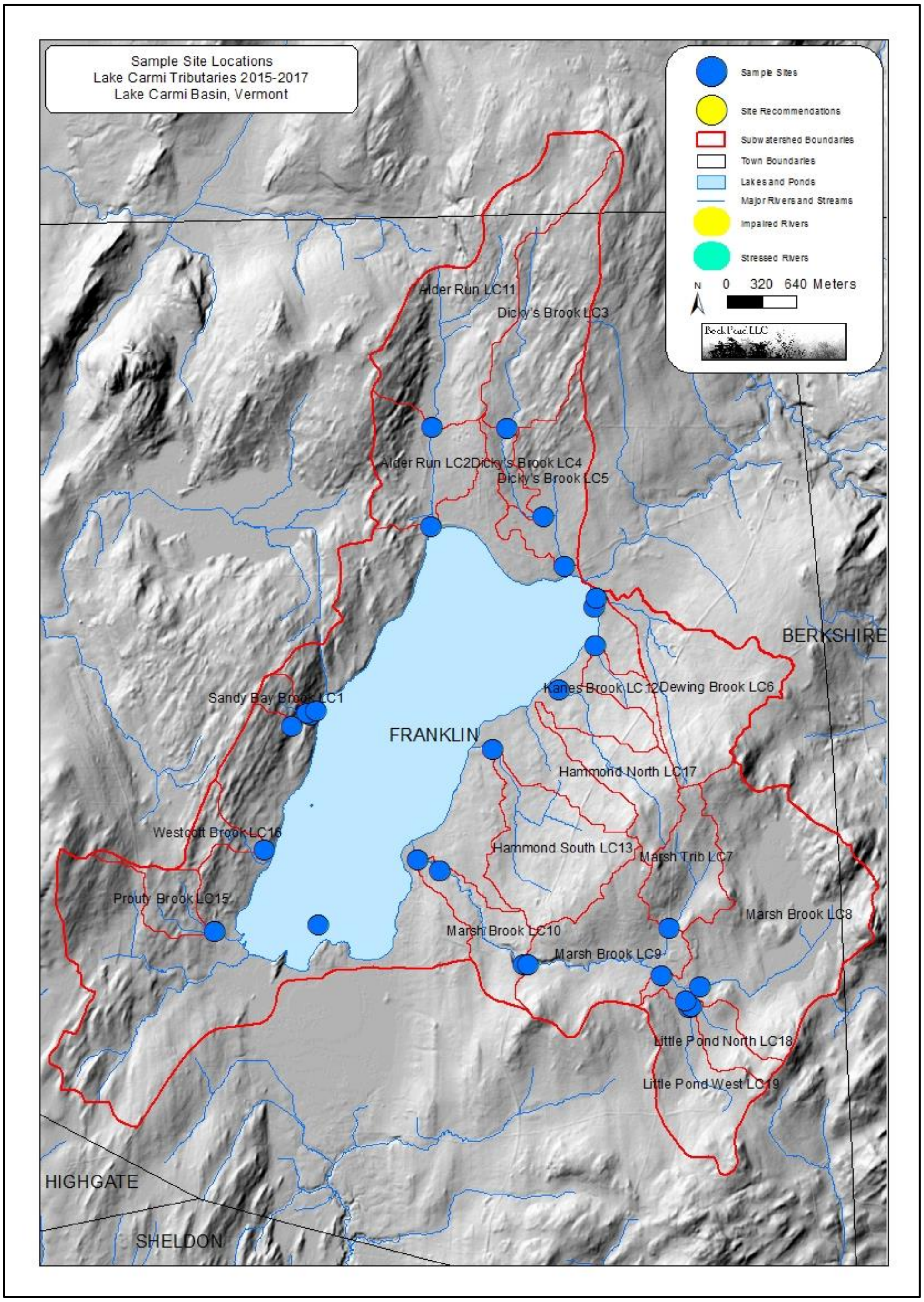

Figure 2. *Locations of 19 sites sampled by the Franklin Watershed Committee in the Lake Carmi watershed during 2015-2017.*

In this study, we analyzed the water quality data collected during 2015-2017 at 19 sites along nine tributaries of Lake Carmi. First, we downloaded all of 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 of the two parameters 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 2008-2014 (Gerhardt 2015). 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), and GIS shapefiles mapping the sample sites and subwatershed boundaries were created and maintained in ArcGIS 10. All data and analyses were archived by the author, and electronic copies were provided to the Franklin Watershed Committee and Vermont Department of Environmental Conservation.

4.1 Statistical Analyses

To compare the water quality data collected during 2015-2017 with those collected during 2008-2014, 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 difference. 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 Quality Assurance Project Plans (QAPP) developed in conjunction with the Vermont DEC. As part of these plans, FWC staff and volunteers collected one field blank and one field duplicate on each sample date during 2015-2017. Blank sample containers were rinsed and filled with distilled 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 indicated that their water quality sampling program was meeting the quality assurance standards for both parameters (quality assurance data are presented in Appendix A). None of the 34 field blanks for total phosphorus exceeded the detection limit (5 µg/l), and only two of the 18 field blanks for turbidity slightly exceeded the detection limit (0.2 NTU). Thus, the field blanks indicated that the water samples were generally not being contaminated during collection and processing.

The mean Relative Percent Differences between duplicate samples were also well below the prescribed differences for one of the two parameters [total phosphorus = 3% (prescribed difference <30%), and none of the 36 pairs of total phosphorus samples exceeded the prescribed difference. In contrast, the mean Relative Percent Difference between the duplicate turbidity samples exceeded the prescribed difference [turbidity = 23% (prescribed difference <15%)], and nine of the 19 pairs of turbidity samples differed by >15% (range = 16-79%). The good results for total phosphorus 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. Nevertheless, at least for total phosphorus, the field duplicates indicated that the water samples were being collected in a repeatable manner.

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). As is typical in northern New England, stream flows generally peaked for extended periods of time following snowmelt in the spring (March-April), were generally low throughout the summer (June-September), and rose again during late autumn (October-November)(Figure 3). However, extremely high flows also occurred for shorter periods of time following heavy rains throughout the year, especially during the summers of 2015 and 2017.

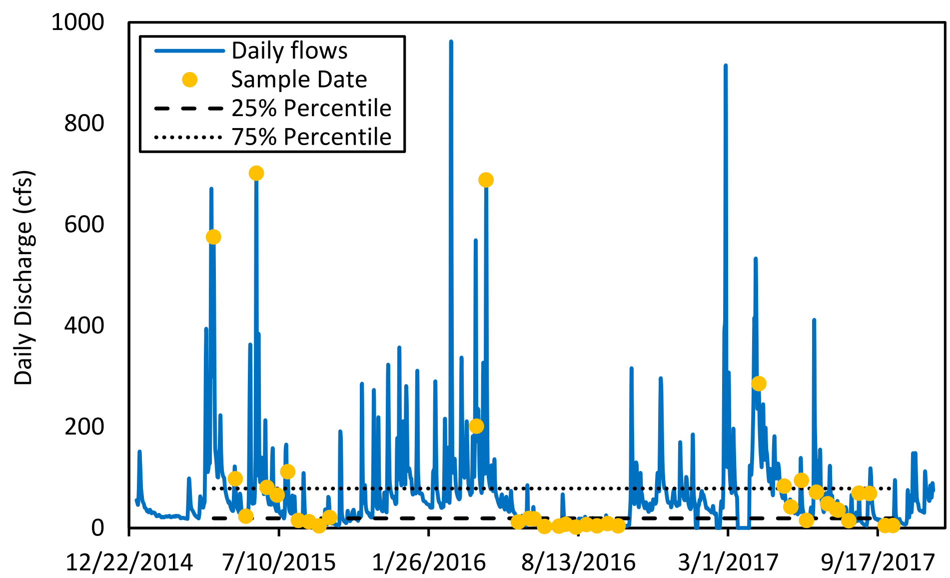

Figure 3. *Stream flows along the Pike River at East Franklin near Enosburg Falls, Vermont during 2015-2017. Stream flows were measured by the U.S. Geological Survey (USGS station 04294300). The 38 dates on which water samples were collected are indicated by orange circles.*

The water quality sampling conducted by the Franklin Watershed Committee largely reflected the limited variation in and relatively low stream flows that typically occur during the summer when most of the sampling occurred (Figure 4). Nevertheless, they did sample moderate and high flows in all three years. Approximately 47% of the water samples were collected at low flows, which are defined as those flows representing the least 25% of all flows; 26% of samples were collected at moderate flows, which represent the middle 50% of all stream flows; and 26% of the samples were collected during high flows, which represent the greatest 25% of all flows (Table 1). Thus, the water quality sampling conducted by the Franklin Watershed Committee was biased towards sampling low flows and against sampling moderate flows.

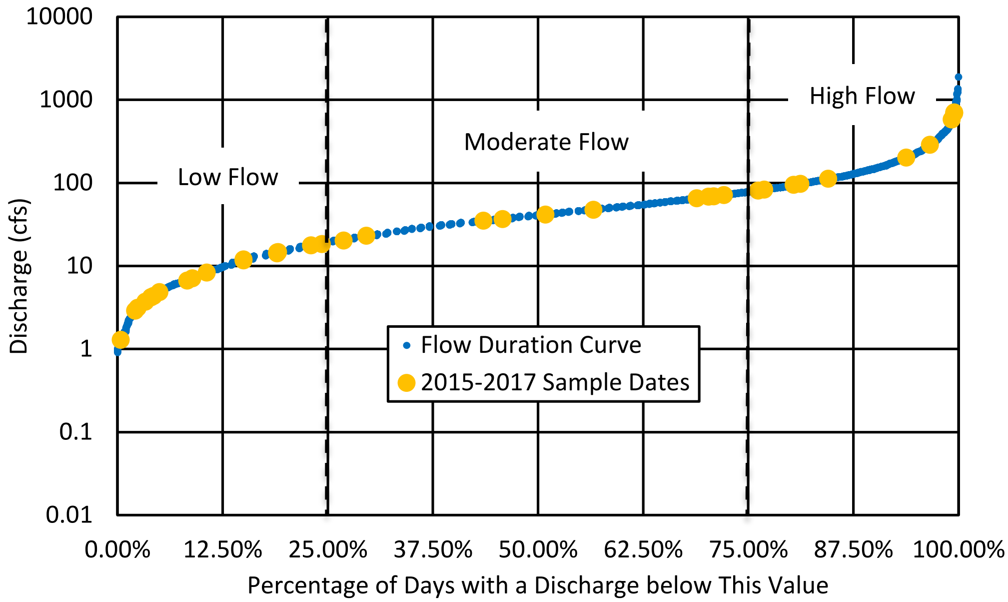

Figure 4. *Flow duration curve for stream flows measured at the USGS gage on the Pike River at East Franklin near Enosburg Falls, Vermont (USGS station 04294300). The 38 dates on which water samples were collected are indicated by orange circles. The dashed vertical lines separate low, moderate, and high flows.*

Table 1. Numbers of low, moderate, and high flows sampled by the Franklin Watershed Committee in the Lake Carmi watershed during 2015-2017. Flows were measured at the USGS gage on the Pike River at East Franklin near Enosburg Falls, Vermont (USGS station 04294300).

Year	Low (<347 cfs)	Moderate (347-1,220 cfs)	High (>1,220 cfs)	% High Flows
2015	3	3	5	45
2016	11	0	2	15
2017	4	7	3	21
All years	18 (47%)	10 (26%)	10 (26%)	26

5.3 Overall Patterns of Water Quality

Water quality data were collected by the Franklin Watershed Committee at 19 sites along nine tributaries of Lake Carmi during 2015-2017 (Table 2, Figure 2). These 19 sites had all been sampled prior to 2015 as well. Seventeen sites were sampled on 15-37 dates during all three years. One site on Sandy Bay Brook (LC23) was sampled on only 13 dates during 2015 and 2017, and one site on Hammond Brook South (LC13) was sampled on only four dates during 2017.

Table 2. Nineteen sites where water quality was sampled by the Franklin Watershed Committee in the Lake Carmi watershed during 2015-2017. The names of many of the streams sampled as part of this study 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
501134	Sandy Bay Brook	LC1	34	2008-2017
501138	Dicky's Brook	LC3	28	2008-2017
501139	Dicky's Brook	LC4	20	2008-2017
501140	Dicky's Brook	LC5	37	2008-2017
501141	Dewing Brook	LC6	33	2008-2017
501142	Unnamed Tributary of Marsh Brook	LC7	26	2008-2017
501143	Marsh Brook	LC8	31	2008-2017
501144	Marsh Brook	LC9	30	2008-2017
501135	Marsh Brook	LC10	36	2008-2017
501136	Alder Run	LC11	30	2009-2017
502649	Kane's Brook	LC12	30	2010-2017
502648	Hammond Brook South	LC13	4	2010-2014, 2017
502651	Little Pond Road Culvert	LC14	28	2010-2017
502652	Westcott Brook	LC16	26	2010-2017
505527	Hammond Brook North	LC17	29	2011-2017
-	Wagner Drain Tile	LC20	23	2013-2017
510254	Sandy Bay Brook 2	LC21	15	2014-2017
510255	Sandy Bay Brook 3	LC22	29	2014-2017
-	Sandy Bay Brook 4	LC23	13	2014-2015, 2017

During 2015-2017, total phosphorus concentrations at the 19 sites ranged between 9.86-1,724 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, Hammond Brook South, and Westcott Brook).

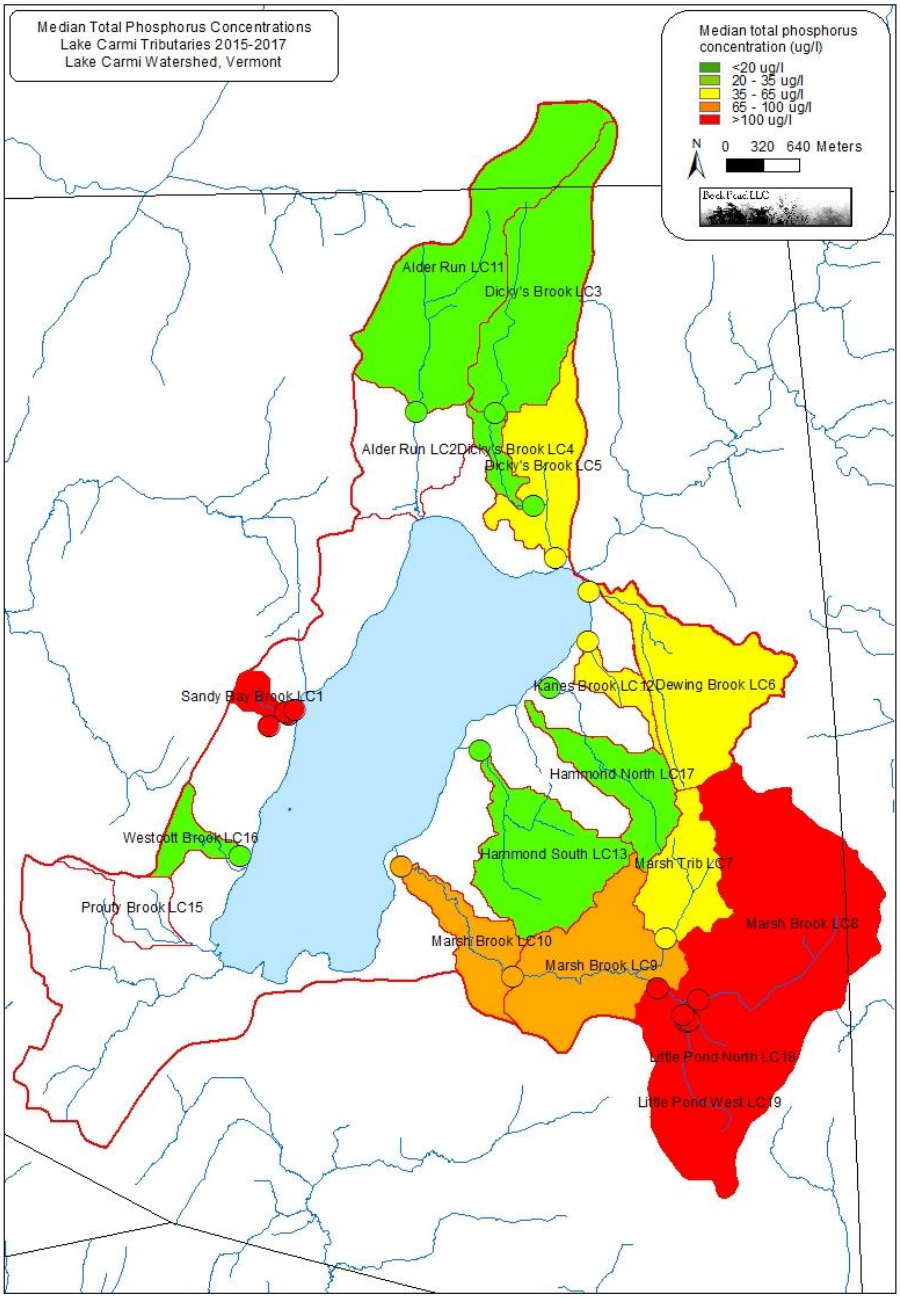

Figure 5. *Median total phosphorus concentrations at 19 sites along the tributaries of Lake Carmi during 2015-2017. The sample site symbols and the subwatersheds drained by each sample site are color-coded according to the median total phosphorus concentrations measured at each site.*

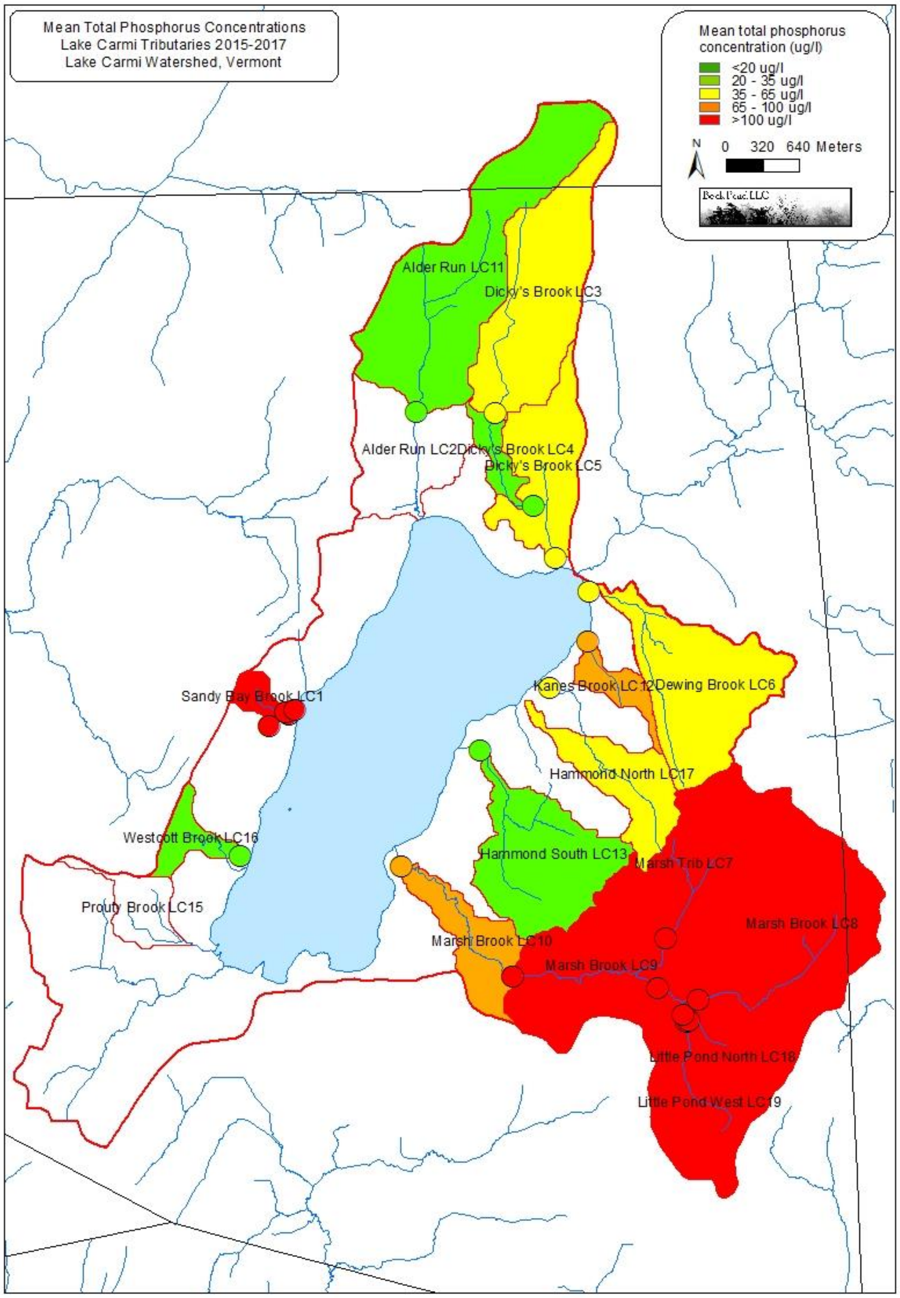

Figure 6. *Mean total phosphorus concentrations at 19 sites along the tributaries of Lake Carmi during 2015-2017. The sample site symbols and the subwatersheds drained by each sample site are color-coded according to the mean total phosphorus concentrations measured at each site.*

In comparing these results (2015-2017) to those obtained from the earlier data (2008-2014), it is clear that water quality has improved in some areas but has deteriorated in other areas. However, across all sites, there appears to be a general improvement in both mean and median total phosphorus concentrations at many sites (Figure 7-8). The specific changes are described more fully in the sections describing the results for individual tributaries.

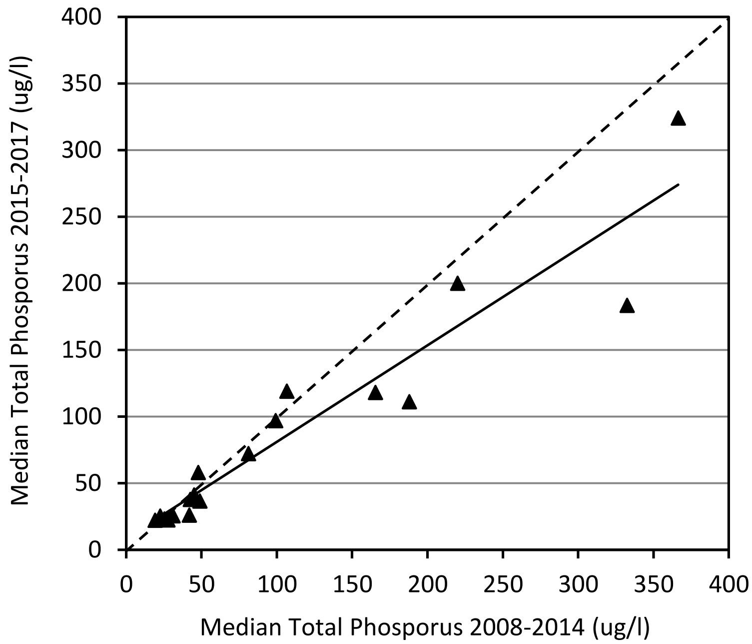

Figure 7. *Median total phosphorus concentrations during 2008-2014 and during 2015-2017 at 19 sites along nine tributaries of Lake Carmi. The dashed line indicates the linear relationship that would exist if there were no change in median values, and the solid line indicates the actual linear relationship between the 2007-2014 and 2015-2017 values. Sites located in the lower right quadrant of the graph showed improvement; those in the upper left quadrant showed deterioration.*

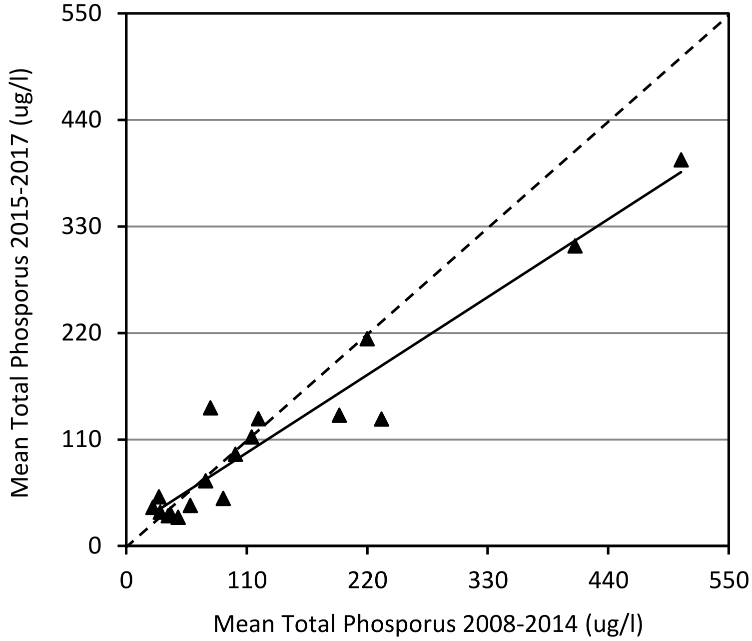

Figure 8. *Mean total phosphorus concentrations during 2008-2014 and during 2015-2017 at 19 sites along nine tributaries of Lake Carmi. The dashed line indicates the linear relationship that would exist if there were no change in mean values, and the solid line indicates the actual linear relationship between the 2007-2014 and 2015-2017 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 2015-2017 exhibited 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 2008-2017, total phosphorus concentrations at the downstream-most site (LC1) decreased significantly (Figure 11; F=9.202, df=1,91, P=0.003). Thus, although total phosphorus concentrations remained high at all four sites, water quality conditions have improved somewhat along this tributary of Lake Carmi in recent years.

Table 3. Summary of total phosphorus concentrations at four sites along Sandy Bay Brook in the Lake Carmi watershed during 2015-2017.

Site Code	Site Name	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
LC1	Sandy Bay Brook	34	111.0	130.9	58-342
LC21	Sandy Bay Brook 2	15	200.0	213.9	128-412
LC22	Sandy Bay Brook 3	29	119.0	131.1	42-358
LC23	Sandy Bay Brook 4	13	124.0	126.9	53-282

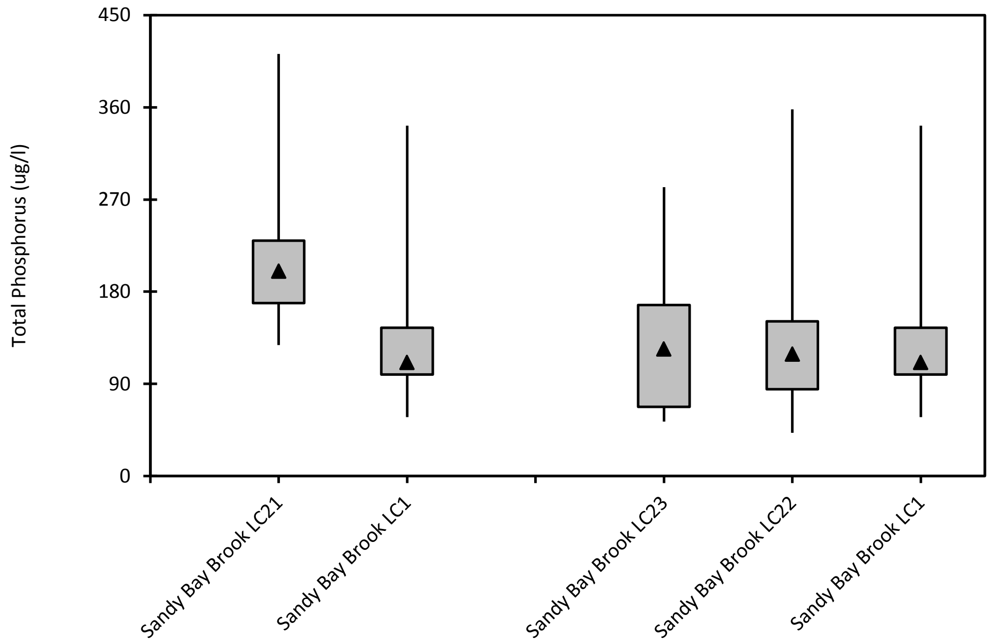

Figure 9. *Total phosphorus concentrations at four sites along the northern branch (left) and southern branch (right) of Sandy Bay Brook during 2015-2017. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line). Note that the downstream-most site (LC1) is included twice, once for each branch.*

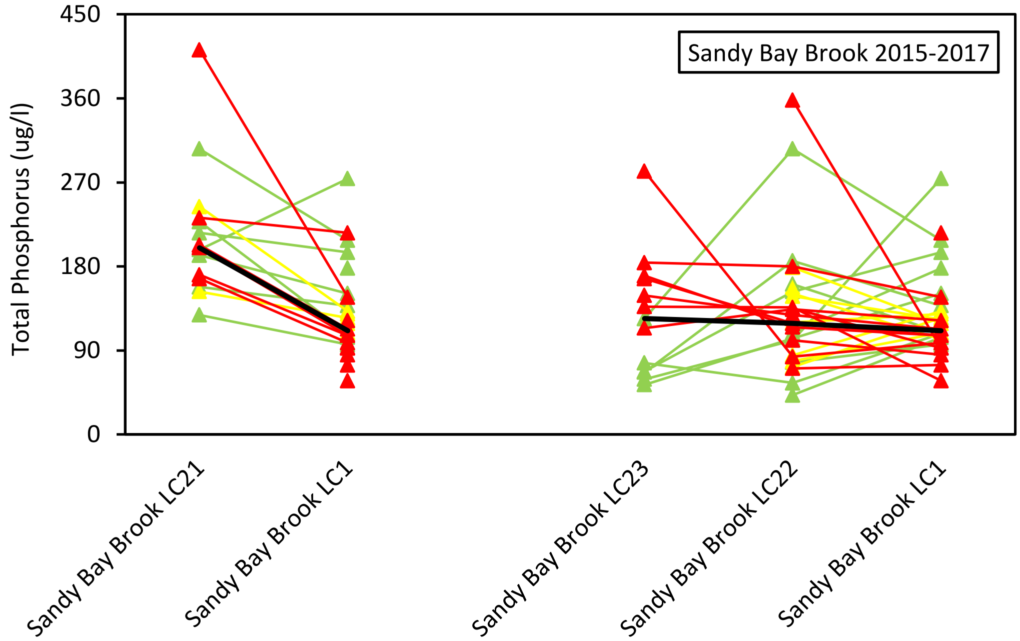

Figure 10. *Total phosphorus "profile" from upstream to downstream along the northern branch (site LC21) and southern branch (sites LC22 and LC23) of Sandy Bay Brook during 2015-2017. The black line represents the median for each site, and the three colors represent data collected during 2015 (green), 2016 (yellow), and 2017 (red). Note that the downstream-most site (LC1) is included twice, once for each branch.*

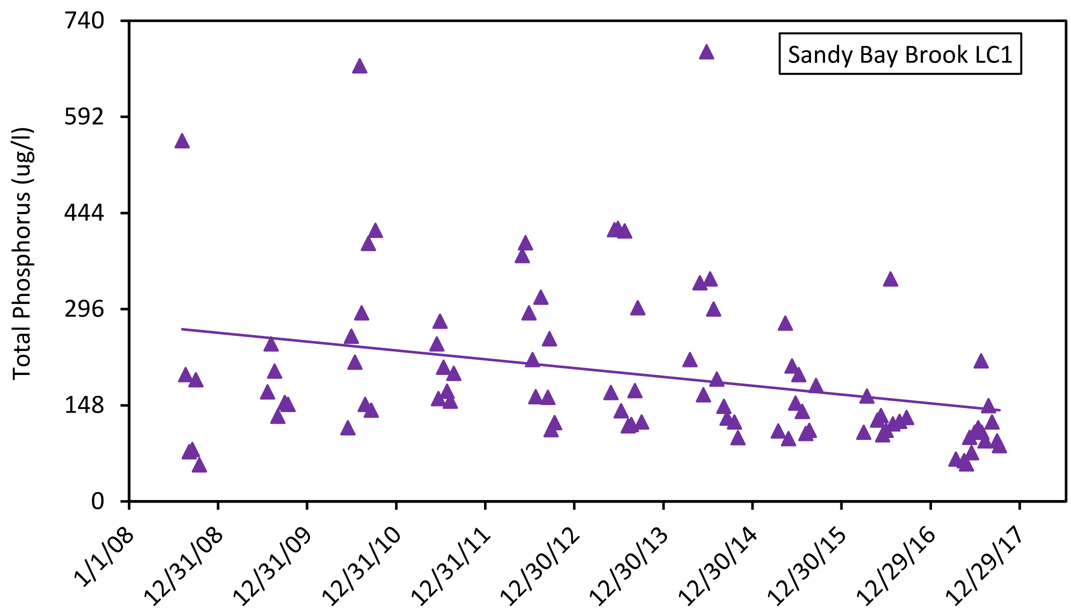

Figure 11. *Total phosphorus concentrations in relation to sample date at the downstream-most site on Sandy Bay Brook (site LC1) during 2008-2017.*

5.4.2 Marsh Brook

The water quality data also indicated that there continued to be serious water quality problems in much of the Marsh Brook watershed. All six sites sampled during 2015-2017 exhibited moderately high to very high total phosphorus concentrations, and this was especially true for the three sites located in the upper watershed (Table 4, Figure 12). In particular, total phosphorus concentrations were highest at the Wagner Drain Tile (site LC20) and generally decreased from the upstream to downstream sites along the main stem of Marsh Brook (Figure 13). During 2008-2017, total phosphorus concentrations at one of the sites along the main stem (LC8) decreased significantly (Figure 14; F=6.573, df=1,89, P=0.012). Thus, although total phosphorus concentrations remained high to very high at all six sites, water quality conditions have improved somewhat over time, at least at one site along this tributary of Lake Carmi.

Table 4. Summary of total phosphorus concentrations at six sites along Marsh Brook in the Lake Carmi watershed during 2015-2017.

Site Code	Site Name	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
LC10	Marsh Brook	36	72.2	94.4	39-462
LC9	Marsh Brook	30	96.9	112.5	53-389
LC8	Marsh Brook	31	118.0	134.8	65-373
LC7	Unnamed Tributary	26	41.1	142.4	15-1,293
LC14	Little Pond Road Culvert	28	183.5	309.7	95-1,724
LC20	Wagner Drain Tile	23	324.0	398.6	115-1,240

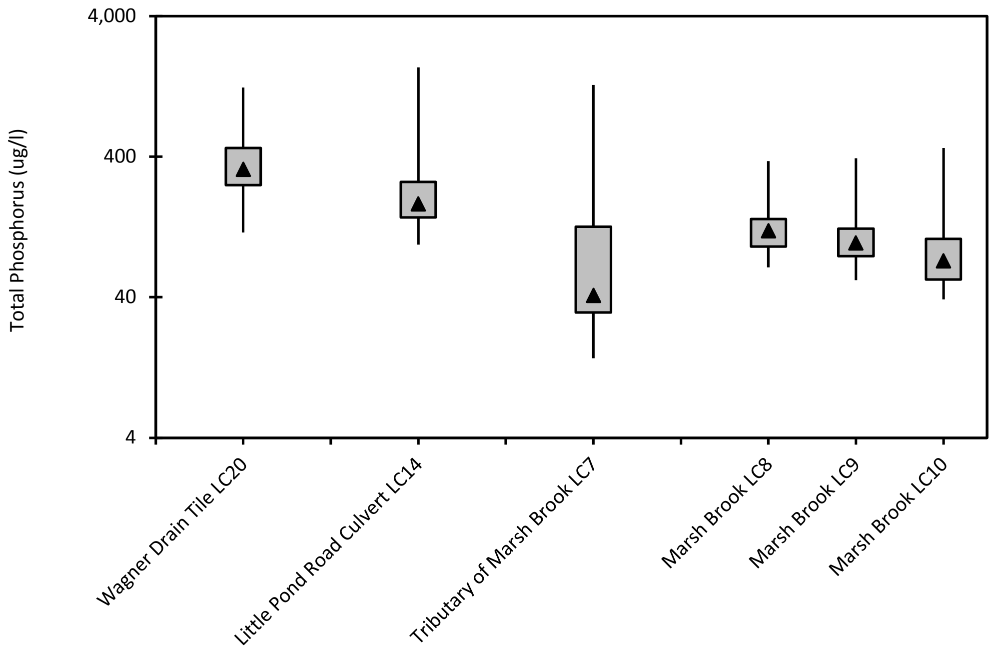

Figure 12. *Total phosphorus concentrations at six sites along Marsh Brook during 2015-2017. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line). Note the logarithmic scale on the y-axis.*

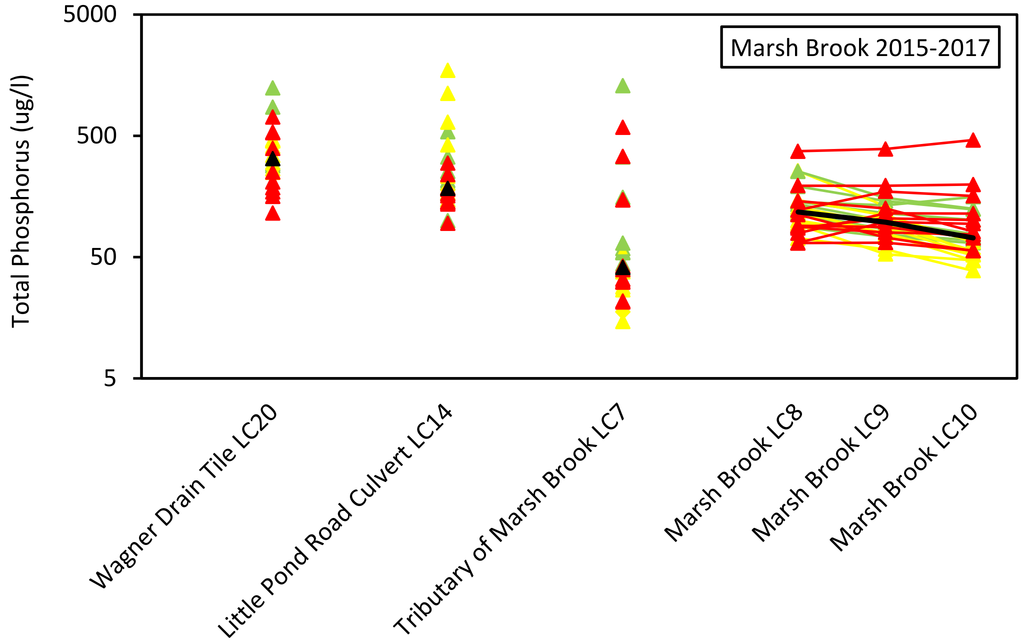

Figure 13. *Total phosphorus "profile" along the main stem and tributaries of Marsh Brook from Wagner Drain Tile (site LC20) downstream to the mouth of Marsh Brook (site LC10) during 2015-2017. The black line and triangles represent the median for each site, and the three colors represent data collected during 2015 (green), 2016 (yellow), and 2017 (red). Note the logarithmic scale on the y-axis.*

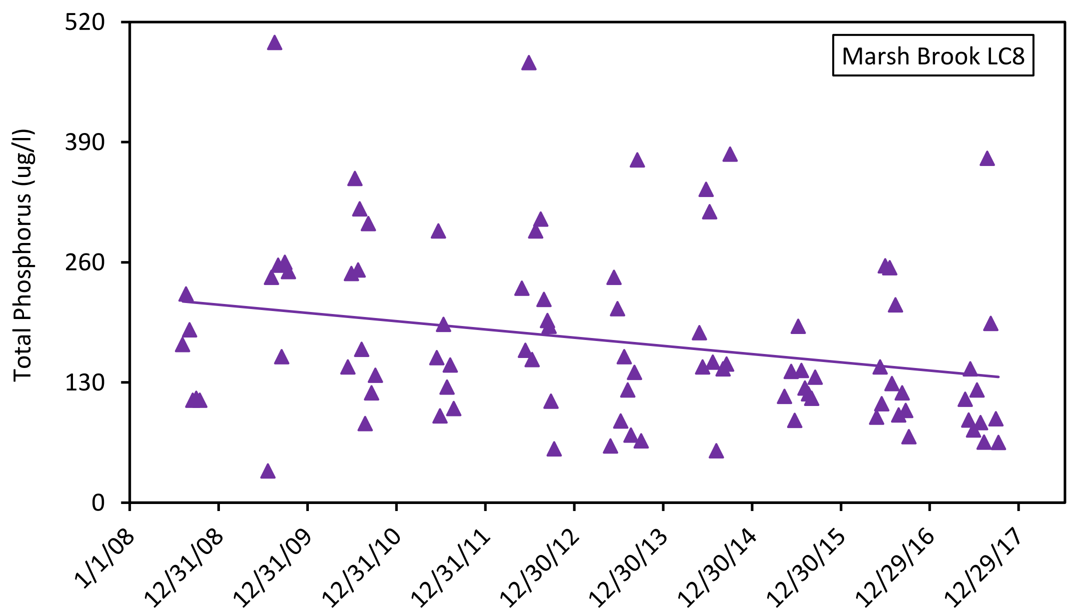

Figure 14. *Total phosphorus concentrations in relation to sample date at the upstream site on the main stem of Marsh Brook (site LC8) during 2008-2017.*

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 2015-2017 exhibited moderate total phosphorus concentrations, although they remained slightly higher at the downstream-most site (Table 5, Figure 15-16). During 2008-2017, total phosphorus concentrations at the downstream-most site (LC5) decreased significantly (Figure 17; F=21.224, df=1,97, P<0.001). Thus, total phosphorus concentrations remained somewhat elevated but have improved 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 2015-2017.

Site Code	Site Name	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
LC5	Dicky's Brook	37	36.6	41.5	21-112
LC4	Dicky's Brook	20	23.2	34.9	15-107
LC3	Dicky's Brook	28	22.1	39.5	10-208

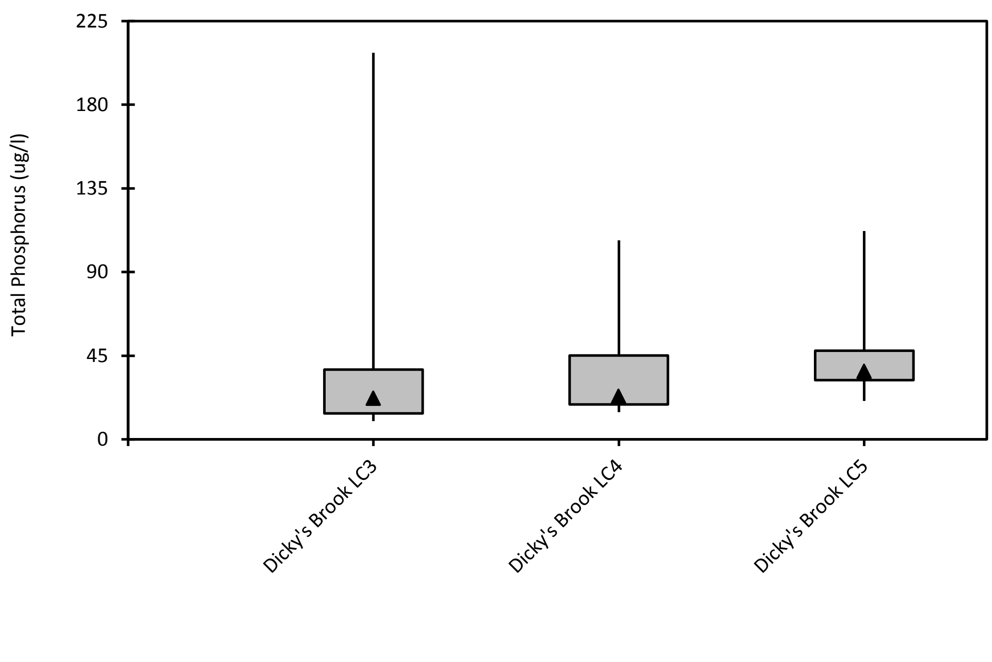

Figure 15. *Total phosphorus concentrations at three sites along Dicky's Brook during 2015-2017. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line).*

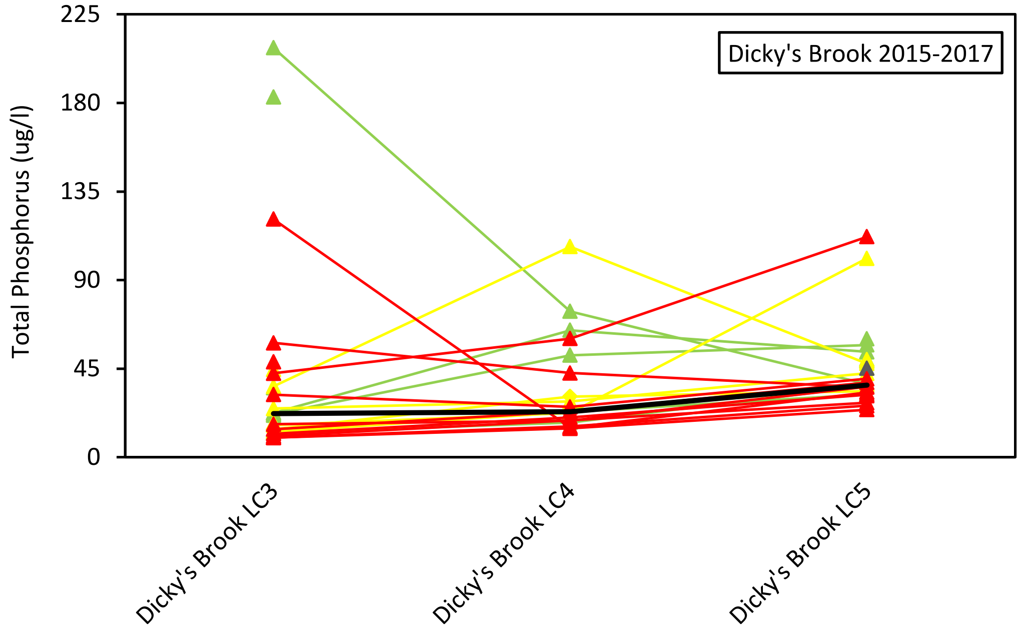

Figure 16. *Total phosphorus "profile" along Dicky's Brook from upstream (site LC3) to downstream (site LC5) during 2015-2017. The black line represents the median for each site, and the three colors represent data collected during 2015 (green), 2016 (yellow), and 2017 (red).*

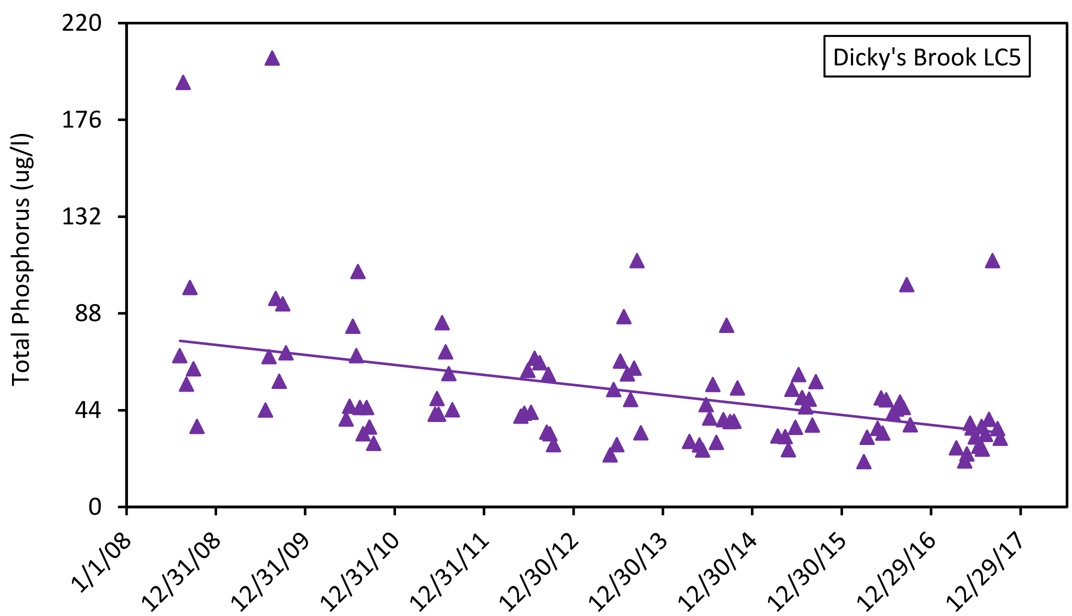

Figure 17. *Total phosphorus concentrations in relation to sample date at the downstream-most site on Dicky's Brook (site LC5) during 2008-2017.*

5.4.4 Other Tributaries

Total phosphorus concentrations were generally low to moderate in five 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, Hammond Brook South, and Westcott Brook (Table 6, Figure 18). During 2008-2017, total phosphorus concentrations changed significantly at two of these six sites: Total phosphorus concentrations decreased significantly at Dewing Brook (Figure 19; F=5.028, df=1,85, P=0.028) but increased significantly at Hammond Brook North (Figure 20; F=4.579, df=1,61, P=0.036).

Table 6. Summary of total phosphorus concentrations at six sites along six tributaries of Lake Carmi during 2015-2017.

Site Code	Site Name	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
LC11	Alder Run	30	22.3	31.2	10-124
LC6	Dewing Brook	33	37.8	49.0	17-164
LC17	Hammond Brook North	29	25.3	50.4	15-153
LC13	Hammond Brook South	4	26.1	29.5	25-41
LC12	Kane's Brook	30	57.9	66.9	29-134
LC16	Westcott Brook	26	25.5	33.1	16-90

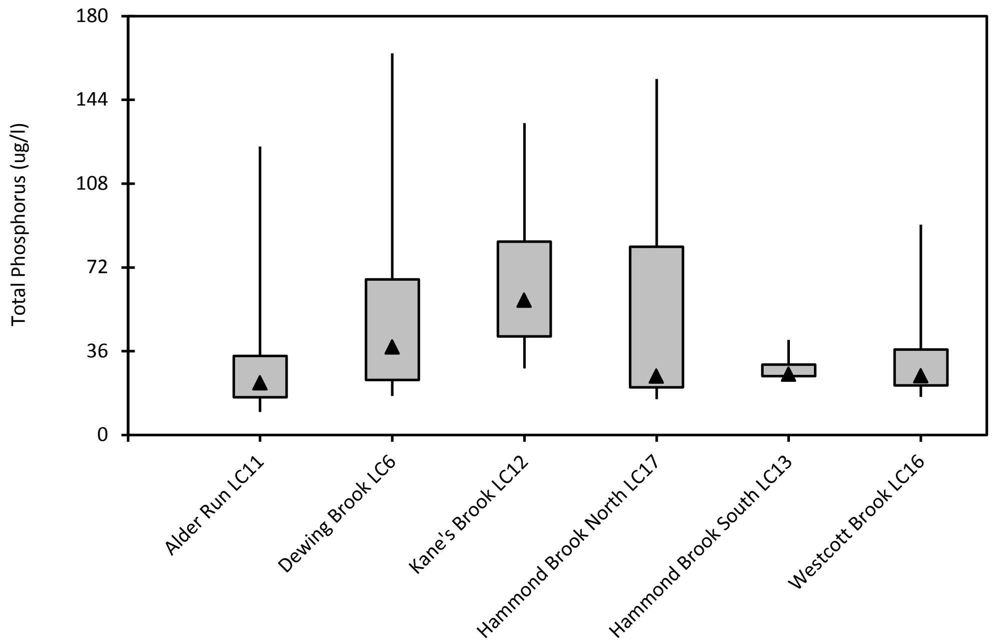

Figure 18. *Total phosphorus concentrations at six sites along six tributaries of Lake Carmi during 2015-2017. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line).*

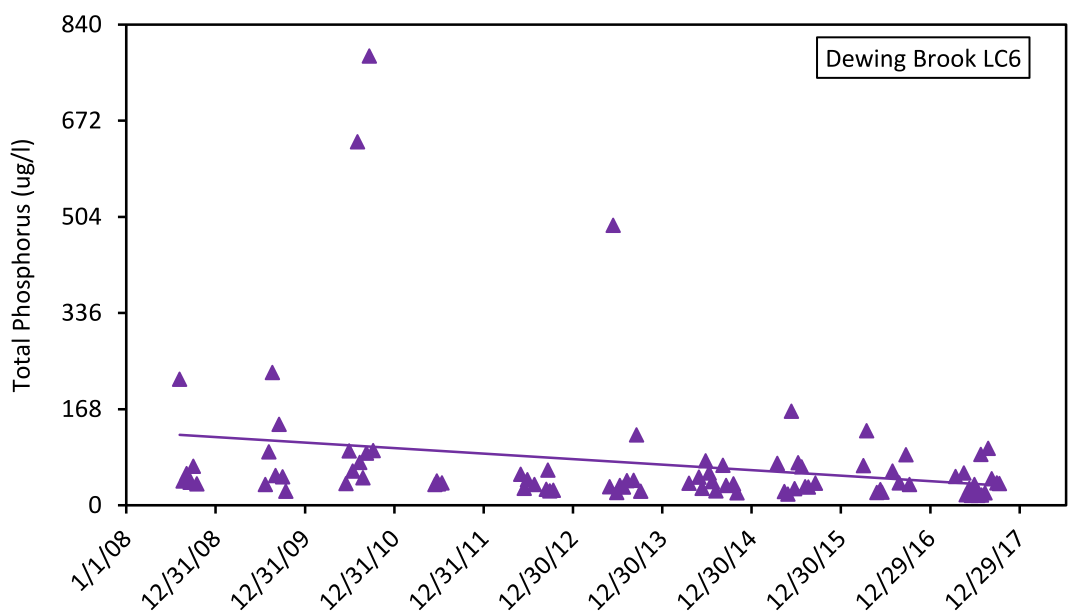

Figure 19. *Total phosphorus concentrations in relation to sample date at Dewing Brook (site LC6) during 2008-2017.*

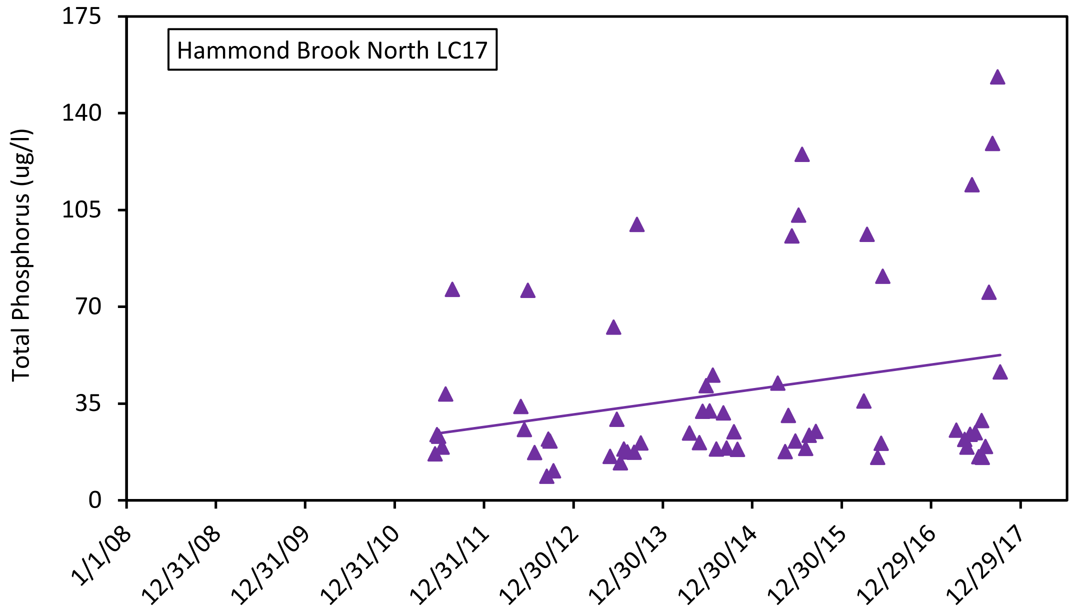

Figure 20. *Total phosphorus concentrations in relation to sample date at Hammond Brook North (site LC17) during 2010-2017.*

6.0 Recommendations

Many of the tributaries of Lake Carmi continued to exhibit moderately high to very 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 2015-2017, as these sites provide an outstanding record of water quality conditions across this watershed over time (most of these sites have been sampled since 2008 or 2009).
2. If resources are unavailable, the sites on Alder Run, Dicky's Brook (one or two upstream sites), Hammond Brook South (only sampled on four dates during 2015-2017), and/or Westcott Brook could be dropped, as these tributaries generally exhibited lower phosphorus levels.
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 Wagner 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 increasing phosphorus levels measured there, the site on Hammond Brook North should continue to be monitored as well.
6. One final possibility is to start measuring total nitrogen, especially in areas where water quality problems may have agricultural sources.

Based on the additional data collected during 2015-2017, 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 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 any of the sites analyzed in this study.

7.0 Conclusions

In this study, we updated our earlier analyses of the spatial patterns in water quality conditions along the tributaries of Lake Carmi and compared these new data with those collected in earlier years. The goals of this effort were threefold: 1) to identify spatial patterns in water quality conditions in these tributary watersheds, 2) to compare the water quality data collected during 2015-2017 with those collected during 2008-2014, 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 2015-2017.

The three years of water quality data collected during 2015-2017 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 two of the sites along Sandy Bay Brook and Marsh Brook. In addition, total phosphorus concentrations were moderately high along Kane's Brook and were moderate but increased significantly along Hammond Brook North. Total phosphorus concentrations also remained moderately high but decreased significantly at one site 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 2008-2017. 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).

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; 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 2015-2017. Bold values indicate field blanks that exceeded detection limits (5 µg/l for total phosphorus and 0.2 NTU for turbidity) or field duplicates that differed by >30% for total phosphorus and >15% for turbidity.

Field Blanks

Site	Date	Total Phosphorus (µg/l)	Turbidity (NTU)
Dicky's Brook at Lake Road	4/14/2015	<5	<0.2
Marsh Brook at State Park Road	5/13/2015	<5	-
Marsh Brook at Lake Carmi State Park	5/27/2015	<5	-
Marsh Brook at State Park Road	6/10/2015	<5	-
Marsh Brook at Lake Carmi State Park	6/24/2015	<5	<0.2
Sandy Bay Brook at Black Woods Road	7/8/2015	<5	**0.2**
Marsh Brook at State Park Road	7/22/2015	<5	-
Marsh Brook at Lake Carmi State Park	8/5/2015	<5	<0.2
Sandy Bay Brook at Black Woods Road	8/19/2015	<5	<0.2
Marsh Brook at State Park Road	9/2/2015	<5	-
Marsh Brook at Lake Carmi State Park	9/16/2015	<5	<0.2
Marsh Brook at Lake Carmi State Park	5/25/2016	<5	<0.2
Marsh Brook at State Park Road	6/8/2016	<5	-
Marsh Brook at Lake Carmi State Park	6/15/2016	<5	<0.2
Marsh Brook at Towle Neighborhood Road South	6/29/2016	<5	-
Marsh Brook at State Park Road	7/27/2016	<5	-
Marsh Brook at State Park Road	8/24/2016	<5	-
Marsh Brook at Lake Carmi State Park	9/7/2016	<5	<0.2
Marsh Brook at State Park Road	9/21/2016	<5	-
Marsh Brook at Lake Carmi State Park	10/5/2016	<5	<0.2
Marsh Brook at Lake Carmi State Park	4/11/2017	<5	<0.2
Marsh Brook at Lake Carmi State Park	5/15/2017	<5	<0.2
Marsh Brook at Lake Carmi State Park	5/24/2017	<5	<0.2
Marsh Brook at State Park Road	6/7/2017	<5	-
Sandy Bay Brook at Black Woods Road	6/14/2017	<5	**0.28**
Marsh Brook at Lake Carmi State Park	6/27/2017	<5	<0.2

Site	Date	Total Phosphorus (µg/l)	Turbidity (NTU)
Marsh Brook at State Park Road	7/12/2017	<5	<0.2
Marsh Brook at Lake Carmi State Park	7/24/2017	<5	<0.2
Marsh Brook at Lake Carmi State Park	7/26/2017	<5	<0.2
Marsh Brook at State Park Road	8/9/2017	<5	-
Marsh Brook at Lake Carmi State Park	8/23/2017	<5	-
Marsh Brook at State Park Road	9/6/2017	<5	-
Marsh Brook at Lake Carmi State Park	9/27/2017	<5	-
Marsh Brook at State Park Road	10/7/2017	<5	-

Field Duplicates: Total Phosphorus

Site	Date	1st Total Phosphorus (µg/l)	2nd Total Phosphorus (µg/l)	Relative % Difference
Dicky's Brook at Lake Road	4/14/15	33.4	32.2	4
Marsh Brook at State Park Road	5/13/15	88.8	84.3	5
Marsh Brook at Lake Carmi State Park	5/27/15	51.2	49.1	4
Marsh Brook at State Park Road	6/10/15	144	134	7
Marsh Brook at Lake Carmi State Park	6/24/15	64.8	65.4	1
Sandy Bay Brook at Black Woods Road	7/8/15	197	195	1
Marsh Brook at State Park Road	7/22/15	116	115	1
Marsh Brook at Lake Carmi State Park	8/5/15	73.9	73.3	1
Sandy Bay Brook at Black Woods Road	8/19/15	113	109	4
Marsh Brook at State Park Road	9/2/15	81.7	76.7	6
Marsh Brook at Lake Carmi State Park	9/16/15	86.3	77.5	11
Marsh Brook at Lake Carmi State Park	3/30/16	43.3	44.1	2
Marsh Brook at Lake Carmi State Park	4/12/16	162	150	8
Marsh Brook at Lake Carmi State Park	5/25/16	42.7	47	10
Marsh Brook at State Park Road	6/8/16	104	110	6
Marsh Brook at Lake Carmi State Park	6/15/16	52.3	52.9	1
Marsh Brook at Towle Neighborhood Road South	6/29/16	238	256.5	7
Marsh Brook at State Park Road	7/27/16	96.3	92.7	4
Marsh Brook at State Park Road	8/24/16	90	88	2

Site	Date	1st Total Phosphorus (µg/l)	2nd Total Phosphorus (µg/l)	Relative % Difference
Marsh Brook at Lake Carmi State Park	9/7/16	45	46.8	4
Marsh Brook at State Park Road	9/21/16	77.9	78	0
Marsh Brook at Lake Carmi State Park	10/5/16	37.6	38.6	3
Marsh Brook at Lake Carmi State Park	4/11/17	52.1	51.1	2
Marsh Brook at Lake Carmi State Park	5/15/17	53	53.5	1
Marsh Brook at Lake Carmi State Park	5/24/17	54.2	56.2	4
Marsh Brook at State Park Road	6/7/17	81.2	79.9	2
Sandy Bay Brook at Black Woods Road	6/14/17	75.6	74.4	2
Marsh Brook at Lake Carmi State Park	6/27/17	113	114	1
Marsh Brook at State Park Road	7/12/17	173	174	1
Marsh Brook at Lake Carmi State Park	7/24/17	157	156	1
Marsh Brook at Lake Carmi State Park	7/26/17	101	101	0
Marsh Brook at State Park Road	8/9/17	97.6	97.7	0
Marsh Brook at Lake Carmi State Park	8/23/17	472	461.5	2
Marsh Brook at State Park Road	9/6/17	194	194	0
Marsh Brook at Lake Carmi State Park	9/27/17	71.5	71.9	1
Marsh Brook at State Park Road	10/7/17	65.8	65.9	0
Mean				**3**

Field Duplicates: Turbidity

Site	Date	1st Turbidity (NTU)	2nd Turbidity (NTU)	Relative % Difference
Dicky's Brook at Lake Road	4/14/15	3.42	3.06	11
Marsh Brook at Lake Carmi State Park	6/24/15	2.49	2.55	2
Sandy Bay Brook at Black Woods Road	7/8/15	6.7	6.7	0
Marsh Brook at Lake Carmi State Park	**8/5/15**	**0.44**	**0.62**	**34**
Sandy Bay Brook at Black Woods Road	**8/19/15**	**12.6**	**20.8**	**49**
Marsh Brook at Lake Carmi State Park	9/16/15	0.56	0.61	9
Marsh Brook at Lake Carmi State Park	3/30/16	6.08	5.89	3
Marsh Brook at Lake Carmi State Park	**4/12/16**	**11.2**	**15.2**	**30**
Marsh Brook at Lake Carmi State Park	5/25/16	2.18	2.05	6
Marsh Brook at Lake Carmi State Park	**6/15/16**	**1.11**	**0.87**	**24**
Marsh Brook at Lake Carmi State Park	**9/7/16**	**0.57**	**1.32**	**79**
Marsh Brook at Lake Carmi State Park	**10/5/16**	**0.38**	**0.76**	**67**
Marsh Brook at Lake Carmi State Park	**4/11/17**	**2.39**	**4.42**	**60**
Marsh Brook at Lake Carmi State Park	**5/15/17**	**1.94**	**2.59**	**29**
Marsh Brook at Lake Carmi State Park	5/24/17	0.91	0.87	4
Sandy Bay Brook at Black Woods Road	**6/14/17**	**5.69**	**6.68**	**16**
Marsh Brook at Lake Carmi State Park	6/27/17	2.87	2.96	3
Marsh Brook at Lake Carmi State Park	7/24/17	8.5	7.63	11
Marsh Brook at Lake Carmi State Park	7/26/17	1.38	1.45	5
Mean				**23**

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