Phosphorus Levels in Six Tributaries of Missisquoi Bay

Prepared for the

Vermont Department of Environmental Conservation

by

Fritz Gerhardt, Ph.D.

31 October 2015

Beck Pond LLC

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Cover. *View of the Missisquoi River looking upstream to the mouth of Black Creek, which enters from the right just across the river from Sheldon Junction, Vermont on 21 May 2015.*

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Abstract

1. Over the past two decades, there has been increasing concern about water quality conditions in Lake Champlain and its tributaries, especially Missisquoi Bay, which has shown alarming increases in both total phosphorus concentrations and the incidence of cyanobacterial (blue-green algal) blooms. Since 2004, the Missisquoi River Basin Association, Franklin Watershed Committee, and Vermont Department of Environmental Conservation have undertaken several water quality monitoring programs to evaluate water quality conditions throughout the Missisquoi Bay Basin and to identify and assess possible sources of water quality problems. This report provides an overview of these water quality monitoring programs, presents the results of the analyses of the total phosphorus data, and provides recommendations for future monitoring efforts and preliminary recommendations for on-the-ground evaluations of possible nutrient and sediment sources.
2. During 2004-2014, staff and volunteers from the Franklin Watershed Council, Missisquoi River Basin Association, and Vermont Department of Environmental Conservation measured total phosphorus concentrations at 76 sites throughout the Missisquoi Bay Basin. In this study, we focused on analyzing those data collected at 41 of those sites along six tributaries of Missisquoi Bay: Hungerford Brook, Black Creek, Tyler Branch, Godin Brook, Mud Creek, and Lake Carmi.
3. Total phosphorus concentrations were generally high along many of these tributaries. In particular, total phosphorus concentrations were extremely high in the watersheds of Hungerford and Godin Brooks and two of the tributaries of Lake Carmi (Marsh and Sandy Bay Brooks). Total phosphorus concentrations were moderately high in the watersheds of Black and Mud Creeks and several tributaries of Lake Carmi. Finally, total phosphorus concentrations were low or moderate along Tyler Branch and several other tributaries of Lake Carmi. Based on these analyses and discussions with other stakeholders, possible sources of the high phosphorus levels were identified for several watersheds, including Godin, Marsh, and Sandy Bay Brooks.
4. Collectively, these data greatly increase our knowledge about water quality problems and their sources in the Missisquoi Bay Basin. Future monitoring efforts should include: 1) continued monitoring of total phosphorus at selected sites 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. Hungerford Brook, Black Creek, Godin Brook, Mud Creek, and Sandy Bay and Marsh Brooks); and 3) monitoring of total nitrogen, especially in areas where water quality problems may have agricultural sources;. Once these problems are better understood, it will be easier to identify and develop the appropriate protection and restoration strategies that will most effectively reduce phosphorus exports from these watersheds into Missisquoi Bay.

Introduction

Water is essential for human life as well as most other forms of life, and, therefore, water quality is important to the health and integrity of both human and natural communities. Surface waters - such as streams, rivers, lakes, ponds, and wetlands - provide important ecosystem services and support a great diversity of natural communities and organisms. Surface waters also provide drinking water, hydroelectric power, and disposal of treated wastewater; support agricultural and industrial production; and serve important flood control and water filtration functions. Furthermore, surface waters provide important opportunities for recreation, whether for swimming, boating, fishing, hunting, nature-viewing, or other outdoor activities. The quality of surface waters can greatly affect the prevalence and spread of many diseases important to human health (e.g. cholera, malaria). Because water is essential for maintaining both aquatic and terrestrial ecosystem health and biodiversity, water quality serves as a valuable tool for measuring ecosystem health, especially since water quality integrates the impacts of a wide range of stressors in both the terrestrial and aquatic ecosystems.

Water quality faces a number of threats across a broad range of geographic scales. At the regional and global scales, water quality is threatened by global climate change (including changes in both temperature and precipitation), atmospheric deposition (e.g. acid precipitation and sulfur and nitrogen deposition), and invasive species [e.g. Eurasian water milfoil (*Myriophyllum spicatum* L.), zebra mussels (*Dreissena polymorpha* Pallas)]. At the local and landscape scales, water quality is threatened by these factors as well as introductions of chemical and biological toxins; changes in land uses such as increased urban and suburban development; poor agricultural and forestry practices; loss of wetlands and shoreline habitats; and construction of in-stream modifications, such as dams and channelization. Collectively, these activities often result in increased sedimentation and nutrient enrichment, which can cause the eutrophication (or "premature aging and death") of water bodies. When allowed to proceed unchecked, excessive plant and algal growth and the resulting decomposition can deplete oxygen levels to levels that are too low to support most aquatic life. At its extreme, this process can lead to the development of "dead zones", where virtually no aquatic life survives due to the lack of oxygen. In addition, excessive sedimentation and nutrient enrichment, especially the combination of high levels of phosphorus, nitrogen, and iron, can lead to increased occurrences of freshwater cyanobacterial (blue-green algal) blooms and marine and estuarine diatom blooms associated with "red tides", and some of these Cyanobacteria produce toxins that can harm humans and wildlife.

Lake Champlain and its tributaries are highly-valued resources that support a wide array of recreational activities, economic benefits, and ecological functions to the residents of and visitors to Vermont, New York, and Quebec. Water bodies in the basin are used extensively for boating, swimming, fishing, hunting, nature-viewing, and other recreational activities. Lake Champlain and the Saranac and Missisquoi Rivers are important links in the Northern Forest Canoe Trail, which extends 1,191 km (740 mi) from Old Forge, New York through Vermont, Quebec, and New Hampshire to Fort Kent, Maine. Lake Champlain and other water bodies in the basin also serve as public water supplies, provide hydroelectric power and disposal of treated wastewater, and support agricultural and industrial production. The floodplains and the many wetlands around the lake and in the tributary watersheds 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 Champlain and its tributaries. This interest has been spurred by concerns that water quality in Lake Champlain has been declining and is now threatened by excessively high nutrient and sediment 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 Champlain and its tributaries currently face a number of threats, including high sediment and nutrient levels, elevated mercury levels, excessive algal growth, eutrophication, and invasions of exotic species (State of Vermont 2014a, 2014b). Although water quality conditions are generally good in much of Lake Champlain, they are often poor in St. Albans and Missisquoi Bays, where blue-green algal blooms are triggered by excessive nutrients most years, and in the South Lake, where the water is often quite muddy (Lake Champlain Basin Program 2015).

Missisquoi Bay and its tributary watersheds represent the northeastern-most corner of the Lake Champlain Basin and straddle the United States/Canada border in the northwestern corner of Vermont and the Montérégie region of Quebec. Unfortunately, the water quality data from Missisquoi Bay and Lake Carmi indicate that both of these water bodies are impaired (Table 1, Figure 1-2). Both Missisquoi Bay and Lake Carmi are the subjects of Total Maximum Daily Loads (TMDL) due to elevated phosphorus levels, nutrient enrichment, and excessive algal growth (Part D, State of Vermont 2014a). The Environmental Protection Agency (EPA) initially approved a TMDL for phosphorus enrichment for all of Lake Champlain in 2002 (State of Vermont 2002) but disapproved of that TMDL in 2011 and is currently developing a new TMDL (Environmental Protection Agency 2015). The Environmental Protection Agency approved a TMDL for algal blooms in Lake Carmi in 2009 (State of Vermont 2008). Finally, the Environmental Protection Agency approved a state-wide TMDL for elevated *Escherichia coli* levels in three tributaries of the Missisquoi River - Berry, Godin, and Sampsonville Brooks - in 2011 (State of Vermont 2011). In addition, numerous surface waters in the Missisquoi Bay Basin have been identified by the State of Vermont as being stressed waters or priority surface waters outside the scope of Clean Water Act Section 303(d)(State of Vermont 2014b).

Table 1. Water quality data collected at Missisquoi Bay (Station 50) during 1992-2014 and Lake Carmi during 1979-2014. Data were collected by the Lake Champlain Long-Term Monitoring Program (Missisquoi Bay) and Lay Monitoring Program (Lake Carmi).

Parameter	Missisquoi Bay (Station 50)	Lake Carmi
Average Secchi disk measurement (m)	1.7	2.0
Average phosphorus concentration (µg/l)	49.0	30.8
Average chlorophyll-a concentration (µg/l)	13.9	17.0
Trophic state	Eutrophic	Eutrophic

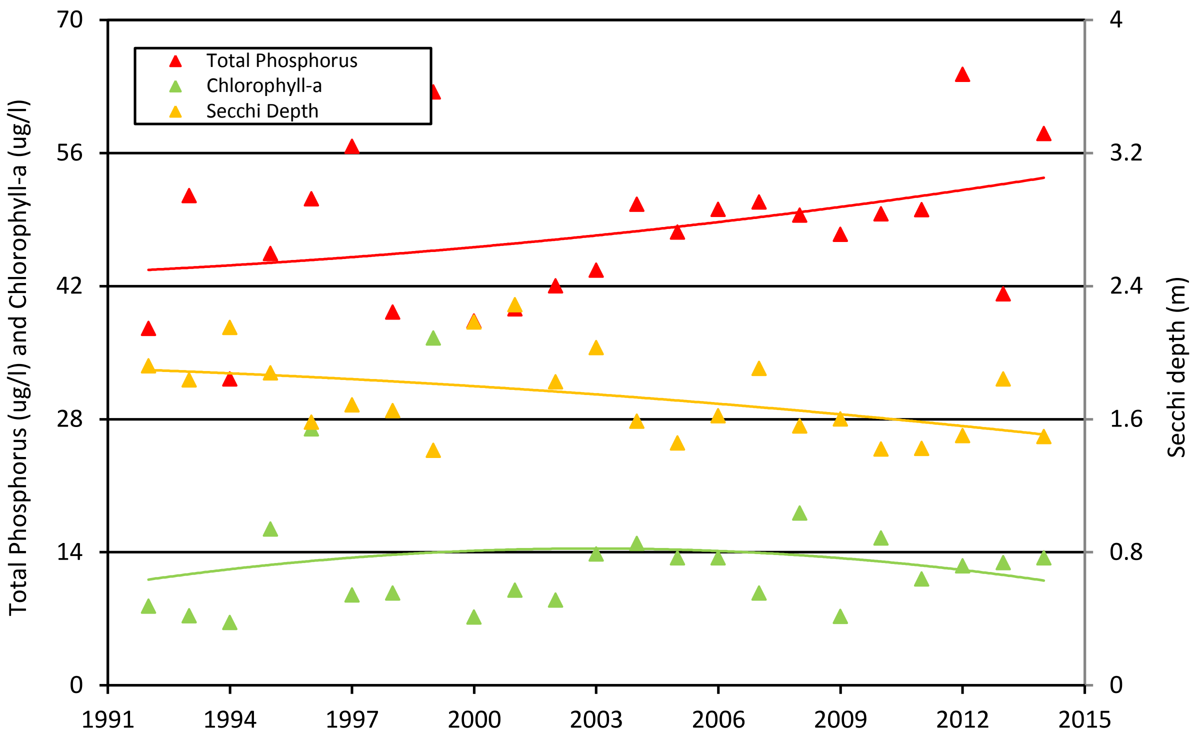

Figure 1. *Water quality conditions measured at Station 50 in Missisquoi Bay during 1992-2014. Data were collected by the Lake Champlain Long-Term Monitoring Program administered by the Vermont Department of Environmental Conservation.*

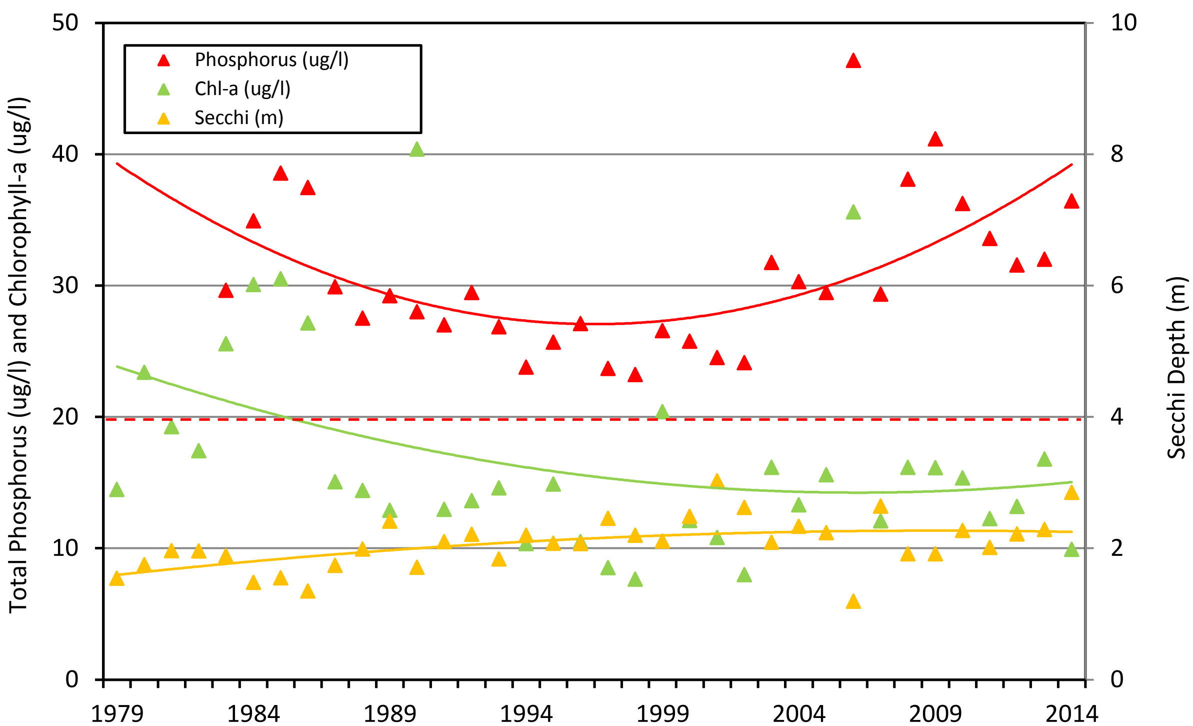

Figure 2. *Water quality conditions at Lake Carmi during 1979-2014. These data were collected through the Lay Monitoring Program administered by the Vermont Department of Environmental Conservation.*

Study Goals

In order to identify and assess possible sources for the high phosphorus levels measured in Missisquoi Bay and Lake Carmi, we analyzed the water quality data collected from six tributary watersheds of Missisquoi Bay: Hungerford Brook, Black Creek, Tyler Branch, Godin Brook, Mud Creek, and the tributaries flowing into Lake Carmi (Figure 3). Previous studies had indicated that several of these tributaries - including Hungerford Brook, Black Creek, Tyler Branch, Mud Creek, and Pike River - exhibited high total phosphorus concentrations and were likely significant sources of the phosphorus flowing into Missisquoi Bay (Howe et al. 2011, Stone Environmental 2011). Water quality data have been collected along the five tributaries of the Missisquoi River watershed since 2005 by the Missisquoi River Basin Association (MRBA) and along the tributaries of Lake Carmi since 2007 by the Franklin Watershed Committee (FWC). Using the 8-10 years of water quality data collected by these two organizations, this study was initiated to conduct a short-term water quality data analysis project to inform water quality management in the Lake Carmi watershed and selected watersheds in the Missisquoi

River basin. More specifically, the goals of this study were fourfold: 1) to assess water quality conditions in these tributary watersheds over time, 2) to pinpoint and assess possible nutrient and sediment sources along these tributaries, 3) to provide recommendations for future monitoring efforts, and 4) to provide some recommendations for preliminary, on-the-ground assessments of possible nutrient and sediment sources.

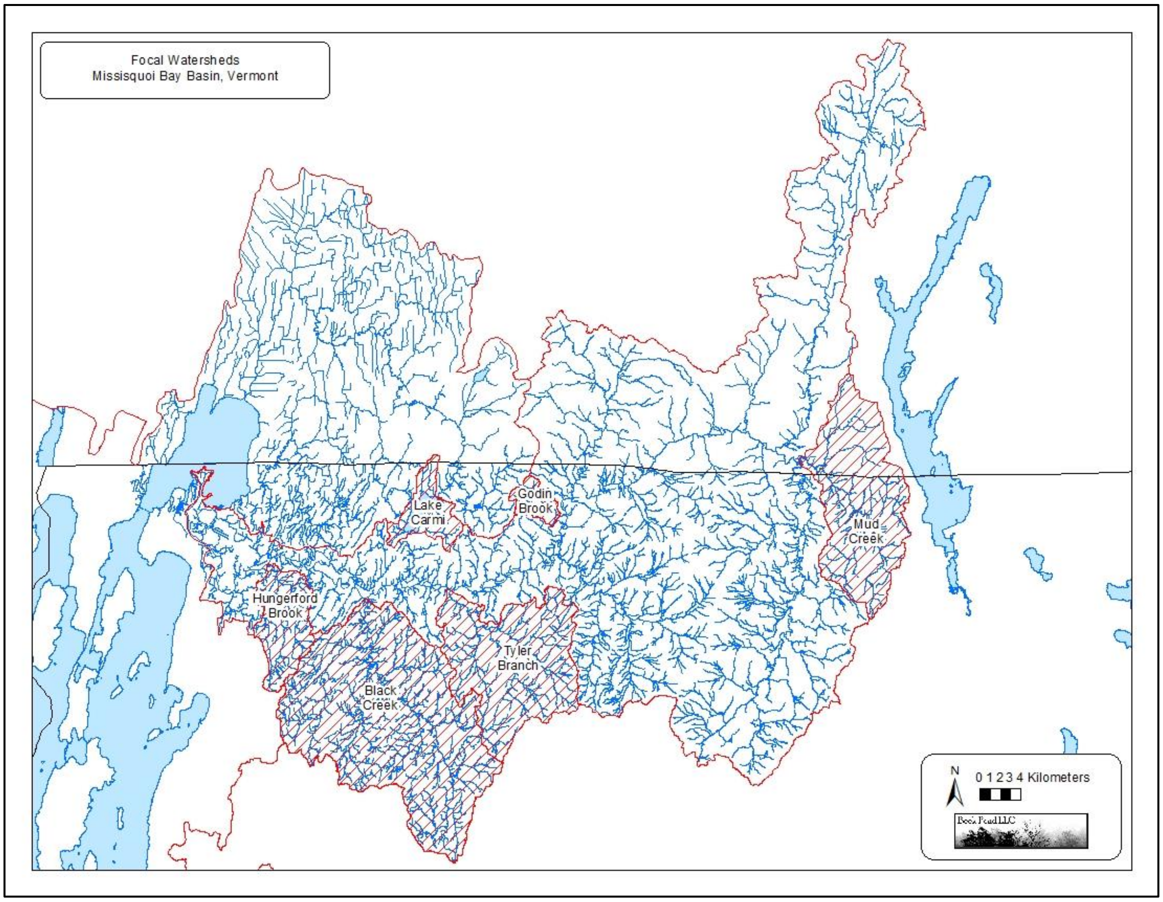

Figure 3. *Six focal watersheds in the Missisquoi Bay Basin, Vermont, where water quality data were analyzed as part of this study.*

Study Area

Missisquoi Bay (Waterbody ID VT05-01L01) is the northeastern-most segment of Lake Champlain and lies in both Vermont and Quebec. Based on extensive water quality sampling, Missisquoi Bay has been determined to be impaired by elevated phosphorus levels and contributes approximately 24% of the phosphorus entering Lake Champlain from Vermont

(Environmental Protection Agency 2015). Missisquoi Bay drains an area of approximately 3,105 km^2 (1,199 mi^2), of which approximately 58% is located in Vermont and 42% in the province of Quebec. Agriculture, primarily dairy farming, and forests represent 91% of the land cover in the Vermont portion of the Missisquoi Bay Basin. Agriculture (42%), streambank instability (29%), forests (15%), and developed lands (12%) are estimated to contribute the majority of the phosphorus entering the bay from the Vermont portion of the watershed. In contrast, the eight wastewater treatment facilities in the watershed contribute only 1% of the phosphorus entering the bay. The topography of the Missisquoi Bay Basin varies dramatically from the generally flat bottomlands of the Champlain Valley to the rugged valleys and mountain ridges of the northern Green Mountains. Elevations range from 29 m (95 ft) at the surface of Missisquoi Bay in Swanton to 1,177 m (3,862 ft) atop Jay Peak in Jay.

In addition to the shorelands and small tributaries that drain directly into Missisquoi Bay, the bay is fed by three principal tributary rivers: the Missisquoi, Rock, and Pike Rivers. The Missisquoi River, the largest of these tributaries, extends approximately 142 km (88 miles) and drains an area of approximately 2,232 km^2 (862 mi^2) in northwestern Vermont and southern Quebec. Its watershed includes parts of the Champlain Valley, much of the northern Green Mountains along the Quebec-Vermont border, and part of Quebec's Eastern Townships (Cantons de l'Est). The Rock River (called the Rivière de la Roche in Quebec) drains an area of approximately 147 km^2 (57 mi^2) in the towns of Highgate and Franklin and in southern Quebec. Finally, the Pike River (called the Rivière aux Brochets in Quebec) drains an area of approximately 662 km^2 (256 mi^2) and flows north into Quebec before entering Missisquoi Bay. The Pike River originates in Lake Carmi in the town of Franklin. Lake Carmi, 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 covers an area of 3,120 ha (7,710 acres) and consists mostly of low hills [the range in elevation is only 148 m (485 feet)]. 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 shoreline of Lake Carmi, and Lake Carmi State Park offers camping facilities at the southern end of the lake.

Methods

Water Quality Sampling

During 2005-2014, the Missisquoi River Basin Association and the Franklin Watershed Committee undertook two independent water quality monitoring programs in the Missisquoi River and Lake Carmi watersheds, respectively. In both programs, the primary focus was measuring total phosphorus concentrations. 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, high 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 synthetic fertilizers applied to lawns and agricultural fields.

Additional data were collected by two programs run by the Vermont Department of Environmental Conservation. First, the Lake Assessment Program was designed to rapidly assess the extent to which lakes meet designated uses and to gather information to focus lake protection efforts. These assessments provided detailed and comprehensive information about shoreline conditions, macrophyte community, water chemistry, and Secchi disk transparency. In this study, we used only the water chemistry data collected during 2007 for two sites in the Lake Carmi watershed (the outlet of the lake on the Pike River and Marsh Brook). Second, the Biomonitoring and Aquatic Studies (BASS) Program assesses the physical habitat features, water chemistry, biological integrity, and fish and aquatic macroinvertebrate communities in running waters throughout the state of Vermont. In this study, we analyzed the water chemistry data collected during 2004-2013 at 29 sites distributed throughout the watersheds of the five tributaries of the Missisquoi River and seven sites in the Lake Carmi watershed.

Data Analyses

To accomplish the objectives of this study, we undertook the following steps:

1. First, we downloaded all of the readily-available data for the project area from the State of Vermont's Integrated Watershed Information System (IWIS) database, including the data collected by the Missisquoi River Basin Association during 2005-2014, the Franklin Watershed Committee during 2007-2014, Vermont DEC Lake Assessment Program during 2007, and Vermont DEC Biomonitoring Program during 2004-2013.
2. Second, we downloaded the relevant stream flow data for all of the U.S. Geological Survey (USGS)-maintained stream gages located in the Missisquoi Bay Basin.
3. Once downloaded, all of the data were screened to identify any errors or outlier data points, and the quality assurance (QA) data were analyzed to verify that water samples were collected in a repeatable manner without any contamination.
4. We then used the geographic coordinates to map all of the sample sites in a Geographic Information System (ArcGIS 10, ESRI, Redlands, California).
5. We summarized the water quality conditions for each sample site, and, where data were sufficient, we analyzed the water quality data in relation to stream flows.
6. Using these data and data summaries, we delineated the subwatersheds drained by each sample site and identified and mapped subwatersheds of differing phosphorus concentrations.

7. We cross-referenced the mapped subwatersheds with the critical source areas identified by the Lake Champlain Basin Program "Critical Source Area" analysis (Stone Environmental 2011) and compared our results to those reported by the Missisquoi River Basin Association (Deeds and Deeds 2013, Sawyer 2015) and the Lake Champlain Basin Program-supported Short-Term Monitoring Program (Howe et al. 2011).
8. We developed recommendations for revising the sampling network, including identifying new sites that would better pinpoint and assess possible nutrient sources.
9. We also developed preliminary recommendations for on-the-ground surveys to further investigate possible nutrient and sediment sources by staff from the appropriate organization (e.g. Vermont Agency of Agriculture, Food & Markets; Vermont Agency of Natural Resources; Natural Resources Conservation Service),
10. Finally, we presented the results of this study at a public outreach meeting with members of the Franklin Watershed Committee and Missisquoi River Basin Association and staff from the Vermont Agency of Natural Resources and Vermont Agency of Agriculture, Food & Markets.

All data were imported into Microsoft Excel spreadsheets, and GIS shapefiles showing the sample sites and watershed and subwatershed boundaries were created and maintained in ArcGIS 10. All data and analyses were archived by the author, and electronic copies were submitted to the Vermont DEC.

Quality Assurance

All of the water quality data collected through these programs were collected in accordance with a Quality Assurance Project Plan (QAPP) developed in conjunction with the Vermont DEC. As part of these plans, volunteers collected one field blank and one field duplicate on each sample date. 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 (total phosphorus <5 μg/l). 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 total phosphorus samples should differ on average by ≤30%.

The quality assurance data for both the Missisquoi River and Lake Carmi watersheds indicated that both sampling programs were generally meeting the quality assurance standards for total phosphorus (quality assurance data are presented in Appendix A). For the Lake Carmi watershed, all 22 field blanks measured below the detection limit (5 μg/l). Likewise, the mean relative percent difference between duplicate samples (9%) was well below the prescribed difference for total phosphorus (30%), and only five of the 79 pairs of duplicate samples exceeded the prescribed difference. In contrast, for the Missisquoi River watershed, two of the 11 field blanks for total phosphorus, which were only collected in 2014, exceeded the detection limit (5 μg/l). However, subsequent review of these data revealed that one of these field blanks, which measured 30.3 µg/l, was collected from a site (Black Creek Bouchard Road), where the total nitrogen and turbidity blanks also exceeded their detection limits on that same date (11 June 2014). All three of these blank samples closely approximated the values of the regular sample collected at that site on that date (total phosphorus = 30.3 vs. 31.7 µg/l). Thus, it seems likely that the field blank was actually a mislabeled duplicate sample, rather than a field blank filled with distilled water; and these data should be reclassified as field duplicates, rather than field blanks, in the State and other databases. The mean relative percent difference between the field duplicates themselves (8%) was well below the prescribed difference for total phosphorus (30%), and only five of the 89 pairs of duplicate samples exceeded the prescribed difference. Thus, the quality assurance data, including both field blanks and field duplicates, indicated that the water samples were generally being collected in a repeatable manner and were generally not being contaminated during collection or processing.

In addition, as part of the data-checking process, we mapped all of the sample sites and reviewed the site locations with the appropriate staff and volunteers from the Franklin Watershed Committee; Missisquoi River Basin Association; Vermont Department of Environmental Conservation; and Vermont Agency of Agriculture, Food & Markets. We detected three errors that should be corrected:

1. First, the latitude and longitude of the sample site located along Kane's Brook (Location ID 502649, Franklin Watershed Committee site LC12) were erroneous and placed the site on the western slope of Jay Peak, approximately 26 km (16 miles) to the east of the correct location. The correct latitude and longitude should be 44.9807° North and 72.8536° West.
2. Second, the longitude of a second sample site located along Alder Run (Location ID 501136, Franklin Watershed Committee site LC11) located the site approximately 1.5 km (0.9 miles) due east of its correct location. The correct latitude and longitude should be 44.9987° North and 72.8727° West.
3. Third, one of the sites along Mud Creek (Location ID 500967, Missisquoi River Basin Association site 20) may actually represent 2-3 distinct sites that were sampled by 2-3 different people during 2006-2014. Based on discussions with one of the samplers and others associated with the Missisquoi River Basin Association, we were able to determine that the original site located behind the former Newport Center Elementary School roughly halfway between Vermont route 105 and Buzzell Road was sampled during the first 2-3 years (2006-2008) and that a different site located behind LNM Garage just east of Newport Center was sampled during the most recent 3-4 years (2012-2015). In addition, a third person sampled this "site" during some of the intervening years, but it was unclear where they sampled. Unfortunately, subsequent discussions have been unable to clarify when each of the 2-3 locations were sampled during this nine-year period. Thus, these data have been presented as if they were collected from a single site; however, they must be treated with caution given this uncertainty in exactly what was being sampled when, especially since the two known sites are separated by approximately 1,460 meters (4,790 feet), a distance that encompasses the village of Newport Center but not any major tributary streams. Ultimately, the data from this site should be assigned to their correct locations.

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 (Figure 4-5).

Figure 4. *View of Mud Creek during low flows near the village of Newport Center, Vermont on 21 May 2015.*

Figure 5. *View of Mud Creek during high flows near the village of Newport Center, Vermont on 15 October 2010.*

To approximate stream flows at the sample sites examined in this study, we relied on stream flow measurements from two gages, both maintained by the U.S. Geological Survey. For the sites in the five tributaries of the Missisquoi River, we used the daily stream flows measured for the Missisquoi River in Berkshire, Vermont [USGS station 04293500 (Missisquoi River near East Berkshire, Vermont)]. For the sites along the tributaries of Lake Carmi, we used the daily stream flows measured for the Pike River downstream of Lake Carmi [USGS station 04294300 (Pike River at East Franklin, near Enosburg Falls, Vermont)]. As is typical in northern New England, stream flows generally peaked for extended periods of time during the spring (March-April) following snowmelt, were generally low during the summer (June-August), and rose again during much of the autumn (September-November)(Figure 6-7). However, extremely high flows also occurred for shorter periods of time following heavy rain events throughout the year.

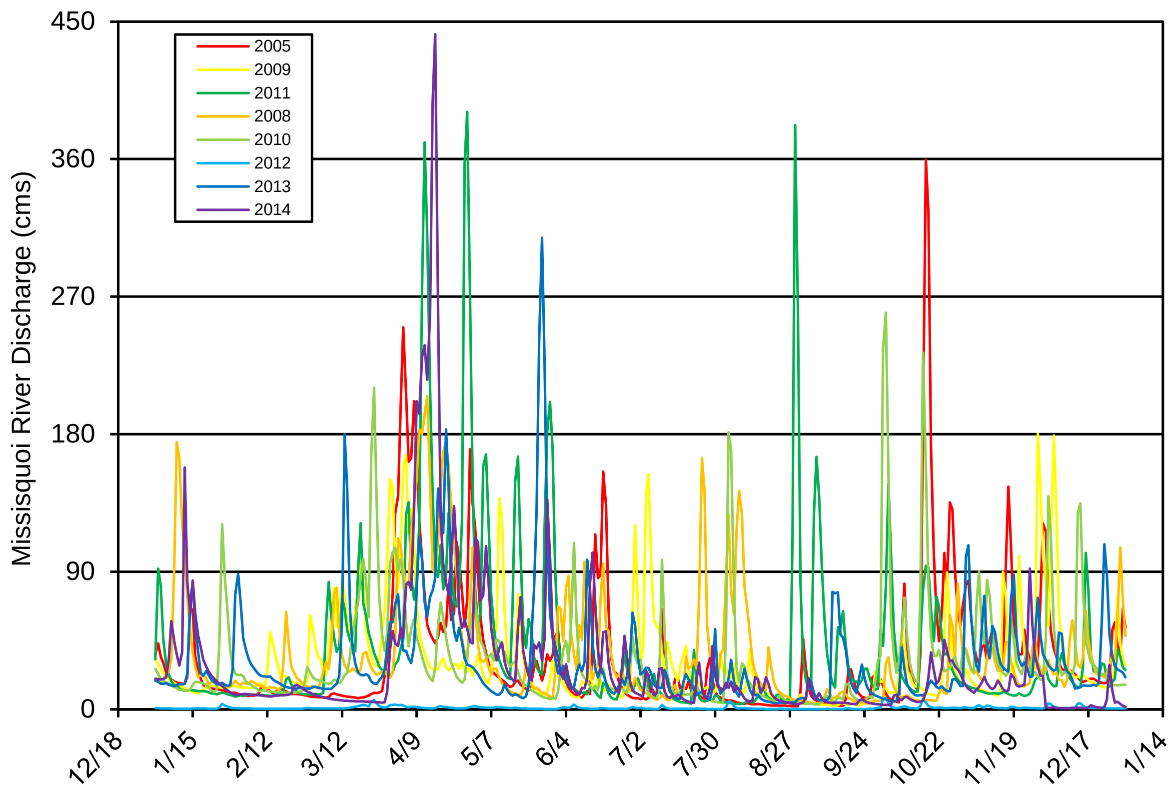

Figure 6. *Stream flows along the Missisquoi River near East Berkshire, Vermont during 2005-2014. Stream flows were measured by the U.S. Geological Survey (USGS station 04293500).*

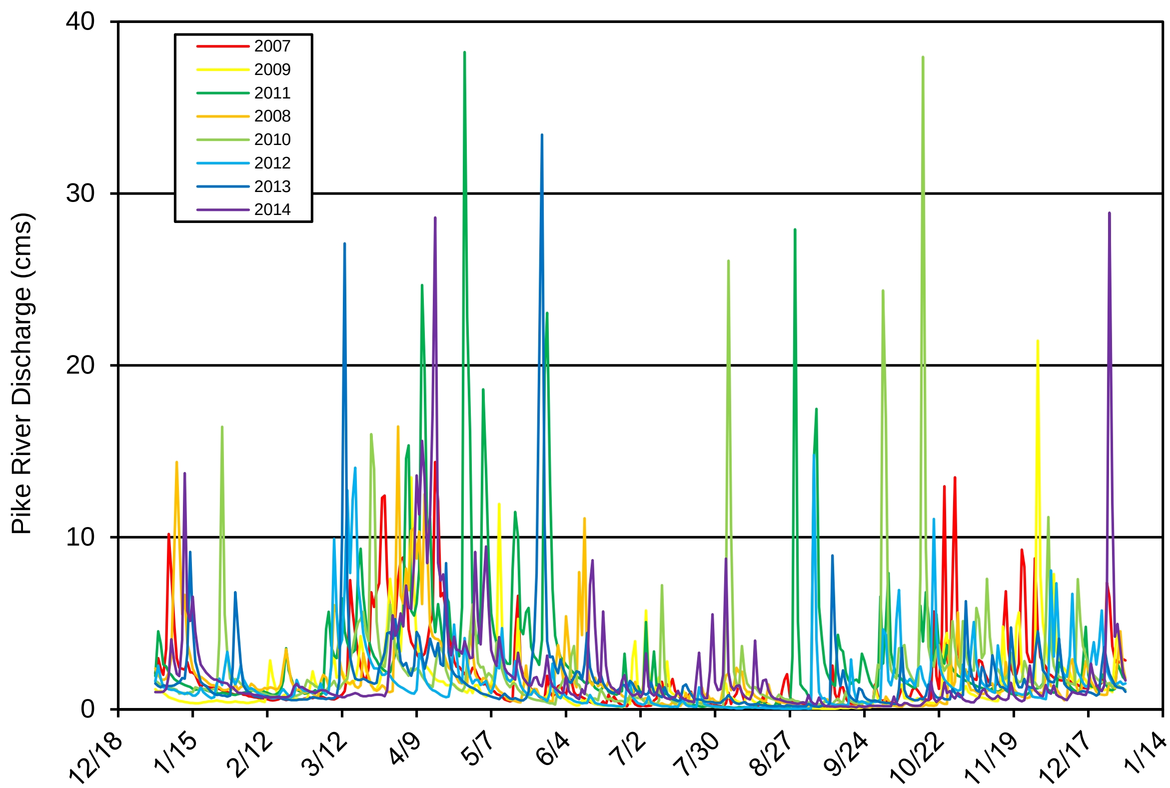

Figure 7. *Stream flows along the Pike River at East Franklin near Enosburg Falls, Vermont during 2007-2014. Stream flows were measured by the U.S. Geological Survey (USGS station 04294300).*

The water quality sampling conducted by both the Franklin Watershed Committee and the Missisquoi River Basin Association largely reflected the limited variation in and relatively low stream flows that typically occur during the summer when most of the sampling occurred (Figure 8-9). In most years, sampling started in May-June and continued through September-October. Thus, the majority of the water samples were collected at low and moderate flows: 89% of the sample dates in the Lake Carmi watershed and 85% of the sample dates in the Missisquoi River watershed. Only ten of the 96 sample dates in the Lake Carmi watershed and 15 of the 102 sample dates in the Missisquoi River basin occurred during high flows (that is, flows representing the highest 25% of all flow measurements).

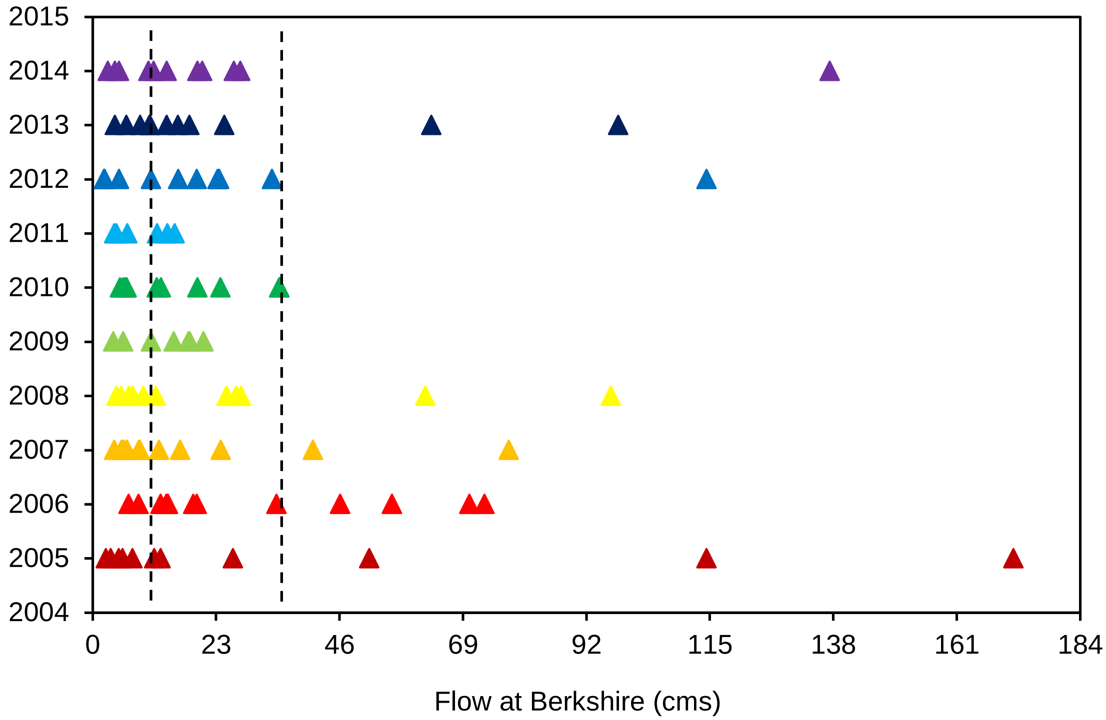

Figure 8. *Stream flows measured at the USGS gage on the Missisquoi River near East Berkshire, Vermont (USGS station 04293500) on each date that water quality samples were collected in the Missisquoi River basin during 2005-2014. The vertical lines separate low (left), moderate (center), and high (right) flows.*

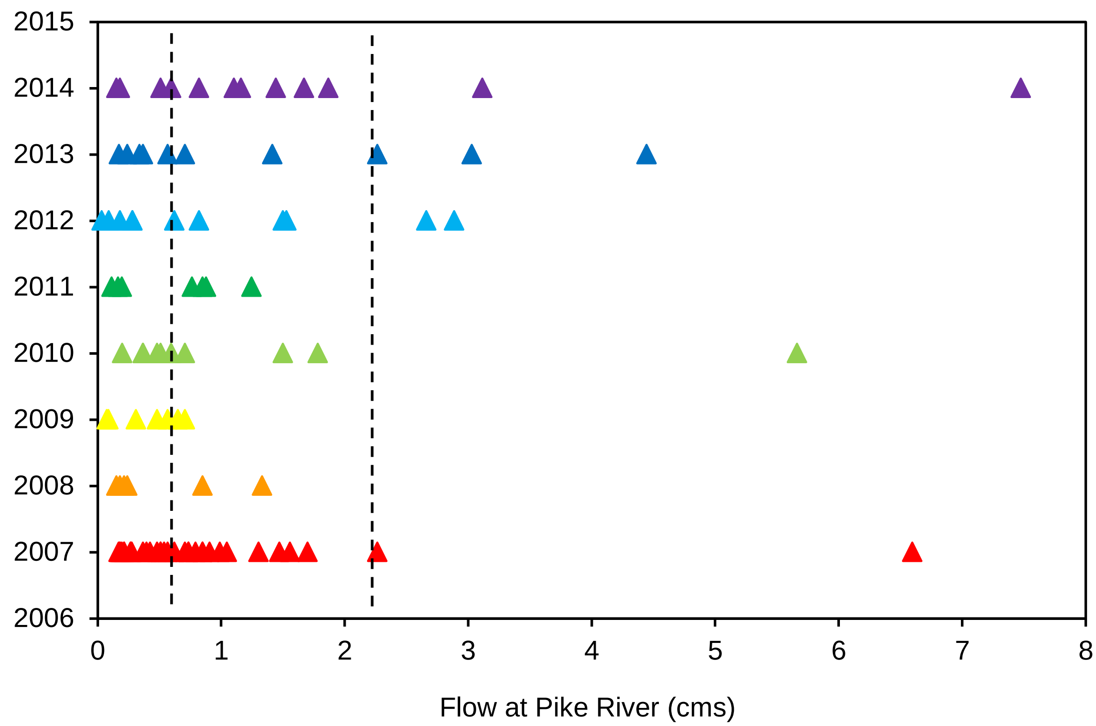

Figure 9. *Stream flows measured at the USGS gage on the Pike River at East Franklin near Enosburg Falls, Vermont (USGS station 04294300) on each date that water quality samples were collected in the Lake Carmi watershed during 2007-2014. The vertical lines separate low (left), moderate (center), and high (right) flows.*

However, the range of stream flows sampled were fairly similar among years and among sites. Across all years, high flows (i.e. those flows representing the highest 25% of all flow measurements) were sampled on only 1-4 dates in seven of the ten years in the Missisquoi River watershed (no high flows were sampled in 2009-2011) and on only 1-3 dates in five of the eight years in the Lake Carmi watershed (no high flows were sampled in 2008-2009 or 2011)(Table 2-3). Low and moderate flows, on the other hand, occurred on 70-100% of the sample dates in each year in these two watersheds. Although not all sites were sampled on all dates and in all years, the flows represented by the samples collected at different sites were remarkably similar. Low and moderate flows represented 75-100% and high flows represented only 0-25% of the samples collected at individual sites. Given that phosphorus concentrations are often strongly correlated with stream flows, this consistent sampling of flows among years and sites allowed us to make meaningful comparisons among sites and watersheds. However, it should be noted that local precipitation events may have affected flows in some but not all areas on some dates and that the smaller streams and larger rivers may have differed in their responses to snow melt and these precipitation events.

Table 2. Numbers of low, moderate, and high flows sampled in the Missisquoi River watershed during 2005-2012. Flows were measured at the USGS gage on the Missisquoi River near East Berkshire, Vermont (USGS station 04293500).

Year	Low (<10.8 cms)	Moderate (10.8-36.5 cms)	High (>36.5 cms)	% Low and Moderate Flows
2005	5	3	3	73
2006	2	6	4	67
2007	7	3	2	83
2008	6	4	2	83
2009	2	5	0	100
2010	4	6	0	100
2011	3	3	0	100
2012	3	6	1	90
2013	5	4	2	82
2014	4	6	1	91
All years	41	46	15	85

Table 3. Numbers of low, moderate, and high flows sampled in the Lake Carmi watershed during 2007-2012. Flows were measured at the USGS gage on the Pike River at East Franklin near Enosburg Falls, Vermont (USGS station 04294300).

Year	Low (<2.2 cms)	Moderate (2.2-4.3 cms)	High (>4.3 cms)	% Low and Moderate Flows
2007	18	13	2	94
2008	4	2	0	100
2009	5	2	0	100
2010	6	2	1	89
2011	3	4	0	100
2012	5	4	2	82
2013	5	2	3	70
2014	4	6	2	83
All years	50	35	10	89

Collecting water samples across this limited range of stream flows diminished our ability to identify and assess water quality problems, especially those associated with higher flows. Low flows are most informative for identifying and assessing nutrient and sediment inputs originating from point and groundwater sources. In contrast, high flows are more informative for identifying and assessing nutrient and sediment inputs originating from nonpoint sources, which typically generate the majority of the sediment and nutrient loads exported from these watersheds (Stone Environmental 2011, Environmental Protection Agency 2015). Thus, the lack of high flows greatly diminished our ability to identify and assess nonpoint sources of sediment and nutrient inputs or to calculate nutrient and sediment loads in the watersheds examined in this study. However, even with the limited range of stream flows sampled, we were able to analyze the relationships between total phosphorus concentrations and stream flows, which allowed us to better identify and assess possible nutrient and sediment sources, especially point vs. nonpoint sources of pollution, and to identify those areas within the six focal watersheds where phosphorus levels were noticeably higher and where protection and restoration projects might be most beneficial in reducing phosphorus exports and improving water quality.

Overall Water Quality Patterns

During 2004-2014, volunteers from the Missisquoi River Basin Association and Franklin Watershed Committee and staff from the Vermont Department of Environmental Conservation sampled water quality at 76 sites in the watersheds of the six tributaries of Missisquoi Bay examined in this study (Figure 10). However, in assessing overall water quality patterns across these six tributaries, we relied primarily on the data collected at 16 sites sampled by the Missisquoi River Basin Association during 2005-2014 and the 24 sites sampled by the Franklin Watershed Committee during 2008-2014 (and one site sampled by the Lake Assessment Program during 2007). These 41 sample sites differed dramatically in the numbers of dates on which they were sampled during 2005-2014: Individual sites were sampled on 1-102 dates over 1-10 years. However, almost 88% (36 of 41) of the sites were sampled on at least ten dates during the ten years covered by this study.

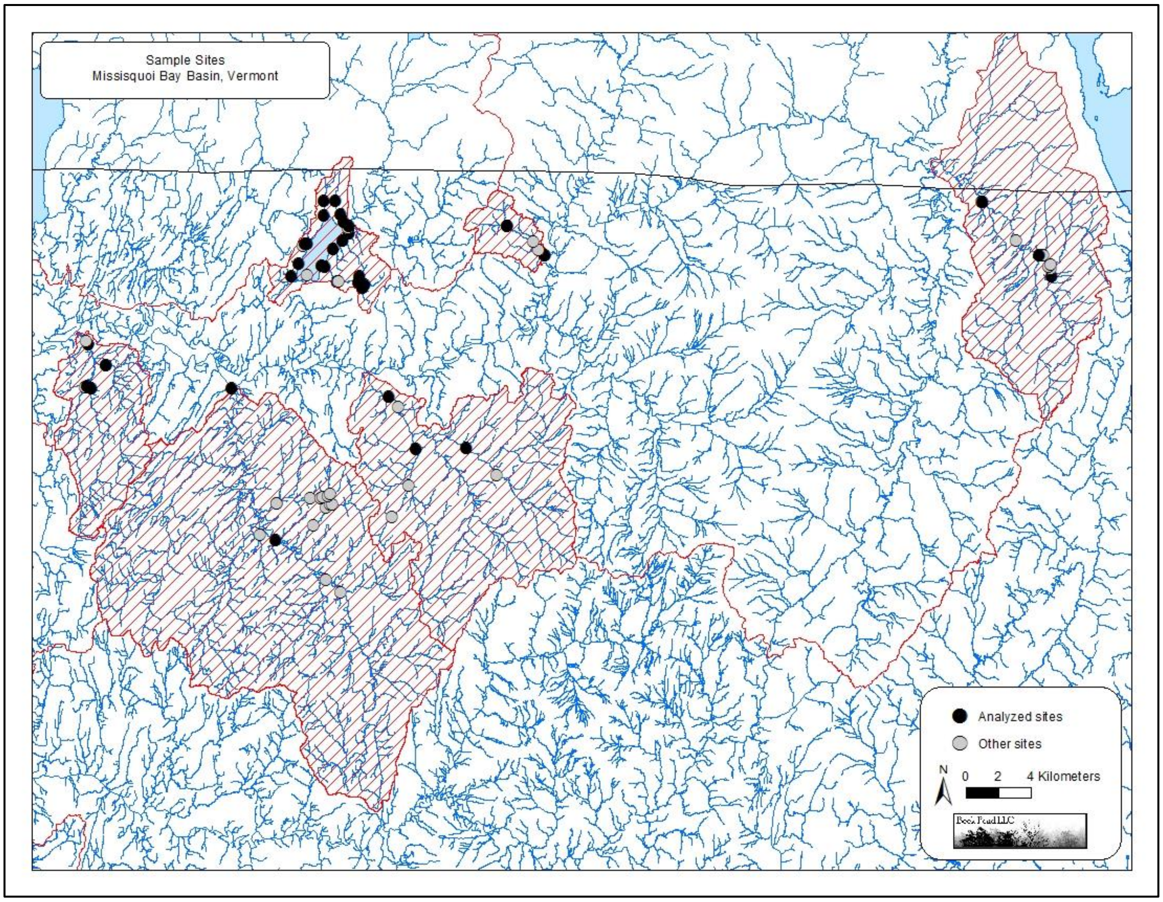

Figure 10. *Locations of the 41 sites where water quality was sampled and analyzed across the watersheds of six tributaries of Missisquoi Bay during 2005-2014. The other 35 sites that were sampled on only 1-7 dates during 2004-2014 are also mapped (small, white circles).*

Because most of the water samples from all 41 sites were collected during low or moderate flows (Table 2-3), we used all of the data to calculate the mean total phosphorus concentrations for each of the 41 sites. In general, the highest total phosphorus concentrations were measured at sites located in the watersheds of Hungerford and Godin Brooks and along two tributaries of Lake Carmi (Figure 11). In contrast, the lowest total phosphorus concentrations were measured at sites located in the watersheds of Tyler Branch, the upper section of Godin Brook, and several other tributaries of Lake Carmi. Finally, intermediate total phosphorus concentrations were measured at sites located in the watersheds of Black Creek, Mud Creek, and a few other tributaries of Lake Carmi. Previous analyses of these data had also found that total phosphorus concentrations were highest in the watersheds of Hungerford Brook, Black Creek, and Mud Creek (Deeds and Deeds 2013, Sawyer 2015). Earlier studies had also found that total phosphorus concentrations were highest in Hungerford Brook, but they also found that total phosphorus concentrations in Tyler Branch were more similar to those measured in Black and Mud Creeks (Howe et al. 2011). Likewise, the Critical Source Area study of the Missisquoi Bay Basin had modeled the highest phosphorus loadings in the watersheds of the Rock and Pike Rivers (the latter flowing out of Lake Carmi), Hungerford Brook, and Mud Creek (Stone Environmental 2011).

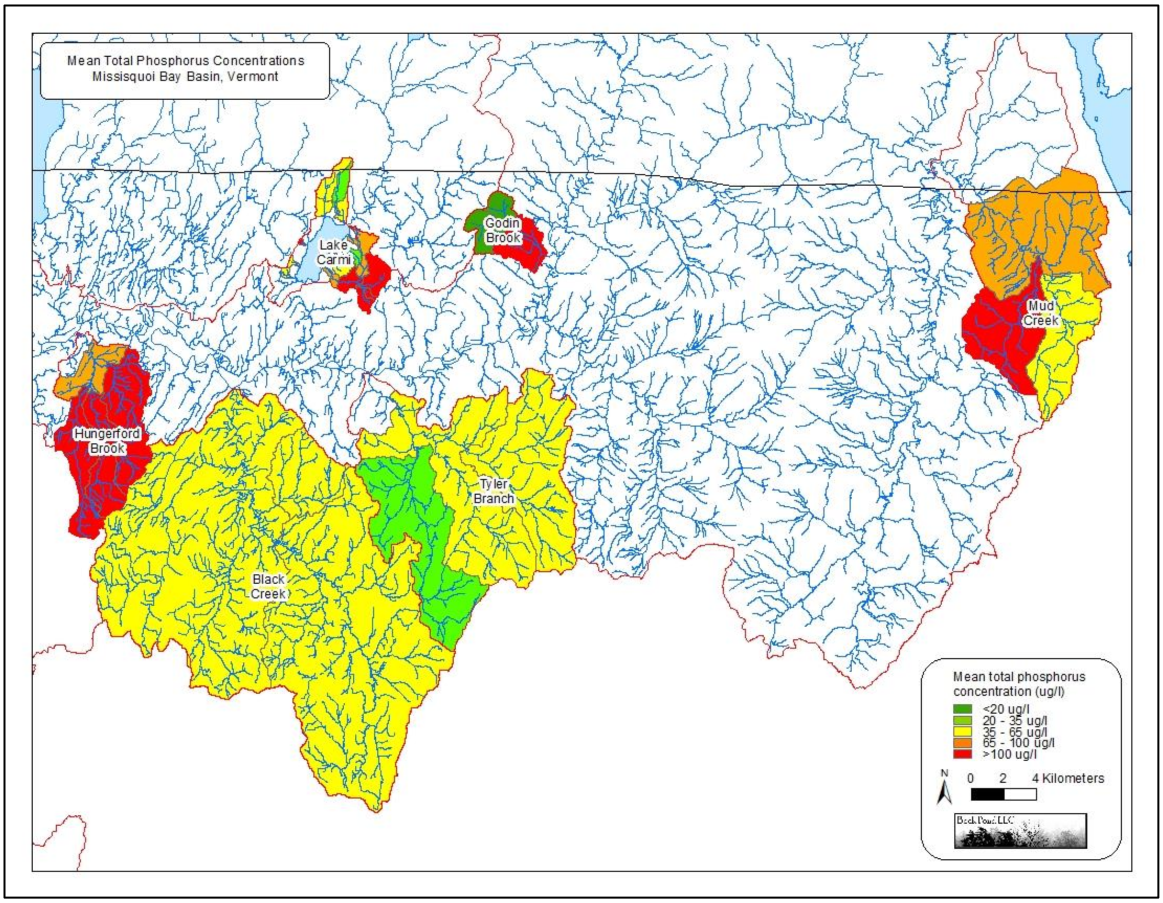

Figure 11. *Mean total phosphorus concentrations in the subwatersheds drained by each of the 41 sample sites located in six tributary watersheds of Missisquoi Bay during 2005-2014.*

Water Quality Conditions in Individual Watersheds

In addition to these overall patterns, we also examined the water quality data separately for each of the six focal tributary watersheds of Missisquoi Bay.

Hungerford Brook

Description

Hungerford Brook (Waterbody ID VT06-03) drains a small tributary watershed of the Missisquoi River in the towns of Highgate, Sheldon, Swanton, and St. Albans Town in Franklin County, Vermont. The watershed encompasses a flat to gently sloping area of approximately 51 km^2 (19.6 mi^2) ranging in elevation from approximately 37 m (120 ft) at its confluence with the Missisquoi River to 354 m (1,160 ft) atop Rocky Ridge in the southeastern part of the watershed. The dominant bedrock types are fine-grained, calcium-rich slate, phyllite, and quartzite. Surficial geology is extremely variable and includes alluvium and marine clays in the north, marine and lacustrine clays and silts in the central part, and marine sands and gravels in the south. Soils are dominated by silt loams and clay loams. The dominant land uses in the watershed are agriculture and residential. Hungerford Brook is listed as stressed due to elevated nutrient and sediment levels that are harming its ability to support aquatic life (State of Vermont 2014b). Previous studies had found that Hungerford Brook exhibited the highest concentrations of total phosphorus and other pollutants among five major tributaries of the Missisquoi River (Hungerford Brook, Black Creek, Tyler Branch, Trout Brook, and Mud Creek) and was a significant source of phosphorus loading into Missisquoi Bay (Howe et al. 2011, Stone Environmental 2011).

Water Quality Sampling

Water quality data were collected at seven sites in the Hungerford Brook watershed during 2004-2014 (Table 4, Figure 12). Three of the sites were sampled on only 1-4 dates as part of the Biomonitoring and Aquatic Studies (BASS) Program. All of these dates represented low to moderate autumnal flows. The other four sites were sampled by the Missisquoi River Basin Association (MRBA). The Highgate Road site, which was the downstream-most site, was only sampled on 24 dates in 2006-2007. The other three sites were sampled on 56-67 dates during 2008-2014 (only the Woods Hill Road site was sampled in 2014).

Table 4. Seven sites where water quality was sampled in the Hungerford Brook watershed during 2004-2014.

Location ID	Description	Sampling Program	# Dates Sampled	Years
500971	Hungerford Brook Highgate Road	MRBA site 24	24	2006-2007
500979	Hungerford Brook Woods Hill Road	MRBA site 32	67	2008-2014
500977	Hungerford Brook Trib 4	MRBA site 30	56	2008-2013
500978	Hungerford Brook Trib 6	MRBA site 31	56	2008-2013
501704	Hungerford Brook	BASS	2	2004, 2007
501705	Hungerford Brook	BASS	4	2004, 2007, 2009, 2011
501706	Hungerford Brook Trib 4	BASS	1	2009

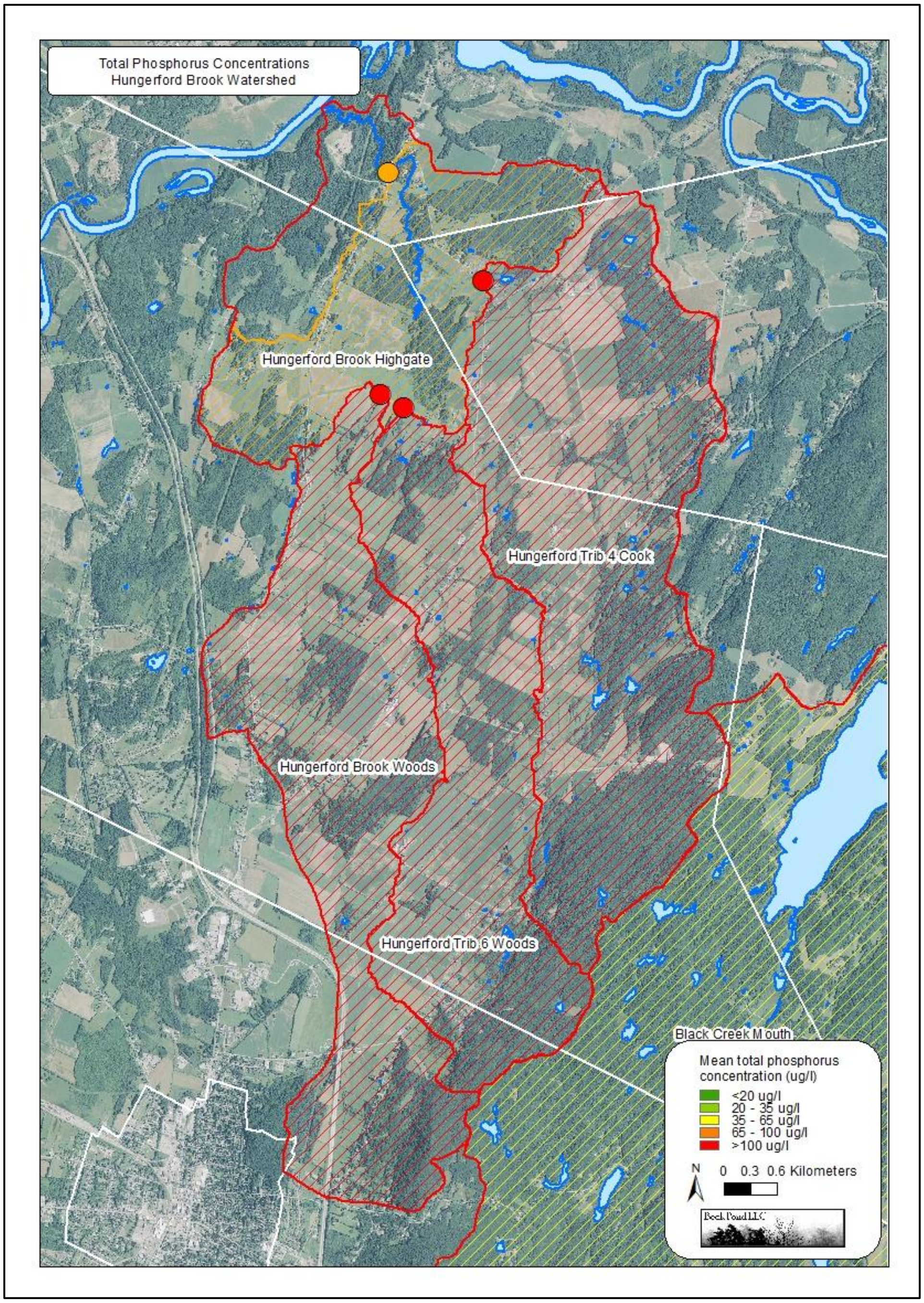

Figure 12. *Locations of seven sample sites in the Hungerford Brook watershed during 2004-2014. The sample site symbols and the subwatersheds drained by each sample site are color-coded according to the mean total phosphorus concentrations measured at each associated site.*

Results and Discussion

Total phosphorus concentrations were very high throughout the Hungerford Brook watershed (Table 5, Figure 12). At the three sites sampled during 2013-2014, total phosphorus concentrations generally increased with increasing stream flows (Figure 13). Finally, there appeared to be no consistent change in total phosphorus concentrations at these three sites during 2008-2014 (Figure 14). In most years, phosphorus levels at all three Biomonitoring and Aquatic Studies (BASS) sites were also high, even though these samples were collected during low autumnal flows. These results also parallel those reported in earlier studies, which found that total phosphorus concentrations were extremely high during both low and high flows and that phosphorus loading rates were very high in Hungerford Brook (Howe et al. 2011, Stone Environmental 2011).

Table 5. Summary of total phosphorus concentrations at four sites in the Hungerford Brook watershed during 2006-2014.

MRBA Site #	Location	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
2006-2014:					
24	Highgate Road	24	78.2	100.0	51-490
32	Woods Hill Road	67	92.7	112.3	31-482
30	Trib 4	56	90.0	118.6	34-497
31	Trib 6	56	87.5	100.9	17-610
2013-2014 Only:					
32	Woods Hill Road	22	90.7	99.3	
30	Trib 4	11	62.6	73.3	
31	Trib 6	11	59.8	65.2	

Figure 13. *Total phosphorus concentrations in relation to stream flow at three sites in the Hungerford Brook watershed during 2013-2014. Stream flows were measured at the USGS gage on the Missisquoi River near East Berkshire, Vermont (USGS station 04293500). The regression lines indicate the exponential relationships between the two parameters.*

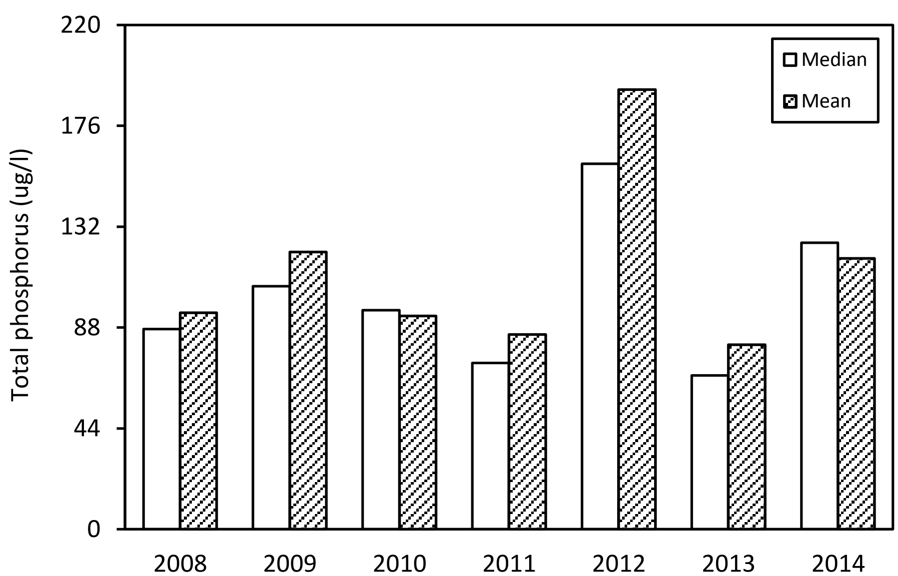

Figure 14. *Mean and median total phosphorus concentrations at the Woods Hill Road site on Hungerford Brook during 2008-2014.*

Based on these data and observations, it seems likely that most of the phosphorus in this watershed is originating from nonpoint sources. Possible nonpoint sources include surface runoff from the many agricultural fields in this watershed and from streambank erosion, especially due to the finer soils found in this watershed (Figure 15).

Figure 15. *Numerous agricultural fields and unstable streambanks border much of Hungerford Brook, such as this area along Woods Hill Road in Swanton, Vermont on 21 May 2015.*

<u>Recommendations</u>

Overall, Hungerford Brook exhibited the highest total phosphorus concentrations of the five Missisquoi River tributaries that we examined. Retaining the three current sites and adding five new sites would further pinpoint and assess possible nutrient and sediment sources along this tributary:

1. Retain the three sites on Hungerford Brook and two of its tributaries (MRBA sites 30-32).
2. Add one site on the main stem of Hungerford Brook where it flows beneath Highgate Road. This site would provide an overall assessment of water quality conditions in most of the Hungerford Brook watershed. This site (MRBA site 24) was sampled previously in 2006-2007 but has not been sampled since.

3. Add four new sites along three tributaries of Hungerford Brook in order to better pinpoint and assess possible nutrient and sediment sources: western tributary further upstream at Hazard Road, southern tributary further upstream at Viens Road, and the two branches further upstream along the eastern tributary.

Due to the low number of sample sites in the Hungerford Brook watershed, it was not possible to identify any specific areas for on-the-ground investigation at this time. Such efforts will require additional, targeted water quality sampling to better pinpoint and assess possible nutrient and sediment sources in this watershed.

Black Creek

Description

Black Creek (Waterbody ID VT06-05) drains a large tributary watershed of the Missisquoi River in the towns of Sheldon, Swanton, St. Albans, Fairfield, Fairfax, Fletcher, and Bakersfield in Franklin and Lamoille Counties, Vermont. The watershed encompasses a flat to steep area of approximately 311 km^2 (120 mi^2) ranging in elevation from approximately 102 m (335 ft) at its confluence with the Missisquoi River to 643 m (2,110 ft) atop Fletcher Mountain in the southeastern corner of the watershed. The dominant bedrock types are mostly fine-grained, calcium-rich phyllite and schist. Surficial geology is variable but dominated by glacial till and bedrock exposures on the ridges and lake sands, glacial lacustrine clays and silts, and alluvium in the valleys. Soils are dominated by silt loams and fine sandy loams. Fairfield Pond, covering 180 ha (446 acres) is located in the western part of this watershed. The Black Creek watershed is dominated by forests in the higher elevations, especially in the southern and western parts of the watershed, and agriculture in the north and central valleys of the watershed. Black Creek is listed as stressed due to elevated nutrient, sediment, and *Escherichia coli* (*E. coli*) levels that are harming its ability to support aquatic life (State of Vermont 2014b), and Wanzer Brook is listed as an impaired surface water needing a TMDL for the elevated nutrient and sediment levels that are harming its ability to support aquatic life (State of Vermont 2014a, Part A). Both Fairfield Pond and Fairfield Swamp Pond are listed as being altered by locally abundant Eurasian watermilfoil (*Myriophyllum spicatum*) populations, an aquatic invasive species (State of Vermont 2014a, Part E).

Water Quality Sampling

Water quality data were collected at 17 sites in the Black Creek watershed during 2004-2014 (Table 6, Figure 16). Of these, 14 sites were sampled on only 1-7 dates as part of the Biomonitoring and Aquatic Studies (BASS) Program. All of these dates represented low to moderate autumnal flows. The other three sites were sampled by the Missisquoi River Basin Association (MRBA) and were sampled on 61-98 dates during 2005-2014.

Table 6. Seventeen sites where water quality was sampled in the Black Creek watershed during 2004-2014.

Location ID	Description	Sampling Program	# Dates Sampled	Years
500961	Black Creek Bouchard Road	MRBA site 14	98	2005-2014
500972	Black Creek Ryan Road	MRBA site 25	76	2007-2014
500976	Wanzer Brook	MRBA site 29	61	2008-2014
501708	Black Creek	BASS	1	2009
501711	Dead Creek	BASS	1	2009
501715	Wanzer Brook	BASS	2	2004, 2006
501716	Wanzer Brook	BASS	3	2004, 2006, 2010
501717	Wanzer Brook	BASS	7	2007, 2010, 2011, 2013
501718	Wanzer Brook	BASS	2	2009-2010
501719	Wanzer Brook	BASS	7	2007, 2010, 2011, 2013
501720	Wanzer Brook	BASS	2	2009-2010
501721	Chester Brook	BASS	1	2007
501722	Chester Brook	BASS	6	2007, 2010
501723	Chester Brook	BASS	2	2007, 2011
502595	Black Creek	BASS	1	2009
506157	Chester Brook	BASS	1	2013
506358	Fairfield River	BASS	1	2013

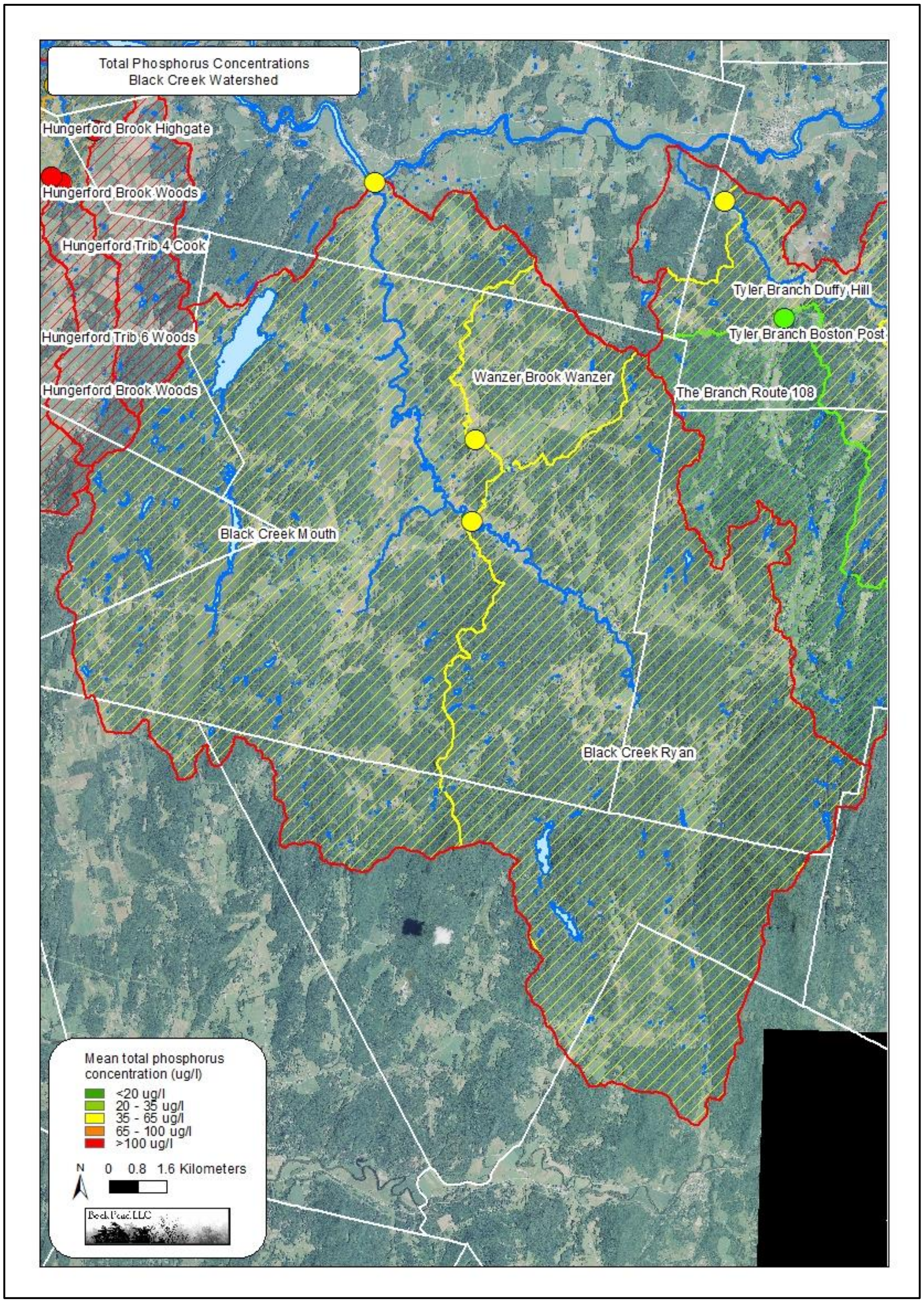

Figure 16. *Locations of seventeen sample sites in the Black Creek watershed during 2004-2014. The sample site symbols and the subwatersheds drained by each sample site are color-coded according to the mean total phosphorus concentrations measured at each associated site.*

Results and Discussion

Total phosphorus concentrations were moderately high throughout the Black Creek watershed (Table 7, Figure 16). At the three sites sampled during 2013-2014, total phosphorus concentrations generally increased with increasing stream flows, especially at the one site on Wanzer Brook (Figure 17). Finally, total phosphorus concentrations at the site located near the mouth of Black Creek (Bouchard Road) were generally lower during 2009-2014 than during 2005-2007 (Figure 18). In contrast, total phosphorus concentrations generally increased during 2007-2014 at the upstream site located along Ryan Road (Figure 19). In most years, phosphorus levels at all of the Biomonitoring and Aquatic Studies (BASS) sites, including those on Wanzer and Chester Brooks, were relatively low, perhaps because these samples were generally collected during low autumnal flows.

Table 7. Summary of total phosphorus concentrations at three sites in the Black Creek watershed during 2005-2014.

MRBA Site #	Location	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
2005-2014:					
14	Bouchard Road	98	44.1	64.0	18-555
25	Ryan Road	76	36.9	63.2	18-959
29	Wanzer Brook	61	23.4	36.6	12-146
2013-2014 Only:					
14	Bouchard Road	21	41.4	53.9	
25	Ryan Road	21	48.1	106.7	
29	Wanzer Brook	18	23.7	37.3	

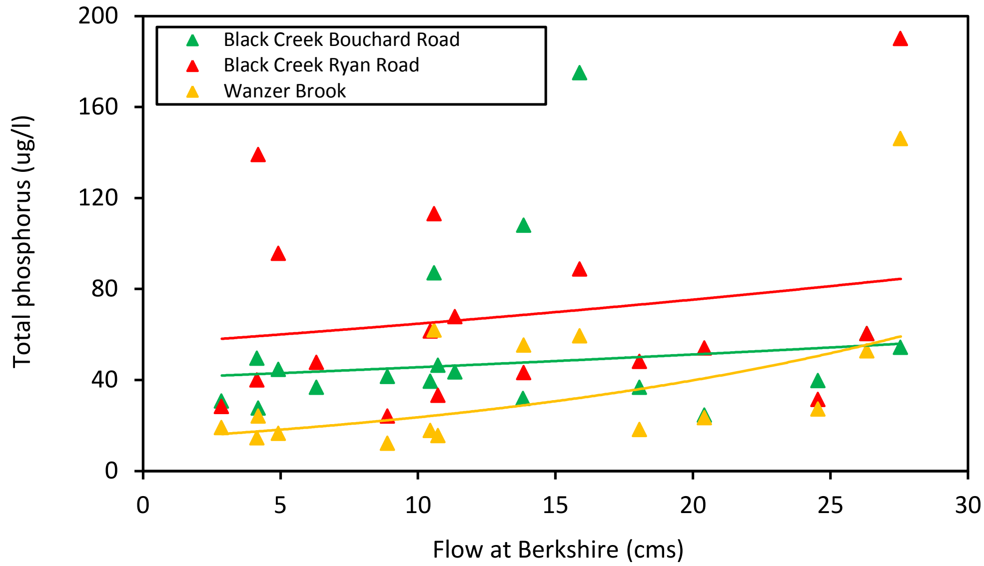

Figure 17. *Total phosphorus concentrations in relation to stream flow at three sites in the Black Creek watershed during 2013-2014. Stream flows were measured at the USGS gage on the Missisquoi River near East Berkshire, Vermont (USGS station 04293500). The regression lines indicate the exponential relationships between the two parameters.*

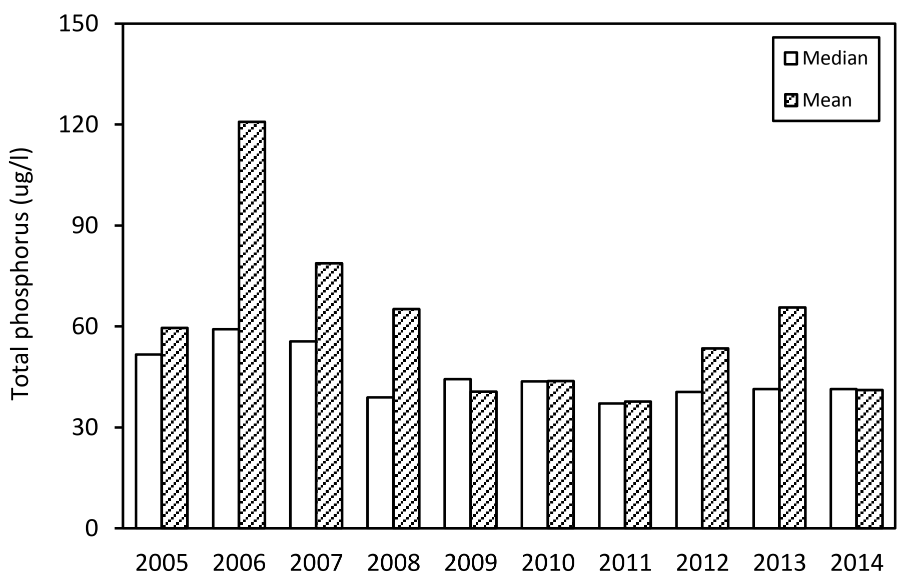

Figure 18. *Mean and median total phosphorus concentrations at the Bouchard Road site on Black Creek during 2005-2014.*

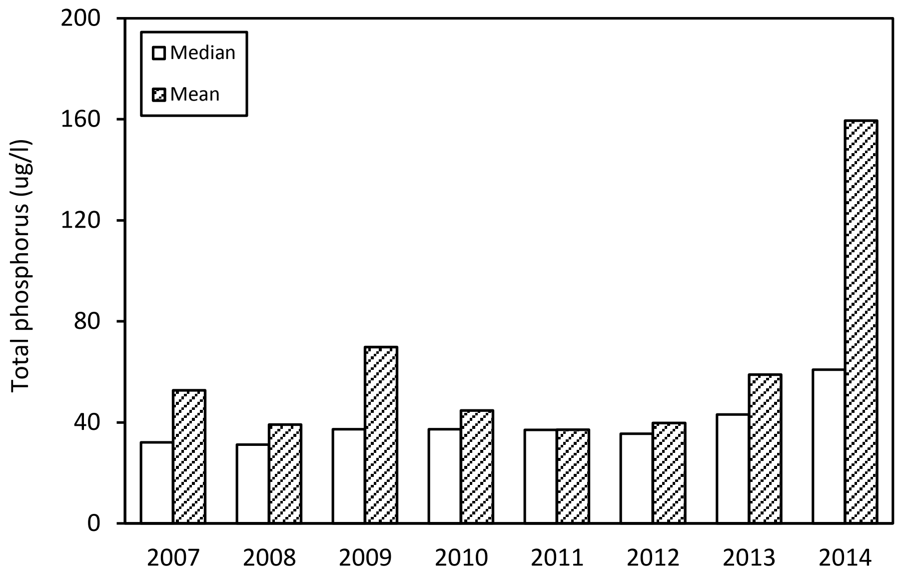

Figure 19. *Mean and median total phosphorus concentrations at the Ryan Road site on Black Creek during 2007-2014.*

Based on these data, it seems likely that most of the phosphorus in this watershed is originating from nonpoint sources. Possible nonpoint sources include surface runoff from the many agricultural fields in this watershed and from streambank erosion (Figure 20). There was some indication that water quality conditions may be deteriorating in the upper watershed. Based on field observations on 21 May 2015, when the water flowing out of Black Creek was very muddy, there may be significant sources of nutrients and sediment between Pumpkin Village and Chester A. Arthur Roads in Sheldon (Figure 21). This area is characterized by the presence of many large agricultural fields in the floodplain along the river and was also flagged by an earlier study as an important source of phosphorus loading into Missisquoi Bay (Stone Environmental 2011).

Figure 20. *Numerous agricultural fields and unstable streambanks border Black Creek, such as this area upstream of Ryan Road in Fairfield, Vermont on 21 May 2015. Note that the channel has been dredged and straightened in this area.*

Figure 21. *The muddy water flowing from Black Creek into the Missisquoi River just across from Sheldon Junction, Vermont on 21 May 2015 indicated that there may be significant nutrient and sediment sources further upstream.*

Recommendations

Black Creek exhibited moderately high total phosphorus concentrations. Retaining two of the three current sites and adding six new sites would further pinpoint and assess possible nutrient and sediment sources along this tributary:

1. The two sites along the main stem of Black Creek (MRBA sites 14 and 25) should be retained, because these sites provide an overall assessment of water quality conditions in much of the Black Creek watershed.
2. The site on Wanzer Brook (MRBA site 29) could be deleted, as water quality is generally good in this tributary, although other data suggest that there may be water quality issues in this tributary.
3. Four sites should be added along the main stem of Black Creek at Pumpkin Village, Paradee, and Chester A. Arthur Roads and upstream of the village of East Fairfield to better pinpoint the areas of the Black Creek watershed that are exporting the largest amounts of nutrients and sediment. The site located upstream of East Fairfield was sampled in 2009 as part of the Biomonitoring and Aquatic Studies (BASS) Program (Location ID 502595).

4. Two sites should be added along two tributaries of Black Creek, including Dead Creek and the Fairfield River. Both of these sites would help pinpoint and assess the areas of the Black Creek watershed that are exporting the largest amounts of nutrients and sediment. Both sites were sampled in 2009 or 2013 as part of the Biomonitoring and Aquatic Studies (BASS) Program (Location ID 501711 and 506358).

Due to the low number of sample sites in the Black Creek watershed, it was not possible to identify specific areas for on-the-ground investigation at this time. Such efforts will require additional, targeted sampling to better pinpoint and assess possible nutrient and sediment sources in this watershed. However, one possible first effort would be to further examine areas along the main stem of Black Creek between Pumpkin Village and Chester A. Arthur Roads in Sheldon, as our field observations indicated that there may be significant nutrient and sediment sources in this area.

Tyler Branch

Description

Tyler Branch (Waterbody ID VT06-06) drains a large tributary watershed of the Missisquoi River in the towns of Sheldon, Fairfield, Enosburg, Bakersfield, and Belvidere in Franklin and Lamoille Counties, Vermont. The watershed encompasses a moderately hilly to steep area of approximately 150 km^2 (58 mi^2) ranging in elevation from approximately 107 m (350 ft) at its confluence with the Missisquoi River to 994 m (3,261 ft) atop the north peak of the Cold Hollow Mountains in the southeastern corner of the watershed. The dominant bedrock types are mostly fine-grained, calcium-rich phyllite and schist. Surficial geology is variable but dominated by glacial till and bedrock exposures on the ridges and fluvial gravels and alluvium in the valleys. Soils are dominated by fine sandy loams, silt loams, and loamy sands. The dominant land uses are forestry on the ridges and agriculture in the river valleys. Tyler Branch is listed as stressed due to elevated nutrient, sediment, and *E. coli* levels that are harming its ability to support aquatic life, aesthetics, and contact recreation; and The Branch is listed as stressed due to elevated sediment levels, streambank erosion, and channelization that are harming aquatic habitats and their ability to support aquatic life (State of Vermont 2014b).

Water Quality Sampling

Water quality data were collected at seven sites in the Tyler Branch watershed during 2004-2014 (Table 8, Figure 22). Four of these sites were sampled on only one date each as part of the Biomonitoring and Aquatic Studies (BASS) Program. All of these dates represented low to moderate autumnal flows. The other three sites were sampled by the Missisquoi River Basin Association (MRBA) and were sampled on 67-101 dates during 2005-2014.

Table 8. Seven sites where water quality was sampled in the Tyler Branch watershed during 2004-2014.

Location ID	Description	Sampling Program	# Dates Sampled	Years
500957	Tyler Branch Duffy Hill Road	MRBA site 10	101	2005-2014
500975	Tyler Branch Boston Post Road	MRBA site 28	67	2008-2014
500974	The Branch	MRBA site 27	67	2008-2014
501726	Tyler Branch	BASS	1	2004
501727	Tyler Branch	BASS	1	2009
501728	The Branch	BASS	1	2004
501730	Beaver Meadow Brook	BASS	1	2004

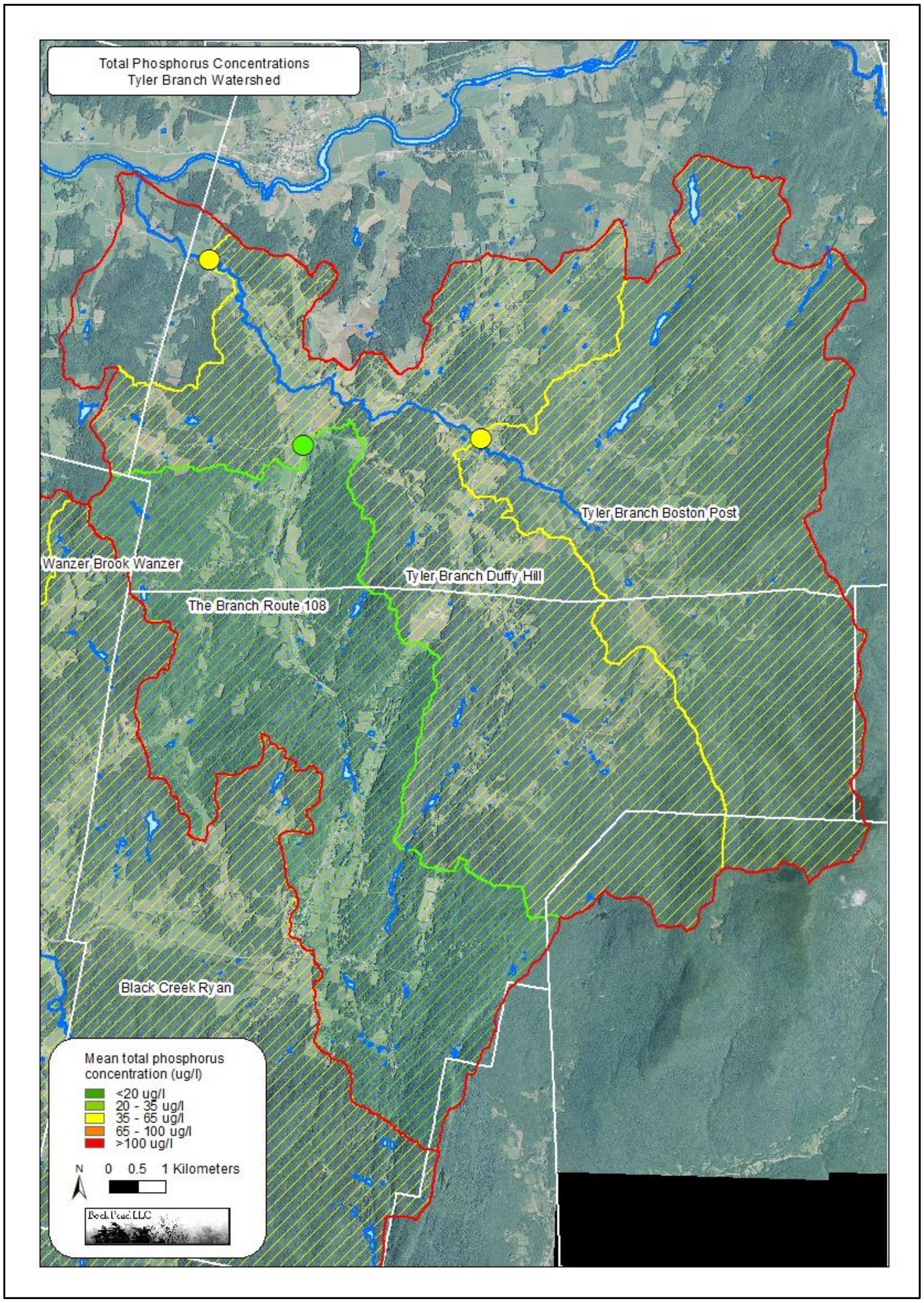

Figure 22. *Locations of seven sample sites in the Tyler Branch watershed during 2004-2014. The sample site symbols and the subwatersheds drained by each sample site are color-coded according to the mean total phosphorus concentrations measured at each associated site.*

Results and Discussion

Total phosphorus concentrations were generally low along Tyler Branch and The Branch (Table 9, Figure 22). At the three sites sampled during 2013-2014, total phosphorus concentrations generally increased with increasing stream flows, especially at downstream-most site (Figure 23). Finally, there seemed to be no consistent change in total phosphorus concentrations at the downstream-most site on Tyler Branch (Duffy Hill Road) during 2005-2014, but there seemed to be slight but consistent decreases at the upstream site on Tyler Branch (Boston Post Road) and the site on The Branch during 2008-2014 (Figure 24-25). In all years, phosphorus levels at all of the Biomonitoring and Aquatic Studies (BASS) sites were relatively low, probably because these samples were collected during relatively low, autumnal flows.

Table 9. Summary of total phosphorus concentrations at three sites in the Tyler Branch watershed during 2005-2014.

MRBA Site #	Location	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
2005-2014:					
10	Duffy Hill Road	101	16.9	49.9	8-1,610
28	Boston Post Road	67	14.0	40.4	6-760
27	The Branch	67	15.8	30.2	5-499
2013-2014 Only:					
10	Duffy Hill Road	22	18.5	50.5	
28	Boston Post Road	22	12.3	43.3	
27	The Branch	22	12.6	25.9	

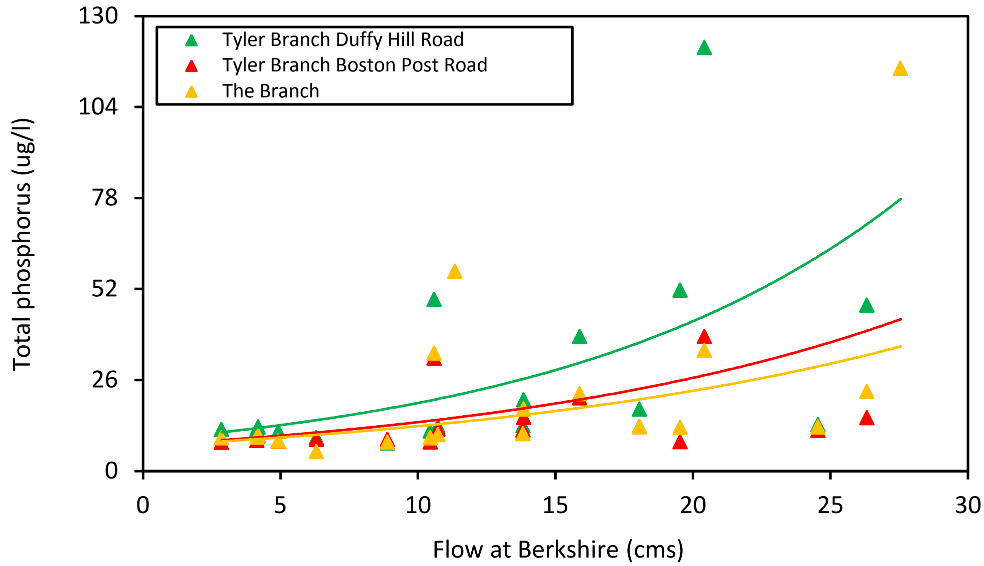

Figure 23. *Total phosphorus concentrations in relation to stream flow at three sites in the Tyler Branch watershed during 2013-2014. Stream flows were measured at the USGS gage on the Missisquoi River near East Berkshire, Vermont (USGS station 04293500). The regression lines indicate the exponential relationships between the two parameters.*

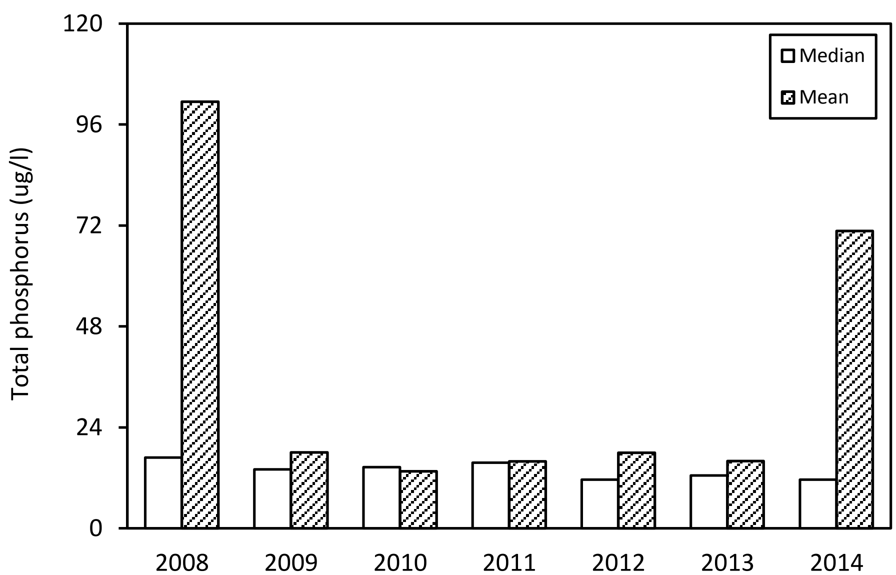

Figure 24. *Mean and median total phosphorus concentrations at the Boston Post Road site on Tyler Branch during 2008-2014.*

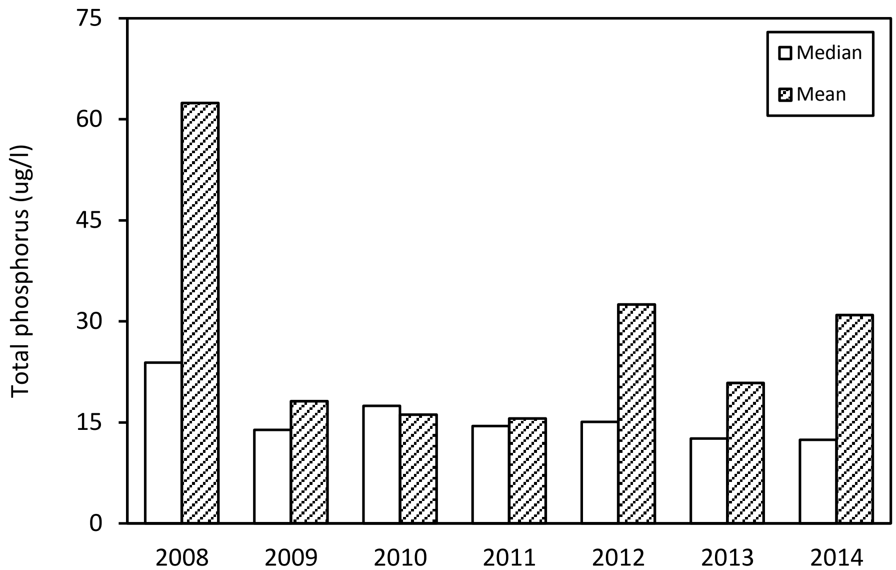

Figure 25. *Mean and median total phosphorus concentrations at the Vermont Route 108 site on The Branch during 2008-2014.*

Based on these data, it seems likely that most of the phosphorus in this watershed is originating from nonpoint sources, such as the agricultural fields located in the valleys of these streams. However, the relatively low phosphorus levels suggest that phosphorus exports from this watershed are less significant, perhaps due to the relatively larger amounts of forested lands and forested riparian buffers (Figure 26). The lower phosphorus concentrations identified in this study generally parallel the Critical Source Area analysis that showed relatively lower phosphorus loadings in much of the Tyler Branch watershed, especially along The Branch and Bogue Branch (Stone Environmental 2011). In contrast, the short-term monitoring program had found that the total phosphorus concentrations were similar to those reported for Black and Mud Creeks (Howe et al. 2011). Perhaps this disparity reflected the improving water quality conditions measured at two of the three sites analyzed (Figure 24-25).

Figure 26. *The watershed of Tyler Branch is more forested than some of the other tributary watersheds of the Missisquoi River as evidenced by this area just upstream of Duffy Hill Road in Enosburg, Vermont on 21 May 2015.*

Recommendations

Given the generally good water quality conditions measured along Tyler Branch and The Branch, no major changes in the water quality monitoring program are recommended at this time. Retaining the three current sites and adding one new site would allow continued monitoring of this stream and its major tributaries:

1. Retain the three sites along Tyler Branch and one of its tributaries (The Branch), because these three sites provide a good overall assessment of water quality in much of the Tyler Branch watershed. However, if resources are needed elsewhere, all but the downstream-most site (MRBA site 10) could be deleted, but the latter should be retained to provide continued monitoring of this major tributary of the Missisquoi River and to provide context for a new site on Bogue Branch.
2. Add one new site along Bogue Branch where it flows alongside or beneath Bogue Road, because this tributary has not been assessed previously.

Given the relative good water quality conditions measured in the Tyler Branch watershed, we did not identify specific areas or possible sediment or nutrient sources for on-the-ground investigation at this time. Such efforts should be undertaken, however, if future, more targeted sampling does pinpoint possible nutrient and sediment sources in this watershed.

Godin Brook

Description

Godin Brook drains a small tributary watershed of the Missisquoi River in the town of Berkshire in Franklin County, Vermont. The watershed encompasses a moderately hilly area of approximately 13.7 km^2 (5.3 mi^2) ranging in elevation from approximately 125 m (410 ft) at its confluence with the Missisquoi River to 355 m (1,165 ft) in the northern part of the watershed. The dominant bedrock types are greenstone and fine-grained, calcium-rich schist and phyllite. Surficial geology is mostly glacial till and occasional bedrock exposures or wetland peats and mucks. Soils are dominated by fine sandy loams. The dominant land uses in the watershed are agriculture, forestry, and residential. Godin Brook already has an approved Total Maximum Daily Load (TMDL) due to elevated *E. coli* levels but also needs a TMDL due to elevated levels of nutrients and sediment that are impacting aquatic habitats, their ability to support aquatic life, and aesthetics (State of Vermont 2014a, Parts A and D).

Water Quality Sampling

Water quality data were collected at six sites in the Godin Brook watershed during 2004-2014 (Table 10, Figure 27). Three of these sites were sampled on only 1-2 dates as part of the Biomonitoring and Aquatic Studies (BASS) Program. Both of these dates represented low to moderate autumnal flows. The other three sites were sampled by the Missisquoi River Basin Association (MRBA) and were sampled on 7-29 dates during 2011-2014.

Table 10. Six sites where water quality was sampled in the Godin Brook watershed during 2004-2014.

Location ID	Description	Sampling Program	# Dates Sampled	Years
505686	Godin Brook Marvin Road	MRBA site 33	29	2011-2014
508499	Godin Brook Upper North	MRBA site 34	10	2013-2014
-	Godin Brook Upper South	MRBA site 35	7	2014
501739	Godin Brook	BASS	1	2004
501740	Godin Brook	BASS	2	2004, 2009
501742	Godin Brook	BASS	1	2009

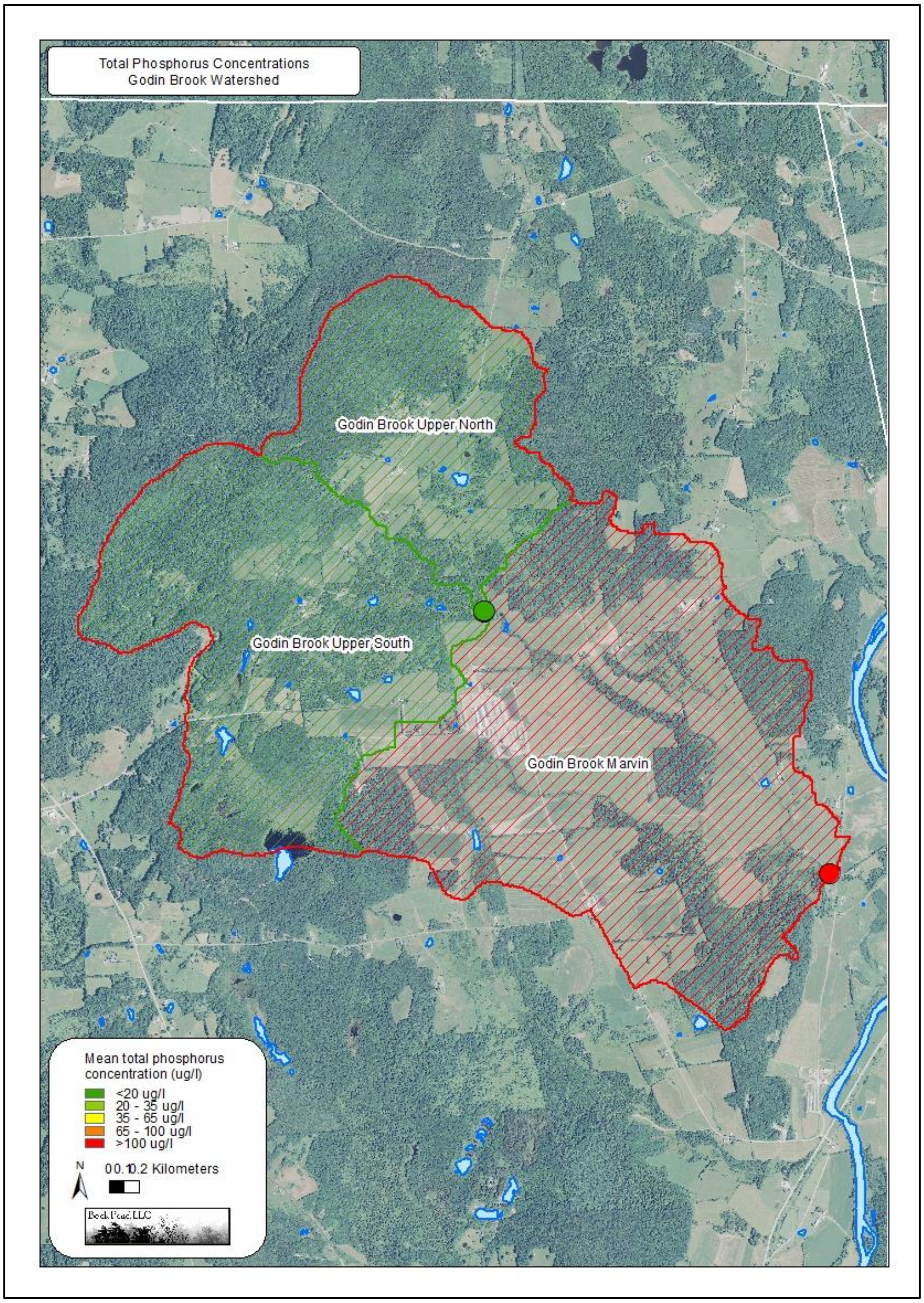

Figure 27. *Locations of six sample sites in the Godin Brook watershed during 2004-2014. The sample site symbols and the subwatersheds drained by each sample site are color-coded according to the mean total phosphorus concentrations measured at each associated site.*

Results and Discussion

The water quality data indicated that there were serious water quality problems in the Godin Brook watershed (Table 11, Figure 27). In particular, the downstream-most site (Marvin Road) exhibited very high total phosphorus concentrations despite all but being collected at low and moderate flows. These high values contrasted sharply with those measured at the two upstream sites, where total phosphorus concentrations were generally low. At the three sites sampled during 2013-2014, total phosphorus concentrations generally increased with increasing stream flows, especially at the downstream-most site (Figure 28). Finally, there was some indication that total phosphorus concentrations may have increased at the downstream-most site during 2011-2014, especially at the higher flows that likely raised the mean relative to the median values (Figure 29). Unfortunately, this analysis was not conclusive due to differences in the numbers of samples collected each year and the numbers of high flows in the different years (none in 2011, one in 2011, two in 2013, and one in 2014). Total phosphorus concentrations at the three Biomonitoring and Aquatic Studies (BASS) sites were moderately high (range = 39.4-60.0 µg/l), despite having been collected during low or moderate flows.

Table 11. Summary of total phosphorus concentrations at three sites in the Godin Brook watershed during 2011-2014.

MRBA Site #	Location	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
2011-2014:					
33	Marvin Road	29	65.0	169.9	11-1,400
34	Upper North	10	16.3	18.7	12-35
35	Upper South	7	16.8	18.9	12-31
2013-2014 Only:					
33	Marvin Road	14	74.2	246.3	
34	Upper North	10	16.3	18.7	
35	Upper South	7	16.8	18.9	

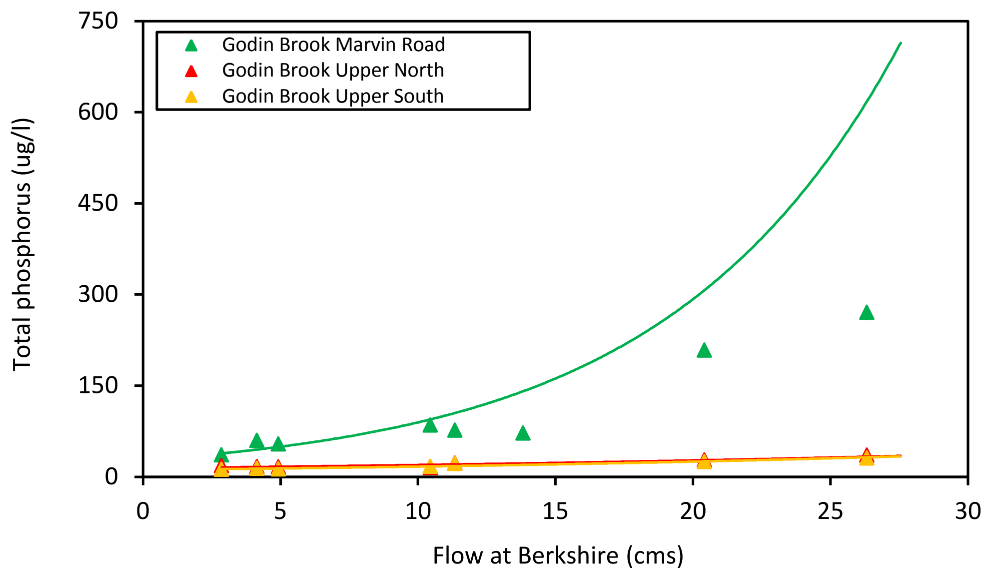

Figure 28. *Total phosphorus concentrations in relation to stream flow at three sites in the Godin Brook watershed during 2013-2014. Stream flows were measured at the USGS gage on the Missisquoi River near East Berkshire, Vermont (USGS station 04293500). The regression lines indicate the exponential relationships between the two parameters.*

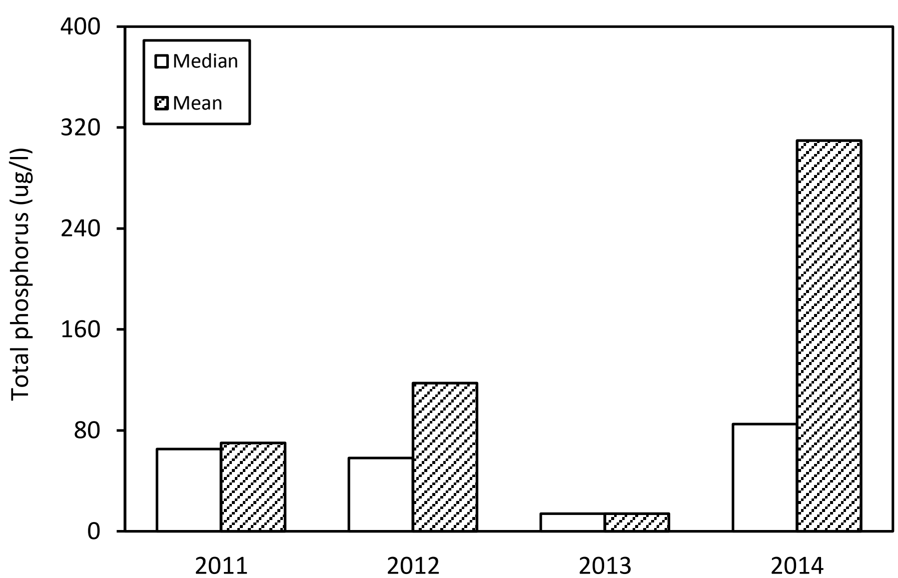

Figure 29. *Mean and median total phosphorus concentrations at the Marvin Road site on Godin Brook during 2011-2014.*

Based on these data, it seems likely that much of the phosphorus in this watershed is originating from nonpoint sources that increase dramatically during heavy rains. Possible nonpoint sources include surface erosion and runoff from the many agricultural fields, especially corn and other row crops (Figure 30). However, the high total phosphorus concentrations at the Marvin Road site, even during low flows, suggest that there may also be point sources of phosphorus, possibly originating from farm roads and other impervious surfaces, such as the large barns, silage pads and other storage bunkers at the large farm operation along Richford Road. In contrast, the part of the watershed upstream of the two upstream sites is dominated by forest interspersed with some agricultural fields, one small farm, and residences. This difference in land uses is likely responsible for the lower phosphorus levels measured at the two upstream sites.

Figure 30. *Numerous agricultural fields border Godin Brook and its tributary streams, such as this area at the end of Godin Road in Berkshire, Vermont on 13 April 2015.*

Recommendations

Godin Brook exhibited the second highest total phosphorus concentrations of the five Missisquoi River tributaries that we examined. Retaining one of the three current sites and adding four new sites would allow us to continue monitoring water quality conditions while also better pinpointing and assessing possible nutrient and sediment sources in this watershed:

1. The downstream-most site (MRBA site 33) should be retained, because this site provides both an overall assessment of water quality conditions across most of the Godin Brook watershed and allows us to assess any changes in water quality conditions in this watershed over time.
2. The two upstream sites (MRBA sites 34 and 35) could be deleted, as water quality is generally very good in the uppermost reaches of this tributary. If it is still important to sample an upstream site, perhaps one site could be added downstream of where these two branches converge, perhaps where it passes underneath Richford Road.
3. If possible, three new sites should be added at the downstream ends of the three major branches of Godin Brook (these are located just to the west and northwest of the small farm at the end of Godin Road). These three sites would allow us to assess which branches are exporting the largest amounts of nutrients and sediment into Godin Brook. The site located along the central branch was sampled in September 2009 as part of Biomonitoring and Aquatic Studies (BASS) program (Location ID 501742).
4. Finally, a fourth new site should be added where the tributary draining the large barn complex on Richford Road crosses Town Highway 32 to assess water quality conditions in this stream.

Given the very poor water quality conditions measured in the Godin Brook watershed, it would be good to begin (or continue, if they have already begun) on-the-ground investigations of possible nutrient and sediment sources in this watershed. In particular, staff from the appropriate agencies (e.g. Vermont Agency of Natural Resources; Vermont Agency of Agriculture, Food & Markets) should continue to build relationships with the owners and operators of the large farm operation in this watershed in order to identify possible sources of water quality problems and also to establish additional sample sites in order to better pinpoint and assess possible nutrient and sediment sources in this watershed. These efforts could initially focus on evaluating field practices (i.e. the need for filter strips to filter runoff from the agricultural fields), farm roads, and the barns and associated infrastructure. For the latter, there may be opportunities to divert clean water (e.g. rain water falling on impervious surfaces such as barn roofs) and capture runoff from impervious surfaces such as barnyards, silage storage bunkers, compost pads, etc. These opportunities may not only improve water quality but may also benefit farm operations (for example, by lessening erosion and loss of soil from agricultural fields, reducing erosion of farm roads, reducing water flowing through barns and other animal areas, and reducing puddling in barnyard areas.

Mud Creek

Description

Mud Creek (Waterbody ID VT06-08) drains a large tributary watershed of the Missisquoi River in the towns of Troy and Newport Town in Orleans County, Vermont as well as the township of Potton in Quebec. The watershed encompasses a moderately hilly area of approximately 149 km^2 (57 mi^2) ranging in elevation in Vermont from approximately 165 m (540 ft) at the Quebec-Vermont border to 550 m (1,805 ft) atop Bear Mountain also along the Quebec-Vermont border. The dominant bedrock types are fine-grained, calcium-rich phyllite and quartzite and igneous metadicite and granodiorite. Surficial geology is dominated by glacial till on the ridges and glaciolacustrine and glaciofluvial deposits in the valleys. Soils are mostly silt loams. Mud Creek is listed as impaired and needing a TMDL due to elevated nutrients that are harming its ability to support aquatic life and aesthetics (State of Vermont 2014a, Part A). Mud Creek is also listed as stressed due to elevated nutrients and turbidity that are harming aesthetics and its ability to support aquatic life (State of Vermont 2014b).

Water Quality Sampling

Water quality data were collected at nine sites in the Mud Creek watershed during 2004-2014 (Table 12, Figure 31). Six of the sites were sampled on only 1-3 dates as part of the Biomonitoring and Aquatic Studies (BASS) Program. All of these dates represented low to moderate autumnal flows. The other three sites were sampled by the Missisquoi River Basin Association (MRBA) and were sampled on 29-97 dates during 2005-2014.

Table 12. Nine sites where water quality was sampled in the Mud Creek watershed during 2004-2014.

Location ID	Description	Sampling Program	# Dates Sampled	Years
500952	Mud Creek Bear Mountain Road	MRBA site 5	97	2005-2014
500967	Mud Creek Route 105	MRBA site 20	88	2006-2014
500973	Mud Creek Trib 10	MRBA site 26	29	2008-2010
501751	Mud Creek	BASS	2	2004, 2013
501752	Mud Creek	BASS	3	2004, 2009, 2013
501753	Mud Creek	BASS	1	2009
501754	Mud Creek Trib 10	BASS	1	2004
501756	Buzzell Brook	BASS	1	2009
506360	Mud Creek	BASS	1	2013

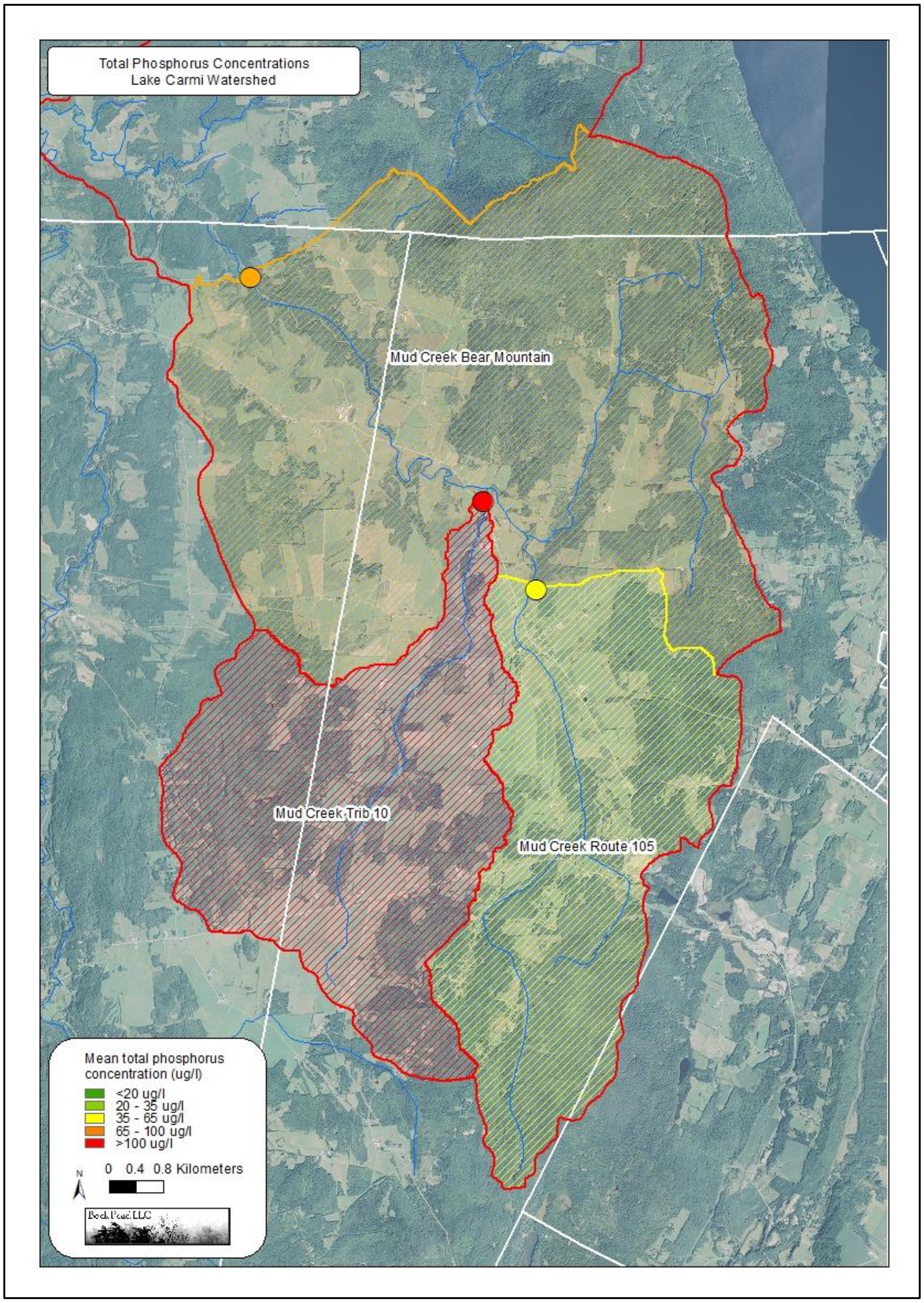

Figure 31. *Locations of nine sample sites in the Mud Creek watershed during 2004-2014. The sample site symbols and the subwatersheds drained by each sample site are color-coded according to the mean total phosphorus concentrations measured at each associated site.*

Results and Discussion

Total phosphorus concentrations were moderately high throughout the Mud Creek watershed (Table 13, Figure 31). At the two sites on the main stem that were sampled during 2013-2014, total phosphorus concentrations generally increased with increasing stream flows (Figure 32). In contrast, total phosphorus concentrations generally decreased with increasing flows at the one site located along Tributary #10 (these data were collected during 2009-2010). Finally, there appeared to be no consistent change in total phosphorus concentrations at these sites during 2005-2014. Even though they were sampled during low autumnal flows, total phosphorus concentrations at the six Biomonitoring and Aquatic Studies (BASS) sites were variable and moderately high (range = 18.1-72.8 μg/l).

Table 13. Summary of total phosphorus concentrations at three sites in the Mud Creek watershed during 2005-2014.

MRBA Site #	Location	# Dates Sampled	Median (μg/l)	Mean (μg/l)	Range (μg/l)
2005-2014:					
5	Bear Mountain Road	97	50.5	84.7	19-885
20	Route 105	88	43.7	64.2	18-456
26	Trib 10	29	94.5	145.9	38-565
2013-2014 Only:					
5	Bear Mountain Road	20	45.6	51.7	
20	Route 105	20	31.3	58.3	

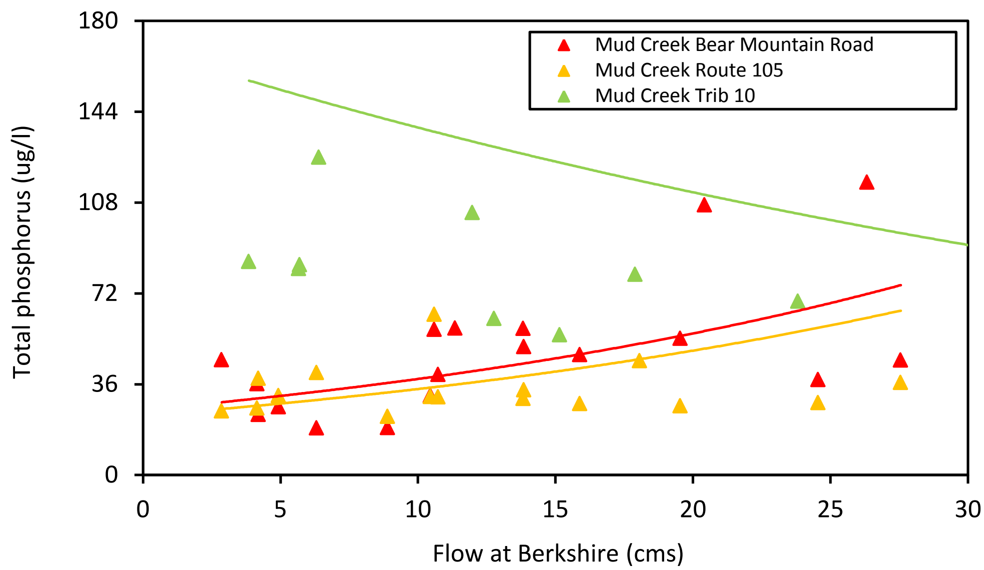

Figure 32. *Total phosphorus concentrations in relation to stream flow at three sites in the Mud Creek watershed during 2013-2014 (the data for the Mud Creek Trib 10 site were collected in 2009-2010). Stream flows were measured at the USGS gage on the Missisquoi River near East Berkshire, Vermont (USGS station 04293500). The regression lines indicate the exponential relationships between the two parameters.*

Based on these analyses, it seems likely that much of the phosphorus along the main stem is originating from nonpoint sources. Possible nonpoint sources include surface runoff from the many agricultural fields in this watershed and from streambank erosion (Figure 33). In contrast, the high phosphorus levels along Tributary #10 may be originating from point source(s), such as the barns and barnyards that occur along this tributary. On 21 May 2015, we noted that abundant benthic algae, an indicator of high nutrient levels, and abundant silt were evident at several locations along Mud Creek and its tributaries (in particular, the Bear Mountain Road and Trib 10 sites, respectively). Previous studies had also noted that phosphorus levels and loadings were high in the Mud Creek watershed, especially in the western and downstream halves of the watershed (Howe et al. 2011, Stone Environmental 2011).

Figure 33. *Numerous agricultural fields and unstable streambanks border much of Mud Creek, such as this area along Vermont Route 105 in Newport Town, Vermont on 21 May 2015.*

Recommendations

Given concerns about water quality conditions in Mud Creek, we recommend retaining the two current sites and adding two new sites in order to better pinpoint nutrient and sediment sources in this watershed:

1. Retain the two sites (MRBA sites 5 and 20) along the main stem of Mud Creek, because these two sites provide a good overall assessment of water quality in this watershed and, based on preliminary analyses of the water quality data, bracket the source areas or tributaries for much of the nutrients and sediment.
2. Resample the site located on the tributary of Mud Creek (MRBA site 26) that was previously sampled during 2008-2010. This site exhibited very high total phosphorus concentrations (median = 94.5 µg/l).
3. Add one new site along the main stem of Mud Creek in order to better pinpoint the source area(s) of the nutrients and sediments being exported from this watershed. This site was sampled in 2004 as part of the Biomonitoring and Aquatic Studies (BASS) Program (Location ID 501752).

Due to the low number of sample sites in the Mud Creek watershed, it was not possible to identify specific areas for on-the-ground investigation at this time. Such efforts will require additional, targeted sampling to better pinpoint and assess possible nutrient and sediment sources. However, one possible first effort would be to further examine areas along the southern tributary (Tributary #10), where very high total phosphorus concentrations were measured in 2008-2010. On the other hand, numerous conservation projects have already been implemented in this watershed, especially restoring forested riparian buffers on a large farm located along Mud Creek in Newport Town (Figure 34).

Figure 34. *Numerous forested riparian buffers have already been restored along Mud Creek, such as this area along Vermont Route 105 in Newport Town, Vermont on 21 May 2015.*

Lake Carmi

Description

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. The watershed encompasses a gently rolling area of approximately 30 km^2 (11.7 mi^2) ranging in elevation from approximately 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 almost entirely fine sandy loams. The dominant land uses are agriculture, forestry, and residential, the latter especially around the lake shore. Lake Carmi is listed as impaired and has a completed and approved TMDL due to elevated phosphorus levels and the occurrence of algal blooms (State of Vermont 2014a, Part D) and has been altered by locally abundant Eurasian watermilfoil, an aquatic invasive species, and water level drawdowns (State of Vermont 2014a, Parts E and F). The Pike River, including the entire Lake Carmi watershed, was one area identified by the Critical Source Areas study as an important source of phosphorus loading into Missisquoi Bay (Stone Environmental 2011).

Water Quality Sampling

During 2007-2014, a total of 27 sites were sampled in the Lake Carmi watershed (Table 14, Figure 35). These 27 Sites included 22 sites sampled by the Franklin Watershed Committee as part of the LaRosa Partnership Program, four sites sampled as part of the Lake Assessment Program (all sampled in 2007 only and two on only one date), and one site sampled on two dates in 2011 and 2013 as part of the Biomonitoring and Aquatic Studies (BASS) Program. (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.)

Table 14. The 27 sites where water quality was sampled in the Lake Carmi watershed during 2007-2014.

Location ID	Description	Sampling Program	# Dates Sampled	Years
501134	Sandy Bay Brook	FWC site LC1	59	2008-2014
501137	Alder Run	FWC site LC2	8	2009-2010
501138	Dicky's Brook	FWC site LC3	59	2008-2014
501139	Dicky's Brook	FWC site LC4	50	2008-2014
501140	Dicky's Brook	FWC site LC5	62	2008-2014
501141	Dewing Brook	FWC site LC6	54	2008-2014
501142	Unnamed tributary of Marsh Brook	FWC site LC7	59	2008-2014
501143	Marsh Brook	FWC site LC8	60	2008-2014
501144	Marsh Brook	FWC site LC9	59	2008-2014
501135	Marsh Brook	FWC site LC10	61	2008-2014
501136	Alder Run	FWC site LC11	54	2009-2014
502649	Kane's Brook	FWC site LC12	47	2010-2014
502648	Hammond's Brook	FWC site LC13	11	2010-2014
502651	Unnamed Tributary to Marsh Brook	FWC site LC14	46	2010-2014
502650	Prouty Brook	FWC site LC15	40	2010-2014
502652	Westcott Brook	FWC site LC16	33	2010-2014
505527	Hammond's Brook North	FWC site LC17	34	2011-2014
505528	Little Pond Road Culvert North	FWC site LC18	26	2011-2014
505529	Little Pond Road Culvert West	FWC site LC19	18	2011-2014
-	Wagner Drain Tile	FWC site LC20	8	2013-2014
-	Sandy Bay Brook	FWC site LC21	1	2014
-	Sandy Bay Brook	FWC site LC22	4	2014
500648	Marsh Brook	Lake Assessment	33	2007
500649	Pike River Outlet	Lake Assessment	12	2007
500655	Dewing Brook Inlet	Lake Assessment	1	2007
500656	Lake Carmi Inlet 6	Lake Assessment	1	2007
505177	Marsh Brook	BASS	2	2011, 2013

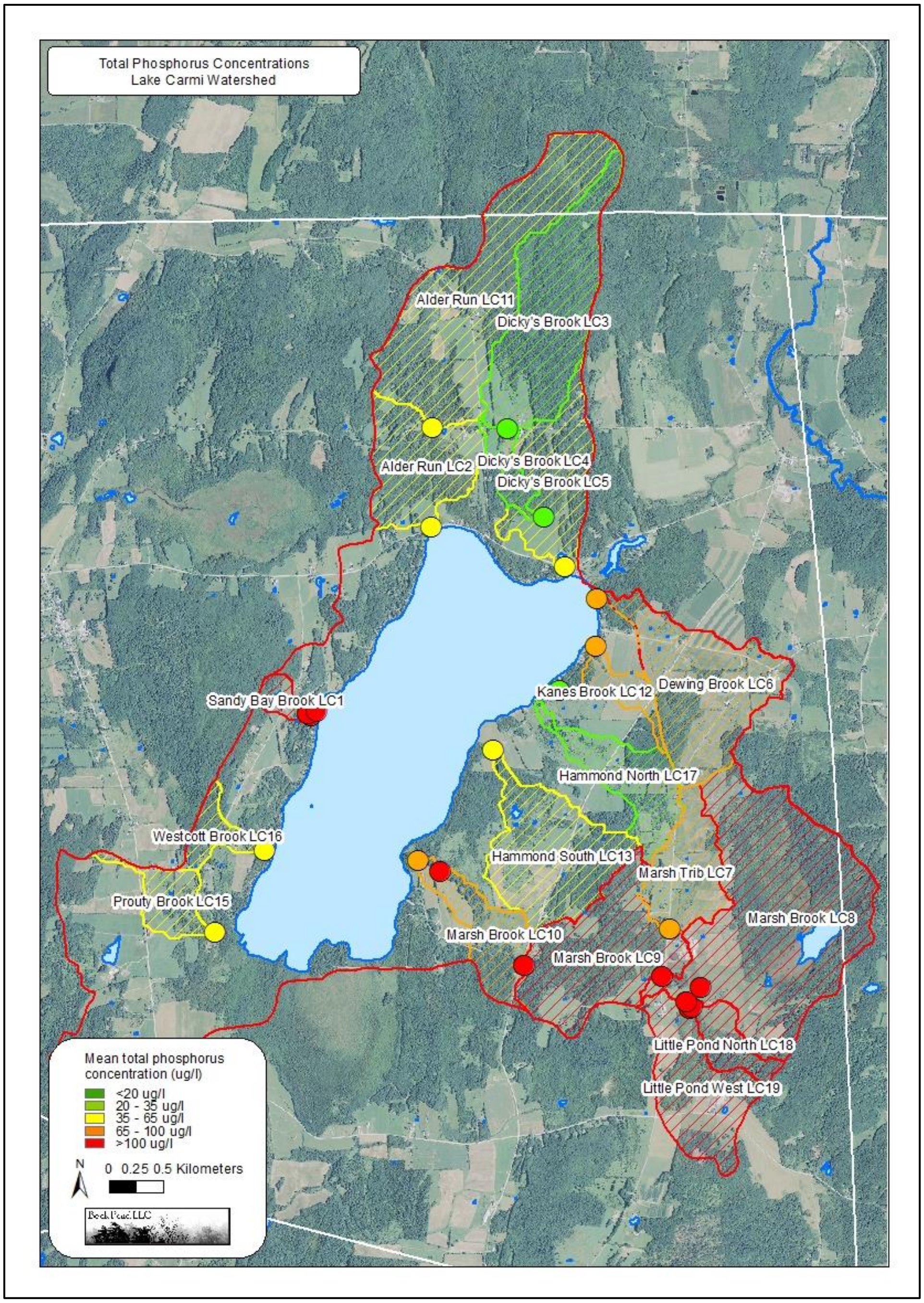

Figure 35. *Locations of 27 sample sites along the tributaries of Lake Carmi during 2007-2014. The sample site symbols and the subwatersheds drained by each sample site are color-coded according to the mean total phosphorus concentrations measured at each associated site.*

Results and Discussion

Total phosphorus concentrations differed dramatically among the different tributaries of Lake Carmi (Figure 35). Mean and median total phosphorus concentrations were very high in the watersheds of Sandy Bay and Marsh Brooks; moderately high in the watersheds of Dewing's and Kane's Brooks; intermediate in the watersheds of Westcott and Prouty Brooks, Hammond's Brook South, the downstream portion of Dicky's Brook, and Alder Run; and relatively low in the watersheds of Hammond's Brook North and the upstream portions of Dicky's Brook.

Sandy Bay Brook

The water quality data indicated that there were serious water quality problems in Sandy Bay Brook. All three sites sampled during 2008-2014 exhibited very high total phosphorus concentrations (Table 15). At the two sites sampled during 2013-2014, total phosphorus concentrations increased markedly with increasing stream flows, especially at the downstream-most site (Figure 36). Finally, there was some indication that total phosphorus concentrations may have increased at the downstream-most site (LC1) during 2008-2014 (Figure 37).

Table 15. Summary of total phosphorus concentrations at three sites along Sandy Bay Brook in the Lake Carmi watershed during 2008-2014.

FWC Site #	Location	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
2008-2014:					
LC1	Sandy Bay Brook	59	188.0	233.1	56-692
LC21	Sandy Bay Brook 2	1	220.0	220.0	220
LC22	Sandy Bay Brook 3	4	106.7	120.7	87-183
2013-2014 Only:					
LC1	Sandy Bay Brook	21	170.0	243.5	
LC21	Sandy Bay Brook 2	1	220.0	220.0	
LC22	Sandy Bay Brook 3	4	106.7	120.7	

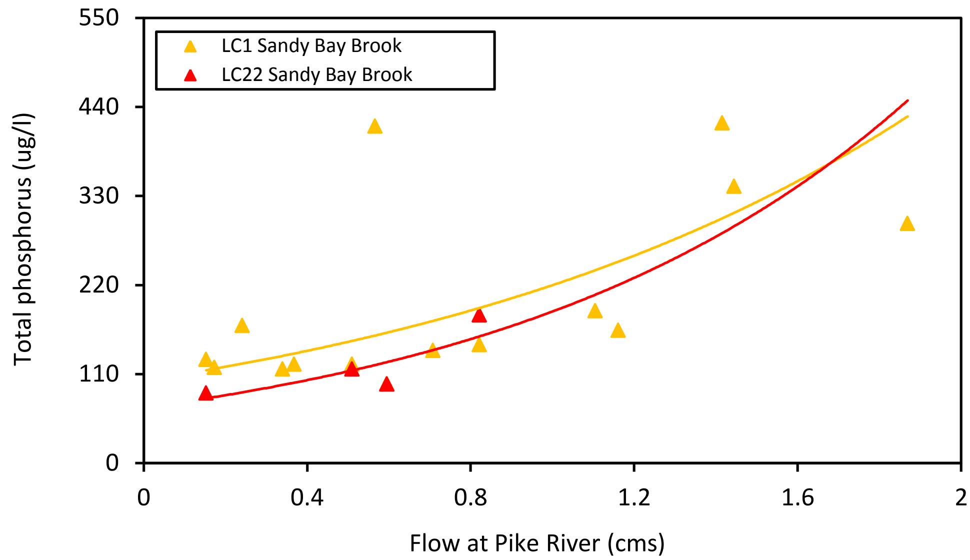

Figure 36. *Total phosphorus concentrations in relation to stream flow at two sites along Sandy Bay Brook during 2013-2014. Stream flows were measured at the USGS gage on the Pike River at East Franklin near Enosburg Falls, Vermont (USGS station 04294300). The regression lines indicate the exponential relationships between the two parameters.*

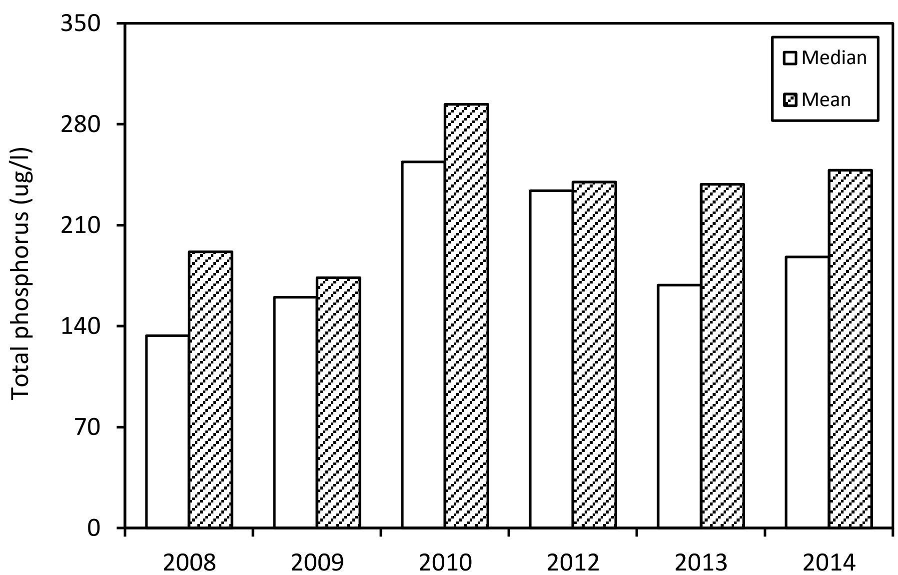

Figure 37. *Mean and median total phosphorus concentrations at the downstream-most Sandy Bay Brook site (LC1) during 2008-2014.*

Based on these data and discussions with other stakeholders, it seems likely that much of the phosphorus is originating from a small farm in the upper reaches of this watershed. In particular, there appear to be an old settling pond that overflows during rain events, runoff from the barns and barnyards, and the possibility of runoff from an area used to stack manure (Figure 38). Staff from the appropriate agencies should continue to engage the owner of this farm in efforts to identify and remediate any nutrient and sediment sources.

Figure 38. *Old settling pond that is nutrient-rich and that often overflows during heavy rains into Sandy Bay Brook in Franklin, Vermont on 21 August 2015.*

Marsh Brook

The water quality data also indicated that there were serious water quality issues in much of the Marsh Brook watershed. In particular, total phosphorus concentrations were extremely high at all of the sites located in the upper part of this watershed, except the northern-most tributary (Table 16). In addition, total phosphorus concentrations generally decreased from the upstream to the downstream sites (Figure 39). At the eight sites sampled during 2013-2014, total phosphorus concentrations generally increased with increasing stream flows at all but one of the sites (Little Pond Road Culvert West), where they decreased dramatically with increasing flows (Figure 40). Finally, there was some indication that total phosphorus concentrations may be decreasing at the downstream-most site (LC10), especially during the past 2-3 years (Figure 41).

Table 16. Summary of total phosphorus concentrations at nine sites along Marsh Brook in the Lake Carmi watershed during 2007-2014.

FWC Site #	Location	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
2007-2014:					
LC10	Marsh Brook	61	81.3	99.7	39-449
LC14	Unnamed Tributary	46	332.5	409.8	64-2,260
LC18	Little Pond Culvert North	26	134.0	212.6	27-930
LC19	Little Pond Culvert West	18	264.0	398.5	89-1,040
LC20	Wagner Drain Tile	8	366.5	506.6	92-1,110
LC7	Unnamed Tributary	59	45.1	77.0	16-757
LC8	Marsh Brook	60	165.5	194.5	35-498
LC9	Marsh Brook	59	99.2	114.6	53-288
MB	Marsh Brook	33	87.7	107.8	53-530
2013-2014 Only:					
LC10	Marsh Brook	22	65.1	78.9	
LC14	Unnamed Tributary	19	333.0	470.3	
LC18	Little Pond Culvert North	13	71.9	113.5	
LC19	Little Pond Culvert West	9	250.0	368.5	
LC20	Wagner Drain Tile	8	366.5	506.6	
LC7	Unnamed Tributary	19	34.9	91.4	
LC8	Marsh Brook	19	150.0	179.0	
LC9	Marsh Brook	19	90.5	109.2	

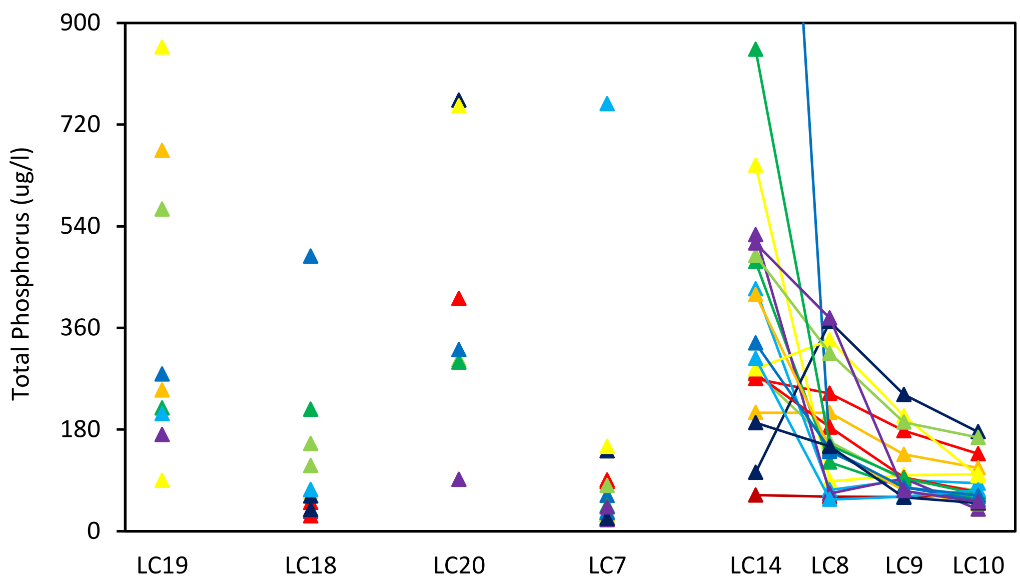

Figure 39. *Total phosphorus "profile" along the main stem and tributaries of Marsh Brook from Little Pond Road (sites LC18 and LC19) downstream to the mouth of Marsh Brook (site LC10) on 20 dates during April-October 2013 and 2014.*

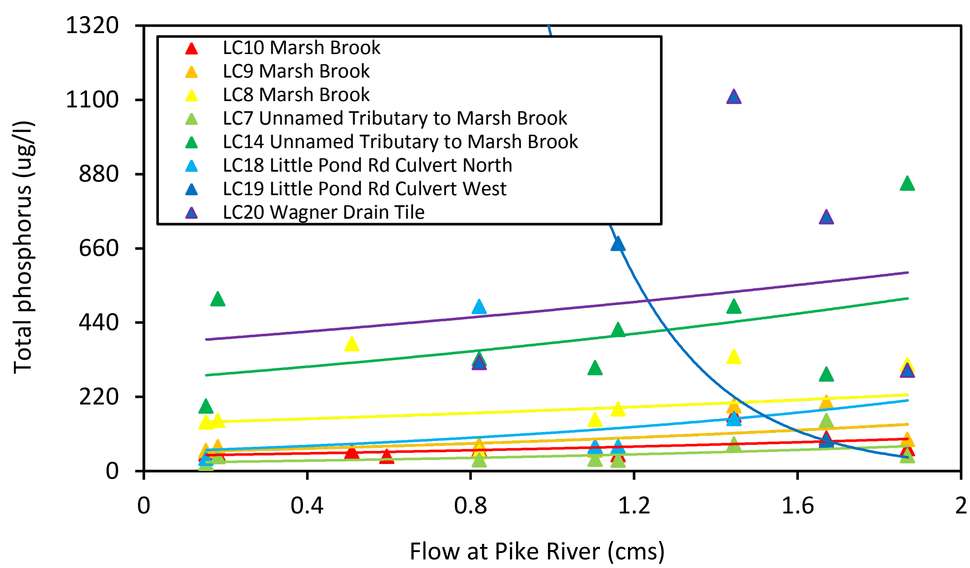

Figure 40. *Total phosphorus concentrations in relation to stream flow at eight sites along Marsh Brook during 2013-2014. Stream flows were measured at the USGS gage on the Pike River at East Franklin near Enosburg Falls, Vermont (USGS station 04294300). The regression lines indicate the exponential relationships between the two parameters.*

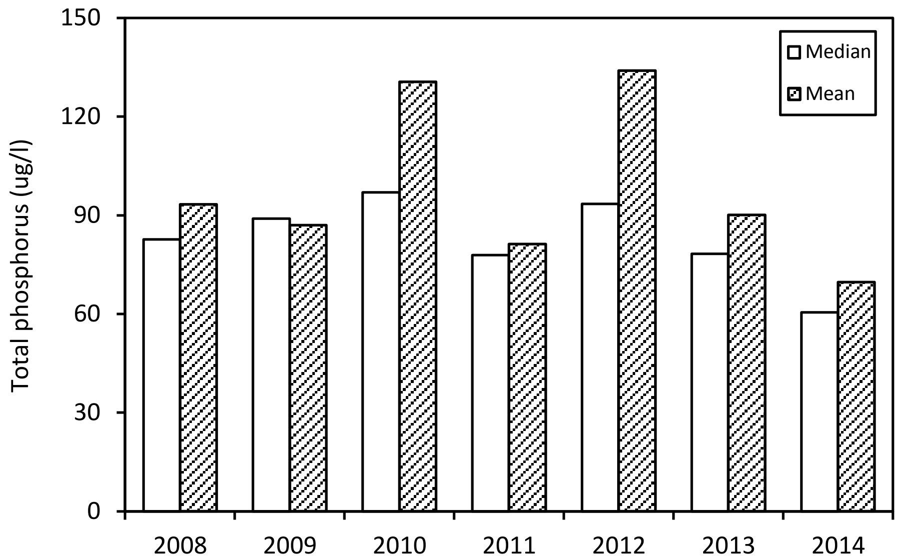

Figure 41. *Mean and median total phosphorus concentrations at the downstream-most Marsh Brook site (LC10) during 2008-2014.*

Based on these analyses and discussions with other stakeholders, it seems likely that much of the phosphorus is originating from one or two farms in the upper reaches of this watershed. These two farms include many large agricultural fields as well as barns, barnyards, and associated infrastructure. In addition, at least one tile drain system has been installed in this watershed, and total phosphorus concentrations in the outflow of this tile drain (site LC20) were extremely high. However, other sources of the high phosphorus levels may be located along the small tributary that flows from the south and beneath Little Pond Road. This tributary drains areas of forested wetland but also another barn complex (Figure 42). Clearly, additional targeted sampling needs to be done to identify and assess possible nutrient and sediment sources in this watershed. It should be noted, however, that considerable work has already been done to restore forested riparian buffers along the unnamed northern tributary of Marsh Brook (sampled at site LC7)(Figure 43).

Figure 42. *Small tributary that flows north underneath Little Pond Road and into Marsh Brook in Franklin, Vermont on 21 August 2015.*

Figure 43. *Forested riparian buffers have already been restored along a small unnamed tributary of Marsh Brook in Franklin, Vermont on 21 August 2015.*

Dicky's Brook

Water quality conditions were somewhat better in Dicky's Brook, another tributary of Lake Carmi. In particular, the three sites sampled during 2008-2014 exhibited relatively low to intermediate total phosphorus concentrations (Table 17). Total phosphorus concentrations were low at the upstream-most site but increased at the mid-stream site and were highest at the downstream-most site (Figure 44). During 2013-2014, total phosphorus concentrations increased with increasing stream flows at the two upstream sites but decreased markedly with increasing stream flows at the downstream-most site (site LC5), which exhibited the highest total phosphorus concentrations (Figure 45). Finally, total phosphorus concentrations at the downstream-most site (site LC5) were markedly lower during 2010-2014 than during 2008-2009 (Figure 46).

Table 17. Summary of total phosphorus concentrations at three sites along Dicky's Brook in the Lake Carmi watershed during 2008-2014.

FWC Site #	Location	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
2008-2014:					
LC3	Dicky's Brook	59	19.3	24.3	8-82
LC4	Dicky's Brook	50	25.3	31.1	14-103
LC5	Dicky's Brook	62	49.1	58.6	24-204
2013-2014 Only:					
LC3	Dicky's Brook	19	17.4	25.7	
LC4	Dicky's Brook	16	28.7	31.5	
LC5	Dicky's Brook	22	43.4	49.3	

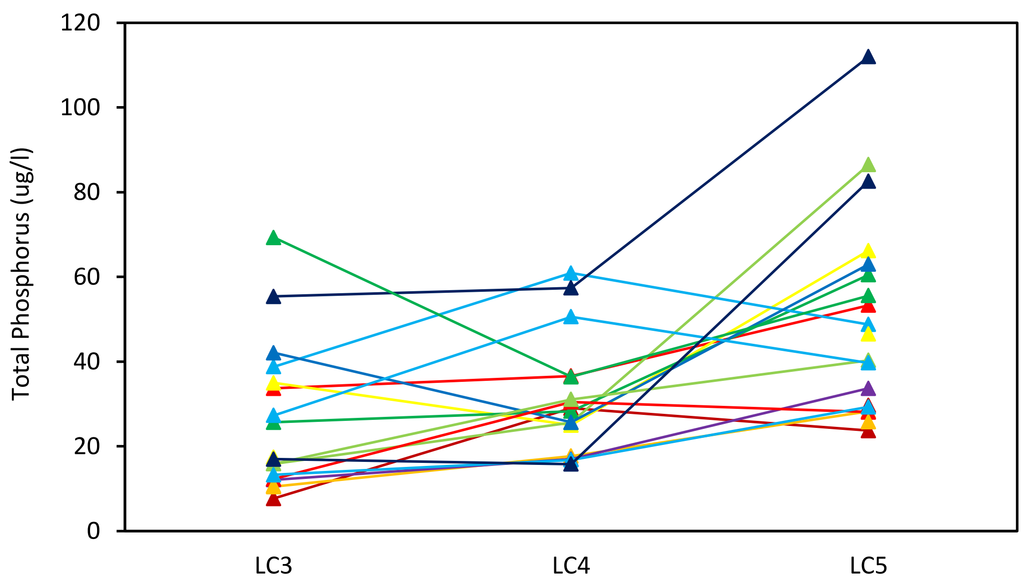

Figure 44. *Total phosphorus "profile" along the main stem of Dicky's Brook from upstream (site LC3) to downstream (site LC5) on 19 dates during April-October 2013 and 2014.*

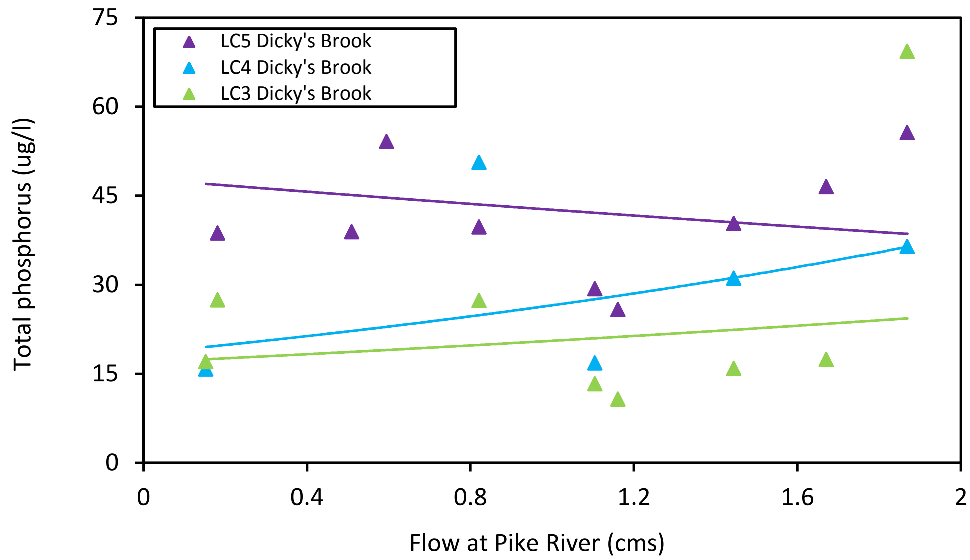

Figure 45. *Total phosphorus concentrations in relation to stream flow at three sites along Dicky's Brook during 2013-2014. Stream flows were measured at the USGS gage on the Pike River at East Franklin near Enosburg Falls, Vermont (USGS station 04294300). The regression lines indicate the exponential relationships between the two parameters.*

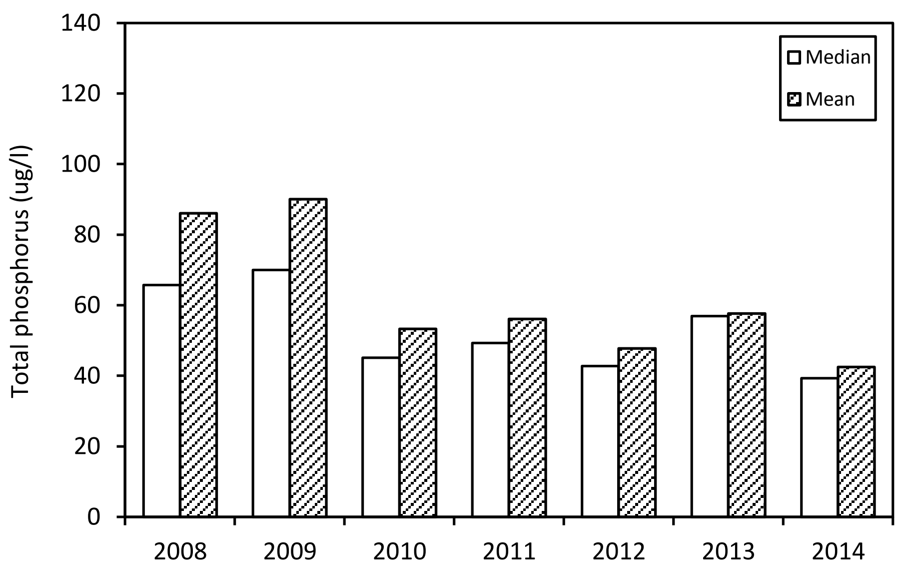

Figure 46. *Mean and median total phosphorus concentrations at the downstream-most Dicky's Brook site (LC5) during 2008-2014.*

Based on these analyses and discussions with other stakeholders, it seems likely that much of the phosphorus flowing from this tributary into Lake Carmi is originating in the downstream section of this stream. However, it is unclear what the source(s) of this phosphorus might be. This short section of stream [approximately 620 m (2,030 ft)] passes alongside a hay field, through an unmown area of old field or pasture, past a residence, and through a small pond before flowing underneath Lake Road (Figure 47). One possibility is that there is an accumulation of phosphorus that is being released from the small pond, so that one possible future effort would be to measure total phosphorus concentrations in the pond itself or to sample immediately upstream and downstream of the pond in order to determine whether or not the pond is the source of the high phosphorus levels.

Figure 47. *Old field and hay field along the downstream section of Dicky's Brook in Franklin, Vermont on 21 August 2015.*

Alder Run

Water quality conditions were similar in Alder Run, another tributary on the north shore of Lake Carmi. In particular, the two sites sampled during 2009-2014 exhibited relatively low or intermediate total phosphorus concentrations (Table 18), but, during the one year that both sites were sampled, total phosphorus concentrations increased markedly from the upstream to the downstream site (Figure 48). During 2009, total phosphorus concentrations at both sites decreased with increasing stream flows but were consistently higher at the downstream site at all flow levels (Figure 49). Finally, total phosphorus concentrations at the upstream site (site LC11) showed no consistent change during 2009-2014, although median and mean concentrations reached their lowest levels in 2014 (Figure 50).

Table 18. Summary of total phosphorus concentrations at two sites along Alder Run in the Lake Carmi watershed during 2009-2014.

FWC Site #	Location	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
2009-2014:					
LC11	Alder Run	54	27.8	38.4	5-202
LC2	Alder Run	8	44.4	47.0	31-65
2013-2014 Only:					
LC11	Alder Run	19	21.7	25.3	

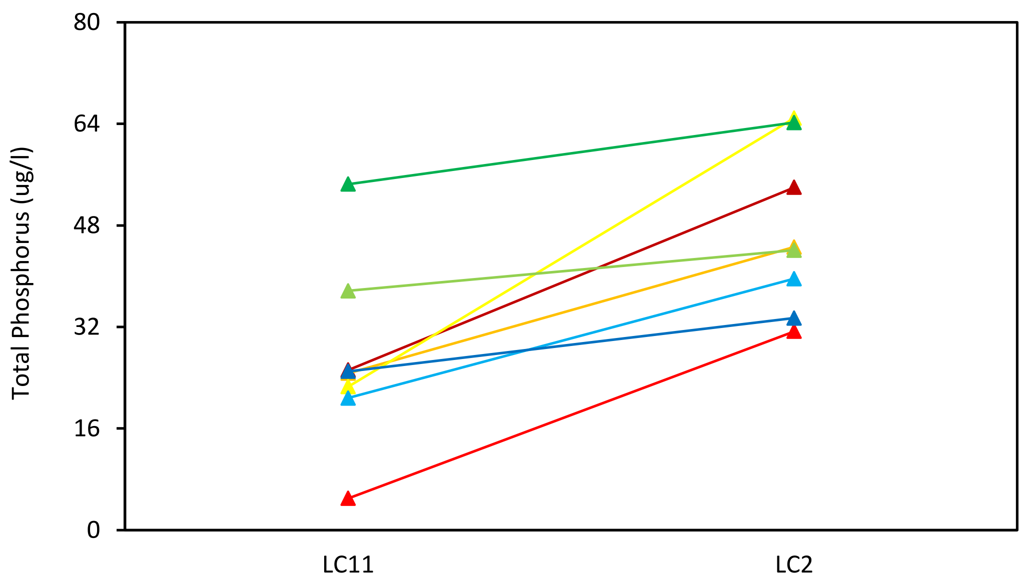

Figure 48. *Total phosphorus "profile" along the main stem of Alder Run from upstream (site LC11) to downstream (site LC2) on ten dates during April-October 2009.*

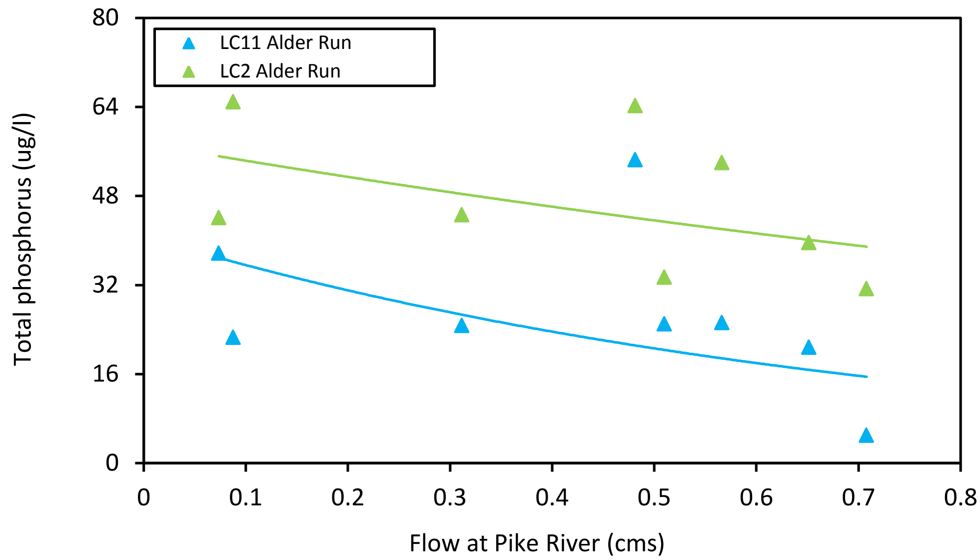

Figure 49. *Total phosphorus concentrations in relation to stream flow at two sites along Alder Run during 2009. Stream flows were measured at the USGS gage on the Pike River at East Franklin near Enosburg Falls, Vermont (USGS station 04294300). The regression lines indicate the exponential relationships between the two parameters.*

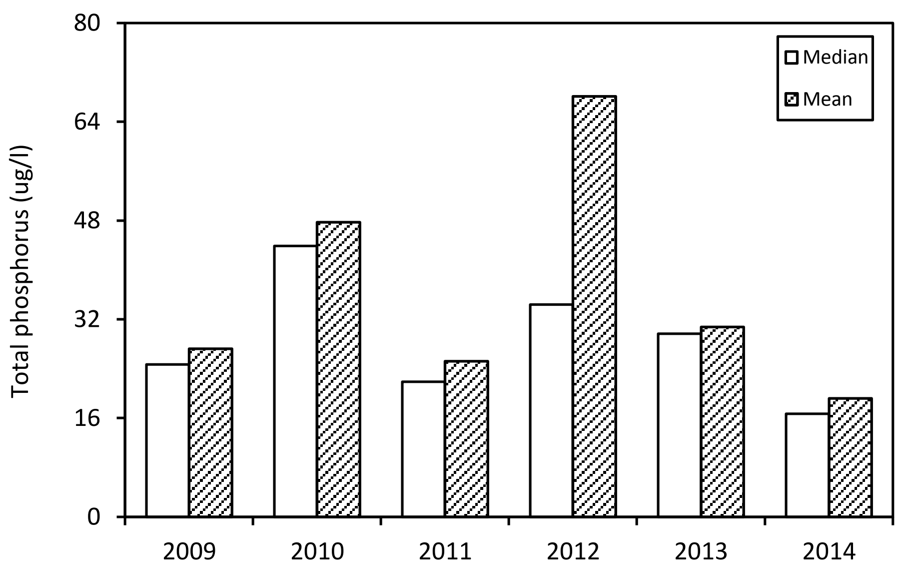

Figure 50. *Mean and median total phosphorus concentrations at the upstream Alder Run site (LC11) during 2009-2014.*

Based on these analyses and discussions with other stakeholders, it seems likely that much of the phosphorus flowing from this tributary into Lake Carmi is originating in the downstream section of this stream. Like Dicky's Brook, it is unclear what the source(s) of this phosphorus might be. This short section of stream [approximately 900 m (3,000 ft)] passes through forested wetlands and a small area of grazed wetlands before flowing underneath Lake Road (Figure 51). It is possible that the grazing is releasing phosphorus from these wetland soils. Given that the downstream site has not been sampled since early in 2010, we recommend resampling phosphorus levels at the downstream site again to verify that this stream continues to export high levels of phosphorus into Lake Carmi.

Figure 51. *The downstream-most section of Alder Run flows through grazed wetlands just north of Lake Road in Franklin, Vermont on 31 March 2015.*

Other Tributaries of Lake Carmi

Total phosphorus concentrations differed considerably in six other tributaries of Lake Carmi. In particular, total phosphorus concentrations were moderately high in Kane's Brook, Hammond's Brook, and Dewing Brook and intermediate in Prouty and Westcott Brooks and Hammond's Brook North (Table 19). Interestingly, total phosphorus concentrations at the two sites located in the southwestern corner of Lake Carmi [Prouty Brook (site LC15) and Westcott Brook (site LC16)] decreased with increasing stream flows, but total phosphorus concentrations increased with increasing stream flows at three other sites (Figure 52). Finally, only the Dewing

Brook site (LC6) showed any trend in total phosphorus concentrations over time: Total phosphorus concentrations there were substantially lower during 2011-2014 than during 2008-2010 (Figure 53).

Table 19. Summary of total phosphorus concentrations at seven sites along several tributaries of Lake Carmi during 2008-2014.

FWC Site #	Location	# Dates Sampled	Median (µg/l)	Mean (µg/l)	Range (µg/l)
2008-2014:					
LC12	Kane's Brook	47	47.9	72.5	23-605
LC13	Hammond's Brook	11	41.9	47.4	36-61
LC15	Prouty Brook	40	37.5	47.9	17-250
LC16	Westcott Brook	33	31.1	40.6	17-174
LC17	Hammond's Brook North	34	22.6	29.8	9-100
LC6	Dewing Brook	54	42.5	88.7	22-785
PRO	Pike River Outlet	12	30.6	40.0	20-106
2013-2014 Only:					
LC12	Kane's Brook	20	53.4	87.1	
LC13	Hammond's Brook	2	51.2	51.2	
LC15	Prouty Brook	14	42.6	51.3	
LC16	Westcott Brook	15	30.2	43.6	
LC17	Hammond's Brook North	20	22.5	30.1	
LC6	Dewing Brook	20	37.7	66.1	

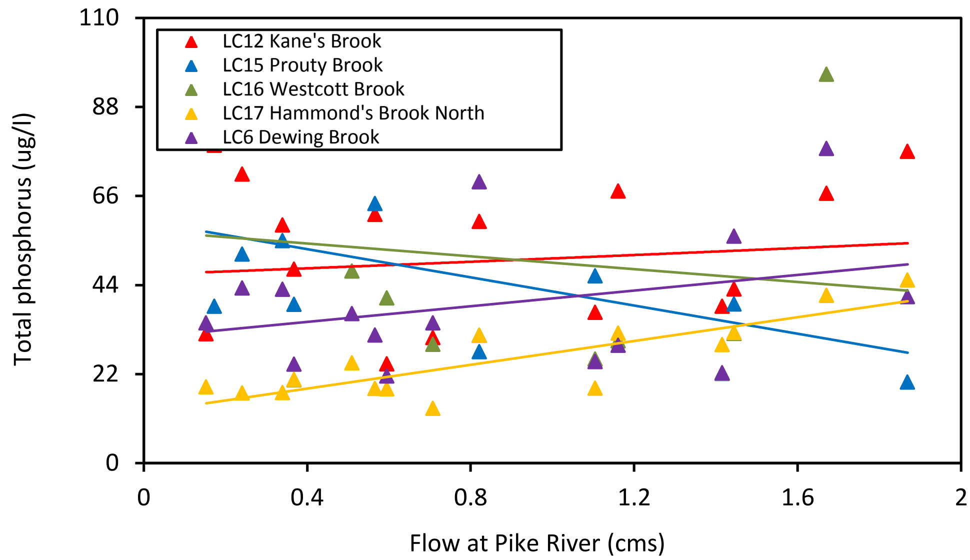

Figure 52. *Total phosphorus concentrations in relation to stream flow at five sites along five small tributaries of Lake Carmi during 2013-2014. Stream flows were measured at the USGS gage on the Pike River at East Franklin near Enosburg Falls, Vermont (USGS station 04294300). The regression lines indicate the exponential relationships between the two parameters.*

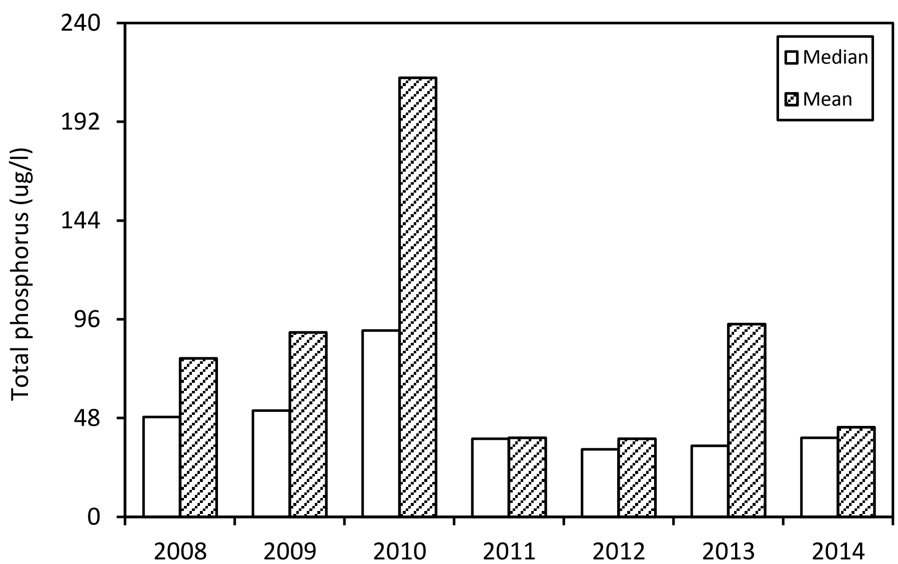

Figure 53. *Mean and median total phosphorus concentrations at the Dewing Brook site (LC6) during 2008-2014.*

Based on these analyses and discussions with other stakeholders, there seem to be potential water quality issues in several of these tributaries. Along Dewing Road, the edge of a field was converted from corn to hay in 2012 in order to reduce nutrient and sediment losses during heavy rains. This change in land management may well have caused the improvements in water quality measured in Dewing Brook during the past few years (Figure 54).

Figure 54. *The edge of this field along Dewing Road was converted from corn to hay to reduce nutrient and sediment losses during heavy rains in Franklin, Vermont on 21 August 2015.*

Recommendations

Based on the analyses of the water quality data and discussions with various stakeholders, it was evident that there were serious water quality problems in several tributaries of Lake Carmi, especially Sandy Bay Brook and Marsh Brook. Thus, many of our recommendations focus on further pinpointing and assessing nutrient and sediment sources along these two tributaries.

Sandy Bay Brook

Due to the very high phosphorus levels measured in Sandy Bay Brook, we recommend retaining the four current sites and adding two new sites:

1. Retain the four sites on the main stem (site LC1) and two branches of Sandy Bay Brook (sites LC21-LC23) in order to continue efforts to pinpoint and assess nutrient and sediment sources along this tributary.
2. Add two new sites to sample the water flowing out of the two culverts under Riley Road in order to assess water quality conditions entering the swale and settling pond along the northern branch and passing alongside a manure stacking area along the southern branch.

Marsh Brook

Due to the high phosphorus levels measured in Marsh Brook, we recommend retaining six of the current sites, adding two new sites, and deleting two sites:

1. Retain the three sites along the main stem of Marsh Brook (sites LC8-LC10) in order to continue monitoring water quality conditions along the length of this tributary.
2. Retain the three sites on the two branches of Little Pond Road Culvert North and West (sites LC18 and LC19) and the Wagner Tile Drain (site LC20) in order to continue efforts to pinpoint and assess possible nutrient and sediment sources along these tributaries.
3. Delete two sites, one along the northern branch of Marsh Brook (site LC7), where water quality conditions are generally good, and the downstream-most one at the Little Pond Road Culvert (site LC14), because the latter is better sampled at the two other Little Pond Road culvert sites (LC18 and LC19).
4. Add one new site just below the pond on the Stanley Farm to bracket possible nutrient and sediment sources on the farm and in the wetlands below the farm but upstream of Little Pond Road.
5. Add one new site just upstream of where the outflow from the Wagner Tile Drain enters this small tributary to separate the effects of the tile drain from the upstream areas of this watershed.

Other Tributaries of Lake Carmi

Beyond these two tributaries, we also recommend retaining, deleting, or adding sites along several other tributaries of Lake Carmi:

1. Delete two sites that generally exhibited low total phosphorus concentrations (median < 35 μg/l) on Westcott Brook (site LC16) and Hammond's Brook North (site LC17). Should land uses or land management practices in the watersheds drained by these two sites change dramatically, however, these sites could be resampled again in future years.

2. Add one site where Alder Run enters the lake (sampled in 2009-2010 as site LC2) in order to better assess conditions in the downstream section of this tributary. If it is not possible to add a suitable site at this location due to access issues and/or back flow from the lake, then the upstream site (LC11) could be deleted, as total phosphorus concentrations at that site are generally low (median = 21.7 μg/l).
3. The upstream-most site (LC3) along Dicky's Brook could be deleted, as total phosphorus concentrations there were relatively low (median = 17.4 μg/l). However, the two downstream sites (LC4 and LC5) should be retained until the source of the moderately high phosphorus levels in this tributary can be identified.
4. The sites on Dewing Brook (site LC6) and Kane's Brook (site LC12) should continue to be sampled in order to evaluate the success of changes in land management practices in the upstream agricultural fields.
5. The sites on Hammond's Brook South (site LC13) and Prouty Brook (site LC15) should be retained to further evaluate water quality conditions in those two tributaries.
6. Finally, one or two sites should be added on the tributary that enters the southwest corner of the lake, as this tributary has not been sampled previously. Depending on access, either one site could be located on the main stem of this tributary, or two sites could be located on each of the two branches of this tributary, which forks just downstream of some agricultural land uses.

Phosphorus Loads

As part of this project, we had proposed to calculate phosphorus loads for the six watersheds analyzed in this study. Due to the limitations imposed by the available data, we determined that the data were not sufficient to calculate useful or accurate load estimates. More specifically, the primary limitation imposed by the data was the low number of samples collected at high flows in any of the years or at any of the sample sites. Across all sites, only 11% of the samples collected in the Lake Carmi watershed were collected at high flows (ten of 96 sample dates), and only 15% of the samples collected along the Missisquoi River tributaries were collected at high flows (15 of 102 sample dates). Given that the majority of phosphorus in these watersheds likely originates from soil erosion, surface runoff, and stormwater overflows during and following heavy rains, calculating load estimates with a data set heavily weighted towards samples collected at low and moderate flows would greatly underestimate the actual phosphorus loads being exported from these watersheds. In order to accurately calculate phosphorus loads, we would need to collect many more samples during rain events and/or high flows, which raises both logistical challenges and safety concerns (e.g. the need for flexible sampling schedules, sampling during flood conditions, etc.). However, measuring water quality during rain events and at high flows would also be extremely valuable for pinpointing and assessing nutrient and sediment sources. If a sampling program were implemented to supplement the high-flow data, the priority areas in which to focus such high-flow or rain-event sampling would be the downstream-most sample sites in the watersheds of each of the five tributaries of the Missisquoi River, the largest tributary of Lake Carmi (Marsh Brook), and the outlet of Lake Carmi.

Education and Outreach

As an integral part of this project, we joined in efforts to educate local communities and stakeholders about water quality issues and efforts to protect and improve water quality in the Missisquoi Bay Basin. First, many individuals from the local community had already volunteered to collect and process water samples, and their efforts and their interactions with the salaried employees, paid consultants, and other volunteers further the education and outreach objectives of this project. Second, the results of this study were presented at a public outreach meeting held in Enosburg Falls on 20 August 2015. Third, the results of this study will be presented to the members of the newly-formed Lake Carmi TMDL Implementation Team and to staff from the Monitoring, Assessment and Planning Program (MAPP) of the Vermont Department of Environmental Conservation (DEC). Finally, we continued to develop collaborative relationships with other agencies and organizations working to protect and improve water quality in the Missisquoi Bay Basin, including the Franklin Watershed Committee; Missisquoi River Basin Association; Vermont Department of Environmental Conservation; Vermont Agency of Agriculture, Food & Markets; and Natural Resources Conservation Service.

General Recommendations

As part of the project, we developed recommendations for revising the water quality sampling program in 2015 and subsequent years. The overall rationale for these recommendations was to maintain and enhance the water quality sampling program in order to 1) best monitor water quality conditions over time and 2) better pinpoint and assess sources of water quality problems in these watersheds. These recommendations were based solely on their scientific merits and their values for monitoring water quality conditions and pinpointing and assessing nutrient and sediment sources in these watersheds. Thus, they were not evaluated in terms of the feasibility of sampling the sites, whether due to the availability of resources and capacity of the involved organizations (e.g. volunteer time, laboratory capacity, etc.) or any logistical challenges (e.g. accessibility, landowner permission, etc.). Although some of the proposed sites are located along public roads, other sites are likely located on private property and will require landowner permission to access (e.g. several of the proposed sites along Marsh, Sandy Bay, and Godin Brooks). As such, these recommendations may need to be modified in order to accommodate these other considerations. In some cases, sites could be relocated if necessary to locations with public access (e.g. the Bogue Branch site), but the locations proposed in this report are the "ideal" locations.

Due to the large number of proposed sites, the implementation of these recommendations may not feasible in a single year. We have tried to highlight those sites that are the highest priorities in each watershed, but it may be necessary to target only one or two watersheds, so that a manageable number of sites are sampled each year. Based on our data analyses, field observations, and discussions with various stakeholders, we recommend that the following tributaries be given the highest priorities for additional sampling in the next few years: 1) Hungerford Brook, 2) Godin Brook, 3) Sandy Bay Brook, and 4) Marsh Brook. In later years, other watersheds might be addressed (e.g. Black Creek and Mud Creek), although it is likely that additional sites will also be needed in each watershed as water quality problems are pinpointed and assessed.

During our discussions with various stakeholders, it became clear that neither the Franklin Watershed Committee nor the Missisquoi River Basin Association had the funding to support staff time to administer and implement these volunteer-based water quality monitoring programs or to analyze and report the water quality data collected through these programs. Such funding is essential for allowing these water quality monitoring programs to effectively monitor water quality conditions over time and especially to pinpoint and assess nutrient and sediment sources, so that nutrient- and sediment-reduction projects and practices can be developed and implemented.

One final caveat, since we examined only a subset of watersheds in the Missisquoi River watershed, these recommendations reflect only those individual watersheds and not the basin in its entirety. Thus, there may be other areas within the entire Missisquoi Bay Basin that would merit and may be higher priorities for additional sampling. In contrast, we examined the entire watershed of Lake Carmi and were able to evaluate and prepare recommendations within the broader context of the entire watershed.

Conclusions

In this project, we undertook a short-term water quality data analysis project to inform water quality management in the Lake Carmi watershed and five selected watersheds in the Missisquoi River basin (Hungerford Brook, Black Creek, Tyler Branch, Godin Brook, and Mud Creek). The goals of this project were fourfold: 1) to assess water quality conditions in these tributary watersheds over time, 2) to pinpoint and assess possible nutrient and sediment sources along these tributaries, 3) to provide recommendations for future monitoring efforts, and 4) to provide preliminary recommendations for on-the-ground assessments of possible nutrient and sediment sources.

To accomplish the goals of this project, we undertook a number of tasks.

First, we downloaded all of the available water quality data for the Missisquoi Bay Basin from the State of Vermont's Integrated Watershed Information System (IWIS) database, including all of the water quality data collected by the Missisquoi River Basin Association during

2005-2014, the Franklin Watershed Committee during 2007-2014, the Vermont Department of Environmental Conservation Lake Assessment Program during 2007, and the Vermont Department of Environmental Conservation Biomonitoring and Aquatic Studies (BASS) Program during 2004-2013. Once downloaded, we then used the geographic coordinates to map all of the sample sites in a Geographic Information System (GIS).

Second, we downloaded the relevant stream flow data for all of the U.S. Geological Survey (USGS)-maintained stream gages located in the Missisquoi Bay Basin. For this project, we used the daily flow data from the gages on the Missisquoi River near East Berkshire, Vermont (USGS station 04293500) and the Pike River at East Franklin near Enosburg Falls, Vermont (USGS station 04294300) as proxies for stream flows for the five tributaries of the Missisquoi River and Lake Carmi, respectively. Based on these data, we determined that 85-90% of the water quality samples were collected at low and moderate flows.

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 without any contamination. Although we detected three errors in site locations, the quality assurance (QA) data indicated that the water samples were being collected correctly (i.e. in a repeatable manner and without any contamination).

We then summarized the water quality conditions for each sample site, and, where data were sufficient, we analyzed the water quality data in relation to stream flows. We then delineated the subwatersheds drained by each sample site and mapped the subwatersheds according to their mean total phosphorus concentrations. In general, total phosphorus concentrations were extremely high in the watersheds of Hungerford Brook, Godin Brook, and two tributaries of Lake Carmi (Sandy Bay and Marsh Brooks); were intermediate in the watersheds of Black Creek, Mud Creek, and several other tributaries of Lake Carmi; and were lowest in the watersheds of Tyler Branch and still other tributaries of Lake Carmi. These results paralleled those reported by earlier studies that had found that phosphorus concentrations and loadings were highest in Hungerford Brook but also high in Black Creek, Mud Creek, and the Lake Carmi watershed (Howe et al. 2011, Stone Environmental 2011, Deeds and Deeds 2013, Sawyer 2015).

Based on these analyses and discussions with other stakeholders, we developed recommendations for improving the sampling network. The existing set of sample sites excels at monitoring yearly trends in water quality conditions in these watersheds. However, except for two tributaries of Lake Carmi (Sandy Bay and Marsh Brooks), the existing network has not been focused on pinpointing and assessing possible nutrient and sediment sources. Thus, we recommend adding a number of sites along the main stems and branches of these tributaries, especially those that exhibit the highest total phosphorus concentrations (e.g. Hungerford Brook, Black Creek, Godin Brook, Mud Creek, Sandy Bay Brook, and Marsh Brook).

We also developed a limited set of preliminary recommendations for on-the-ground surveys to further investigate possible nutrient and sediment sources by staff from the appropriate agencies or organizations (e.g. Vermont Agency of Agriculture, Food & Markets; Vermont Agency of Natural Resources; Natural Resources Conservation Service). In particular, initial efforts should focus on several large and small farms along Godin Brook, Sandy Bay Brook, and Marsh Brook.

Finally, we presented the results of this project to members of the Franklin Watershed Committee and Missisquoi River Basin Association and staff from the Vermont Agency of Natural Resources and Vermont Agency of Agriculture, Food & Markets at a public outreach meeting in Enosburg Falls on 20 August 2015. We will also present this work to the newly-formed Lake Carmi TMDL Implementation Team and staff from the Monitoring, Assessment and Planning Program (MAPP) of the Vermont Department of Environmental Conservation (DEC).

Bibliography

Deeds, J. and S.S. Deeds. 2013. *Missisquoi River Basin Association Water Quality Monitoring Program Summary of Results 2005-2012*. Missisquoi River Basin Association, East Berkshire, Vermont.

Dyer, M. and F. Gerhardt. 2007. *Restoring Water Quality in the Lake Memphremagog Basin: Water Quality in the Four Vermont Tributaries*. NorthWoods Stewardship Center, East Charleston, Vermont.

Environmental Protection Agency. 2015. *Phosphorus TMDLs for Vermont Segments of Lake Champlain*. Environmental Protection Agency, Boston, Massachusetts.

Howe, E., S. Strouse and W. Howland. 2011. *Missisquoi Bay Basin Project: Short-term Monitoring Program*. Lake Champlain Basin Program, Grand Isle, Vermont.

Lake Champlain Basin Program. 2015. *2015 State of the Lake and Ecosystem Indicators Report*. Lake Champlain Basin Program, Grand Isle, Vermont.

Picotte, A. and L. Boudette. 2005. *Vermont Volunteer Surface Water Monitoring Guide*. Vermont Department of Environmental Conservation, Waterbury, Vermont.

Sawyer, A. 2015. *Missisquoi River Basin Association Water Quality Monitoring Program Summary of Results 2005-2014*. Missisquoi River Basin Association, East Berkshire, Vermont.

State of Vermont. 2008. *Phosphorus Total Maximum Daily Load (TMDL) for Lake Carmi Waterbody VT05-02L01*. Vermont Agency of Natural Resources, Waterbury, Vermont.

State of Vermont. 2011. *Vermont Statewide Total Maximum Daily Load (TMDL) for Bacteria-Impaired Waters*. Vermont Department of Environmental Conservation, Waterbury, Vermont.

State of Vermont. 2013. *Missisquoi Bay Basin Water Quality Management Plan*. Vermont Agency of Natural Resources, Montpelier, Vermont.

State of Vermont. 2014a. *303(d) List of Impaired Waters*. Vermont Department of Environmental Conservation, Montpelier, Vermont.

State of Vermont. 2014b. *Stressed Waters List*. Vermont Department of Environmental Conservation, Montpelier, Vermont.

Stone Environmental. 2011. *Identification of Critical Source Areas of Phosphorus Within the Vermont Sector of the Missisquoi Bay Basin*. Lake Champlain Basin Program, Grand Isle, Vermont.

Appendix A. Quality assurance data, including field blanks and field duplicates, collected at 41 sample sites along six tributaries of Missisquoi Bay during 2005-2014. Bold values indicate field blanks that exceeded detection limits (5 µg/l for total phosphorus) or field duplicates that differed by >30% for total phosphorus.

Field Blanks:

Site	Date	Total Phosphorus (µg/l)
Missisquoi River Tributaries:		
The Branch	5/28/2014	<5
Mud Creek Bear Mountain Road	6/11/2014	**6.55**
Black Creek Bouchard Road	6/11/2014	**30.3 ***
Godin Brook Marvin Road	6/25/2014	<5
Tyler Branch Boston Post Road	7/9/2014	<5
Hungerford Trib 4	7/23/2014	<5
Hungerford Trib 6	9/3/2014	<5
Wanzer Brook	9/16/2014	<5
Godin Brook Marvin Road	9/17/2014	<5
Tyler Branch Duffy Hill Road	10/1/2014	<5
Mud Creek Route 105	10/1/2014	<5

Site	Date	Total Phosphorus (µg/l)
Lake Carmi Tributaries:		
LC10 Marsh Brook	5/29/2013	<5
LC1 Sandy Bay Brook	6/12/2013	<5
LC5 Dicky's Brook	6/26/2013	<5
LC9 Marsh Brook	7/10/2013	<5
LC8 Marsh Brook	7/24/2013	<5
LC1 Sandy Bay Brook	8/7/2013	<5
LC9 Marsh Brook	8/21/2013	<5
LC17 Hammond's Brook North	9/4/2013	<5
LC10 Marsh Brook	9/16/2013	<5
LC8 Marsh Brook	10/2/2013	<5
LC10 Marsh Brook	4/18/2014	<5
LC10 Marsh Brook	5/28/2014	<5
LC1 Sandy Bay Brook	6/11/2014	<5
LC5 Dicky's Brook	6/25/2014	<5
LC10 Marsh Brook	7/9/2014	<5
LC10 Marsh Brook	7/23/2014	<5
LC9 Marsh Brook	8/6/2014	<5
LC1 Sandy Bay Brook	9/3/2014	<5
LC10 Marsh Brook	9/17/2014	<5
LC9 Marsh Brook	10/1/2014	<5
LC10 Marsh Brook	10/17/2014	<5
LC1 Sandy Bay Brook	10/31/2014	<5

* This field blank was likely a field duplicate instead (see text for explanation).

Field Duplicates:

Site	Date	1st Total Phosphorus (µg/l)	2nd Total Phosphorus (µg/l)	Relative % Difference
Missisquoi River Tributaries:				
Black Creek Bouchard Road	9/7/2005	47	46	2
Mud Creek Bear Mountain Road	9/7/2005	47.2	47.8	1
Wanzer Brook	9/26/2006	13.6	14.4	6
Hungerford Brook Highgate Road	5/16/2007	98	95.8	2
Hungerford Brook Highgate Road	8/8/2007	150	151	1
Black Creek Ryan Road	8/22/2007	35.6	32.1	10
Mud Creek Bear Mountain Road	9/5/2007	28.9	25.2	14
Black Creek Ryan Road	9/19/2007	32.9	34	3
Tyler Branch Duffy Hill	9/19/2007	10.1	10.1	0
Mud Creek Bear Mountain Road	10/3/2007	37.6	34.7	8
Hungerford Brook	10/12/2007	105	103	2
The Branch Route 108	5/14/2008	23.9	23.5	2
Hungerford Brook Woods Hill Road	6/25/2008	32.7	31.7	3
Tyler Branch Boston Post	6/25/2008	16.7	15.8	6
Tyler Branch Duffy Hill	7/23/2008	29.3	28.6	2
Black Creek Ryan Road	8/6/2008	30.9	31.1	1
Hungerford Trib 6 Woods Hill Road	8/6/2008	75.8	107	**34**
Mud Creek Trib 10	8/6/2008	133	130	2
Mud Creek Route 105	8/20/2008	46.1	43.2	6
Wanzer Brook Wanzer Road	8/20/2008	34	33.6	1
The Branch Route 108	9/3/2008	26.9	25.1	7
Hungerford Trib 4 Cook Road	10/1/2008	161	152	6
Black Creek Bouchard Road	10/15/2008	37.2	38.2	3
Hungerford Trib 4 Cook Road	7/22/2009	68	66.8	2
Hungerford Brook Woods Hill Road	8/19/2009	107	106	1
Hungerford Trib 6 Woods Hill Road	8/19/2009	111	94.8	16
Tyler Branch Duffy Hill	8/19/2009	15.1	22.7	**40**
Black Creek Ryan Road	9/2/2009	28.8	27.8	4
Mud Creek Trib 10	9/2/2009	84.9	83.3	2
Hungerford Trib 6 Woods Hill Road	9/16/2009	158	165	4
Mud Creek Bear Mountain Road	9/16/2009	45.6	45.7	0
Tyler Branch Boston Post	9/16/2009	43.8	9.78	**127**
Mud Creek Route 105	10/14/2009	31.8	34.3	8

Site	Date	1st Total Phosphorus (µg/l)	2nd Total Phosphorus (µg/l)	Relative % Difference
Black Creek Bouchard Road	6/16/2010	33.1	32.2	3
Hungerford Trib 6 Woods Hill Road	7/14/2010	108	105	3
Tyler Branch Duffy Hill	7/14/2010	25.7	23.5	9
Black Creek Ryan Road	7/28/2010	35.6	34.9	2
Mud Creek Trib 10	7/28/2010	540	565	5
Hungerford Brook Woods Hill Road	8/11/2010	70.6	68.6	3
Mud Creek Bear Mountain Road	8/11/2010	127	127	0
Wanzer Brook Wanzer Road	8/25/2010	17.2	17	1
Mud Creek Route 105	9/8/2010	38.5	37.9	2
Tyler Branch Boston Post	9/8/2010	23.5	11	**72**
Hungerford Trib 4 Cook Road	9/22/2010	98.8	102	3
Black Creek Bouchard Road	10/6/2010	49.6	41	19
Mud Creek Trib 10	10/6/2010	71.6	68.9	4
The Branch Route 108	10/6/2010	16.8	17.3	3
Mud Creek Bear Mountain Road	10/20/2010	53.4	51.5	4
Godin Brook Marvin Road	6/8/2011	51.4	51.3	0
Black Creek Ryan Road	6/22/2011	48	37.5	25
Hungerford Trib 4 Cook Road	6/22/2011	85.3	75.9	12
Hungerford Trib 6 Woods Hill Road	7/20/2011	99.8	101	1
Mud Creek Route 105	7/20/2011	66.1	63.2	4
Tyler Branch Boston Post	7/20/2011	19	17	11
Wanzer Brook Wanzer Road	8/3/2011	17.2	17	1
Hungerford Brook Woods Hill Road	8/17/2011	147	150	2
Black Creek Bouchard Road	6/13/2012	41	40.5	1
Mud Creek Bear Mountain Road	6/13/2012	69.3	65.4	6
The Branch Route 108	6/27/2012	81.4	77.7	5
Tyler Branch Boston Post	7/11/2012	7.94	8.45	6
Black Creek Ryan Road	7/25/2012	48.3	54.6	12
Hungerford Trib 4 Cook Road	7/25/2012	172	179	4
Hungerford Trib 6 Woods Hill Road	9/5/2012	620	610	2
Mud Creek Route 105	9/5/2012	260	260	0
Wanzer Brook Wanzer Road	9/19/2012	88	84	5
Tyler Branch Duffy Hill	10/3/2012	11.5	11	4
Hungerford Brook Woods Hill Road	10/17/2012	39.4	38	4

Site	Date	1st Total Phosphorus (µg/l)	2nd Total Phosphorus (µg/l)	Relative % Difference
Hungerford Brook Woods Hill Road	5/29/2013	55.2	62.2	12
The Branch Route 108	5/29/2013	18.4	15.7	16
Black Creek Bouchard Road	6/12/2013	80.4	82	2
Mud Creek Bear Mountain Road	6/12/2013	121	122	1
Tyler Branch Boston Post	7/10/2013	16.4	15.3	7
Black Creek Ryan Road	7/24/2013	111	113	2
Hungerford Trib 4 Cook Road	7/24/2013	74.6	73.9	1
Hungerford Trib 6 Woods Hill Road	9/4/2013	77	76.6	1
Wanzer Brook Wanzer Road	9/18/2013	26.8	27.1	1
Fairfield River	9/24/2013	23.5	23.3	1
Mud Creek Route 105	10/2/2013	42.9	40.6	6
Tyler Branch Duffy Hill	10/2/2013	9.59	9.48	1
The Branch Route 108	5/28/2014	30.9	51.3	**50**
Mud Creek Bear Mountain Road	6/11/2014	59.7	58.1	3
Tyler Branch Boston Post Road	7/9/2014	15.8	15.2	4
Hungerford Trib 4 Cook Road	7/23/2014	74	72.5	2
Godin Brook Upper North	9/3/2014	29.6	27.3	8
Hungerford Trib 6 Woods Hill Road	9/3/2014	98.3	95.7	3
Wanzer Brook	9/16/2014	14.6	14.5	1
Godin Brook Marvin Road	9/17/2014	59.9	59.4	1
Mud Creek Route 105	10/1/2014	27.3	25.3	8
Tyler Branch Duffy Hill Road	10/1/2014	11.7	11.8	1
Lake Carmi Tributaries:				
MB Marsh Brook	6/20/2007	94.9	94.2	1
MB Marsh Brook	6/21/2007	91	85.9	6
MB Marsh Brook	7/8/2007	81.5	86.1	5
MB Marsh Brook	7/13/2007	139	530	**117**
MB Marsh Brook	10/31/2007	67.8	66	3
MB Marsh Brook	7/6/2007	24.1	35.2	**37**
LC1 Sandy Bay Brook	8/6/2008	566	555	2
LC1 Sandy Bay Brook	9/17/2008	81.2	79.6	2
LC1 Sandy Bay Brook	7/22/2009	170	168	1
LC1 Sandy Bay Brook	6/16/2010	105	113	7
LC1 Sandy Bay Brook	6/30/2010	260	254	2
LC1 Sandy Bay Brook	7/14/2010	154	214	**33**

Site	Date	1st Total Phosphorus (µg/l)	2nd Total Phosphorus (µg/l)	Relative % Difference
LC1 Sandy Bay Brook	6/15/2011	210	242	14
LC1 Sandy Bay Brook	8/24/2011	199	197	1
LC1 Sandy Bay Brook	5/30/2012	494	378	27
LC1 Sandy Bay Brook	8/15/2012	254	314	21
LC1 Sandy Bay Brook	6/12/2013	417	418	0
LC1 Sandy Bay Brook	8/7/2013	131	116	12
LC10 Marsh Brook	7/27/2011	83	83.8	1
LC10 Marsh Brook	8/29/2012	91.1	81.3	11
LC10 Marsh Brook	10/10/2012	58.9	56.2	5
LC10 Marsh Brook	5/29/2013	62.9	64.2	2
LC10 Marsh Brook	9/16/2013	178	176	1
LC3 Dicky's Brook	10/1/2008	24.4	24.4	0
LC3 Dicky's Brook	8/5/2009	74.7	41.6	**57**
LC3 Dicky's Brook	9/8/2010	37.3	37	1
LC5 Dicky's Brook	8/20/2008	199	193	3
LC5 Dicky's Brook	9/2/2009	95.5	94.8	1
LC5 Dicky's Brook	7/28/2010	87.7	68.8	24
LC5 Dicky's Brook	6/22/2011	66.1	49.3	29
LC5 Dicky's Brook	7/11/2012	42.6	43	1
LC5 Dicky's Brook	6/26/2013	27.8	28.3	2
LC6 Dewing Brook	9/20/2010	795	785	1
LC6 Dewing Brook	6/27/2012	44	44.3	1
LC6 Dewing Brook	9/19/2012	59.7	61.1	2
LC7 Unnamed Tributary	9/3/2008	76.9	101	27
LC7 Unnamed Tributary	10/15/2008	73.1	52.8	**32**
LC7 Unnamed Tributary	8/19/2009	65.2	60.5	7
LC8 Marsh Brook	9/16/2009	118	158	29
LC8 Marsh Brook	9/30/2009	254	260	2
LC8 Marsh Brook	6/29/2011	94.7	94	1
LC8 Marsh Brook	6/13/2012	169	165	2
LC8 Marsh Brook	9/12/2012	194	197	2
LC8 Marsh Brook	9/26/2012	111	110	1
LC8 Marsh Brook	7/24/2013	148	158	7
LC8 Marsh Brook	10/2/2013	66.5	66.8	0

Site	Date	1st Total Phosphorus (µg/l)	2nd Total Phosphorus (µg/l)	Relative % Difference
LC9 Marsh Brook	10/14/2009	111	112	1
LC9 Marsh Brook	8/11/2010	95.7	93.4	2
LC9 Marsh Brook	10/6/2010	90.7	90.6	0
LC9 Marsh Brook	7/13/2011	112	116	4
LC9 Marsh Brook	8/10/2011	96.1	97.1	1
LC9 Marsh Brook	7/25/2012	136	145	6
LC9 Marsh Brook	7/10/2013	104	99.2	5
LC9 Marsh Brook	8/21/2013	91.3	90.5	1
LC12 Kane's Brook	8/3/2010	192	200	4
LC15 Prouty Brook	8/25/2010	19.9	20	1
LC17 Hammond's Brook North	9/4/2013	21	17.3	19
LC1 Sandy Bay Brook	6/12/2013	417	418	0
LC5 Dicky's Brook	6/26/2013	27.8	28.3	2
LC9 Marsh Brook	7/10/2013	104	99.2	5
LC8 Marsh Brook	7/24/2013	148	158	7
LC1 Sandy Bay Brook	8/7/2013	131	116	12
LC9 Marsh Brook	8/21/2013	91.3	90.5	1
LC17 Hammond's Brook North	9/4/2013	21	17.3	19
LC10 Marsh Brook	9/16/2013	178	176	1
LC8 Marsh Brook	10/2/2013	66.5	66.8	0
LC10 Marsh Brook	4/18/2014	48.1	49.8	3
LC10 Marsh Brook	5/28/2014	70.2	69.3	1
LC1 Sandy Bay Brook	6/11/2014	172	164	5
LC5 Dicky's Brook	6/25/2014	49.6	46.5	6
LC10 Marsh Brook	7/9/2014	167	166	1
LC10 Marsh Brook	7/23/2014	65.3	65.9	1
LC9 Marsh Brook	8/6/2014	62.3	61.2	2
LC1 Sandy Bay Brook	9/3/2014	152	146	4
LC10 Marsh Brook	9/17/2014	49.2	49.7	1
LC9 Marsh Brook	10/1/2014	71	71.5	1
LC10 Marsh Brook	10/17/2014	58.9	57.6	2
LC1 Sandy Bay Brook	10/31/2014	102	97.8	4

Appendix B. Glossary [based largely on Picotte and Boudette (2005) and Dyer and Gerhardt (2007)].

Algae – Aquatic organisms that generally are capable of photosynthesis but lack the structural complexity of plants. Algae range from single-celled to multicellular organisms and can grow on the substrate or suspended in the water column (the latter are also known as phytoplankton).

Algal bloom – A population explosion of algae usually in response to high nutrient levels (particularly phosphorus and nitrogen), warm water temperatures, and long periods of sunlight. When these algae die, their decomposition can deplete oxygen to levels that are too low to support most aquatic life.

Basin – A geographic area bounded peripherally by a divide and draining into a particular water body. The relative size of a basin and the human alterations to that basin greatly affect water quality in the water body into which it drains.

Concentration – The quantity of a dissolved substance per unit of volume.

Detection limit – The lowest value of a physical or chemical parameter that can be measured reliably and reported as a value greater than zero by a given method or piece of equipment.

Erosion – The loosening and transport of soil and other particles. Erosion is a natural process but can be accelerated by human activities, such as forest clearance and stream channel alteration.

Eutrophication – The natural aging process of a water body whereby nutrients and sediments increase in the lake over time, increase its productivity and eventually turn it into a wetland. Human activities often accelerate this process.

Flow – The volume of water moving past a given location per unit of time (usually measured as cubic meters or feet per second).

Groundwater – Water that lies beneath the earth's surface in porous layers of clay, sand, gravel, and bedrock.

Limiting nutrient – A nutrient that is scarce relative to demand and that limits plant and animal growth in an ecosystem.

Load – The total amount of a physical or chemical substance, such as sediment or a nutrient, being transported in the water column per unit of time.

Median – A number describing the central tendency of a group of numbers and defined as the value in an ordered set of numbers below and above which there are equal numbers of values.

Nonpoint source pollution – Pollution that originates from many, diffuse sources spread across the landscape (e.g. in surface runoff from lawns or agricultural fields).

Nutrient – A chemical required for growth, development, or maintenance of a plant or animal. Nutrients are essential for sustaining life, but too much of any one nutrient can upset the balance of an ecosystem.

Photosynthesis – The biological process by which plants, algae, and some other organisms convert sunlight, carbon dioxide, and water into sugar and oxygen.

Point source pollution – Pollution that originates from a single location or source (e.g. discharge pipes from a wastewater treatment plant or industrial facility).

Quality assurance (QA) – An integrated system of measures designed to ensure that data meet predefined standards of quality with a stated level of confidence.

Quartile – The value at the boundary of the 25th, 50th, or 75th percentiles of an ordered set of numbers divided into four equal parts, each containing one quarter of the numbers.

Riparian buffer – A strip of unmanaged vegetation growing along the shoreline of a river or stream. Riparian buffers reduce erosion, filter sediments and pollutants, and provide important aquatic and riverine habitats.

Standard deviation (SD) – A statistic that measures the variability of a set of data.

Surface waters – Water bodies that lie on top of the earth's surface, including lakes, ponds, rivers, streams, and wetlands.

Tributary – A water body, such as a river or stream, that flows into another body of water.

Total Maximum Daily Load (TMDL) – The maximum amount of a pollutant that a water body can receive in order to meet water quality standards.

Watershed – See basin.

Wetland – Land on which water saturation is the dominant factor determining the nature of soil development and the types of plant and animal communities that live there.

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