Water Quality Conditions in the Mad River Watershed, Vermont 1985-2015

Prepared for the

Friends of the Mad River

by

Fritz Gerhardt, Ph.D.

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Beck Pond LLC

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Cover. Looking downstream along the Mad River just downstream of the village of Moretown, Vermont on 15 October 2015. Note the large bedrock outcrops and sand and gravel bars, both characteristic of this dynamic river system. The pools among the distant rock outcrops are one of many popular swimming areas along the Mad River.

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Executive Summary

1. Since 1985, the Friends of the Mad River has monitored water quality conditions throughout the Mad River watershed of Vermont to identify, assess, and correct water quality problems. The resulting water quality data are perhaps unparalleled in Vermont, especially in terms of the length of the record (31 years) and the consistent and repeated sampling of the same sites throughout this time period, and provide an outstanding, long-term record of water quality conditions in the Mad River watershed during 1985-2015. This report provides an overview of the Friends of the Mad River water quality monitoring program, presents the results of the analyses of the biological and chemistry data collected through this program, identifies several areas and issues of concern, and provides recommendations for future monitoring efforts.
2. Starting in 1985 and continuing through 2015, staff and volunteers from the Friends of the Mad River used portable field equipment and an in-house laboratory to quantify various physical, chemical, and biological parameters at a total of 57 sites along the Mad River and its tributaries (only 18-40 sites were sampled in any one year). Starting in 2006, the Friends of the Mad River partnered with the LaRosa Analytical Laboratory of the Vermont Department of Environmental Conservation to measure total phosphorus, turbidity, and *Escherichia coli* (*E. coli*) at a subset of those 57 sites (*E. coli* was only analyzed through this partnership during 2006-2011). In executing this project, staff and volunteers adhered to a rigorous set of quality assurance standards in order to collect the most precise and accurate measures of the physical, chemical, and biological conditions in the Mad River watershed. Review of the quality assurance data and examination of the stream flows sampled indicated that the data were generally collected across a broad but consistent range of stream flows and in a repeatable manner and without contamination.
3. Water temperatures were measured at 52 sites on 143 dates during 1988-2014. Water temperatures along both the main stem and the tributaries were generally high, primarily because these measurements were only recorded during the summer months (June-August). However, water temperatures were highest in the middle and lower reaches of the main stem and were lowest along the upper reaches of the main stem and many of the tributaries. These higher temperatures likely reflected the more open land uses, lack of vegetative cover, and more meandering river channel along the lower reaches of the main stem. Thus, these data did allow us to identify areas that provide suitable habitat for cold-water fish, such as brook trout (*Salvelinus fontinalis*) and other cold-water organisms.
4. pH, which measures the acidity or alkalinity of water, was measured at 51 sites on 1-80 dates during 1988-1995 and 1997-2005 (34-40 sites were sampled in each year). All sites, including those along both the main stem and the tributaries, exhibited generally neutral pHs (mean at each site = 6.7-7.2). Because pH is largely influenced by the underlying

bedrock and surficial geology, pH levels showed no pronounced relationships with stream flow, but they did show an almost universal pattern of change over time. That is, pH levels initially decreased at all sites in the years prior to 1995, but, after 1995, they increased markedly and consistently at all sites, presumably in response to improvements in air quality and decreased acid deposition following implementation of the Clean Air Act and its amendments starting in the mid-1990s.

5. Total phosphorus, which measures the concentration of all forms of phosphorus in the water column and is an important measure of nutrient levels in rivers and streams, was measured at 19 sites on 55 dates during 2006-2015 (18 sites were sampled in all ten years). Total phosphorus concentrations were remarkably low across almost all of the sample sites. The only areas of concern were along two tributaries (High Bridge and Folsom Brooks) and the main stem in the vicinity of Moretown village. At two of these three sites, total phosphorus concentrations have increased over time, and the positive relationships with stream flow suggested that much of the phosphorus at these two sites may be originating from nonpoint sources, such as surface runoff from agricultural and other land uses and from unpaved roads, especially along High Bridge Brook.

6. Turbidity, which measures water clarity, was measured at the same 19 sites on 55 dates during 2006-2015 (18 sites were again sampled in all ten years). Turbidity levels were also remarkably low across all sample sites. Turbidity levels were slightly higher at two sites located along the main stem near the villages of Moretown and Waitsfield, especially during the two most recent years of this study (2014-2015). At a third site along High Bridge Brook, turbidity levels were also slightly higher than elsewhere, and there the turbidity levels had increased markedly, especially during the past five years. Like total phosphorus, turbidity levels at this site increased markedly with stream flow, and this positive relationship again suggested that nonpoint sources, such as surface runoff from agricultural and other land uses and from unpaved roads, may be impacting water quality in this stream.

7. Fecal coliform bacteria and *Escherichia coli* (*E. coli*), which is one type of fecal coliform bacteria, are valuable indicators of the health and safety of surface waters, especially in areas valued for recreational uses such as swimming. Fecal coliform bacteria were measured at 56 sites on 59 dates during 1985-1991 and 2002-2005 (18-39 sites were sampled in any one year), and *Escherichia coli* were measured at 47 sites on 3-83 dates during 2002-2015 (36-39 sites were sampled in any one year). Both fecal coliform and *E. coli* counts were very high at a number of sites along the lower section of the main stem as well as along several tributaries. Both fecal coliform and *E. coli* counts increased consistently from upstream to downstream areas along the main stem and were markedly higher from the village of Waitsfield downstream to the mouth of the Mad River. At several of the downstream sites, *E. coli* counts also showed a disturbing trend towards higher values during the past 10-15 years. The positive relationship between *E. coli* and stream flow at many of these sites suggested that the source(s) of the *E. coli* may be related to stormwater runoff, especially from areas contaminated by manure, leakage or overflows from septic systems, and wastewater.

8. Collectively, these data greatly increased our understanding of water quality problems in the Mad River watershed. In general, water quality conditions in the Mad River and its tributaries were very good to excellent; however, a few areas exhibited total phosphorus concentrations and turbidity and *E. coli* levels that were higher than desirable. In order to maintain this outstanding long-term data set and to further pinpoint and assess the sources of these water quality problems, we recommend that future monitoring efforts include: 1) continued monitoring of *E. coli* and fecal coliform bacteria at selected sites along the main stem and several tributaries, primarily where swimming and other recreational activities are popular; 2) the addition of new sample sites in areas where water quality problems were identified but are not fully understood (e.g. lower reaches of the main stem and Welder, High Bridge, Folsom, and Clay Brooks); and 3) sampling total nitrogen, which will allow us to better pinpoint and identify possible sources of water quality problems, especially in areas where the high *E. coli*, phosphorus, and turbidity levels may have agricultural or wastewater sources. Better understanding these water quality problems will facilitate efforts to identify and develop the appropriate protection and restoration strategies that will most effectively protect and improve water quality throughout the Mad River watershed.

Introduction

Water is essential for human life as well as most other forms of life. Consequently, water quality is important to the health and integrity of both the human and natural communities. Surface waters - such as streams, rivers, lakes, ponds, and wetlands - provide numerous important ecosystem services and functions and support a great diversity of natural communities and organisms. In addition, surface waters 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, including swimming, boating, fishing, hunting, nature-viewing, and other outdoor activities. The quality of surface waters can also greatly affect the prevalence and spread of many diseases that can be harmful to human health (e.g. cholera and malaria). Because water is essential for maintaining both aquatic and terrestrial ecosystems, water quality serves as a valuable indicator of 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 climate change (including changes in both temperature and the frequency and intensity of precipitation events), atmospheric deposition (e.g. acid precipitation and sulfur and nitrogen deposition), and invasive species [e.g. Eurasian water milfoil (*Myriophyllum spicatum*) and zebra mussels (*Dreissena polymorpha*)]. At the local and landscape scales, water quality is threatened by these factors as well as chemical and biological toxins; changes in land uses such as forest clearing and conversion, construction and maintenance of paved and unpaved roads, and increased urban and suburban development; poor agricultural and forestry practices; loss of wetlands and shoreline habitats; and in-stream modifications, such as dams and channelization. Collectively, these stressors 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, elevated nutrient and sediment levels can cause excessive plant and algal growth, and the subsequent 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 oxygen depletion. In addition, excessive nutrients and sediment, 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 (e.g. "red tides"). Some of these cyanobacteria and diatoms produce toxins that can be harmful or even fatal to humans and wildlife. Finally, these stressors can also eliminate or compromise important aquatic and riverine habitats for fish and wildlife [e.g. warmer water temperatures result in loss of brook trout (*Salvelinus fontinalis*) habitat].

The Mad River is a tributary of the Winooski River (which is itself a tributary of Lake Champlain). The Mad River drains the valley (popularly known as the "Mad River Valley") that separates the main range of the Green Mountains to the west and the Northfield Mountains to the east. The Mad River and its tributaries, nestled in a deep valley between high mountains, give the Mad River Valley its unique sense of place and are highly-valued resources that support a wide array of recreational activities, economic benefits, and ecological functions. The Mad River and its tributaries are used extensively for boating, swimming, fishing, nature-viewing, and other recreational activities (Figure 1). The Mad River hosts nineteen swimming holes along the main stem and three tributaries (Stetson, Lincoln, and Shepard Brooks)(Jenkins et al. 1992). The Mad River is also popular for recreational boating and offers a range of conditions from calm water (Class I) to white water (Class III-IV). The 19 km (12 miles) between Warren and Moretown are a mix of relatively calm Class I and II waters, although there are two areas of more challenging ledges. The 11 km (7 miles) between Moretown Gorge and the Winooski River include a mix of flat water, quick water, a few short Class II rapids, as well as more significant Class III-IV rapids. The Mad River Valley is also popular for its scenic beauty and as home to two popular ski areas (Sugarbush Resort and Mad River Glen). In addition, the Mad River Valley hosts important historic and cultural resources, including several National Historic Districts (Mad River Valley Rural, McLaughlin Farm, Waitsfield Common, Waitsfield Village, and Warren Village) and sites listed on the National Register of Historic Places (the Warren, Great Eddy, and Pine Brook Covered Bridges and the Joslin and McLaughlin Farms). Finally, the Mad River and its tributaries serve as public water supplies, provide hydroelectric power, and support agricultural and industrial production; and the floodplains serve important flood control and water filtration functions.

Figure 1. Swimming is one of several popular recreational activities that occur at many locations along the Mad River, including this area known locally as Ward's Access in Moretown, Vermont viewed on 15 October 2015.

The Mad River Valley also hosts a number of unique and important geologic, hydrologic, and ecological features. There are numerous waterfalls, cascades, and gorges along the Mad River and several of its tributaries (Lincoln, Slide, Stetson, and Mills Brooks), including Moretown Gorge, Mad River Natural Bridge (one of only three in Vermont), and Warren Falls (Jenkins & Zika 1988, State of Vermont 2008). The upper reaches of the Mad River and most of the tributaries are cold-water streams that support native brook trout as well as stocked rainbow trout (*Oncorhynchus mykiss*). The warm-water lower reaches of the main stem support stocked brown trout (*Salmo trutta*) and rainbow trout. Unfortunately, the dams in Warren and Moretown fragment and degrade the aquatic habitats used by these and other fish. Numerous deer wintering areas are located throughout the Mad River watershed, including along the main stem and Dowsville, Shepard, Mill, Folsom, Clay, Lincoln, Stetson, and Mills Brooks. 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. In recognition of these natural features, a number of areas have been conserved to protect public access and the natural heritage of the Mad River watershed, including the Green Mountain National Forest, Camels Hump State Park, and Granville Reservation State Park.

Over the past three decades, there has been considerable interest in protecting and improving water quality and its associated values along the Mad River and its tributaries. This interest has been spurred by concerns that water quality in the Mad River was threatened by rapid development; excessively high levels of nutrients, sediment, and *Escherichia coli* (*E. coli*); and increasing frequency and intensity of flooding. In addition, the State of Vermont has listed a number of locations along the Mad River and its tributaries as impaired or stressed by *Escherichia coli*, sedimentation, stormwater impacts, and insufficient flows due to water withdrawal activities (State of Vermont 2014b, 2014c).

Study Goals

Since 1985, the Friends of the Mad River has been monitoring water quality conditions in the Mad River and its tributaries through its Mad River Watch program, one of the longest-running, volunteer-based water quality monitoring programs in the United States. The overarching goal of this program has been to identify and address water quality problems in order to protect and restore the physical, chemical, and biological integrity of the Mad River and to protect the health and human use of the river. More specifically, the goals of the Mad River Watch program have been 1) to collect baseline information on water quality conditions in the Mad River; 2) to document the impact of point and nonpoint pollution sources on selected physical, chemical, and biological water quality indicators; 3) to document long-term changes in water quality conditions resulting from the implementation of best management practices; 4) to determine whether or not it is safe for humans to use the river; and 5) to determine whether the river meets Vermont Water Quality Standards for bacteria, nutrients, and other indicators. To this end, volunteers have collected water samples every summer since 1985 to document water temperature, pH, total phosphorus, turbidity, fecal coliform bacteria, and *Escherichia coli* at numerous sites along the Mad River and its tributaries. Given this long-term record of water quality conditions, the Friends of the Mad River contracted to have these water quality data compiled, summarized, and analyzed and to recommend options for maintaining and upgrading the Mad River Watch program in future years.

Study Area

One of the largest tributaries of the Winooski River, the Mad River (Waterbody ID VT08-18) extends approximately 42 km (26 miles) and drains an area of approximately 373 km^2 (144 miles^2) in the towns of Moretown, Duxbury, Waitsfield, Fayston, Warren, Lincoln, and Granville in central Vermont (Figure 2). The Mad River drains a narrow valley (popularly known as the "Mad River Valley") that separates the spine of the Green Mountains to the west and the Northfield Mountains to the east. Elevations in the Mad River watershed range between approximately 133 m (435 ft) at the mouth of the Mad River in Moretown to 1,244 m (4,083 ft) atop Mount Ellen in Warren. The Mad River originates in Granville Notch in the town of Granville and flows downstream in a northerly direction through the towns of Warren, Waitsfield, and Moretown before flowing into the Winooski River just downstream of the village of Middlesex. The Mad River is fed by numerous tributary streams, including Lincoln, Freeman, Folsom, Mill, Shepard, and Dowsville Brooks, among others. Blueberry Lake, an artificial impoundment, is the only significant lake in the Mad River watershed and covers an area of 19 ha (48 acres) to a maximum depth of 4.9 m (16 ft). The Mad River is impounded by two dams, the Moretown-8 hydroelectric dam, which has a rated capacity of 920 kW, in Moretown and a second, wooden crib dam in the village of Warren. There are other dams and weirs located along several tributaries of the Mad River, including the earthen dam that impounds Blueberry Lake. The dominant land uses in the Mad River watershed include forestry (86% of the watershed), agriculture (7.3% of the watershed), urban and suburban development in the village centers, and scattered areas of residential development throughout the watershed (all developed lands encompass 4.3% of the watershed)(Stone Environmental 2016).

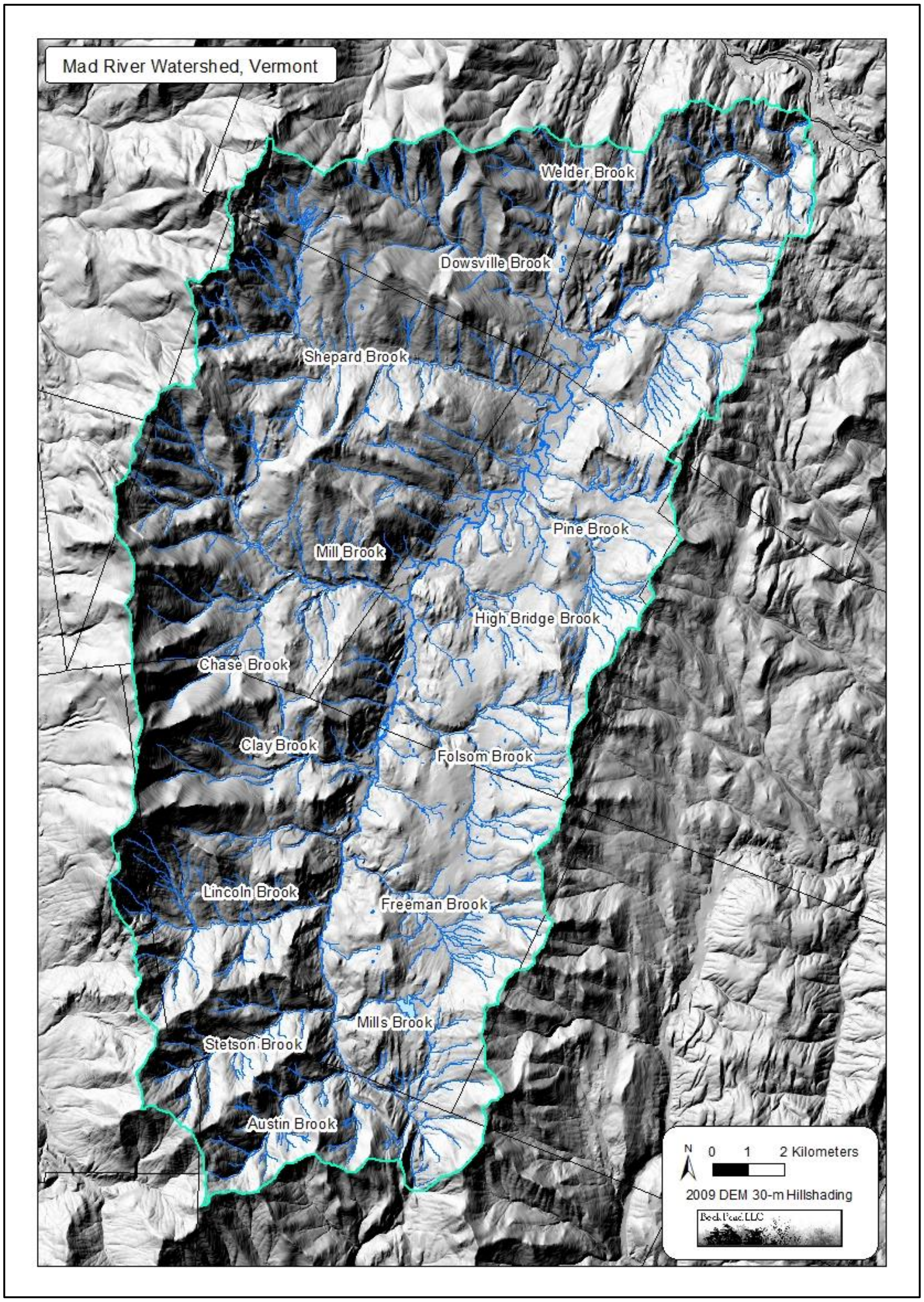


Figure 2. Map of the Mad River watershed (outlined in turquoise) showing the locations of the major tributaries and the topography illustrated by hill-shading.

A number of water quality concerns have been identified in the Mad River watershed, and parts of the Mad River and its tributaries have been listed by the State of Vermont as either impaired or stressed (State of Vermont 2014b, 2014c). The downstream-most 10 km (6.2 miles) of the Mad River from its mouth to Moretown village are already part of an approved Total Maximum Daily Load (TMDL) addressing elevated *Escherichia coli* levels due to possible failing septic systems and other unknown sources (State of Vermont 2011; Part D, State of Vermont 2014b). Clay Brook, from River Mile 1.8 to River Mile 2.3, is impaired and in need of a Total Maximum Daily Load (TMDL) due to increased peak stormwater flows, stormwater runoff, erosion and sedimentation from construction activities and from a gravel parking lot, and iron deposits, all of which are impacting aesthetics and aquatic life support (Part A, State of Vermont 2014b). A 3.4-km (2.1-mile) section of Mill Brook is listed as partially failing to support aquatic life due to artificial and insufficient flows below the Mad River Glen snow-making water withdrawal (Part F, State of Vermont 2014b). Another 1.3 km (0.8 miles) of Slide Brook are listed as failing to support aquatic life due to artificial and insufficient flows below the Mount Ellen snow-making water withdrawal (Part F, State of Vermont 2014b). Finally, a short section of the Mad River from Warren Dam upstream to Vermont Route 100 is listed as stressed due to elevated sediment levels originating from morphological instability and nearby sand and gravel pits, all of which are impacting aesthetics and aquatic life support (State of Vermont 2014c).

In addition, staff from the Biomonitoring and Aquatic Studies Section (BASS) of the Vermont Department of Environmental Conservation (DEC) have monitored the fish and macroinvertebrate communities at numerous sites along the Mad River and its tributaries during 1991-2008 . In general, the macroinvertebrate communities have been ranked as good to excellent at most sites along the main stem, and several tributaries, including Austin, Lockwood, Shepard, Dowsville, and Kewvasseur Brooks. In contrast, during the 1990s, the macroinvertebrate communities in Clay, Rice, Chase, and Slide Brooks, all of which drained parts of the Sugarbush Resort, were ranked as fair or poor due to erosion and sediment transport by stormwater. However, following improvements to the parking areas and other stormwater infrastructure, the macroinvertebrate communities in those streams improved dramatically, and all of these streams, except Clay Brook, were removed from the list of impaired waters (State of Vermont 2008, 2014b). Three other areas of concern include Bradley Brook, where the macroinvertebrate community was ranked as only fair to good in 2006; High Bridge Brook, where there were concerns about the higher water temperatures and excessive sediment on the streambed in an area of pasture; and Welder Brook, where houses, lawns, and a gravel road are encroaching upon the stream (State of Vermont 2008).

Methods

Starting in 1985 and continuing through 2015, staff and volunteers from the Friends of the Mad River have used portable field equipment, an in-house laboratory , and a partnership program through the State of Vermont to quantify various physical, chemical, and biological parameters at 57 sites along the Mad River and its tributaries. Each year during 1985-2015, staff and volunteers from the Friends of the Mad River sampled water quality at 18-40 sites on 2-6 dates during June, July, and August. On each sample date, volunteers collected water samples from each site to be analyzed for total phosphorus, turbidity, fecal coliform bacteria, and/or *E. coli* bacteria. These samples were collected in pre-labeled, sterilized bottles according to protocols established by the Friends of the Mad River and, in the case of those samples being analyzed by the LaRosa Analytical Laboratory, in conjunction with the Vermont DEC (State of Vermont 2006, 2009). At each site, volunteers collected grab samples either directly into the sample bottle or with a dip sampler. In general, water samples were collected 20-30 cm (8-12 in) beneath the water's surface (or mid-way between the surface and the streambed if the water was too shallow) and as far from the streambank and as close to the center of the current as was safely and practically possible. Before collecting the samples, they rinsed the turbidity bottles and, if using one, the dip sampler with sample water three times. All samples were collected in the morning, stored in coolers, and delivered to the Friends of the Mad River office in Waitsfield, Vermont by 10 a.m., and those samples being analyzed by the LaRosa Analytical Laboratory were delivered to the laboratory the same day. This schedule ensured that the laboratories were able to process the samples in a timely manner. While sampling, the volunteers also measured air temperature in the shade, water temperature, and pH and recorded sample date and time, current and previous weather conditions, flow level and category, and general observations about the river or stream and any factors potentially affecting water quality. To avoid spreading invasive species, volunteers disinfected all gear that was touched by water (e.g. boots, sandals, etc.) between sample sites, especially when traveling upstream along the main stem or from the main stem into tributaries.

The fecal coliform and *E. coli* samples were analyzed by Friends of the Mad River staff at their offices in Waitsfield using two different methodologies. During 1992-2002, fecal coliform and *Escherichia coli* samples were processed and counted using a membrane filtration method, in which fecal coliform and *Escherichia coli* samples were collected, processed, and grown on a nutrient medium, so that the numbers of fecal coliform and *E. coli* colonies could be counted by the naked eye. During 2002-2015, fecal coliform and *E. coli* colonies were processed and counted using the Quanti-Tray 2000 system (IDEXX Laboratories, Westbrook, Maine). In this method, fecal coliform and *Escherichia coli* samples were collected, processed, and placed in an incubator within six hours; and the numbers of fecal coliform and *E. coli* colonies were counted after the samples were incubated for 24 hours. This method is widely used, provides very accurate and precise measures of fecal coliform and *E. coli* levels, and is approved by the Environmental Protection Agency as well as other accrediting agencies and organizations.

Quality Assurance

All of the water quality data collected in partnership with the LaRosa Analytical Laboratory during 2006-2015 were collected in accordance with a Quality Assurance Project Plan (QAPP) developed in conjunction with the Vermont DEC and U.S. Environmental Protection Agency. Based on this Quality Assurance Project Plan, the volunteers collected two field blanks and two field duplicates, representing approximately 10% of the number of samples collected on each sample date. Blank sample containers were rinsed and filled only with de-ionized water using the same procedures that were used to collect the field samples and, if done properly, should result in values below the detection limits (5 µg/l for total phosphorus, 0.2 NTU for turbidity, and 1 colony/100 ml for *E. coli*). Field duplicates required collecting a second set of samples at the same time and place as the original samples. When done properly, the mean relative percent difference among all pairs of duplicate samples should be <30% for total phosphorus, <15% for turbidity, and <50% (if >25 colonies/100 ml) or <125% (if <25 colonies/100 ml) for *E. coli*.

Stream Flow

To relate the water quality data to stream flows, we relied on a single source of stream flow data [the U.S. Geologic Survey gage station on the Mad River near Moretown, Vermont (USGS station 04288000)]. The daily stream flow data were downloaded from the USGS website (http://waterdata.usgs.gov/usa/nwis/uv?04288000). Using these data, we calculated the criteria distinguishing four flow levels (low, moderate, high, and flood) based on guidance from the Vermont DEC. Across the entire range of stream flows, low flows were defined as the lowest 25% of all stream flows; moderate flows were defined as the intermediate 50% of all stream flows; high flows were defined as the highest 25% of all stream flows; and flood flows were defined as the top 5% of all stream flows. For the Mad River, these four categories of flow level were calculated using all of the daily stream flow data collected during 1928-2015. In addition, the Friends of the Mad River also qualitatively categorized stream flows based on their field observations and the same stream gage measurements. Their categories included 1) low and steady (LS, when it has not rained in several days and the flow is low), 2) low and rising (LR, when recent rains caused a low-flowing river to rise), 3) low and declining (LD, when rain caused a low-flowing river to rise earlier in the week, but the flow is now dropping), 4) high and steady (HS, when the river has been running higher than normal for several days), 5) high and rising (HR, when recent rains caused a high river to rise even further), and 6) high and declining (HD, after reaching peak flow, a high-flowing river is falling). These qualitative assessments were not used in the quantitative analyses presented in this report but were used to better understand individual data points and water quality conditions at individual sites.

Data Analysis

To accomplish the goals of this study, we undertook the following steps to compile, summarize, and analyze the water quality data collected by the Friends of the Mad River during 1985-2015:

1. First, the Friends of the Mad River provided all of the readily-available data collected by the Mad River Watch program during 1985-2015. In addition, the Vermont DEC provided all of the data housed in their Integrated Watershed Information System (IWIS) database.
2. Second, we downloaded all of the stream flow data from the U.S. Geological Survey (USGS) stream gage located along the Mad River near Moretown, Vermont during 1928-2015.
3. Once downloaded, all of these data were imported into and compiled in electronic spreadsheets (Excel 2007, Microsoft, Redmond, Washington).
4. All of the data were screened to identify any errors or outlying data points, and the available quality assurance (QA) data were analyzed to verify that water samples were collected in a repeatable manner without any contamination.
5. We used the geographic coordinates to map all of the sample sites in a Geographic Information System (ArcGIS 10, ESRI, Redlands, California).
6. We summarized the water quality data for each sample site, and, where data were sufficient, we analyzed the water quality data in relation to stream flow, and year.
7. We compared the results of our analyses to those reported in earlier reports prepared by the Friends of the Mad River and other agencies and organizations.
8. We developed recommendations for updating and upgrading the water quality monitoring program, including identifying new sites and new parameters that would best pinpoint and assess possible sources of water quality problems.
9. We identified locations within the Mad River watershed, where on-the-ground assessments should be conducted by the appropriate agency or organization (e.g. Friends of the Mad River; Vermont DEC; and/or Vermont Agency of Agriculture, Food & Markets) to investigate possible sources of water quality problems.
10. Finally, in July 2016, we will present the results of this study at a public outreach meeting with staff, members, and volunteers from the Friends of the Mad River; staff from the Vermont Agency of Natural Resources and Vermont Agency of Agriculture, Food & Markets; and other interested parties.

Throughout this project, we coordinated our efforts with staff, board members, and volunteers from the Friends of the Mad River and other water quality professionals, including personnel from the Vermont DEC and the University of Vermont. All these stakeholders were targeted with specific questions and concerns and given the opportunity to review and comment on earlier drafts this report and the sampling recommendations.

All data were compiled and maintained in Excel spreadsheets and ArcGIS shapefiles, were archived by the author, and were provided to the Friends of the Mad River.

Results and Discussion

The water quality monitoring completed by the Friends of the Mad River represents an outstanding, long-term record of water quality conditions in the Mad River watershed during 1985-2015 (Table 1). This effort is perhaps unparalleled in the state of Vermont, especially in terms of the length of the record (31 years) and the consistent and repeated sampling of the same sites throughout this time period. Thus, these data provide outstanding baseline monitoring of past and current water quality conditions, identify reference and other outstanding waters, identify and/or confirm the stressors that are impacting these rivers and streams, and assess whether or not water quality conditions are safe for swimming and other recreational activities. On the other hand, these monitoring data were not designed to and were less useful for calculating nutrient and sediment loading into rivers and streams and pinpointing and assessing possible nutrient and sediment sources, although, in the process of collecting water samples, staff and volunteers from the Friends of the Mad River documented possible sources of water quality problems.

During 1985-2015, the Friends of the Mad River sampled water quality at a total of 57 sites distributed throughout the Mad River watershed (Table 2, Figure 3). However, not all sites were sampled in all years. Only 16 sites were sampled in all 31 years during 1985-2015, but another 18 sites were sampled during at least 25 of the 31 years. Of these 34 sites, 16 sites were located along the main stem of the Mad River, and 18 sites were located along tributaries. Largely due to differences in the numbers of years sampled, the 57 sample sites differed dramatically in the numbers of dates on which they were sampled during 1985-2015 (Figure 4). Individual sites were sampled on 1-143 dates over 1-31 years. However, 53% of the sites (30 of the 57 sites) were sampled on at least 105 dates during 1985-2015. In our analyses of the water quality data, we focused primarily on the data collected at those sites that were sampled on the majority of the dates sampled for each parameter.

Table 1. Water quality data collected by the Mad River Watch program of the Friends of the Mad River during 1985-2015. This summary is based solely on the data and documents that were provided to the author in electronic format. Total numbers of dates and sites sampled indicate the total numbers across all sites and all years, but not all sites were sampled on all dates or in all years (those numbers are presented in the discussions of the individual parameters).

Parameter	Year(s) Sampled	Total # Dates Sampled	Total # Sites Sampled	Notes
Parameters Measured In-House by the Friends of the Mad River (1985-2015)				
Air temperature	?	?	?	Data collected but not entered into database
Water temperature	1988-2014	143	52	Data collected in 2015 but not entered into database
pH	1988-1995, 1997-2005	80	51	Data collected in 2006-2015 but not entered into database
Total phosphorus	1993	3	15	Data not analyzed
Turbidity	1988-1990	14	39	Data not analyzed
Fecal coliform	1985-1991, 2002-2005	59	56	Data collected in other years but not entered into database
Escherichia coli (*E. coli*)	1992-2015	83	47	-
Parameters Measured through the LaRosa Partnership Program (2006-2015)				
Total phosphorus	2006-2015	55	19	-
Turbidity	2006-2015	55	19	-
Escherichia coli (*E. coli*)	2006-2011	12	14	Data analyzed for quality assurance purposes only

Table 2. The 57 sites sampled by the Friends of the Mad River during 1985-2015. Sites highlighted in bold were sampled in all years but not necessarily on all dates.

River/Stream	Site #	Site Name	Total # Dates	Year(s) Sampled
Mad River	1	Warren Falls	140	1985-1986, 1988-2015
Lincoln Brook	**2**	**Bobbin Mill**	**140**	**1985-2015**
Mad River	**3**	**Warren Covered Bridge**	**141**	**1985-2015**
Freeman Brook	**4**	**Warren Store**	**140**	**1985-2015**
Freeman Brook	4.5	Freeman Brook	105	1997-2015
Mad River	**5**	**Warren Village North**	**140**	**1985-2015**
Bradley Brook	6	Bradley Brook	136	1985-1986, 1988-2015
Mad River	6.5	Mad River	55	2006-2015
Mad River	**7**	**Riverside Park**	**137**	**1985-2015**
Clay Brook	**8**	**Clay Brook**	**138**	**1985-2015**
Mad River	8.5	-	29	1997-2005
Mad River	9	-	107	1985-2009
Folsom Brook	**10**	**Folsom Brook**	**141**	**1985-2015**
-	10.1	-	5	1985
-	10.2	-	4	1985
-	10.3	-	4	1985
-	10.4	-	1	1985
Folsom Brook	10.5	-	29	1989, 1997-2003, 2005
Folsom Brook	10.6	Folsom Brook	77	1988-1995, 2003-2015
Folsom Brook	10.7	-	36	1988-1995, 1997, 2003-2005
Rice Brook	**11**	**Rice Brook**	**136**	**1985-2015**
Clay Brook	12	Clay Brook	136	1985-1986, 1988-2015
Slide Brook	13	-	65	1985-1986, 1988-2005
Slide Brook	13.1	Slide Brook	77	1988-1995, 1997-2015
Lockwood Brook	14	-	64	1985-1986, 1988-2002, 2012-2014
-	15	-	58	1985, 1988-2002
Chase Brook	16	Chase Brook	137	1985-1986, 1988-2015
Mill Brook	17	Mill Brook German Flats	136	1985-1986, 1988-2015
Mill Brook	17.1	Mill Brook West	75	1988-1995, 1997-2015
Mill Brook	18	-	67	1985-1986, 1988-2005
Mill Brook	18.1	Mill Brook Mouth	76	1988-1995, 1997-2015
Mad River	**19**	**Lareau Swimhole**	**143**	**1985-2015**
Mad River	19.1	-	71	1988-2005
Mad River	19.2	Couples Club	140	1988-2015
-	19.5	-	4	1987

Table 2 (continued).

River/Stream	Site #	Site Name	Total # Dates	Year(s) Sampled
Mad River	**20**	**Waitsfield Covered Br.**	**141**	**1985-2015**
High Bridge Brook	20.1	High Bridge Brook	77	1985, 1988-1995, 1997-2015
Mad River	21	Waitsfield Elem. School	123	1985-1986, 1988-2011
Mad River	21.5	Tremblay Road	25	1991, 2012-2015
Pine Brook	**22**	**Pine Brook**	**142**	**1985-2015**
Mad River	**23**	**Meadow Road Bridge**	**140**	**1985-2015**
Shepard Brook	24	Shepard Brook	140	1985-1986, 1988-2015
Dowsville Brook	25	Dowsville Brook	140	1985-1986, 1988-2015
-	25.1	-	76	1988-1995, 1997-2005
Mad River	**26**	**North Road**	**136**	**1985-2015**
Mad River	**27**	**Moretown Village**	**137**	**1985-2015**
Doctor’s Brook	27.1	Doctor's Brook	137	1988-2015
Mad River	**28**	**Moretown**	**137**	**1985-2015**
Welder Brook	28.05	Welder Brook	125	1988-2015
Unnamed Tributary	28.1	-	77	1988-2005
Unnamed Tributary	28.2	-	77	1988-2005
Unnamed Tributary	28.3	-	78	1988-2005
Mad River	28.4	-	78	1988-1995, 1997-2005
Mad River	**29**	**Ward's Access**	**136**	**1985-2015**
Mad River	30	-	79	1985-2005
Mad River	31	Lover's Lane Bridge	123	1985-1986, 1988-2015
Blueberry Lake	BBL	Blueberry Lake	81	1987-1995, 1997-2015

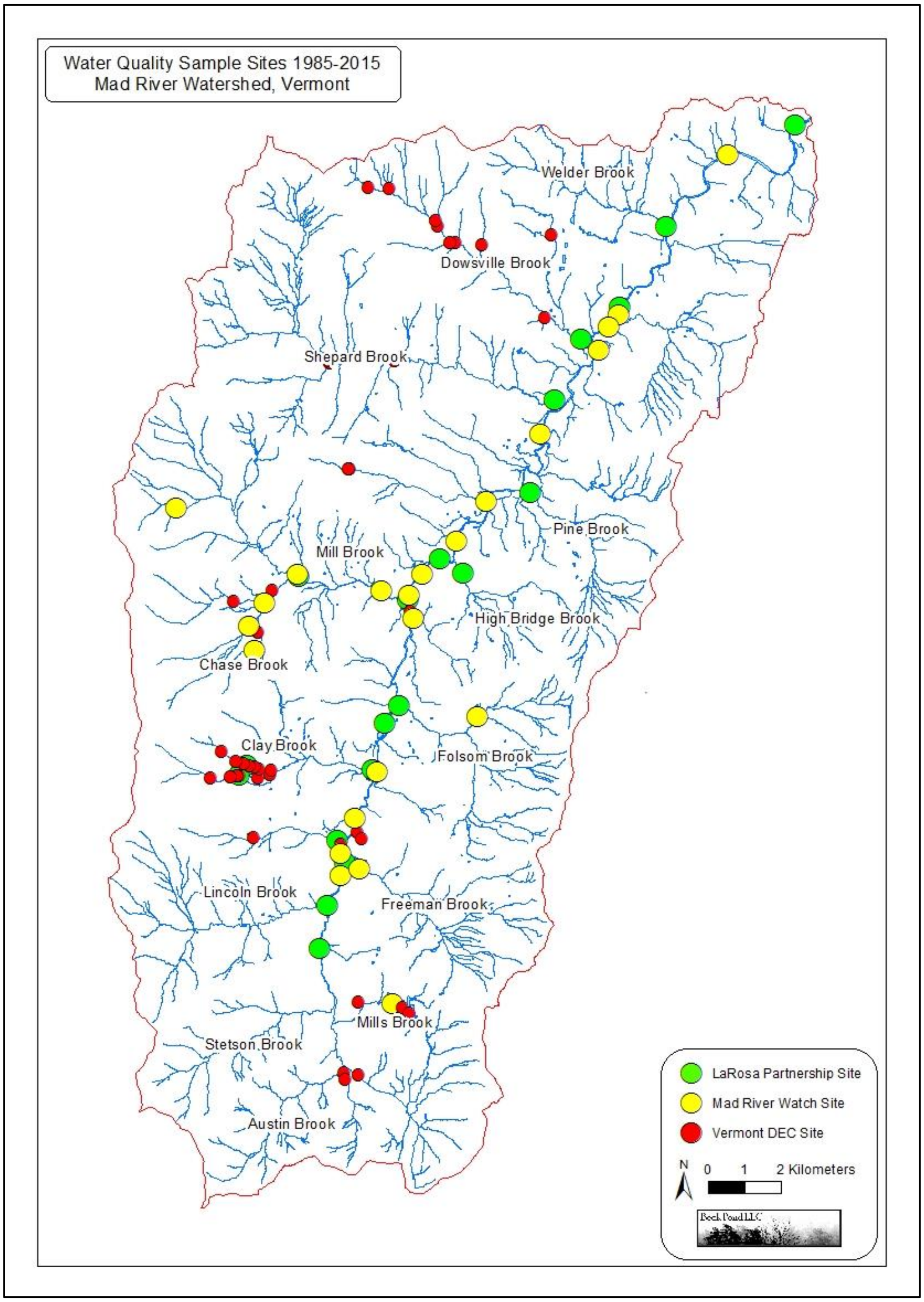


Figure 3. Locations of the 57 sites sampled by the Friends of the Mad River during 1985-2015. Note that not all of these sites were sampled on all dates, in all years, or for all parameters. All of the sites sampled through the LaRosa Partnership Program were also sampled in-house by the Friends of the Mad River. In addition, staff from the Vermont DEC sampled water quality and/or macroinvertebrate and fish communities at another 41 sites.

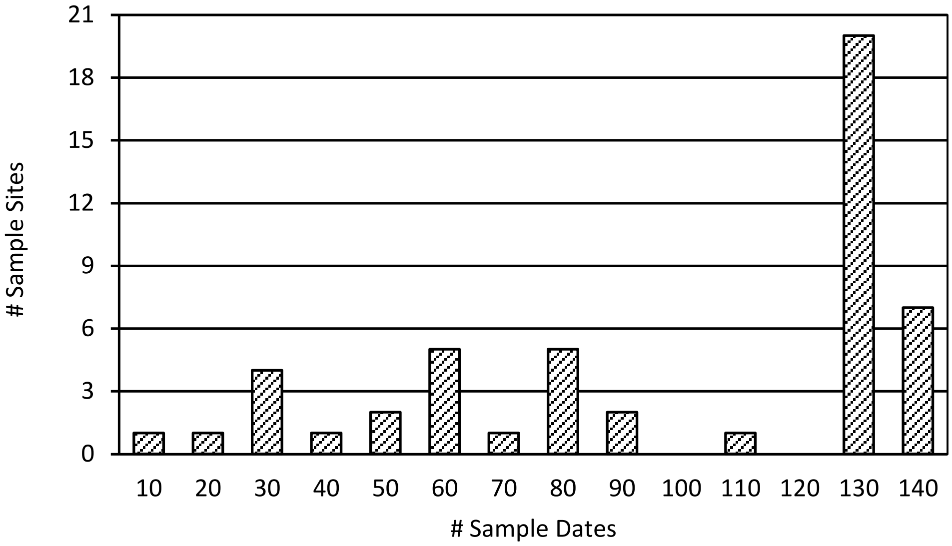


Figure 4. Frequency histogram showing the number of dates on which one or more water quality parameters were sampled at each site in the Mad River watershed during 1985-2015.

Quality Assurance

For the data collected through the LaRosa Partnership Program, this project was conducted in accordance with a Quality Assurance Project Plan (QAPP) developed in conjunction with the Vermont DEC and the U.S. Environmental Protection Agency. The quality assurance data for the Mad River watershed indicated that the sampling program was generally meeting the quality assurance standards for total phosphorus, turbidity, and *E. coli* during 2006-2015. Quality assurance data, at least field duplicates, were also collected for the parameters measured in-house by the Friends of the Mad River; however, these data were not entered into electronic databases, have not been formally analyzed as part of the water quality monitoring program, and were not analyzed as part of this study. The only exception was that duplicate *E. coli* samples were collected and analyzed separately by the Friends of the Mad River and LaRosa Analytical Laboratory at 14 sites on 12 dates during 2006-2011.

Total Phosphorus

The quality assurance samples, including both field blanks and field duplicates, indicated that the total phosphorus samples were generally being collected in a repeatable manner and were generally not being contaminated during collection and processing. Twelve of the 109 field blanks exceeded the detection limit (5 µg/l). However, of these twelve, three were likely mislabeled field duplicates. Two other field blanks (300 and 442 µg/l) greatly exceeded both the detection limit and the values of the regular and duplicate samples collected at those two sites on those two dates. The reason(s) for these extreme values remains unclear. Ignoring these five values, the seven remaining field blanks ranged in value between 5.13-8.13 µg/l, which were relatively minor deviations above the detection limit. Likewise, the mean relative percent difference between duplicate samples (11%) was well below the prescribed relative percent difference (30%). In addition, only twelve of the 109 pairs of total phosphorus samples exceeded the prescribed difference (range = 30-86%).

Turbidity

The quality assurance samples, including both field blanks and field duplicates, indicated that, as has been observed in other water quality monitoring programs, this program encountered difficulties in collecting repeatable and uncontaminated turbidity samples for some unknown reason. Thirteen of the 110 field blanks exceeded the detection limit (0.2 NTU). However, of these 13, four were likely mislabeled field duplicates. Ignoring those four values, the range in values for six of the eight remaining field blanks was 0.26-0.34 NTU, which were relatively minor deviations above the detection limit. The two remaining values (0.80 and 2.19 NTU), however, were relatively high. Similarly, the mean relative percent difference between the duplicate turbidity samples (20%) did exceed the prescribed relative percent difference (15%), and 52 of the 109 pairs of turbidity samples did differ by >15% (range = 16-108%).

Escherichia coli

The quality assurance samples indicated that the *E. coli* samples were generally being collected in a repeatable manner (field blanks, which indicate possible contamination during sampling, were not collected for *E. coli*). We were able to compare field duplicates for *E. coli* in two different ways. First, we compared field duplicates of *E. coli* collected through the LaRosa Partnership Program. The mean relative percent difference between these duplicate samples (49%) was slightly below both of the prescribed differences (<50% if >25 colonies/100 ml and <125% if <25 colonies/100 ml). However, 18 of the 76 pairs of *E. coli* samples exceeded the relevant prescribed difference (range = 50-186%). Second, we compared field duplicates of *E. coli* collected and analyzed independently at the Friends of the Mad River laboratory and the LaRosa Analytical Laboratory. The mean relative percent difference between these duplicate samples (39%) was also below the prescribed relative percent differences (<50% if >25 colonies/100 ml and <125% if <25 colonies/100 ml). However, 17 of the 78 pairs of *E. coli* samples exceeded the appropriate prescribed difference (range = 66-196%). In addition, the correlation between the two sets of values (those measured in-house by the Friends of the Mad River and those measured by the LaRosa Analytical Laboratory) was very good ($y=0.78x-0.43$, where x = value measured by the LaRosa Analytical Laboratory and y = value measured by the Friends of the Mad River; $R^2 = 0.65$)(Figure 5). Thus, the results of these analyses, which met the quality assurance requirements, all indicated that the *E. coli* data were generally being collected in a repeatable manner.

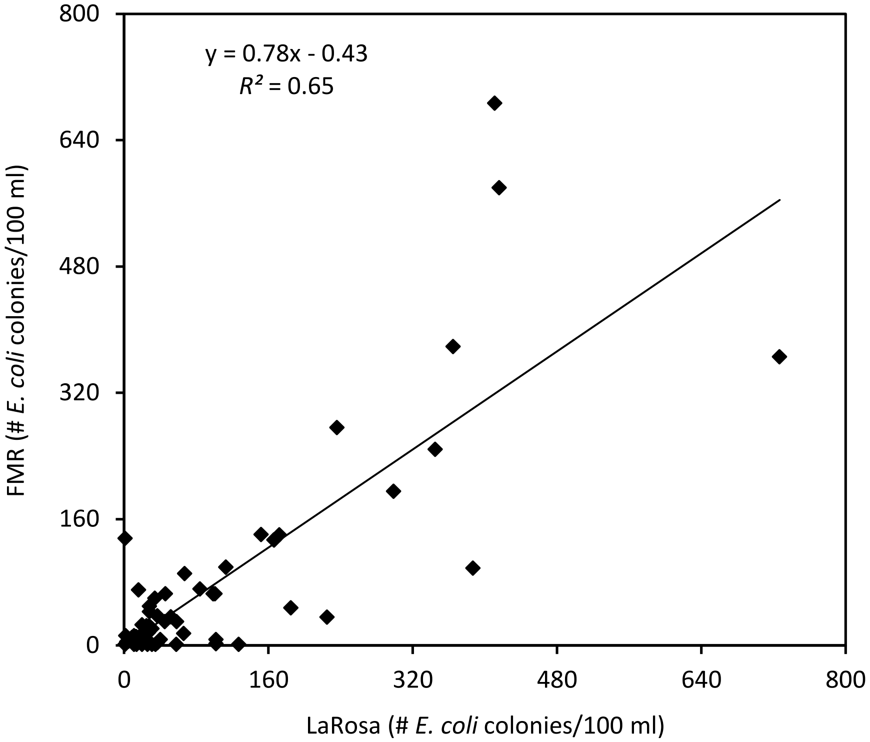


Figure 5. Correlation between the *E. coli* values obtained from paired samples analyzed independently by the Friends of the Mad River laboratory and the LaRosa Analytical Laboratory during 2006-2011. These data represent field duplicates that were collected at the same times and at the same sites but were analyzed in separate laboratories.

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 and characteristics 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 sediments and nutrients. Stream flow is extremely dynamic and changes frequently and sometimes dramatically in response to changes in temperature, precipitation, and season.

To approximate stream flows at the sample sites examined in this study, we used the daily stream flows measured at a stream gage maintained by the U.S. Geological Survey (USGS) on the Mad River near Moretown, Vermont (USGS station 04288000). As is typical in northern New England, stream flows at this gage generally peaked for extended periods of time during the spring and early summer (April-June) following snowmelt, were generally low during the summer and early autumn (July-September), and rose again during late autumn and winter (October-March)(Figure 6). However, extremely high flows also occurred for shorter periods of time following heavy rains and winter thaws throughout the year.

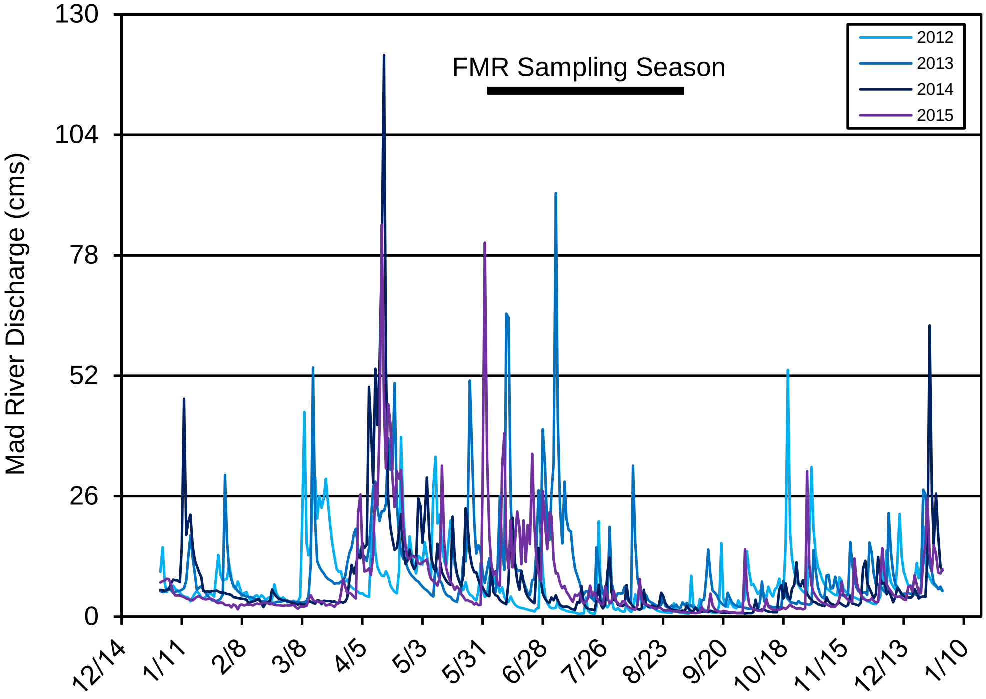


Figure 6. Stream flows along the Mad River near Moretown, Vermont during 2012-2015. Stream flows were measured by the U.S. Geological Survey (USGS station 04288000). The horizontal bar represents the general range of dates sampled by the Friends of the Mad River during 1985-2015.

The water quality sampling conducted by the Friends of the Mad River largely reflected the more limited variation and low to moderate stream flows that typically occurred during June-August when the sampling occurred (Table 3, Figure 7). Despite this more limited variation, the sampling did capture a slightly higher proportion of moderate- and high-flow events. During 2006-2015, 16 of the 55 sample dates (29%) occurred during high flows (that is, when flows were greater than or equal to the highest 25% of all flows), and 30 of the 55 sample dates (55%) occurred during moderate flows (i.e. when flows were within the intermediate 50% of all flows). In contrast, only 9 of the 55 sample dates (16%) occurred during low flows (that is, when flows were less than or equal to the lowest 25% of all flows). In addition, the ranges of stream flows sampled were somewhat similar among years. High flows were sampled on 1-3 dates, representing 17-50% of the sample dates, in nine of the ten years (no high flows were sampled in

2012). Moderate flows were sampled on 1-5 dates, representing 33-83% of the sample dates, across the ten years. However, low flows were only sampled on 1-3 dates during 2011-2015, representing 17-50% of the sample dates (no low flows were sampled during 2006-2010). Given that the water quality standards for certain parameters (State of Vermont 2014a) are referenced to "low median monthly flows" (total phosphorus) or "dry weather base-flow conditions" (turbidity), this small number of samples collected at low flows limited our ability to use these data to evaluate whether or not individual streams or sites were meeting State water quality standards. It should also be noted that localized precipitation events may have affected flows in some but not all areas of the watershed on some dates and that the smaller streams and larger rivers may have responded differently to individual precipitation events. Given these caveats, the stream flows measured at the USGS gage on the Mad River near Moretown may not always provide an accurate representation of stream flows at individual sites on each sample date.

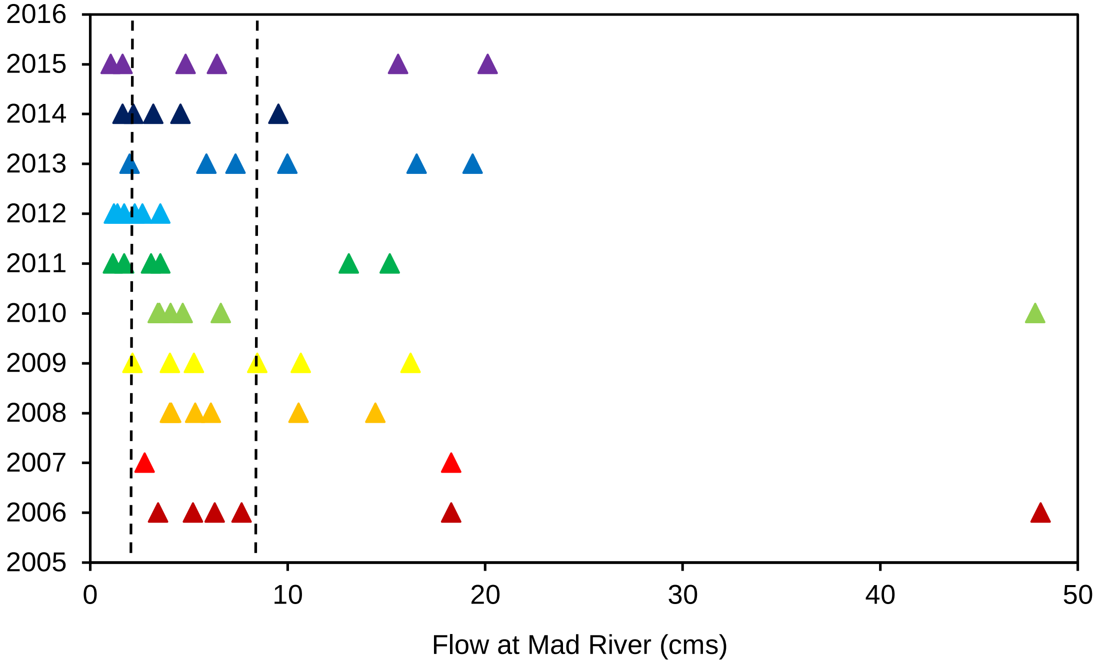


Figure 7. Stream flows measured at the USGS gage on the Mad River near Moretown, Vermont (USGS station 04288000) on each date that water quality samples were collected in the Mad River watershed during 2006-2015. The vertical, dashed lines separate low (left), moderate (center), and high (right) flows.

Table 3. Numbers of low, moderate, and high flows sampled in the Mad River watershed during 2006-2015. The criteria defining low, moderate, and high flows were calculated from the daily stream flows measured at the USGS gage on the Mad River near Moretown, Vermont (USGS station 04288000)(see text for definitions).

Year	Low (<2.1 cms)	Moderate (2.1-8.5 cms)	High (>8.5 cms)	Total	% High Flows
2006	0	4	2	6	33
2007	0	1	1	2	50
2008	0	4	2	6	33
2009	0	4	2	6	33
2010	0	5	1	6	17
2011	2	2	2	6	33
2012	3	3	0	6	0
2013	1	2	3	6	50
2014	1	3	1	5	20
2015	2	2	2	6	33
All ten years	9	30	16	55	29

Because not all sample sites were sampled in all years or on all sample dates, the stream flows represented by the samples collected at each site did differ among sites. Thus, we focused our analyses on those sites that were sampled consistently across most or all of the years for each parameter. By focusing on these sites, we were able to analyze the physical, biological, and chemical data across a consistent and representative set of stream flows and to make meaningful comparisons, especially since nutrient concentrations and sediment loads are often strongly correlated with stream flows. Data collected at low flows were particularly informative for identifying and assessing nutrients originating from point and groundwater sources. In contrast, data collected at high flows were more informative for identifying and assessing nutrients and sediment originating from nonpoint sources, which typically generate the majority of the sediment and nutrient loads being exported into the Lake Champlain Basin (Stone Environmental 2011, Environmental Protection Agency 2015). Thus, analyzing data collected across a range of low, moderate, and high flows allowed us to better identify and evaluate the relationships between water quality parameters and stream flows; to identify and assess possible nutrient and sediment sources, especially point vs. nonpoint sources; and to identify those areas within the Mad River watershed where additional water quality sampling might be most beneficial in pinpointing and assessing possible sources of water quality problems.

Water Temperature

Water temperature regulates many biological and chemical processes, and many aquatic organisms are dependent on specific temperature ranges (Picotte & Boudette 2005). Water temperatures are highly variable in space and time and vary daily, seasonally, annually, and in response to precipitation and other weather events and among sites depending on elevation, stream size, stream type, vegetative cover, groundwater inputs, and a host of other factors. Water temperatures affect the oxygen content of water (e.g. cold water holds more dissolved oxygen), rates of plant and animal growth, and the metabolic rates of many aquatic organisms. In addition, water temperatures directly affect the survival of certain, sensitive aquatic organisms, such as cold-water fish. For example, brook trout cannot survive temperatures exceeding 22°C for an extended period of time.

Water temperature data were collected by the Friends of the Mad River during 1988-2014 (water temperatures were also apparently measured in 2015, but the data were not provided to the author). During these 27 years, water temperatures were measured at 34-39 sites each year. Across all years, 28 of the 52 sites were sampled on at least 117 of the 143 sample dates and across almost all of the years (two of these 28 sites were not sampled in 3-5 years). The remaining 24 sites were sampled on 1-107 dates, often for only a subset of years. Thus, we used the data from all of the years to calculate the median, geometric mean, 25% and 75% quartiles, and range in water temperatures for each of the 28 sites that were well sampled throughout the full time period (1988-2014). However, because the water temperature data for each site represented only single point in time on each sample date (and only six or fewer dates each year), the presentation and interpretation of these data are somewhat limited in scope.

During 1988-2014, water temperatures at the 28 sites ranged between 8.0-27.8°C (46.4-82.0°F), but mean temperatures only ranged between 13.7-19.0°C (56.7-66.2°F)(Table 4). It is important to remember, however, that these temperatures were measured in the early morning hours (prior to 10 a.m.) and only during the summer months (June-August). Within this range, the lowest mean temperatures [<16°C (<60.8°F)] were measured along the upper reaches of the main stem and along most of the tributaries (Figure 8-9). In contrast, the highest mean temperatures [>17°C (>62.6°F)] were measured along the lower reaches of the main stem. Finally, intermediate mean temperatures [16-17°C (60.8-62.6°F)] were measured along the middle reaches of the main stem and the downstream section of Mill Brook.

Table 4. Water temperatures (ºC) at 28 sites along the Mad River and its tributaries during 1988-2014. Only sites that were sampled on at least 117 of the 143 sample dates are included.

Site #	Site Name	# Dates	Median	Mean	Range
1	Warren Falls	140	14.5	14.2	8-21.1
2	Bobbin Mill	140	14.8	14.3	9-19
3	Warren Covered Bridge	141	15.0	14.9	9-23.9
4	Warren Store	140	15.0	14.6	9-20.6
5	Warren Village North	140	15.5	14.9	9-21.7
6	Bradley Brook	136	15.0	14.3	8-23.3
7	Riverside Park	137	15.6	15.2	10-23.3
8	Clay Brook	138	15.0	14.4	9-21.1
10	Folsom Brook	141	15.5	15.0	10-22.2
11	Rice Brook	136	15.0	14.4	10-22.2
12	Clay Brook	136	14.0	13.7	8.9-22.2
16	Chase Brook	137	15.0	14.7	10-21.1
17	Mill Brook German Flats	136	15.0	15.2	10-23.3
19	Lareau Swimhole	143	16.5	16.3	11.1-23.9
19.2	Couples Club	140	16.5	16.6	11.1-26.7
20	Waitsfield Covered Bridge	141	16.7	16.7	11.1-23.9
21	Waitsfield Elementary School	123	17.0	16.9	11-25.6
22	Pine Brook	142	15.6	15.4	11-20.6
23	Meadow Road Bridge	140	17.0	17.3	11.1-25
24	Shepard Brook	140	16.0	15.7	10-24.4
25	Dowsville Brook	140	15.0	14.7	9-22.8
26	North Road	136	17.8	17.5	10-26.1
27	Moretown Village	137	17.8	17.5	11.1-25.6
27.1	Doctor's Brook	137	16.0	16.0	10.6-22.8
28	Moretown	137	17.8	17.5	11.7-25.6
28.05	Welder Brook	117	16.0	16.0	10.6-21
29	Ward's Access	136	18.5	18.3	12.2-27.8
31	Lover's Lane Bridge	118	19.5	19.0	12.2-26

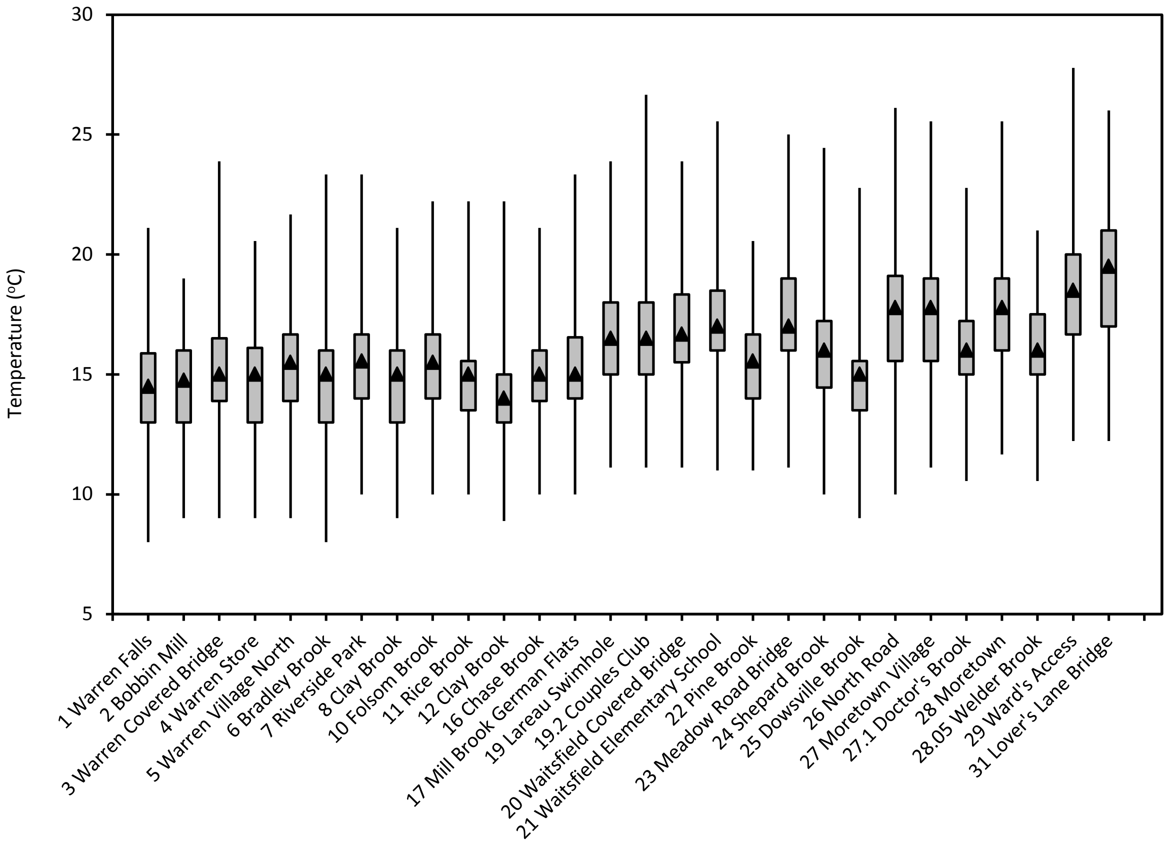


Figure 8. Water temperatures at 28 sites along the Mad River and its tributaries during 1988-2014. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line). Only sites that were sampled on at least 117 of the 143 sample dates are included.

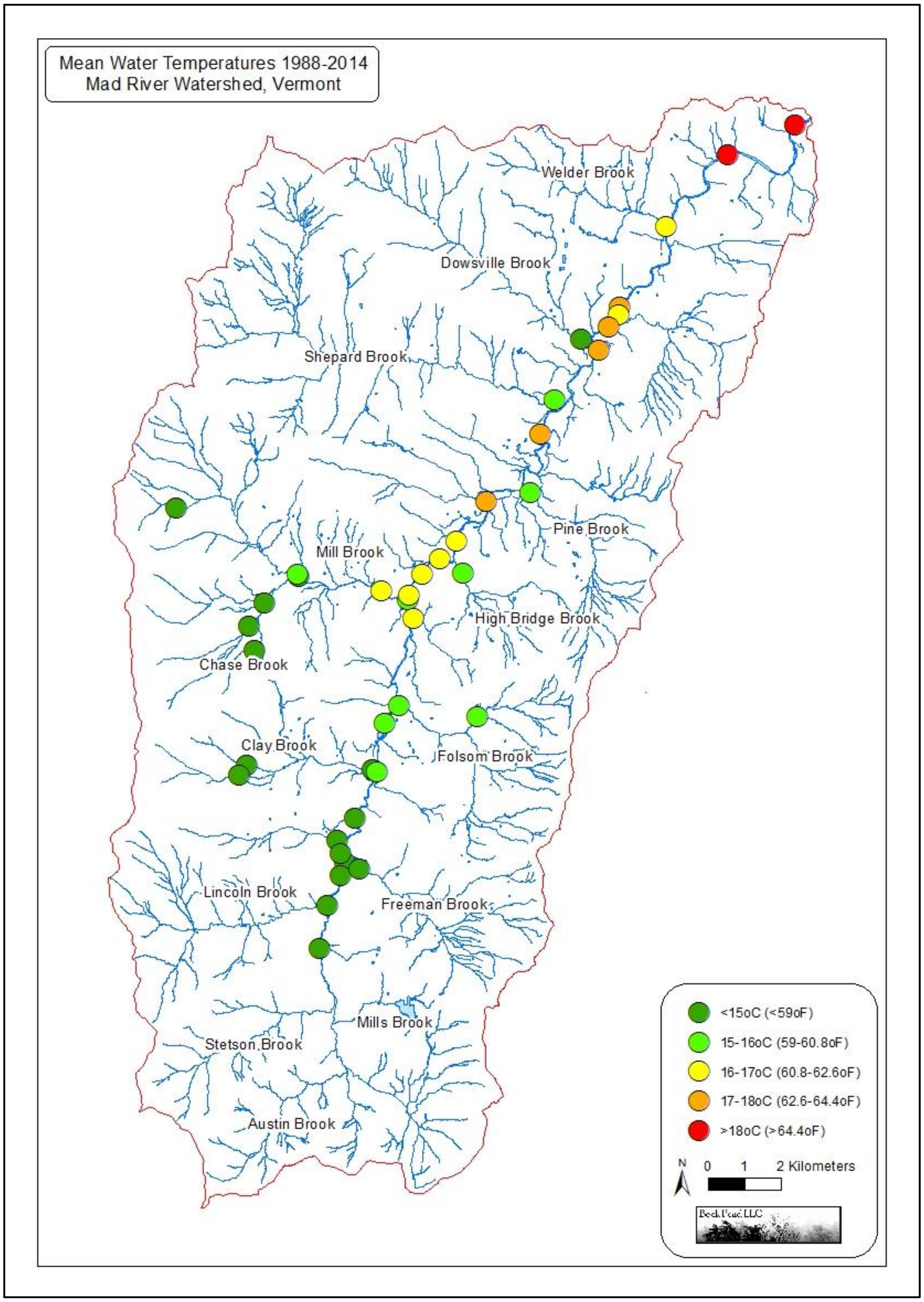


Figure 9. Mean water temperatures (°C) at 52 sites along the Mad River and its tributaries during 1988-2014.

During the last two years (2013-2014), water temperatures showed steady and consistent increases along the length of the main stem of the Mad River from Site #1 (Warren Falls) downstream to Site #31 (Lover's Lane Bridge)(Figure 10). Across the length of the main stem, median temperatures increased by approximately 3.7°C (6.5°F).

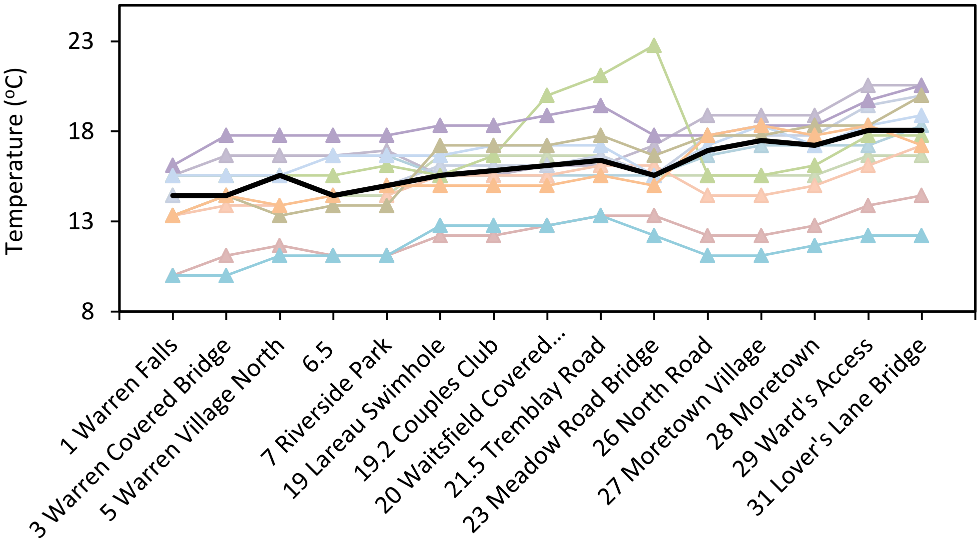


Figure 10. Water temperature "profile" at 15 sites along the main stem of the Mad River from Site #1 (Warren Falls) downstream to Site #31 (Lover's Lane Bridge) during 2013-2014. The light, colored lines show the values measured on each sample date; the bold, black line shows the median values for each site during those two years.

In summary, water temperatures were measured at 52 sites on 143 dates during 1988-2014 (but not all sites were sampled on all dates or in all years). In general, water temperatures along both the main stem and the tributaries were moderately high, as temperatures were only measured during the summer months (June-August). Mean and median water temperatures were highest in the middle and lower reaches of the main stem and were lowest along the upper reaches of the main stem and many of the tributaries. The higher temperatures likely reflected the more open land uses, lack of vegetative cover, and more meandering channel plan of the lower reaches of the main stem. The limited number of temperature measurements recorded at each site in each year (typically 4-6 data points each year) limited the utility of these data. Nevertheless, they did provide some indication of those areas with lower and higher water temperatures during the summer months, the former being important for identifying suitable habitat for cold-water fish, such as brook trout, and other cold-water organisms.

pH

pH, which is typically measured in the field with a hand-held meter, is a measure of the acidity or alkalinity of the water. pH is measured on a logarithmic scale from 0 (most acidic) to 14 (most alkaline) with a pH of 7 considered neutral. pH is an important measure of water chemistry, as pH determines the solubility, biological availability, and toxicity of nutrients (e.g. phosphorus and nitrogen) and heavy metals (e.g. lead, copper, and arsenic). Different organisms have different tolerances for and ranges of pH in which they flourish, but most aquatic organisms prefer a pH between 6.5-8.0. In surface waters, pH is usually relatively stable over time, as it primarily reflects the underlying bedrock and surficial geology. However, changes in pH can be caused by atmospheric deposition (e.g. "acid rain") and wastewater discharges. In Vermont, the Water Quality Standards for pH in Class A(1) Ecological Waters, Class A(2) Public Water Supplies, and all Class B Waters are that the pH shall not exceed 8.5 standard units (State of Vermont 2014a). In the Mad River watershed, all surface waters are classified as Class B Waters, except those located above 762 m (2,500 ft) in elevation, which are classified as Class A(1) Ecological Waters.

pH was measured by the Friends of the Mad River during 1988-1995 and 1997-2005 (pH was also apparently measured during 2006-2015, but these data were not entered into the electronic databases provided to the author). During these 17 years, 34-40 sites were sampled each year. Across all years, 34 of the 51 sites were sampled on at least 48 of the 80 sample dates and across almost all of the years (seven of the 34 sites were not sampled in 1-5 years). The remaining 17 sites were sampled on 1-39 dates, often for only a subset of years (e.g. six sites were only sampled on 15-17 dates during 2003-2005). Thus, we used the data from all of the years to calculate the median, geometric mean, 25% and 75% quartiles, and range in pH levels for each of the 34 sites that were well sampled throughout the full time period (1988-2005).

During 1988-2005, pH levels at the 34 sites ranged between 4.4-8.7, but mean pH levels ranged between 6.7-7.2 (Table 5). Thus, pH levels were generally neutral (generally defined as pH = 6.6-7.3) at all sites in the Mad River watershed, although the full set of 2,429 values did include nine values that were strongly acidic (pH <5.5) and ten values that were strongly alkaline (pH >8.5.). The lowest mean pH levels (pH <6.8) were measured along Chase and Clay Brooks (Figure 11-12). In contrast, the highest mean pH levels (pH >7.2) were measured along the lower reaches of the main stem and several other tributaries (Welder, Doctor's, Mill, Folsom, and Freeman Brooks). Intermediate mean pH levels (pH = 6.8-7.2) were measured throughout the main stem, especially its middle and upper reaches, and along several other tributaries.

Table 5. pH levels at 34 sites along the Mad River and its tributaries during 1988-1995 and 1997-2005. Only sites that were sampled on at least 48 of the 80 sample dates are included.

Site #	Site Name	# Dates	Median	Mean	Range
1	Warren Falls	75	7.0	7.0	5.8-7.9
2	Bobbin Mill	76	7.2	7.1	6-8.7
3	Warren Covered Bridge	77	7.1	7.0	6-8.7
4	Warren Store	77	7.2	7.1	6.2-8.6
5	Warren Village North	77	7.2	7.1	5.3-8.7
6	Bradley Brook	73	7.2	7.1	5.1-8.7
7	Riverside Park	75	7.0	7.0	5-8.6
8	Clay Brook	73	7.1	7.0	5.6-7.9
9	-	74	7.0	7.0	5.6-8.3
10	Folsom Brook	75	7.0	7.0	6.1-8.1
11	Rice Brook	75	6.9	6.7	4.4-8
12	Clay Brook	75	7.1	7.0	5-7.9
13	Slide Brook	59	6.8	6.9	5.8-8.1
14	Lockwood Brook	58	6.8	6.8	5.9-7.9
16	Chase Brook	74	6.9	6.9	5.8-7.9
17	German Flats	76	7.0	6.9	5.9-8
18	-	57	6.9	6.9	5.9-7.8
19	Lareau Swimhole	79	6.9	6.9	6.1-8.6
19.1	-	62	6.9	6.9	6.3-8.7
19.2	Couples Club	78	6.9	6.9	6.1-8.6
20	Waitsfield Covered Bridge	78	6.9	6.9	6.1-8.1
21	Waitsfield Elementary School	79	6.9	6.9	6.1-7.8
22	Pine Brook	80	6.9	6.9	6.1-7.8
23	Meadow Road Bridge	79	6.9	6.9	6.2-7.8
24	Shepard Brook	77	7.0	6.9	5.5-7.9
25	Dowsville Brook	77	6.9	6.8	6.0-7.8
26	North Road	67	7.2	7.1	6.1-7.7
27	Moretown Village	71	7.3	7.1	6.2-7.9
27.1	Doctor's Brook	70	7.3	7.2	6.3-8.2
28	Moretown	70	7.3	7.2	6.3-8.2
28.05	Welder Brook	49	7.3	7.2	6.3-7.8
28.2	-	52	7.1	7.1	6-8.3
29	Ward's Access	76	7.3	7.2	6.0-8.4
31	Lover's Lane Bridge	59	7.2	7.2	6.2-8.5

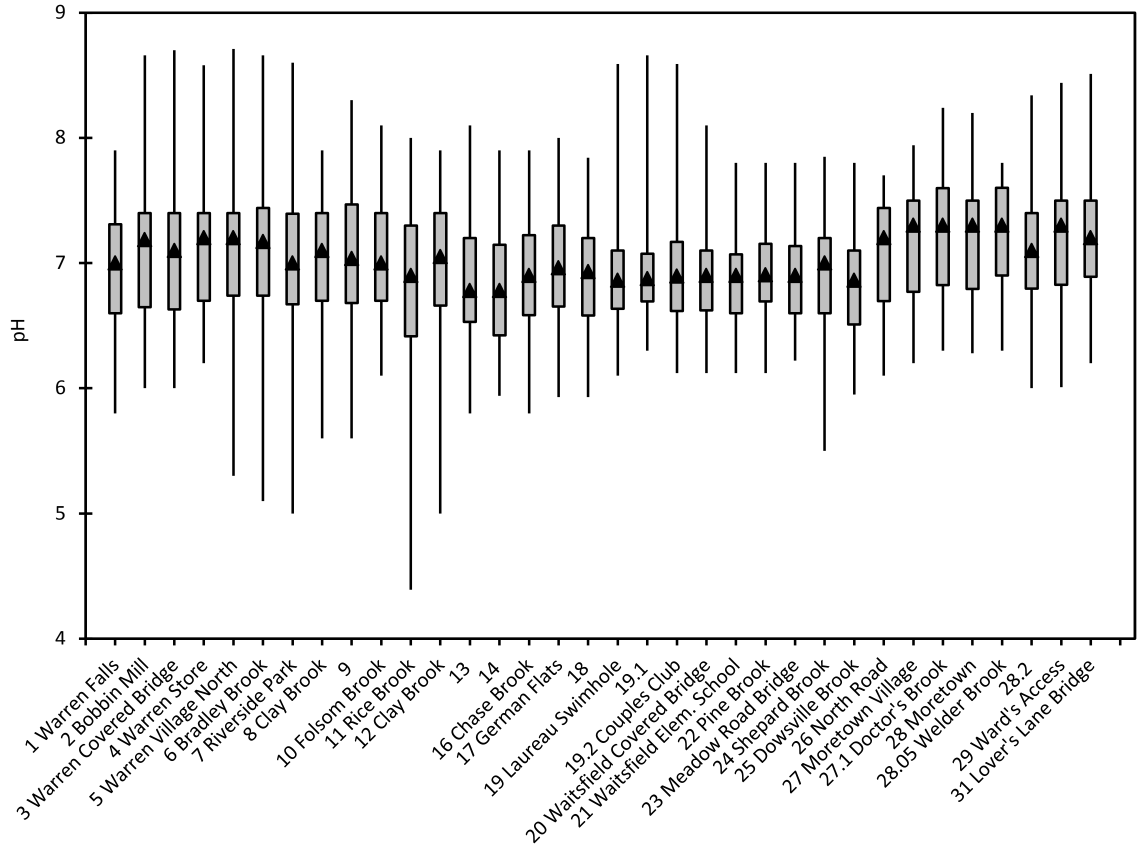


Figure 11. pH levels at the 34 sites at which >49 samples were collected along the Mad River and its tributaries during 1988-2005. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line). Only sites that were sampled on at least 48 of the 80 sample dates are included.

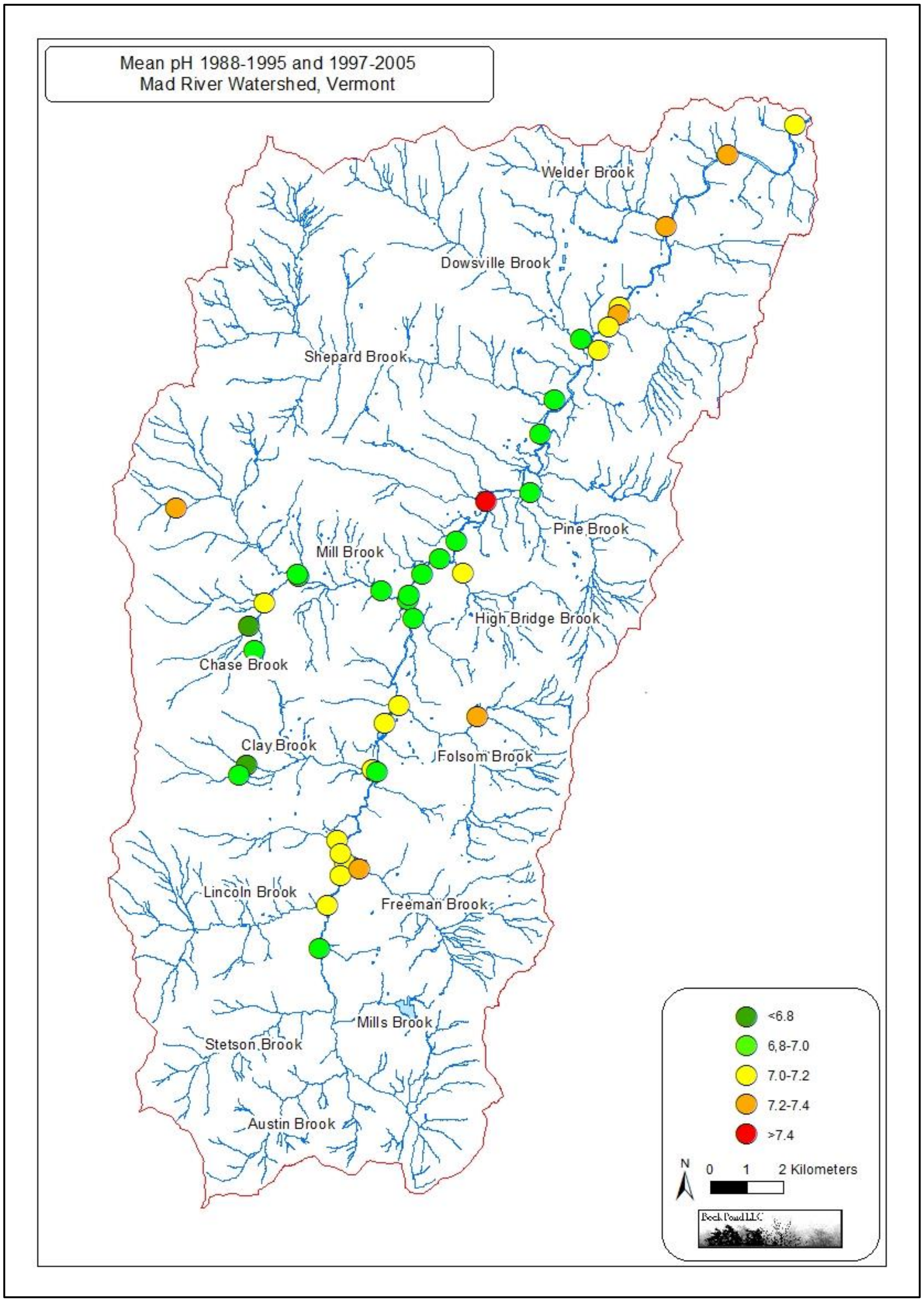


Figure 12. Mean pH levels at 51 sites along the Mad River and its tributaries during 1988-2005.

During 2004-2005 (the two most recent years of data provided to the author), pH levels were generally similar along the length of the main stem of the Mad River (Figure 13). However, on five of the six dates in 2005, pH levels were considerably lower between Site #19 (Lareau Swimhole) and Site #23 (Meadow Road Bridge). The reason(s) for this consistent but temporary decrease in pH were not clear but may reflect either real differences in pH on those dates or problems with the field equipment.

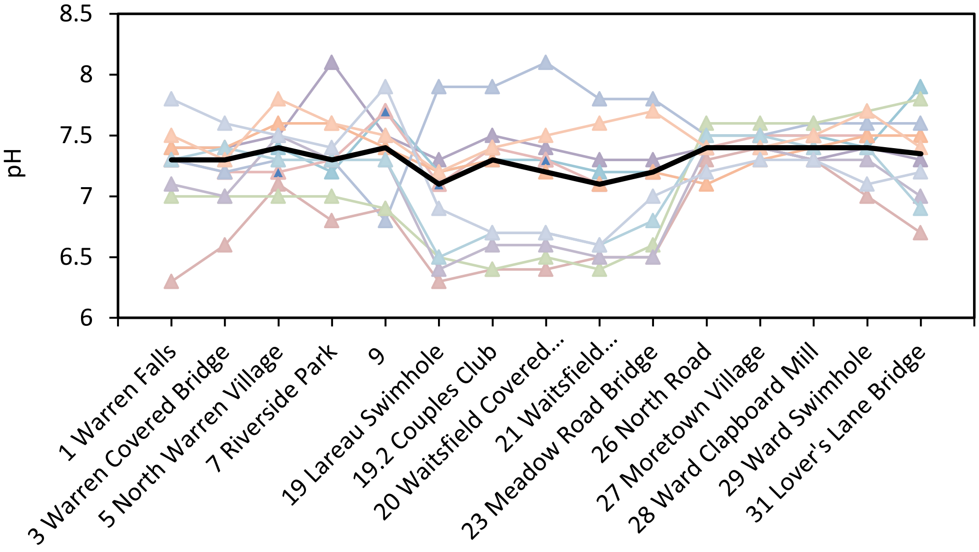


Figure 13. pH "profile" at 15 sites along the main stem of the Mad River from Site #1 (Warren Falls) downstream to Site #31 (Lover's Lane Bridge) during 2004-2005. The light, colored lines show the values measured on each sample date; the bold, black line shows the median values for each site during those two years.

One of the most pronounced patterns in pH levels in the Mad River watershed is the clear and consistent decreases in pH prior to 1995 and the subsequent clear and consistent increases in pH after 1995 (Figure 14). This pattern occurred at all ten sites examined and across the spectrum of sites from those with "average" pH levels to those with either lower and higher mean pH levels [e.g. Site #25 (Dowsville Brook) and Site #27.1 (Doctor's Brook), respectively]. Presumably, this clear and consistent pattern, especially the increases in pH after 1995, reflected the improvements in air quality and reduced acid deposition (e.g. "acid rain") that resulted from the implementation of the Clean Air Act and its amendments beginning in the mid-1990s.

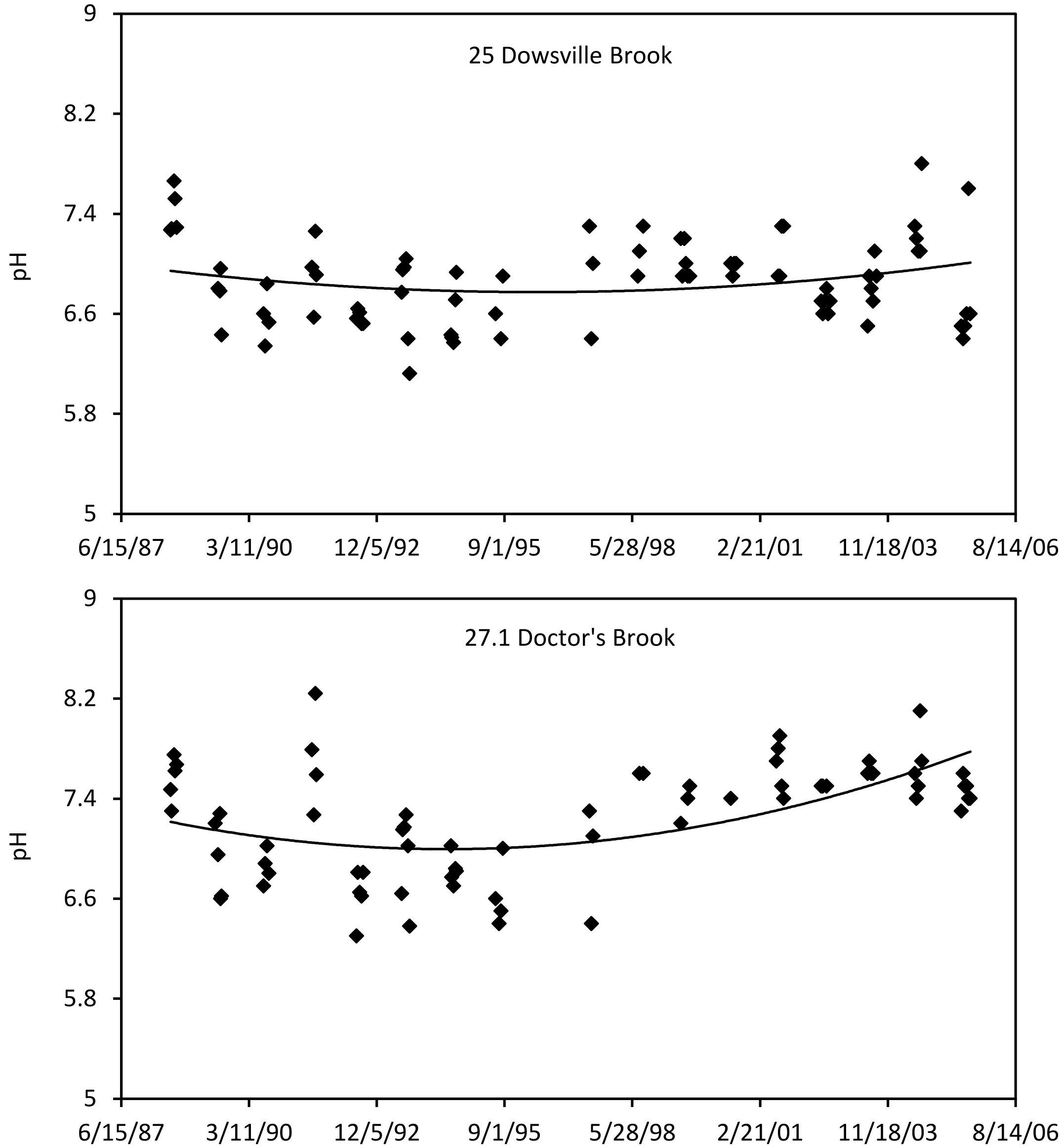
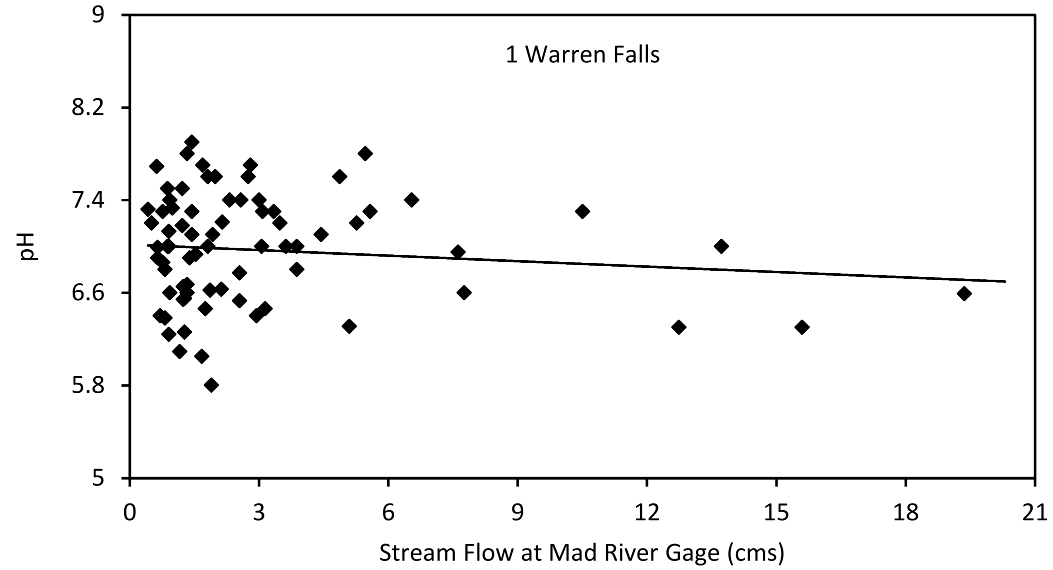


Figure 14. Changes in pH over time at two sites along the Mad River during 1988-2005. Site #25 (Dowsville Brook) represented those sites with lower mean pH levels (mean = 6.8), and Site #27.1 (Doctor's Brook) represented sites with higher mean pH levels (mean = 7.2). The regression lines indicate the polynomial relationships between the two parameters.

Finally, we analyzed pH in relation to the stream flows measured at the USGS gage on the Mad River near Moretown. At the four sites examined, there were no clear or convincing relationships between pH and stream flow, although pH levels might have been slightly lower at the highest stream flows (Figure 15). The lack of clear relationships with stream flow likely reflected the primary importance of bedrock and surficial geology in determining pH and the region-wide decreases in acid deposition over the past 20 years. On the other hand, the slightly lower pH values at the highest flows may reflect the more acidic nature of the precipitation that caused the rivers and streams to rise during these high-flow events.

In summary, the pH data provided a valuable long-term record of improvements in air quality and acid precipitation in the northeastern United States. pH, which measures the acidity or alkalinity of water, was measured at 51 sites on 80 dates during 1988-1995 and 1997-2005 (but not all sites were sampled on all dates or in all years). All of the sites, including those along both the main stem and the tributaries, exhibited generally neutral pH values (mean = 6.7-7.2). Because pH is largely influenced by the underlying bedrock and surficial geology, pH showed no pronounced relationships with stream flow, but they did show an almost universal pattern of change over time. That is, pH levels decreased at all sites in the years prior to 1995 but increased markedly at all sites after 1995, presumably in response to improvements in air quality and decreased acid deposition following implementation of the Clean Air Act and its amendments starting in the mid-1990s.



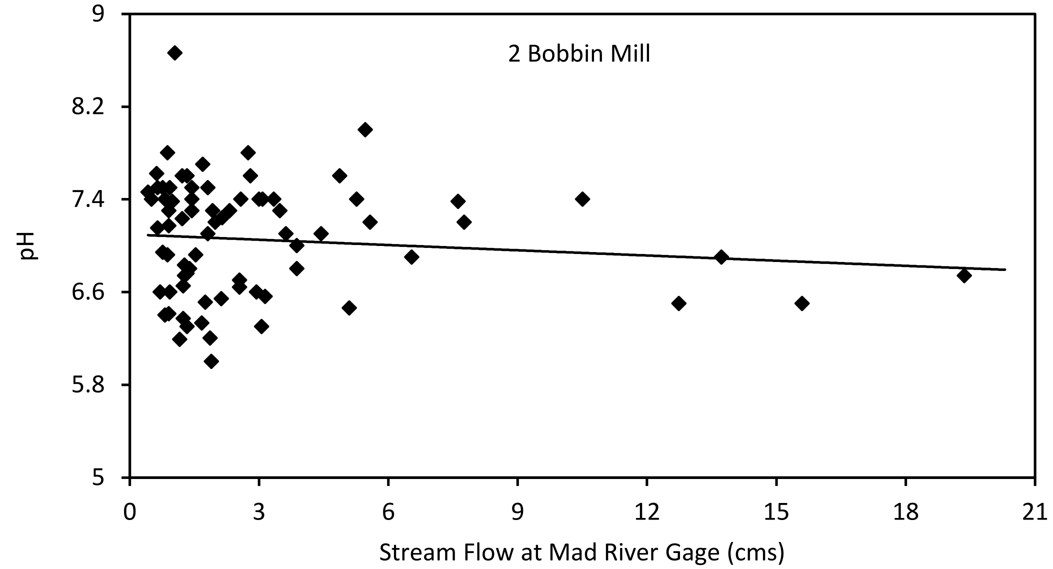


Figure 15. pH in relation to stream flow at two sites [Site #1 (Warren Falls) and Site #2 (Bobbin Mill)] during 1988-2005. Stream flows were measured at the USGS stream gage on the Mad River near Moretown, Vermont (USGS station 04288000). The regression lines indicate the exponential relationships between the two parameters. Note that two extreme high flows were not included in this analysis.

Total Phosphorus

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 an essential nutrient and is typically the limiting nutrient and regulates the amount of aquatic life in northern freshwater ecosystems. Consequently, elevated phosphorus concentrations can lead to eutrophication, in which excessive algal and plant growth and the subsequent decomposition lead to oxygen depletion and increased mortality of aquatic life. In Vermont, most phosphorus originates from soil erosion, wastewater, manure, and synthetic fertilizers applied to lawns and agricultural fields. In Vermont, the Water Quality Standards for phosphorus differ for different types of rivers, streams, lakes, and ponds (Table 6; State of Vermont 2014a).

Table 6. Water Quality Standards for total phosphorus (in µg/l) in Vermont (State of Vermont 2014a). In rivers and streams, these criteria are not to be exceeded at low median monthly flows during June-October in areas representative of well-mixed flows. In lakes and reservoirs, these criteria are not to be exceeded in the photosynthetic (euphotic) zone at a central location in the lake during June-September.

Class of Waters	Small, High-Gradient Streams	Medium, High-Gradient Streams	Warm-Water, Medium-Gradient Streams	Lakes and Reservoirs
Class A(1) Waters	10	9	18	12
Class A(2) Waters	12	15	27	17
Class B Waters	12	15	27	18

Total phosphorus was measured in-house by the Friends of the Mad River on three dates during 1993 and again through the LaRosa Partnership Program during 2006-2015. Because total phosphorus was measured on only three dates during 1993 and because the methods used were not identified, we did not analyze those data but, rather, focused on analyzing those data collected through the LaRosa Partnership Program during 2006-2015. For the 2006-2015 data, all but one of the 19 sites were sampled across the full range of stream flows and on almost all of the 55 sample dates (1-4 of the 55 dates were missed at each of five sites, and Site #9 was only sampled on six dates in 2008). Thus, we used all of the data to calculate the median, geometric mean, 25% and 75% quartiles, and range in total phosphorus concentrations for each of the 19 sites across two time periods (2006-2015 and 2014-2015, the latter better representing the current conditions at each site).

During 2006-2015, total phosphorus concentrations at the 19 sites ranged between 5.0-1,760 µg/l, and mean total phosphorus concentrations ranged between 7.4-22.3 µg/l (Table 7). During these ten years, the highest mean total phosphorus concentrations (>20 µg/l) were measured at two sites, both located along tributaries of the Mad River [Site #20.1 (High Bridge Brook) and Site #10 (Folsom Brook)](Figure 16-17). In contrast, the lowest mean total phosphorus concentrations (<10 µg/l) were measured at several sites along the upper reaches of the main stem, along Mill Brook, and at two upstream sites along Clay Brook. Finally, intermediate mean total phosphorus concentrations (10-20 µg/l) were measured at several sites along the main stem, especially the lower reaches, and several tributaries, including Welder, Dowsville, Clay (downstream site), Bradley, Pine, and Shepard Brooks.

Table 7. Total phosphorus concentrations at 19 sites along the Mad River and its tributaries for two time periods (2006-2015 and 2014-2015).

		#	2006-2015			2014-2015 Only		
Site #	Site Name	Dates	Median	Mean	Range	Median	Mean	Range
1	Warren Falls	55	6.0	7.4	5-55.6	11.9	9.9	5-54
2	Bobbin Mill	55	6.1	8.0	5-195	7.3	7.8	5-18.8
4	Warren Store	54	10.0	12.1	6.1-415	9.9	11.3	6.2-56
6	Bradley Brook	54	9.5	11.6	5.2-645	8.7	9.8	7.2-19.1
8	Clay Brook	54	9.5	12.7	5-305	8.0	11.9	5-117
9	-	6	7.9	7.4	5-10.1	-	-	-
10	Folsom Brook	55	19.0	22.3	11.9-252	16.2	16.8	11.9-30.4
11	Rice Brook	55	6.3	8.1	5-272	6.1	6.1	5-12.7
12	Clay Brook	55	6.3	8.0	5-310	6.3	8.7	5-36.8
16	Chase Brook	55	6.2	8.7	5-1760	6.1	6.8	5-13.2
18.1	Mill Brook Mouth	52	6.9	9.5	5-244	5.9	6.7	5-11.2
20	Covered Bridge	55	8.5	10.7	5-208	8.2	12.9	5-173
20.1	High Bridge Brook	55	16.4	21.3	8.8-196	21.6	24.0	9.8-103
22	Pine Brook	55	9.4	11.5	5.9-136	9.5	12.2	7.3-34.4
24	Shepard Brook	55	8.2	10.3	5-405	7.1	8.0	5-30
25	Dowsville Brook	55	11.1	13.6	5.7-330	10.6	11.4	6.3-67.6
28	Moretown	55	9.3	13.6	5-377.6	9.3	16.4	5.1-377.6
28.05	Welder Brook	55	13.6	16.8	6.6-268	11.8	12.9	8.4-56.9
31	Lover's Lane Bridge	51	11.3	13.9	6.0-510	13.1	13.3	6.7-46.1

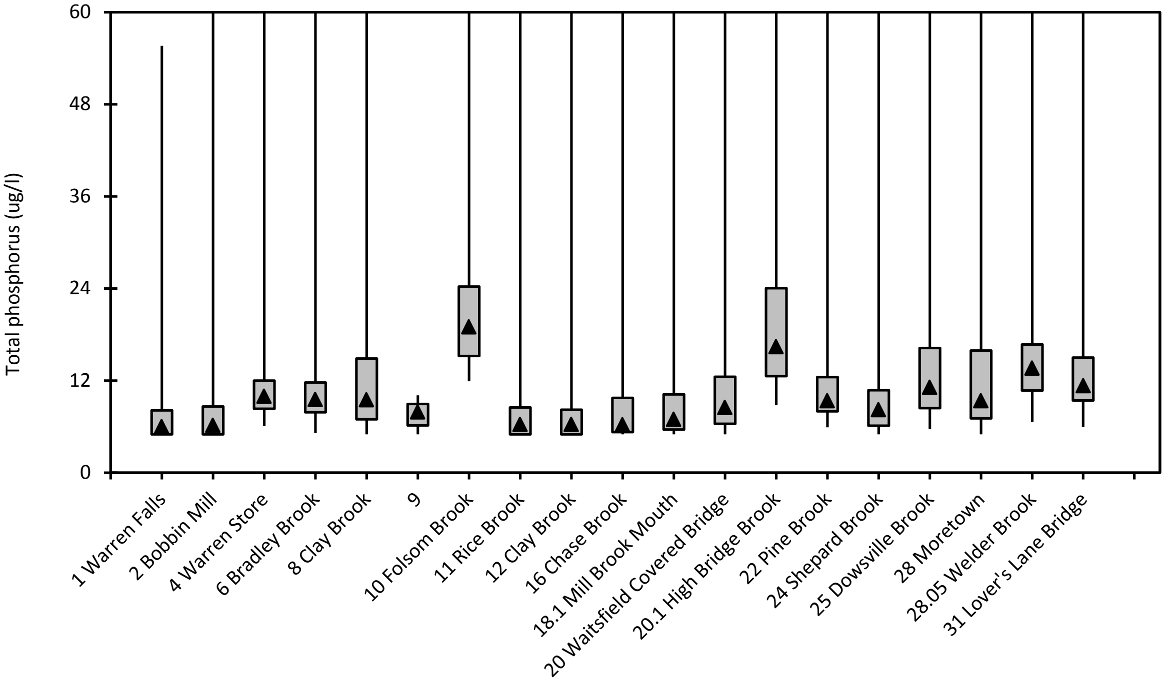


Figure 16. Total phosphorus concentrations at 19 sites along the Mad River and its tributaries during 2006-2015. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line).

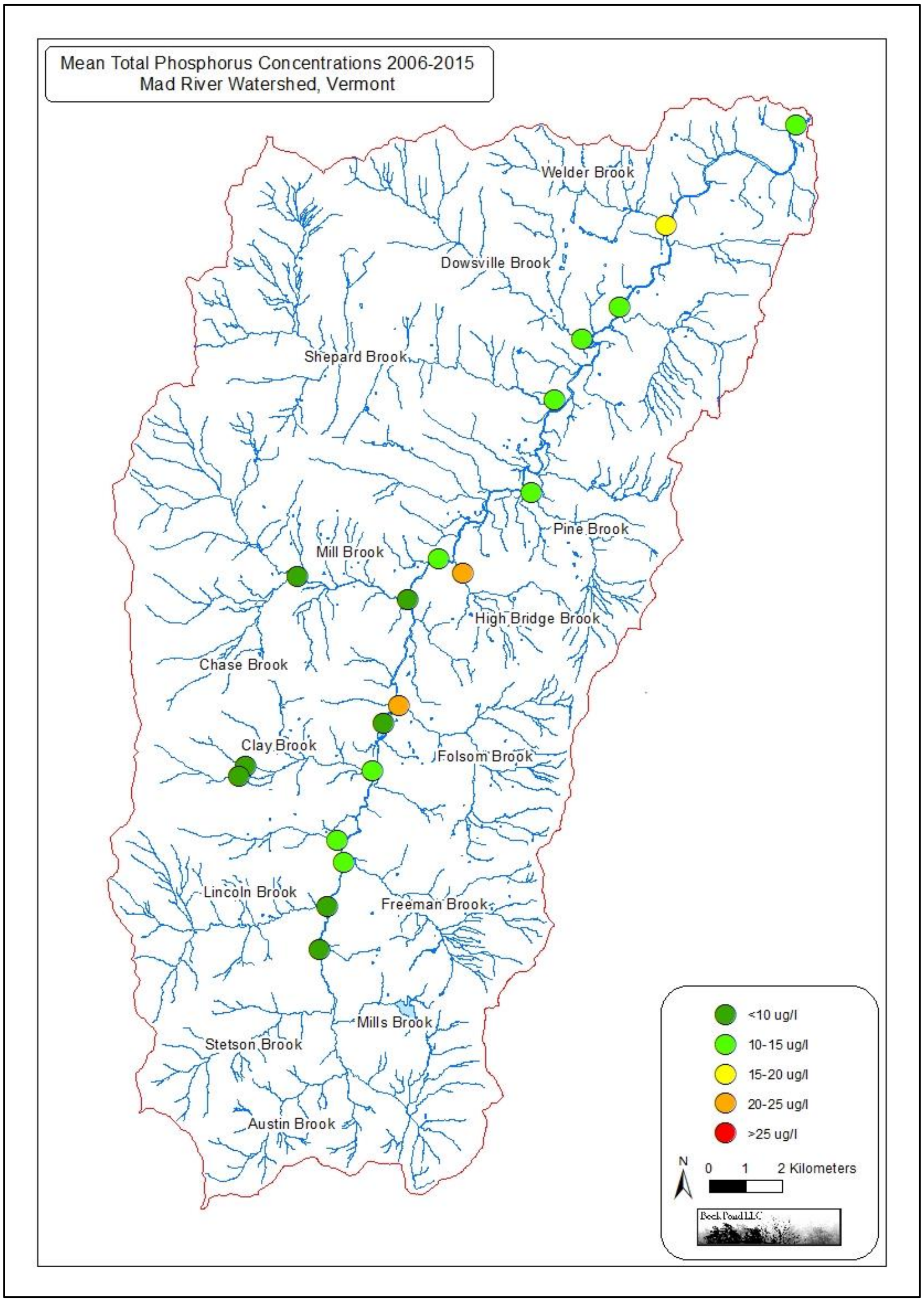


Figure 17. Mean total phosphorus concentrations at 19 sites along the Mad River and its tributaries during 2006-2015.

During 2014-2015, total phosphorus concentrations at the 18 sites (Site #9 was not sampled in these two years) ranged between 5.0-377.6 µg/l, and mean total phosphorus concentrations ranged between 6.1-24.0 µg/l (Table 7). In these two years, the highest mean total phosphorus concentrations (>20 µg/l) were measured at only one site [Site #20.1 (High Bridge Brook)](Figure 18-19). In contrast, lower mean total phosphorus concentrations (<10 µg/l) were measured at numerous sites along both the main stem, especially the upper reaches, and several tributaries, including Mill, Clay, and Shepard Brooks. Finally, intermediate mean total phosphorus concentrations (10-20 µg/l) were measured at several sites along the main stem, especially the lower reaches, and several tributaries, including Welder, Dowsville, and Pine Brooks.

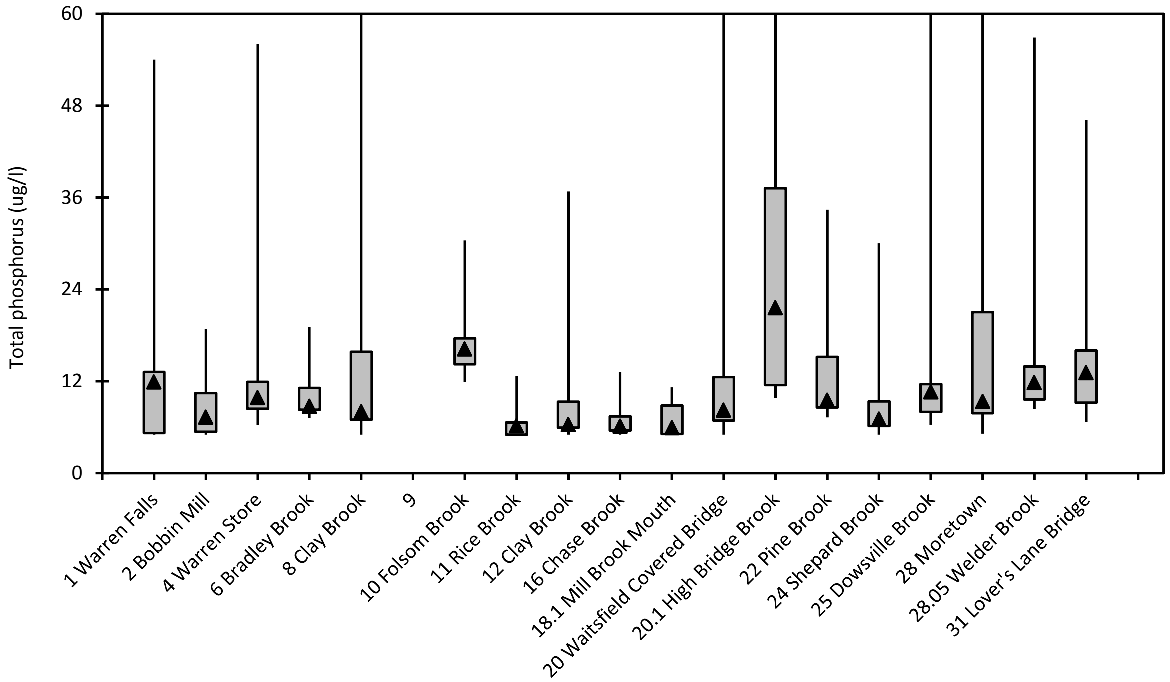


Figure 18. Total phosphorus concentrations at 18 sites along the Mad River and its tributaries during 2014-2015. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line). Site #9 was not sampled in these two years.

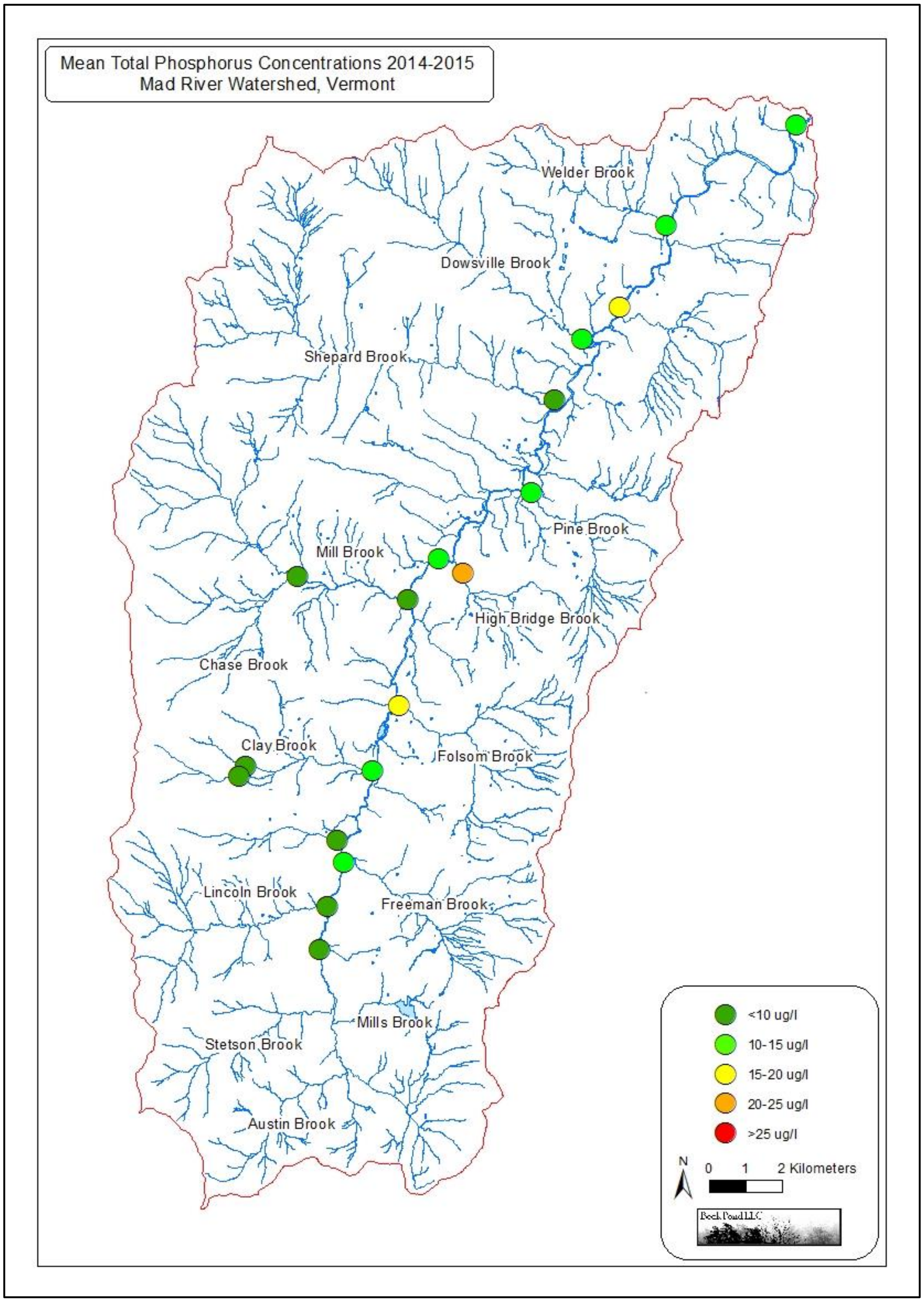


Figure 19. Mean total phosphorus concentrations at 18 sites along the Mad River and its tributaries during 2014-2015.

During 2014-2015, there was no clear or consistent pattern in total phosphorus concentrations along the length of the main stem of the Mad River (Figure 20). Total phosphorus concentrations decreased slightly from Site #1 (Warren Falls) to Site #20 (Waitsfield Covered Bridge) and then increased slightly from there downstream through Site #28 (Moretown) to Site #31 (Lover's Lane Bridge). Thus, total phosphorus concentrations did increase roughly 5 µg/l on average over the course of 21 km (13 miles) from Waitsfield village downstream towards the mouth of the Mad River.

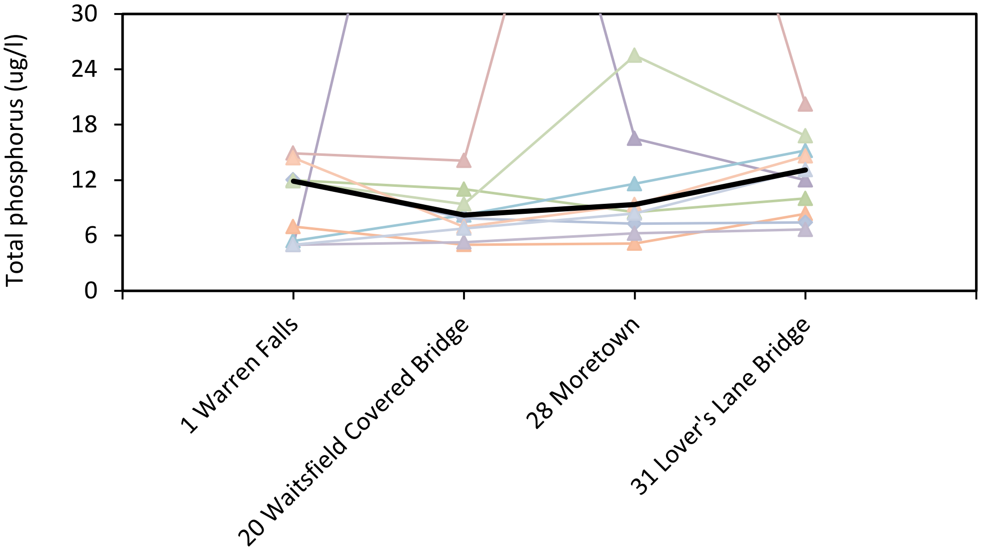


Figure 20. Total phosphorus "profile" at four sites along the main stem of the Mad River from Site #1 (Warren Falls) downstream to Site #31 (Lover's Lane Bridge) during 2014-2015. The light, colored lines show the values measured on each sample date; the bold, black line shows the median values for each site during those two years. Note that some of the values exceed the range of the y-axis.

Total phosphorus concentrations exhibited no consistent change over time, as total phosphorus concentrations increased at some sites and decreased at other sites along both the main stem and tributaries of the Mad River (Figure 21). The sites with the greatest decreases in total phosphorus concentrations during 2006-2015 included Site #8 (Clay Brook), Site #10 (Folsom Brook), and Site #25 (Dowsville Brook). In contrast, total phosphorus concentrations increased markedly at four sites, including Site #1 (Warren Falls), Site #2 (Bobbin Mill), Site #20.1 (High Bridge Brook), and Site #28 (Moretown).

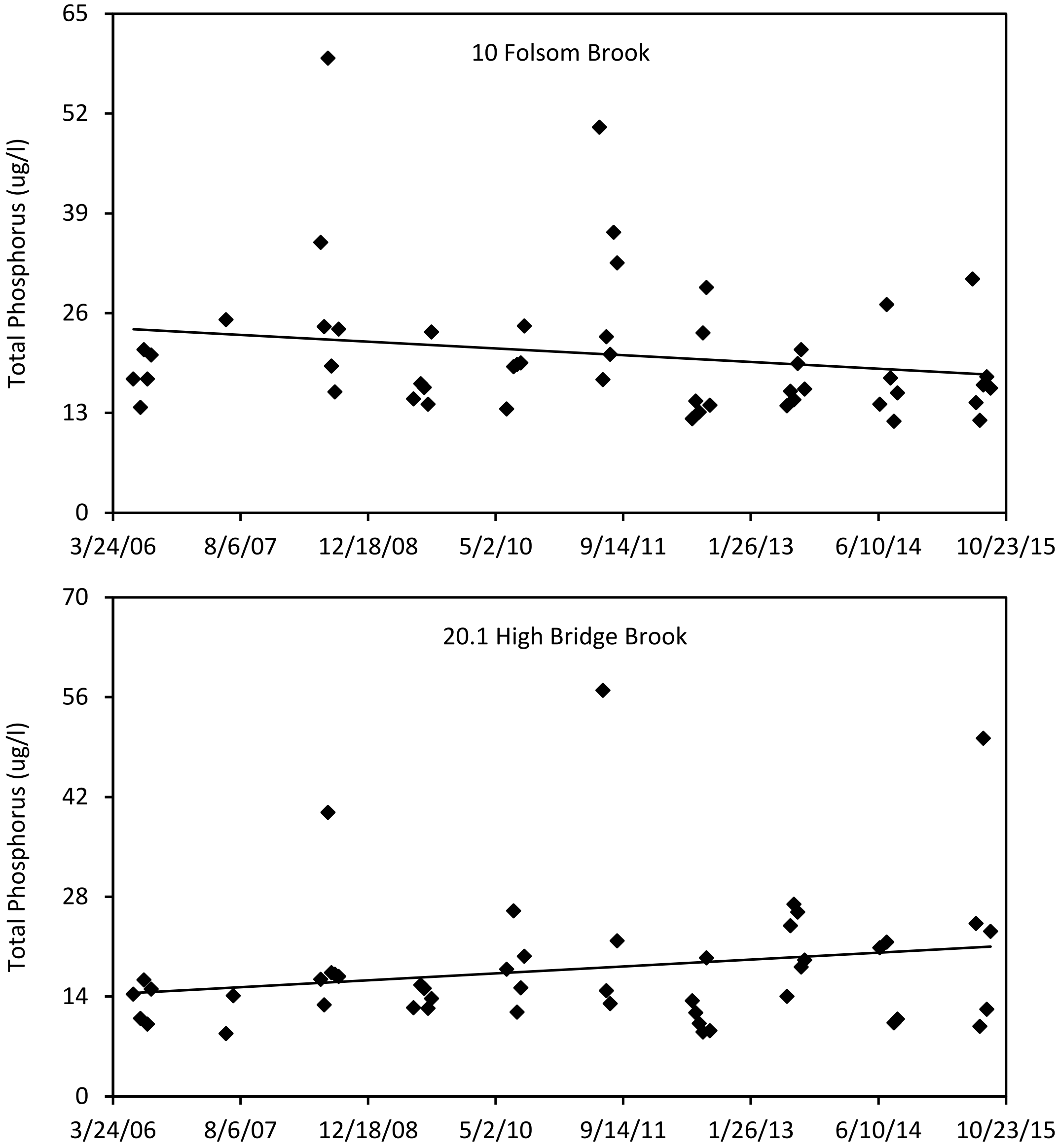


Figure 21. Total phosphorus concentrations over time at two sites [Site #10 (Folsom Brook) and Site #20.1 (High Bridge Brook)] with decreasing and increasing total phosphorus concentrations during 2006-2015. The regression lines indicate the linear relationships between the two parameters. Note that some of the values exceed the range of the y-axis.

At the two sites with the highest median total phosphorus concentrations during 2006-2015, we examined total phosphorus concentrations in relation to the stream flows measured at the USGS gage on the Mad River near Moretown. At both Site #10 (Folsom Brook) and Site

#20.1 (High Bridge Brook), total phosphorus concentrations generally increased with increasing stream flows (Figure 22). However, the patterns differed among the two sites over time. At Site #10 (Folsom Brook), total phosphorus concentrations generally decreased over time, especially at the higher stream flows. In contrast, at Site #20.1 (High Bridge Brook), no consistent change was apparent over time. The generally positive relationships between total phosphorus concentrations and stream flows suggested that the source(s) of these high phosphorus levels were likely to be nonpoint sources, such as surface runoff from agricultural lands, unpaved roads, and other land uses. Both Folsom Brook and High Bridge Brooks pass through agricultural areas, although, on Folsom Brook, the agricultural uses are primarily dairy, whereas, on High Bridge Brook, they are mostly equine. In addition, roads and stream crossings are particularly abundant in the watershed drained by High Bridge Brook (Stone Environmental 2016).

In summary, total phosphorus, which measures the concentration of all forms of phosphorus in the water column and is an important measure of nutrient levels in rivers and streams, was measured at 19 sites on 55 dates during 2006-2015 (although not all sites were sampled on all dates). Total phosphorus concentrations were remarkably low across almost all of the sites. The only areas of concern were along two tributaries (High Bridge Brook and Folsom Brook) and the main stem in the vicinity of Moretown village. At two of these three sites, total phosphorus concentrations have increased over time, and the positive relationships with stream flow suggested that much of the phosphorus at these two sites may be originating from nonpoint sources, such as surface runoff from agricultural and other land uses. Unpaved roads may be another significant source of the high phosphorus levels, especially along High Bridge and Folsom Brooks, where an earlier study estimated that approximately 35% and 11%, respectively, of the phosphorus load may have originated from unpaved roads (Wemple 2013).

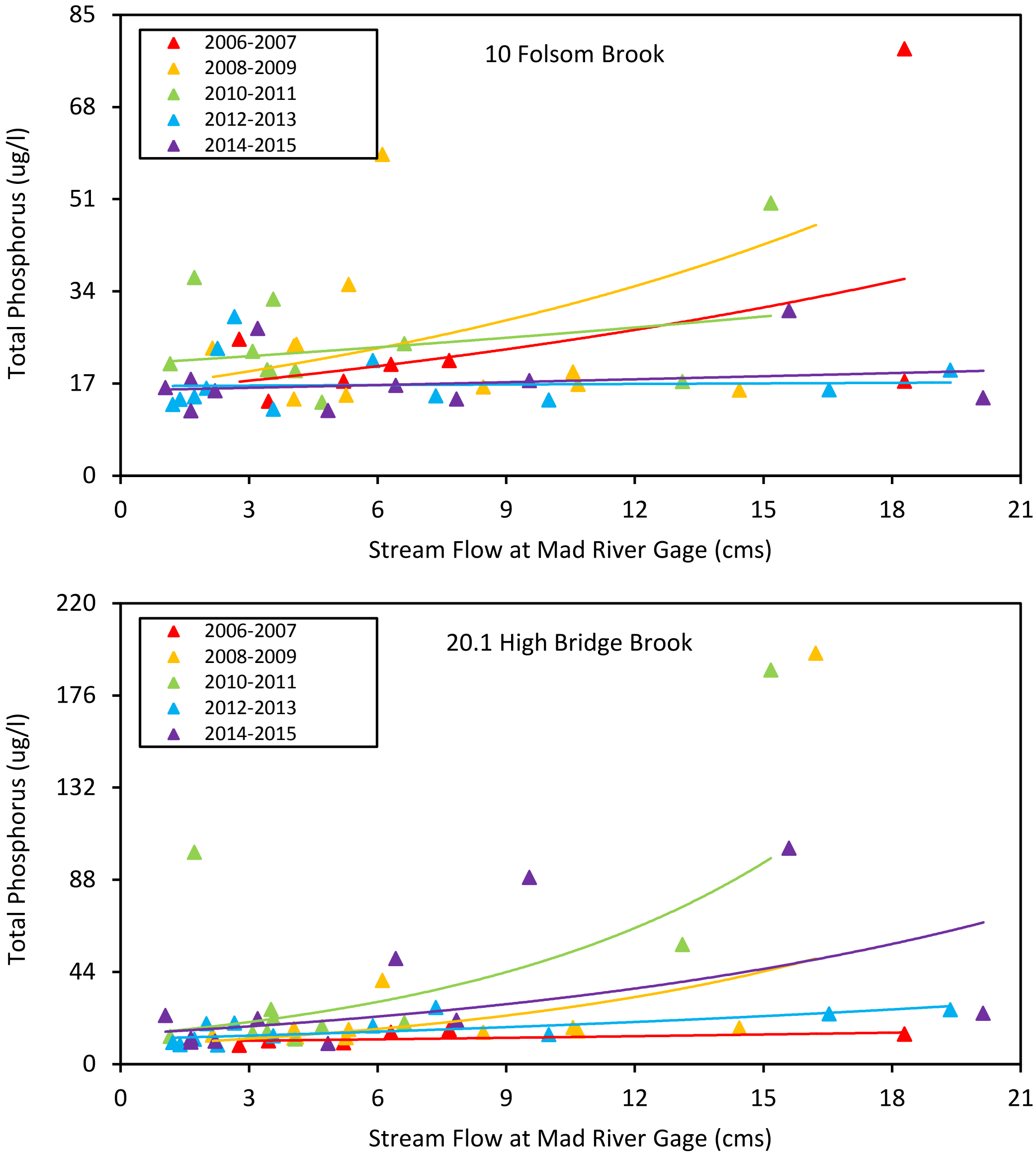


Figure 22. Total phosphorus concentrations in relation to stream flow at two sites [Site #10 (Folsom Brook) and Site #20.1 (High Bridge Brook)] in two-year intervals during 2006-2015. Stream flows were measured at the USGS stream gage on the Mad River near Moretown, Vermont (USGS station 04288000). The regression lines indicate the exponential relationships between the two parameters. Note that two extreme high flows were not included in this analysis.

Turbidity

Turbidity, which is measured in Nephelometric Turbidity Units (NTU), measures the light-scattering properties of all of the dissolved and suspended materials in the water column. Turbidity greatly affects the health of aquatic ecosystems, as more turbid waters allow less light to penetrate into the water column and transport more pollutants, nutrients, and sediment. In addition, sediment and other suspended materials can settle out of the water column and smother aquatic biota and their habitats. Much of the dissolved and suspended material in the water column originates from erosion associated with agriculture, forestry, urban and suburban development, unpaved roads, and stream channel adjustment. However, turbidity is also affected by natural biological and chemical processes and by the presence of chemical pollutants. In Vermont, the Water Quality Standards for turbidity are twofold: 1) 10 NTU as an annual average under dry weather, base-flow conditions in all Class A(1) Ecological Waters, Class A(2) Public Water Supplies, and Cold-Water Class B Waters; and 2) 25 NTU as an annual average under dry weather, base-flow conditions in all Warm-Water Class B Waters (State of Vermont 2014a).

Like total phosphorus, turbidity was measured in-house by the Friends of the Mad River for only a short time period during 1988-1990 and again through the LaRosa Partnership Program during 2006-2015. Because turbidity was measured on only a few dates during 1988-1990 and because the methods used were not identified, we did not analyze those data but, rather, focused on analyzing those data collected through the LaRosa Partnership Program during 2006-2015. For the 2006-2015 data, all but one of the 19 sites were sampled on almost all of the 55 sample dates (1-4 of the 55 dates were missed at each of five sites, and Site #9 was only sampled on six dates in 2008) and across the full range of stream flows. Thus, we used all of the data to calculate the median, geometric mean, 25% and 75% quartiles, and range in turbidity levels for each of the 19 sites across two time periods (2006-2015 and 2014-2015, the latter better representing the current conditions at each site).

During 2006-2015, turbidity levels at the 19 sites ranged between 0.2-472 NTU, but mean turbidity levels only ranged between 0.6-2.9 NTU (Table 8). Thus, turbidity levels were generally relatively low at all sites in the Mad River watershed. During these ten years, the highest mean turbidity levels (>2 NTU) were measured at only five sites, including two sites along the lower reaches of the main stem [Site #31 (Lover's Lane Bridge) and Site #28 (Moretown)] and one site along each of three tributaries [Site #25 (Dowsville Brook), Site #20.1 (High Bridge Brook), and Site #8 (Clay Brook)](Figure 23-24). In contrast, lower mean turbidity levels (<2 NTU) were measured throughout the main stem, especially the upper reaches, and along numerous tributaries of the Mad River.

Table 8. Turbidity levels at 19 sites along the Mad River and its tributaries for two time periods (2006-2015 and 2014-2015).

		#	2006-2015			2014-2015 Only		
Site #	Site Name	Dates	Median	Mean	Range	Median	Mean	Range
1	Warren Falls	55	0.7	0.8	0.2-44.1	0.9	1.6	0.4-44.1
2	Bobbin Mill	55	0.8	1.0	0.2-54	0.8	0.8	0.33-4.73
4	Warren Store	54	1.1	1.3	0.2-166	1.3	1.4	0.41-19.5
6	Bradley Brook	54	1.2	1.8	0.34-187	1.1	1.6	0.52-7.95
8	Clay Brook	54	2.3	2.7	0.29-116	2.9	2.9	0.52-85.6
9	-	6	0.8	0.8	0.39-1.48	-	-	-
10	Folsom Brook	55	0.8	1.1	0.21-56.5	1.2	1.3	0.47-6.28
11	Rice Brook	55	0.6	0.8	0.2-88	0.5	0.5	0.2-1.73
12	Clay Brook	55	0.7	0.8	0.2-59.1	0.7	1.1	0.21-10.1
16	Chase Brook	55	0.4	0.6	0.2-358	0.4	0.5	0.2-1.89
18.1	Mill Brook Mouth	54	0.6	0.9	0.2-88	0.9	0.9	0.23-8.55
20	Covered Bridge	54	1.3	1.6	0.32-173.8	1.7	3.0	0.36-174
20.1	High Bridge Brook	55	2.0	2.9	0.43-217	2.0	3.4	0.96-69.3
22	Pine Brook	55	0.8	0.9	0.2-88.9	1.1	1.0	0.28-12.9
24	Shepard Brook 55		0.7	1.1	0.2-89.7	0.9	0.8	0.2-8.18
25	Dowsville Brook	55	2.0	2.5	0.26-106	1.7	2.5	0.79-40
28	Moretown	55	1.6	2.3	0.54-472	1.6	3.3	0.65-472
28.05	Welder Brook	55	1.7	1.9	0.21-36.3	1.2	1.3	0.55-16.1
31	Lover's Lane Bridge	51	2.0	2.7	0.58-260	2.0	2.9	0.85-15.6

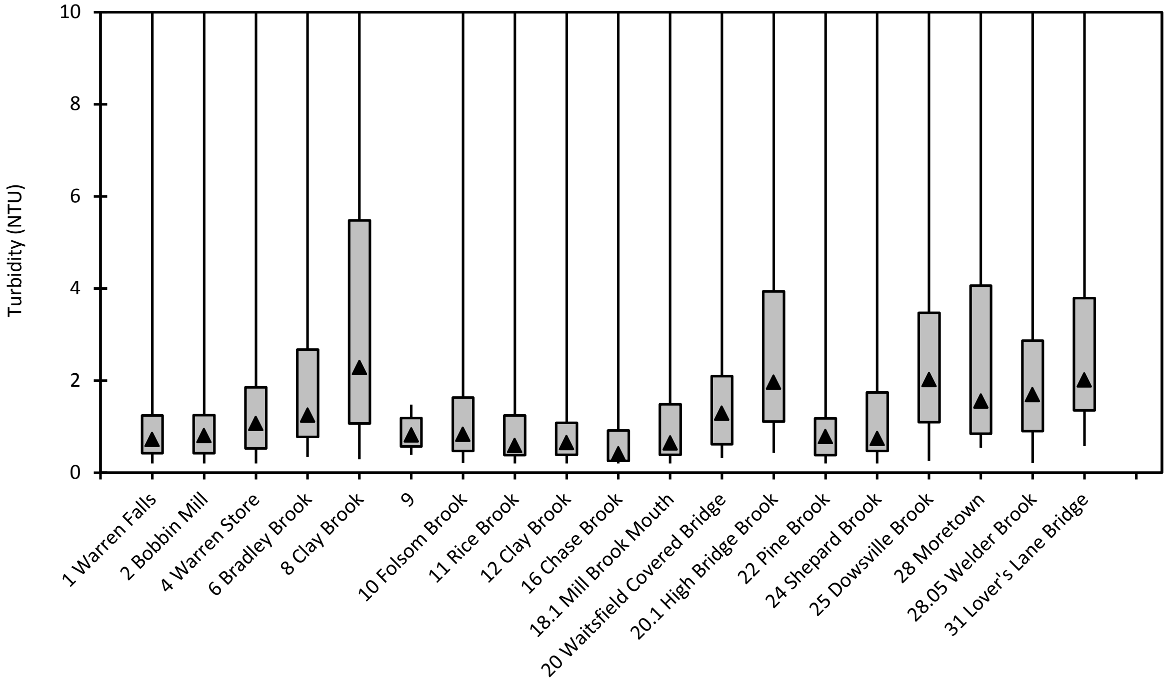


Figure 23. Turbidity levels at 19 sites along the Mad River and its tributaries during 2006-2015. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line).

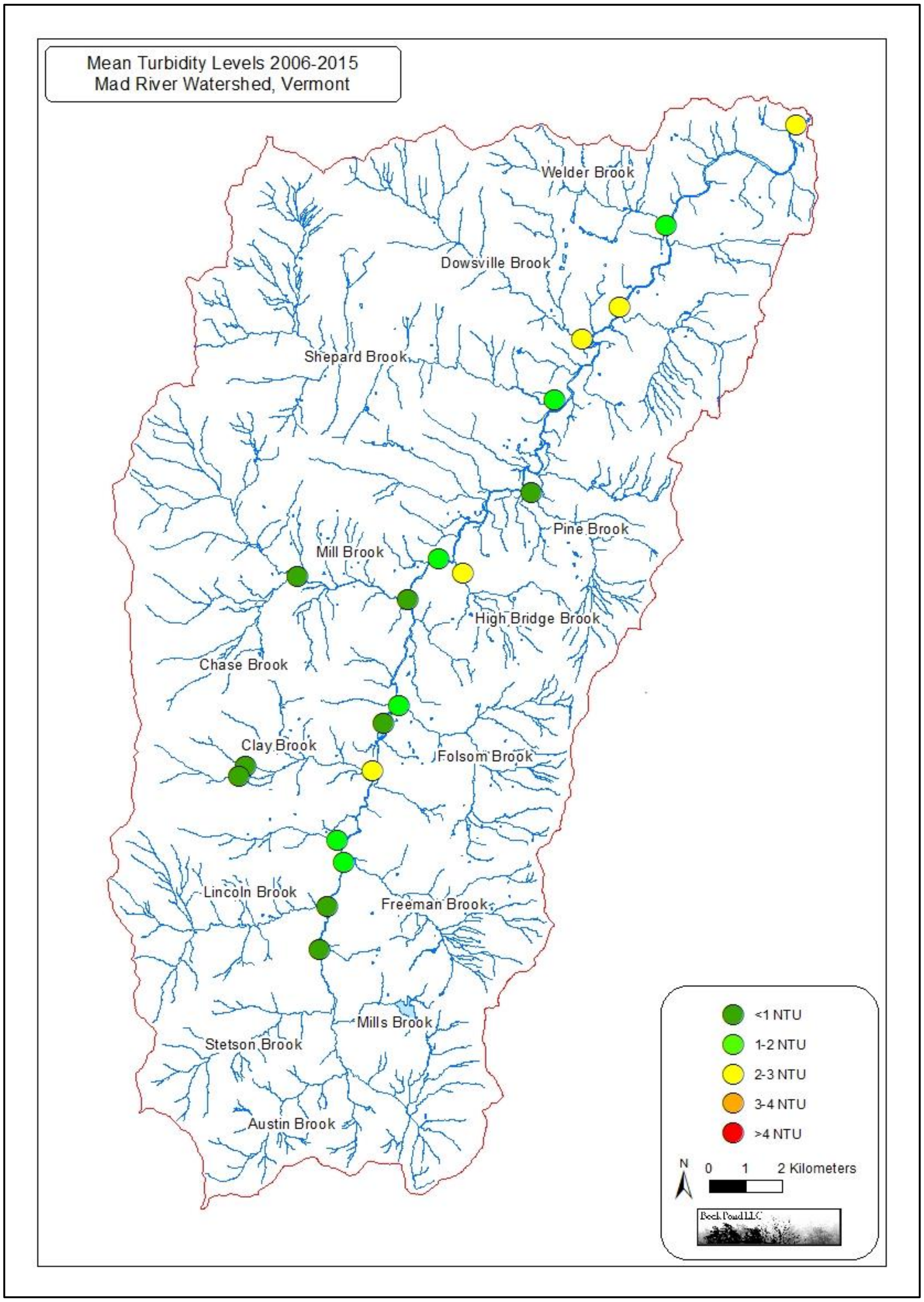


Figure 24. Mean turbidity levels at 19 sites along the Mad River and its tributaries during 2006-2015.

During 2014-2015, turbidity levels at the 18 sites (Site #9 was not sampled in these two years) ranged between 0.2-472 NTU, and mean turbidity levels ranged between 0.5-3.4 NTU (Table 8). In these two years, the highest mean turbidity levels exceeded 3 NTU and were measured at three sites, including two sites along the main stem [Site #28 (Moretown) and Site #20 (Waitsfield Covered Bridge)] and one site along one of the tributaries [Site #20.1 (High Bridge Brook)](Figure 25-26). Unfortunately, all three sites had registered markedly lower mean turbidity levels across the full ten years (2006-2015). In contrast, lower mean turbidity levels (<3 NTU) were measured throughout the main stem, especially the upper reaches, and along most of the tributaries.

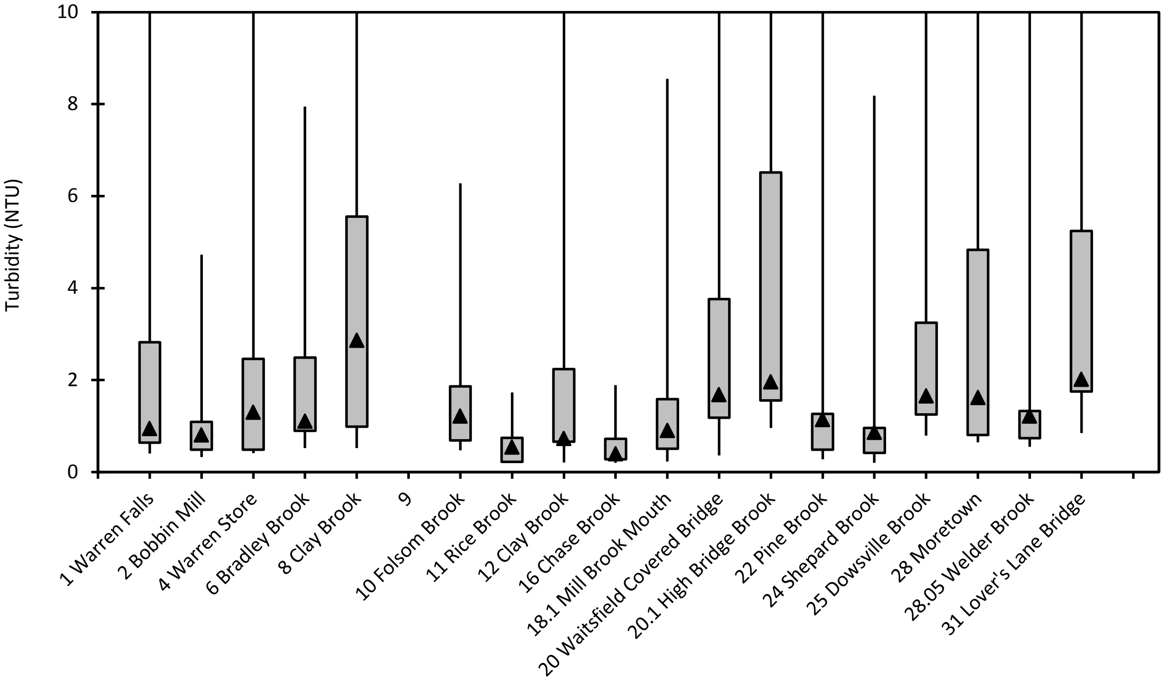


Figure 25. Turbidity levels at 18 sites along the Mad River and its tributaries during 2014-2015. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line). Site #9 was not sampled in these two years.

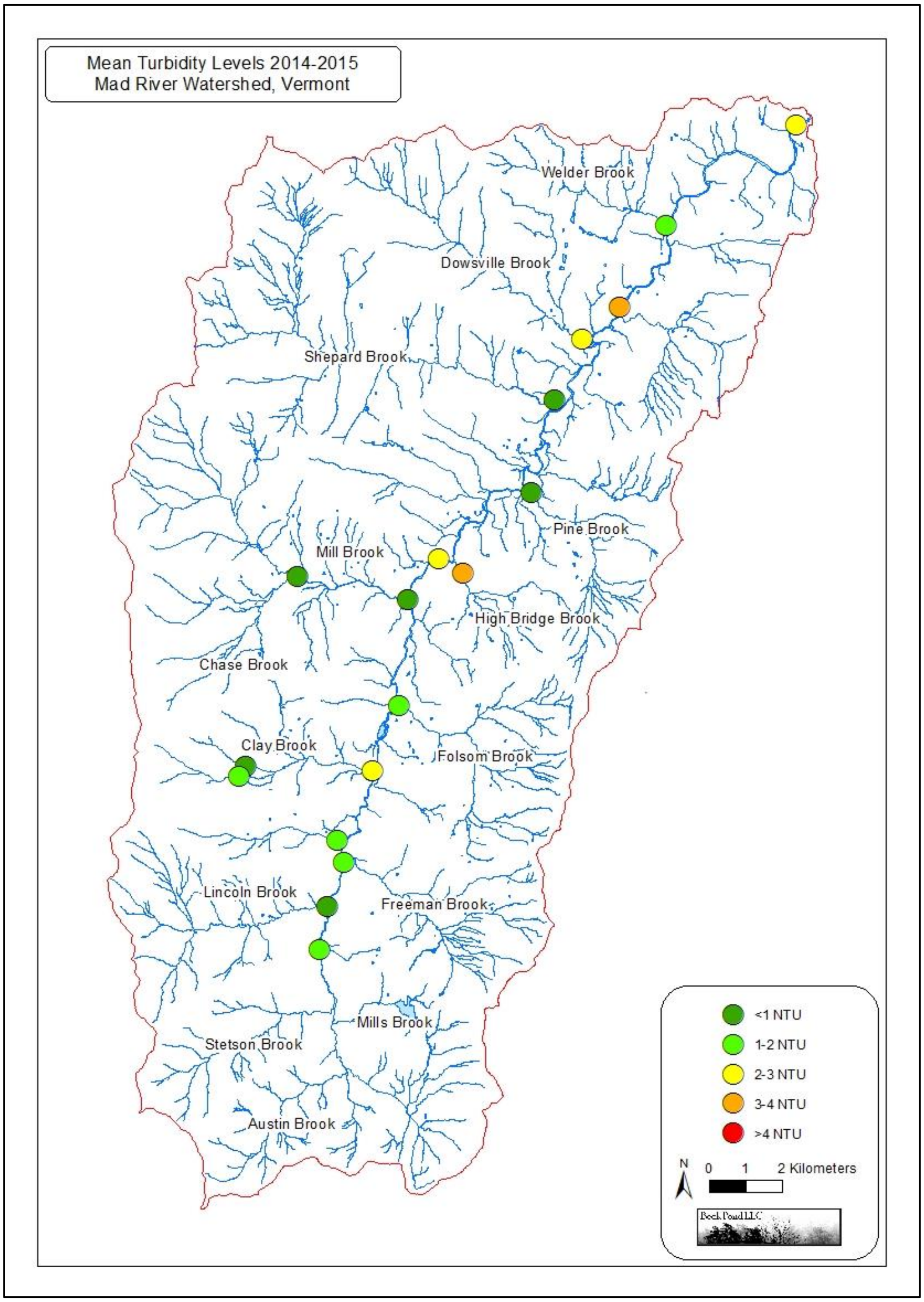


Figure 26. Mean turbidity levels at 18 sites along the Mad River and its tributaries during 2014-2015.

During 2014-2015, turbidity levels consistently increased along the length of the main stem of the Mad River (Figure 27). More specifically, turbidity levels increased most dramatically between Site #1 (Warren Falls) and Site #20 (Waitsfield Covered Bridge) and then leveled off from there downstream through Site #28 (Moretown) to Site #31 (Lover's Lane Bridge). Thus, turbidity levels roughly doubled from <1 NTU to >2 NTU over the course of the 30 km (19 miles) from upstream of Warren village downstream towards the mouth of the Mad River.

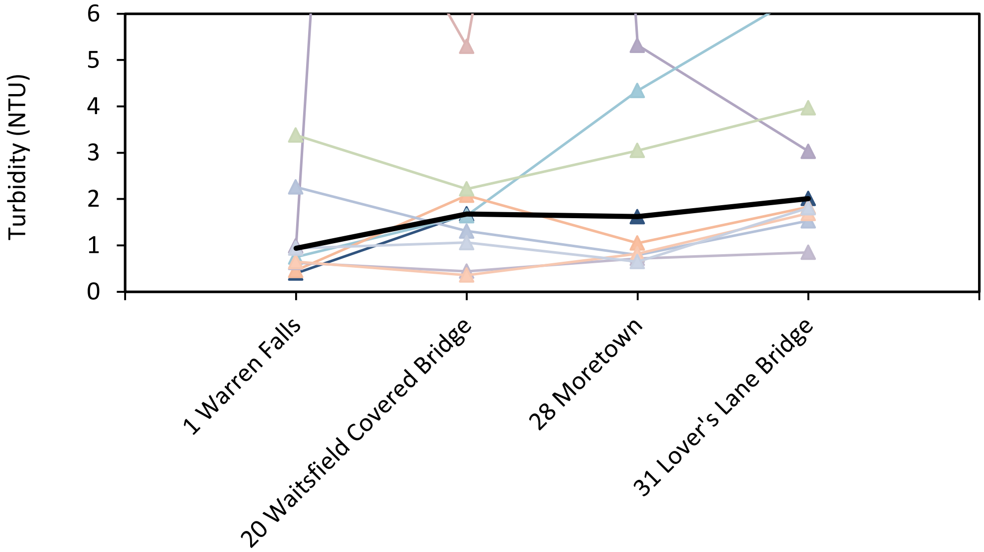


Figure 27. Turbidity "profile" at four sites along the main stem of the Mad River from Site #1 (Warren Falls) downstream to Site #31 (Lover's Lane Bridge) during 2014-2015. The light, colored lines show the values measured on each sample date; the bold, black line shows the median values for each site during those two years. Note that some of the values exceed the range of the y-axis.

Like total phosphorus, turbidity levels showed both increases and decreases over time at different sites along the main stem and tributaries of the Mad River (Figure 28). Six sites exhibited marked decreases in turbidity levels during 2006-2015 [Site #10 (Folsom Brook), Site #11 (Rice Brook), Site #22 (Pine Brook), Site #25 (Dowsville Brook), Site #28 (Moretown), and Site #28.05 (Welder Brook)]. In contrast, turbidity levels only increased markedly at one site [Site #20.1 (High Bridge Brook)] in large part due to a number of very high values measured during 2011-2015. The increase in mean turbidity levels but the overall trend of decreased turbidity values at Site #28 (Moretown) is likely due to a single, extremely high turbidity value measured on 27 July 2015 (472 NTU); for some unknown reason, this value was almost three times the next highest value measured during all of 2006-2015.

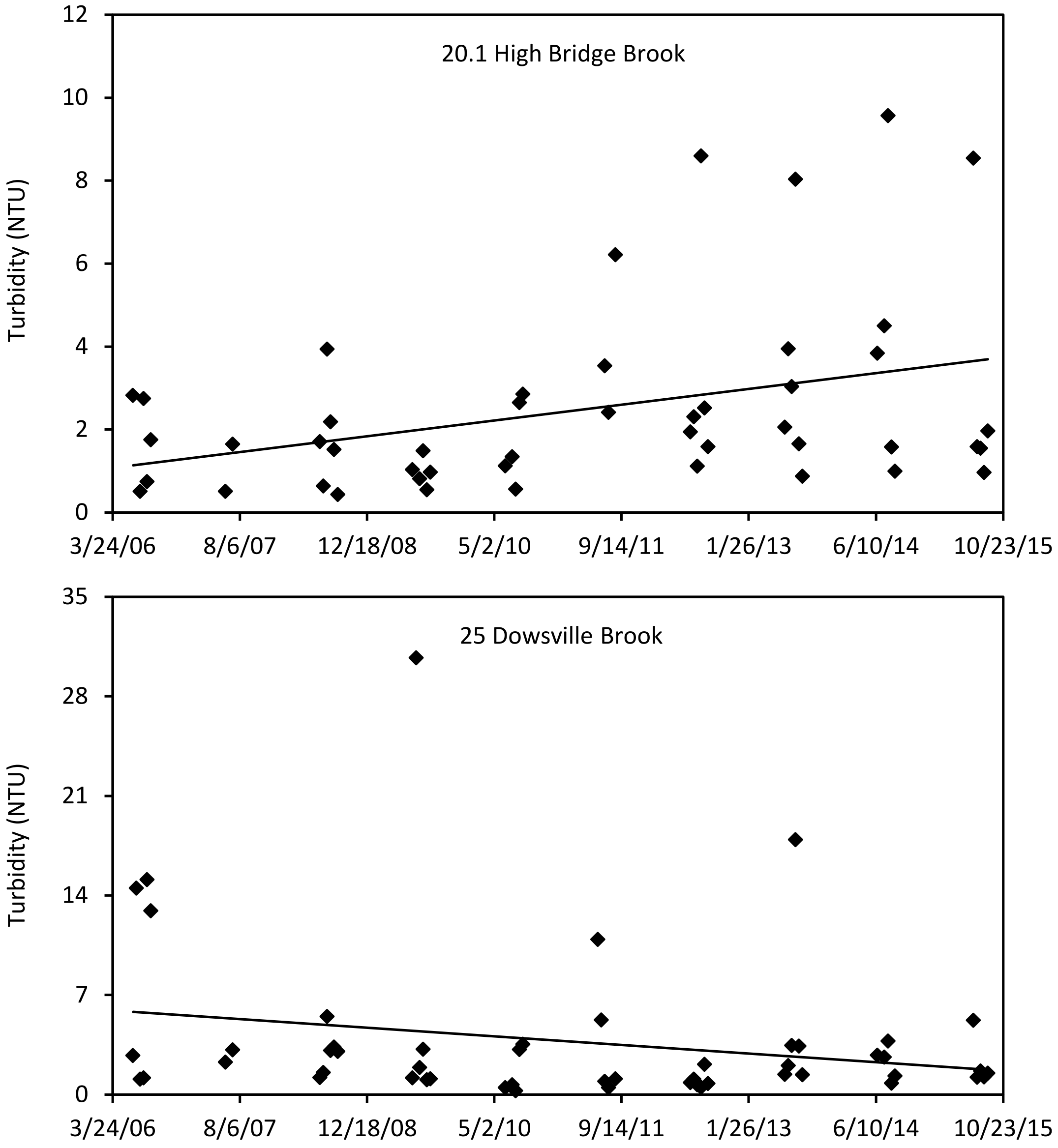


Figure 28. Turbidity levels over time at two sites [Site #20.1 (High Bridge Brook) and Site #25 (Dowsville Brook)] with increasing and decreasing turbidity levels during 2006-2015. The regression lines indicate the linear relationships between the two parameters. Note that some of the values exceed the range of the y-axis.

At the three sites with the highest median turbidity levels during 2014-2015, we analyzed the turbidity levels in relation to the stream flows measured at the USGS gage on the Mad River near Moretown. At all three sites [Site #20 (Waitsfield Covered Bridge), Site #20.1 (High Bridge

Brook), and Site #28 (Moretown)], turbidity levels increased with increasing stream flows (Figure 29). At two of the three sites [Site #20 (Waitsfield Covered Bridge) and especially Site #28 (Moretown)], both of which were located along the main stem, the relationship between stream flow and turbidity became more pronounced over time. These generally positive relationships between turbidity levels and stream flow suggested that the source(s) of the higher turbidity levels were likely to be nonpoint sources, such as surface runoff. High Bridge Brooks passes through an agricultural area that is primarily used for horses but that also has very high densities of unpaved roads and stream crossings (Stone Environmental 2016). The other two sites, on the other hand, are located along the main stem, where there is both more agricultural land but also more suburban and urban development.

In summary, turbidity, which measures water clarity, was measured at the 19 sites on 55 dates during 2006-2015 (although not all sites were sampled on all dates). Turbidity levels were remarkably low across all sites, and, even though they included a mix of low, moderate, and high flows, they were well below the Vermont water quality standards (State of Vermont 2014a). Turbidity levels were slightly higher at two sites located along the main stem near the villages of Moretown and Waitsfield [Site #28 (Moretown) and Site #20 (Waitsfield Covered Bridge)], especially during the two most recent years of this study (2014-2015). At a third site [Site #20.1 (High Bridge Brook)], turbidity levels were also slightly higher than elsewhere, but they had also increased markedly, especially during the past five years. In addition, the positive relationship between turbidity levels and stream flow at this site again suggested that nonpoint sources, such as surface runoff from agricultural and other land uses may be impacting water quality. Unpaved roads may be another significant source of the high turbidity levels, especially along High Bridge Brook, where an earlier study estimated that approximately 11% of the sediment flux may have originated from unpaved roads (Wemple 2013, Stone Environmental 2016).

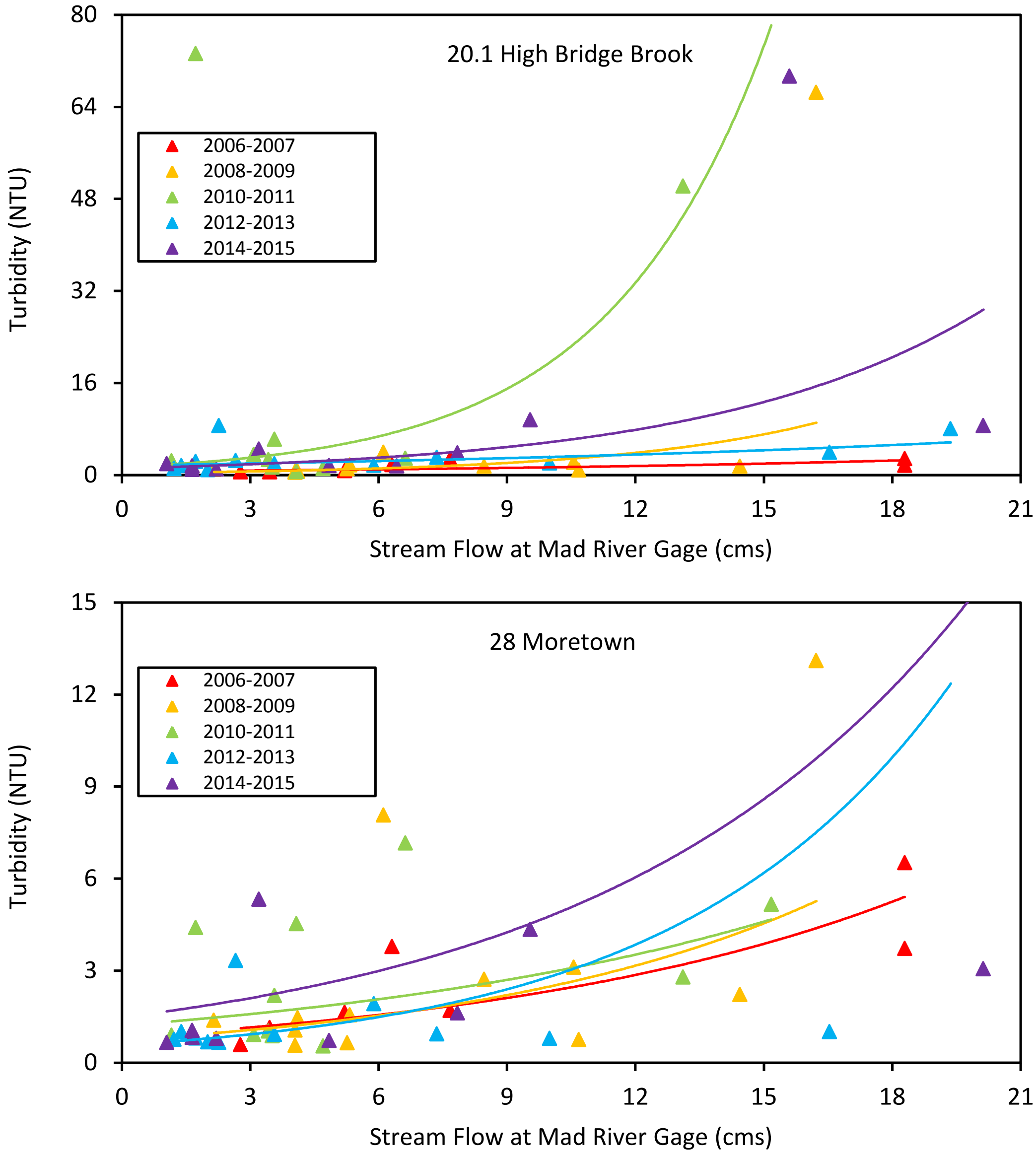


Figure 29. Turbidity levels in relation to stream flow at two sites [Site #20.1 (High Bridge Brook) and Site #28 (Moretown)] at two-year intervals during 2006-2015. Stream flows were measured at the USGS stream gage on the Mad River near Moretown, Vermont (USGS station 04288000). The regression lines indicate the exponential relationships between the two parameters. Note that two extreme high flows were not included in this analysis.

Fecal Coliform Bacteria

Fecal coliform are a generic group of bacteria primarily found in human and animal intestines and wastes and that include both pathogenic and harmless forms (*Escherichia coli* is one species of fecal coliform bacteria). While not necessarily harmful themselves, their presence indicates that other disease-causing organisms may be present and that swimming and other water-based recreation may carry a health risk. Thus, fecal coliform counts provide valuable information that is useful for both protecting public health, especially in areas used for swimming and other recreational activities, and the health of the riverine ecosystem. Potential sources of fecal coliform bacteria include wastewater treatment plants, septic systems, domestic and wild animals, and urban runoff. Fecal coliform are routinely counted as part of the protocol for measuring *E. coli*, and the results are reported as the most probable number (MPN) of colonies per 100 ml.

Fecal coliform bacteria were counted by the Friends of the Mad River during two time periods (1985-1991 and 2002-2005) and were likely counted in all of the intervening and subsequent years, although those data were not entered into the electronic databases used for these analyses. Unlike total phosphorus and turbidity, fecal coliform bacteria were not sampled as consistently across all sites, years, and corresponding stream flows. During the eleven years, 18-39 sites were sampled each year. Only three of the 56 sites were sampled on all 59 sample dates, and another 22 sites were sampled on at least 50 of the 59 sample dates. All 25 of these sites were sampled every year during 1985-1991 and 2002-2005, except eight sites that were not sampled in 1997 for unknown reasons. The remaining 31 sites were sampled on 1-42 dates, often for only a subset of years (e.g. ten sites were only sampled on 1-5 dates in a single year). Thus, we used the data from all the years to calculate the median, geometric mean, 25% and 75% quartiles, and range in fecal coliform counts for each of the 25 sites that were well sampled across the two time periods (1988-1991 and 2002-2005).

Across all eleven years, fecal coliform counts at the 25 sites ranged between <1 and 2,419.2 colonies/100 ml, and mean fecal coliform counts ranged between 18.3-196.4 colonies/100 ml (Table 9). During these eleven years, the highest mean fecal coliform counts (>189 colonies/100 ml) were measured at two sites located along the lower reaches of the main stem [Site #28 (Moretown) and Site #26 (North Road)](Figure 30-31). Intermediate levels of fecal coliform bacteria (126-189 colonies/100 ml) were measured at four sites along the lower reaches of main stem [Site #29 (Ward's Access), Site #27 (Moretown Village), Site #23 (Meadow Road Bridge), and Site #21 (Waitsfield Elementary School)]. Finally, the lowest mean fecal coliform counts (<126 colonies/100 ml) were measured throughout the main stem, especially the middle and upper reaches, and along many of the tributaries, especially Mill, Chase, and Clay Brooks.

Table 9. Fecal coliform counts at 25 sites along the Mad River and its tributaries during 1988-1991 and 2002-2005. Only sites that were sampled on at least 50 of the 59 sample dates are included.

Site #	Site Name	# Dates	Median	Mean	Range
1	Warren Falls	54	29.5	25.1	0.5-1414
2	Bobbin Mill	56	27.0	22.1	0.5-1986
3	Warren Covered Bridge	59	26.0	31.4	0.5-1300
4	Warren Store	58	68.0	82.3	0.5-2420
5	Warren Village North	57	48.0	55.5	1-2420
6	Bradley Brook	52	21.5	31.9	1-2420
7	Riverside Park	58	47.0	54.4	0.5-2420
8	Clay Brook	58	49.0	50.0	0.5-2420
9	-	59	44.3	46.4	0.5-2420
10	Folsom Brook	57	122.4	124.5	0.5-2420
11	Rice Brook	59	24.0	23.8	0.5-1153
12	Clay Brook	54	16.0	18.3	0.5-1203
16	Chase Brook	52	21.5	21.0	0.5-2420
17	German Flats	55	24.0	35.1	0.5-2420
19	Lareau Swimhole	57	94.0	81.7	1-2420
20	Covered Bridge	57	106.0	118.5	1-2420
21	Waitsfield Elem. School	53	107.1	133.1	3.1-2420
22	Pine Brook	56	40.8	51.7	1-2420
23	Meadow Road Bridge	58	156.5	162.4	4.1-2420
24	Shepard Brook	54	53.0	71.6	1-2420
25	Dowsville Brook	51	34.5	54.9	0.5-2419
26	North Road	56	160.5	194.0	1-2420
27	Moretown Village	54	142.5	160.8	1-2420
28	Moretown	53	172.0	196.4	3.1-2420
29	Ward's Access	55	154.0	180.3	2-2420

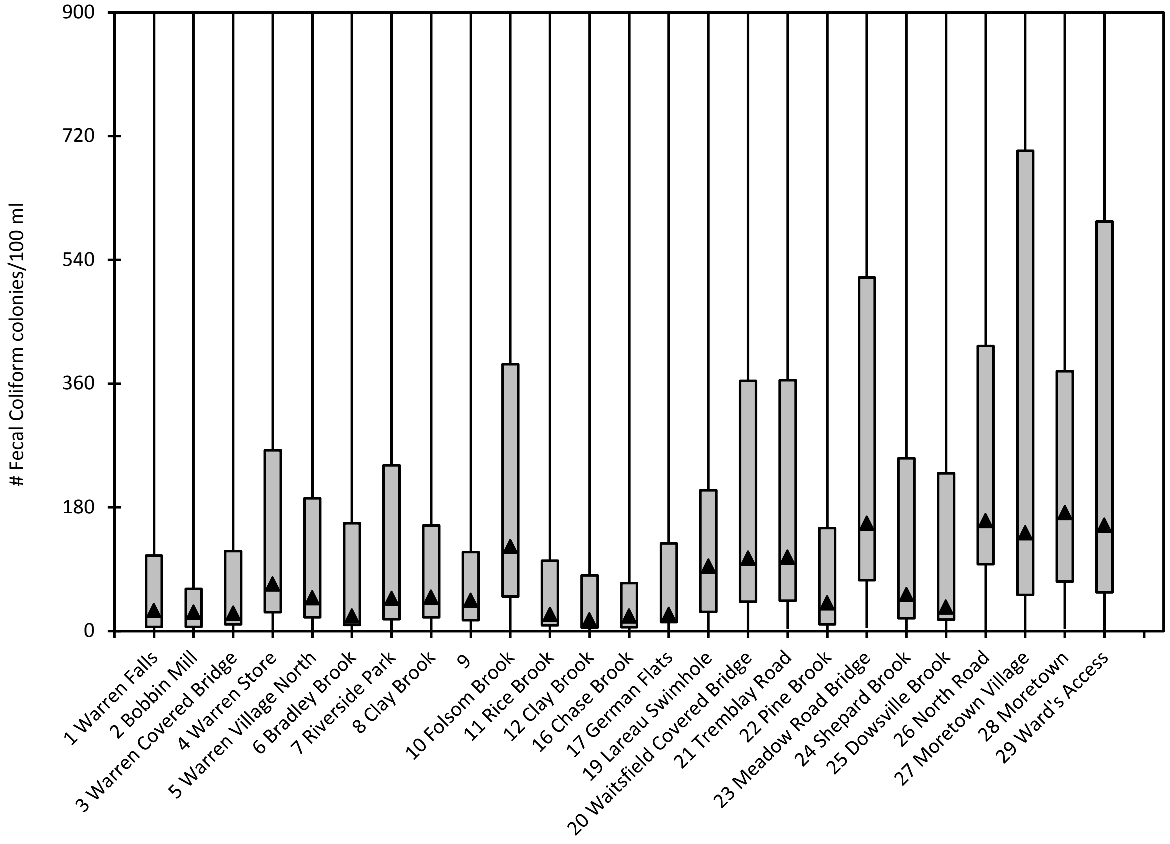


Figure 30. Fecal coliform counts at 25 sites along the Mad River and its tributaries during 1988-1991 and 2002-2005. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line). Only sites that were sampled on at least 50 of the 59 sample dates are included.

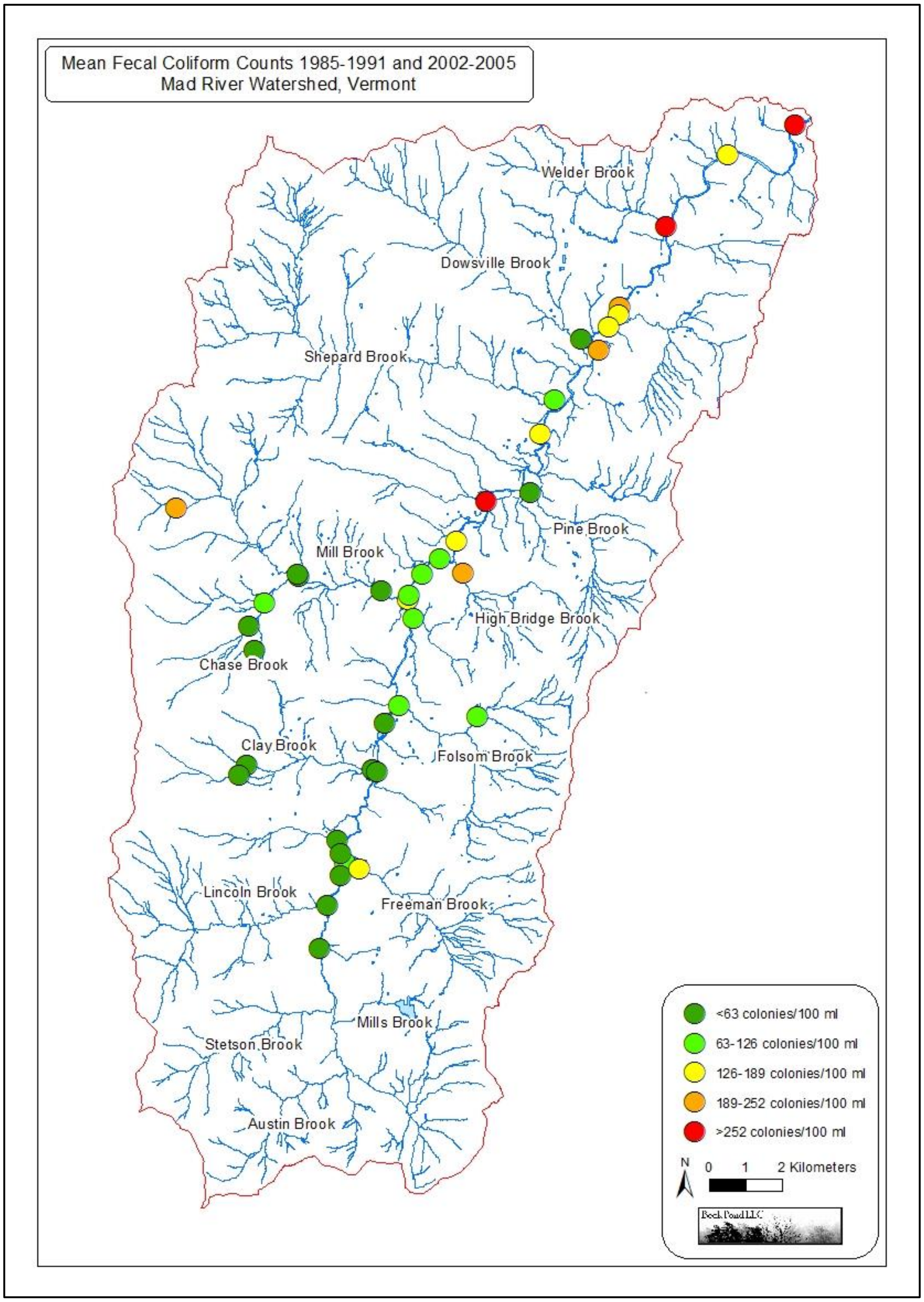


Figure 31. Mean fecal coliform counts at 56 sites along the Mad River and its tributaries during 1988-1991 and 2002-2005.

Fecal coliform counts showed steady and consistent increases along the main stem of the Mad River from Site #1 (Warren Falls) downstream to Site #31 (Lover's Lane Bridge)(Figure 32). The most pronounced increases in fecal coliform counts occurred between Site #26 (North Road) and Site #27 (Moretown Village). In this section of the Mad River, median fecal coliform counts almost doubled from a median of 408 colonies/100 ml at Site #26 (North Road) to a median of 798 colonies/100 ml at Site #27 (Moretown Village).

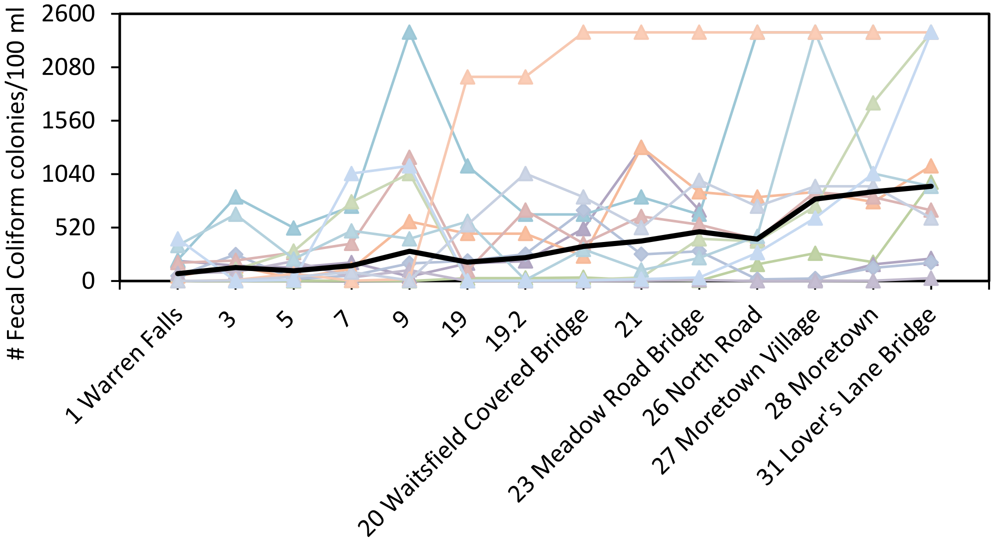


Figure 32. Fecal coliform "profile" at 14 sites along the main stem of the Mad River from Site #1 (Warren Falls) downstream to Site #31 (Lover's Lane Bridge) during 2004-2005. The light, colored lines show the values measured on each sample date; the bold, black line shows the median values for each site during those two years.

In summary, fecal coliform bacteria are valuable indicators of the health and safety of surface waters, especially in areas highly prized for recreational uses such as swimming. Fecal coliform bacteria were measured at 56 sites on 59 dates during 1985-1991 and 2002-2005 (but not all sites were sampled on all dates or in all years). Fecal coliform counts increased consistently from upstream to downstream areas along the main stem and were markedly higher from the village of Waitsfield downstream to the mouth of the Mad River. Fecal coliform counts also were very high at a number of sites along several tributaries of the Mad River. Based on just these analyses, it is difficult to pinpoint and identify likely sources of the high fecal coliform counts measured along the main stem and tributaries; however, a few observations suggested several possibilities. Site #20.1 (High Bridge Brook) is located on a stream that passes through agricultural areas (primarily horse farms), which may be the source of animal wastes that contribute to these higher counts. Along the lower reaches of the main stem, the river passes through agricultural areas as well as village centers and residential areas, which may have failing septic systems and stormwater runoff that carries manure and other organic wastes into the river. Hopefully, future sampling efforts will further pinpoint and assess possible sources of these high fecal coliform counts.

Escherichia coli (E. coli)

As discussed previously, *Escherichia coli* (*E. coli*) is one species of fecal coliform bacteria, which are primarily found in human and animal intestines and wastes. Most strains of *E. coli* are harmless to humans, and some, in fact, are normal residents of the human digestive system, where they aid digestion. A few virulent strains, however, are capable of causing disease in humans and can even be fatal. *Escherichia coli* counts provide valuable information that is useful for both protecting public health, especially in areas used for swimming and other recreational activities, and the health of riverine ecosystems. *Escherichia coli* are widely used as an indicator of fecal contamination and the possible presence of pathogenic (disease-causing) bacteria in surface waters, to ensure that surface waters are safe for swimming and other recreational activities, and to identify possible pollution sources, such as failing septic systems and manure pits. *Escherichia coli* counts [measured as the most probable number (MPN) of colonies/100 ml of water] are typically measured in the laboratory. In Vermont, the Water Quality Standard for *E. coli* in all Class A(1) Ecological Waters, Class A(2) Public Water Supplies, and Class B Waters is that the *E. coli* counts shall not exceed a geometric mean of 126 colonies/100 ml measured over a representative period of 60 days, and no more than 10% of the samples shall exceed 235 colonies/100 ml (State of Vermont 2014a). In addition, none of the *E. coli* should be attributable to the discharge of wastes, and, in all Class B Waters receiving combined sewer overflows (CSO), the representative period is 30 days.

Unfortunately, *E. coli* were not counted or recorded using a consistent methodology during the 24 years sampled (1992-2015). Instead, *E. coli* were counted using a membrane filtration technique during 1992-2001, but the maximum value recorded differed among years (1,001 colonies/100 ml during 1992-1996 but 200 colonies/100 ml during 1997-2001). Beginning in 2002, *E. coli* were counted using the IDEXX Quanti-Tray method. Due to the different methodologies and the differences in the maximum values recorded, we were not able to analyze the data collected during 1992-2001 or to compare those data with data collected after 2001. Nevertheless, the *E. coli* data collected during 2002-2015 provide a valuable, long-term record of *E. coli* levels in the Mad River and its tributaries and are immensely valuable in identifying areas where there may be public health risks for swimming and other recreational activities.

Escherichia coli (*E. coli*) were counted in-house by the Friends of the Mad River using the IDEXX Quanti-Tray method every year during 2002-2015 (14 years). Unlike total phosphorus and turbidity, *E. coli* were not sampled as consistently across all sites, years, and corresponding stream flows. In fact, only five of the 47 sites were sampled on all 83 sample dates during the 14 years. However, 34 of the 47 sites (72%) were sampled on at least 75 dates, and all but six of these 34 sites were sampled every year during 2002-2015 (Figure 33). The remaining 13 sites were sampled on 3-58 dates and often for only a subset of years. Thus, we used the data from all of the years during 2002-2015 to calculate the median, geometric mean, 25% and 75% quartiles, and range in *E. coli* counts for each of the 34 sites that were well sampled throughout 2002-2015.

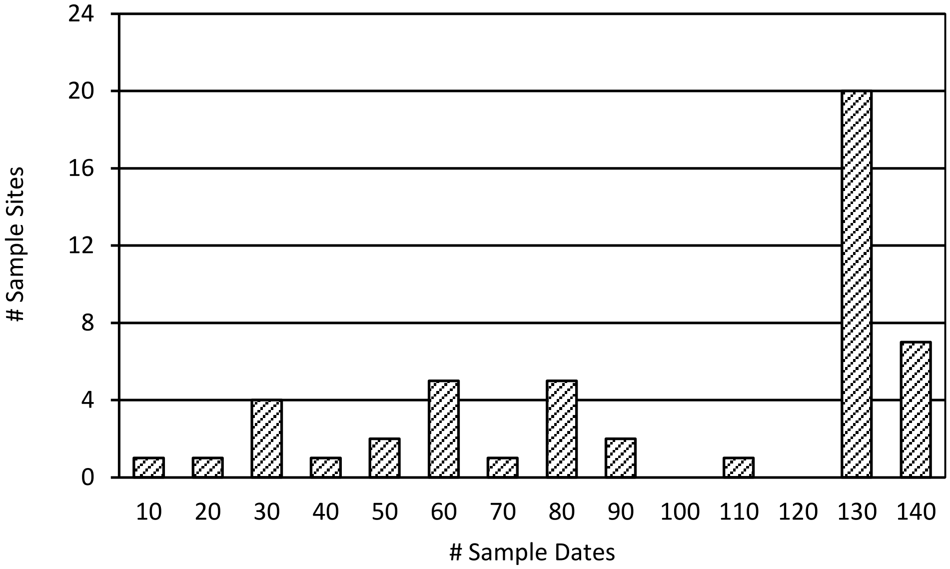


Figure 33. Frequency histogram showing the number of dates on which each site was sampled for *E. coli* in the Mad River watershed during 2002-2015.

During 2002-2015, *E. coli* counts at the 34 sites ranged between <1 and >2,419.2 colonies/100 ml, and mean *E. coli* counts ranged between 9.9-113.2 colonies/100 ml (Table 10). During these 14 years, the highest mean *E. coli* counts (>94.5 colonies/100 ml) were measured at three sites, all located along the lower reaches of the main stem [Site #31 (Lover's Lane Bridge), Site #29 (Ward's Access), and Site #28 (Moretown)](Figure 34-35). Intermediate levels of *E. coli* (63-94.5 colonies/100 ml) were measured at four other sites located along the lower reaches of main stem [Site #27 (Moretown Village) and Site #26 (North Road)] and two tributaries of the Mad River [Site #28.05 (Welder Brook) and Site #28.1]. Finally, lower mean *E. coli* counts were measured throughout the main stem, especially the upper reaches, and along almost all of the tributaries of the Mad River.

Table 10. *E. coli* counts at 34 sites along the Mad River and its tributaries for two time periods (2002-2015 and 2014-2015). The column labeled "%>235" indicates the proportion of counts at each site that exceeded 235 colonies/100 ml during 2014-2015. Only sites that were sampled on at least 75 of the 83 sample dates are included.

		2002-2015			2014-2015 Only			
Site #	# Dates	Median	Mean	Range	Median	Mean	Range	% >235
1	83	16.0	16.9	1-579.4	14.0	18.9	6.3-110	0
2	82	11.0	12.9	1-1413.6	16.3	16.5	5.2-125.9	0
3	82	18.3	20.5	1-2420	14.5	16.8	4.1-160.7	0
4	82	33.8	39.3	1-2420	58.4	38.0	1-461.1	8
4.5	81	22.1	20.0	1-2419.2	27.7	21.9	3.1-1046.2	8
5	81	27.5	30.2	1-640.5	29.9	33.1	5.2-228.2	0
6	80	14.2	15.9	1-1986.3	11.0	15.2	4.1-115.3	0
7	82	25.3	32.5	1-2420	20.9	36.3	11-980.4	8
8	82	17.3	18.4	1-1300	22.1	20.4	1-198.9	0
10	82	27.4	34.3	1-2420	19.4	39.2	5.2-1986.3	17
10.6	77	18.9	23.5	1-2420	21.2	34.4	6.3-920.8	8
11	82	10.9	10.8	1-2420	6.9	10.7	3.1-90.6	0
12	82	4.1	5.5	1-920.8	5.2	7.1	1-143.9	0
13.1	77	11.9	10.5	1-1046.2	11.5	11.9	3-51.2	0
16	82	9.8	10.6	1-2419.2	20.2	17.3	5.2-61.3	0
17	82	17.4	18.6	1-866.4	13.5	15.7	3.1-72.3	0
17.1	75	13.2	13.9	1-1120	14.9	11.3	2-47.5	0
18.1	76	27.0	26.0	1-2419.2	24.7	25.5	6.3-110.6	0
19	83	32.0	24.6	1-2420	41.0	45.2	10.9-770.1	8
19.2	82	30.5	27.2	1-2420	36.5	52.0	12.1-1203.3	8
20	83	35.0	31.3	1-2419.2	25.6	52.3	12-816.4	17
20.1	77	27.8	24.6	1-2420	51.5	79.7	9.8-1553.1	25
22	82	14.8	15.8	1-2420	17.3	16.9	2-547.5	8
23	81	47.9	57.0	1-2420	47.3	66.5	12.2-770.1	8
24	82	29.4	34.7	1-1733	23.3	33.7	10.9-387.3	8
25	81	22.8	25.2	1-2420	19.8	18.5	1-204.6	0
26	81	83.6	84.1	1-2420	100.1	112.4	24.6-866.4	17
27	83	87.0	92.6	1-2420	88.0	110.9	28.7-1413.6	17
27.1	82	38.9	46.9	1-2420	36.2	52.0	14.8-920.8	8
28	82	85.9	103.6	1-2420	90.8	131.3	36.9-1046.2	25
28.05	81	70.0	71.0	1-2420	27.7	61.9	10.7-1299.7	17
29	83	86.0	104.5	7.2-2420	69.4	90.1	27.2-920.8	8
31	77	113.7	113.2	5-2420	68.7	75.9	22.8-770	17
BBL	75	9.7	13.3	1-2420	6.9	7.9	2-69.7	0

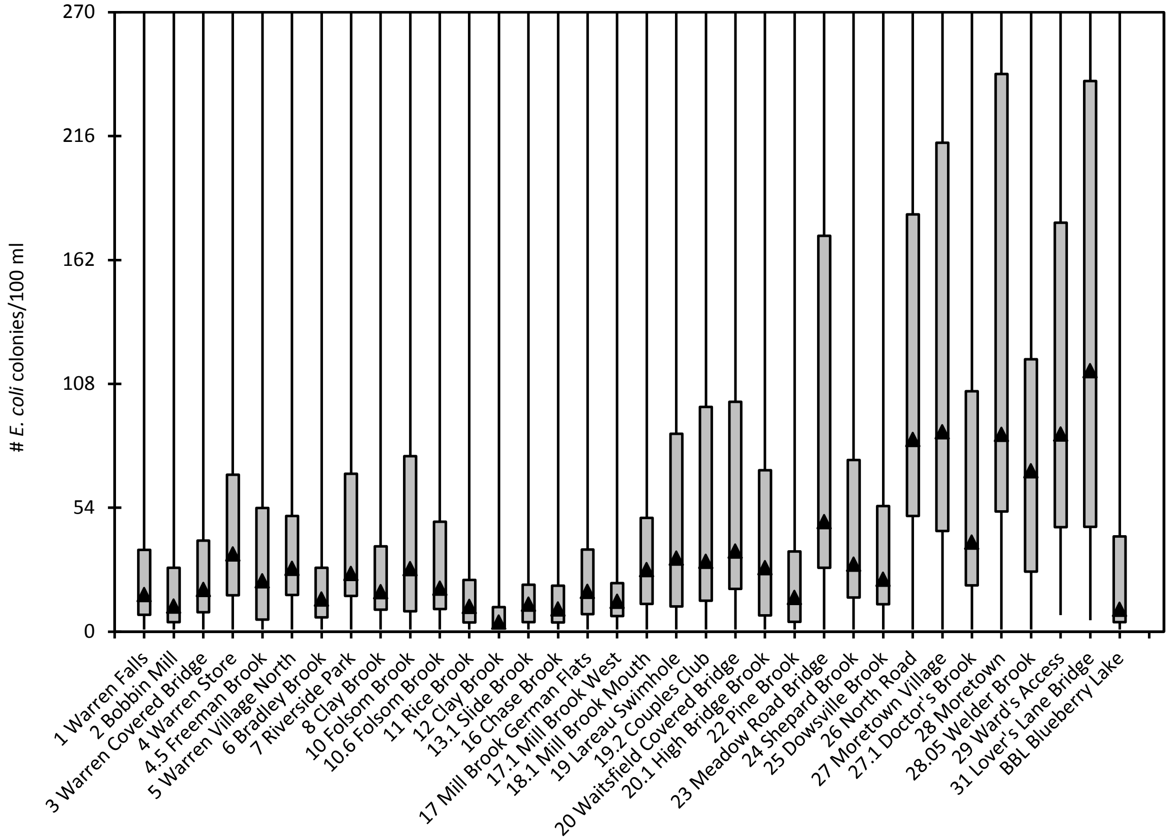


Figure 34. *E. coli* counts at 34 sites along the Mad River and its tributaries during 2002-2015. Values are the median (triangle), 1st and 3rd quartiles (rectangle), and minimum and maximum (line). Only sites that were sampled on at least 75 of the 83 sample dates are included.

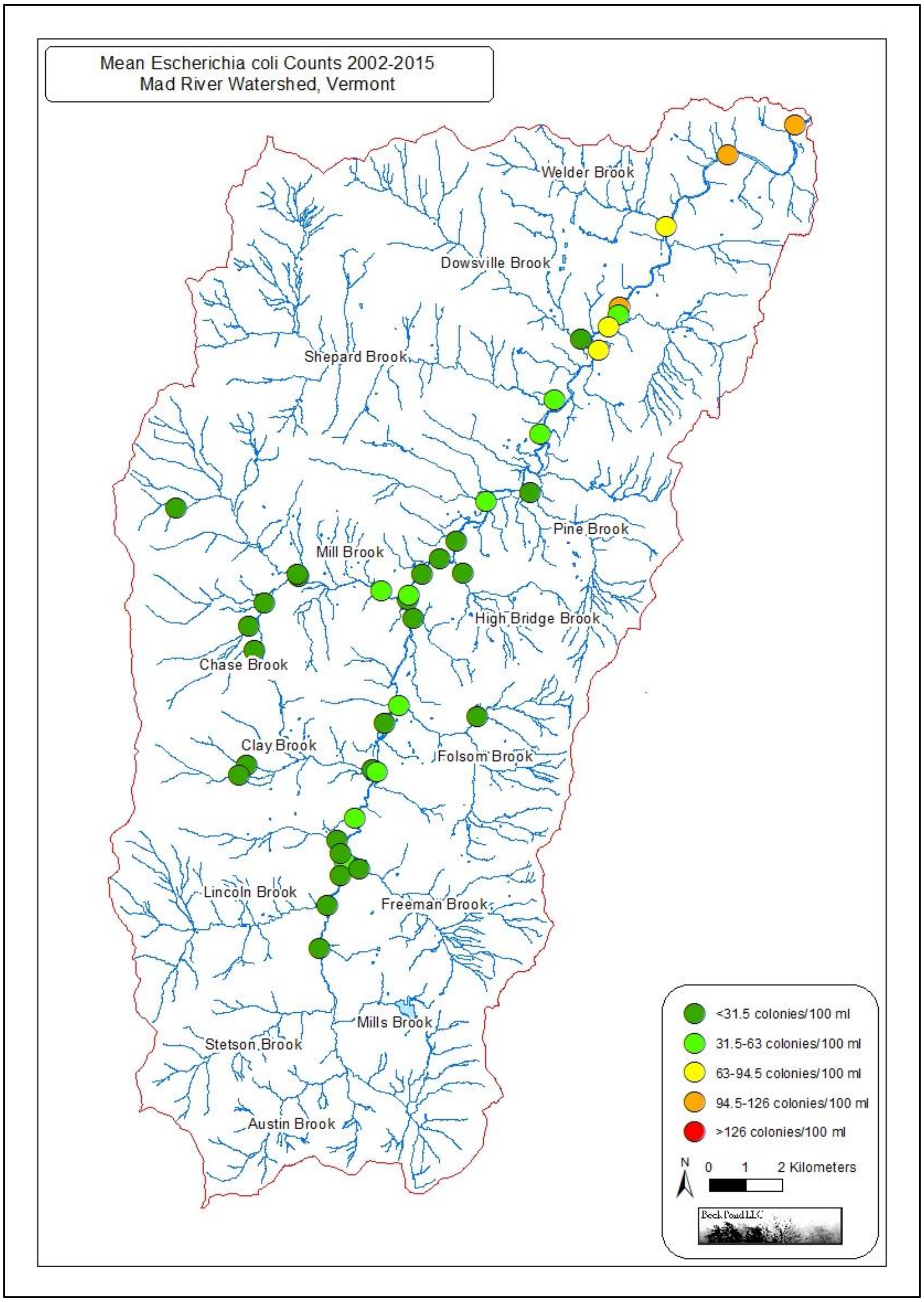


Figure 35. Mean *E. coli* counts at 47 sites along the Mad River and its tributaries during 2002-2015.

During 2014-2015, *E. coli* counts at the 34 sites ranged between 1-1,553.1 colonies/100 ml, and mean *E. coli* counts ranged between 7.9-131.3 colonies/100 ml (Table 10). In these two years, the highest mean *E. coli* counts (>94.5 colonies/100 ml) were measured at three sites, all located along the lower reaches of the main stem in the vicinity of Moretown village [Site #28 (Moretown), Site #26 (North Road), and Site #27 (Moretown Village)](Figure 36-37). Intermediate levels of *E. coli* (63-94.5 colonies/100 ml) were measured at four other sites, including three sites along the lower reaches of the main stem [Site #29 (Ward's Access), Site #31 (Lover's Lane Bridge), and Site #23 (Meadow Road Bridge)] and one site on a tributary [Site #20.1 (High Bridge Brook)]. Finally, lower mean *E. coli* counts (<63 colonies/100 ml) were measured throughout the upper watershed of the Mad River, including the upper reaches of the main stem and many of the tributaries of the Mad River.

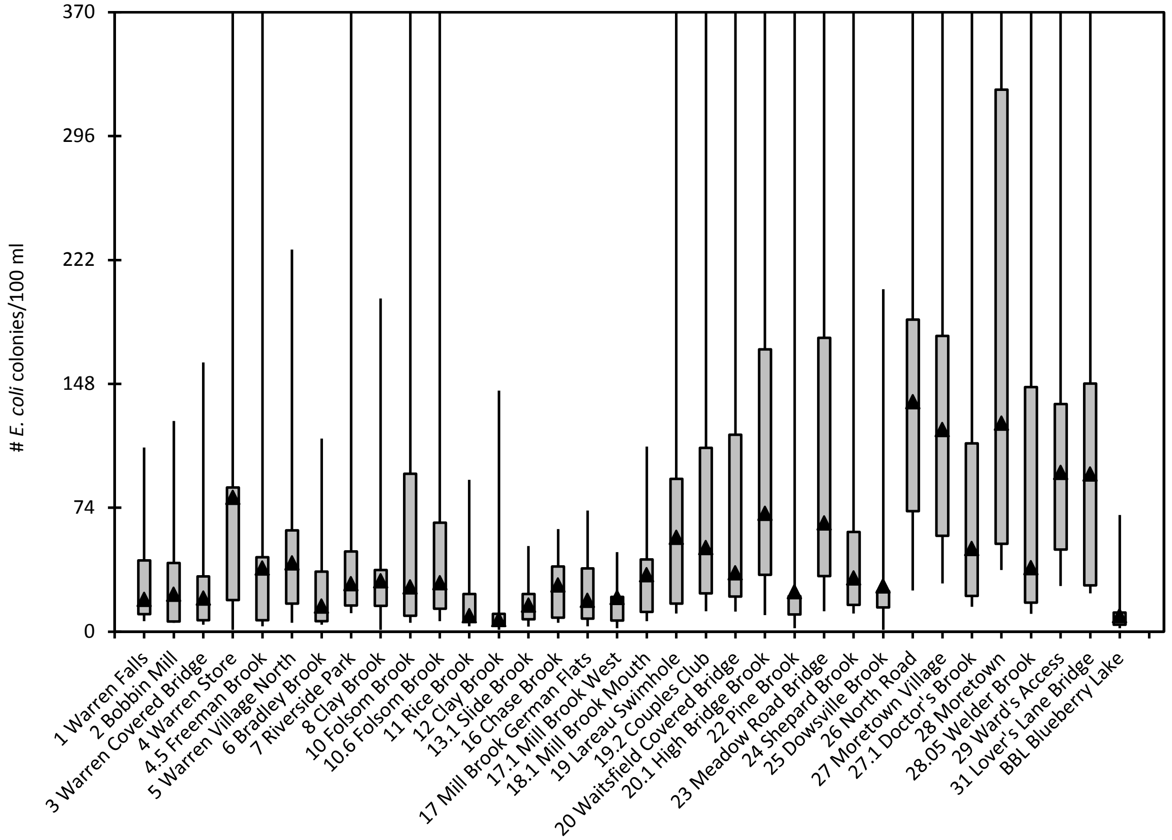


Figure 36. *E. coli* counts at 34 sites along the Mad River and its tributaries during 2014-2015. Values are the median (triangle), 1^{st} and 3^{rd} quartiles (rectangle), and minimum and maximum (line). Only sites that were sampled on at least 75 of the 83 sample dates are included.

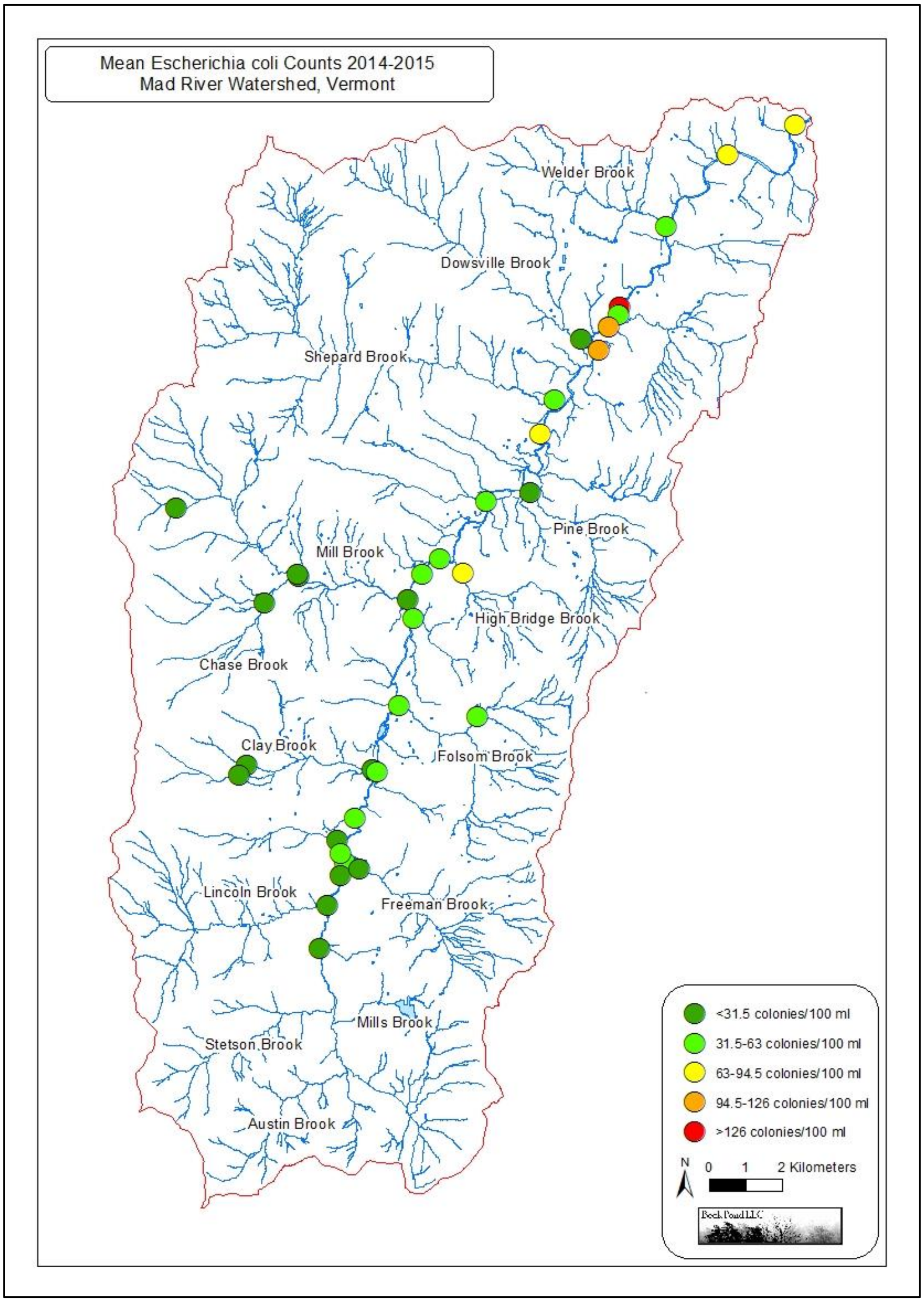


Figure 37. Mean *E. coli* counts at 47 sites along the Mad River and its tributaries during 2014-2015.

During 2014-2015, *E. coli* counts showed steady and consistent increases along the main stem of the Mad River from Site #1 (Warren Falls) downstream to Site #31 (Lover's Lane Bridge)(Figure 38). The most dramatic increases in *E. coli* counts occurred between Site #23 (Meadow Road Bridge) and Site #26 (North Road), and then counts declined somewhat but remained high from there downstream to Site #31 (Lover's Lane Bridge). In this section of the Mad River, median *E. coli* counts more than doubled from a median of 47.3 colonies/100 ml at Site #23 (Meadow Road Bridge) to a median of 100.1 colonies/100 ml at Site #26 (North Road). The steady but slight decline in *E. coli* abundance downstream of Site #26 (North Road) suggested that there may be consistent source of *E. coli* between Site #23 (Meadow Road Bridge) and Site #26 (North Road), and, from there downstream, there is a "decay function" wherein bacteria die-off longitudinally downstream from that source (N. Kamman, personal communication).

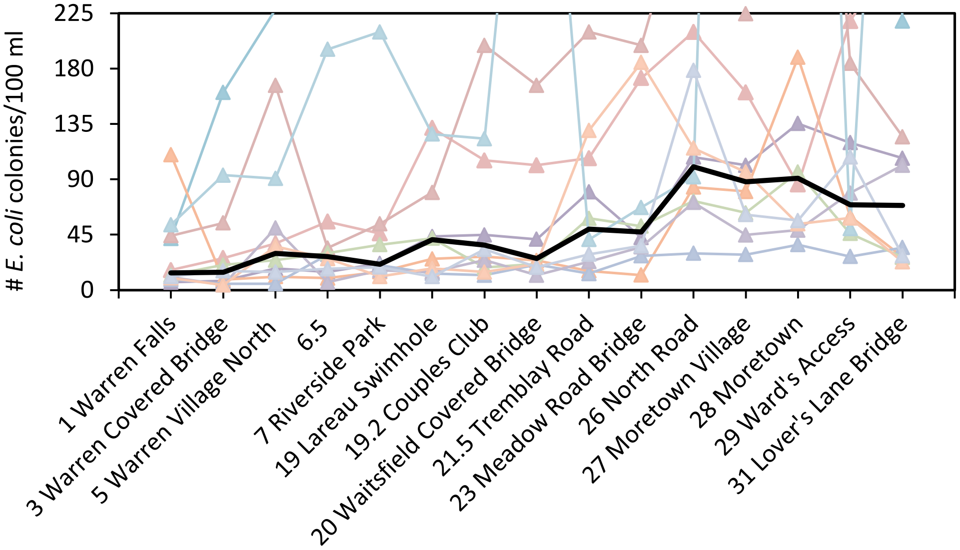


Figure 38. *E. coli* "profile" at 15 sites along the main stem of the Mad River from Site #1 (Warren Falls) downstream to Site #31 (Lover's Lane Bridge) during 2014-2015. The light, colored lines show the values measured on each sample date; the bold, black line shows the median values for each site during those two years. Note that some of the values exceed the range of the y-axis.

For seven of the nine sites with the highest mean *E. coli* counts during 2002-2015 and/or 2014-2015, we examined the *E. coli* counts over time. Only two of these sites showed pronounced changes in *E. coli* counts over time: Both Site #23 (Meadow Road Bridge) and Site #28.05 (Welder Brook) showed marked increases in *E. coli* counts during 2002-2015, primarily due to higher counts (>550 colonies/100 ml) in 2009 and later years (Figure 39). The remaining five sites showed either no changes in *E. coli* counts [Site #26 (North Road) and Site #29 (Ward's Access)] or only slight increases [Site #27 (Moretown Village)] or decreases [Site #28 (Moretown) and Site #31 (Lover's Lane Bridge)].

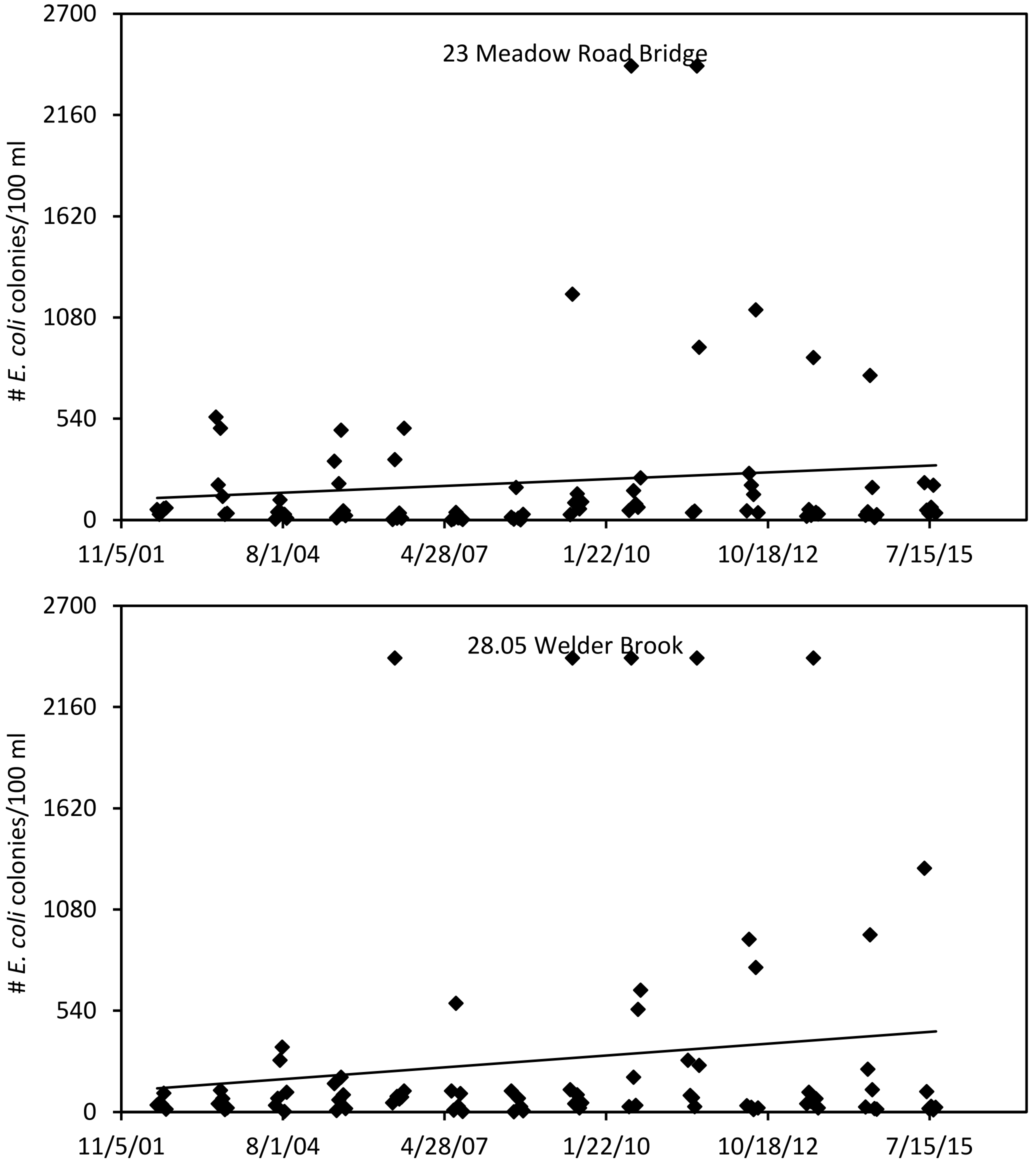
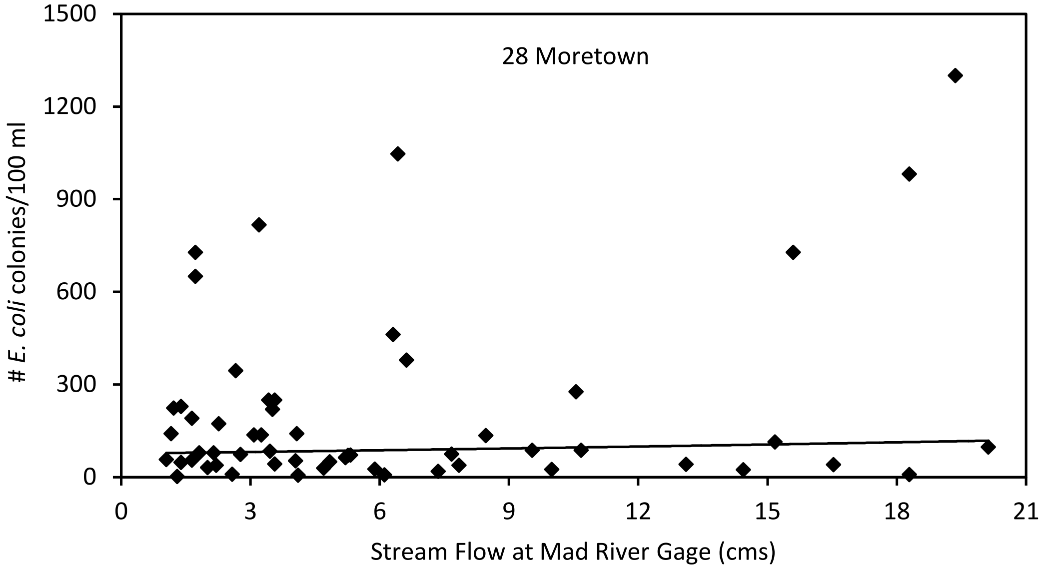


Figure 39. *E. coli* counts over time at two sites [Site #23 (Meadow Road Bridge) and Site #28.05 (Welder Brook)] along the main stem and one tributary of the Mad River during 2002-2015.

For those same seven sites with the highest mean *E. coli* counts during 2002-2015 and/or 2014-2015, we also analyzed the *E. coli* counts in relation to the stream flows measured at the USGS gage on the Mad River near Moretown. At the one site located on a tributary [Site #28.05 (Welder Brook)], *E. coli* counts increased markedly with increasing stream flows (Figure 40). On the other hand, *E. coli* counts showed more modest but consistent increases with increasing stream flows at the six sites located along the main stem [Site #23 (Meadow Road Bridge), Site #26 (North Road), Site #27 (Moretown Village), Site #28 (Moretown), Site #29 (Ward's Access), and Site #31 (Lover's Lane Bridge)].



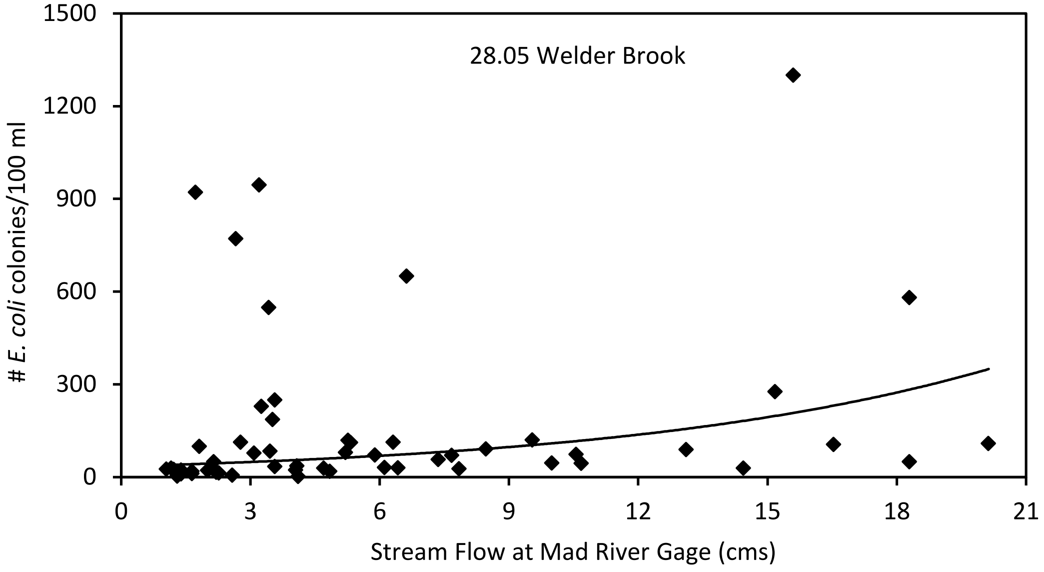


Figure 40. *E. coli* counts in relation to stream flow at two sites [Site #28 (Moretown) and Site #28.05 (Welder Brook)] along the main stem and a tributary of the Mad River during 2006-2015. Stream flow was measured at the USGS stream gage on the Mad River near Moretown, Vermont (USGS station 04288000). The regression lines indicate the exponential relationships between the two parameters. Note that two extreme high flows were not included in this analysis.

Finally, in analyzing these data, we compared the mean and maximum *E. coli* counts from 2014-2015 with the State of Vermont Water Quality Standards for *E. coli* (State of Vermont 2014a). As mentioned previously, the Vermont Water Quality Standards for *E. coli* in all Class A(1) Ecological Waters, Class A(2) Public Water Supplies, and Class B Waters is that the *E. coli* counts shall not exceed a geometric mean of 126 organisms/100 ml measured over a representative period of 60 days, and no more than 10% of the samples shall exceed 235 organisms/100 ml (State of Vermont 2014a). One site [Site #28 (Moretown)] exceeded the geometric mean of 126 organisms/100 ml measured over a representative period of 60 days in 2015 (mean = 148.6 colonies/100 ml) but not in 2014 (mean = 116.0 colonies/100 ml). In addition, 10% of the samples exceeded 235 organisms/100 ml at eight sites during 2014-2015 (Figure 41). These sites included five sites along the main stem [Site #20 (Waitsfield Covered Bridge), Site #26 (North Road), Site #27 (Moretown Village), Site #28 (Moretown), and Site #31 (Lover's Lane Bridge)] and one site along each of three tributaries [Site #10 (Folsom Brook), Site #20.1 (High Bridge Brook), and Site #28.05 (Welder Brook)].

In summary, *E. coli*, which is one species of fecal coliform bacteria, is a valuable indicator of the health and safety of surface waters, especially in areas highly prized for recreational uses such as swimming. *Escherichia coli* were measured at 47 sites on 83 dates during 2002-2015 (but not all sites were sampled on all dates or in all years). *Escherichia coli* counts were high at a number of sites along the lower reaches of the main stem as well as along several tributaries. Along the main stem, *E. coli* counts increased consistently from upstream to downstream areas and were markedly higher from the village of Waitsfield downstream to the mouth of the Mad River. At two sites [Site #23 (Meadow Road Bridge) and Site #28.05 (Welder Brook)], *E. coli* counts showed marked increases over time during the past 14 years. The positive relationship between *E. coli* and stream flow at many of these sites suggested that the source(s) of the *E. coli* may be related to surface and stormwater runoff, especially from areas contaminated by manure, leakage or overflows of septic systems, and wastewater. Based on just these analyses, it is difficult to pinpoint and identify likely sources of the high *E. coli* counts measured along the main stem and tributaries; however, a few observations suggested several possibilities. Site #20.1 (High Bridge Brook) is located on a stream that passes through agricultural areas (primarily horse farms), which may be the source of animal wastes that contribute to these higher counts. Along the lower reaches of the main stem, the Mad River passes through agricultural areas as well as village centers and residential areas, particularly in the vicinity of Moretown village, which may have failing septic systems and stormwater runoff that carries manure and other organic wastes into the river. Hopefully, future sampling efforts will further pinpoint and assess possible sources of these high *E. coli* counts.

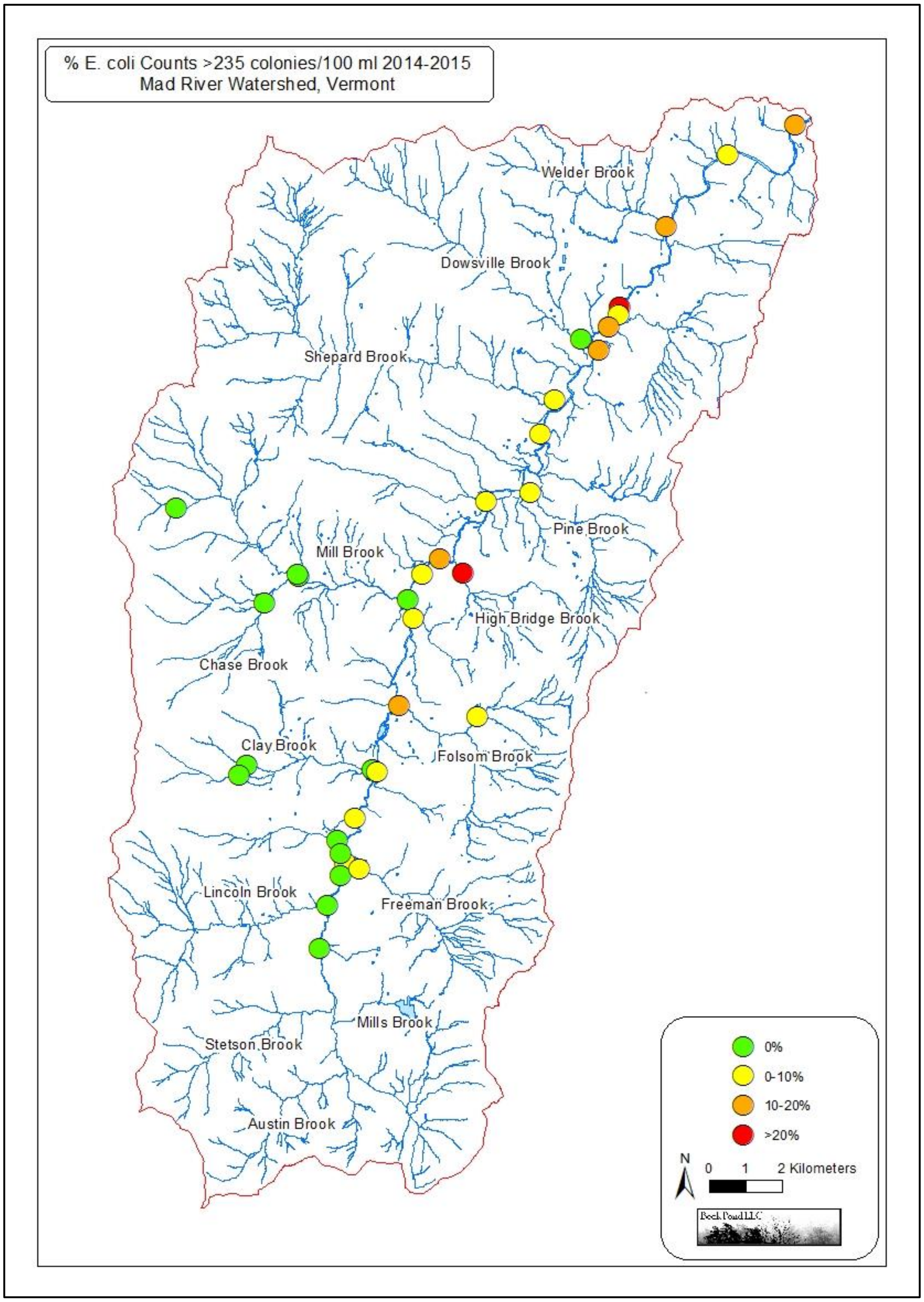


Figure 41. Proportion of *E. coli* counts that exceeded 235 colonies/100 ml at 34 sites in the Mad River watershed during 2014-2015. Only sites that were sampled on at least 100 of the 134 sample dates are included.

Blueberry Lake

Blueberry Lake is the only significant lake in the Mad River watershed (Figure 42). Blueberry Lake is a man-made lake impounded by an earthen dam and covers an area of 19.4 ha (48 acres) to a maximum depth of 4.9 m (16 ft). As part of their spring phosphorus monitoring program, the Lakes and Ponds Section of the Vermont DEC has been monitoring total phosphorus concentrations and Secchi depths at two stations in Blueberry Lake since 1985. Based on these data, mean total phosphorus concentrations equaled 15.8 and 15.4 µg/l, and mean Secchi depths equaled 1.8 m (5.8 ft) and 1.7 m (5.6 ft) at these two stations (Figure 43). During 1985-2011, both total phosphorus concentrations and Secchi depths increased slightly at the two stations. According to the Vermont DEC, Blueberry Lake is classified as mesotrophic, which indicates a lake with an intermediate level of productivity. Such lakes are commonly clear-water lakes with beds of submerged vegetation and moderate levels of nutrients.

Figure 42. Blueberry Lake is the only significant lake in the Mad River watershed. This artificial lake is impounded by an earthen dam and is nestled at the base of the western slopes of the Northfield Mountains in Warren, Vermont as seen on 15 October 2015.

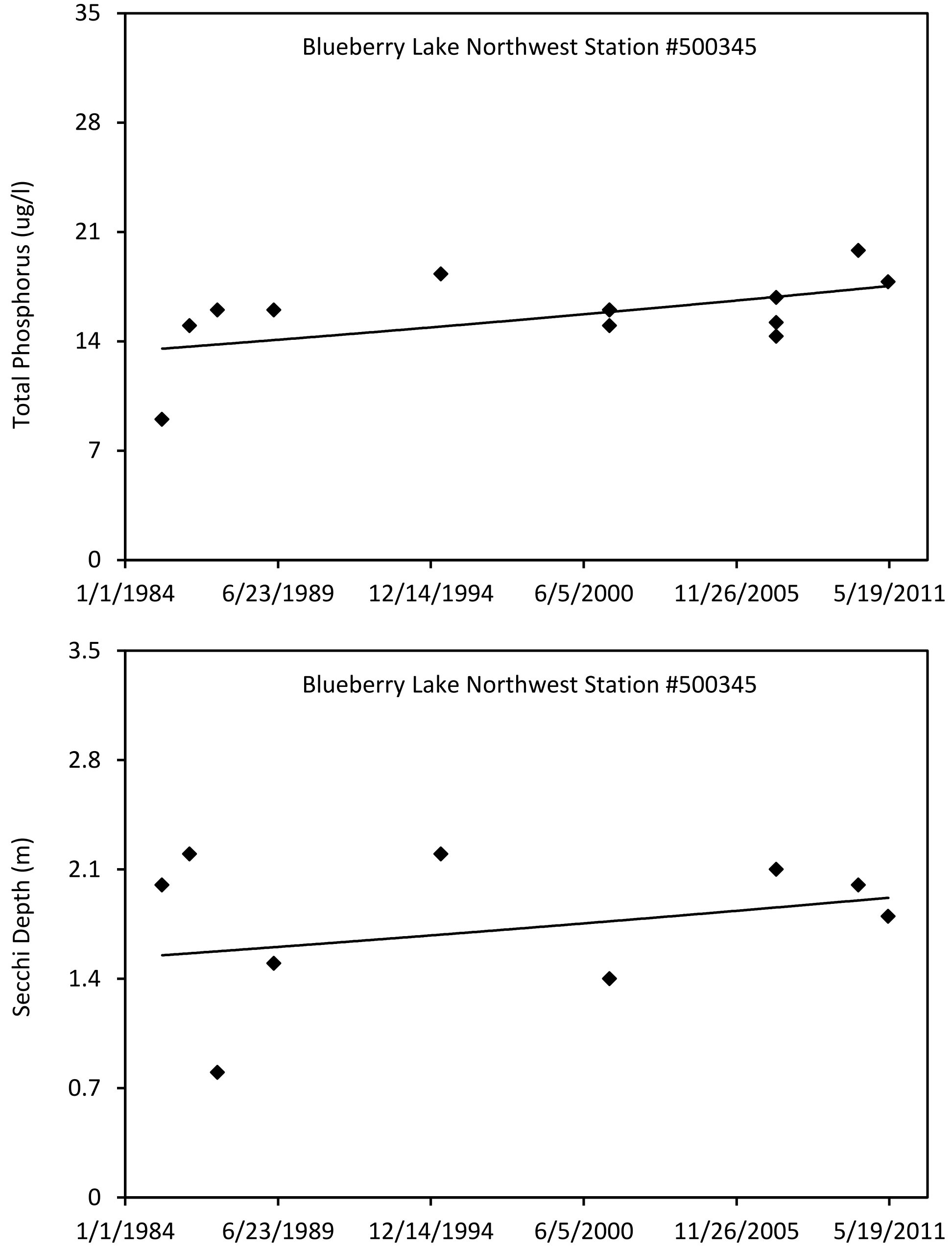


Figure 43. Total phosphorus concentrations and Secchi depths measured as part of Vermont DEC's spring phosphorus sampling at the Northwest Station (Location ID #500345) in Blueberry Lake during 1985-2011. The regression lines indicate the exponential relationships between the two parameters.

Tropical Storm Irene

One final area of discussion is understanding how Tropical Storm Irene might have impacted water quality conditions in the Mad River and its tributaries. On 27-28 August 2011, Tropical Storm Irene deposited greater than 15 cm (6") of rain on several watersheds in the central and south-eastern portions of Vermont. Following these torrential rains, the U.S. Geological Survey reported record discharges [193.7 cms (6,840 cfs)] at the USGS gage station on the Mad River near Moretown, Vermont (USGS station 04288000). These torrential rains and the subsequent flooding caused extensive damage to public and private property, including transportation infrastructure, such as roads, culverts, and bridges. Interestingly, however, we detected no pronounced or obvious impacts on the water quality parameters measured in this study (e.g. total phosphorus, turbidity, and *E. coli*) following this storm and the subsequent floods. More specifically, total phosphorus, turbidity, and *E. coli* levels all showed no consistent increases or decreases between 2011 and 2012 despite the massive and potentially long-lasting impacts that this storm had on the river channels and floodplains of the Mad River and its tributaries. This apparent lack of long-term impacts on these water quality measures may reflect the fact that the 2011 sampling program had ended one week prior to Tropical Storm Irene (22 August 2011) and did not resume until more than nine months later (11 June 2012). However, other studies have shown that Tropical Storm Irene and the subsequent recovery activities were harmful to aquatic habitats and had longer-term impacts on the fish and macroinvertebrate communities. For example, in Slide Brook (a tributary of the Mad River), wild trout populations declined to less than 40% of their pre-storm levels in the year following Tropical Storm Irene (Kirn 2012).

Sampling Recommendations

As part of these efforts to summarize and analyze the water quality data collected by the Friends of the Mad River during 1985-2015, we developed a set of recommendations for updating and upgrading the water quality monitoring programs to 1) more efficiently monitor water quality conditions over time; 2) better identify, pinpoint, and assess the source(s) of specific water quality problems; and 3) maintain and enhance their public health and educational values. In the sections that follow, we describe and present the rationales for these recommendations. It should be understood, however, that any decisions about modifying these monitoring programs ultimately rest with the Friends of the Mad River, not the author of these recommendations.

General Approach

In suggesting revisions and upgrades to the Friends of the Mad River water quality monitoring program, we emphasize maintaining its long-term baseline monitoring, public health, and educational values while adding elements that will allow better identification, pinpointing, and assessment of possible sources of the water quality problems already identified along the Mad River and its tributaries. Based on our analyses and review of these data, we make the following recommendations for updating and upgrading the Friends of the Mad River water quality monitoring program in 2016 and future years.

Parameters

Air Temperature

At several times, we noted that air temperature was measured as part of the water quality monitoring program. However, none of these data were entered into the electronic databases that were provided to the author. Because air temperatures vary greatly from hour to hour, day to day, season to season, and year to year and because they are less "connected" to most measures of water quality, the value of these data for understanding or protecting and improving water quality conditions is minimal. Thus, we recommend discontinuing to measure air temperature as part of the Friends of the Mad River water quality monitoring program.

Water Temperature

Water temperature data were collected during 1988-2014 (and presumably in 2015 as well). Like air temperatures, water temperatures vary daily, seasonally, annually, in response to precipitation and other weather events, and among sites depending on elevation, stream size, stream type, vegetative cover, groundwater inputs, and a host of other factors. Although there are better methods for recording water temperatures over the long term (e.g. water temperature data loggers that provide continuous, long-term records), these instantaneous measures of water temperatures may be useful for understanding the dynamics of certain other water quality parameters (e.g. fecal coliform and *E. coli* counts). Thus, we recommend continuing to measure water temperatures any time and place that fecal coliform and/or *E. coli* samples are collected.

pH

pH is an important measure of water chemistry, as pH determines the solubility, biological availability, and toxicity of nutrients (e.g. phosphorus and nitrogen) and heavy metals (e.g. lead, copper, and arsenic). However, pH is often relatively stable over time, as it is primarily determined by the underlying bedrock and surficial geology of the region. However, pH is also affected by atmospheric deposition (e.g. "acid rain"). Although the long-term record of pH collected by the Friends of the Mad River during 1988-1995 and 1997-2005 (and apparently also during 2006-2015) provides a valuable record of improvements in air quality and reductions in acid deposition in the northeastern United States, these data are less compelling in terms of protecting and improving water quality and freshwater habitats, and they are also more difficult to collect due to the need to calibrate the field equipment. Thus, we recommend discontinuing to measure pH as part of the Friends of the Mad River water quality monitoring program.

Total Phosphorus

Total phosphorus was measured as part of the LaRosa Partnership Program during 2006-2015 and in-house by the Friends of the Mad River on three dates during 1993. Total phosphorus is generally the limiting nutrient in northern freshwater ecosystems and also an important measure of water quality conditions. Because total phosphorus can be more precisely and accurately measured by the LaRosa Analytical Laboratory, we recommend that any future phosphorus measurements be collected through the LaRosa Partnership Program, rather than being measured in-house by the Friends of the Mad River. We do, however, recommend altering the sites sampled for total phosphorus, so that these data can be used to better pinpoint and assess possible sources of nutrients and *E. coli* contamination.

Total Nitrogen

Although typically not the limiting nutrient in northern freshwater ecosystems, high levels of nitrogen can impact both in-lake and in-stream water quality and can exacerbate algal blooms and eutrophication and lead to more frequent and more toxic cyanobacterial blooms. Total nitrogen measures the concentration of all forms of nitrogen in the water column, including nitrogen gas (N_2), nitrite (NO_2), nitrate (NO_3), ammonia (NH_3), ammonium (NH_4), and particulate nitrogen (N). In Vermont, most nitrogen in surface waters originates from wastewater, stormwater, agricultural runoff, and atmospheric deposition. Total nitrogen is a valuable indicator of certain water quality problems, especially those caused by fecal matter (e.g. wastewater effluent, failed septic systems, and manure), and an important nutrient supporting growth of fecal coliform bacteria, including *E. coli*. Thus, we recommend measuring total nitrogen at all sites sampled through the LaRosa Partnership Program in order to better pinpoint and identify possible sources of water quality problems, especially those that may have agricultural or wastewater sources.

Turbidity

Like total phosphorus, turbidity was measured as part of the LaRosa Partnership Program during 2006-2015 but also in-house by the Friends of the Mad River for a short period of time during 1988-1990. Like total phosphorus and total nitrogen, turbidity is an important measure of water quality conditions. Because turbidity can be more precisely and accurately measured by the LaRosa Analytical Laboratory, we recommend that any future turbidity measurements be collected through the LaRosa Partnership Program, rather than being measured in-house by the Friends of the Mad River. We do, however, recommend altering the sites sampled for turbidity, so that these data can be used to better pinpoint and assess possible sources of nutrients and *E. coli* contamination.

Fecal Coliform Bacteria

Fecal coliform are a generic group of bacteria that include both pathogenic and harmless taxa. Fecal coliform bacteria are routinely counted as part of the protocol for measuring *E. coli*. In the Mad River watershed, fecal coliform were measured during two time periods (1985-1991 and 2002-2005) and were likely counted in all of the intervening years, although those data were not entered into the electronic databases provided to the author. Because fecal coliform are routinely counted as part of the *E. coli* sampling, we recommend continuing to count fecal coliform bacteria any time and any place that *E. coli* are measured. In addition, because the fecal coliform data represent the longest record of water quality data collected by the Friends of the Mad River, all of the data from the intervening years should be entered into and made available in the electronic databases.

Escherichia coli

Escherichia coli (*E. coli*) were measured as part of the LaRosa Partnership Program during six years (2006-2011) but also were measured in-house every year during 1992-2015 (24 years) by the Friends of the Mad River. The *E. coli* data provide valuable information that is useful for both protecting public health, especially in areas used for swimming and other recreational activities, and the health of the Mad River ecosystem. Because the in-house protocols used by the Friends of the Mad River to count *E. coli* are widely used and provide precise and accurate counts of *E. coli*, there is no need to sample *E. coli* as part of the LaRosa Partnership Program, except perhaps occasionally as a second set of quality assurance tests for the data collected in-house by the Friends of the Mad River (even then, the Friends of the Mad River should incorporate quality assurance methods, including both field blanks and field duplicates, into their own in-house analyses of *E. coli*). Because of their importance for public health and their value for educating the public about water quality issues, we recommend continuing to measure *E. coli* in those areas regularly used for swimming and other recreational activities. In contrast, those sites located in areas not used for swimming or other recreational activities could be dropped from future sampling efforts. We do, however, recommend that quality assurance procedures (e.g. field blanks and field duplicates like those collected for the parameters analyzed through the LaRosa Partnership Program) be incorporated into future in-house *E. coli* sampling efforts.

Sample Sites

Based on our analyses of the water quality data and discussions with various stakeholders, we recommend a number of changes to the sites sampled by the Friends of the Mad River in 2016 and future years (Table 11, Figure 44):

1) Due to the high *E. coli* and turbidity levels measured there historically, we recommend sampling total phosphorus, total nitrogen, and turbidity to better pinpoint and assess possible source(s) of the high turbidity and *E. coli* levels at five sites along the downstream reaches of the main stem of the Mad River.
2) Due to the high phosphorus and *E. coli* levels measured along High Bridge Brook previously, we recommend retaining the one site and adding three new sites on the three major branches of this tributary to better pinpoint and assess possible source(s) of these high phosphorus and *E. coli* levels.
3) Due to the high *E. coli* levels measured along Folsom Brook previously, we recommend retaining the one site and adding two new sites on the two major branches of this tributary to better pinpoint and assess possible source(s) of these high *E. coli* levels.
4) Due to the higher *E. coli* levels measured along Welder Brook, especially in recent years, we recommend retaining the one site and adding one new site further upstream to better pinpoint and assess possible source(s) of these high *E. coli* levels.
5) Due to the high turbidity levels measured along Clay Brook historically, we recommend retaining the three sites and adding one new site in the middle reach of this tributary to better pinpoint and assess possible source(s) of these high turbidity levels. The ideal location would be immediately upstream of any clay deposits that occur in this section of Clay Brook.
6) Based on stakeholder concerns about runoff from the parking lots at the ski area, we recommend retaining the four sites to further identify and assess possible water quality problems in the Mill Brook watershed.
7) Due to their importance for public health and their educational value, we recommend continuing to monitor *E. coli* levels at twelve sites that are popular for recreation or that otherwise are publicly accessible along the main stem and tributaries of the Mad River.

In summary, we recommend 1) sampling only total phosphorus, total nitrogen, and turbidity through the LaRosa Partnership Program at 20 sites where high *E. coli*, phosphorus, and turbidity levels were measured previously along the main stem of the Mad River and Folsom, High Bridge, Chase, Mill, Clay, and Rice Brooks; 2) sampling only *E. coli* and water temperature in-house for the ten sites located at swimming areas along the main stem of the Mad River and Freeman and Lincoln Brooks; and 3) sampling all five parameters (*E. coli*, water temperature, total phosphorus, total nitrogen, and turbidity) at two sites located at swimming areas where high *E. coli*, turbidity, and/or phosphorus levels were measured previously (Table 11, Figure 44). It should be noted that not all of the sites need to be sampled in the first year. However, if staggering these recommendations over multiple years, it is imperative that all of the sites along a single tributary (e.g. the exploratory sites along Mill Brook) be sampled in the same year in order to most effectively pinpoint and assess possible sources of water quality problems. Depending on the results of the 2016 sampling, these sample sites might be further modified in future years to best accomplish the twin goals of monitoring water quality conditions and pinpointing and assessing possible nutrient and sediment sources. Finally, these 32 sites include 13 sites that have been sampled every year during 1985-2015. Maintaining these 13 sites would maintain the long-term record of the Friends of the Mad River water quality monitoring program.

Finally, we recommend not continuing to sample the outlet stream of Blueberry Lake (Site #BBL) as part these water quality monitoring programs, because sampling the water flowing in the outlet stream is not a very accurate or meaningful measure of water quality in the lake itself. If the Friends of the Mad River is interested in monitoring water quality conditions in the lake itself, then we recommend enrolling Blueberry Lake in the Lay Monitoring Program administered by the Vermont DEC. Participating in this program would provide valuable data on water quality conditions in the lake, including chlorophyll-*a* (a measure of primary productivity), total phosphorus, and Secchi disk transparency. Unfortunately, the Lay Monitoring Program does not measure fecal coliform or *E. coli* bacteria as part of their assessments, so, if these data are useful and meaningful in a lake setting, then the Friends of the Mad River could start sampling *E. coli* in the open waters of the lake while collecting water samples for the Lay Monitoring Program. Staff from the Vermont DEC have already collected nine years of Secchi depth and spring phosphorus data from Blueberry Lake during 1985-2011.

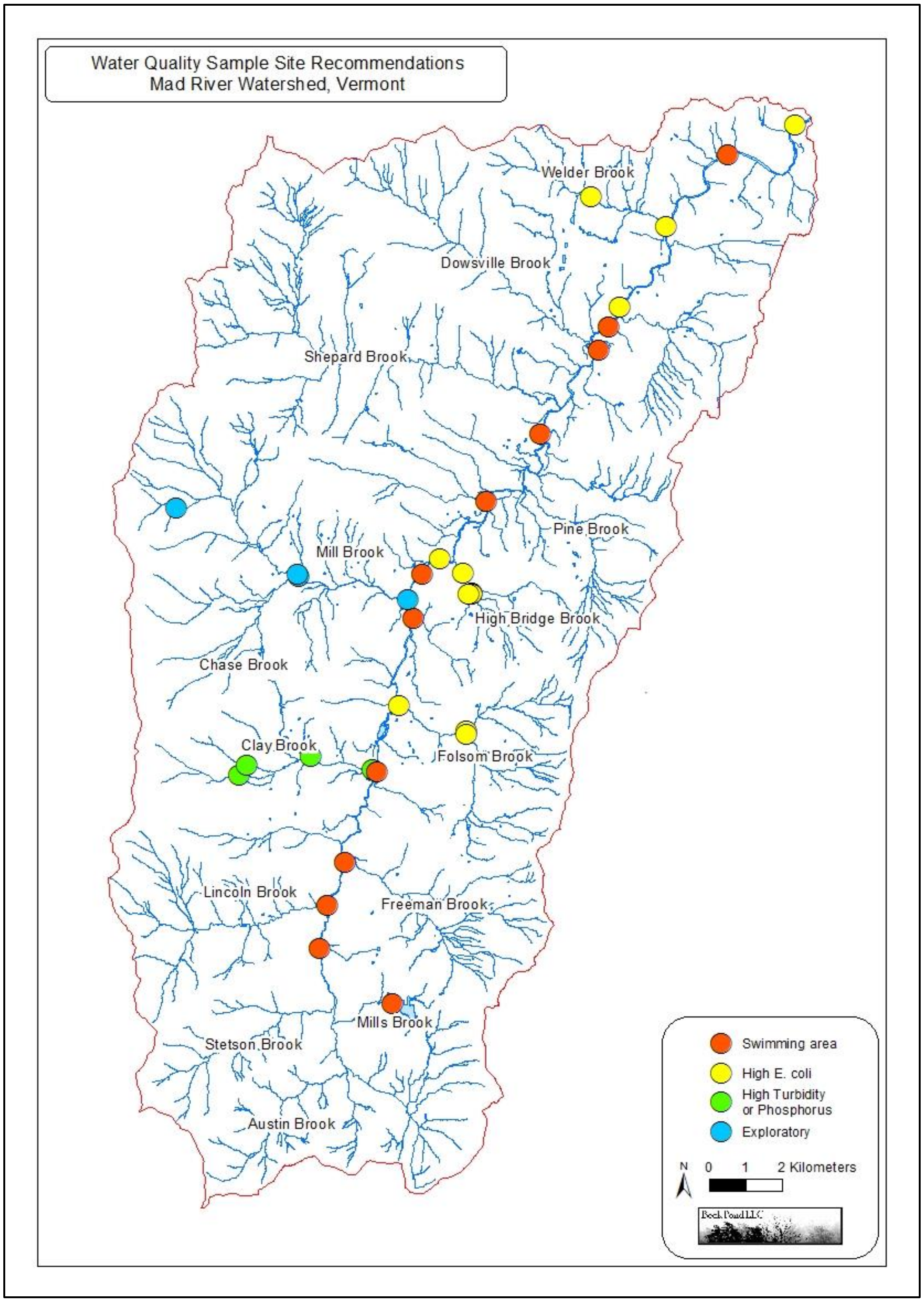


Figure 44. Locations of 32 sites recommended for water quality sampling by the Friends of the Mad River in 2016. Ten of the twelve sites designated as swimming areas would be sampled for *E. coli* and water temperature; the 20 sites designated as high *E. coli*, high turbidity, high phosphorus, or exploratory would be sampled for total phosphorus, total nitrogen, and turbidity; and the two other sites designated as swimming areas would be sampled for all five parameters.

Table 11. List of 32 sites recommended for water quality sampling by the Friends of the Mad River in 2016. The 13 sites highlighted in bold have been sampled every year during 1985-2015 and would maintain the long-term value of the Friends of the Mad River water quality monitoring program.

Site #	Site Name	Rationale	*E. coli*	TP, TN & Turbidity
1	Warren Falls	Swimming	X	-
2	**Bobbin Mill**	**Swimming**	**X**	**-**
4	**Warren Store**	**Swimming**	**X**	**-**
7	**Riverside Park**	**Swimming**	**X**	**-**
8	**Clay Brook**	**High turbidity**	**-**	**X**
10	**Folsom Brook**	**High *E. coli***	**-**	**X**
11	**Rice Brook**	**High turbidity**	**-**	**X**
12	Clay Brook	High turbidity	-	X
16	Chase Brook	Exploratory	-	X
17	Mill Brook German Flats	Exploratory	-	X
17.1	Mill Brook West	Exploratory	-	X
18.1	Mill Brook Mouth	Exploratory	-	X
19	**Lareau Swimhole**	**Swimming**	**X**	**-**
19.2	Couples Club	Swimming	X	-
20	**Waitsfield Covered Bridge**	**High *E. coli*, high turbidity, and swimming**	**X**	**X**
20.1	High Bridge Brook	High *E. coli* and high phosphorus	-	X
21.5	Tremblay Road	Swimming	X	-
23	**Meadow Road Bridge**	**Swimming**	**X**	**-**
26	**North Road**	**High *E. coli* and swimming**	**X**	**X**
27	**Moretown Village**	**High *E. coli* and swimming**	**X**	**X**
28	**Moretown**	**High *E. coli* and high turbidity**	**-**	**X**
28.05	Welder Brook	High *E. coli*	-	X
29	**Ward's Access**	**Swimming**	**X**	**-**
31	Lover's Lane Bridge	High *E. coli*	-	X
0	(New site Blueberry Lake)	Swimming	X	-
0	(New site Clay Brook)	High turbidity	-	X
0	(New site Folsom Brook)	High *E. coli*	-	X
0	(New site Folsom Brook)	High *E. coli*	-	X
0	(New site High Bridge Brook)	High *E. coli* and high phosphorus	-	X
0	(New site High Bridge Brook)	High *E. coli* and high phosphorus	-	X
0	(New site High Bridge Brook)	High *E. coli* and high phosphorus	-	X
0	(New site Welder Brook)	High *E. coli*	-	X

Sampling Schedule

Sampling across a range of stream flows, including rain events and/or high flows, is essential for understanding nutrient and sediment dynamics and possible sources of nutrients and *E. coli* contamination. Because past sampling efforts have adequately sampled a broad range of stream flows, we recommend retaining the current sampling schedule of six sample dates every two weeks during June-August. However, if none of the dates in any one year sample high flows or rain events, then we suggest adding one or two sample rounds to target rain events or high flows to gain the data needed to better understand nutrient and sediment dynamics and *E. coli* contamination. If there is interest, the Friends of the Mad River could also consider sampling earlier in the spring to catch the high flows associated with spring snowmelt and later in the autumn to catch the seasonal rise in water levels as evaporation and transpiration rates decrease. However, as long as the regular sampling schedule continues to capture high-flow and rain events, such an extended season is not essential.

Summary

Based on our analyses of the water quality data collected by the Friends of the Mad River during 1985-2015, we make the following recommendations for maintaining and enhancing the water quality monitoring program undertaken by the Friends of the Mad River:

1) Using the in-house methods, continue to measure *E. coli* levels in those areas where the Mad River is considered impaired or stressed by high *E. coli* levels (e.g. the main stem from Moretown village downstream to the mouth of the Mad River and Welder, High Bridge, and Folsom Brooks) and other sites regularly used for swimming and other recreational activities.

2) Incorporate quality assurance tests, including both field blanks and field duplicates, into future in-house *E. coli* sampling efforts.

3) Continue to measure fecal coliform bacteria and water temperature any place and any time that *E. coli* samples are collected.

4) Continue to measure total phosphorus and turbidity through the LaRosa Partnership Program, but modify the sample sites to better pinpoint and assess possible sources of nutrients and *E. coli* contamination, especially in areas where high levels of *E. coli*, turbidity, and/or total phosphorus have been detected previously (e.g. the main stem from Moretown village downstream to the mouth of the Mad River and Welder, High Bridge, Mill, Clay, and Folsom Brooks).

5) Begin measuring total nitrogen at all sites sampled through the LaRosa Partnership Program to better identify and assess possible sources of nutrients and *E. coli* contamination, especially in areas where high levels of *E. coli* and/or total phosphorus have been detected previously.

6) Discontinue measuring air temperature and pH as part of these monitoring efforts.
7) Retain the current sampling schedule (six dates every two weeks during June-August), unless none of the dates sample high-flow or rain events, in which case, consider targeting one or two rain events or high flows.
8) Enroll Blueberry Lake in the Lay Monitoring Program administered by the Vermont DEC as a better approach for assessing water quality in the lake, rather than in the outlet stream.

Documentation and Data Entry

This study was challenged by three unanticipated problems that made this study more difficult and less complete than desired. First, given the long-term nature of these monitoring programs, it is essential that the methods used to collect, process, and analyze the water samples be completely and thoroughly documented and available to those analyzing or reporting these data. Unfortunately, the documentation that was provided to the author of this study was not always complete. Second, all of the quality assurance data for all of the parameters, both those measured in-house and those measured in through the LaRosa Partnership Program, should be collected and entered into the same databases used to house all of the other data. Having these data would have allowed us to conduct additional quality assurance checks (e.g. field blanks and field duplicates) to ensure that the *E. coli* data were being collected in a repeatable manner and without contamination. Finally, through the process of compiling, analyzing, and reporting these data, we learned that additional data had been collected but had not been entered into the electronic databases. These data are only useful if they are made available for analysis. Having these data would have allowed us to establish and analyze longer records for water temperature [one additional year (2015)], pH [ten additional years (2006-2015)], and fecal coliform bacteria [20 additional years (1992-2001 and 2006-2015)]. Thus, we strongly recommend that all data, including those collected in prior years, be entered into and housed in the electronic databases, so that they can be analyzed along with the existing data in the future. These data and the long-term record that they provide of water quality conditions in the Mad River watershed are exceptional and should be well-documented, quality assured, and readily available for analysis and reporting.

Nutrient Loading

During 1985-2015, the Friends of the Mad River have not collected the water quality data needed to calculate nutrient and sediment loads. Estimating nutrient and sediment loads would allow us to quantify the total amounts of nutrients and sediment entering or being exported from the Mad River, and these estimates might be useful for developing strategies for protecting and improving water quality in the Mad River and downstream surface waters. However, calculating nutrient and sediment loads is not a trivial task and should only be undertaken if the rationale justifies the complexities involved.

Calculating nutrient and sediment loads is not a trivial task. To calculate nutrient and/or sediment loads, many more samples would need to be collected, especially at high flows, when the majority of the nutrient and sediment loading typically occurs. For example, in the Lake Memphremagog Basin, the Watershed Coordinator has calculated phosphorus loads for only four sites, but, to do this, he has had to collect as many as 30 samples per year, primarily at high flows. In the larger rivers (such as the Mad River), samples must be collected with a bomb sampler or some other tool that integrates water samples collected throughout the water column. In smaller streams (e.g. most of the tributaries of the Mad River), such samples could probably be collected using a dip sampler. Given that sampling high flows is essential for accurately estimating loads, safety is an important concern and likely would preclude wading into streams to collect water samples in all but the smallest streams. In addition, stream flows need to be measured or estimated for each site where loads will be calculated. Ideally, measuring stream flows requires a lot of effort and special equipment (e.g. a flow tracker, a sonde or some tool for continuously measuring water depths) and would ideally be done continuously throughout the season(s) in which the nutrient and sediment samples were collected. Alternatively, stream flows could be estimated based on watershed size from the stream flows measured at the existing gage on the main stem of the Mad River, but such estimates would only be approximate and may not accurately measure stream flows at the individual sites.

Given these considerations, a second, more general question also needs to be raised: What would the Friends of the Mad River gain by calculating nutrient and/or sediment loads for one or more sites in the Mad River watershed? Given that water quality is generally good in most areas of the Mad River watershed, it is not clear that calculating loads is necessary or particularly useful for successfully accomplishing the Friends of the Mad River's goal of "protecting, improving and enhancing the ecological, recreational, and community values of the Mad River and its watershed". Although calculating nutrient and sediment loads would identify which tributaries or sections of the main stem are exporting the largest amounts of nutrients and/or sediments, this information is likely already available based on the existing data on nutrient concentrations and turbidity levels and the staff's and volunteers' observations and knowledge of the watershed. Although there certainly is interest in understanding the nutrient and sediment loads entering Lake Champlain, of which the Mad River is one distant tributary, the Mad River is likely to be a relatively low priority for calculating nutrient and sediment loads given the relatively low nutrient concentrations and turbidity levels there. In addition, calculating nutrient and sediment loads for the Mad River would really only make sense as part of a larger effort to calculate loads emanating from the other tributaries of the Winooski River and/or other tributaries of Lake Champlain.

In conclusion, we do not recommend undertaking such a project unless there are clear and concrete reasons for calculating nutrient and sediment loads for the Mad River and its tributaries. Such an effort would face significant challenges, would require considerable effort, and would only be justified if a clear rationale could be articulated clearly and in light of the considerable challenges and complexities involved.

Conclusions

The water quality data collected by the Friends of the Mad River during 1985-2015 represent an outstanding, long-term record of water quality conditions in the Mad River watershed. This effort is perhaps unparalleled in the state of Vermont, especially in terms of the length of the record (31 years) and the consistent and repeated sampling of the same sites throughout this time period. This report provides an overview of the Friends of the Mad River water quality monitoring program, presents the results of the analyses of the biological and chemistry data collected through this program, identifies several areas and issues of concern, and provides recommendations for future monitoring efforts. Based on these data and analyses, it is clear that water quality conditions in the Mad River and its tributaries are generally very good, the major exception being some areas along the lower section of the main stem and several tributaries that exhibited elevated *E. coli* levels, turbidity levels, and/or total phosphorus concentrations.

During 1985-2015, staff and volunteers from the Friends of the Mad River used portable field equipment, an in-house laboratory, and a partnership with the LaRosa Analytical Laboratory to quantify various physical, chemical, and biological parameters at 57 sites along the Mad River and its tributaries. Based on the data obtained, we can make the following conclusions about water quality conditions in the Mad River watershed:

- The quality assurance and stream flow data indicated that the water quality data were generally collected in a repeatable manner, without contamination, and across a broad but fairly consistent range of stream flows.
- pH, which measures the acidity or alkalinity of water, was generally neutral (mean = 6.7-7.2) at the 51 sites sampled during 1988-1995 and 1997-2005, including those along the main stem and the tributaries. Because pH is largely influenced by the underlying bedrock and surficial geology, pH levels showed no pronounced relationships with stream flow, but they did show an almost universal pattern of change over time. That is, pH levels decreased at all sites in the years prior to 1995 but, after 1995, increased markedly at all sites, presumably due to improvements in air quality and decreased acid deposition following implementation of the Clean Air Act and its amendments starting in the mid-1990s.
- Total phosphorus, which measures the concentration of all forms of phosphorus in the water column, is an important measure of nutrient levels in rivers and streams. Total phosphorus concentrations were remarkably low across almost all of the 19 sites sampled during 2006-2015. The only areas of concern were along two tributaries (High Bridge Brook and Folsom Brook) and the main stem in the vicinity of Moretown village. At two of these three sites, total phosphorus concentrations have increased over time, and the positive relationships with stream flow suggested that much of the phosphorus at these two sites may be originating from nonpoint sources, such as surface runoff from agricultural and other land uses, such as unpaved roads.

- Turbidity levels, which measure the clarity of the water, were also remarkably low across the 19 sites sampled during 2006-2015. Turbidity levels were slightly higher at two sites located along the main stem near the villages of Moretown and Waitsfield, especially during the two most recent years of this study (2014-2015). At a third site along High Bridge Brook, turbidity levels were also slightly higher than elsewhere, and, there, the turbidity levels have increased markedly, especially during the past five years. Like total phosphorus, turbidity levels at this site increased with increasing stream flows, and this positive relationship again suggested that nonpoint sources, such as surface runoff from agricultural and other land uses, including unpaved roads, may be impacting water quality.
- Fecal coliform bacteria and *Escherichia coli* (*E. coli*), which is one type of fecal coliform bacteria, are valuable indicators of the health and safety of surface waters, especially in areas highly prized for recreational uses such as swimming. Both fecal coliform and *E. coli* counts were very high at a number of sites along the lower section of the main stem as well as along several tributaries. Fecal coliform and *E. coli* counts increased consistently from upstream to downstream areas along the main stem and were markedly higher from the village of Waitsfield downstream to the mouth of the Mad River. At two sites (one along the main stem and one along Welder Brook), *E. coli* counts also showed marked increases, especially during the last five years. The positive relationship between *E. coli* and stream flow at these sites suggested that the source(s) of the *E. coli* may be related to stormwater runoff, especially from areas contaminated by manure, leakage or overflows of septic systems, and wastewater.

Collectively, these data greatly increased our understanding of water quality problems in the Mad River watershed. In general, water quality conditions in the Mad River and its tributaries were very good to excellent; however, a few areas exhibited total phosphorus concentrations and turbidity and *E. coli* levels that were higher than desirable (Table 12). In order to maintain this outstanding long-term data set and to further pinpoint and assess the sources of these water quality problems, we recommend that future monitoring efforts include: 1) continued monitoring of *E. coli* and fecal coliform bacteria at selected sites along the main stem and several tributaries, especially sites that are popular for swimming; 2) the addition of new sample sites in areas where water quality problems were identified but were not completely understood (e.g. High Bridge Brook, Folsom Brook, and lower reaches of the main stem); and 3) sampling total nitrogen, especially in areas where water quality problems may have agricultural or wastewater sources. Once these water quality problems are better understood, it will be easier to identify and develop the appropriate protection and restoration strategies that will most effectively protect and improve water quality throughout the Mad River watershed.

Table 12. Priority locations for future monitoring and project implementation in the Mad River watershed of Vermont.

River/Stream	Concern(s)	Needs and Opportunities
Mad River (mouth upstream to village of Waitsfield)	High *E. coli* High turbidity	Likely originating from stormwater runoff, especially from areas contaminated by manure, leakage or overflows of septic systems, and wastewater
Folsom Brook (upstream of Vermont route 100)	High *E. coli* High phosphorus	May be originating from stormwater runoff - especially from areas contaminated by manure, leakage or overflows of septic systems, and wastewater nonpoint sources - and surface runoff from agricultural and other land uses, such as unpaved roads
High Bridge Brook (upstream of Joslin Hill Road)	High *E. coli* High phosphorus High turbidity	May be originating from stormwater runoff - especially from areas contaminated by manure, leakage or overflows of septic systems, and wastewater nonpoint sources - and surface runoff from agricultural and other land uses, such as unpaved roads
Welder Brook (upstream of Vermont route 100B)	High *E. coli*	May be originating from stormwater runoff, especially from areas contaminated by manure, leakage or overflows of septic systems, and wastewater
Clay and Rice Brooks (upstream of Vermont route 100)	High turbidity	May have a natural source (e.g. clay deposits in streambed) or an anthropogenic source (e.g. runoff from parking lots and other infrastructure at ski area)

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Appendix A. 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 a 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).

Geometric mean – A number describing the central tendency of a group of numbers and obtained by calculating the nth root of the product of all of their values (where the nth root is defined by the number of values in the group).

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. 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.

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.

Appendix B. Geographic coordinates of the 57 sites sampled by the Friends of the Mad River during 1985-2015. Note that the geographic coordinates for a number of sites are unknown.

Site #	River/Stream	Site Name	Vermont LocationID	Latitude	Longitude
1	Mad River	Warren Falls	501042	44.09274	-72.86403
2	Lincoln Brook	Bobbin Mill	501048	44.10345	-72.86162
3	Mad River	Warren Covered Bridge	-	44.11096	-72.85706
4	Freeman Brook	Warren Store	501057	44.11431	-72.85576
4.5	Freeman Brook	Freeman Brook	-	44.11258	-72.85046
5	Mad River	Warren Village North	-	44.11633	-72.85698
6	Bradley Brook	Bradley Brook	501058	44.11969	-72.85831
6.5	Mad River	-	-	44.12509	-72.85222
7	Mad River	Riverside Park	-	44.13654	-72.84463
8	Clay Brook	Clay Brook	501059	44.13707	-72.84629
8.5	Mad River	-	-	-	-
9	Mad River	-	501060	44.14880	-72.84231
10	Folsom Brook	Folsom Brook	501043	44.15309	-72.83708
10.1	-	-	-	-	-
10.2	-	-	-	-	-
10.3	-	-	-	-	-
10.4	-	-	-	-	-
10.5	Folsom Brook	-	-	-	-
10.6	Folsom Brook	Folsom Brook	-	44.15029	-72.81016
10.7	Folsom Brook	-	-	-	-
11	Rice Brook	Rice Brook	501044	44.13801	-72.88966
12	Clay Brook	Clay Brook	501045	44.13554	-72.89195
13	Slide Brook	-	502076	44.16668	-72.88716
13.1	Slide Brook	Slide Brook	-	44.17842	-72.88359
14	Lockwood Brook	-	-	44.17243	-72.88908
15	-	-	-	-	-
16	Chase Brook	Chase Brook	501046	44.18498	-72.87213
17	Mill Brook	Mill Brook German Flats	-	44.18549	-72.87235
17.1	Mill Brook	Mill Brook West	-	44.20161	-72.9144
18	Mill Brook	-	-	44.18147	-72.84340
18.1	Mill Brook	Mill Brook Mouth	501047	44.17917	-72.83432
19	Mad River	Lareau Swimhole	-	44.17454	-72.83243
19.1	Mad River	-	-	44.18030	-72.83395
19.2	Mad River	Couples Club	-	44.18562	-72.82939
19.5	-	-	-	-	-

Site #	River/Stream	Site Name	Vermont LocationID	Latitude	Longitude
20	Mad River	Waitsfield Covered Bridge	501049	44.18933	-72.82356
20.1	High Bridge Brook	High Bridge Brook	501050	44.18595	-72.81542
21	Mad River	Waitsfield Elem. School	502055	44.19388	-72.81777
21.5	Mad River	Tremblay Road	-	44.20375	-72.80733
22	Pine Brook	Pine Brook	501051	44.20584	-72.79214
23	Mad River	Meadow Road Bridge	-	44.22027	-72.78903
24	Shepard Brook	Shepard Brook	501052	44.22886	-72.78409
25	Dowsville Brook	Dowsville Brook	501053	44.24386	-72.77489
25.1	-	-	-	-	-
26	Mad River	North Road	-	44.24116	-72.76900
27	Mad River	Moretown Village	-	44.24693	-72.7654
27.1	Doctors Brook	Doctor's Brook	-	44.24983	-72.76200
28	Mad River	Moretown	501054	44.25173	-72.76165
28.05	Welder Brook	Welder Brook	501055	44.27186	-72.74608
28.1	Unnamed Tributary	-	-	-	-
28.2	Unnamed Tributary	-	-	-	-
28.3	Unnamed Tributary	-	-	-	-
28.4	Mad River	-	-	-	-
29	Mad River	Ward's Access	-	44.28976	-72.72457
30	Mad River	-	-	-	-
31	Mad River	Lover's Lane Bridge	501056	44.29700	-72.70133
BBL	Blueberry Lake	Blueberry Lake	-	44.07929	-72.83891

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