Waterbury, Vermont
Middle Winooski River Corridor Plan

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1.0 EXECUTIVE SUMMARY

A stream geomorphic assessment of the Winooski River and tributaries was conducted by Bear Creek Environmental, LLC (BCE) under the direction of Central Vermont Regional Planning Commission and the Vermont Agency of Natural Resources (VANR) during the summer of 2014. Funding for the project was provided through the State of Vermont Ecosystem Restoration Program. A planning strategy based on fluvial geomorphic science (see glossary at end of report for associated definitions) was chosen because it provides a holistic, watershed-scale approach to identifying the stressors on river ecosystem health. The stream geomorphic assessment data can be used by resource managers, community watershed groups, municipalities and others to identify how changes to land-use alter the physical processes and habitat of rivers.

The Town and Village of Waterbury experienced major flooding in August 2011 and subsequent damage to infrastructure as a result of Tropical Storm Irene (TSI). As part of the long term plan to mitigate the impact of flooding, improve aquatic habitat, and increase river stability, Central Vermont Regional Planning Commission secured state funding to complete a Phase 2 stream geomorphic assessment within the mid-Winooski River watershed. The stream geomorphic assessment data will be used to help focus stream restoration and protection activities within the watershed and assist towns with flood resiliency planning.

The study encompassed approximately 31 miles of stream channel within 23 reaches on the Winooski River, the Little River, Graves Brook, Thatcher Brook, and two unnamed tributaries of Thatcher Brook. This stream geomorphic assessment facilitated the identification of major stressors to geomorphic stability and habitat conditions within the study area. The predominant stressor observed within the mid-Winooski watershed is stream channel straightening and corridor encroachment associated with the existence of roads and development. In many cases, this encroachment has limited floodplain access and has caused moderate to extreme channel degradation (lowering of the bed) resulting in sediment build up, channel widening, and planform adjustment (lateral movement). Numerous federal, state, and town highways were historically built into river valleys throughout the watershed, including critical travel routes such as Interstate 89, U.S. Route 2, Vermont Route 100, and the New England Central Railroad. Waterbury Village, a hub of economic and residential activity, lies within the Winooski River and Graves Brook valleys.

Despite the impact that development has had on the mid-Winooski River watershed, its surface waters have proven to be very resilient. Six miles of the study area were assessed in 2010, before Tropical Storm Irene hit Central Vermont, which allowed for a comparison of pre- and post-flood conditions. Major changes in channel dimensions and processes were not observed, suggesting that extremely high flows during Tropical Storm Irene did not drastically change the morphology of these streams like it did in so many other places in Vermont. The mid-Winooski River watershed in Waterbury has many assets that mitigate some of its anthropogenic impacts. Undeveloped floodplains and extensive wetlands in Waterbury Center along Graves Brook, Thatcher Brook, and their tributaries provide tremendous storage of floodwaters and sediment. These areas allow raging floodwaters to disperse energy, drop out sediment, and slow down before reaching Waterbury Village, where development is dense along the banks of Graves Brook. It is of critical importance to protect these floodplains and wetlands upstream to mitigate future flooding and protect people and infrastructure.

Following Tropical Storm Irene, immense recovery efforts were undertaken to repair roads, buildings, and other infrastructure that were damaged by the flooding. Moving forward, it is important for communities to continually prepare for the next flood by taking steps to become more flood resilient. This report outlines several strategies that can be implemented on both site-specific and community-wide levels to mitigate flood damage and losses in the future.

The river corridor planning effort in the mid-Winooski River watershed is a continuous and collaborative process. The stream geomorphic assessment data collected in this study build on other data that have been collected throughout the Winooski River watershed in the past decade. Analysis of these data has aided the identification of major impacts and stressors and the development of projects to mitigate impacts, increase geomorphic stability, and improve aquatic habitat.

A list of 59 potential restoration, conservation, and flood resiliency projects was developed using the stream geomorphic assessment data collected within the study area. The projects fall within four primary categories:

Project Category	Number of Proposed Projects
Floodplain Improvement and Conservation	40
Public Safety Improvement	1
Stream Channel Improvement and Restoration	8
Structure Replacement/ Removal	10
Total Number of Projects	**59**

These projects provide flood resiliency measures to prepare communities for the next flood and strategies to restore riparian and instream habitat. Types of projects include river corridor easements, riparian buffer improvements, berm removals, bridge and culvert replacements, floodplain creation, and many more. Potential projects were prioritized based on several factors, including ease of implementation, cost, landowner interest, effectiveness, and site-specific factors. Further project development, including additional data collection, may be required for project design, permitting, and implementation.

2.0 LOCAL PLANNING PROGRAM OVERVIEW

There are many scientific terms used in this river corridor plan, and the reader is encouraged to refer to the glossary at the end of the document. Important terms that are in the glossary are shown in italics the first time they are used in the text.

2.1 Overview

This project focuses on the Winooski River watershed in the town of Waterbury, Vermont. Small sections of Bolton, Duxbury, Middlesex, and Moretown are also within the study area due to their location along the southern bank of the Winooski River. This study builds upon a smaller assessment conducted in Waterbury in 2010. A total of 6 river miles was assessed in 2010 and 25 river miles in 2014.

The main stem of the Winooski River and several of its *tributaries* were assessed during the summer of 2014 using the Vermont Agency of Natural Resources Phase 2 Stream Geomorphic Assessment protocol. The Winooski River tributaries included in this assessment are the Little River, Graves Brook, Thatcher Brook, and two unnamed tributaries to Thatcher Brook. Included in this report are sections of Graves and Thatcher Brooks that were assessed in 2010.

Phase 2 geomorphic assessments have occurred in numerous areas in the Winooski River watershed within the past decade. Corridor plans for other phase 2 assessment areas in the Winooski River watershed can be found at https://anrweb.vt.gov/DEC/SGA/finalReports.aspx.

The Vermont Rivers Program has developed state-of-the-art Stream Geomorphic Assessment (SGA) protocols that utilize the science of *fluvial geomorphology* (fluvial = water, geo = earth, and morphology = the study of structure or form). Fluvial geomorphology focuses on the processes and pressures operating on river systems. The Vermont protocol includes three phases:

1. Phase 1 – Remote sensing and cursory field assessment;
2. Phase 2 – Rapid habitat and rapid geomorphic assessments to provide field data to characterize the current physical condition of a river; and
3. Phase 3 – Detailed survey information for designing “active” channel management projects.

2.2 River Corridor Planning Team

The river corridor planning team for the mid-Winooski River watershed is comprised of Central Vermont Regional Planning Commission (CVRPC), Bear Creek Environmental (BCE), the Vermont Agency of Natural Resources (VANR), and the Town of Waterbury. The 2014 study was funded through The State of Vermont Ecosystem Restoration Program under contract to Central Vermont Regional Planning Commission. Gretchen Alexander from the Vermont River Management Program of VANR provided a quality control/assurance review of the stream geomorphic assessment data, and the Central Vermont Regional Planning Commission assisted with the field work and provided the overall project coordination.

2.3 Local Project Objectives

The stream geomorphic assessment data are useful to resource managers, community watershed groups, municipalities and others for identifying how changes to land-use alter the physical processes and *habitat* of rivers. Characterizing stream type, identifying stressors in the watershed, and assessing the health of aquatic habitat and the riparian corridor are essential for the preparation of an effective and long-term river corridor plan. Central Vermont Regional Planning Commission and project partners, in collaboration with towns and other organizations, have the opportunity to address and mitigate major watershed stressors through the design and implementation of *restoration* and protection projects outlined in this corridor plan.

The Water Quality Management Plan (WQMP) for Basin 8 (Winooski River) outlines several strategies to restore and protect all surface waters within the Winooski River watershed. Goals in the Winooski River basin include improving water quality, protecting habitat, and reducing river-development conflicts. There are numerous reaches within the Mid-Winooski River sub-watershed that have impaired water quality. Specific to the study area, the basin plan identifies that sedimentation is an issue on Graves Brook, which could be coming from development and/or corridor encroachment. On Thatcher Brook, sediment from physical channel instability is an issue. Also, the water withdrawal for the Waterbury Village drinking water supply on Thatcher Brook poses a concern. On the Winooski River mainstem and on the Little River, the alteration of flows by regulation at large hydroelectric dams is identified as a potential stressor (Vermont Agency of Natural Resources, 2012b).

2.4 Goals of the Vermont River Management Program

The State of Vermont's Rivers Program has set out several goals and objectives that are supportive of the local initiative in the Middle Winooski River Watershed. The state management goal is to, "manage toward, protect, and restore the fluvial geomorphic equilibrium condition of Vermont rivers by resolving conflicts between human investments and river dynamics in the most economically and ecologically sustainable manner" (Vermont Agency of Natural Resources, 2009b). The objectives of the Program include *fluvial erosion* hazard mitigation and sediment and nutrient load reduction, as well as aquatic and riparian habitat protection and restoration. The Program seeks to conduct river corridor planning in an effort to remediate the geomorphic instability that is largely responsible for problems in a majority of Vermont's rivers. Additionally, the Vermont River Management Program has set out to provide funding and technical assistance to facilitate an understanding of river instability and the establishment of well-developed and appropriately scaled strategies to protect and restore river equilibrium.

3.0 BACKGROUND WATERSHED INFORMATION

3.1 Geographic Setting

3.1.1 Watershed Description

The Winooski River begins in Cabot, Vermont and flows for approximately 90 miles before entering Lake Champlain in Colchester, Vermont. The river flows southwest out of Cabot toward the city of Montpelier, where it turns northwest and flows toward the lake. It flows through such communities as Waterbury Village, Richmond Village, and Downtown Winooski on its course. The Winooski River drains a total of 1,080 square miles, which is approximately 12% of the area of Vermont (Vermont Agency of Natural Resources, 2012b).

The study area for this phase 2 assessment falls within the boundaries of the Middle Winooski sub-watershed, primarily in the town of Waterbury, Vermont. The sub-watershed is approximately 240 square miles in size and includes such major tributaries as Joiner Brook, the Little River, Graves Brook, Thatcher Brook, Crossett Brook, and Great Brook (Bear Creek Environmental, 2007).

3.1.2 Political Jurisdictions

The Middle Winooski River watershed is located in Chittenden County (towns of Bolton, Essex, Hinesburg, Huntington, Jericho, Richmond, Underhill, and Williston), Washington County (Berlin, Duxbury, Middlesex, Montpelier, Moretown, Waterbury, and Worcester), and Lamoille County (Stowe). The 2014 Phase 2 assessment focused on streams within the towns of Waterbury, Vermont. Short sections of the assessment area are also located in Duxbury, Bolton, Middlesex, and Moretown, Vermont.

3.1.3 Land-Use

A land cover layer (2011) was obtained from the Vermont Center for Geographic Information (VCGI) to present land-use within the Mid-Winooski River watershed for the river corridor plan. The 2011 land cover data indicate that the Mid-Winooski River watershed is 83% forested, 7% agriculture, 1% open water, and 6% developed (Figure 3.2). While forest is the dominant land cover in the watershed, agricultural and developed areas are geographically centered on the Winooski River and its tributaries. Agriculture is particularly abundant in the towns of Williston, Richmond, Waterbury, and Stowe. Development is most common in Essex, Williston, Waterbury, and Middlesex. Interstate 89, U.S. Route 2, and Vermont Route 100 are among the most important travel corridors within the Mid-Winooski River watershed.

3.2 Geologic Setting

The Mid-Winooski River watershed is located in the Northern Green Mountain physiographic region, which is characterized by high elevations, hosting the tallest peaks in the state. Most of the study area lies within the Hazens Notch Formation, the Stowe Formation, and the Fayston Formation, which are all of the Cambrian and Neoproterozoic Eras. The primary bedrock types underlying the Winooski River mainstem within the study area are schist and phyllite, rocks of sedimentary origin that have been modified over time through metamorphic processes. The majority of the tributaries included in this study are underlain by greenstone, which is of metamorphic (volcanic) origin (Bedrock Geologic Map of Vermont, USGS, 2011).

3.3 Geomorphic Setting

A Phase 1 Stream Geomorphic Assessment of the Mid-Winooski River watershed was completed in 2007 by Bear Creek Environmental. During Phase 1, the Mid-Winooski River watershed was broken into 129 *reaches;* each reach represents a similar section of the stream based on physical attributes such as valley confinement, slope, sinuosity, bed material, dominant *bedform*, land-use, and other hydrologic characteristics. A total of 23 reaches were included in this Phase 2 assessment, which equates to 31 river miles (see Figures 3.3 and 3.4). Each point in Figures 3.3 and 3.4 represents the downstream end of the reach.

The Winooski River flows through a very low *gradient* valley overall, with the exception of three reaches, R15, R20, and R33, which have slopes between 1 and 2%. The majority of the main stem has a channel slope of less than 0.5%. Within the study area, the average channel slope for the reaches on the Winooski River varies from 0.1 to 0.23%. The average reach slope of tributaries included in this study varies widely. The Little River has an average reach slope of less than 0.6%; Graves Brook varies from 0.3 to 3%, Thatcher Brook from 0.4 to 3.5%, and the unnamed tributaries to Thatcher Brook range from 2.4% to 6.4%.

3.4 Flood Mitigation Study

In 2013, the Lake Champlain Basin Program funded a study aimed at evaluating the costs and benefits of floodplain protection activities in Waterbury, Vermont and Willsboro, New York. The study, which was completed over the course of nearly two years, involved significant hydraulic modeling, including flood damage simulations and flood risk reduction modeling. The report details several scenarios that were evaluated to mitigate flooding in Waterbury Village. These included floodplain creation at several locations in Waterbury and recommendations pertaining to future development in the Village. The report can be accessed at the following link:
http://www.floods.org/ace-files/documentlibrary/committees/78_CostsBenefitsFloodplains.pdf

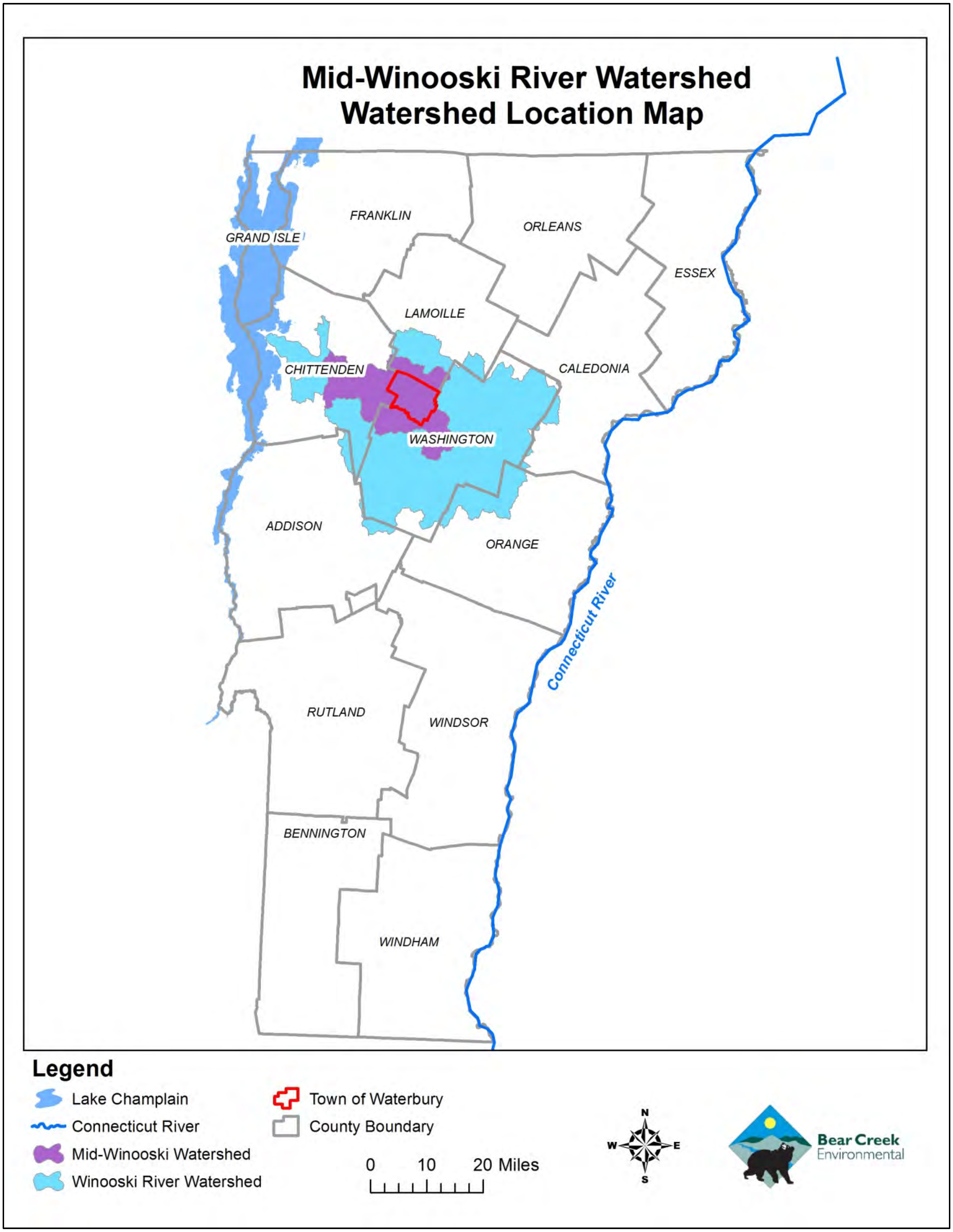


Figure 3.1. Watershed Location Map for the Mid-Winooski River watershed.

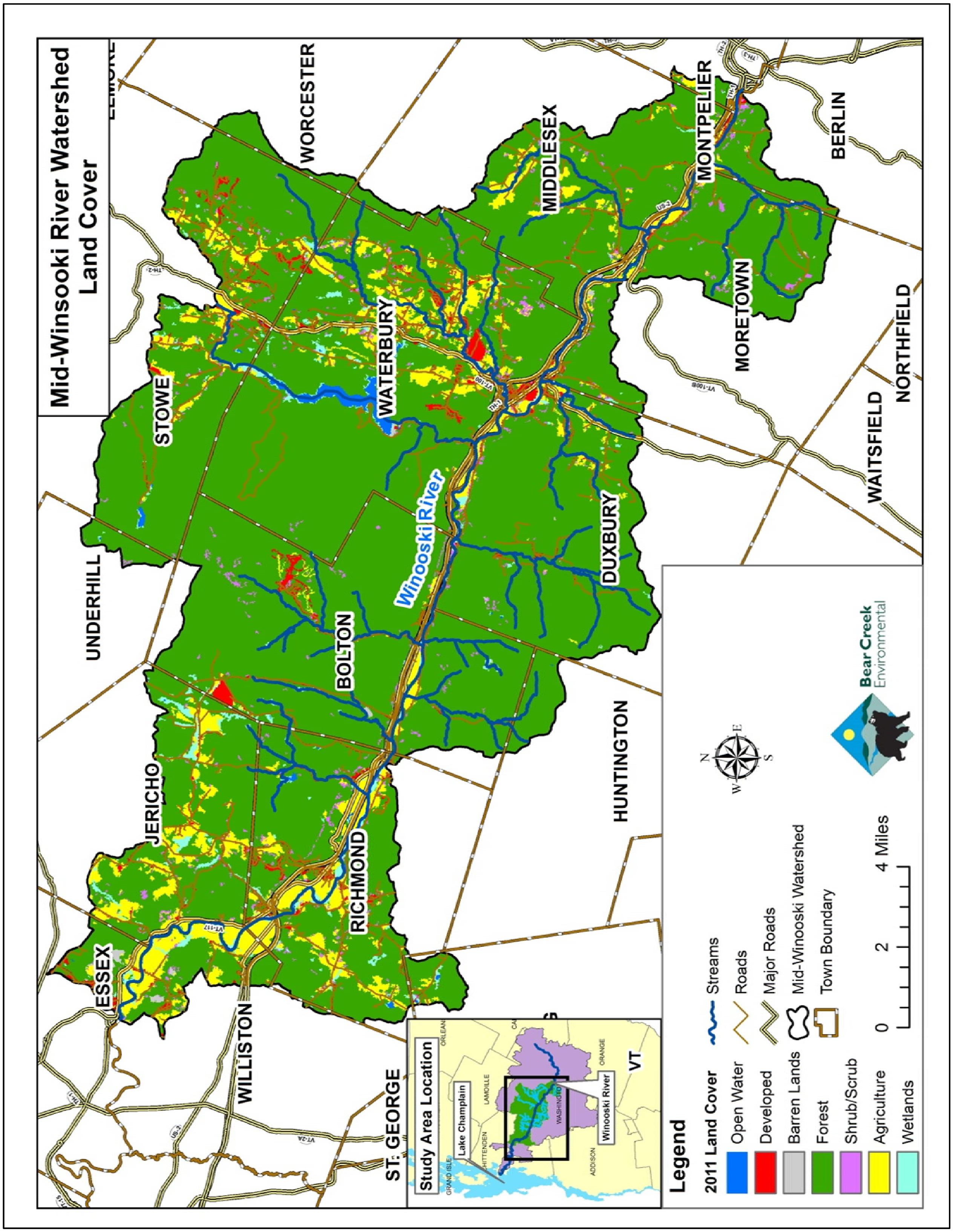


Figure 3.2. Land Cover Map for the Mid-Winooski watershed.

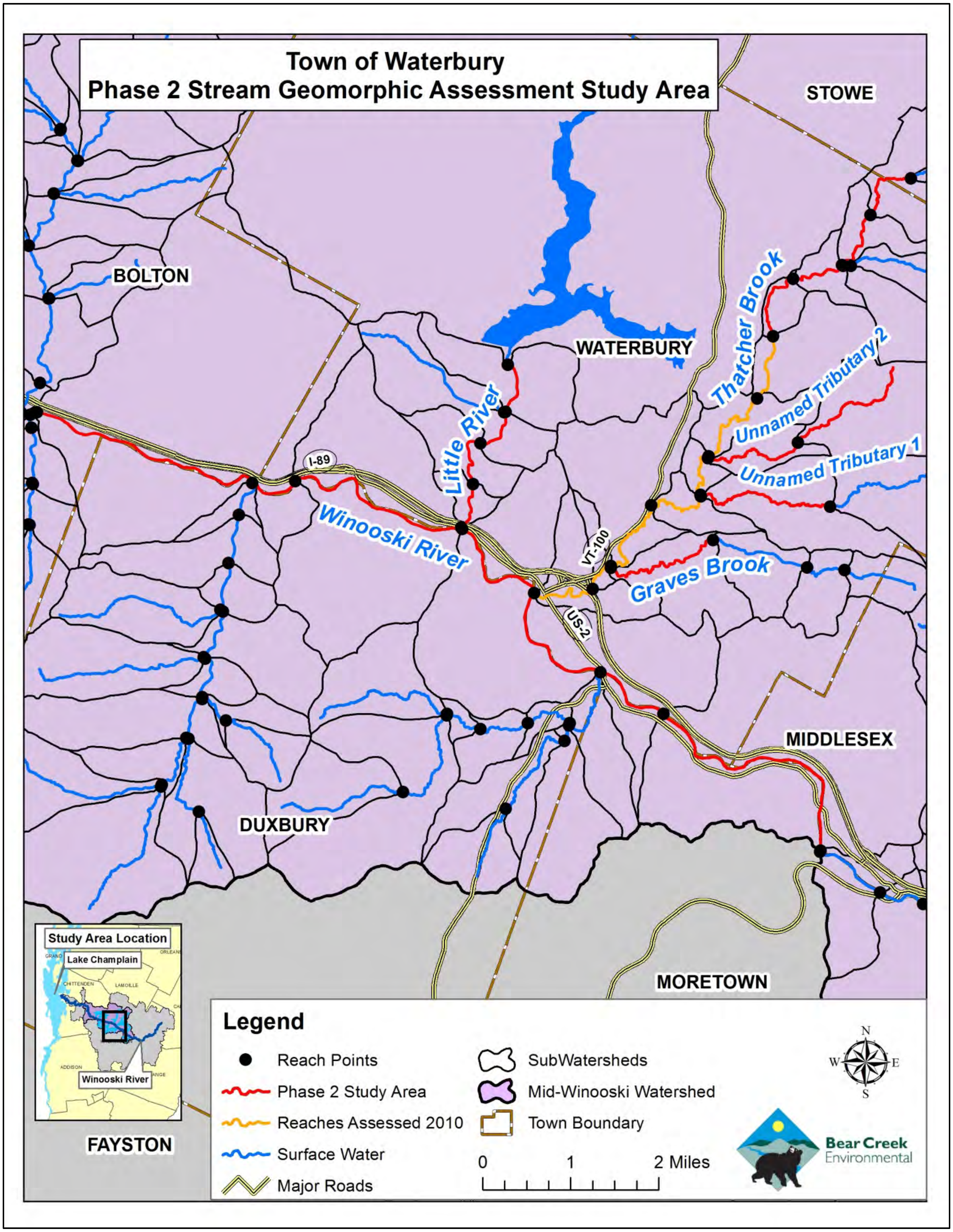
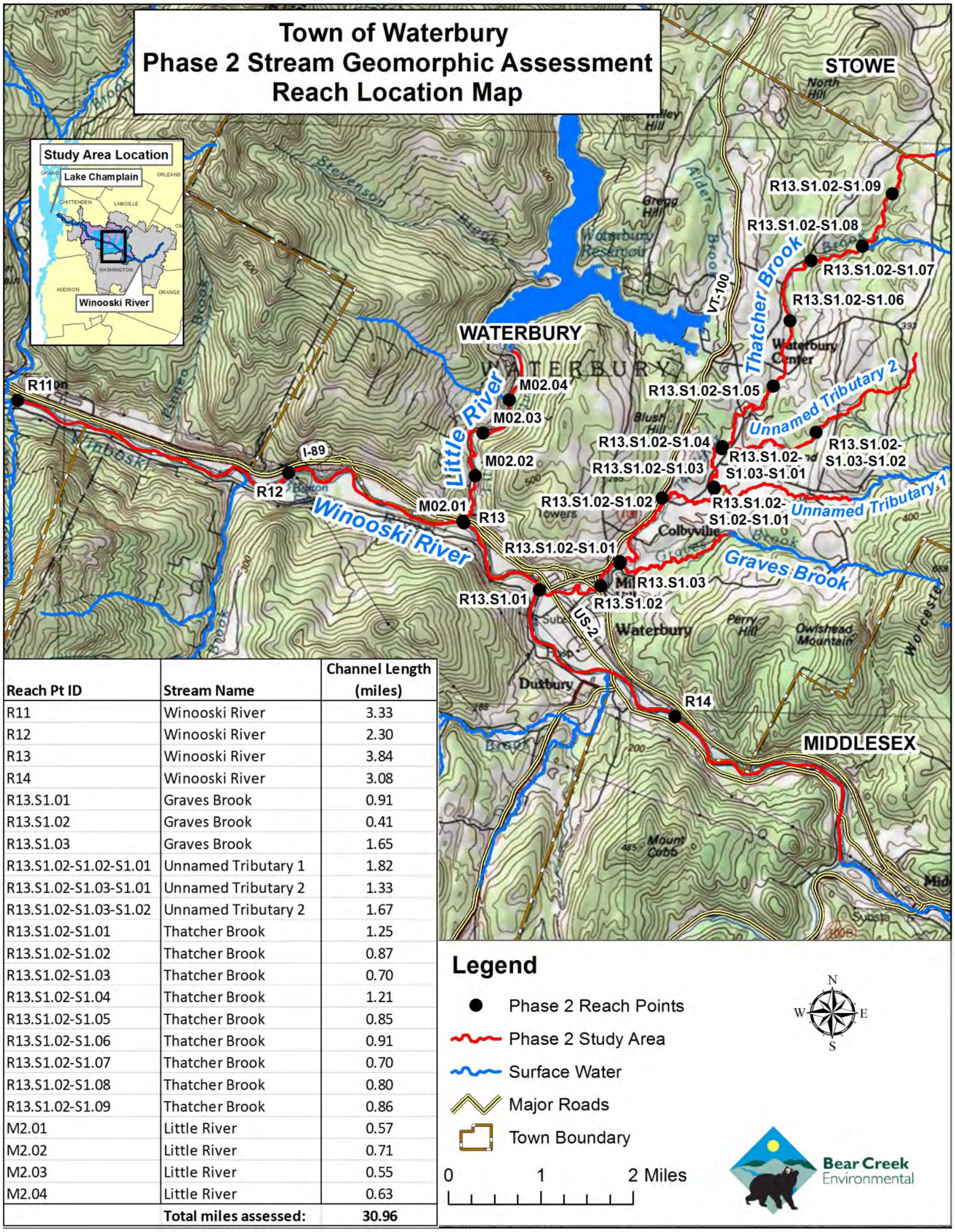


Figure 3.3. Mid-Winooski River watershed 2014 and 2010 stream geomorphic assessment study reaches.



Reach Pt ID	Stream Name	Channel Length (miles)
R11	Winooski River	3.33
R12	Winooski River	2.30
R13	Winooski River	3.84
R14	Winooski River	3.08
R13.S1.01	Graves Brook	0.91
R13.S1.02	Graves Brook	0.41
R13.S1.03	Graves Brook	1.65
R13.S1.02-S1.02-S1.01	Unnamed Tributary 1	1.82
R13.S1.02-S1.03-S1.01	Unnamed Tributary 2	1.33
R13.S1.02-S1.03-S1.02	Unnamed Tributary 2	1.67
R13.S1.02-S1.01	Thatcher Brook	1.25
R13.S1.02-S1.02	Thatcher Brook	0.87
R13.S1.02-S1.03	Thatcher Brook	0.70
R13.S1.02-S1.04	Thatcher Brook	1.21
R13.S1.02-S1.05	Thatcher Brook	0.85
R13.S1.02-S1.06	Thatcher Brook	0.91
R13.S1.02-S1.07	Thatcher Brook	0.70
R13.S1.02-S1.08	Thatcher Brook	0.80
R13.S1.02-S1.09	Thatcher Brook	0.86
M2.01	Little River	0.57
M2.02	Little River	0.71
M2.03	Little River	0.55
M2.04	Little River	0.63
	Total miles assessed:	**30.96**

Figure 3.4. Mid-Winooski River watershed 2014 Phase 2 study reaches.

3.5 Hydrology

In late August of 2011, Vermont was hit hard by Tropical Storm Irene (TSI). Heavy rain totaled over seven inches in areas over the course of one day. This immense downpour caused raging floodwaters to tear through Vermont's streams, devastating people and infrastructure throughout central and southern Vermont. In some areas, TSI flooding approached historic flood levels, while in other areas, the storm greatly exceeded them. Over 500 miles of state roads, in addition to over 2000 segments of municipal roads, were damaged as a result of TSI. In total, approximately 500 bridges were damaged or destroyed, as well as almost 1,000 culverts. Approximately 1,500 residences were significantly damaged or destroyed as a result of flooding, as well as state, municipal, and commercial buildings (VANR 2012a). The Winooski River and tributaries were impacted by flooding from Tropical Storm Irene, as were the communities located on their floodplains.

Within the Phase 2 study area, Tropical Storm Irene was the most damaging storm since the Flood of 1927. During Tropical Storm Irene, flood levels throughout many areas in Vermont equaled or approached the historic flood of 1927 (Vermont Agency of Natural Resources, 2012a). Many towns along the Winooski River experienced significant flooding and damage of property and infrastructure. Waterbury was particularly hard hit by *inundation flooding*, which occurs when slowly flowing or standing water causes the submersion of low-lying lands adjacent to a river. A map on page 1 of Appendix A shows the area inundated during Tropical Storm Irene along the Winooski River within the study area. Waterbury Village, which is an important local hub of commercial and residential activities, was mostly under water during the flood. Numerous homes and businesses sustained major water damage, including town offices, emergency facilities, and a large state office campus. Tropical Storm Irene floodwaters from the Winooski River destroyed one single family home within the study area in Duxbury. This property was acquired by the town through the FEMA buyout program. Road damage was widespread as tributaries to the Winooski River washed out shoulders and undersized culverts. The historic bridge on Winooski Street over the river was damaged as floodwaters rose and flowed over it.

In order to better understand the flood history of the Winooski River and its tributaries, long-term data from the U.S. Department of the Interior, U.S. Geological Survey (USGS), were obtained (USGS 2015). There is one USGS *gaging* station within the study area on the Little River, but due to flow regulation at the Waterbury Reservoir Dam, this station could not be analyzed for historic peak flows. Peak flow data from two stations at nearby locations in the Winooski River watershed were reviewed instead. One station included in this analysis has a drainage area of 397 square miles and is located on the Winooski River main stem in the City of Montpelier. A second station, located on the Dog River in Northfield (drainage area 76 square miles), was included in this analysis. A map showing the location of these two gaging stations in relation to the study area is shown in Figure 3.5. Comparing annual peak flow data at these two stations for all years on record allows for an analysis of the recurrence interval of Tropical Storm Irene within the Mid-Winooski River watershed.

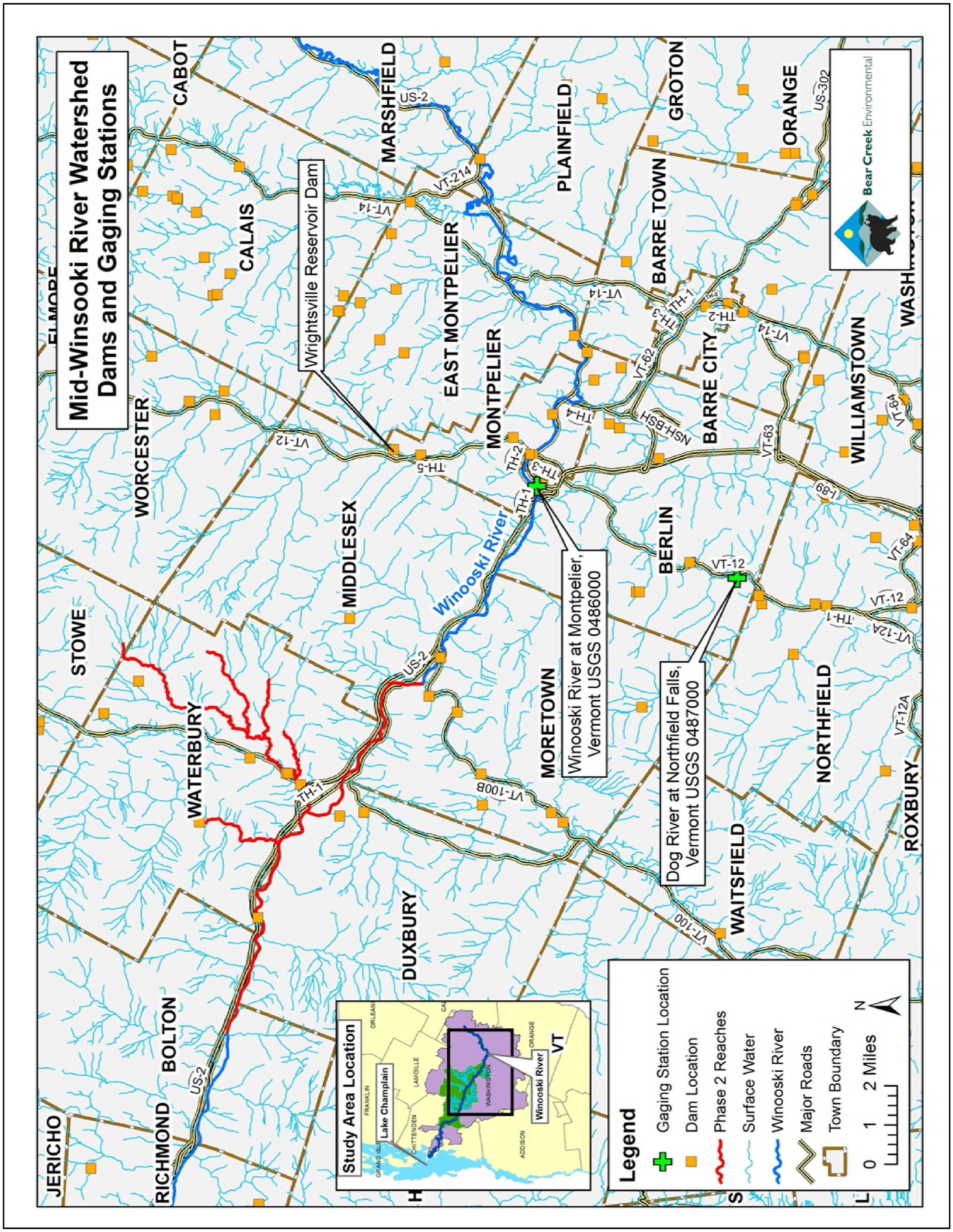


Figure 3.5. Gaging station and dam locations in relation to study area.

Peak discharge records are available for the Dog River at Northfield Falls, Vermont from 1935 through 2014 (Figure 3.6) (USGS, 2015). The highest annual peak flow on record is from Tropical Storm Irene in August 2011, which exceeded a 500 year recurrence interval.

At the Winooski River gaging station, peak discharge records are available from 1912 through 2014. The highest peak discharge available over the period of record for this station is from the Flood of 1927, which caused immense damage in central Vermont. Following the Flood of 1927, several flood control dams were installed in the Winooski River watershed. The Wrightsville Reservoir Dam on the North Branch of the Winooski River was completed in late 1935 and is located a short distance from the gaging station. The installation of this dam and another flood control dam farther upstream in East Barre has regulated the flows on the Winooski River. This regulation has resulted in lower peak flows at the gaging station in Montpelier due to increased floodwater storage capacity (Figure 3.7).

Of all the natural hazards experienced in Vermont, flooding is the most frequent, damaging, and costly. During the period of 1995-1998 alone, flood losses in Vermont totaled nearly $57 Million (Vermont Agency of Natural Resources, 2010b). The Vermont Agency of Administration (2012) states that over 733 million dollars has been estimated in funding resources for Tropical Storm Irene recovery. While some flood losses are caused by inundation (i.e. waters rise, fill, and damage low-lying structures), most flood losses in Vermont are caused by fluvial erosion.

Fluvial erosion is caused by rivers and streams, and can range from gradual bank erosion to catastrophic changes in river channel location and dimension during flood events (Vermont Agency of Natural Resources, 2010b). The VANR (2010b) attributes the high cost and frequency of fluvial erosion in Vermont to its geography (mountainous setting with narrow valleys and extreme climate) and past land-use practices (forest clearing).

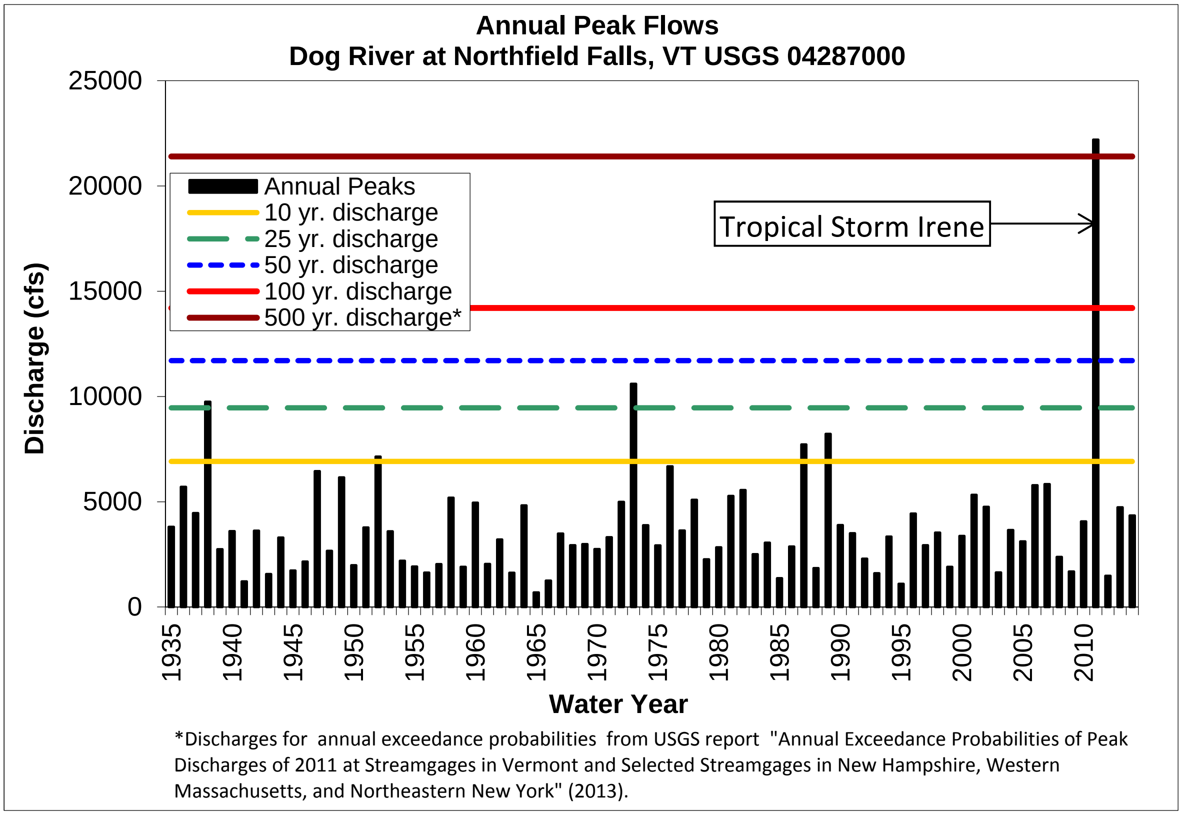


Figure 3.6. Annual Peak Flows for the Dog River at Northfield Falls, Vermont.

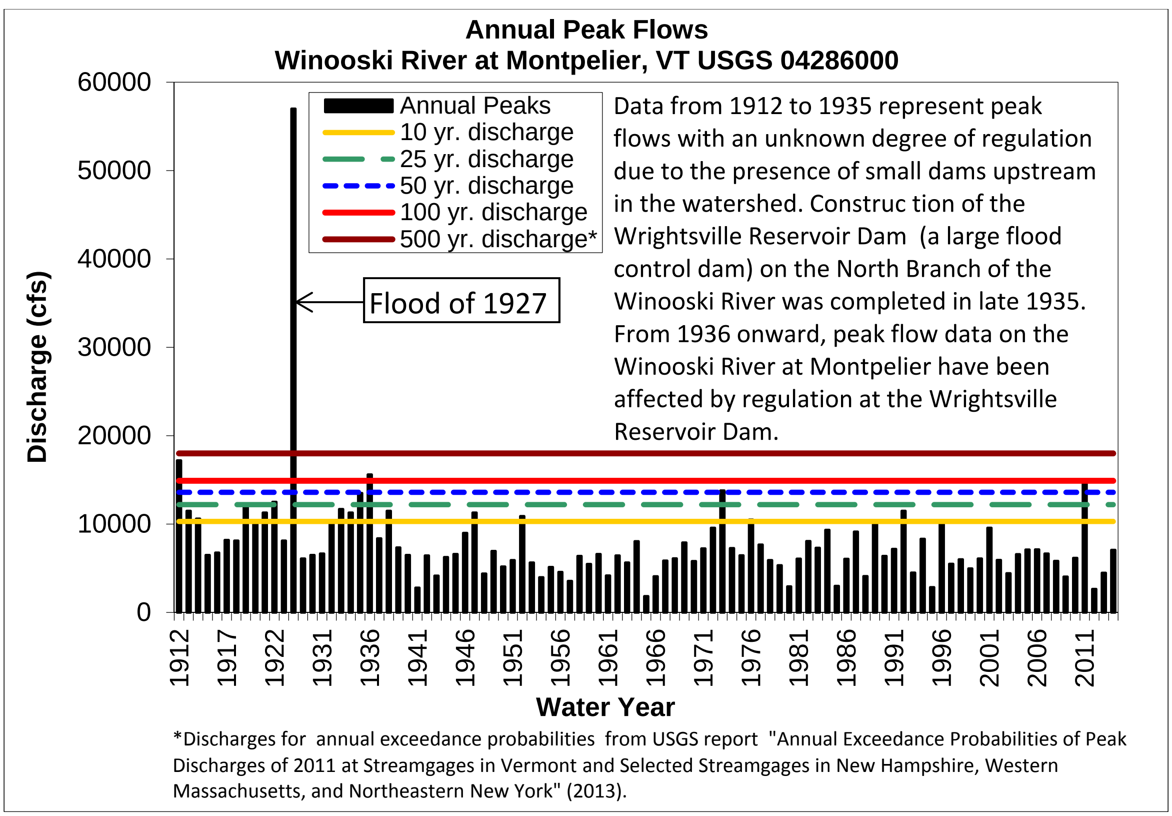


Figure 3.7. Annual Peak Flows for the Winooski River at Montpelier, Vermont.

3.6 Ecological Setting

The mid-Winooski watershed lies within the Northern Green Mountains biophysical region. This region is characterized by Thompson and Sorenson (2000) as an area of high elevations, which includes Vermont's tallest peaks. These mountains greatly influence the climate of the region. Precipitation is abundant in this region, and temperatures are colder than in other areas due to higher elevations. The typical zonation of forest types can be found in this biophysical region. From the lower slopes to the summits, Northern Hardwood Forest change to Montane Yellow Birch-Red Spruce Forest, to Montane Spruce-Fir Forest, and finally to Subalpine Krummholz at the tree lines (Thompson and Sorenson, 2000). The Northern Green Mountains contain extensive habitat for mammals such as bear, white-tailed deer, bobcat, fisher, beaver, and red squirrel. Bird species that nest in high elevations include blackpoll warblers, Swainson's thrush, and the rare Bicknells' thrush (Thompson and Sorenson, 2000).

Deer wintering areas are present within the study area, especially along the Little River, Graves Brook, and upper Thatcher Brook. Most land abutting the Little River is part of protected state forest, while the majority of land throughout the rest of the study area is privately owned (residential). Core habitat, which represents areas that are at least 100 meters from a zone of human disturbance, is abundant within the watershed, as shown on page 2 of Appendix A.

4.0 METHODS

A summary of the Phase 1, Phase 2, and Bridge and *Culvert* methodologies is provided in the following sections.

4.1 Phase 1 Methodology

The Phase 1 assessment followed procedures specified in the Vermont Stream Geomorphic Assessment Phase 1 Handbook (Vermont Agency of Natural Resources), and used the Stream Geomorphic Assessment Tool (SGAT). SGAT is an ArcGIS extension. Phase 1, the remote sensing phase, involves the collection of data from topographic maps and aerial photographs, from existing studies, and from very limited field studies, called "windshield surveys". The Phase 1 assessment provides an overview of the general physical nature of the watershed. As part of the Phase 1 study, stream reaches are determined based on geomorphic characteristics such as: valley confinement, valley slope, geologic materials, and tributary influence.

4.2 Phase 2 Methodology

The Phase 2 assessment within the mid-Winooski River watershed followed procedures specified in the Vermont Stream Geomorphic Assessment (SGA) Phase 2 Handbook (Vermont Agency of Natural Resources, 2009b), and used version 10.2.1 of the SGAT Geographic Information System (GIS) extension to index impacts within each reach.

The geomorphic condition for each Phase 2 reach is determined using the Rapid Geomorphic Assessment (RGA) protocol, and is based on the degree of departure of the channel from its reference stream type (Vermont Agency of Natural Resources, 2009b). The study used the 2008 Rapid Habitat Assessment (RHA) protocol (Vermont Agency of Natural Resources, 2008; Milone and MacBroom, Inc., 2008). The RHA is used to evaluate the physical components of a stream (channel bed, banks, and riparian vegetation) and how the physical condition of the stream affects aquatic life. The RHA results can be used to compare physical habitat condition between sites, streams, or watersheds, and they can also serve as a management tool in watershed planning.

RHA and RGA field forms were completed for the Phase 2 reaches. The appropriate RHA and RGA forms were selected based on segment characteristics and scored according to the data collected from the field assessment. A segment score and corresponding condition were determined for both the RHA and the RGA. Additionally for the RGA, major geomorphic processes were identified, the stage of channel evolution was determined, and a stream sensitivity rating was assigned.

To assure a high level of confidence in the Phase 2 SGA data, strict quality assurance/quality control (QA/QC) procedures were followed by Bear Creek Environmental. These procedures involved a thorough in-house review of all data, which took place during January 2015. The Project Team conducted the assessment according to the approved Quality Assurance procedures specified in the Phase 2 handbook. Gretchen Alexander of the State of Vermont Watershed Management Division conducted a QA/QC review of the data collected by (BCE) for the mid-Winooski River watershed during February 2015.

4.3 Bridge and Culvert Methodology

Bridge assessments were conducted by BCE on all public and private crossings within the selected Phase 2 reaches. The Agency of Natural Resources Bridge and Culvert protocols (Vermont Agency of Natural Resources, 2009a) were followed. Latitude and Longitude at each of the structures was determined using a MobileMapper 100 GPS unit. The assessment included photo documentation of the inlet, outlet, upstream, and downstream of each of the structures.

The Vermont Culvert Geomorphic Compatibility Screening Tool (Milone and MacBroom, Inc. 2008) was used to determine geomorphic compatibility for each bridge. Bridges are not typically screened for geomorphic compatibility in the VANR protocol because they are usually more robust and have less impact on stream channel function than culverts. Bridges also do not have potential to become perched above the water surface, because the bottom of the structure is natural substrate. Bridges in this study were screened using the geomorphic compatibility tool that was modified to exclude the slope parameter. Tables 1 and 2 in Appendix B explain how each bridge was scored using the Screening Tool. The compatibility rating is based on four criteria: structure width in relation to bankfull channel width, sediment continuity, river approach angle, and erosion & armoring and the ratings span the following range:

- Fully Compatible
- Mostly Compatible
- Partially Compatible
- Mostly incompatible
- Fully Incompatible

All culverts were evaluated for Aquatic Organism Passage (AOP) using the Vermont Culvert Aquatic Organism Passage Screening Tool (Milone and MacBroom, 2009). Tables 3 through 5 in Appendix B explain how each culvert was scored. The screening guide has the four following categories:

- Full AOP for all organisms
- Reduced AOP for all aquatic organisms
- No AOP for all aquatic organisms except adult salmonids
- No AOP for all aquatic organisms

5.0 RESULTS

5.1 Condition and Departure Analysis

5.1.1 Stream Types

Reference stream types are based on the valley type, geology and climate of a region and describe what the channel would look like in the absence of human-related changes to the channel, floodplain, valley width, and/or watershed. Table 1 shows the typical characteristics used to determine reference stream types (Vermont Agency of Natural Resources, 2009b). Reference reach typing was based on both the Rosgen (1996) and the Montgomery and Buffington (1997) classification systems. Stream and valley characteristics including valley confinement, and slope were determined from digital United States Geological Survey (USGS) topographic maps (Table 2).

Table 1. Reference Stream Type			
Stream Type	**Confinement**	**Valley Slope**	**Bed Form**
A	Narrowly Confined	Very steep > 6.5 %	Cascade
A	Confined	Very steep 4.0 - 6.5 %	Step-Pool
B	Confined or Semi- confined	Steep 3.0 – 4.0 %	Step-Pool

Table 1. Reference Stream Type			
Stream Type	**Confinement**	**Valley Slope**	**Bed Form**
B	Confined, Semi- confined or Narrow	Moderate to Steep 2.0 – 3.0 %	Plane Bed
C or E	Unconfined (Narrow, Broad or Very Broad)	Moderate to Gentle <2.0 %	Riffle-Pool or Dune-Ripple
D	Unconfined (Narrow, Broad or Very Broad)	Moderate to Gentle <4.0 %	Braided Channel
F	Confined or Semi-confined	Moderate to Gentle <4.0 %	Variable

Table 2 lists the reference stream types for the assessed reaches in the mid-Winooski River watershed. Most reaches assessed for Phase 2 in the mid-Winooski River watershed are "C" channels by reference. Reference "C" channels have unconfined valleys with moderate to gentle valley slopes and moderate to high width to depth ratios and sinuosity. Reference valley confinement varies from narrowly confined to very broad throughout the study area. Most reaches have a reference bedform of *riffle-pool* except for short sections on the Little River, Graves Brook, and Thatcher Brook, which represent plane bed, step-pool, or dune-ripple systems. The reference reach characteristics were refined during the Phase 2 Assessment.

During the Phase 2 assessment, the 23 study reaches were broken into 53 segments based on detailed field observations. A segment is distinct in one or more of the following parameters: degree of floodplain encroachment or channel alteration, *grade control* occurrence (e.g. ledge), channel dimensions, channel sinuosity and slope, *riparian buffer* and corridor conditions, and degree of flow regulation. The most downstream segment within a reach is labeled "A", the second from the reach point is "B, etc. (i.e. R11-A is the most downstream segment on Reach R11) (Figures 5.1, 5.2, 5.3, 5.4 and 5.5). Of the 53 segments, seven were not fully assessed; two segments are impounded due to dams (Winooski River and upper Thatcher Brook), four are bedrock gorges (on the Little River, Graves Brook, Thatcher Brook, and Unnamed Tributary 1 to Thatcher Brook), and one is not flowing due to the presence of a wetland (on Unnamed Tributary 2 to Thatcher Brook).

The existing stream type is based on channel dimensions measured during the Phase 2 assessment. Maps of the reference and existing stream type for each assessed reach/segment are included on pages 3 through 5 of Appendix A. Most of the segments in the assessment have the same reference and existing stream type. However, the existing stream type differs from the reference stream type in 9 of the 46 fully-assessed segments. This indicates that a stream type departure has taken place in those areas. A stream type departure occurs when the channel dimensions deviate so far from the reference condition that the existing stream type is no longer the reference stream type. These stream type departures represent a significant change in floodplain access and stability. Watersheds that have lost attenuation or sediment storage areas due to human related constraints are generally more sensitive to erosion hazards, transport greater quantities of sediment and nutrients to receiving waters, and lack the sediment storage and distribution processes that create and maintain habitat (Vermont Agency of Natural Resources, 2009b).

Table 2: Geomorphic Setting of Phase 2 Assessment Reaches

Stream	Reach ID	Reference Stream Type	Reference Confinement	Valley Slope (%)	Bedform
Winooski River	R11	C	Semi-confined	0.23	Riffle-Pool
	R12	C	Broad	0.18	Riffle-Pool
	R13	C	Broad	0.12	Riffle-Pool
	R14	B_c	Narrow	0.13	Riffle-Pool
Little River	M02.1	C	Broad	0.18	Riffle-Pool
	M02.02	C	Narrow	0.62	Riffle-Pool
	M02.03	B	Narrowly Confined	0.00	Plane Bed
	M02.04	C	Broad	0.49	Riffle-Pool
Graves Brook	R13.S1.01	C	Very Broad	1.07	Riffle-Pool
	R13.S1.02	B	Semi-confined	3.37	Step-Pool
	R13.S1.03	C	Very Broad	2.13	Riffle-Pool
Thatcher Brook	R13.S1.02-S1.01	E	Broad	1.61	Dune-Ripple
	R13.S1.02-S1.02	C	Very Broad	0.52	Riffle-Pool
	R13.S1.02-S1.03	C	Very Broad	0.73	Riffle-Pool
	R13.S1.02-S1.04	C	Very Broad	1.13	Riffle-Pool
	R13.S1.02-S1.05	C	Very Broad	1.28	Riffle-Pool
	R13.S1.02-S1.06	C_b	Very Broad	2.65	Riffle-Pool
	R13.S1.02-S1.07	B	Broad	3.67	Step-Pool
	R13.S1.02-S1.08	C_b	Very Broad	3.54	Step-Pool
	R13.S1.02-S1.09	C	Very Broad	2.75	Riffle-Pool
Unnamed Tributary 1 to Thatcher Brook	R13.S1.02-S1.02-S1.01	C	Very Broad	3.04	Riffle-Pool
Unnamed Tributary 2 to Thatcher Brook	R13.S1.02-S1.03-S1.01	C	Very Broad	2.68	Riffle-Pool
	R13.S1.02-S1.03-S1.02	C	Broad	6.47	Riffle-Pool

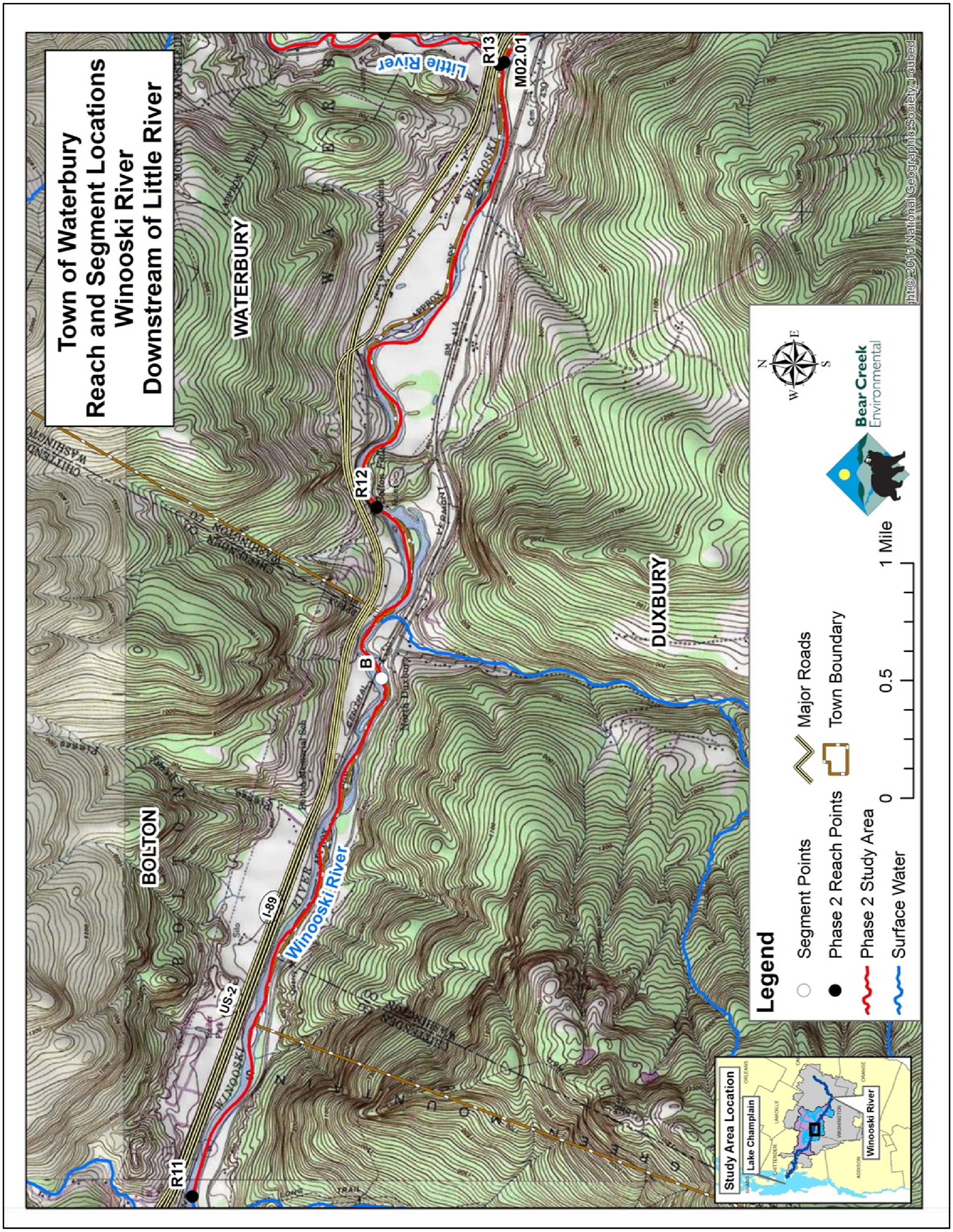


Figure 5.1. Reach and segment locations on the Winooski River below the Little River.

Figure 5.2. Reach and segment locations on the Little River.

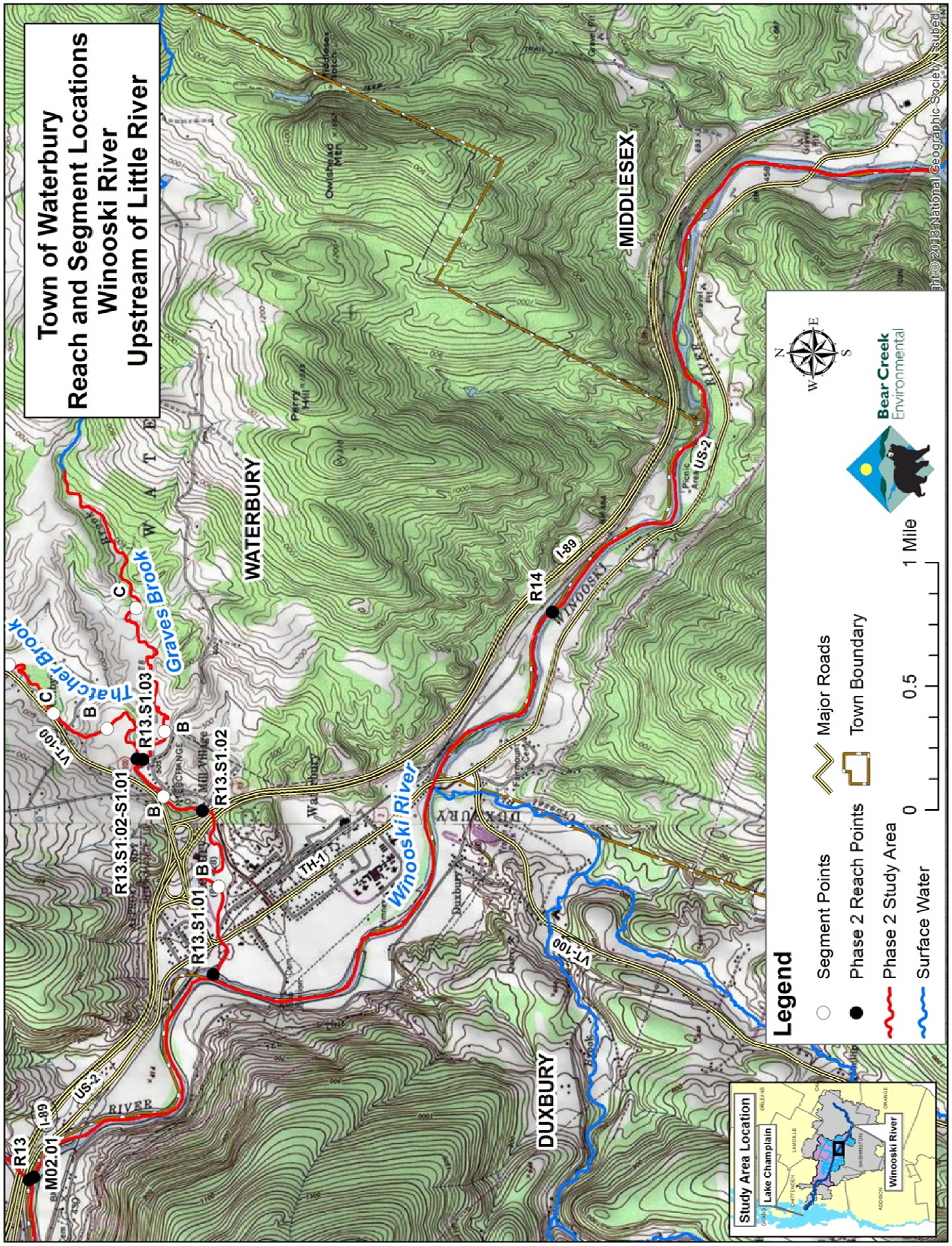


Figure 5.3. Reach and segment locations on the Winooski River above the Little River.

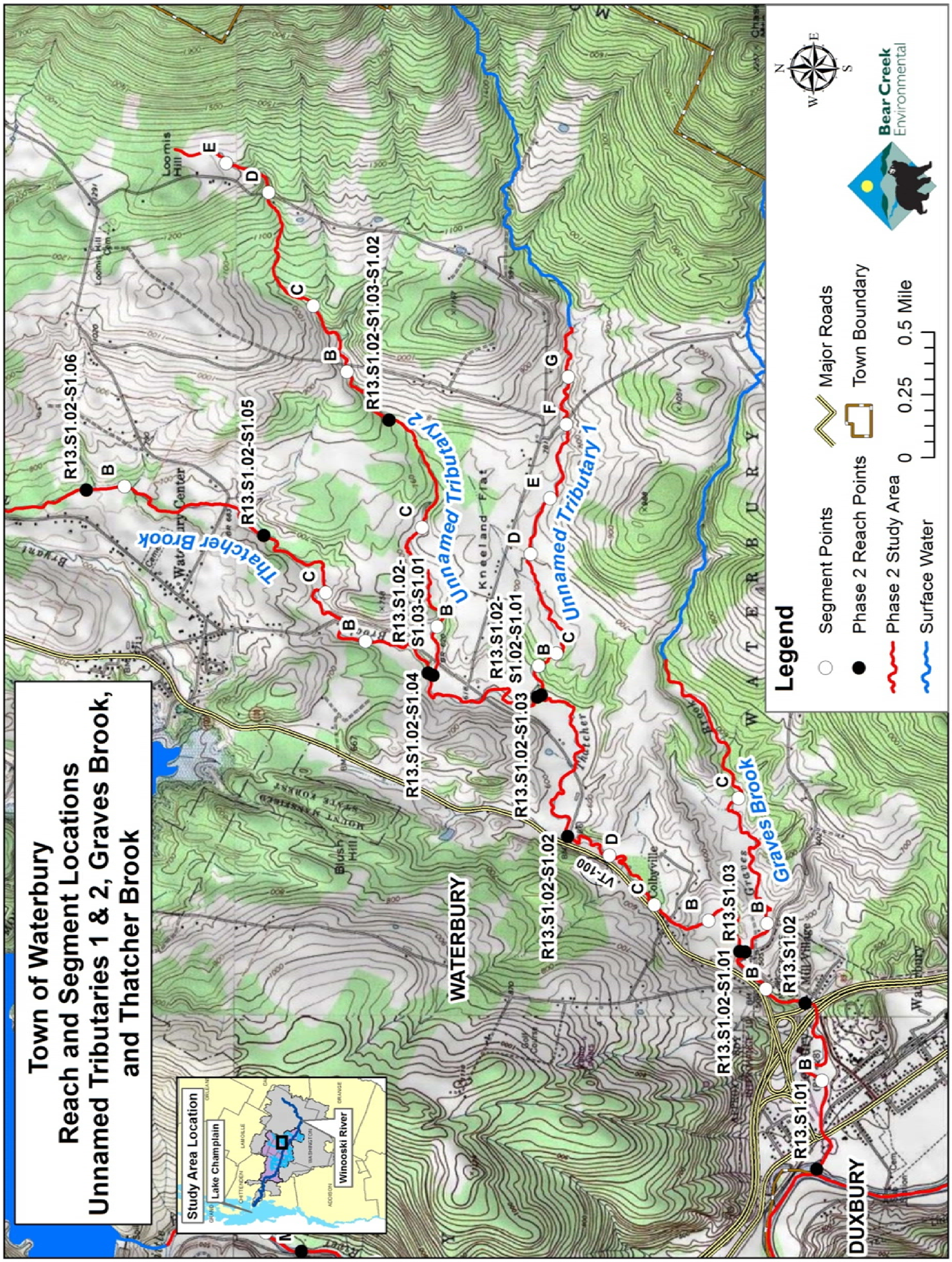


Figure 5.4. Reach and segment locations on Graves Brook, lower Thatcher Brook, and the unnamed tributaries

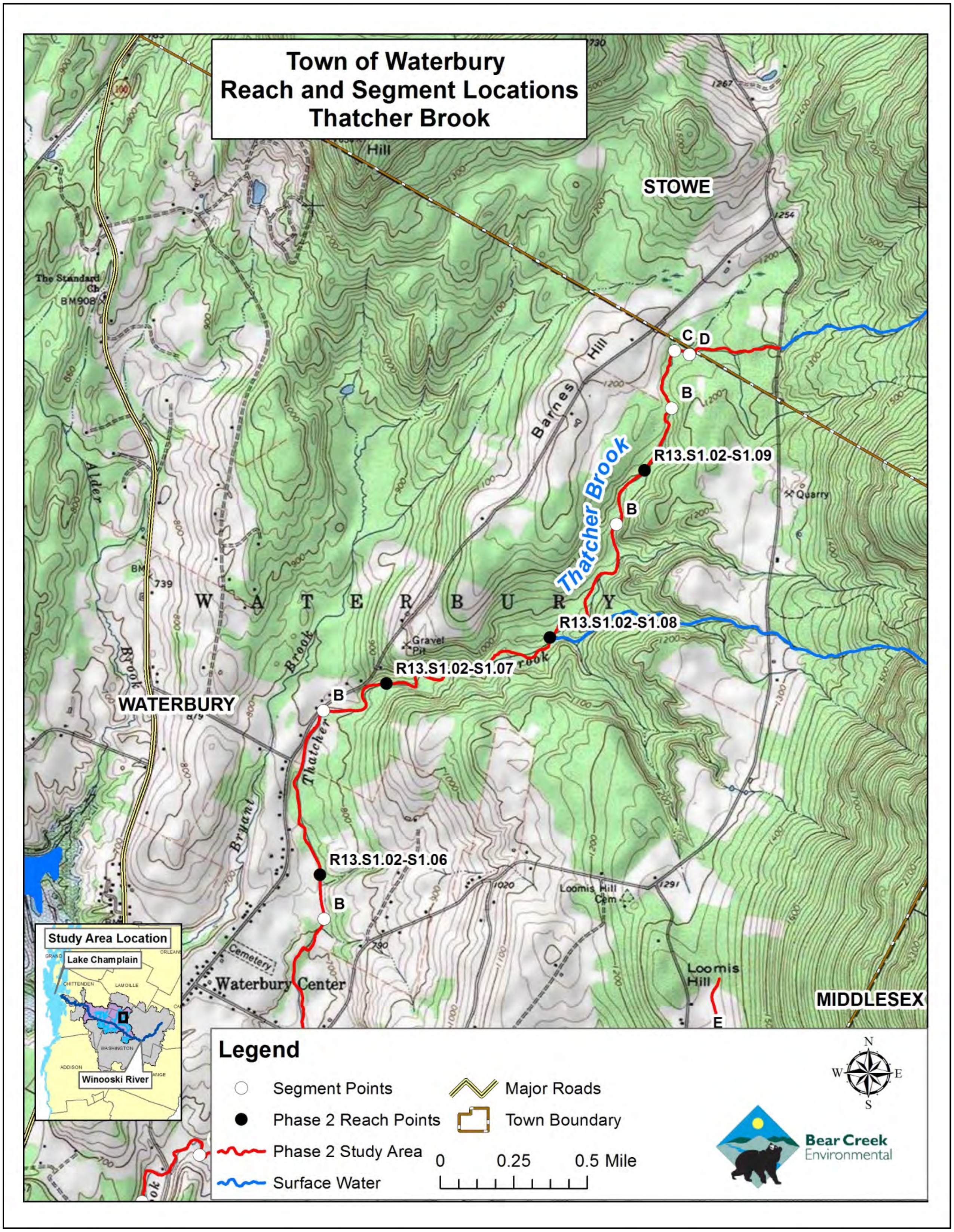


Figure 5.5. Reach and segment locations on upper Thatcher Brook.

5.1.2 Geomorphic Condition

The stream condition is determined using the scores on the rapid assessment field forms, and is defined in terms of departure from the reference condition. There are four categories to describe the condition (reference, good, fair and poor). These ratings are defined below.

- Reference – no departure
- Good – minor departure
- Fair – major departure
- Poor – severe departure

Maps of the existing geomorphic condition for each segment are depicted on pages 6 through 8 Appendix A. Geomorphic condition is determined based on the degree (if any) of channel degradation, aggradation, widening and *planform* adjustment. Degradation is the term used to describe the process whereby the stream bed lowers in elevation through erosion, or scour, of bed material. Aggradation is a term used to describe the raising of the bed elevation through an accumulation of sediment. The planform of a channel is its shape as seen from the air. Planform change can be the result of a straightened course imposed on the river through different channel management activities, or a channel response to other *adjustment processes* such as aggradation and widening. Channel widening is a result of channel degradation or sediment build-up in the channel. In both situations the stream's energy is concentrated into both banks.

Within the Phase 2 study area in the mid-Winooski River watershed, 2 of 53 segments are in "poor" geomorphic condition, 37 are in "fair" condition, and 7 are in "good" condition. No segment is in "reference" geomorphic condition. Seven segments were not assessed due to such constraints as bedrock gorges and impoundment. The current geomorphic conditions in the assessed segments are a result of several factors. Corridor encroachments are common throughout the study area, as many roads run directly along these streams and houses exist on their banks. U.S. Route 2, I-89, and the New England Central Railroad significantly encroach upon the Winooski River for much of the study area, Route 100 encroaches upon Graves Brook and Thatcher Brook, and numerous town roads also cause widespread floodplain encroachment. Development within a river *corridor* can cause a loss of floodplain access, changes in valley confinement, and overall geomorphic instability.

During Tropical Storm Irene, high stream flows likely caused changes within the study reaches. *Mass failures*, erosion, and aggradation were exacerbated by TSI in some locations, and are contributing to the unstable geomorphic condition of many assessment reaches. Also, new flood chutes likely formed, and some sections of stream took new courses through channel avulsions.

5.1.3 Habitat Condition

The habitat condition for each segment within the mid-Winooski study area is presented on pages 6 through 8 of Appendix A. Nineteen segments in the study are in "good" habitat condition and are located in areas where the stream channel flows away from major roads and into forested and wetland areas. These segments have minimal to no corridor encroachments, allowing for high quality vegetated banks and buffers. The segments in "good" condition have high amounts of large woody debris in the channel, many *pools*, and good canopy cover; all of which provide habitat for aquatic life. Twenty-seven segments are in "fair" habitat condition. Segments are in "fair" habitat condition mainly as a result of corridor encroachments, poor bank and buffer vegetation, erosion and revetments, channel straightening, and incision. Some of the segments in "fair" habitat condition exhibit a habitat stream type departure to a *plane bed*, featureless channel.

The maps on pages 6 through 8 of Appendix A include both the geomorphic and habitat condition maps side by side. The habitat and geomorphic conditions were often similar, suggesting that the ecological health of the mid-Winooski River watershed is related to the geomorphic condition of the stream.

As shown in Table 1 (Appendix A, pages 12 through 16), many of the segments have *incised* and are undergoing widening, as exhibited by high incision and width to depth ratios. Historically, many encroachments, namely roads and development, have led to straightening of the stream channels and their degradation (incision). Widening has occurred in response to this streambed lowering in many segments. Aggradation as a result of increased flows from TSI in 2011 may have exacerbated the widening process in certain locations. A high width to depth ratio indicates that the channel is relatively wide and shallow. Wide, shallow channels tend to have a reduced number of deep pools, canopy cover in the center of the stream, undercut banks, and sometimes a higher water temperature (Foster, Stein, & Jones, 2001). These factors can contribute to a lower habitat score.

5.1.4 Sediment Regime

Functioning floodplains play a crucial role in providing long-term stability to a river system. Natural and anthropogenic impacts may alter the equilibrium of sediment and discharge in natural stream systems and set in motion a series of morphological responses (aggradation, degradation, widening, and/or planform adjustment) as the channel tries to reestablish a dynamic equilibrium. Small to moderate changes in slope, discharge, and/or sediment supply can alter the size of transported sediment as well as the geometry of the channel; while large changes can transform reach level channel types (Ryan, 2001). Human-induced practices that have contributed to stream instability within the Mid-Winooski River watershed include:

- Channelization and bank armoring
- Removal of woody riparian vegetation
- Floodplain encroachments
- Major flow alteration (e.g. dams)

These anthropogenic practices have altered the balance between water and sediment discharges within the Mid-Winooski River watershed. The sediment regime is the quantity, size, transport, sorting, and distribution of sediments. The sediment regime may be influenced by the proximity of sediment sources, the hydrologic characteristics of the region, and the valley, floodplain, and stream morphology (ANR, 2010a). Sediment can be supplied to the river through bank erosion, large flooding events, and stormwater inputs. Sediment regime maps depicting the reference and existing sediment regimes can be found on pages 9 through 11 of Appendix A. Reference and existing sediment regimes were derived from the Agency of Natural Resources Data Management System according to the sediment regime criteria established by the Vermont Agency of Natural Resources (2010a).

Changes in hydrology (such as flow alteration and development of land within the riparian corridor) as well as sediment storage within the watershed have altered the reference sediment regime types for many segments within the study area. The analysis of sediment regimes at the watershed level is useful for summarizing the stressors affecting geomorphic condition of river channels. Sediment regime mapping provides a context for understanding the sediment transport and channel evolution processes.

5.1.5 Channel Evolution Model

Channel morphologic responses to anthropogenic practices contribute to channel adjustment that may further create unstable channels. All three adjustment processes, aggradation, widening and planform migration as a result of active and historic degradation and recent channel work are present within the mid-Winooski watershed in the Waterbury study area. The placement of state and federal highways, including U.S. Route 2, Interstate 89 and Vermont Route 100, has significantly changed river valley widths, floodplain access, and ability of streams to meander within the study area. The floods that came through the area during TSI in August, 2011 have resulted in aggradation and planform change within some reaches.

The segment condition ratings of the mid-Winooski watershed indicate that most of the segments are actively undergoing or have historically undergone a process of major geomorphic adjustment. Many of the reaches studied in the Waterbury area are undergoing a channel evolution process in response to human influences on the watershed.

The “F” stage channel evolution model (Vermont Agency of Natural Resources, 2009b; Vermont Agency of Natural Resources, 2004) is helpful for explaining the channel adjustment processes underway in the mid-Winooski River watershed, and is used to understand the process that occurs when a stream degrades (incises).

The common stages of the "F" channel evolution stage, as depicted in Figure 5.4 include:

- Stable (F-1) - a pre-disturbance period
- Incision (F-II) – channel degradation (*headcutting*)
- Widening (F-III) – bank failure
- Stabilizing (F-IV) – channel narrows through sediment build up and moves laterally building juvenile floodplain
- Stable (F-V) - gradual formation of a stable channel with access to its floodplain at a lower elevation

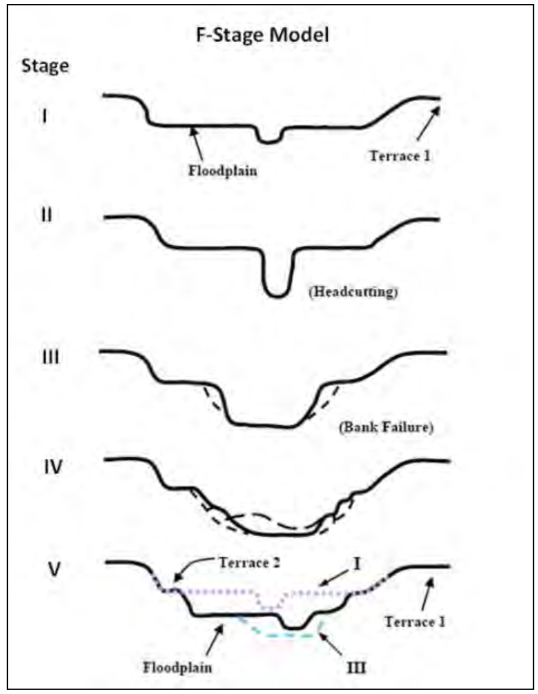


Figure 5.6 Typical channel evolution models for F-Stage (Vermont Agency of Natural Resources, 2009b)

When stream channels are altered through straightening, it can set this evolution process into motion and cause adjustment processes to occur. The bed erosion that occurs when a meandering river is straightened in its valley is a problem that translates to other sections of the stream. Localized incision will travel upstream and into tributaries, thereby eroding sediments from otherwise stable streambeds. These bed sediments will move into and clog reaches downstream, leading to lateral scour and erosion of the stream banks. Channel evolution processes may take decades to play out. Even landowners that have maintained wooded areas along their stream and riverbanks may have experienced eroding banks as stream channel slopes adjust to match the valley slopes. It is difficult for streams to attain a new equilibrium where the placement of roads and other infrastructure has resulted in little or no valley space for the stream to access or to create a floodplain.

A second channel evolution model, known as the "D" channel evolution model is helpful for explaining channel adjustments that are driven by major aggradation. In the "D" model, channel degradation has not occurred, but rather the accumulation of sediment on the streambed causes channel widening and planform adjustment.

The channel evolution stage for each Phase 2 segment was determined based on field data and observations. A summary of the channel evolution stage by segment is provided on pages 12 through 16 of Appendix A. Three segments on the unnamed tributaries to Thatcher Brook are in stage I of the "F-stage" channel evolution model, indicating that they have not undergone a channel incision process. Twelve segments within the study area are currently in stage "F-II", indicating that they have incised but not widened, often due to *boundary conditions* limiting lateral channel movement.

Nineteen segments are in stage III of the "F-stage" channel evolution model. Most of these segments have undergone moderate to severe historic incision. The placement of numerous state and town roads has likely led to this incision and the subsequent loss of floodplain access. In stage F-III, the entrenched channel begins to widen and migrate laterally through bank erosion caused by the increased stream power.

Nine segments have moved into stage IV of the "F-stage" channel evolution model. This means that the channel has stabilized itself by changes in its migration pattern and is building a new floodplain at a lower elevation. Some of these segments are highly depositional and have become braided with many large *bar* features including transverse (*diagonal*) bars. This buildup of sediment has led to channel widening and planform adjustment.

Three segments can be described by stage D-IIc of the "D" model. These segments have not undergone incision but are widening and adjusting planform as a result of aggradation.

5.2 Reach/Segment Descriptions

A description of each segment is provided in this section, including major stressors and evolution processes. The segments are listed by stream location from downstream to upstream in the watershed and on each stream. Phase 2 Segment Summary Reports from the Agency of Natural Resources' Data Management System, which contain all the data for the Phase 2 steps, can be found at the following link:
https://anrweb.vt.gov/DEC/SGA/projects/phase2/reports.aspx?pid=112.

Site-specific projects have been developed to facilitate restoration, conservation, and increased *flood resiliency* within the mid-Winooski River watershed. Proposed project locations are provided on maps in Appendix C. Tables and photos provide greater detail about proposed projects in Appendix C. The Phase 2 stream geomorphic assessment provides a picture of the condition of the channel and the adjustment process occurring; however, it is not a comprehensive study for determining site specific actions. The Phase 2 study provides a foundation for project development, and additional work is recommended to further develop these projects.

Winooski River

R11

Reach 11 on the Winooski River is located in the towns of Bolton, Duxbury, and Waterbury, Vermont. It is nearly three and a half miles long, flowing between the New England Central Railroad/Interstate 89 on the north and River Road/Duxbury Road on the south. Ridley Brook flows into the Winooski River within R11. Reach 11 begins just above the confluence of Joiner Brook and continues upstream to just above the Bolton Falls Dam. It was split into two segments to account for changes in planform and slope as well as valley width.

R11-A

The downstream segment on R11 is characterized by an unnaturally straight channel due to historic straightening along the railroad/I-89 and River Road/Duxbury Road. The encroachment of I-89/the New England Central Railroad, one of the most important travel corridors in Vermont, has caused significant narrowing of the river valley. This, as well as the presence of a major dam just upstream, has led to channel incision, stream type departure, and loss of floodplain access. Riprap is prevalent along both banks of the river within R11-A, especially in areas where it flows directly along a road or railroad. Bank erosion is scattered between the riprap. The Winooski River is in the process of widening in R11-A, but lateral planform adjustment is restricted by the aforementioned encroachments. For these reasons, R11-A is in **fair** geomorphic condition. This segment is also in **fair** habitat condition due to altered channel planform, impacted banks and buffers, and lacking instream cover.

Figure 5.7. M2.01 impacted by valley width changes by placement of I 89 and Route 2 bridges.

R11-A Data Summary		Reference	Existing
Length: 12,857 ft Drainage Area: 842 sq. mi. Evolution Stage: F-III Sensitivity: Very High	Confinement	Narrow	Semi-Confined
	Stream Type	C	B_C
	Entrenchment Ratio	> 2.2	1.8
	Incision Ratio	< 1.2	1.4
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Encroachments, Channel Straightening, Revetments, Erosion**		

R11-B

The upstream segment on reach 11 of the Winooski River is nearly 5,000 feet in length and contains the Bolton Falls Dam. The large, run-of-river dam was built in 1898 in a short bedrock gorge to generate hydroelectricity. The dam is approximately 70 feet tall. Despite the presence of the dam, the river does not appear to have incised in R11-B. The river valley is naturally confined and the channel slope is steeper than the surrounding reaches. The New England Central Railroad crosses the river in this segment and creates an encroachment on the southern bank. The channel has widened substantially in R11-B, which could be attributable to the upstream flow regulation. Overall, the segment is in **fair** geomorphic condition due to its over-widened state. It is also in **fair** habitat condition as a result of poor bank and buffer vegetation, morphology, and hydrologic characteristics.

Figure 5.8. M2.01 impacted by valley width changes by placement of I 89 and Route 2 bridges.

R11-B Data Summary		Reference	Existing
Length: 4,735 ft Drainage Area: 842 sq. mi. Evolution Stage: F-III Sensitivity: High	Confinement	Semi-Confined	Semi-Confined
	Stream Type	B_C	B_C
	Entrenchment Ratio	1.4 – 2.2	1.3
	Incision Ratio	< 1.2	1.0
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Flow Regulation, Encroachments, Erosion**		

R12

This reach was not divided into segments during assessment. It begins just above the Bolton Falls Dam and continues upstream for 2.3 miles to above the confluence of the Little River. This entire reach is affected by the large dam at Bolton Falls, which impounds the river and has a backwatering effect of over two miles. At the time of assessment, there were no riffles present in R12 due to the flow regulation at the dam. Impacts and habitat features were recorded during field work, but a full assessment was not done on this reach due to its impounded nature. Based on qualitative field observations, the Winooski River in R12 appears to have good access to its floodplain. The New England Central Railroad cuts across the southern floodplain, while US Route 2 encroaches upon the northern side of the river. Riparian buffers are lacking along nearly the entire reach due to the presence of agricultural fields. Most of this reach appears to have been historically straightened due to the placement of I-89, Route 2, and the railroad. Bank erosion and armoring are scattered along both banks in R12.

Figure 5.9. R12 is impounded and lacks bed features due to the presence of the Bolton Falls Dam.

R12 Data Summary	*NOT ASSESSED	Reference	Existing
Length: 12,157 ft Drainage Area: 820 sq. mi. Evolution Stage: N/A Sensitivity: N/A	Confinement	Broad	Narrow
	Stream Type	C	C
	Entrenchment Ratio	> 2.2	N/A
	Incision Ratio	< 1.2	N/A
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Dune-Ripple
Major Stressors:	**Channel Straightening, Encroachments, Revetments, Erosion, Flow Regulation**		

R13

Reach 13 on the Winooski River begins just above the Little River and continues upstream for nearly four miles to above Waterbury Village near the Waterbury Ice Center. The reach was not divided into any segments during assessment. The Winooski River is extensively encroached upon by development in R13. Waterbury Village is located on the northeastern bank of the river, River Road in Duxbury is on the south western bank, and US Route 2 is on both banks. The river appears to have been historically straightened to accommodate this development for most of the length of R13. This straightening likely caused moderate channel incision, which has led to a loss of some floodplain access and a stream type departure. In response, the channel has widened and will likely continue to widen before building a juvenile floodplain. The banks of the river are frequently eroding in R13, but have been armored in areas of infrastructure. Several large flood chutes in this reach indicate that the river is moving laterally, however surrounding development limits that movement. Stormwater inputs are common in R13 due to its urbanized surroundings. The river is in **fair** geomorphic condition due to historic incision, active widening, and limitations to planform adjustment due to surrounding developed land. It is also in **fair** habitat condition as a result of poor bank and buffer vegetation, lacking woody debris, and altered channel morphology.

Figure 5.10. Development is prevalent along the Winooski River in R13 (Winooski Street Bridge pictured).

R13 Data Summary		**Reference**	**Existing**
Length: 20,271 ft Drainage Area: 704 sq. mi. Evolution Stage: F-III Sensitivity: Very High	Confinement	Broad	Broad
	Stream Type	C	B_C
	Entrenchment Ratio	> 2.2	1.9
	Incision Ratio	< 1.2	1.7
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Encroachments, Straightening, Erosion, Revetments, Stormwater Inputs, Poor Buffers**		

R14

The upstream-most reach on the Winooski River included in this assessment is R14. It is just over 3 miles long and extends from just above Waterbury Village to just below the confluence of the Mad River in Middlesex/Moretown. The river has a steeper slope in this reach than in the surrounding reaches, and bedrock is prevalent along the banks. The river valley is naturally narrow, but has been further narrowed due to the placement of Route 2, the New England Central Railroad, and I-89. In R14, the river has incised slightly, but bedrock outcrops may be preventing further downcutting. The channel has not widened in comparison to the reaches below it. Small areas of bank erosion are present, as well as small areas of riprap. Several large flood chutes and three islands are present in R14 in areas where bedrock is not present. Buffers are comprised of nice floodplain forests where the river flows away from development. Geomorphic condition is **fair** in R14 due to incision and planform change. Habitat condition is also **fair** as a result of lacking woody debris and areas of poor bank vegetation.

Figure 5.11. Bedrock is abundant on the bed and banks of the Winooski River in R14.

R14 Data Summary		Reference	Existing
Length: 16,253 ft Drainage Area: 671 sq. mi. Evolution Stage: F-II Sensitivity: Very High	Confinement	Narrow	Semi-Confined
	Stream Type	B_C	B_C
	Entrenchment Ratio	1.4 – 2.2	2.2
	Incision Ratio	< 1.2	1.5
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Encroachments, Straightening, Poor Bank Vegetation, Revetments**		

Little River

The Little River is a major tributary of the Winooski River that drains approximately 112 square miles of land in Waterbury and Stowe. A large dam, known as the Waterbury Dam, was constructed on the river in the 1930s for flood control and hydroelectric power. The dam creates the Waterbury Reservoir, a popular location for recreational activities. It is a store-and-release dam and thus causes significant flow alteration, as well as preventing sediment transport downstream.

M2.01

The most downstream reach on the Little River is 3,000 feet in length and was not segmented during assessment. Extreme channel incision has resulted in M2.01 from historic channel straightening and the upstream dam. This channel degradation has led to a stream type departure and loss of floodplain access. The natural valley in M2.01 has been altered from broad to narrow due to I-89 and Route 2 crossing the Little River just upstream of the confluence with the Winooski River. Incision has led to extreme widening and major aggradation and planform change. One mass failure is present in the reach and is contributing sediment to the channel. This reach's riffle-pool bedform is not well defined, and a featureless, plane bed system is subdominant. It is also lacking in large woody debris and has poor bed substrate cover. M2.01 is in **poor** geomorphic condition due to extreme historic incision and widening. The segment is also in **fair** habitat condition due to the lack of diverse bed features and flow alteration.

Figure 5.12. M2.01 impacted by valley width changes by placement of I 89 and Route 2 bridges.

M2.01 Data Summary		Reference	Existing
Length: 3,009 ft	Confinement	Broad	Narrow
Drainage Area: 112 sq. mi.	Stream Type	C	F
Evolution Stage: F-III	Entrenchment Ratio	> 2.2	1.1
Sensitivity: Extreme	Incision Ratio	< 1.2	3.3
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Channel Straightening, Poor bed features and cover, Encroachments, Revetments, Stormwater Inputs**		

M2.02

This reach was not segmented and begins just upstream of the start of the Little River State Park. It continues upstream for approximately 3,750 feet to just above a large meander where the valley narrows naturally. Extensive channel straightening and the presence of a major dam upstream have led to the geomorphic instability observed in this reach. The channel has incised, causing a stream type departure and loss of floodplain access. Major aggradation, widening and planform change have followed the incision process. Like M2.01, plane bed is the subdominant bedform in this reach due to a poorly-defined riffle-pool pattern. Bed cover has also been compromised with increased fining and algae growth. This reach is in **fair** geomorphic condition due to the aforementioned adjustments and processes. M2.02 is in **fair** habitat condition due to its channel morphology, lack of diverse bed features, abundant aggradation and flow alteration.

Figure 5.13. Cross section of M2.02 showing major aggradation and widening.

M2.02 Data Summary		**Reference**	**Existing**
Length: 3,747 ft Drainage Area: 112 sq. mi. Evolution Stage: F-III Sensitivity: Very High	Confinement	Narrow	Narrow
	Stream Type	C	B_C
	Entrenchment Ratio	>2.2	1.5
	Incision Ratio	< 1.2	1.6
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Channel Straightening, Poor bed features and cover, Encroachments**		

M2.03

Reach M2.03 was split into two segments during assessment due to the presence of a bedrock gorge in the middle of the reach.

M2.03-A

Segment M2.03-A begins where the valley becomes more confined and continues upstream for approximately 900 feet until the bedrock gorge. M2.02-A was similar to M2.02 with major channel incision. Flow alteration from the dam upstream at Waterbury Reservoir has most likely led to a series of events beginning with the channel incision due to the dam "starving" the channel of sediment by holding it back. The stream flow is regulated from this dam with scheduled releases daily to every other day. The decrease in sediment in the channel from the dam has historically caused the channel to cut into the bed followed by minor channel widening and major planform change as seen through islands and large flood chutes. M3.02-A is in **fair** geomorphic condition as a result of the flow alteration and processes that have followed. The segment is in **fair** habitat condition due to the presence of algae on the substrate, a lack of large woody debris, and channel morphology.

Figure 5.14. Large flood chute in cross section of M2.03-A.

M2.03-A Data Summary		Reference	Existing
Length: 931 ft Drainage Area: 111 sq. mi. Evolution Stage: F-IV Sensitivity: Very High	Confinement	Semi-confined	Semi-confined
	Stream Type	B_C	B_C
	Entrenchment Ratio	1.4-2.2	2.1
	Incision Ratio	< 1.2	1.5
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Encroachments, Algae, Flow alteration**		

M2.03-B

This segment is a 2,000 foot bedrock gorge. At the top of the gorge there is an old concrete run-of-river dam. Due to the nature of the channel, M2.03-B was not fully assessed and was placed in **good** geomorphic condition based on administrative judgement.

Figure 5.15. Looking downstream into bedrock gorge and old dam in M2.03-B.

M2.03-B Data Summary	*NOT ASSESSED	Reference	Existing
Length: 1,991 ft Drainage Area: 111 sq. mi. Evolution Stage: N/A Sensitivity: N/A	Confinement	Narrowly Confined	Narrowly Confined
	Stream Type	B	B
	Entrenchment Ratio	1.4-2.2	N/A
	Incision Ratio	< 1.2	N/A
	Dominant Bed Material	Bedrock	Bedrock
	Dominant Bedform	Plane Bed	Plane Bed
Major Stressors:	**None**		

M2.04

This reach of the Little River was split into two segments during assessment due to differences in bedform and processes. The downstream segment is more braided and depositional than the upstream segment.

M2.04-A

This segment begins just above the bedrock gorge where there is an old concrete dam and continues upstream for approximately 900 feet. The channel flows through a broad valley and there has been a stream habitat type departure from riffle-pool to braided due to extreme channel aggradation and planform change. Flow alteration from the Waterbury Dam has resulted in major historic incision and subsequent severe widening. The incision caused a stream type departure. Major planform adjustment is also occurring in this segment as water flows around depositional features and islands. The old dam and constriction at the bedrock gorge downstream in M2.03-B have likely exacerbated aggradation in M2.04-A. Due to extreme geomorphic processes occurring in M2.04-A, it is in **poor** geomorphic condition. The flow alteration, channel morphology, and lack of large woody debris have resulted in **fair** habitat condition.

Figure 5.16. Extreme aggradation and braided condition in M2.04-A.

M2.04-A Data Summary		Reference	Existing
Length: 891 ft Drainage Area: 110 sq. mi. Evolution Stage: F-III Sensitivity: Very High	Confinement	Broad	Broad
	Stream Type	C	B_c
	Entrenchment Ratio	> 2.2	1.9
	Incision Ratio	< 1.2	1.9
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Braided
Major Stressors:	**Flow Alteration, Encroachments**		

M2.04-B

The upstream-most segment assessed on the Little River begins about 275 feet downstream of the Vermont Association of Snowmobile Trails (VAST) bridge crossing and continues to approximately 900 feet below the Waterbury Reservoir Dam. As in the downstream segment, M2.04-B has adjusted vertically and horizontally. The channel degradation is a result of the Waterbury Dam holding back sediment, although in this segment the incision is more severe than downstream (incision ratio = 4.2). The channel is also extremely wide and has abundant bank erosion, resulting in minor planform adjustment and aggradation. Frequent releases from the dam (daily or every other day) have formed the channel and are likely responsible for the over-widening. M2.04-B is in **fair** geomorphic condition due to the extreme incision and widening. Habitat condition is **fair** due to changes in channel morphology, flow alteration, unstable river banks, and lack of large woody debris.

Figure 5.17. Bank erosion along western bank in M2.04-B.

M2.04-B Data Summary		Reference	Existing
Length: 2,460 ft Drainage Area: 110 sq. mi. Evolution Stage: F-III Sensitivity: High	Confinement	Broad	Broad
	Stream Type	C	B_C
	Entrenchment Ratio	> 2.2	1.5
	Incision Ratio	< 1.2	4.2
	Dominant Bed Material	Gravel	Cobble
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Bank Erosion, Flow Alteration, Encroachments**		

Graves Brook

Graves Brook is a tributary of the Winooski River that originates in Waterbury Center, flows through Waterbury Village, and enters the Winooski River in R13. Reaches one and two on Graves Brook underwent a Phase 2 assessment in 2010, before Tropical Storm Irene struck the area. The data displayed below reflect the 2010 assessment. Cross sections from segments assessed in 2010 were measured during 2014 to determine changes in channel dimensions that could have occurred during the flood in 2011. A comparison of 2010 and 2014 cross sections can be found in the Post-Flood Update in Appendix D.

R13.S1.01

Reach one on Graves Brook drains approximately 19 square miles and was split into two segments during its 2010 assessment to account for changes in channel dimensions.

R13.S1.01-A

The downstream-most segment on Graves Brook begins at the confluence with the Winooski River and ends between the Armory Drive and I-89 bridges. Almost this entire segment was historically straightened around development in the Village, which caused major historic incision. The stream channel is deep and narrow and abundant bank armoring is preventing widening throughout the majority of the segment. Development is dense in R13.S1.01-A and the New England Central Railroad, Armory Drive, and Union Street encroach upon the stream channel. Stormwater inputs to Graves Brook are abundant in this segment, especially where it flows under road and railroad crossings. R13.S1.01-A is in **fair** geomorphic condition as a result of historic straightening and boundary factors limiting further adjustment. It is also in **fair** habitat condition due to lacking habitat features and a conversion of its natural riffle-pool bedform to featureless plane bed.

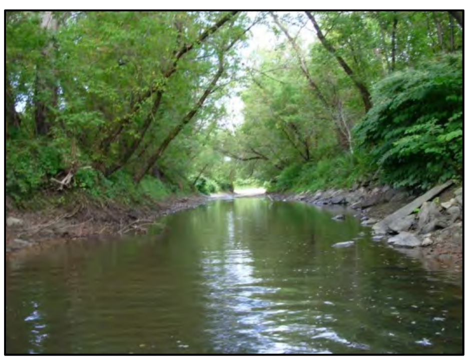


Figure 5.18. Graves Brook has a narrow and deep channel with abundant bank armoring in R13.S1.01-A.

R13.S1.01-A Data Summary		Reference	Existing
Length: 2,089 ft	Confinement	Very Broad	Very Broad
Drainage Area: 19 sq. mi.	Stream Type	C	E
Evolution Stage: F-II	Entrenchment Ratio	> 2.2	3.4
Sensitivity: Extreme	Incision Ratio	< 1.2	1.8
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Plane Bed
Major Stressors:	**Straightening, Encroachments, Revetments, Development, Stormwater Inputs, Undersized Bridges**		

R13.S1.01-B

The second segment on Graves Brook assessed in 2010 begins between the Armory Drive and I-89 bridges and continues upstream for 2,700 feet to just above the bridge on the I-89 Waterbury exit. It appears that all of R13.S1.01-B was historically straightened due to the placement of roads and development. The brook has undergone moderate incision here and is aggradational. Some areas are widening and changing planform via flood chutes. Bank revetments are abundant in R13.S.01-B, preventing widening in several locations. The brook flows under the interstate through three bridges in this segment. Despite some incision, floodplain access remains intact. Due to historic channel management around development and the brook's geomorphic responses, R13.S1.01-B is in **fair** geomorphic condition. It is also in **fair** habitat condition because woody debris is lacking and bank and buffer vegetation are frequently impacted.

Figure 5.19. R13.S1.01-B is more aggradational and wider than surrounding segments.

R13.S1.01-B Data Summary			**Reference**	**Existing**
Length:	2,703 ft	Confinement	Very Broad	Very Broad
Drainage Area:	19 sq. mi.	Stream Type	C	C
Evolution Stage:	F-III	Entrenchment Ratio	> 2.2	3.5
Sensitivity:	Very High	Incision Ratio	< 1.2	1.6
		Dominant Bed Material	Gravel	Gravel
		Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:		**Channel Straightening, Encroachments, Revetments, Stormwater Inputs**		

R13.S1.02

Reach two on Graves Brook drains just over 18 square miles and is nearly 2,200 feet in length. It was split into two segments during the 2010 assessment due to the presence of a bedrock gorge at the downstream end of the segment.

R13.S1.02-A

The downstream-most segment on reach two of Graves Brook is a bedrock gorge, beginning just above the I-89 bridges and continuing upstream nearly 1,000 feet to just below the Stowe Street crossing where bedrock becomes less dominant in the channel. This segment was not fully assessed during 2010 because it is bedrock controlled and very stable. Graves Brook flows through a confined valley and has minimal human impacts. Bank erosion and one mass failure are present in short sections where bedrock does not dominate the stream banks.

Figure 5.20. R13.S1.02-A is a bedrock gorge and is very stable.

R13.S1.02-A Data Summary		**Reference**	**Existing**
	Confinement	Semi-Confined	Semi-Confined
Length: 986 ft	Stream Type	B	N/A
Drainage Area: 18.3 sq. mi.	Entrenchment Ratio	1.4 – 2.2	N/A
Evolution Stage: N/A	Incision Ratio	< 1.2	N/A
Sensitivity: N/A	Dominant Bed Material	Bedrock	Bedrock
	Dominant Bedform	Cascade	Cascade
Major Stressors:	**Development, Encroachments, Erosion, Mass Failure**		

R13.S1.02-B

The second segment on reach two of Graves Brook flows through a confined valley for 1,200 feet from the Stowe Street Bridge to just upstream of where Thatcher Brook flows into Graves Brook. Much of this segment was historically straightened due to surrounding development. The floodplain was filled in to construct roads, which has obscured the degree of channel downcutting in this segment. R13.S1.02-B is afforded some vertical stability due to the presence of abundant bedrock just downstream and one bedrock grade control within the segment. Riprap is common along both banks, which may be preventing widening in areas. R13.S1.02-B is in **fair** geomorphic condition as a result of historic channel alteration. It is also in **fair** habitat condition because woody debris is lacking, floodplain connectivity has been altered, and banks and buffers are not consistently vegetated.

Figure 5.21. Graves Brook is entrenched in R13.S1.02-B due to historic floodplain filling.

R13.S1.02-B Data Summary		**Reference**	**Existing**
Length: 1,187 ft Drainage Area: 18.3 sq. mi. Evolution Stage: F-II Sensitivity: High	Confinement	Semi-Confined	Semi-Confined
	Stream Type	B_C	B_C
	Entrenchment Ratio	1.4 – 2.2	1.4
	Incision Ratio	< 1.2	3.5
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Step-Pool	Plane Bed
Major Stressors:	**Channel Straightening, Encroachments, Revetments, Floodplain Filling**		

R13.S1.03

The third reach assessed on Graves Brook, R13.S1.03, was split into three segments due to channel dimensions, valley widths and variable banks and buffers. Its assessment was conducted in 2014.

R13.S1.03-A

The most downstream segment assessed on Graves Brook is approximately 900 feet in length, beginning at the confluence with Thatcher Brook and continuing upstream where Perry Hill Road exits the river corridor. This section of the reach has been extensively straightened and armored for development. The channel alteration has resulted in degradation and a stream type departure due to the channel becoming deeper but not wider. Abundant bank armoring is preventing widening throughout R13.S1.03-A; however, where armoring is lacking the banks are eroding. The downstream portion of the segment is more incised and entrenched than the upstream end. The stream bed substrate feels soft underfoot from fine sediments, and the channel has lost its riffle-pool bedform, which is now dominated by plane bed. Major channel incision and increased fine sediment coupled with extensive channel alteration have caused R13-S1.03-A to be in **fair** geomorphic condition. Due to unstable river banks, a featureless bed, poor riparian buffers, and channel alterations, habitat conditions in this segment are **fair**.

Figure 5.22. Concrete block wall against Lincoln Street armoring the stream bank along Graves Brook.

R13.S1.03-A Data Summary		**Reference**	**Existing**
Length: 903 ft	Confinement	Very Broad	Very Broad
Drainage Area: 2.7 sq. mi.	Stream Type	C	E
Evolution Stage: F-II	Entrenchment Ratio	> 2.2	9.6
Sensitivity: Extreme	Incision Ratio	< 1.2	1.6
	Dominant Bed Material	Gravel	Sand
	Dominant Bedform	Riffle-Pool	Plane Bed
Major Stressors:	**Channel Straightening, Encroachments, Bank Erosion, Fine Sediment, Revetments, Stormwater Inputs**		

R13.S1.03-B

The middle segment on Graves Brook is characterized by a very broad river valley. Stream banks and buffers are well vegetated, with the exception of the upstream end in the vicinity of the Waterbury Country Club golf course. There are two beaver dams in the segment causing some localized impoundment. The segment is 3,873 feet long, and begins where roads no longer encroach upon the river corridor. This segment has undergone minor incision, but is experiencing major aggradation, widening and planform change. Abundant erosion is present and numerous large bars are forming a juvenile floodplain. Aggradation may be due in part to a drop in slope from the upstream segment. Planform adjustment is common via flood chutes, neck cut offs, and one channel avulsion. This segment is in **fair** geomorphic condition as a result of the aforementioned processes and **good** habitat condition in part due to well vegetated banks and buffers and abundant large woody debris.

Figure 5.23. Abundant aggradation and juvenile floodplain being built on large bar in R13.S1.03-B

R13.S1.03-B Data Summary		**Reference**	**Existing**
Length: 3,873 ft Drainage Area: 2.7 sq. mi. Evolution Stage: F-IV Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	> 2.2	6.9
	Incision Ratio	< 1.2	1.4
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Bank Erosion**		

R13.S1.03-C

The most upstream segment assessed on Graves Brook begins at the upstream end of the golf greens at the Waterbury Country Club, where the valley becomes narrower, and continues approximately 4,000 feet until the reach break for R13.S1.04. Although the valley is narrower on the downstream end of the segment, the channel flows through a very broad valley for much of the segment. The riparian area and stream banks are well forested and there is very little human disturbance in the corridor of this segment. Nonetheless, the channel has incised slightly and has abundant bank erosion indicating that the channel is now widening. There are numerous depositional features and flood chutes as the channel seeks to navigate around the bars and a few debris jams. Mass failures and gullies are introducing sediment to the channel. Overall, R13.S1.03-C is in **fair** geomorphic condition due to various adjustment processes occurring in the segment. Despite the fair geomorphic condition, its habitat condition is **good** due to abundant large woody debris, good substrate cover and well preserved riparian habitat.

Figure 5.24. Planform change in R13.S1.03-C as channel navigates through debris and aggradation.

R13.S1.03-C Data Summary		**Reference**	**Existing**
Length: 3,950 ft Drainage Area: 2.7 sq. mi. Evolution Stage: F-III Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	> 2.2	12.2
	Incision Ratio	< 1.2	1.4
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Bank Erosion, Mass Failures, Gullies**		

Thatcher Brook

Thatcher Brook is a tributary of Graves Brook that originates in Stowe and drains just over 15 square miles as it flows through Waterbury Center and into Graves Brook in reach two. Similarly to Graves Brook, a portion of Thatcher Brook underwent a Phase 2 assessment during 2010. Reaches one through five were assessed in 2010 and six through nine in 2014. The segment descriptions below reflect the 2010 assessment data. Cross sections from segments assessed in 2010 were measured during 2014; a comparison of the two sets of cross sections can be found in the Post-Flood Update in Appendix D.

R13.S1.02-S1.01

The first reach on Thatcher Brook was split into four segments during assessment to account for the presence of a bedrock gorge, as well as changes in channel dimensions and planform.

R13.S1.02-S1.01-A

The first segment on reach one of Thatcher Brook is just over 1,900 feet in length, beginning at the mouth and continuing upstream to the base of the bedrock gorge. Beaver activity is prevalent in this segment, and beaver dams are causing frequent channel adjustment. Over two-thirds of this segment appears to have been historically straightened, which has led to slight historic incision. The stream channel is in the process of widening, aggrading, and adjusting planform. Bank erosion is common along both banks as the stream widens and moves laterally. R13.S1.02-S1.01-A is in **fair** geomorphic condition due to these active adjustments. It is also in **fair** habitat condition due to lacking pool habitat and unstable banks.

Figure 5.25. Beaver activity is common in R13.S1.02-S1.01-A.

R13.S1.02-S1.01-A Data Summary		**Reference**	**Existing**
Length: 1,903 ft	Confinement	Very Broad	Very Broad
Drainage Area: 15.3 sq. mi.	Stream Type	E	E
Evolution Stage: F-III	Entrenchment Ratio	>2.2	14.4
Sensitivity: Extreme	Incision Ratio	< 1.2	1.5
	Dominant Bed Material	Sand	Sand
	Dominant Bedform	Dune-Ripple	Dune-Ripple
Major Stressors:	**Beaver Activity, Straightening, Erosion, Mass Failure**		

R13.S1.02-S1.01-B

The second segment on Thatcher Brook is approximately 1,400 feet in length, beginning behind Shaw's and continuing upstream to almost 500 feet above the Laurel Lane stream crossing. This segment was not fully assessed during 2010 because the lower portion flows through a bedrock gorge and the upper portion is impounded by a historic dam at the top of the gorge. In the upper portion of the segment, roads and development encroach on the river corridor, and the stream has been straightened in a few areas.

Figure 5.26. R13.S1.02-S1.01-B flows through a bedrock gorge that has two dams in it.

R13.S1.02-S1.01-B Data Summary	*NOT ASSESSED	Reference	Existing
Length: 1,391 ft Drainage Area: 15.3 sq. mi. Evolution Stage: N/A Sensitivity: N/A	Confinement	Semi-Confined	Semi-Confined
	Stream Type	B	N/A
	Entrenchment Ratio	>2.2	N/A
	Incision Ratio	< 1.2	N/A
	Dominant Bed Material	Bedrock	Bedrock
	Dominant Bedform	Step-Pool	Step-Pool
Major Stressors:	**Dam, Straightening**		

R13.S1.02-S1.01-C

Segment C on reach one of Thatcher Brook is nearly 2,000 feet in length and flows along Route 100 in Waterbury Center. Similarly to downstream, R13.S1.02-S1.01-C is affected by beaver activity. Just over half of this segment appears to have been historically straightened along Route 100. Despite this, Thatcher Brook does not appear to have incised in this section. The dams and bedrock outcrops downstream afford vertical stability to this segment, and are likely deterring downcutting. Aggradation is major in segment C and is causing some planform adjustment. Beaver dams, which are scattered throughout the segment, are exacerbating lateral movement. Bank erosion is common along both banks and may be associated with these adjustments. Riprap is present where the brook flows directly along Route 100, toward the downstream end of the segment. R13.S1.02-S1.01-C is in **fair** geomorphic condition as a result of the major active adjustment occurring here. It is also in **fair** habitat condition due to a lack of diverse bed features and impacted bank and buffer vegetation.

Figure 5.27. R13.S1.02-S1.01-C is a meandering wetland channel with current beaver activity.

R13.S1.02-S1.01-C Data Summary		Reference	Existing
Length: 1,953 ft	Confinement	Very Broad	Very Broad
Drainage Area: 15.3 sq. mi.	Stream Type	E	E
Evolution Stage: D-IIc	Entrenchment Ratio	>2.2	13.9
Sensitivity: Extreme	Incision Ratio	< 1.2	1.0
	Dominant Bed Material	Sand	Sand
	Dominant Bedform	Dune-Ripple	Dune-Ripple
Major Stressors:	**Straightening, Encroachment, Bank Erosion, Beaver Dams**		

R13.S1.02-S1.01-D

The upstream-most segment on reach one of Thatcher Brook is approximately 1,400 feet in length, flowing between Route 100 to the west and Country Club Road to the east and ending just above the bridge on Guptil Road. Approximately half of the segment was subjected to historic straightening due to surrounding development, which likely sparked slight historic incision. Major aggradation is present in R13.S1.02-S1.01-D and the channel is in the process of widening. Thatcher Brook is undergoing planform adjustment in this segment via several flood chutes and one avulsion. Segment D is in **fair** geomorphic condition due to historic incision and major active aggradation and planform adjustment. Similarly, the segment is in **fair** habitat condition because bed cover is lacking and substrate is very small.

Figure 5.28. Depositional features are abundant in segment D of reach one of Thatcher Brook.

R13.S1.02-S1.01-D Data Summary		**Reference**	**Existing**
Length: 1,358 ft	Confinement	Broad	Broad
Drainage Area: 15.3 sq. mi.	Stream Type	C	C
Evolution Stage: F-III	Entrenchment Ratio	>2.2	6.9
Sensitivity: Very High	Incision Ratio	< 1.2	1.5
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Straightening, Encroachment, Bank Erosion**		

R13.S1.02-S1.02

The second reach on Thatcher Brook flows away from Route 100 through wetlands, residential, and agricultural land. It was not divided into any segments during the 2010 assessment. The segment is just over 4,600 feet in length, beginning near the intersection of Guptil Road and Route 100 and ending upstream between the Guptil Road and Kneeland Flats Road bridges. R13.S1.02-S1.02 is characterized by a meandering wetland channel with a mostly natural planform. Historic straightening appears to have occurred in the vicinity of the two bridges within this reach. The brook has undergone slight historic incision and has begun to widen in this area. Floodplain access throughout R13.S1.02-S1.02 is excellent, and it retains a natural riffle-pool bedform. Bank erosion is scattered along both banks, as is bank armoring. The sinuous planform of Thatcher Brook within this reach has led to major planform adjustment including several flood chutes and channel avulsions. Debris jams appear to be exacerbating lateral adjustment in this area. R13.S1.02-S1.02 is in **fair** geomorphic condition as a result of all the aforementioned adjustments. The reach is in **good** habitat condition due to its natural planform and excellent diversity of streambed features.

Figure 5.29. Woody debris is abundant in R13.S1.02-S1.02.

R13.S1.02-S1.02 Data Summary		**Reference**	**Existing**
Length: 4,611 ft Drainage Area: 13.5 sq. mi. Evolution Stage: F-III Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	>2.2	18.1
	Incision Ratio	< 1.2	1.3
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Erosion, Straightening, Encroachment, Mass Failure**		

R13.S1.02-S1.03

The third reach on Thatcher Brook is approximately 3,700 feet in length, extending from just above the confluence of Unnamed Tributary 1 to Thatcher Brook to just above the confluence of Unnamed Tributary 2 to Thatcher Brook. The reach was not split into any segments during assessment. The majority of this reach was likely subjected to channel straightening in the past due to surrounding development and agricultural land. Despite this, the channel has not undergone any incision. Aggradation is the major process in this reach that is driving adjustment. As sediment accumulates in the channel, widening and planform adjustment are occurring in response. Bank erosion is common along both banks as the brook works to establish lost meanders. Flood chutes are abundant in R13.S1.02-S1.03, crossing over deposited material and meander bends. The brook's riffle pool bedform has been impacted by sedimentation, creating mostly short, steep riffles. This reach is in **fair** geomorphic condition as a result of the aggradation-driven adjustments observed. It is in **good** habitat condition, though, because woody debris, pools, and bank vegetation create good instream cover for aquatic organisms.

Figure 5.30. Aggradation and debris jams are driving adjustments in R13.S1.02-S1.03.

R13.S1.02-S1.03 Data Summary		Reference	Existing
Length: 3,706 ft Drainage Area: 10.3 sq. mi. Evolution Stage: D-IIc Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	>2.2	16.4
	Incision Ratio	< 1.2	1.0
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Erosion, Mass Failure, Encroachment**		

R13.S1.02-S1.04

This reach was divided into three segments to account for the presence of depositional features and differences in substrate size and channel evolution stage.

R13.S1.02-S1.04-A

This segment is characterized by a very broad valley with a C stream type that has been almost 100 percent historically straightened. The segment begins at the confluence of Unnamed Tributary 2 and continues to approximately 1,000 feet downstream of the Guptil Road Bridge. Development and encroachment from Guptil Road is common along the eastern bank lending to abundant armoring and pasture with no buffer is common along the western bank. Approximately halfway up the segment there is an animal ford across two pastures. Depositional features are abundant including mid-channel bars. The channel has experienced moderate incision, is widening and a new floodplain is being built up in some areas. Riparian buffers are poor in many locations due to pastures and development. Habitat and geomorphic conditions are both **fair** in this segment due to the processes and lack of riparian buffers and adequate bank vegetation.

Figure 5.31. River corridor encroachment and lack of riparian buffer in R13.S1.02-S1.04-A.

R13.S1.02-S1.04-A Data Summary		**Reference**	**Existing**
Length: 1,785 ft	Confinement	Very Broad	Very Broad
Drainage Area: 7.8 sq. mi.	Stream Type	C	C
Evolution Stage: F-III	Entrenchment Ratio	>2.2	11.9
Sensitivity: Very High	Incision Ratio	< 1.2	1.5
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Channel alteration, Bank Erosion, Encroachments, Armoring, Animal Ford, Poor Buffer Vegetation**		

R13.S1.02-S1.04-B

This segment begins approximately 1,000 feet below the Guptil Hill Road Bridge and continues for 2,250 feet just downstream of where the stream goes away from Thatcher Brook Road. Similar to the downstream segment, riparian buffers are poorly vegetated, which has created unstable, eroding banks. Stormwater inputs from field ditches, overland flow, and tile drains are abundant but channel alteration is not as extensive as the downstream segment. Two gullies and one mass failure are present contributing sediment to the channel. The major processes that have occurred are historic channel incision followed by aggradation, widening and planform adjustment. The geomorphic condition is **fair** as a result of the incision and subsequent processes. Habitat conditions in this segment are also **fair** due to impacted hydrologic characteristics from land use change and stormwater and compromised river banks and riparian buffers.

Figure 5.32. Bank erosion and lack of riparian buffer along pasture in R13.S1.02-S1.04-B.

R13.S1.02-S1.04-B Data Summary		**Reference**	**Existing**
Length: 2,253 ft Drainage Area: 7.8 sq. mi. Evolution Stage: F-III Sensitivity: High	Confinement	Broad	Broad
	Stream Type	C	C
	Entrenchment Ratio	>2.2	8.5
	Incision Ratio	< 1.2	1.8
	Dominant Bed Material	Gravel	Cobble
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Channel alteration, Stormwater inputs, Bank Erosion, Encroachments, Armoring, Poor Buffer Vegetation, Gullies**		

R13.S1.02-S1.04-C

The most upstream segment in this reach begins approximately 1,300 feet upstream from the Guptil Road Bridge near Thatcher Brook Road and continues to about 1,000 feet downstream of the Loomis Hill Road Bridge. Riparian buffers are well vegetated along the southeastern bank and the upstream end of the northwestern bank in this segment. Corridor encroachments are minimal and pasture is limited to the downstream end of the northern side of the channel. Historic channel degradation and subsequent widening has led to major aggradation as seen by the formation of numerous depositional features. Major planform adjustment has resulted as the channel has sought equilibrium from the widening and aggradation forming many flood chutes and one channel avulsion. The channel has mostly moved past the widening stage and is building a new floodplain on larger bars. Similar to downstream segments, mass failures and gullies are present contributing sediment to the channel. The geomorphic condition is **fair** due to the abundance of deposition, widened channel and planform change. Bank conditions and compromised riffle-pool patterns and hydrologic characteristics due to sedimentation have led to the **fair** habitat condition in this segment.

Figure 5.33. Large bar in R13.S1.02-S1.05-C causing major channel widening.

R13.S1.02-S1.04-C Data Summary		Reference	Existing
Length: 2,370 ft Drainage Area: 7.8 sq. mi. Evolution Stage: F-IV Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	>2.2	4.1
	Incision Ratio	< 1.2	1.5
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Bank erosion, Lack of buffers, Gullies, Mass failures**		

R13.S1.02-S1.05

The most upstream reach that was assessed in 2010 on Thatcher Brook was split into two segments in the field due to variability in dominant processes and channel evolution stage. The downstream segment was much more depositional and in stage F-IV while the upstream segment was in stage F-II.

R13.S1.02-S1.05-A

This segment begins approximately 1,125 feet downstream of the Loomis Hill Road Bridge and continues for 3,660 feet upstream. The bedform in R13.S1.02-S1.05-A is riffle-pool by reference but it has been altered to plane bed as a result of extensive historic channel straightening for agriculture. Gravel mining was noted in two locations during the 2010 assessment. This channel alteration likely resulted in incision, followed by aggradation, widening and planform adjustment. River scientists observed greater aggradation and widening in 2014 than 2010, before Tropical Storm Irene. The segment is in **fair** geomorphic condition due to the various processes resulted from channel alteration and **good** habitat condition as a result of abundant large woody debris and good bank vegetation.

Figure 5.34. Large bar in R13.S1.02-S1.05-A where gravel mining appears to have occurred.

R13.S1.02-S1.05-A Data Summary		**Reference**	**Existing**
Length: 3,664 ft	Confinement	Very Broad	Very Broad
Drainage Area: 7.1 sq. mi.	Stream Type	C	C
Evolution Stage: F-IV	Entrenchment Ratio	>2.2	3.8
Sensitivity: Very High	Incision Ratio	< 1.2	1.7
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Plane Bed
Major Stressors:	**Channel alteration, Gravel Mining, Lack of buffers**		

R13.S1.02-S1.05-B

Segment B begins approximately 2,500 feet upstream of the Loomis Hill Bridge and continues for 800 feet to the confluence of a tributary. Like the downstream segment, the dominant reference bedform of riffle-pool has been converted to plane bed as a result of historic channel straightening. Berms are common along both banks, most likely from previous windrowing of the channel. Thatcher Brook has incised in this segment but has not yet widened. Aggradation was observed to be more pronounced in 2014 than in 2010, most likely due to Tropical Storm Irene. The geomorphic condition is **fair** due to channel alterations and incision. R13.S1.02-S1.05-B is also in **fair** habitat condition as a result of lacking woody debris, poor pool habitat, and past channel alterations.

Figure 5.35. Historic berm preventing floodplain access in R13.S1.02-S1.05-B.

R13.S1.02-S1.05-B Data Summary		**Reference**	**Existing**
Length: 805 ft Drainage Area: 7.1 sq. mi. Evolution Stage: F-II Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	>2.2	6.7
	Incision Ratio	< 1.2	1.6
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Plane Bed
Major Stressors:	**Channel alteration, Berms**		

R13.S1.02-S1.06

The most downstream reach that BCE assessed on Thatcher Brook, R13.S1.02-S1.06, was split into two segments in the field due to differences in channel dimensions.

R13.S1.02-S1.06-A

This segment flows through a very broad valley and is characterized by a historically straightened depositional channel whose banks contain many mass failures and abundant erosion. R13.S1.01-S1.06-A begins approximately 3,200 feet upstream of the Loomis Hill Road crossing and continues upstream for another 3,200 feet along Maple Street. Floodplain access is variable throughout the segment but mostly it is incised and currently widening. Planform change is evident as there are many flood chutes and islands. Three mass failures in this segment are contributing to bank instability and increased sediment to Thatcher Brook. The riparian buffers are well forested on the eastern side of the segment but the western side has areas lacking a vegetated woody buffer. The segment is in **fair** geomorphic condition due to adjustment processes resulting from channel alteration. Reduced large woody debris, lacking bank vegetation, and the straightened planform have contributed to the **fair** habitat condition. .

Figure 5.36. One of three mass failures in R13.S1.02-S1.06-A contributing sediment to the channel.

R13.S1.02-S1.06-A Data Summary		**Reference**	**Existing**
Length: 3,243 ft Drainage Area: 6.2 sq. mi. Evolution Stage: F-III Sensitivity: High	Confinement	Very Broad	Very Broad
	Stream Type	C_b	C_b
	Entrenchment Ratio	>2.2	3.5
	Incision Ratio	< 1.2	1.5
	Dominant Bed Material	Gravel	Cobble
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Channel alteration, Bank Erosion, Mass Failures, Revetments, Encroachments**		

R13.S1.02-S1.06-B

This segment begins approximately 1,100 feet northeast of the intersection of Guild Hill Road and Maple Street and continues upstream for about 1,500 feet. Overall, planform is mostly natural and undisturbed in R13.S1.02-S1.06-B, and the brook has been very minimally straightened. Thatcher Brook has incised moderately in this section but retains access to its floodplain. It is currently in the process of widening, and bank erosion is common along both banks. Major planform adjustment is occurring in this segment, which has led to the formation of two islands. Short sections of braiding occur where the brook is aggrading. Due to the channel incision and planform adjustment, the segment is in **fair** geomorphic condition. Well forested riparian buffers, vegetated banks, abundant large woody debris, and a well-defined bedform have resulted in a **good** habitat condition in R13.S1.02-S1.06-B.

Figure 5.37. Typical channel in R13.S1.02-S1.06-B.

R13.S1.02-S1.06-B Data Summary		**Reference**	**Existing**
Length: 1,565 ft Drainage Area: 6.2 sq. mi. Evolution Stage: F-III Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C_b	C_b
	Entrenchment Ratio	> 2.2	3.0
	Incision Ratio	< 1.2	1.6
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Bank Erosion, Mass failure**		

R13.S1.02-S1.07

The next reach upstream on Thatcher Brook, R13.S1.02-S1.07, was not segmented during assessment. It begins approximately 800 feet northeast of the intersection of Mountain View Drive and Maple Street and continues 3,700 feet through forested land until the confluence with tributary R13.S1.02-S1.07-S1. No development is present in the river corridor except for a small deck and stone wall. This segment is steeper than most of the downstream segments and its valley narrower. The channel has incised and has begun to widen, as evidenced by its eroding banks. Mass failures are common in R13.S1.02-S1.07, and are contributing sediment to the stream. Short sections within this reach have major flood chutes and large bars containing abundant sediment that may have been deposited during Tropical Storm Irene. There is also an incised tributary that appears to have windrowed after the storm. R13.S1.02-S1.07 is in **fair** geomorphic condition as a result of the downcutting of the stream channel and planform adjustment around bars, debris jam and one island. Habitat conditions in this reach, however, are **good** due to well vegetated riparian buffers and good substrate cover.

Figure 5.38. Large point bar where material from TSI may have been deposited.

R13.S1.02-S1.07 Data Summary		**Reference**	**Existing**
Length: 3,704 ft	Confinement	Broad	Broad
Drainage Area: 6 sq. mi.	Stream Type	B	B
Evolution Stage: F-III	Entrenchment Ratio	1.4 - 2.2	1.3
Sensitivity: High	Incision Ratio	< 1.2	1.9
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Step-Pool	Step-Pool
Major Stressors:	**Mass Failures**		

R13.S1.02-S1.08

This reach was divided into two segments to account for variability in stream type and valley width.

R13.S1.02-S1.08-A

This segment is 2,960 feet in length, beginning just above the confluence with tributary R13.S1.02-S1.07-S1. The brook flows through a densely forested area for the whole segment, with no development. Overall, the channel has incised and not yet widened but there are locations with good floodplain access. Some areas have more planform adjustment than others via flood chutes, neck cut offs, and bifurcation around islands. Mass failures and small areas of bank erosion are present as well, but overall the banks are stable and mossy. The geomorphic condition of this segment is **fair** due mostly to the channel degradation and localized planform adjustment. However, the segment is in **good** habitat condition due to well forested banks and buffers, abundant woody debris in the channel, excellent substrate cover, and a well-defined step-pool habitat.

Figure 5.39. Well forested banks and buffers in R13.S1.02-S1.08-A.

R13.S1.02-S1.08-A Data Summary		**Reference**	**Existing**
Length: 2,960 ft Drainage Area: 3.8 sq. mi. Evolution Stage: F-II Sensitivity: High	Confinement	Very Broad	Very Broad
	Stream Type	C_b	C_b
	Entrenchment Ratio	> 2.2	3.7
	Incision Ratio	< 1.2	1.5
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Step-Pool	Step-Pool
Major Stressors:	**Mass Failures**		

R13.S1.02-S1.08-B

Conditions in this segment are very similar to downstream: well forested riparian habitat with no development along the valley wall. The segment comprises the top 1,250 feet of the reach and begins where the valley width becomes narrower. Valley confinement is variable with some areas semi-confined and some very broad. If not for the extreme incision in this segment, it would be in great condition. Although the degree of incision was extreme in the vicinity of the cross section location, there are areas where incision was not as severe and there was better floodplain access. The channel has not yet widened and there is minor bank erosion resulting in very stable and mossy banks except for two locations where there are mass failures. The segment is in **fair** geomorphic condition due to channel incision but in **good** habitat condition as a result of stable banks and undisturbed riparian habitat.

Figure 5.40. Mossy and stable stream banks in R13.S1.02-S1.08-B.

R13.S1.02-S1.08-B Data Summary		Reference	Existing
Length: 1,246 ft	Confinement	Very Broad	Very Broad
Drainage Area: 3.8 sq. mi.	Stream Type	B	B
Evolution Stage: F-II	Entrenchment Ratio	1.4 - 2.2	1.6
Sensitivity: High	Incision Ratio	< 1.2	2.1
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Step-Pool	Step-Pool
Major Stressors:	**Mass Failures**		

R13.S1.02-S1.09

This reach was divided into four segments to account for variability in stream type and banks and buffers and to split out a wetland section.

R13.S1.02-S1.09-A

The most downstream segment in reach 9 of Thatcher Brook has characteristics similar to the reach 8. Segment A is 1,340 feet long and flows through densely forested land. The valley is very broad on average but it is narrower toward the upstream end of the segment. Where the valley opens up significantly is where the next segment begins. The downstream section has experienced some planform adjustment around two islands. This segment has incised but retains its reference stream type and access to its floodplain. The channel has not widened and bank erosion is minimal. Overall, Thatcher Brook is in **good** geomorphic condition in this segment despite moderate channel incision. It also is in **good** habitat condition due to undisturbed riparian habitat and stable, well-vegetated banks.

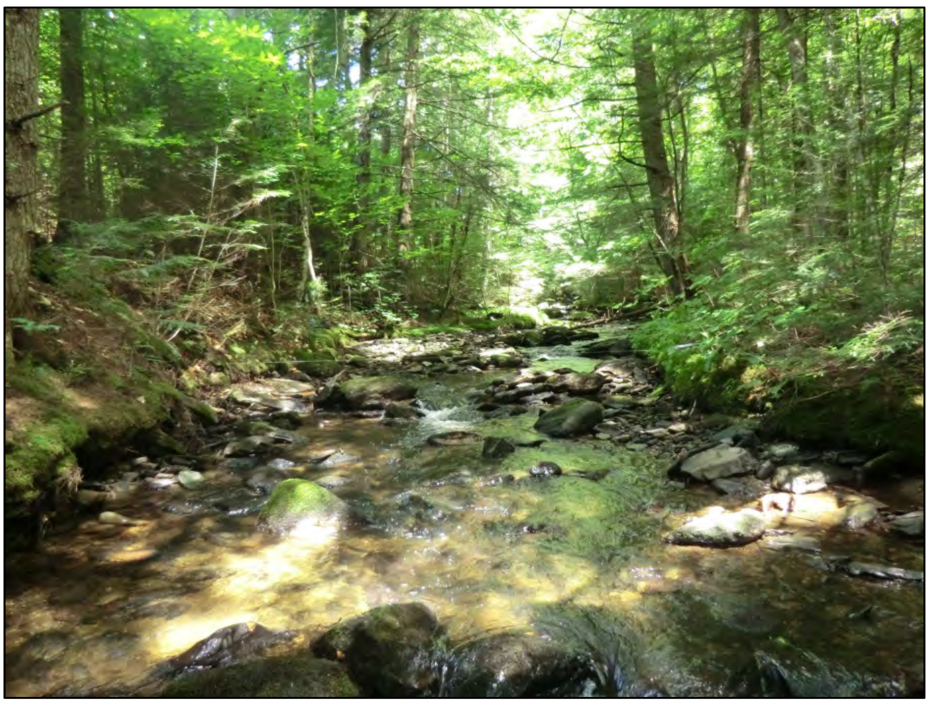


Figure 5.41. R13.S1.02-S1.09-A has well forested banks and buffers.

R13.S1.02-S1.09-A Data Summary		**Reference**	**Existing**
Length: 1,339 ft Drainage Area: 2.8 sq. mi. Evolution Stage: F-II Sensitivity: Moderate	Confinement	Very Broad	Very Broad
	Stream Type	B	B
	Entrenchment Ratio	1.4 - 2.2	2.1
	Incision Ratio	< 1.2	1.7
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Step-Pool	Step-Pool
Major Stressors:	**None**		

R13.S1.02-S1.09-B

The next segment is characterized by a wetland channel through a very broad valley. The segment begins where the valley opens way up and there is a hay field in the western riparian corridor. The channel continues for approximately 1,100 feet and ends just upstream of a road crossing at a beaver dam, which has created a wetland. Flow out of the wetland is split and results in three culverts at the road crossing. The split flow is reconnected downstream of the crossing. This segment is also incised but only slightly and widening is minor. Aggradation is a major process in this segment and is perhaps a natural condition as the segment is a transition zone between the wetland upstream and the steeper forested section downstream. Many flood chutes indicate major planform change, but this is natural for this type of system. Segment R13.S1.02-S1.09-B is in **fair** geomorphic condition due to the channel incision, aggradation and planform adjustment. However, the habitat condition is **good** as a result of well vegetated banks and buffers, good hydrologic characteristics through wetland drainage and abundant large woody debris.

Figure 5.42. Thatcher Brook in R13.S1.02-S1.09-B is a wetland channel.

R13.S1.02-S1.09-B Data Summary		**Reference**	**Existing**
Length: 1,161 ft Drainage Area: 2.8 sq. mi. Evolution Stage: F-IV Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	> 2.2	4.2
	Incision Ratio	< 1.2	1.4
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Undersized culverts**		

R13.S1.02-S1.09-C
This segment is approximately 300 feet long and was not assessed because it is an impounded wetland. A beaver dam at its downstream end just above a driveway crossing is causing the impoundment.

Figure 5.43. Segment R13.S1.02-S1.09-C is a wetland.

R13.S1.02-S1.09-C Data Summary		**Reference**	**Existing**
Length: 293 ft Drainage Area: 2.8 sq. mi. Evolution Stage: N/A Sensitivity: N/A	Confinement	Very Broad	Very Broad
	Stream Type	N/A	N/A
	Entrenchment Ratio	N/A	N/A
	Incision Ratio	N/A	N/A
	Dominant Bed Material	N/A	N/A
	Dominant Bedform	N/A	N/A
Major Stressors:	**None**		

R13.S1.02-S1.09-D

The upstream-most segment on Thatcher Brook is approximately 1,700 feet long and begins at the top of the wetland and continues until just above the Waterworks Road crossing. The riparian conditions are well vegetated and there is little erosion, but the main impact of this segment is flow regulation from the upstream water withdrawal by the Town of Waterbury. At the first visit to this segment, the streambed was completely dry at the upstream end. When BCE returned to the stream to assess the segment, there was flow in the channel. The stream has undergone minor channel incision and retains its reference stream type and access to its floodplain except for one location where the channel material has been windrowed creating a berm. R13.S1.02-S1.09-D is in **fair** geomorphic condition as a result of historic incision, major aggradation and planform adjustment. Despite the impacted flow regime in the upstream end of the segment, overall it is in **good** habitat condition due to stable well vegetated banks and buffers and abundant large woody debris.

Figure 5.44. Dry streambed in R13.S1.02-S1.09-D.

R13.S1.02-S1.09-D Data Summary		Reference	Existing
	Confinement	Very Broad	Very Broad
Length: 1,736 ft	Stream Type	C	C
Drainage Area: 2.8 sq. mi.	Entrenchment Ratio	> 2.2	5.8
Evolution Stage: F-IV	Incision Ratio	< 1.2	1.3
Sensitivity: Very High	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Windrowing, Flow Regulation**		

Unnamed Tributary 1 to Thatcher Brook

R13.S1.02-S1.02-S1.01

The first unnamed tributary to Thatcher Brook flows from state forest land down through Waterbury Center and enters Thatcher Brook in reach R13.S1.02-S1.02. It drains approximately 2.8 square miles of forested and agricultural lands. R13.S1.02-S1.02-S1.01 was split into seven segments during assessment to account for changes in channel dimensions and surrounding land use.

R13.S1.02-S1.02-S1.01-A

The downstream-most segment on reach one of the first unnamed tributary to Thatcher Brook is an *alluvial fan*, which forms as the channel slope drops and river valley widens from the upstream bedrock gorge to meet Thatcher Brook. It is a dynamic area where abundant aggradation and planform change naturally occur. The segment is short, extending from the confluence with Thatcher Brook upstream about 700 feet to the start of a bedrock gorge. The stream channel has incised historically and is in the process of widening. Due to these adjustments, R13.S1.02-S1.02-S1.01-A is in **fair** geomorphic condition. It is also in **fair** habitat condition as a result of lacking pool habitat, eroding stream banks, and lacking forested buffer.

Figure 5.45. R13.S1.02-S1.02-S1.01-A is an alluvial fan with abundant aggradation.

R13.S1.02-S1.02-S1.01-A Data Summary		**Reference**	**Existing**
Length: 740 ft Drainage Area: 2.8 sq. mi. Evolution Stage: F-III Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	> 2.2	5.3
	Incision Ratio	< 1.2	1.8
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Erosion**		

R13.S1.02-S1.02-S1.01-B

The second segment on reach one of Unnamed Tributary 1 is nearly 500 feet in length. It was not fully assessed because it is a bedrock gorge. There are three large bedrock grade controls present in this segment and abundant bedrock lining the valley walls. The stream channel is stable, but bank erosion is occurring where bedrock is not present on the banks. Based on qualitative field observations, the segment was estimated to be in **good** geomorphic condition.

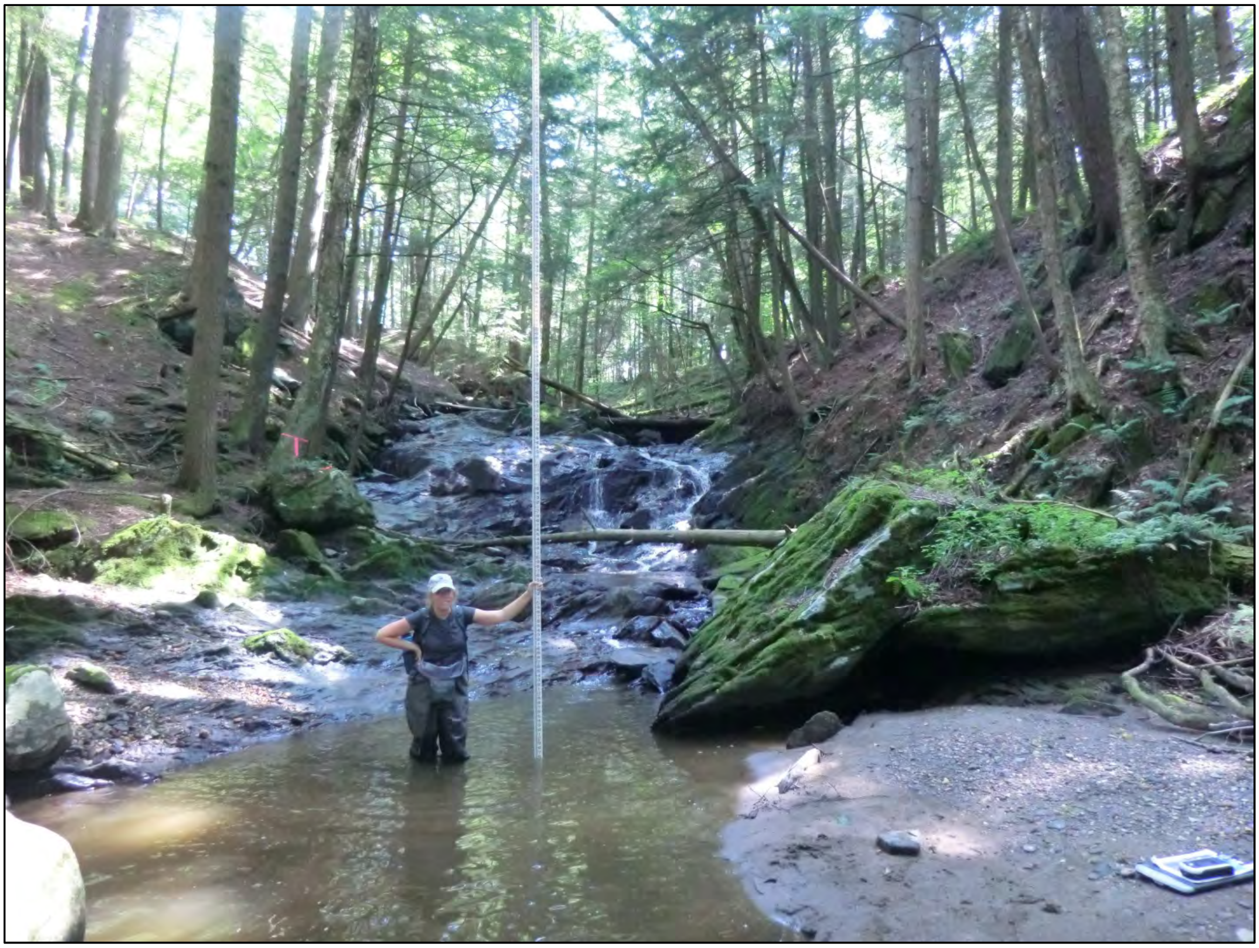


Figure 5.46. R13.S1.02-S1.02-S1.01-B is a bedrock gorge and was not fully assessed.

R13.S1.02-S1.02-S1.01-B Data Summary	***NOT ASSESSED**	**Reference**	**Existing**
Length: 487 ft Drainage Area: 2.8 sq. mi. Evolution Stage: N/A Sensitivity: N/A	Confinement	Broad	Broad
	Stream Type	A	A
	Entrenchment Ratio	< 1.4	N/A
	Incision Ratio	< 1.2	N/A
	Dominant Bed Material	Bedrock	Bedrock
	Dominant Bedform	Cascade	Cascade
Major Stressors:	**Erosion, Mass Failures**		

R13.S1.02-S1.02-S1.01-C

The next most upstream segment on Unnamed Tributary 1 to Thatcher Brook is about 2,700 feet in length, extending from the upper end of the bedrock gorge upstream to slightly above the Twin Peaks Road stream crossing. This section of the stream has incised historically and is actively adjusting planform via flood chutes, but has not widened much. Areas within this segment have majorly aggraded and bank erosion is scattered throughout. One short section was recently windrowed and bermed to protect a landowner's lawn. Segment C mostly flows undisturbed through the woods, though the upstream end is more residential. Geomorphic condition is **fair** because of historic incision and active planform adjustment. R13.S1.02-S1.02-S1.01-C is in **good** habitat condition, as it has ample woody debris to provide in-channel cover and well forested banks and buffers.

Figure 5.47. Segment C flows through the woods in Waterbury Center and is largely undisturbed.

R13.S1.02-S1.02-S1.01-C Data Summary		**Reference**	**Existing**
Length: 2,730 ft Drainage Area: 2.8 sq. mi. Evolution Stage: F-IV Sensitivity: High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	> 2.2	3.2
	Incision Ratio	< 1.2	2.0
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Erosion, Windrowing**		

R13.S1.02-S1.02-S1.01-D

Segment D on reach one begins about 900 feet above the Twin Peaks Road crossing and continues upstream for about 1,300 feet. The stream is surrounded by agricultural lands in this area and is lacking sufficient buffer vegetation for most of the segment. Over two-thirds of this segment was historically straightened, likely to produce contiguous cropland. In response to this straightening, the stream channel has incised substantially, and continues to incise via one active headcut. Clay and glacial till are common on the bed and banks, further suggesting that the channel has downcut. The stream in this area has not yet begun to widen, creating a deep, narrow channel. Scour is prevalent along both banks of the stream within R13.S1.02-S1.02-S1.01-D. This segment is in **fair** geomorphic condition due to historic planform alteration and active downcutting. It is also in **fair** habitat condition because pools, large woody debris, and bank and buffer vegetation are lacking.

Figure 5.48. Segment C flows through the woods in Waterbury Center and is largely undisturbed.

R13.S1.02-S1.02-S1.01-D Data Summary		Reference	Existing
Length: 1,321 ft Drainage Area: 2.8 sq. mi. Evolution Stage: F-II Sensitivity: Extreme	Confinement	Very Broad	Very Broad
	Stream Type	E	E
	Entrenchment Ratio	> 2.2	3.1
	Incision Ratio	< 1.2	2.0
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Straightening, Poor Buffers, Headcut, Erosion**		

R13.S1.02-S1.02-S1.01-E

This segment is approximately 1,900 feet in length and ends upstream at the Perry Hill Road crossing. The stream flows through pasture land for cows and horses for the entirety of this segment. Due to surrounding land use, riparian buffers are lacking throughout the segment. There are eight crossings for animals and farm vehicles in the segment. It appears that the stream underwent an avulsion in recent years at the upstream end of the segment, causing it to flow about 100 feet to the north of its previous location. Over half of the segment was likely straightened historically to produce agricultural lands, which appears to have caused slight historic incision. The stream channel is currently beginning to widen and adjust planform as evidenced by bank erosion and flood chutes. Mass failures occur along the poorly vegetated southern valley wall where the stream flows adjacent to it. Due to slight historic incision and current widening, as well as geomorphic instability related to pastured animals grazing in the stream, R13.S1.02-S1.02-S1.01-E is in **fair** geomorphic condition. Banks and buffers are lacking vegetation, pool habitat is absent, and woody debris is scarce in this segment, which all contribute to its **fair** habitat condition.

Figure 5.49. R13.S1.02-S1.02-S1.01-E flows through pastured lands and is impacted by grazing animals.

R13.S1.02-S1.02-S1.01-E Data Summary		**Reference**	**Existing**
Length: 1,880 ft Drainage Area: 2.8 sq. mi. Evolution Stage: F-III Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	> 2.2	3.4
	Incision Ratio	< 1.2	1.4
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Straightening, Animal Grazing, Poor Buffers, Poor Bank Vegetation, Erosion, Mass Failures**		

R13.S1.02-S1.02-S1.01-F

Segment F on R13.S1.02-S1.02-S1.01 is characterized by a narrow channel flowing through shrubby wetlands. The channel has a natural planform in this segment, except for where it was straightened at the downstream-most end where it crosses under Perry Hill Road. The segment is approximately 1,200 feet in length, beginning just below the Perry Hill Road crossing and continuing upstream. The stream channel in R13.S1.02-S1.02-S1.01-F has incised very slightly but has not widened and has great floodplain access. Bank erosion is common along this sinuous stretch of stream. Its undisturbed planform and good floodplain access cause it to be in **good** geomorphic condition. R13.S1.02-S1.02-S1.01-F is in **fair** habitat condition because it is lacking in channel woody debris, there are few pools, and the banks are unstable in areas.

Figure 5.50. Segment F is a naturally narrow channel flowing through a shrubby wetland.

R13.S1.02-S1.02-S1.01-F Data Summary		**Reference**	**Existing**
Length: 1,245 ft Drainage Area: 2.8 sq. mi. Evolution Stage: F-II Sensitivity: High	Confinement	Very Broad	Very Broad
	Stream Type	E	E
	Entrenchment Ratio	> 2.2	8.1
	Incision Ratio	< 1.2	1.2
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Erosion, Mass Failure**		

R13.S1.02-S1.02-S1.01-G

This segment is the uppermost segment included in this study on the first unnamed tributary to Thatcher Brook. It is approximately 1,200 feet in length and flows in the woods behind houses on the south side of Kneeland Flats Road. R13.S1.02-S1.02-S1.01-G is steeper than the downstream segments (other than B) and is undisturbed. Its planform is natural and it has not incised or widened. Floodplain access is excellent. Areas of minor erosion exist on both banks and one short mass failure is present on each side of the stream. Surrounding lands are primarily forested with short sections of agricultural land and residential land closer to Kneeland Flats Road. R13.S1.02-S1.02-S1.01-G is in **good** geomorphic condition due to its stability and undisturbed nature, as well as excellent floodplain access. The segment is also in **good** habitat condition, as large woody debris is abundant in the channel, there is a diversity of bed features, and the banks and buffers are well forested.

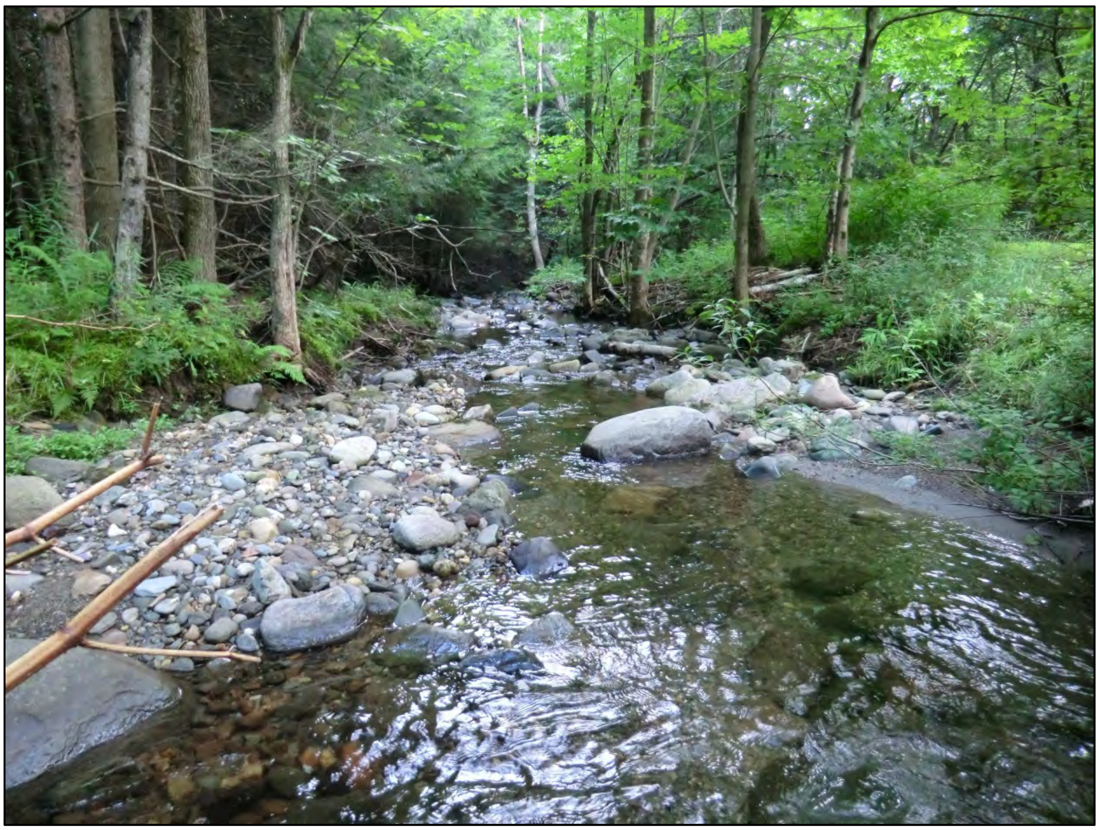


Figure 5.51. R13.S1.02-S1.02-S1.01-G flows through forested land and is stable and undisturbed.

R13.S1.02-S1.02-S1.01-G Data Summary		**Reference**	**Existing**
Length: 1,226 ft Drainage Area: 2.8 sq. mi. Evolution Stage: F-I Sensitivity: Moderate	Confinement	Very Broad	Very Broad
	Stream Type	C_b	C_b
	Entrenchment Ratio	> 2.2	4.2
	Incision Ratio	< 1.2	1.0
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Erosion, Mass Failures**		

Unnamed Tributary 2 to Thatcher Brook

R13.S1.02-S1.03-S1.01

The second unnamed tributary to Thatcher Brook included in this assessment flows into Thatcher Brook in reach R13.S1.02-S1.03 and has a drainage area of almost 2.3 square miles. It parallels the course of the first unnamed tributary but is located slightly to the north. Reach one on the second unnamed tributary to Thatcher Brook is 7,000 feet in length and flows through forested and residential lands in Waterbury Center. It was split into three segments during assessment to account for changes in planform and banks and buffers.

R13.S1.02-S1.03-S1.01-A

The downstream-most segment on this tributary begins at the confluence with Thatcher Brook and continues upstream to about 900 feet above the bridge on Guptil Road. It flows through residential land and was historically straightened for about half of its length. This section of the stream has not incised or widened and retains excellent floodplain access. Aggradation is abundant in this segment, as is bank armoring, especially in the vicinity of the bridge and directly above it. The section above the bridge is used as pasture land and cows have access to the stream. Bank erosion is minimal in R13.S1.02-S1.03-S1.01-A. A short section at the confluence with Thatcher Brook appears to have been windrowed. This segment is in **fair** geomorphic condition as a result of historic straightening and the encroachment of development. It is also in **fair** habitat condition due to lacking woody debris, poor diversity of bed features, and impacted buffer zones.

Figure 5.52. Riprap and development are common in R13.S1.02-S1.03-S1.01-A.

R13.S1.02-S1.03-S1.01-A Data Summary		**Reference**	**Existing**
	Confinement	Very Broad	Very Broad
Length: 1,162 ft	Stream Type	C	C
Drainage Area: 2.3 sq. mi.	Entrenchment Ratio	> 2.2	12.1
Evolution Stage: F-I	Incision Ratio	< 1.2	1.0
Sensitivity: High	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Straightening, Encroachments, Animal Grazing, Revetments**		

R13.S1.02-S1.03-S1.01-B

The second segment on reach one of the second unnamed tributary to Thatcher Brook is nearly 3,000 feet in length and ends just upstream of the bridge on Harvey Farm Road. Much of the segment flows through shrubby wetlands and lacustrine, clay-laden soils. Historic straightening occurred very minimally in this segment, only in the vicinity of the bridge and a short section along an agricultural field. Similarly to downstream, this segment has not incised or widened, however major aggradation is causing widespread planform adjustment. Numerous steep riffles and flood chutes are present and contributing to lateral movement of the channel. This adjustment has caused bank erosion throughout R13.S1.02-S1.03-S1.01-B as well as multiple mass failures. There is one bedrock outcrop in a short section of this segment where the river valley pinches in, which is holding the grade and deterring downcutting above it. Overall, T13.S1.02-S1.03-S1.01-B is in **fair** geomorphic condition because aggradation is causing the channel to move laterally. The segment is in **good** habitat condition because there is plenty of woody debris in the channel, the riffle-pool bedform is well defined, and the buffers are well forested.

Figure 5.53. Aggradation is driving planform adjustment in R13.S1.02-S1.03-S1.01-B.

R13.S1.02-S1.03-S1.01-B Data Summary		Reference	Existing
Length: 2,990 ft Drainage Area: 2.3 sq. mi. Evolution Stage: D-IIc Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	> 2.2	4.1
	Incision Ratio	< 1.2	1.0
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Erosion, Mass Failures**		

R13.S1.02-S1.03-S1.01-C

R13.S1.02-S1.03-S1.01-C is the upstream-most segment on reach one of this tributary. It flows through the woods and has a natural planform and minimal human impacts. The stream channel has incised and is beginning to widen and adjust planform. During Tropical Storm Irene, the channel avulsed, taking a new course, and created multiple large flood chutes. The channel is braided in one location under low flow conditions. Stormwater inputs are present in this segment, and one large, unstable gully is delivering substantial amounts of sediment to the stream channel from adjacent developed land. This sediment contributes to the major aggradation observed in this segment. Debris jams are also exacerbating planform adjustment as the channel moves around them. Bank erosion is common in R13.S1.02-S1.03-S1.01-C as the channel adjusts. This segment is in **fair** geomorphic condition due to active adjustment and **good** habitat condition as a result of ample woody debris, diverse bed features, and well forested banks and buffers.

Figure 5.54. Deposition and woody debris are common in the stream channel of R13.S1.02-S1.03-S1.01-C.

R13.S1.02-S1.03-S1.01-C Data Summary		**Reference**	**Existing**
Length: 2,850 ft Drainage Area: 2.3 sq. mi. Evolution Stage: F-IV Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	B	B
	Entrenchment Ratio	1.4 – 2.2	2.0
	Incision Ratio	< 1.2	1.5
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Stormwater Inputs, Gully, Erosion, Mass Failure**		

R13.S1.02-S1.03-S1.02

The second reach on Unnamed Tributary 2 to Thatcher Brook is almost 9,000 feet in length and drains 1.8 square miles. It flows through primarily forested land and was split into five segments during assessment to account for changes in valley width, channel dimensions, and planform.

R13.S1.02-S1.03-S1.02-A

The downstream-most segment on reach two of the second unnamed tributary to Thatcher Brook is characterized by a narrow river valley with abundant bedrock outcrops. There are four bedrock grade controls present in this segment, which have likely prevented channel incision. This segment is very stable and the channel has not undergone widening overall. Bank erosion and mass failures are present in some areas where bedrock is not dominant on the banks and/or valley walls. The stability of this segment and its overall lack of adjustment have caused it to be in **good** geomorphic condition. It is also in **good** habitat condition as a result of good cover on the streambed and well forested banks and buffers.

Figure 5.55. Bedrock outcrops are common in R13.S1.02-S1.03-S1.02-A and afford vertical stability to the channel.

R13.S1.02-S1.03-S1.02-A Data Summary		Reference	Existing
Length: 1,512 ft Drainage Area: 1.8 sq. mi. Evolution Stage: F-I Sensitivity: Moderate	Confinement	Narrow	Narrow
	Stream Type	B	B
	Entrenchment Ratio	1.4 – 2.2	1.5
	Incision Ratio	< 1.2	1.0
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Step-Pool	Step-Pool
Major Stressors:	**Erosion, Mass Failure, Gully**		

R13.S1.02-S1.03-S1.02-B

The second segment on reach two of this tributary is 1,800 feet in length, beginning just below the stream crossing on Shaw Mansion Road and ending in the woods between Shaw Mansion Road and Ripley Road where a large tributary enters. This section of stream has incised, but has not widened. Bedrock outcrops are present toward the upstream end of this segment and are holding the grade and deterring further incision. Bank erosion is scattered throughout the segment and one mass failure is present along the southern valley wall. The culvert under Shaw Mansion Road is significantly undersized and is likely contributing to localized geomorphic instability. The stream is adjusting laterally via several flood chutes. For these reasons, R13.S1.02-S.03-S1.01-B is in **fair** geomorphic condition. This segment is in **good** habitat condition because of its well-defined bedform, good floodplain connectivity, and forested banks and buffers.

Figure 5.56. R13.S1.02-S1.03-S1.02-B has well forested banks and buffers.

R13.S1.02-S1.03-S1.02-B Data Summary		Reference	Existing
Length: 1,798 ft	Confinement	Very Broad	Very Broad
Drainage Area: 1.8 sq. mi.	Stream Type	C_b	C_b
Evolution Stage: F-II	Entrenchment Ratio	> 2.2	5.0
Sensitivity: High	Incision Ratio	< 1.2	1.7
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Undersized Culvert, Erosion, Mass Failure, Stormwater Inputs**		

R13.S1.02-S1.03-S1.02-C

Segment C on reach two of Unnamed Tributary 2 to Thatcher Brook is about 3,000 feet in length and ends just above the Ripley Road stream crossing. It is characterized by major active incision via three headcuts. The channel is widening in some areas due to downcutting and continues to incise, cutting down to glacial till below the streambed. Flood chutes and bifurcation are present in this segment where the stream is adjusting planform. A stream type departure has occurred in R13.S1.02-S1.03-S1.02-C as a result of incision, and some floodplain access has been lost. There are some areas within this segment that are less incised where floodplain access is better, but overall incision dominates. The culvert under Ripley Road in this segment is significantly undersized, which is causing aggradation above it and scour below, and may pose a barrier to aquatic organism passage. Due to major active channel adjustment, R13.S1.02-S1.03-S1.02-C is in **fair** geomorphic condition. It is also in **fair** habitat condition due to unstable stream banks and loss of floodplain access.

Figure 5.57. R13.S1.02-S1.03-S1.02-C is actively incising via headcuts.

R13.S1.02-S1.03-S1.02-C Data Summary		**Reference**	**Existing**
	Confinement	Very Broad	Very Broad
Length: 3,066 ft	Stream Type	C_b	B
Drainage Area: 1.8 sq. mi.	Entrenchment Ratio	> 2.2	1.9
Evolution Stage: F-II	Incision Ratio	< 1.2	2.0
Sensitivity: Very High	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Headcuts, Erosion, Undersized Culvert, Mass Failures**		

R13.S1.02-S1.03-S1.02-D

Segment D on reach two is approximately 1,200 feet in length, beginning just above the culvert under Ripley Road and continuing upstream to where the forest canopy opens into a wetland complex. This segment is characterized by having a steep channel slope and a natural planform. R13.S1.02-S1.03-S1.02-D has incised very slightly, but has not widened. Small flood chutes are present in this segment where it is adjusting laterally. The stream's drainage area is very small at the upstream end of this segment, but a tributary enters within this segment and contributes more flow to the channel. This segment is in **good** geomorphic condition because it has not majorly incised, widened, or changed planform. It is also in **good** habitat condition, as there are diverse bed features and well forested banks and buffers.

Figure 5.58. The stream channel in R13.S1.02-S1.03-S1.02-D is small and steep for most of the segment.

R13.S1.02-S1.03-S1.02-D Data Summary		**Reference**	**Existing**
Length: 1,244 ft Drainage Area: 1.8 sq. mi. Evolution Stage: F-II Sensitivity: Moderate	Confinement	Broad	Broad
	Stream Type	B	B
	Entrenchment Ratio	1.4 – 2.2	1.8
	Incision Ratio	< 1.2	1.2
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Step-Pool	Step-Pool
Major Stressors:	**Erosion, Mass Failures**		

R13.S1.02-S1.03-S1.02-E

The upstream-most segment on the Unnamed Tributary 2 to Thatcher Brook included in this study was not fully assessed due to a lack of flowing water. The upstream end of the segment is a wetland complex, which empties into a man-made pond. The pond is piped out under a trail and becomes the flowing channel of this stream. Surrounding land in this segment is wetland and agricultural.

Figure 5.59 The upstream end of segment R13.S1.02-S1.03-S1.02-E is a wetland complex.

Figure 5.60. R13.S1.02-S1.03-S1.02-E is a man-made pond for part of its length.

R13.S1.02-S1.03-S1.02-E Data Summary	*NOT ASSESSED	Reference	Existing
Length: 1,223 ft Drainage Area: 1.8 sq. mi. Evolution Stage: N/A Sensitivity: N/A	Confinement	Very Broad	Very Broad
	Stream Type	N/A	N/A
	Entrenchment Ratio	N/A	N/A
	Incision Ratio	N/A	N/A
	Dominant Bed Material	N/A	N/A
	Dominant Bedform	N/A	N/A
Major Stressors:	**Poor Buffers**		

5.3 Stream Crossings

The Vermont Culvert Geomorphic Compatibility Screen Tool and the Vermont Aquatic Organism Passage Coarse Screen Tool (Appendix B pages 1 through 3) were used to evaluate bridges and culverts within the Phase 2 study area. The maps on pages 7 through 12 of Appendix B show the location and geomorphic compatibility rating of each structure. Of the 20 bridges and culverts assessed, none were determined to be "fully incompatible," one is "mostly incompatible," sixteen are "partially compatible," three are "mostly compatible," and none are "fully compatible."

Tables 6 and 7 in Appendix B (pages 4 through 6) summarize the data collected for the assessed structures and recommendations for replacement of the structures. Two bridges and four culverts within the study area have been recommended for replacement at a high priority. Five bridges and three culverts are recommended for replacement at a moderate priority, two bridges and one culvert at a low priority, and three bridges are not recommended for replacement at all. This information can be used by municipalities and the Vermont Agency of Transportation to prioritize bridge and culvert replacements.

6.0 PRELIMINARY PROJECT IDENTIFICATION

During early 2015, Phase 2 Stream Geomorphic data were analyzed for the mid-Winooski watershed in order to determine major stressors and impacts to each segment. These data were used to identify potential projects to mitigate adverse impacts, increase geomorphic stability, and improve habitat throughout the study area. Many projects utilize restoration and conservation strategies to bring the study streams closer to equilibrium conditions.

6.1 Project Identification

A total of 59 projects were identified within the study area. These include a variety of types of projects, such as riparian buffer plantings, river corridor easements, berm removals, floodplain creation, bridge and culvert replacements, and many more. Detailed information about proposed projects can be found in Appendix C. There are four categories of projects – floodplain improvement and conservation, public safety improvement, stream channel improvement and restoration, and structure replacement/removal. Examples of types of these projects, as well as their flood resiliency and habitat benefits, are shown in the table below.

Project Category	Project Type	Flood Resiliency and Habitat Enhancement Measures
Floodplain Improvement and Conservation	1. Riparian Buffer Planting 2. Road Lowering/ Relocation 3. Floodplain Creation 4. ANR River Corridor Easement 5. Conservation Easement 6. Conservation Reserve Enhancement Program	➢ Plant native tree and shrub species to restore riparian habitat, provide floodplain roughness and cover along banks, and stabilize eroding banks. ➢ Reduce river-road conflicts by relocating vulnerable infrastructure. Improve floodplain access to provide storage of floodwaters and sediment. ➢ Adopt river corridor and/or conservation easements on large tracts of land to provide room for the river to reach an equilibrium condition and protect against new encroachments. ➢ Protect floodplains and wetland habitat to preserve floodwater and sediment storage.
Public Safety Improvement	1. Floodproofing	➢ Retrofit vulnerable municipal infrastructure to protect public health and safety during flooding.
Stream Channel Improvement and Restoration	1. Livestock Exclusion 2. Return/Remove Windrowed Material 3. Remove Berms 4. Build up Streambed with Boulder Weirs/ Arrest Headcut	➢ Improve physical stability and habitat condition of a river by excluding livestock from accessing it; also allow buffer regeneration at previous access points. ➢ Windrowing can disconnect streams from their floodplains through excavation and berming. Return windrowed material to a channel or remove it to improve floodplain access. ➢ Remove berms to improve stream access to floodplains. ➢ Severe channel degradation can lead to a featureless channel lacking floodplain access. Building up the bed with weirs can create channel diversity and restore floodplain connectivity.
Structure Replacement/ Removal	1. Bridge Replacement 2. Culvert Replacement 3. Bridge Removal 4. Culvert Removal 5. Dam Removal 6. Culvert Retrofit	➢ Incorporate ecologically-based stream crossings with natural channel bottom to improve aquatic organism passage. Structures that mimic the natural stream channel are more flood resilient. ➢ Upgrade undersized structures to reduce road washouts. ➢ Remove abandoned bridges and culverts to improve channel stability and water quality. ➢ Remove unused and unpermitted dams to improve aquatic organism passage and channel stability. ➢ Retrofit newer culverts to improve aquatic organism passage.

6.2 Program Descriptions

River Restoration and Conservation Programs

There are a number of federal, state, and local programs available for river restoration and protection. Funding sources provided below could be leveraged for further project development and implementation. These programs are as follows:

- ANR River Corridor Easement Program (RCE)
- Ecosystem Restoration Program (ERP)
- Conservation Reserve Enhance Program (CREP)
- Trees for Streams (TFS)
- Environmental Quality Incentives Program (EQIP)
- Wildlife Habitat Incentives Program (WHIP)
- Wetland Reserve Program

River Corridor Easement
The River Corridor Easement is designed to promote the long-term physical stability of the river by allowing the river to achieve a state of equilibrium (where sediment and water loads are in balance). River corridor easements are vital for a passive geomorphic restoration approach and can also be used for conserving rivers that are in good condition (equilibrium). Rivers that are in equilibrium have access to their floodplains and therefore experience less *erosion* and negative impacts from flooding events. Corridor easements are a high priority for reaches that are not in equilibrium; these channels are experiencing channel adjustments, which are causing conflicts with current/future land-use expectations. Providing an easement on these reaches reduces the conflict and provides a long-term solution to sediment storage and flood water attenuation needs.

- Easements are in perpetuity, meaning the agreement stays with the land forever.
- A onetime payment is received by the landowner for transferal of channel management rights to a second party (a land trust).
- Transferal of channel management rights means that the landowner would no longer be able to rock line river banks or remove gravel for personal use.
- A RCE requires a minimum 50 foot buffer that floats with the river. No active land-use is allowed within the buffer. The buffer can be actively planted or allowed to revegetate passively.
- The easement does not take away the agricultural land-use rights, so the landowner could continue to crop or pasture the farm land mapped outside of the buffer, yet within the corridor, for as long as the river allows.

Ecosystem Restoration Program
The Ecosystem Restoration Program, formerly called the Clean and Clear Program, is a Vermont program designed to improve water quality by addressing one or more of the following areas: stream stability, protecting against flood hazards, enhancing in-stream and riparian habitat,

reducing stormwater runoff, restoring riparian wetlands, enhance the environmental and economic sustainability of agricultural lands. Funding is available for project identification, project development and project implementation. Vermont municipalities, local or regional governmental agencies, non-profit organizations, and citizens groups are eligible to receive funding.

Conservation Reserve Enhancement Program
The USDA Farm Service administers a program called the Conservation Reserve Enhancement Program that helps agricultural producers to take farmland out of production in sensitive areas, such as river corridors. This helps to improve water quality and restore wildlife habitat.

- CREP can be either a 15 or 30 year contract to plant trees.
- 90% of the practice costs are covered with the remaining 10% either resting with the participants or could be paid by the US Partners for Fish and Wildlife. Examples of the practice costs include fencing, watering facilities, and trees. There are some costs that are capped, but generally all the practice costs can be paid through the program.
- To provide additional incentives to enroll in CREP, the program offers upfront and annual rental payments for the land where agricultural production is lost during the contract period.

Trees for Streams
Programs offered by the US Fish and Wildlife Service or through State funding to work with local partners and landowners to restore native streamside vegetation along river banks.

Environmental Quality Incentives Program
EQIP is a voluntary program available through the Natural Resources Conservation Service (NRCS) that provides financial and technical assistance to implement conservation practices to meet local environmental regulations. Owners of land in agricultural or forest production are eligible for the program. Contracts with landowners can be up to ten years in length.

Wildlife Habitat Incentives Program
WHIP is a voluntary program offered to landowners to improve wildlife habitat on their land. Owners of agricultural land, nonindustrial private forest land, and Native American land are eligible. Technical assistance and up to 75 percent cost-share is available to improve fish and wildlife habitat.

Wetland Reserve Program
WRP is a voluntary program offered by NRCS to landowners to protect, restore and enhance wetlands on their property. NRCS provides technical assistance and financial support for projects that establish long-term conservation and wildlife practices and protection.

Flood Resiliency Programs and Initiatives

Additionally, there are numerous programs in place to aid communities in becoming more flood resilient. A collection of several of these programs follows:

- Vermont Emergency Relief Assistance Fund (ERAF)
- Vermont Municipal Planning Grants (MPG)
- Clean Water State Revolving Fund
- National Flood Insurance Program Community Rating System (CRS)
- U.S. Department of Housing and Urban Development Community Development Block Grants (CDBG)
- Federal Emergency Management Agency Buyout Program
- Vermont Agency of Natural Resources River Corridor Protection

Emergency Relief Assistance Fund

In 2014, the state of Vermont established an Emergency Relief Assistance Fund (ERAF) to provide matching funding for federal assistance after federally-declared disasters. This program allows towns in Vermont to increase the amount of state aid money they could receive as a match to federal aid for post-disaster recovery. By taking certain steps to become more prepared and resilient, a town can be eligible for increased state aid money. Certain damage costs from federally-declared disasters are reimbursed 75% by federal money. The state of Vermont contributes a minimum of 7.5% of the total cost, but if a town takes additional steps, the state aid can increase to 12.5% or 17.5% of the cost, leaving less for the town itself to pay (State, 2015). The table below shows the ERAF status of each town within the mid-Winooski study area.

Town ERAF Rating	Waterbury & Waterbury Village 12.5%	Bolton 7.5%	Duxbury 12.5%	Moretown 12.5%	Middlesex 17.5%
12.5%					
Participate in the National Flood Insurance Program	X	X	X	X	X
Adopt 2013 Road & Bridge Standards	X		X	X	X
Adopt a Local Emergency Operations Plan	X	X	X	X	X
Adopt a Local Hazard Mitigation Plan	X	X	X	X	X
17.5% (need one to quality)					
Protect River Corridors from new encroachment		X			X
Protect flood hazard areas from new encroachments and participate in the FEMA Community Rating System					

Vermont Municipal Planning Grants Program
The Vermont Department of Housing and Community Development has established the MPG program to support local planning and revitalization initiatives for municipalities. Funding can go toward such projects as municipal and hazard mitigation plan updates, natural resource inventories, and flood resiliency planning. Grants over $8,000 in value require small cash matching funds (ACCD, 2015).

Clean Water State Revolving Fund
The Clean Water State Revolving Fund is a program sponsored by the Vermont Department of Environmental Conservation to minimize water pollution that occurs as a result of wastewater treatment operations and stormwater. Municipalities can apply for funding for design and implementation of such projects as wastewater treatment facility upgrades, repairs to municipal wastewater and stormwater infrastructure, development of stormwater infrastructure, and repair of homeowner on-site wastewater treatment systems. Upgrades could improve wastewater utilities by flood-proofing and making infrastructure more flood resilient.

National Flood Insurance Community Rating System
In 1990, the National Flood Insurance Program implemented the Community Rating System, which is a voluntary program aimed at encouraging floodplain management activities that exceed NFIP minimum standards. The program allows communities to reduce their flood insurance payments by engaging in any of nineteen qualified activities that fall into the categories of

- Public Information
- Mapping and Regulations
- Flood Damage Reduction, and
- Warning and Response.

This program not only reduces flood insurance costs, it improves community flood resiliency and can reduce future damage and losses (FEMA, 2014a).

U.S. Department of Housing and Urban Development Community Development Block Grants
The CDBG program provides communities with resources to address community development needs. Funding is available for recovery assistance after federally-declared disasters, as well as in the form of state administered grants.

FEMA Buyouts
Property acquisition, also known as buyouts, is a hazard mitigation assistance program offered through FEMA. Buyouts involve the purchase of at-risk properties by municipalities with 75% FEMA Hazard Mitigation Grant Program money and 25% municipality money. These properties are purchased for fair market (pre-disaster if disaster has occurred). The properties are required to be cleared and left in open space indefinitely. A buyout property may never be sold or developed again (FEMA, 2014b).

VANR River Corridor Protection
In 2014, the Vermont Agency of Natural Resources developed river corridors on a state-wide scale. The purpose of defining and regulating river corridors is to prevent increases in man-made conflicts that can result from development in identified river corridor areas; minimize property loss and damage due to fluvial erosion; and prohibit land-uses and development in river corridors that pose a danger to health and safety. Additionally, river corridor delineation and protection facilitates stream stability and dynamic equilibrium. By limiting conflicts between rivers and development, management actions that lead to channel instability are also limited. The basis of a river corridor is a defined area which includes the course of a river and its adjacent lands. The width of the corridor is defined by many model parameters, and may be modified to incorporate field verified data. Certain development is limited within the delineated river corridor, but corridors can be further protected by adopting development regulations at the municipality level. More information on ANR river corridor protection can be found at:
http://www.watershedmanagement.vt.gov/rivers.htm

6.3 Next Steps

There are many opportunities to restore the mid-Winooski River watershed to a more stable condition. Proposed projects are part of a greater strategy to recover from Tropical Storm Irene through improving flood resiliency in the watershed. Further, the implementation of river corridor protection is recommended to restrict future development within the river corridor, minimize damage to infrastructure during flood events, and save money on flood recovery.

Specific steps recommended following this study are as follows:

- Outreach to private landowners and the public about the plan and potential restoration and protection opportunities.
- Meetings held with project partners and landowners to prioritize projects and discuss implementation.
- Apply to funding sources for implementation grants.
- Phase 3 stream survey work where applicable for restoration projects.
- Implementation of priority projects with project partners and landowners.

For additional information about project development, please contact the Vermont River Management Program or Central Vermont Regional Planning Commission.

In addition to site-specific projects, the towns within the study area can take steps to become more flood resilient. Modifying existing zoning regulations at the municipality level could protect buildings and infrastructure from future flood damage and losses. For example, new development could be restricted to outside of mapped flood hazard areas only. These communities could also participate at the highest level of the Vermont ERAF program, which can involve joining the NFIP Community Rating System.

7.0 LIST OF ACRONYMS AND GLOSSARY OF TERMS

List of Acronyms

ACCD – Agency of Commerce and Community Development
BCE – Bear Creek Environmental, LLC
CDBG – Community Development Block Grant
CREP – Conservation Reserve Enhancement Program
CRS – Community Rating System
CVRPC – Central Vermont Regional Planning Commission
EQIP – Environmental Quality Incentives Program
ERAF – Emergency Relief Assistance Fund
ERP – Ecosystem Restoration Program
GIS – Geographic Information System
FEMA – Federal Emergency Management Agency
MPG – Municipal Planning Grant
NFIP – National Flood Insurance Program
NWI – National Wetlands Inventory
QA/QC – quality assurance/quality control
RCE – ANR River Corridor Easement Program
RHA- Rapid Habitat Assessment
RGA-Rapid Geomorphic Assessment
SGA – Stream Geomorphic Assessment
SGAT – Stream Geomorphic Assessment Tool
TFS – Trees for Streams
TRORC – Two Rivers-Ottauquechee Regional Commission
TSI – Tropical Storm Irene
US ACOE – United States Army Corps of Engineers
USGS – United States Geological Survey
VANR – Vermont Agency of Natural Resources
VTDEC – Vermont Department of Environmental Conservation
VDFW _ Vermont Department of Fish and Wildlife
WHIP – Wildlife Habitat Incentives Program
WRP – Wetland Reserve Program

Glossary of Terms

Adapted from:
Restoration Terms, by Craig Fischenich, February, 2000, USAE Research and Development Center, Environmental Laboratory, 3909 Halls Ferry Rd., Vicksburg, MS 39180
And
Vermont Stream Geomorphic Assessment Handbook, Appendix Q, 2009, VT Agency of Natural Resources, Waterbury, VT.
http://www.vtwaterquality.org/rivers/docs/assessmenthandbooks/rv_apxqglossary.pdf

Adjustment Process – type of change that is underway due to natural causes or human activity that has or will result in a change to the valley, floodplain, and/or channel condition (e.g., vertical, lateral, or channel plan form adjustment processes).

Aggradation - A progressive buildup or rising of the channel bed and floodplain due to sediment deposition. The geologic process by which streambeds are raised in elevation and floodplains are formed. Aggradation indicates that the stream discharge and/or bed load characteristics are changing. Opposite of degradation.

Alluvial Fan – A fan-shaped accumulation of alluvium (alluvial soils) deposited at the mouth of a ravine or at the juncture of a tributary stream with the main stem where there is an abrupt change in slope.

Alluvial Soils – Soil deposits from rivers.

Alluvium – A general term for detrital deposits made by streams on riverbeds, floodplains, and alluvial fans.

Avulsion – A change in channel course that occurs when a stream suddenly breaks through its banks, typically bisecting an overextended meander arc.

Bank Stability – The ability of a stream bank to counteract erosion or gravity forces.

Bankfull Channel Depth - The maximum depth of a channel within a riffle segment when flowing at a bankfull discharge.

Bankfull Channel Width - The top surface width of a stream channel when flowing at a bankfull discharge.

Bankfull Discharge - The stream discharge corresponding to the water stage that overtops the natural banks. This flow occurs, on average, about once every 1 to 2 years and given its frequency and magnitude is responsible for the shaping of most stream or river channels.

Bar – An accumulation of alluvium (usually gravel or sand) caused by a decrease in sediment transport capacity on the inside of meander bends or in the center of an over wide channel.

Berms – Mounds of dirt, earth, gravel or other fill built parallel to the stream banks designed to keep flood flows from entering the adjacent floodplain.

Bifurcated Channel – a river channel that has split into two branches as a result of planform adjustment (i.e. split flow due to island).

Boundary Conditions – Factors that are acting upon a stream and preventing adjustment (e.g. bank armoring prevents channel widening).

Cascade – River bed form where the channel is very steep with narrow confinement. There are often large boulders and bedrock with waterfalls.

Channelization – The process of changing (usually straightening) the natural path of a waterway.

Confluence – The location where two streams flow together.

Culvert – A buried pipe that allows flows to pass under a road.

Degradation – (1) A progressive lowering of the channel bed due to scour. Degradation is an indicator that the stream's discharge and/or sediment load is changing. The opposite of aggradation. (2) A decrease in value for a designated use.

Delta Bar – A deposit of sediment where a tributary enters the main stem of a river.

Depositional Features – Types of sediment deposition and storage areas in a channel (e.g. mid-channel bars, point bars, side bars, diagonal bars, delta bars, and islands).

Diagonal Bar – Type of depositional feature perpendicular to the bank that is formed from excess sedimentation and within the channel and from the development of steep riffles.

Drainage Basin – The total area of land from which water drains into a specific river.

Dredging – Removing material (usually sediments) from wetlands or waterways, usually to make them deeper or wider.

Erosion – The wearing away of rock or soil by the gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical, chemical, or biological forces.

Flood Resiliency – The ability to withstand and recover from flooding and associated damages.

Floodplain – Land built of sediment that is regularly covered with water as a result of the flooding of a nearby stream.

Floodprone Width – the wetted width of the channel when the water level is twice the maximum bankfull depth. For most channels this is associated with less than a 50 year return period (Rosgen, 1996).

Fluvial Erosion – Erosive forces created by flowing water.

Fluvial Geomorphology – the physics of flowing water, sediments, and other products of watersheds in relation to various land forms.

Gaging Station – A particular site in a stream, lake, reservoir, etc., where hydrologic data are obtained.

Grade Control - A fixed feature on the streambed that controls the bed elevation at that point, effectively fixing the bed elevation from potential incision; typically bedrock, dams or culverts.

Gradient – Vertical drop per unit of horizontal distance.

Habitat – The local environment in which organisms normally grow and live.

Headwater – Referring to the source of a stream or river.

Headcut – Sudden change in elevation or knickpoint on a streambed. Headcutting is the process by which a streambed lowers as headcuts migrate upstream.

Inundation Flooding – Submersion of low-lying areas surrounding a stream by slowly flowing or standing water.

Incised River – A river that erodes its channel by the process of degradation to a lower base level than existed previously or is consistent with the current hydrology.

Islands – Mid-channel bars that are above the average water level and have established woody vegetation.

Lacustrine Soils- Soil deposits from lakes.

Mass Failure – A landslide that has occurred adjacent to a stream and on its valley wall. Involves mass slumping of land down the valley wall.

Meander - The winding of a stream channel, usually in an erodible alluvial valley. A series of sine-generated curves characterized by curved flow and alternating banks and shoals.

Meander Migration – The change of course or movement of a channel. The movement of a channel over time is natural in most alluvial systems. The rate of movement may be increased if the stream is out of balance with its watershed inputs.

Meander Belt Width – The horizontal distance between the opposite outside banks of fully developed meanders determined by extending two lines (one on each side of the channel) parallel to the valley from the lateral extent of each meander bend along both sides of the channel.

Meander Wavelength - The lineal distance downvalley between two corresponding points of successive meanders of the same phase.

Meander Wavelength Ratio – The meander wavelength divided by the bankfull channel width.

Meander Width Ratio – The meander belt width divided by the bankfull channel width.

Mid-Channel Bar – Sediment deposits (bar) located in the channel away from the banks, generally found in areas where the channel runs straight. Mid-channel bars caused by recent channel instability are unvegetated.

Neck Cutoff – This is the occurrence of an avulsion on the inside of a very long and tight meander.

Planform - The channel shape as if observed from the air. Changes in planform often involve shifts in large amount of sediment, bank erosion, or the migration of the channel.

Plane Bed – Channel lacks discrete bed features (such as pools, riffles, and point bars) and may have long stretches of featureless bed.

Point Bar –The convex side of a meander bend that is built up due to sediment deposition.

Pool -- A habitat feature (section of stream) that is characterized by deep, low-velocity water and a smooth surface.

Reach - Section of river with similar characteristics such as slope, confinement (valley width), and tributary influence.

Restoration – The return of an ecosystem to a close approximation of its condition prior to disturbance.

Riffle - A habitat feature (section of stream) that is characterized by shallow, fast-moving water broken by the presence of rocks and boulders.

Riffle-pool - Channel has undulating bed that defines a sequence of riffles, runs, pools, and point bars. Occurs in moderate to low gradient and moderately sinuous channels, generally in unconfined valleys with well-established floodplains.

Riparian Buffer – The width of naturally vegetated land adjacent to the stream between the top of the bank and the edge of other land-uses. A buffer is largely undisturbed and consists of the trees, shrubs, groundcover plants, duff layer, and naturally uneven ground surface.

Riparian Corridor – Lands defined by the lateral extent of a stream's meanders necessary to maintain a stable stream dimension, pattern, profile, and sediment regime.

Segment – A relatively homogeneous section of stream contained within a reach that has the same reference stream characteristics but is distinct from other segments in the reach.

Sensitivity – The valley, floodplain and/or channel condition's likelihood to change due to natural causes and/or anticipated human activity.

Side Bar – Unvegetated sediment deposits located along the margins or the channel in locations other than the inside of channel meander bends.

Step-Pool – Characterized by longitudinal steps formed by large particles (boulder/cobbles) organized into discrete channel-spanning accumulations that separate pools, which contain smaller sized materials. Often associated with steep channels in confined valleys.

Steep Riffle – Associated with aggradation where sediment has dropped out to form a steep face of sediment on the downstream side.

Surficial Sediment/Geology – Sediment that lies on top of bedrock.

Tributary – A stream that flows into another stream, river, or lake.

Tributary Rejuvenation – As the bed of the main stem is lowered, head cuts (incision) begin at the mouth of the tributary and move upstream.

Urban Runoff – Storm water from city streets and gutters that usually carries a great deal of litter and organic and bacterial wastes into the receiving waters.

Valley Wall – The edge of a river valley where the slope of the land increases and a stream is unlikely to ever flow beyond.

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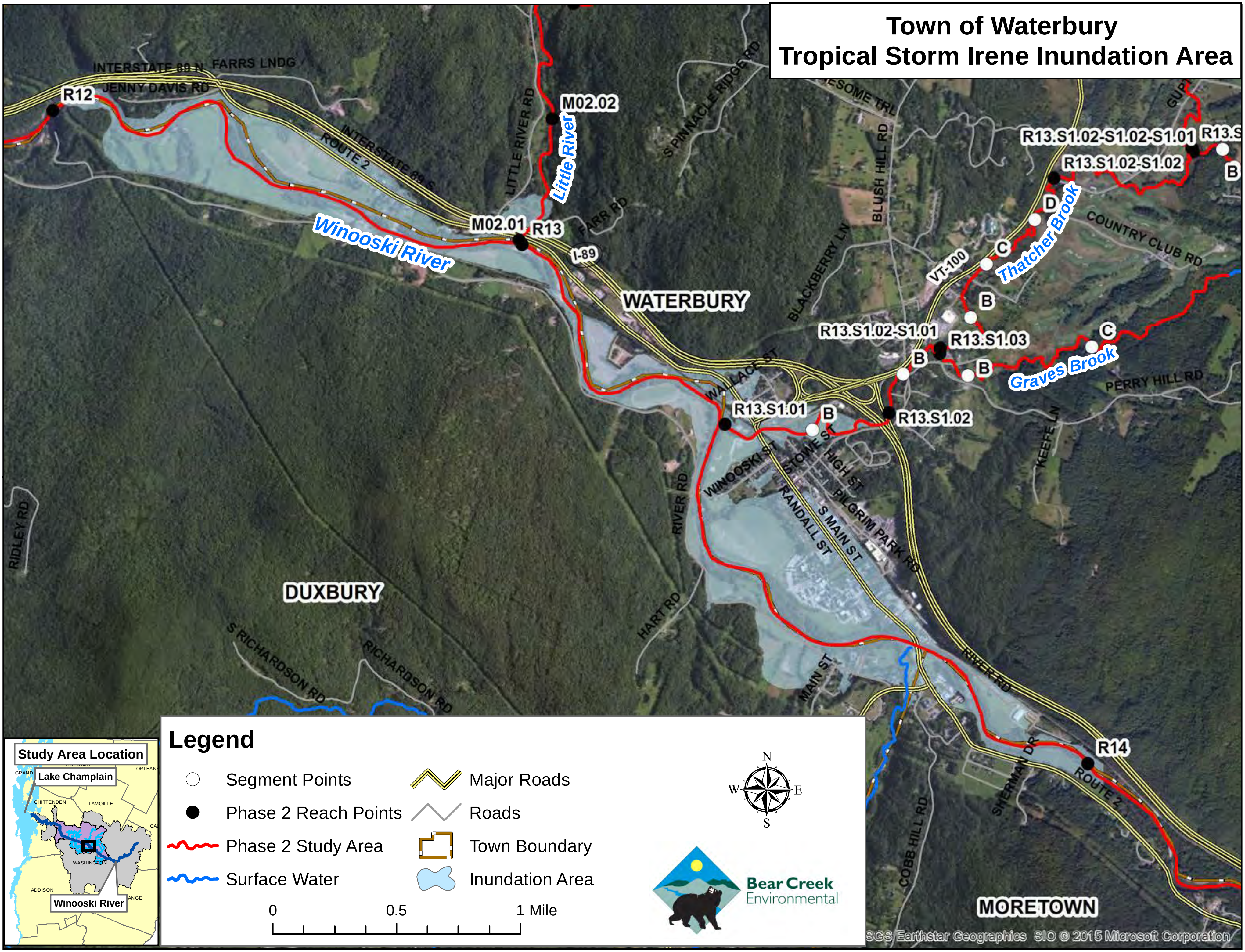
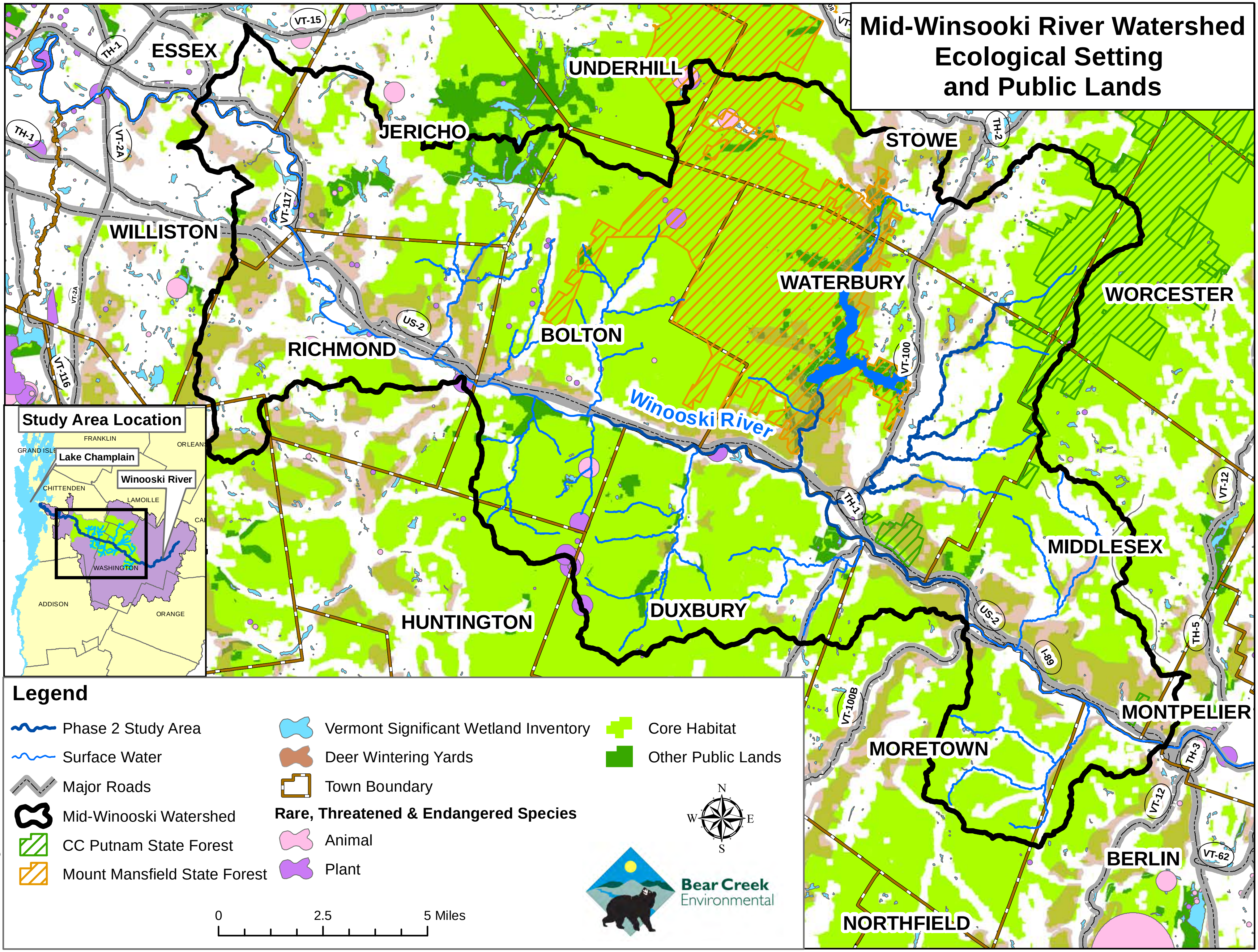
APPENDIX A

Maps

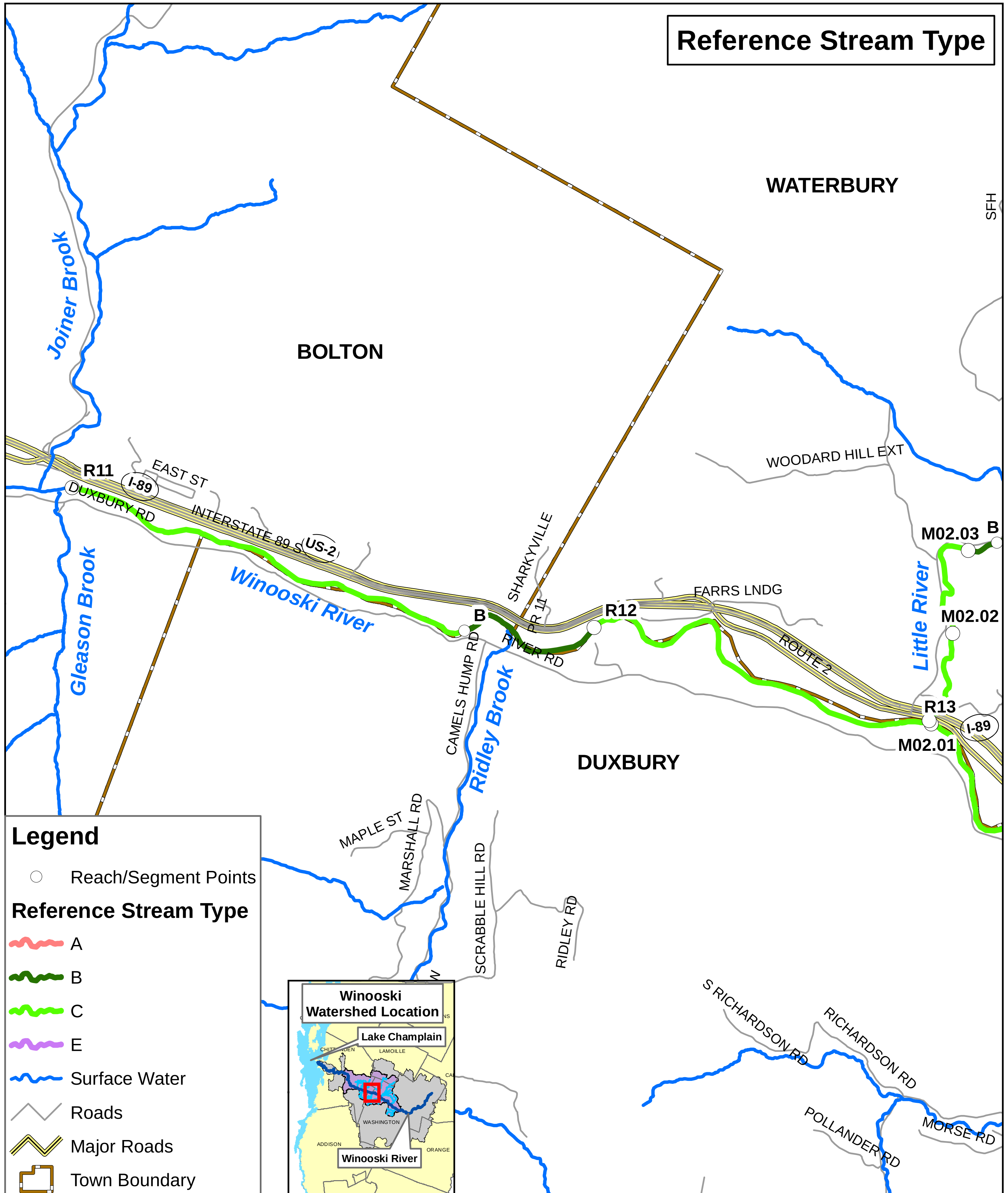


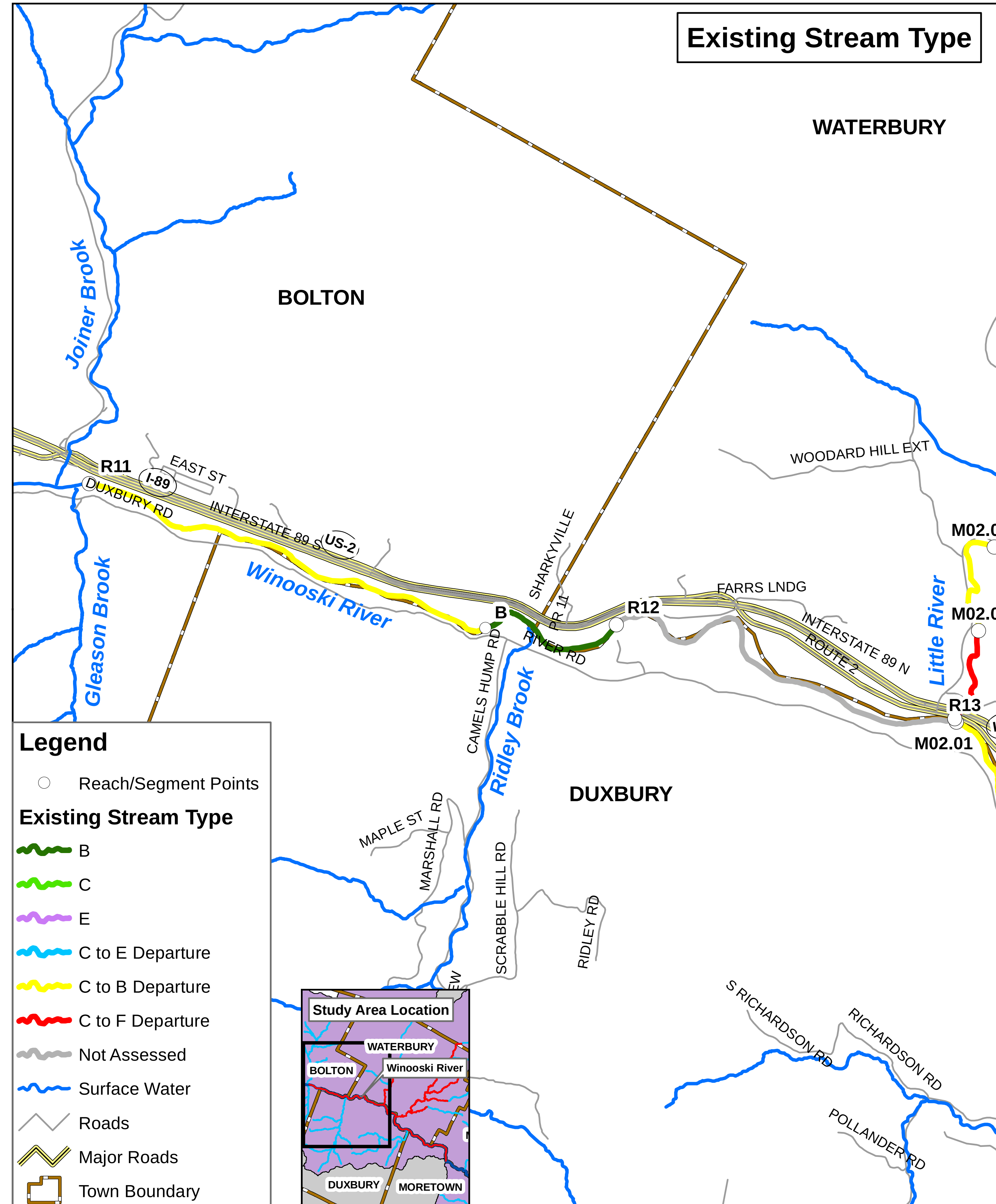
Town of Waterbury
Tropical Storm Irene Inundation Area
Winooski River
Little River
Thatcher Brook
Graves Brook
WATERBURY
DUXBURY
MORETOWN
R12
R13
R14
M02.01
M02.02
R13.S1.01
R13.S1.02
R13.S1.03
R13.S1.02-S1.01
R13.S1.02-S1.02
R13.S1.02-S1.02-S1.01
INTERSTATE 89 N
INTERSTATE 89 S
FARRS LNDG
JENNY DAVIS RD
ROUTE 2
LITTLE RIVER RD
S PINNACLE RIDGE RD
FARR RD
I-89
BLUSH HILL RD
BLACKBERRY LN
VT-100
COUNTRY CLUB RD
PERRY HILL RD
KEEFE LN
WALLACE ST
WINOOSKI ST
STOWE ST
HIGH ST
PILGRIM PARK RD
RANDALL ST
S MAIN ST
MAIN ST
RIVER RD
HART RD
RIDLEY RD
S RICHARDSON RD
RICHARDSON RD
SHERMAN DR
COBB HILL RD
Legend
Segment Points
Phase 2 Reach Points
Phase 2 Study Area
Surface Water
Major Roads
Roads
Town Boundary
Inundation Area
0
0.5
1 Mile
N
S
E
W
Study Area Location
Lake Champlain
Winooski River
CHITTENDEN
LAMOILLE
WASHINGTON
ADDISON
Bear Creek Environmental
USGS Earthstar Geographics SIO © 2015 Microsoft Corporation



Mid-Winsooki River Watershed
Ecological Setting
and Public Lands
ESSEX
UNDERHILL
JERICHO
STOWE
WILLISTON
WATERBURY
WORCESTER
RICHMOND
BOLTON
Winooski River
MIDDLESEX
HUNTINGTON
DUXBURY
MONTPELIER
MORETOWN
BERLIN
NORTHFIELD
VT-15
TH-1
VT-2A
VT-117
US-2
VT-116
VT-100
VT-12
TH-2
TH-5
I-89
TH-3
VT-100B
VT-62
Study Area Location
FRANKLIN
GRAND ISLE
ORLEANS
Lake Champlain
Winooski River
CHITTENDEN
LAMOILLE
WASHINGTON
ADDISON
ORANGE
Legend
Phase 2 Study Area
Surface Water
Major Roads
Mid-Winooski Watershed
CC Putnam State Forest
Mount Mansfield State Forest
Vermont Significant Wetland Inventory
Deer Wintering Yards
Town Boundary
Rare, Threatened & Endangered Species
Animal
Plant
Core Habitat
Other Public Lands
0
2.5
5 Miles
N
S
E
W
Bear Creek
Environmental

2



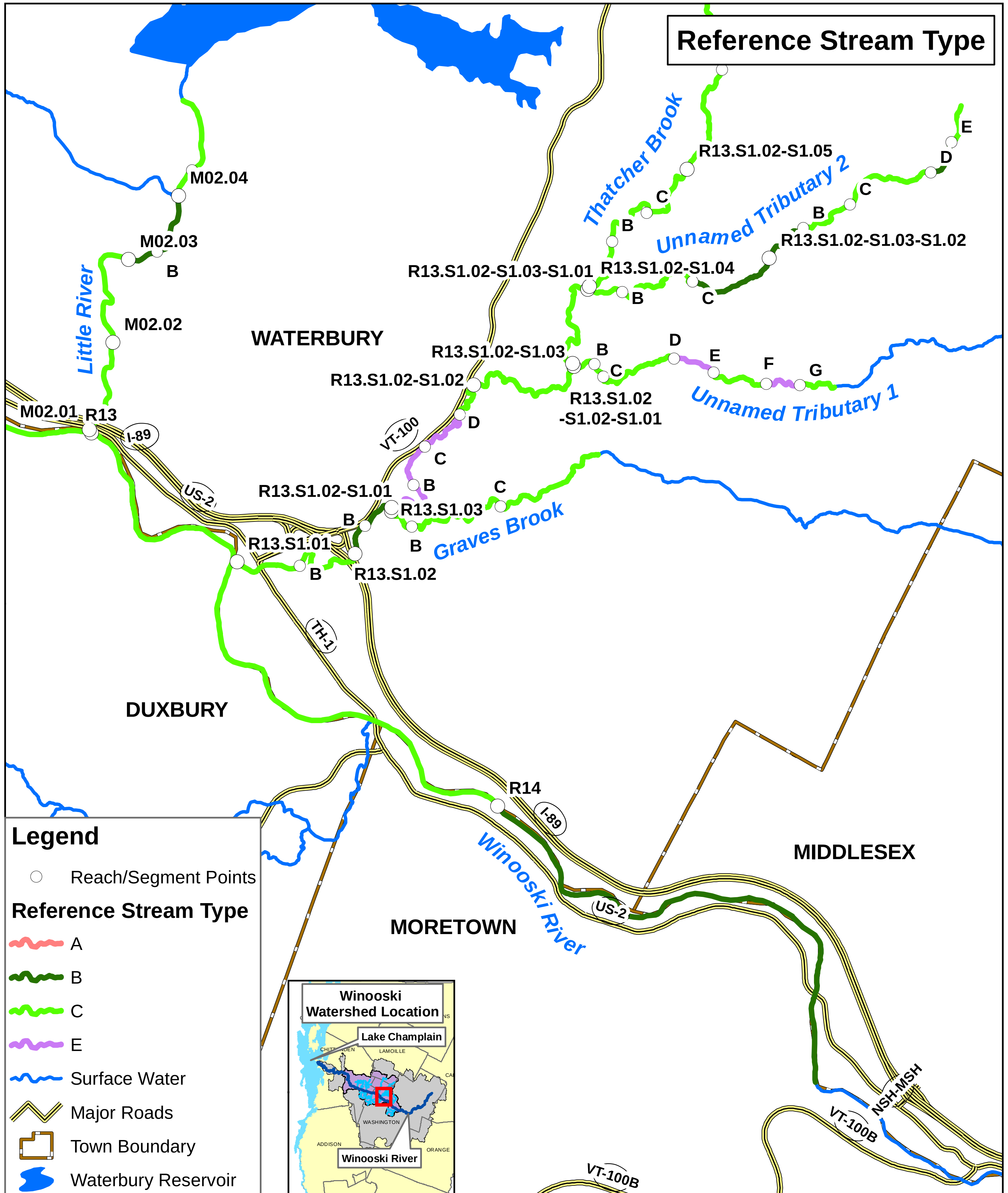


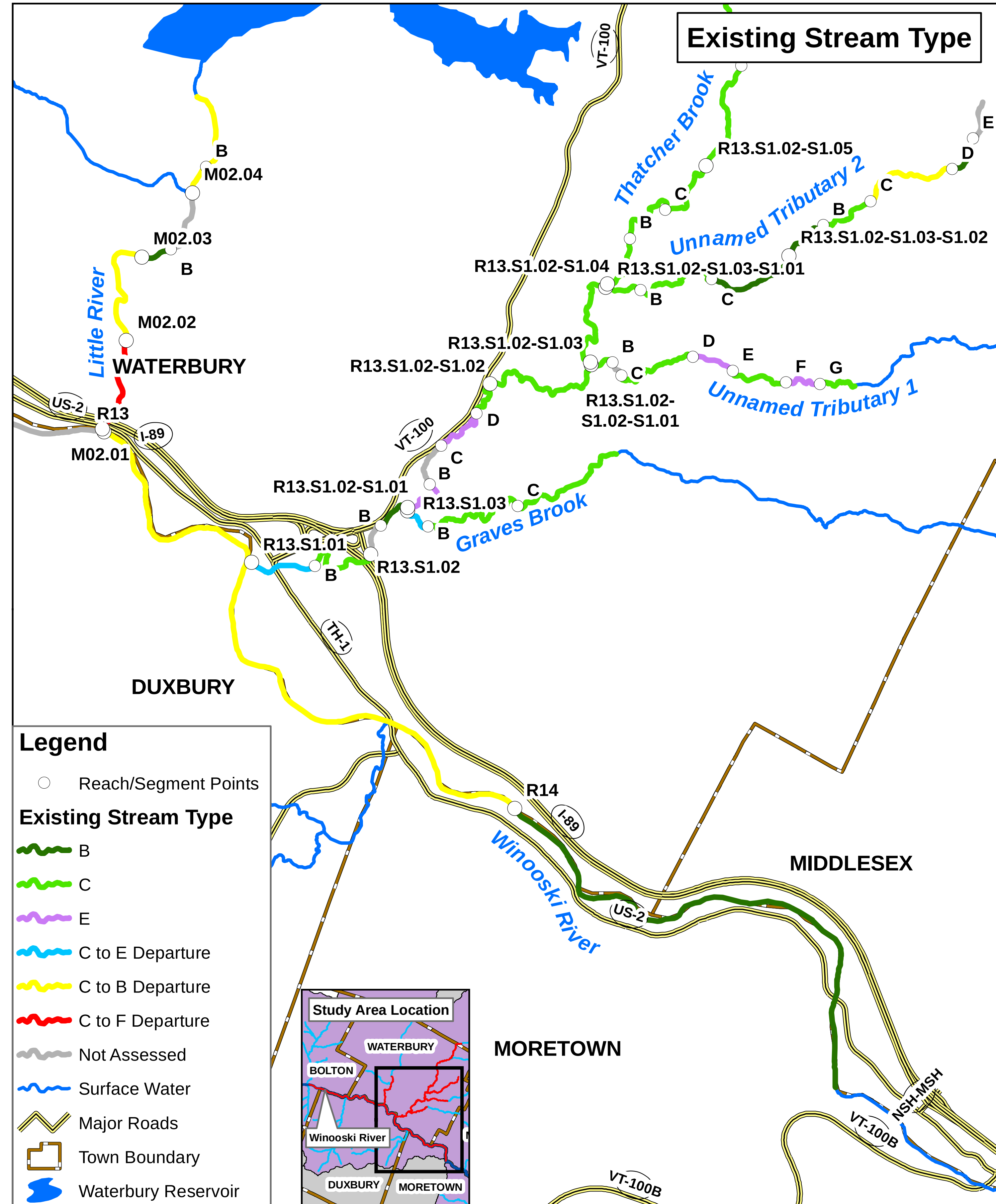
Winooski River
Stream Type - Duxbury, Waterbury, & Bolton, Vermont

N
W E
S

0 1 2 Miles

Bear Creek Environmental



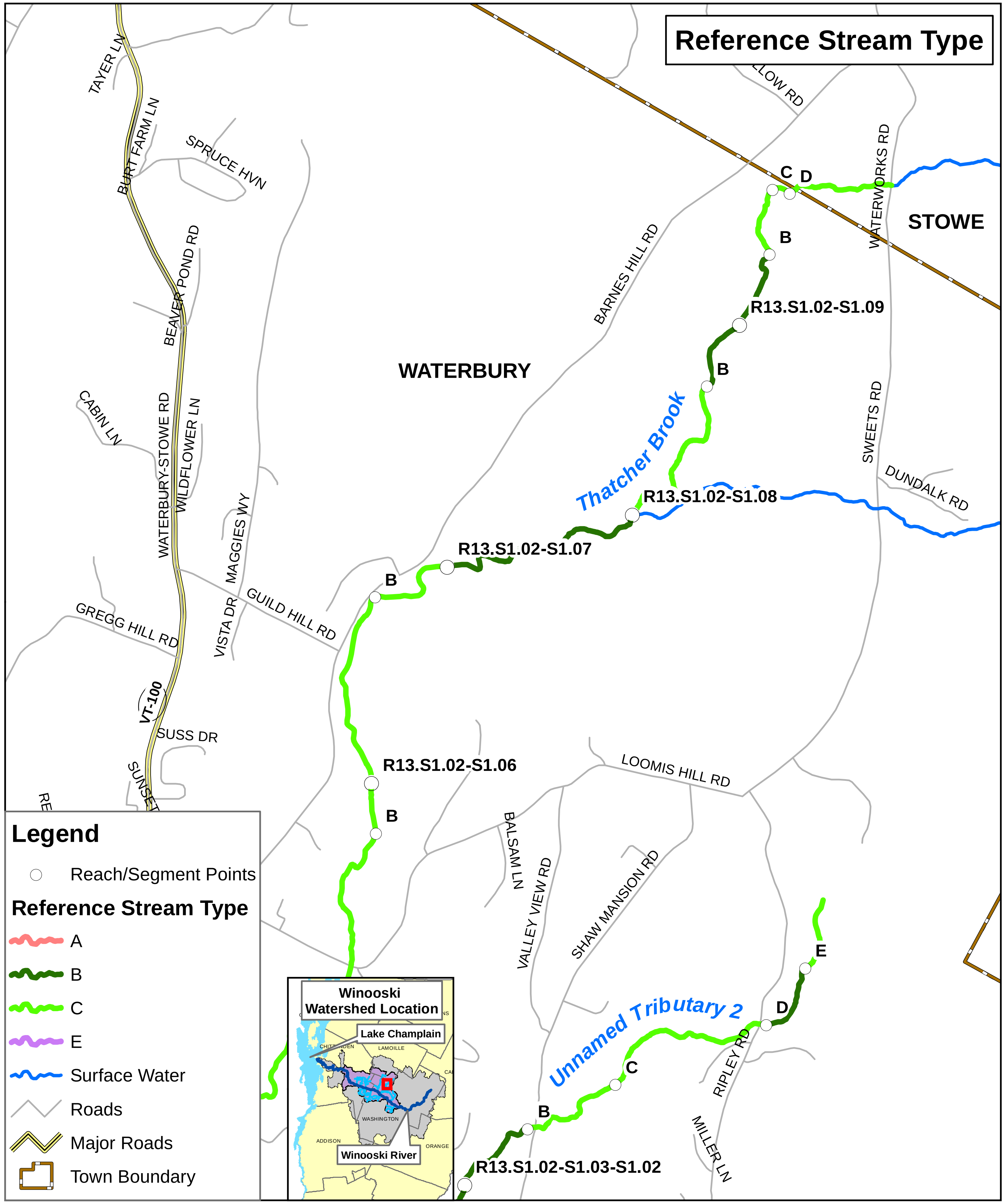


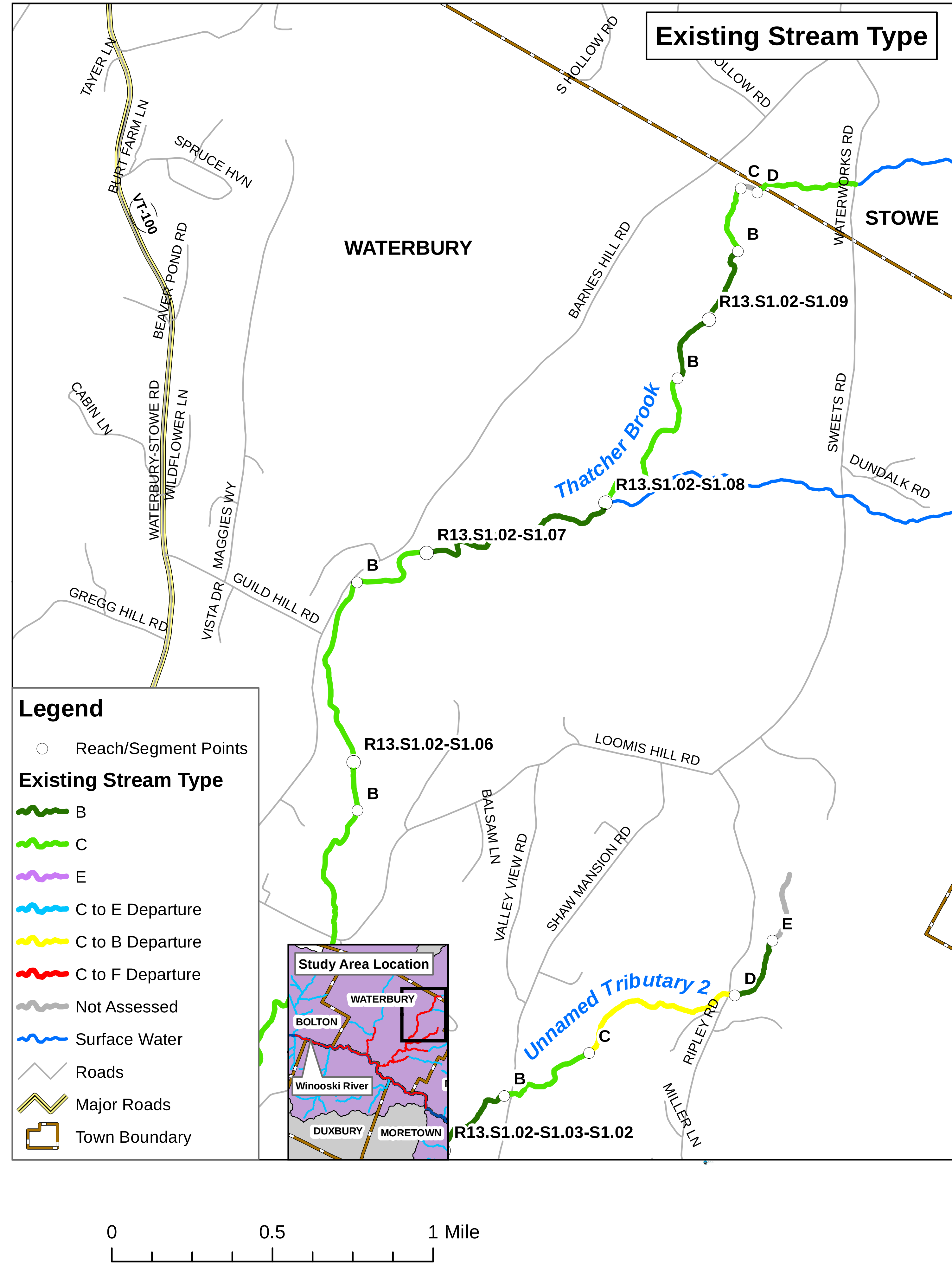
Winooski River, Little River, Thatcher Brook, Graves Brook, Unnamed Tributary 1, & Unnamed Tributary 2 Stream Type - Duxbury, Waterbury, Moretown, and Middlesex, Vermont

0 1 2 Miles

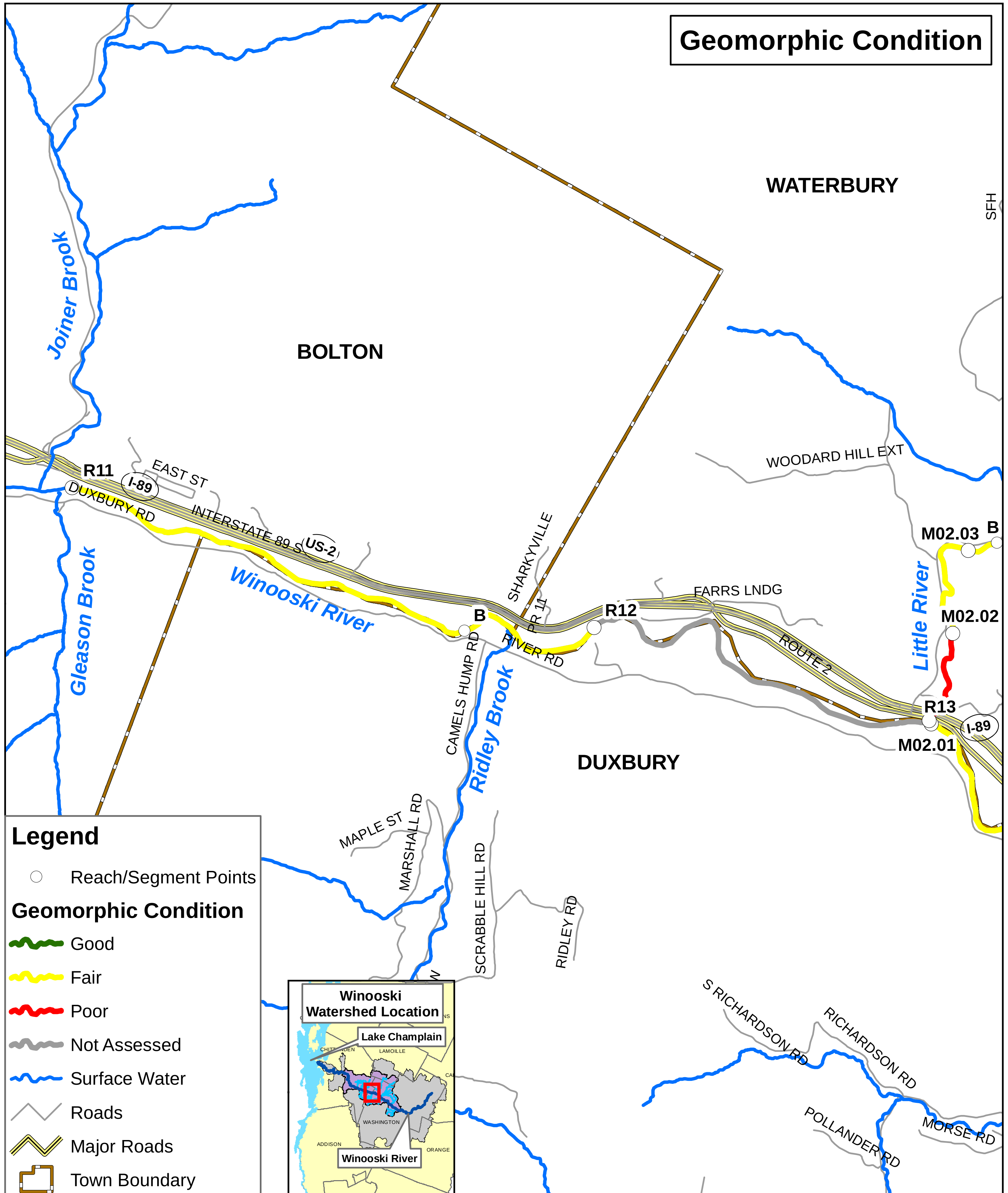
N W E S

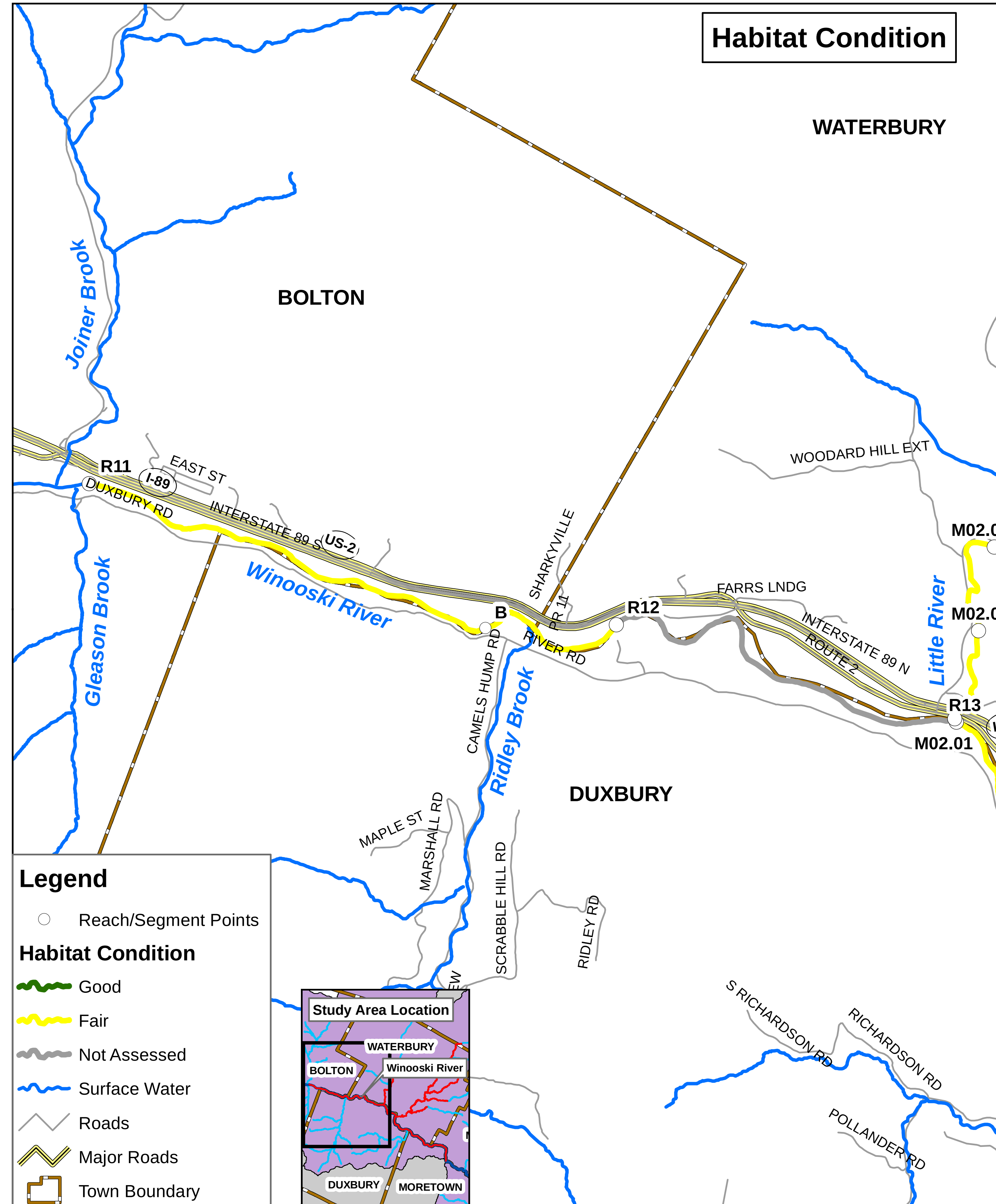
Bear Creek Environmental





Thatcher Brook
Stream Type - Waterbury & Stowe, Vermont



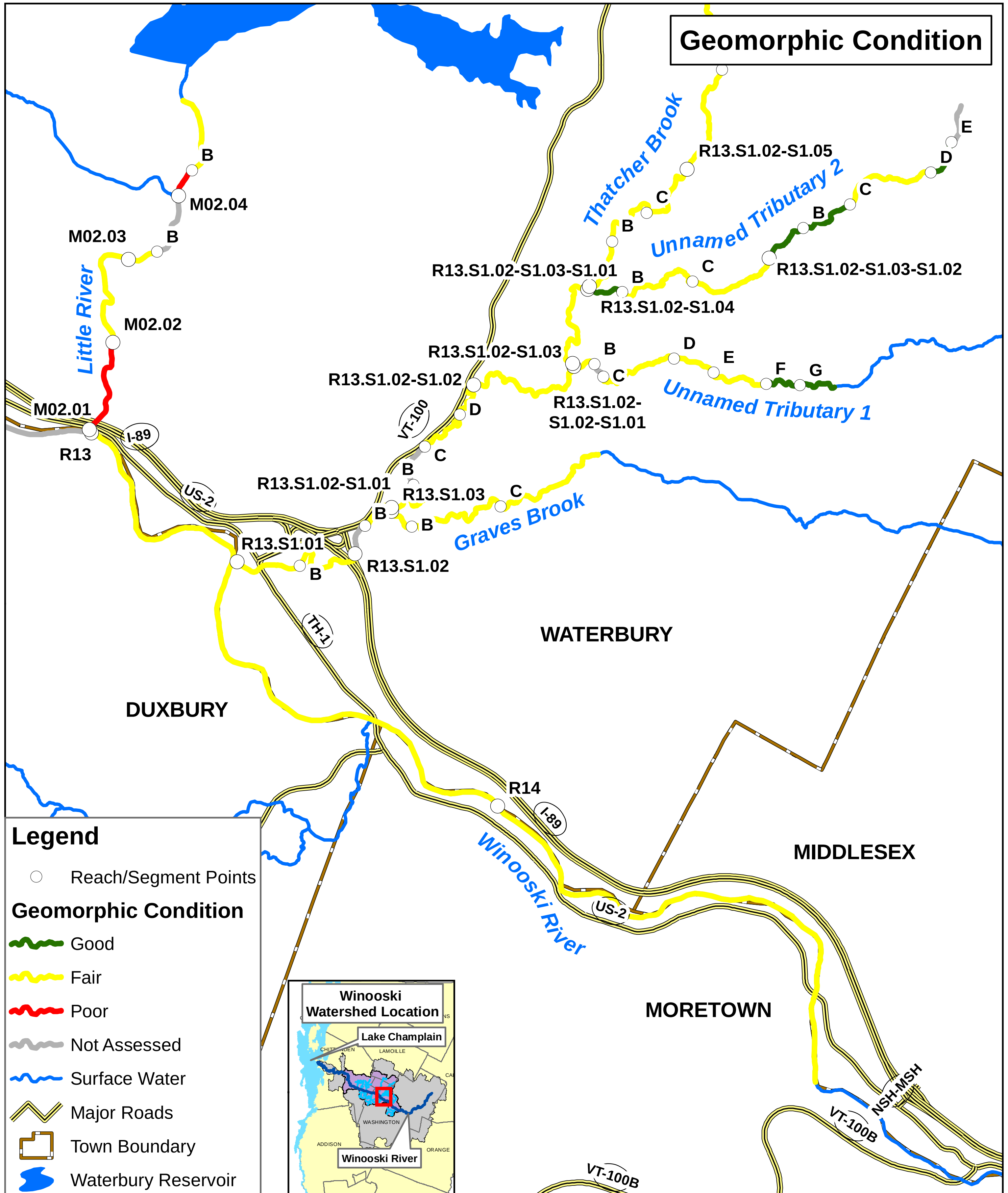


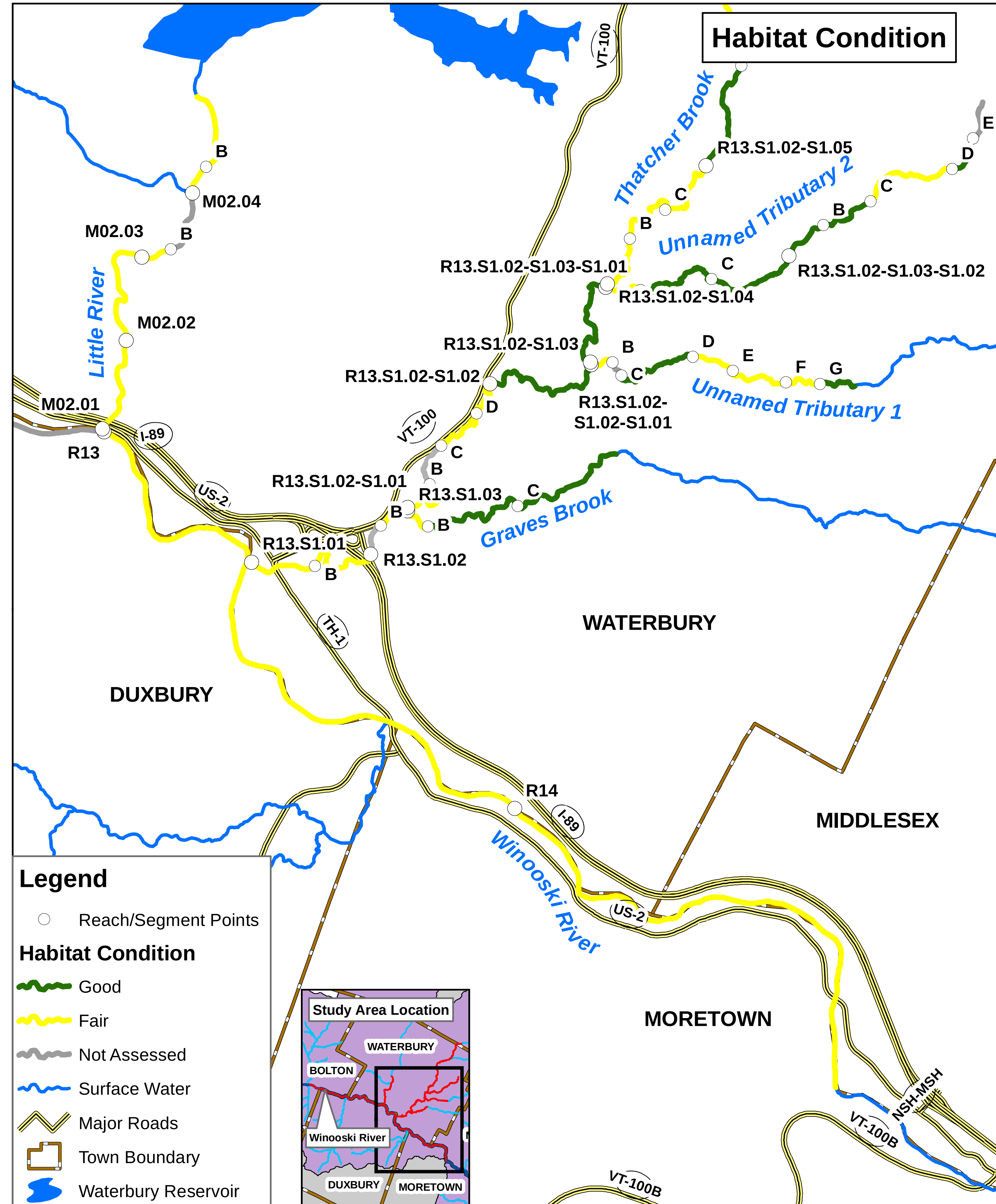
Winooski River
Stream Condition - Duxbury, Waterbury, & Bolton, Vermont

N W E S

0 1 2 Miles

Bear Creek Environmental



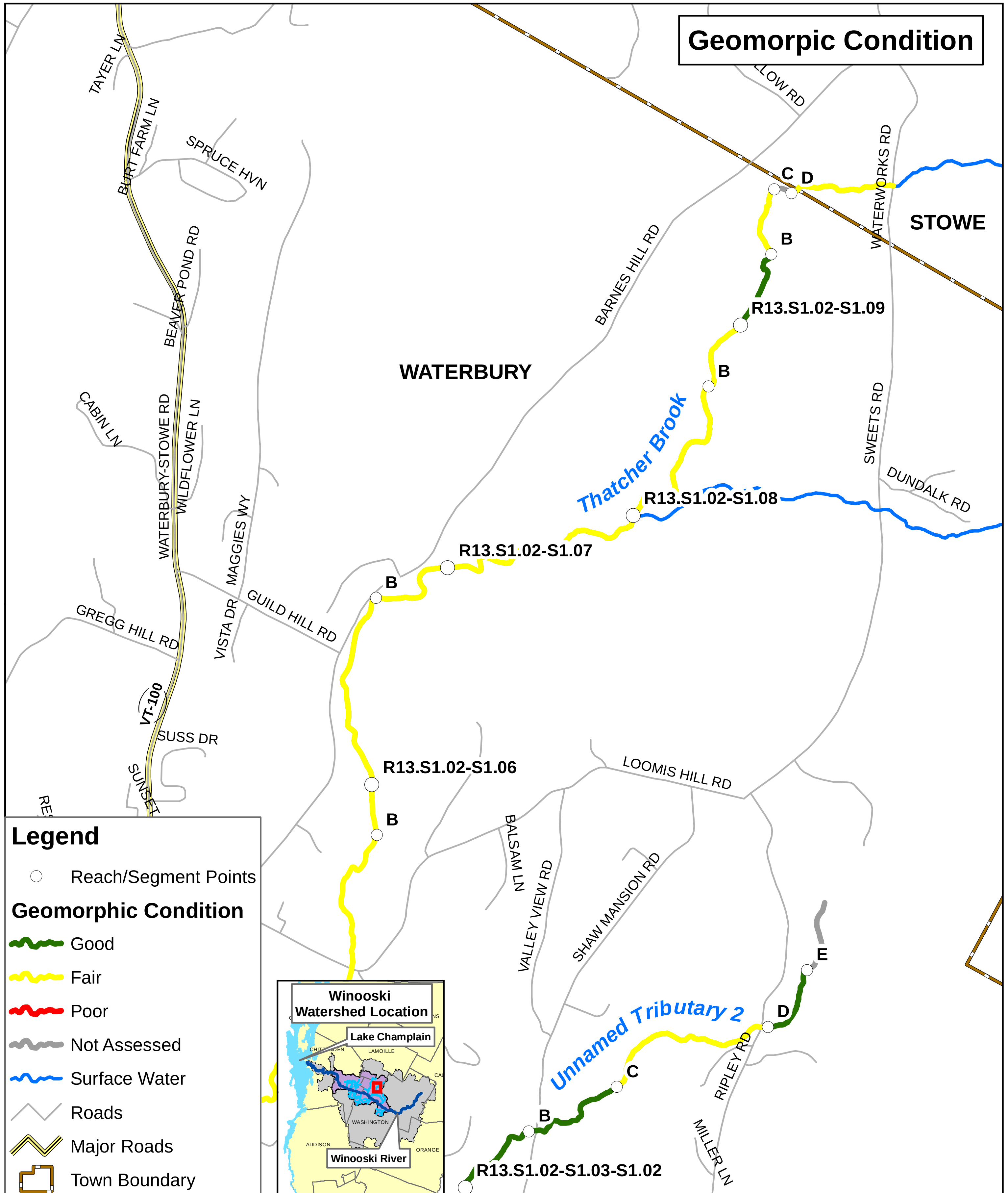


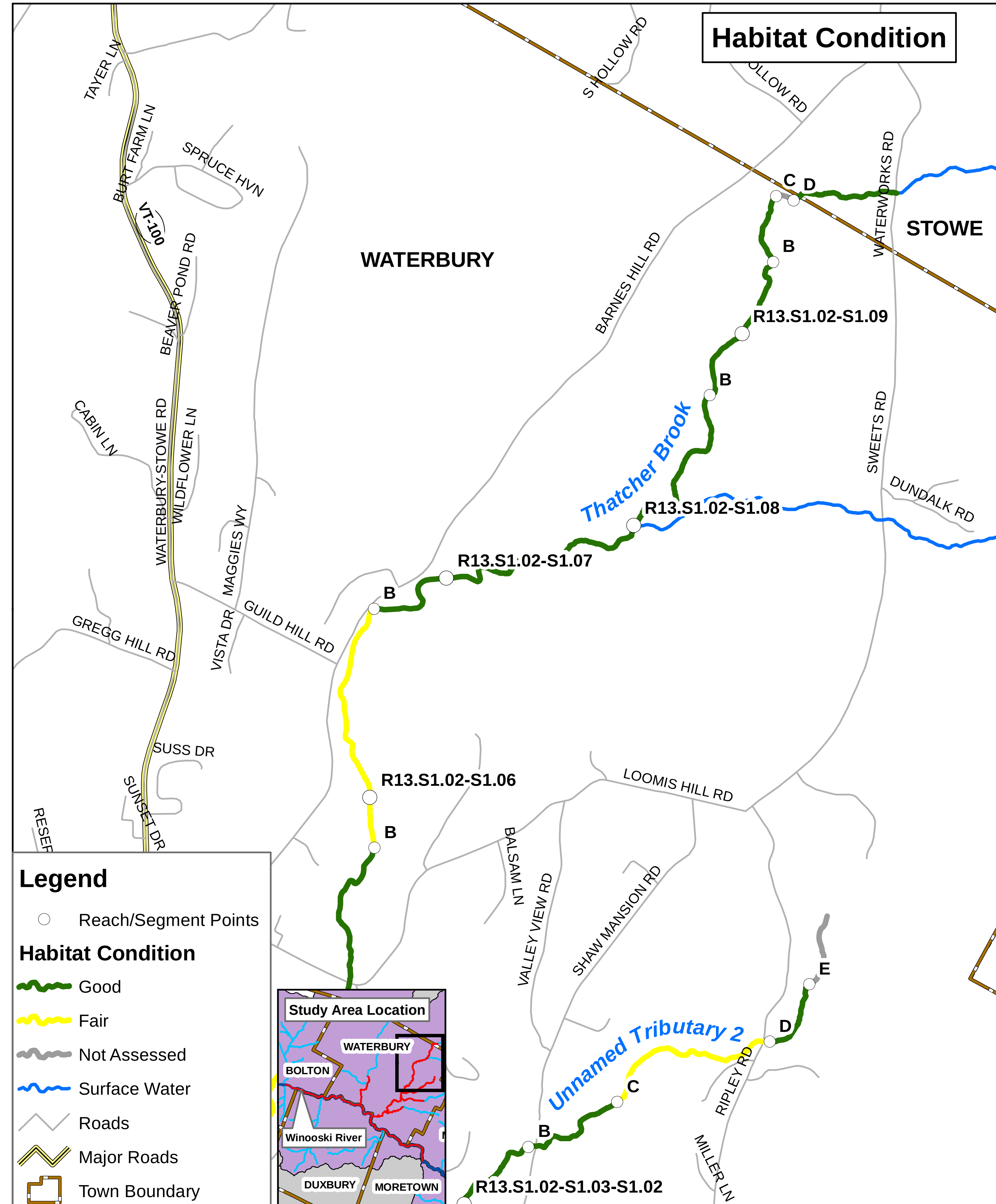
Winooski River, Little River, Thatcher Brook, Graves Brook, Unnamed Tributary 1, & Unnamed Tributary 2 Stream Condition - Duxbury, Waterbury, Moretown, and Middlesex, Vermont

0 1 2 Miles

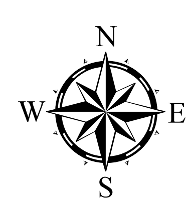
N S E W

Bear Creek Environmental



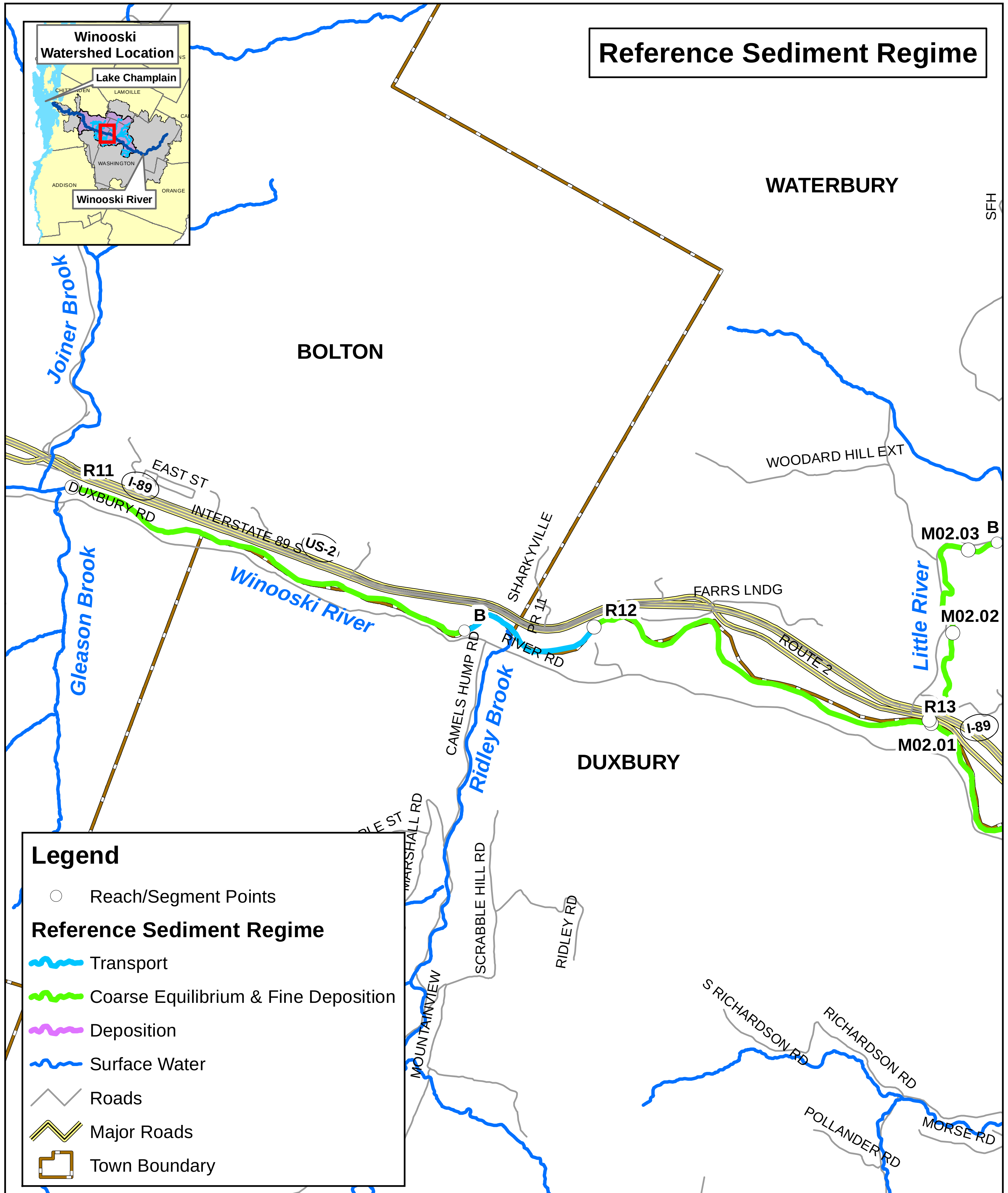


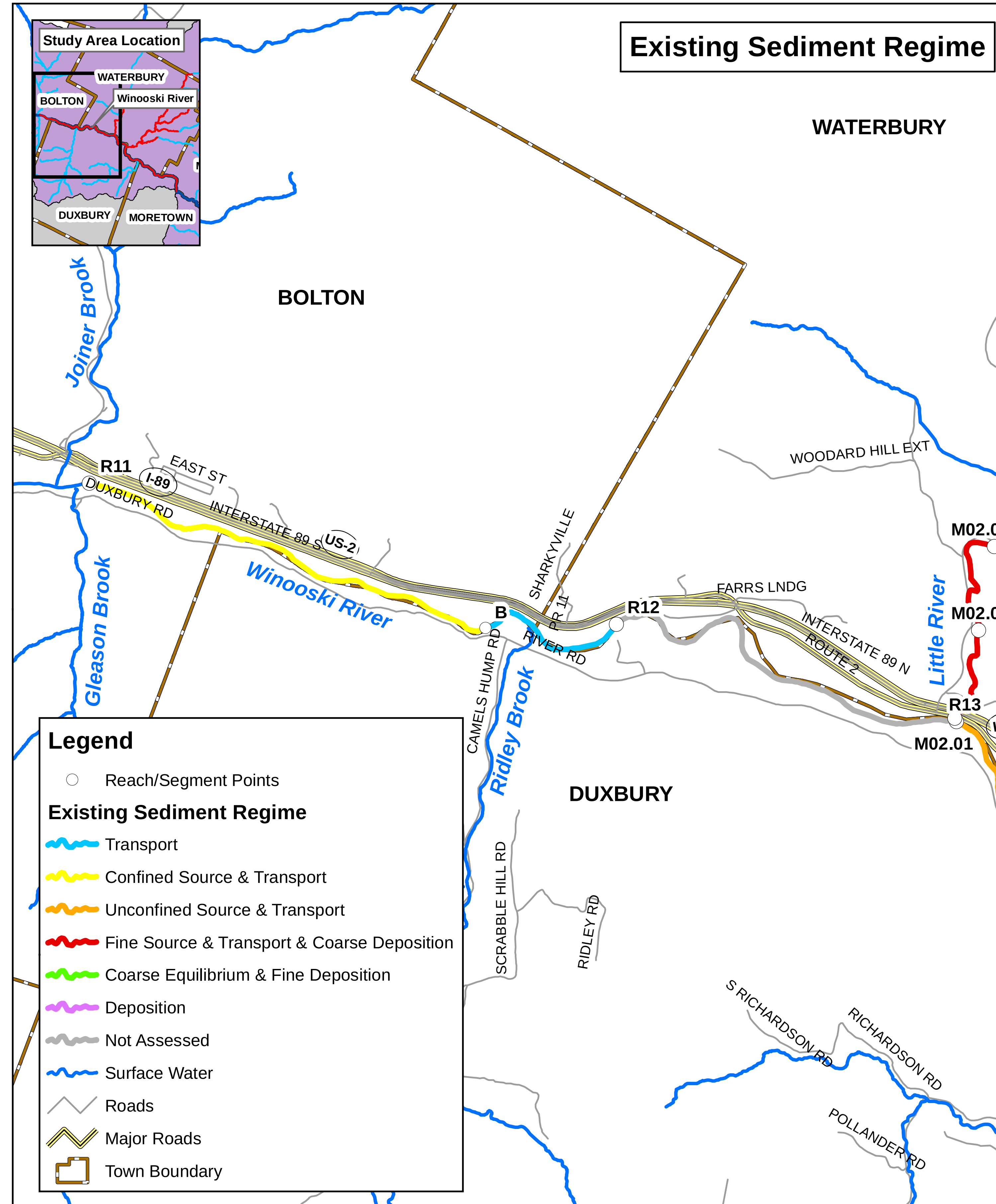
Thatcher Brook
Stream Condition - Waterbury & Stowe, Vermont



0 0.5 1 Mile

Bear Creek Environmental

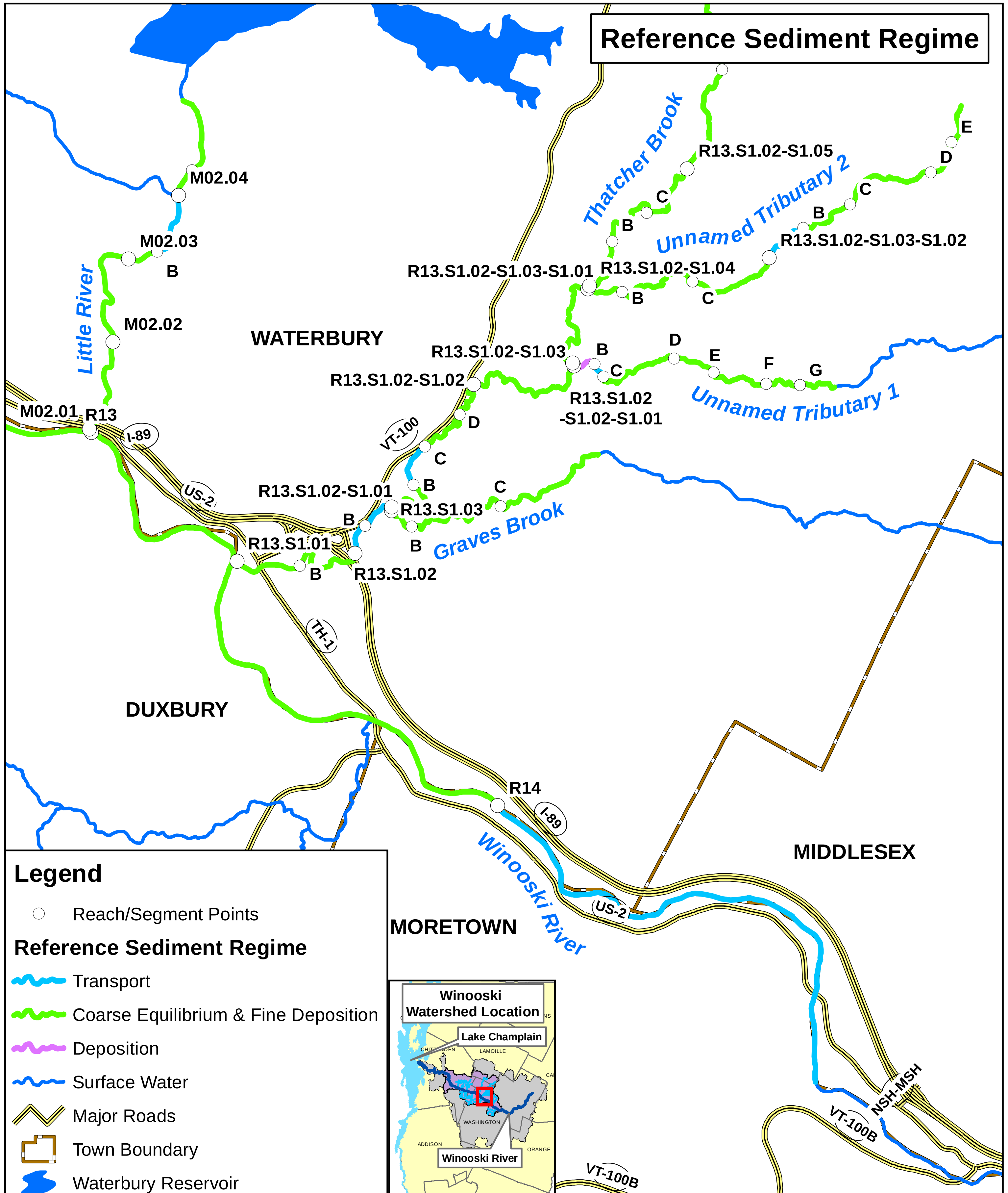


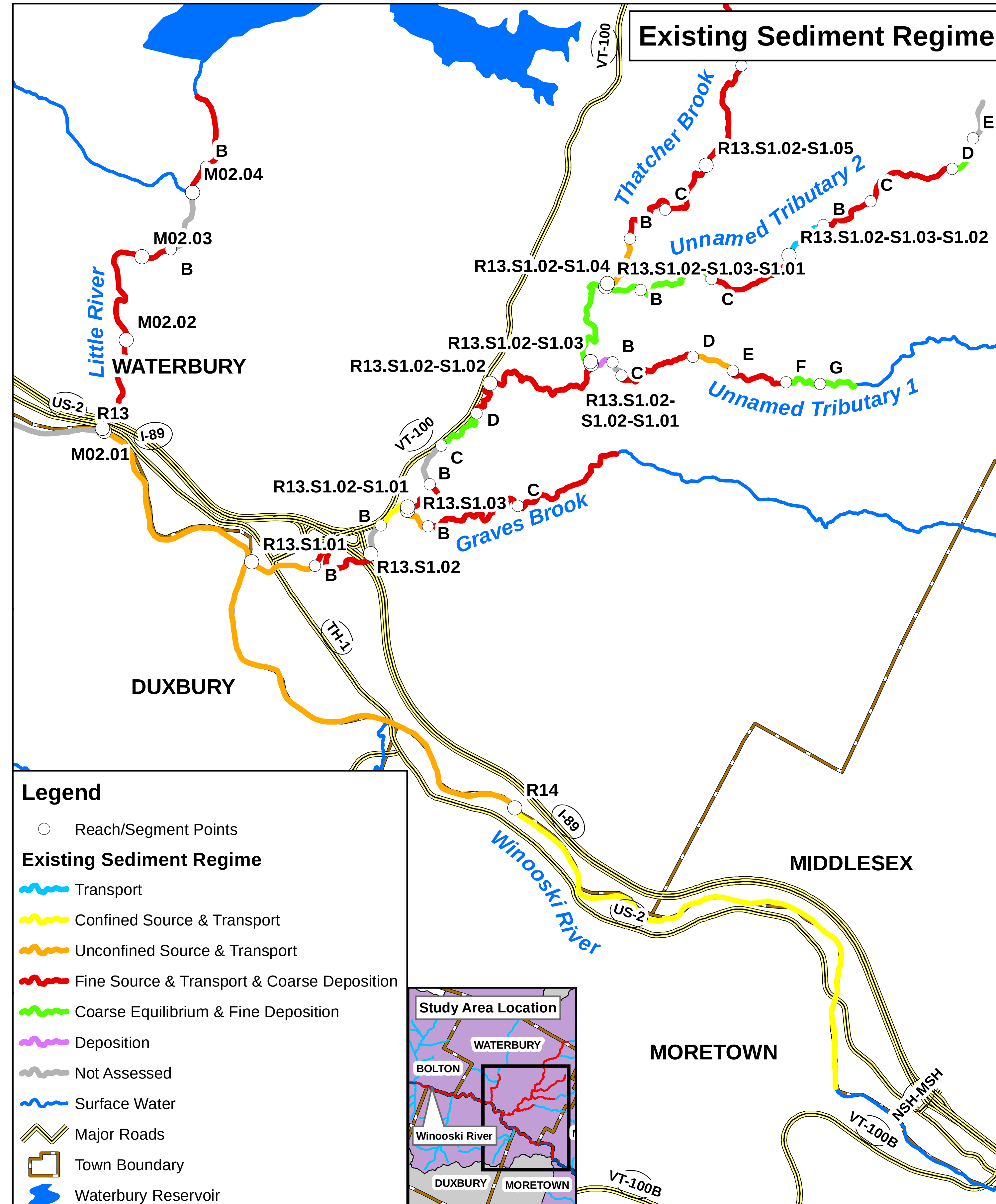


Winooski River
Sediment Regime - Duxbury, Waterbury, & Bolton, Vermont

0 1 2 Miles

Bear Creek Environmental



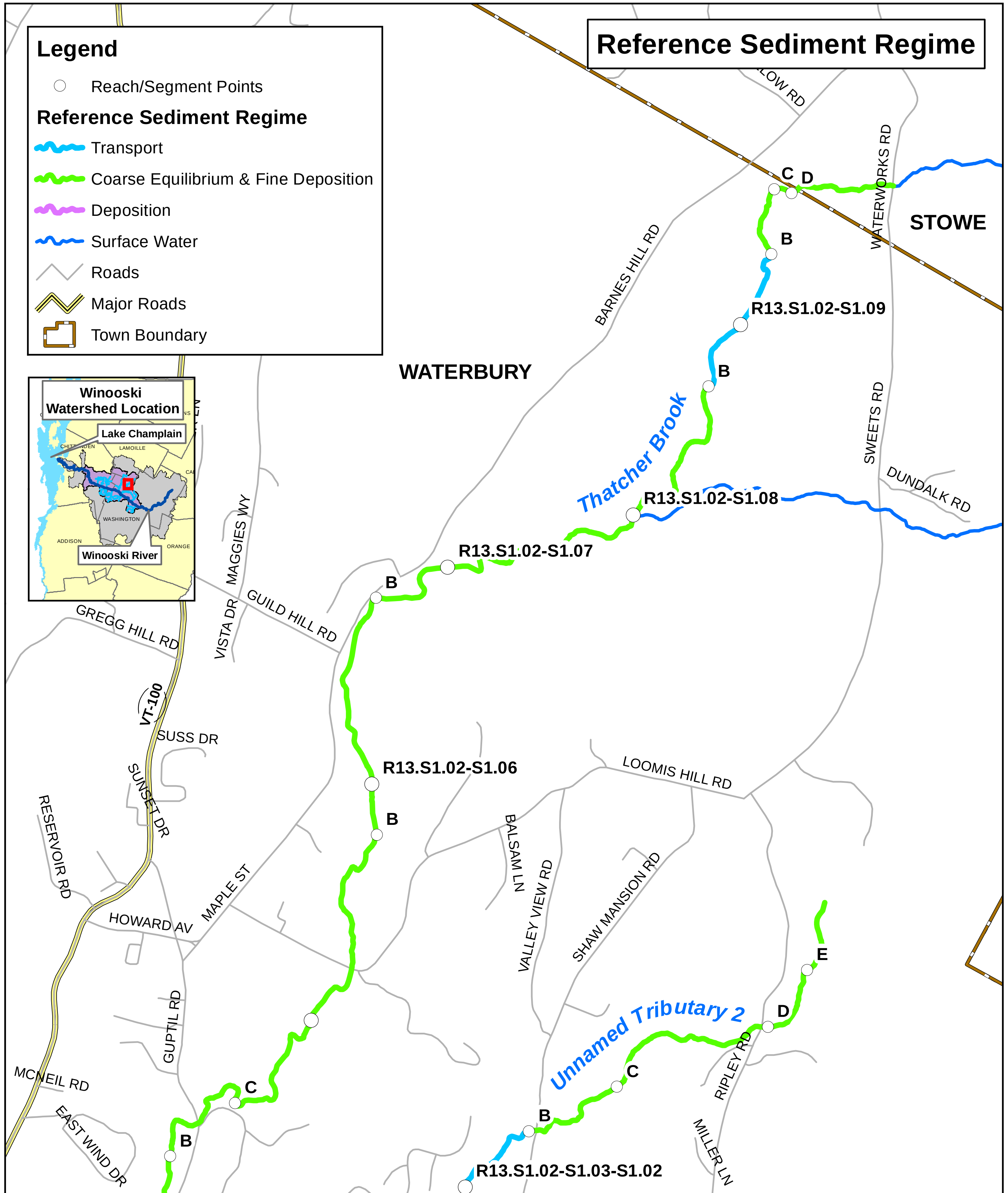


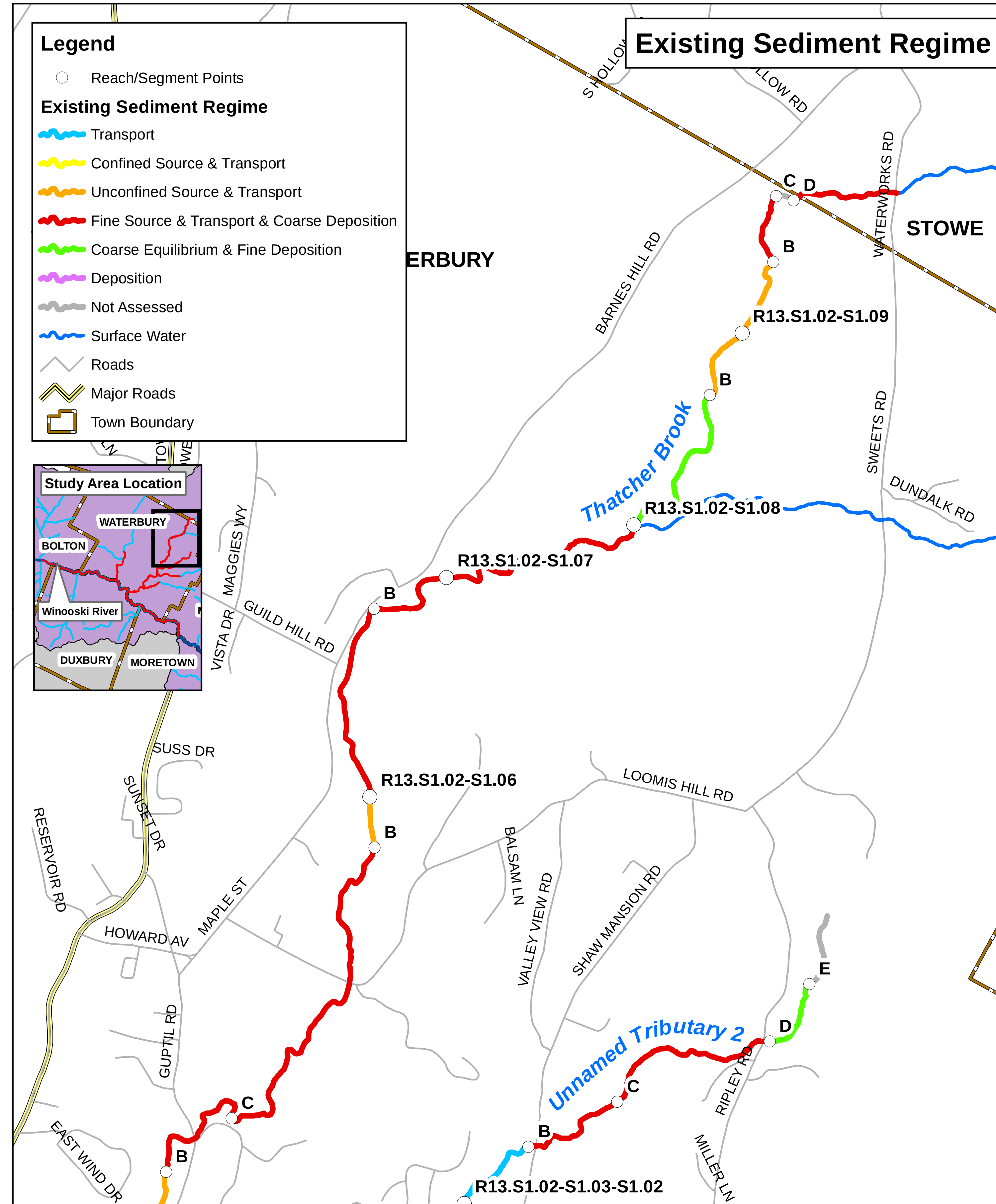
Winooski River, Little River, Thatcher Brook, Graves Brook, Unnamed Tributary 1, & Unnamed Tributary 2 Sediment Regime - Duxbury, Waterbury, Moretown, and Middlesex, Vermont

0 1 2 Miles

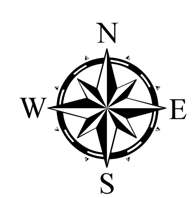
N S E W

Bear Creek Environmental





Thatcher Brook
Sediment Regime - Waterbury & Stowe, Vermont



0 0.5 1 Mile

Bear Creek Environmental

Table 1. Stream Type and Channel Evolution Stage Summary Mid-Winooski River Watershed							
Segment Number	**Entrenchment Ratio**	**Width to Depth Ratio**	**Reference Stream Type**	**Incision Ratio**	**Existing Stream Type**	**Channel Evolution Stage**	**Active Adjustment Process**
Winooski River Mainstem							
R11-A	1.8	49.8	C	1.4	B_c	F-III	**Incision** Aggradation **Widening** **Planform**
R11-B	1.3	43.3	B_c	1.0	B_c	F-III	Aggradation **Widening** Planform
R13	1.9	31.8	C	1.7	B_c	F-III	**Incision** Aggradation **Widening** Planform
R14	2.2	27.9	B_c	1.5	B_c	F-II	**Incision** Aggradation Widening Planform
Little River							
M2.01	1.0	41.2	C	3.3	F	F-III	**Incision** **Aggradation** **Widening** **Planform**
M2.02	1.5	38.0	C	1.6	B_c	F-III	**Incision** **Aggradation** **Widening** **Planform**
M2.03-A	2.1	26.9	B_c	1.5	B_c	F-IV	**Incision** **Aggradation** Widening **Planform**
M2.04-A	1.9	67.3	C	1.9	B_c	F-III	**Incision** **Aggradation** **Widening** **Planform**
M2.04-B	1.5	46.7	C	4.2	B_c	F-III	**Incision** Aggradation **Widening** Planform

	F Stream Type	B Stream Type	C Stream Type	E Stream Type
Entrenchment Ratio	< 1.4	1.4 – 2.2	> 2.2	> 2.2
Width to Depth Ratio	> 12	> 12	> 12	< 12

Bold Red lettering – denotes severe adjustment process
Bold Black lettering – denotes major adjustment process
Black lettering (no bold) – denotes minor adjustment process
Red denotes severe incision ratio (≥2.0)
Blue denotes moderate incision ratio (1.4 – <2.0)
Green denotes no incision to minor incision (<1.4)
Orange denotes a stream type departure

Table 1. Stream Type and Channel Evolution Stage Summary
Mid-Winooski River Watershed

Segment Number	Entrenchment Ratio	Width to Depth Ratio	Reference Stream Type	Incision Ratio	Existing Stream Type	Channel Evolution Stage	Active Adjustment Process
Graves Brook							
R13.S1.01-A	3.4	8.5	C	1.8	E	F-II	**Incision** Aggradation **Widening** **Planform**
R13.S1.01-B	3.5	16.1	C	1.6	C	F-III	**Incision** **Aggradation** Widening **Planform**
R13.S1.02-B	1.4	15.2	B_c	3.5	B_c	F-II	**Incision** Aggradation Widening Planform
R13.S1.03-A	9.6	8.2	C	1.6	E	F-II	**Incision** **Aggradation** Widening **Planform**
R13.S1.03-B	6.9	17.9	C	1.4	C	F-IV	Incision **Aggradation** **Widening** **Planform**
R13.S1.03-C	12.2	13.3	C	1.4	C	F-III	**Incision** **Aggradation** **Widening** **Planform**
Thatcher Brook							
R13.S1.02-S1.01-A	14.4	12.3	E	1.5	E	F-III	Incision **Aggradation** **Widening** **Planform**
R13.S1.02-S1.01-C	13.9	12.2	E	1.0	E	D-IIc	**Aggradation** **Widening** Planform
R13.S1.02-S1.01-D	6.9	14.6	C	1.5	C	F-III	Incision **Aggradation** **Widening** **Planform**

	F Stream Type	B Stream Type	C Stream Type	E Stream Type
Entrenchment Ratio	< 1.4	1.4 – 2.2	> 2.2	> 2.2
Width to Depth Ratio	> 12	> 12	> 12	< 12

Bold Red lettering – denotes severe adjustment process
Bold Black lettering – denotes major adjustment process
Black lettering (no bold) – denotes minor adjustment process
Red denotes severe incision ratio (≥2.0)
Blue denotes moderate incision ratio (1.4 – <2.0)
Green denotes no incision to minor incision (<1.4)
Orange denotes a stream type departure

Table 1. Stream Type and Channel Evolution Stage Summary
Mid-Winooski River Watershed

Segment Number	Entrenchment Ratio	Width to Depth Ratio	Reference Stream Type	Incision Ratio	Existing Stream Type	Channel Evolution Stage	Active Adjustment Process
R13.S1.02-S1.02	18.1	15.9	C	1.3	C	F-III	Incision **Aggradation** **Widening** **Planform**
R13.S1.02-S1.03	16.4	15.0	C	1.0	C	D-IIc	Incision **Aggradation** Widening Planform
R13.S1.02-S1.04-A	11.9	11.2	C	1.5	C	F-III	Incision **Aggradation** **Widening** **Planform**
R13.S1.02-S1.04-B	8.5	13.9	C	1.8	C	F-III	**Incision** Aggradation **Widening** **Planform**
R13.S1.02-S1.04-C	4.1	30.9	C	1.5	C	F-IV	Incision **Aggradation** **Widening** **Planform**
R13.S1.02-S1.05-A	3.8	17.1	C	1.7	C	F-IV	**Incision** **Aggradation** **Widening** **Planform**
R13.S1.02-S1.05-B	6.7	12.6	C	1.6	C	F-II	**Incision** Aggradation Widening Planform
R13.S1.02-S1.06-A	3.5	21.5	C_b	1.5	C_b	F-III	**Incision** **Aggradation** **Widening** **Planform**
R13.S1.02-S1.06-B	3.0	26.3	C_b	1.6	C_b	F-III	**Incision** Aggradation Widening **Planform**
R13.S1.02-S1.07	1.3	21.6	B	1.9	B	F-III	**Incision** Aggradation Widening **Planform**

	F Stream Type	B Stream Type	C Stream Type	E Stream Type
Entrenchment Ratio	< 1.4	1.4 – 2.2	> 2.2	> 2.2
Width to Depth Ratio	> 12	> 12	> 12	< 12

Bold Red lettering – denotes severe adjustment process
Bold Black lettering – denotes major adjustment process
Black lettering (no bold) – denotes minor adjustment process
Red denotes severe incision ratio (≥2.0)
Blue denotes moderate incision ratio (1.4 – <2.0)
Green denotes no incision to minor incision (<1.4)
Orange denotes a stream type departure

Table 1. Stream Type and Channel Evolution Stage Summary
Mid-Winooski River Watershed

Segment Number	Entrenchment Ratio	Width to Depth Ratio	Reference Stream Type	Incision Ratio	Existing Stream Type	Channel Evolution Stage	Active Adjustment Process
R13.S1.02-S1.08-A	3.7	19.1	C_b	1.5	C_b	F-II	**Incision** Aggradation Widening **Planform**
R13.S1.02-S1.08-B	1.6	16.0	B	2.1	B	F-II	**Incision** Aggradation Widening Planform
R13.S1.02-S1.09-A	2.1	15.1	B	1.7	B	F-II	**Incision** Widening Planform
R13.S1.02-S1.09-B	4.2	11.7	C	1.4	C	F-IV	Incision **Aggradation** Widening **Planform**
R13.S1.02-S1.09-D	5.8	15.2	C	1.3	C	F-IV	Incision **Aggradation** Widening **Planform**
Unnamed Tributary 1 to Thatcher Brook							
R13.S1.02-S1.02-S1.01-A	5.3	17.1	C	1.8	C	F-III	**Incision** Aggradation Widening Planform
R13.S1.02-S1.02-S1.01-C	3.2	18.0	C	2.0	C	F-IV	**Incision** **Aggradation** Planform
R13.S1.02-S1.02-S1.01-D	3.1	7.2	E	2.0	E	F-II	**Incision** Aggradation Planform
R13.S1.02-S1.02-S1.01-E	3.4	18.7	C	1.4	C	F-III	Incision Aggradation Widening Planform
R13.S1.02-S1.02-S1.01-F	8.1	8.6	E	1.2	E	F-II	Incision Aggradation Planform
R13.S1.02-S1.02-S1.01-G	4.2	12.0	C_b	1.0	C_b	F-I	Planform

	F Stream Type	B Stream Type	C Stream Type	E Stream Type
Entrenchment Ratio	< 1.4	1.4 – 2.2	> 2.2	> 2.2
Width to Depth Ratio	> 12	> 12	> 12	< 12

Bold Red lettering – denotes severe adjustment process
Bold Black lettering – denotes major adjustment process
Black lettering (no bold) – denotes minor adjustment process
Red denotes severe incision ratio (≥2.0)
Blue denotes moderate incision ratio (1.4 – <2.0)
Green denotes no incision to minor incision (<1.4)
Orange denotes a stream type departure

Table 1. Stream Type and Channel Evolution Stage Summary Mid-Winooski River Watershed							
Segment Number	**Entrenchment Ratio**	**Width to Depth Ratio**	**Reference Stream Type**	**Incision Ratio**	**Existing Stream Type**	**Channel Evolution Stage**	**Active Adjustment Process**
Unnamed Tributary 2 to Thatcher Brook							
R13.S1.02-S1.03-S1.01-A	12.1	16.8	C	1.0	C	F-I	**Aggradation** Widening Planform
R13.S1.02-S1.03-S1.01-B	4.1	15.8	C	1.0	C	D-IIc	**Aggradation** **Planform**
R13.S1.02-S1.03-S1.01-C	2.0	21.4	B	1.5	B	F-IV	**Incision** **Aggradation** **Planform**
R13.S1.02-S1.03-S1.02-A	1.5	14.8	B	1.0	B	F-I	Aggradation
R13.S1.02-S1.03-S1.02-B	5.0	10.0	C_b	1.7	C_b	F-II	**Incision** Aggradation Planform
R13.S1.02-S1.03-S1.02-C	1.9	15.6	C_b	2.0	B	F-II	**Incision** Aggradation Planform
R13.S1.02-S1.03-S1.02-D	1.8	10.6	B	1.2	B	F-II	Aggradation Planform

	F Stream Type	B Stream Type	C Stream Type	E Stream Type
Entrenchment Ratio	< 1.4	1.4 – 2.2	> 2.2	> 2.2
Width to Depth Ratio	> 12	> 12	> 12	< 12

Bold Red lettering – denotes severe adjustment process
Bold Black lettering – denotes major adjustment process
Black lettering (no bold) – denotes minor adjustment process
Red denotes severe incision ratio (≥2.0)
Blue denotes moderate incision ratio (1.4 – <2.0)
Green denotes no incision to minor incision (<1.4)
Orange denotes a stream type departure

APPENDIX B

Bridge & Culvert Assessment Data

Table 1. Scoring Table
(Vermont Culvert Geomorphic Compatibility Screen Tool, adapted by BCE for bridges)

Score	% Bankfull Width	Sediment Continuity	Approach Angle	Erosion and Armoring
5	%BFW ≥ 120	No upstream deposition or downstream bed scour	Naturally Straight	No erosion **or** armoring
4	100 ≤ %BFW < 120	**Either** upstream deposition **or** downstream bed scour, **without** upstream deposits taller than 0.5 bankfull height **or** high downstream banks	n/a	No erosion **and** intact armoring, **or** low upstream **or** downstream erosion **without** armoring
3	75 ≤ %BFW < 100	**Either** upstream deposition **or** downstream bed scour, **with** either upstream deposits taller than 0.5 bankfull height **or** high downstream banks	Mild bend	Low upstream **or** downstream erosion **with** armoring
2	50 ≤ %BFW < 75	**Both** upstream deposition **and** downstream bed scour, **without** upstream deposits taller than 0.5 bankfull height **or** high downstream banks	Channelized Straight	Low upstream **and** downstream erosion
1	30 ≤ %BFW < 50	**Both** upstream deposition **and** downstream bed scour, **with** upstream deposits taller than 0.5 bankfull height **or** high downstream banks	n/a	Severe upstream **or** downstream erosion
0	%BFW < 30	**Both** upstream deposition **and** downstream bed scour, **with** upstream deposits taller than 0.5 bankfull height **and** high downstream banks	Sharp Bend	Severe upstream **and** downstream erosion, **or** failing armoring upstream **or** downstream

Table 2. Compatibility Rating Results
(Vermont Culvert Geomorphic Compatibility Screen Tool, adapted by BCE for bridges)

Category Name	Screen Score	Threshold Conditions	Description of Structure-channel Geomorphic Compatibility
Fully Compatible	16<GC≤20	n/a	Structure fully compatible with natural channel form and process. There is a low risk of failure. No replacement anticipated over the lifetime of the structure. A similar structure is recommended when replacement is needed.
Mostly Compatible	12<GC≤16	n/a	Structure mostly compatible with current channel form and process. There is a low risk of failure. No replacement anticipated over the lifetime of the structure. Minor design adjustments recommended when replacement is needed to make fully compatible.
Partially Compatible	8<GC≤12	n/a	Structure compatible with either current form or process, but not both. Compatibility likely short term. There is a moderate risk of structure failure and replacement may be needed. Re-design suggested to improve geomorphic compatibility.
Mostly Incompatible	4<GC≤8	% Bankfull Width + Approach Angle scores ≤ 2	Structure mostly incompatible with current form and process, with a moderate to high risk of structure failure. Re-design and replacement planning should be initiated to improve geomorphic compatibility.
Fully Incompatible	0≤GC≤4	% Bankfull Width + Approach Angle scores ≤ 2 **AND** Sediment Continuity + Erosion and Armoring scores ≤ 2	Structure fully incompatible with channel and high risk of failure. Re-design and replacement should be performed as soon as possible to improve geomorphic compatibility.

Table 3. Scoring Table Vermont Culvert Geomorphic Compatibility Screen Tool (Milone & MacBroom, 2008)					
Score	**% Bankfull Width**	**Sediment Continuity**	**Slope**	**Approach Angle**	**Erosion and Armoring**
5	%BFW ≥ 120	No upstream deposition or downstream bed scour	Structure slope equal to channel slope, and no break in valley slope	Naturally Straight	No erosion **or** armoring
4	100 ≤ %BFW < 120	**Either** upstream deposition **or** downstream bed scour, **without** upstream deposits taller than 0.5 bankfull height **or** high downstream banks	n/a	n/a	No erosion **and** intact armoring, **or** low upstream **or** downstream erosion **without** armoring
3	75 ≤ %BFW < 100	**Either** upstream deposition **or** downstream bed scour, **with** either upstream deposits taller than 0.5 bankfull height **or** high downstream banks	Structure slope equal channel slope, with local break in valley slope	Mild bend	Low upstream **or** downstream erosion **with** armoring
2	50 ≤ %BFW < 75	**Both** upstream deposition **and** downstream bed scour, **without** upstream deposits taller than 0.5 bankfull height **or** high downstream banks	Structure slope higher or lower than channel slope, and no break in valley slope	Channelized Straight	Low upstream **and** downstream erosion
1	30 ≤ %BFW < 50	**Both** upstream deposition **and** downstream bed scour, **with** upstream deposits taller than 0.5 bankfull height **or** high downstream banks	n/a	n/a	Severe upstream **or** downstream erosion
0	%BFW < 30	**Both** upstream deposition **and** downstream bed scour, **with** upstream deposits taller than 0.5 bankfull height **and** high downstream banks	Structure slope higher or lower than channel slope, with local break in valley slope	Sharp Bend	Severe upstream **and** downstream erosion, **or** failing armoring upstream **or** downstream

Table 4. Geomorphic Compatibility Rating Results Vermont Culvert Geomorphic Compatibility Screen Tool (Milone & MacBroom, 2008)			
Category Name	**Screen Score**	**Threshold Conditions**	**Description of Structure-channel Geomorphic Compatibility**
Fully Compatible	20<GC≤25	n/a	Structure fully compatible with natural channel form and process. There is a low risk of failure. No replacement anticipated over the lifetime of the structure. A similar structure is recommended when replacement is needed.
Mostly Compatible	15<GC≤20	n/a	Structure mostly compatible with current channel form and process. There is a low risk of failure. No replacement anticipated over the lifetime of the structure. Minor design adjustments recommended when replacement is needed to make fully compatible.
Partially Compatible	10<GC≤15	n/a	Structure compatible with either current form or process, but not both. Compatibility likely short term. There is a moderate risk of structure failure and replacement may be needed. Re-design suggested to improve geomorphic compatibility.
Mostly Incompatible	5<GC≤10	% Bankfull Width + Approach Angle scores ≤ 2	Structure mostly incompatible with current form and process, with a moderate to high risk of structure failure. Re-design and replacement planning should be initiated to improve geomorphic compatibility.
Fully Incompatible	0≤GC≤5	% Bankfull Width + Approach Angle scores ≤ 2 **AND** Sediment Continuity + Erosion and Armoring scores ≤ 2	Structure fully incompatible with channel and high risk of failure. Re-design and replacement should be performed as soon as possible to improve geomorphic compatibility.

Table 5. Aquatic Organism Passage (AOP) Coarse Screen Tool (Milone & MacBroom, 2009)						
VT Aquatic Organism Passage Coarse Screen	**Full AOP**	**Reduced AOP**	**No AOP**			
Updated 2/25/2008	**for all aquatic organisms**	**for all aquatic organisms**	**for all aquatic organisms except adult salmonids**		**for all aquatic organisms including adult salmonids**	
AOP Function Variables / Values	**Green (if all are true)**	**Gray (if any are true)**	**Orange**		**Red**	
Culvert outlet invert type	at grade **OR** backwatered	cascade	free fall **AND**		free fall **AND**	
Outlet drop (ft)	= 0		> 0 , < 1 ft **OR**		≥ 1 ft **OR**	
Downstream pool present			= yes	(= yes **AND**	= no **OR**	(= yes **AND**
Downstream pool entrance depth / outlet drop			n/m	≥ 1)	n/a	< 1) **OR**
Water depth in culvert at outlet (ft)					< 0.3 ft	
Number of culverts at crossing	1	> 1				
Structure opening partially obstructed	= none	≠ none				
Sediment throughout structure	yes	no				

Notes:
Assessment completed during low flows
Outlet drop = invert of structure to water surface
Pool present variable is used alone if pool depths are not measured
n/m = not measured
n/a = not applicable

Table 6. Town of Waterbury Bridge Assessment (2009/2014) Geomorphic Compatibility													
Reach/ Segment Number	Town	Road Name	Structure ID[1]	Percent Bankfull Channel Constriction Width[2]	Phase 2 Notes	Scoring							Priority for Replacement
						% Bankfull Width[3]	Sediment Continuity	Approach Angle	Erosion & Armoring	Total Score	Geomorphic Compatibility	
R11-B	Bolton	Railroad	200000000104012	450/253.8 = 177	Very old railroad bridge. Scour around piers, reinforced with failing riprap. One pier is built onto bedrock. Bridge decking is very rusty.	5	2	3 Mild Bend	2	**12**	Partially Compatible	Moderate (Poor condition, scour)
R12	Waterbury /Duxbury	VAST Trail	700000000012183	240/250.9 = 96	Cable suspension bridge on VAST Trail. Bridge is built on top of the river banks and does not appear to be impacting the river.	3	5	0 Sharp Bend	1	**9**	Partially Compatible	Not recommended for replacement (Not impacting river)
R13	Waterbury /Duxbury	Railroad	200000000012182	450/234.5 = 192	Old railroad bridge constructed in 1926. I-beams rusted, piers cracked, scour around piers. Significant deposition between piers and an island at the outlet.	5	2	3 Mild Bend	0	**10**	Partially Compatible	Moderate (Poor condition)
R13	Waterbury /Duxbury	Route 2	200013004812182	279/234.5 = 119	New structure in good condition and not a channel constriction. Bridge is curved horizontally and does not go straight across the river.	4	5	2 Channelized Straight	0	**11**	Partially Compatible	Not recommended for replacement (Newly constructed)
R13	Waterbury /Duxbury	Winooski Street	101218003112181	207/23.45 = 88	Bridge was damaged and overtopped during Tropical Storm Irene. The right side approach was washed out during TSI. Bedrock along left bank.	3	4	2 Channelized Straight	2	**11**	Partially Compatible	Moderate (Damaged and overtopped during TSI)
R14	Moretown/ Middlesex	Route 2	200284005012122	285/229.6 = 124	New bridge in good condition. Left side abutment built into bedrock. Bald eagle sighted at time of assessment.	5	5	2 Channelized Straight	2	**14**	Mostly Compatible	Not recommended for replacement (Newly constructed)
M2-04-B	Waterbury	Trail	700000000112183	75/105.3 = 71	Bridge appears to have been used by cars at one time but is now blocked off. Current use most likely snowmobiles; connects into VAST trail. Fair condition. Decking is old and worn. Large pool below bridge due to bend in channel. Left abutment built into bedrock.	2	5	3 Mild Bend	0	**10**	Partially Compatible	Low (Slightly undersized; deteriorating decking)
R13.S1.01-A	Waterbury	North Main Street[4]	200013004712182	37/47.9 = 77	Bridge on US Route 2 (North Main Street) at Union Street intersection (brook flows under both roads); railroad bridge crosses above the road	3	3	3 Mild Bend	0	**9**	Partially Compatible	Low (Slightly undersized with failing armoring)
R13.S1.01-A	Waterbury	Armory Drive[4]	101218003312181	51/47.9 = 106	Bridge has minimal issues	4	5	2 Channelized Straight	0	**11**	Partially Compatible	Not recommended for replacement (Bridge span is wider than bankfull width; minimal problems)
R13.S1.02-B	Waterbury	Stowe Street[4]	101218003612181	42/47 = 89	None	3	4	3 Mild Bend	0	**10**	Partially Compatible	Low (Slightly undersized)
R13.S1.02-S1.01-B	Waterbury	Private Drive[4]	700423000012183	60/43.5 = 137	Bridge decking is wooden boards over steel I-beams; 6x6" post is acting as a pier; scour around abutments and wing walls	5	3	5 Naturally Straight	0	**13**	Mostly Compatible	Moderate (Bridge is not a channel constriction but has abutment and wing wall scour)
R13.S1.02-S1.01-B	Waterbury	Laurel Lane[4]	101218001612181	62/43.5 = 142	Beams are rusty and bridge appears to be fairly old; scour around abutments	5	4	2 Channelized Straight	0	**11**	Partially Compatible	Moderate (Bridge is not a channel constriction but has abutment scour)

Table 6. Town of Waterbury Bridge Assessment (2009/2014)
Geomorphic Compatibility

Reach/ Segment Number	Town	Road Name	Structure ID[1]	Percent Bankfull Channel Constriction Width[2]	Phase 2 Notes	Scoring						Priority for Replacement
						% Bankfull Width[3]	Sediment Continuity	Approach Angle	Erosion & Armoring	Total Score	Geomorphic Compatibility	
R13.S1.01-S1.01-D	Waterbury	Guptil Road[4]	101218000512181	63/43.5 = 144	Bridge appears to be fairly new and has minimal issues	5	3	0 Sharp Bend	3	**11**	Partially Compatible	Not recommended for replacement (Bridge is in good condition)
R13.S1.02-S1.02	Waterbury	Guptil Road[4]	101218000312181	45/41.2 = 109	Streambed scour around abutments. Not a channel constriction	4	1	3 Mild Bend	0	**8**	Mostly Incompatible	Low (Not a channel constriction)
R13.S1.02-S1.03	Waterbury	Guptil Road[4]	101218000412181	78/36.6 = 213	Structure is not a channel constriction; aggradation is typical in this reach and not excessive in vicinity of bridge	5	3	2 Channelized Straight	3	**13**	Mostly Compatible	Not recommended for replacement (Bridge has minimal impacts)
R13.S1.02-S1.04-B	Waterbury	Guptil Road[4]	101218000212181	52/32.5 = 160	Bridge is well sized and has minimal issues	5	2	3 Mild Bend	0	**10**	Partially Compatible	Not recommended for replacement (Bridge has minimal impacts)
R13.S1.02-S1.04-C	Waterbury	Trail[4]	700000000612183	30/32.5 = 92	Although stream does not appear directly manipulated, channel avulsion just downstream of structure makes stream appear channelized straight. Left abutment slumping toward brook	3	3	2 Channelized Straight	2	**10**	Partially Compatible	Moderate (Left abutment slumping)
R13.S1.02-S1.05-A	Waterbury	Loomis Hill Road[4]	101218001412181	36/31.4 = 114	Not a channel constriction and few issues	4	3	3 Mild Bend	0	**10**	Partially Compatible	Low (Not a channel constriction)
R13.S1.02-S1.09-D	Stowe	Waterworks Road	990056001508081	13/20.7 = 63	Structure in good condition but very low clearance (3.7 feet). Heavily choked with sediment. Dam upstream of bridge regulates flow and channel dry at low flow.	2	4	2 Channelized Straight	2	**10**	Partially Compatible	Moderate (Undersized; low clearance)
R13.S1.02-S1.02-S1.01-D	Waterbury	Trail to Green Mountain Garlic	700000000212183	18.5/20.6 = 90	Poor condition: failing abutments and rusted I-beams. Bridge is falling into river. Trail is used to access pasture/crop fields across river. Scour below.	3	4	2 Channelized Straight	0	**9**	Partially Compatible	Moderate (Poor condition but not very undersized)
R13.S1.02-S1.02-S1.01-G	Waterbury	VAST Trail	700000000312183	11/20.6 = 53	Bridge appeared to be part of VAST Trail network. Poor condition and unsafe: half of left abutment has fallen into river. Right abutment is also falling and decking is collapsing. Deposition above and below.	2	2	3 Mild Bend	2	**9**	Partially Compatible	**High** (Poor condition and unsafe for travel)
R13.S1.02-S1.03-S1.01-A	Waterbury	Guptil Road	990001000112181	16.5/18.7 = 88	Poor condition; armor failing; low clearance. Significant sediment built up under bridge obstructing flow. Scour below also.	3	4	2 Channelized Straight	0	**9**	Partially Compatible	**High** (Poor condition and low clearance)
R13.S1.02-S1.03-S1.01-B	Waterbury	Harvey Farm Road	400000000112181	16/18.7 = 86	Bridge in good condition overall and relatively new structure. Deposition below. Poor channel alignment.	3	5	0 Sharp Bend	1	**9**	Partially Compatible	Low (Slightly undersized; poor alignment)

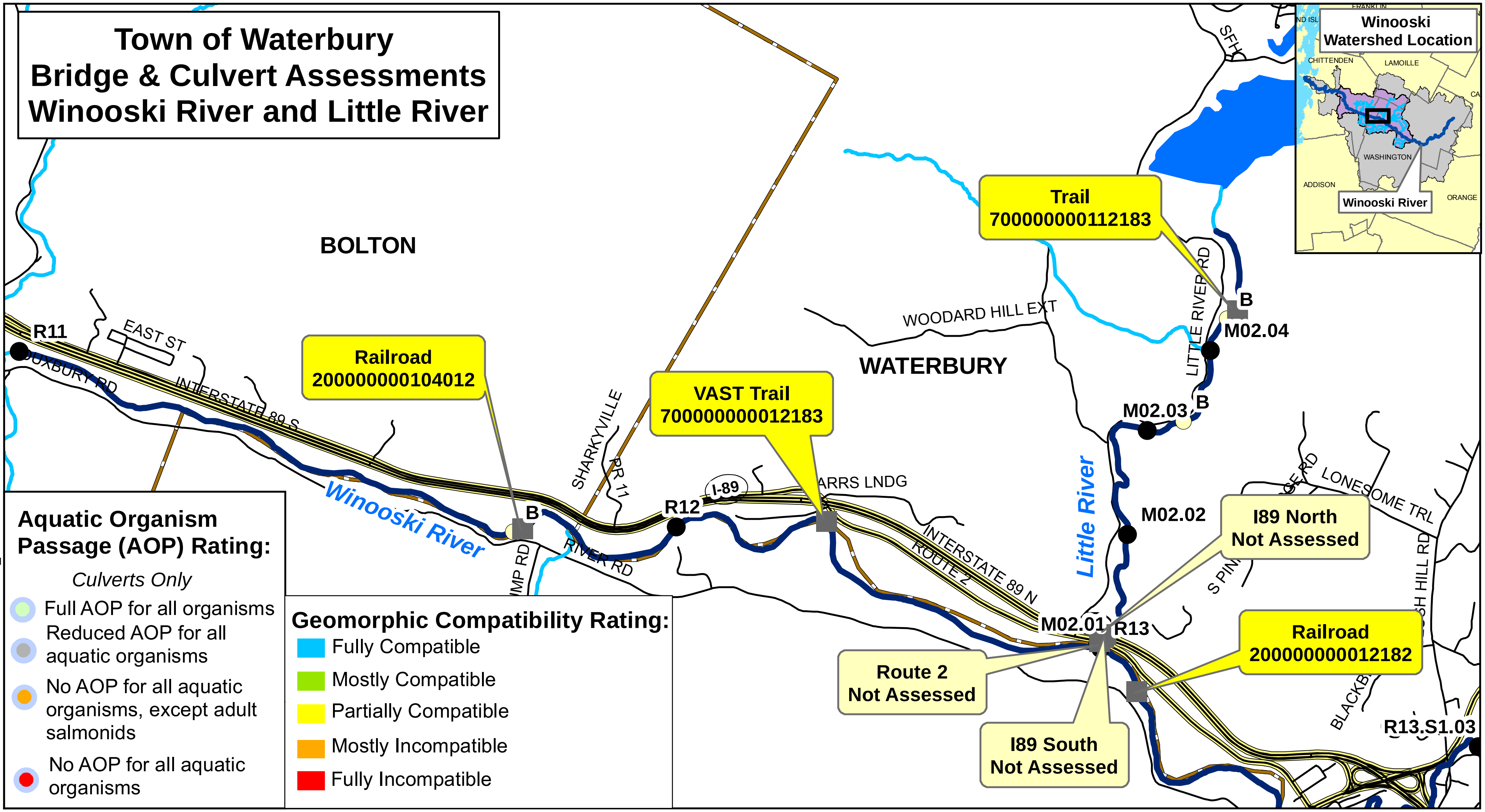
[1]The structure ID is the identification number provided by the 2010 "TransStructures_TRANSTRUC" shapefile from the Vermont Center for Geographic Information, unless no number was available. In this case, the SGAID is provided.
[2]Percent Bankfull Channel Width percentages are calculated based on the reference channel width for each reach. The percentage is calculated by dividing the present constriction width by the reference channel width.
[3]The % bankfull width is based on the constriction calculation.
[4]Structure was assessed in 2009. All other structures assessed in 2014.

Table 7. Town of Waterbury Culvert Assessment (2014)
Geomorphic Compatibility and Aquatic Organism Passage (AOP)

Reach/ Segment Number	Road Name	Structure Type and ID[1]	Percent Bankfull Channel Width[2]	Phase 2 Notes	Scoring (Geomorphic Compatibility - Milone & MacBroom, 2008; AOP – Milone & MacBroom, 2009)								Priority for Replacement
					% Bankfull Width	Sediment Continuity	Slope	Approach Angle	Erosion & Armoring	Total Score	Geomorphic Compatibility	AOP	
R13.S1.03-A	Lincoln Street	700019024312183	9/20.6 = 44	Elliptical culvert. If blocked stream could flood nearby homes, road, and park and ride. Extensive riprap falling into streambed. Significantly undersized. Poor alignment.	1	4	5	2 Channelized Straight	0	**12**	Partially Compatible	Reduced AOP	**High** (Significantly undersized)
R13.S1.02-S1.09-B	Private Drive	100000000212181	NA	Three culverts. Two in main channel (each 4 feet wide) one in side channel (4 feet wide). Downstream of wetland complex therefore not really applicable for bankfull assessment. Deposition and scour below.	NA	4	5	3 Mild Bend	0	**12**	Partially Compatible	No AOP Including Adult Salmonids	**High** (No AOP)
R13.S1.02-S1.02-S1.01-C	Twin Peaks Road	700055032412183	11.1/20.6 = 54	Culvert height at outlet is 5.2 feet with 1.8 feet of sediment in pipe at outlet. Culvert completely backwatered with a slope that is too low. Deposition above and below.	2	4	2	3 Mild Bend	0	**11**	Partially Compatible	Full AOP	Moderate (Undersized, low slope)
R13.S1.02-S1.02-S1.01-F	Perry Hill Road	700004008712183	12.9/20.6 = 63	Bottom of culvert is rusty, but overall good condition. Slope lower than channel slope.	2	5	2	3 Mild Bend	0	**12**	Partially Compatible	Reduced AOP	Moderate (Undersized, low slope)
R13.S1.02-S1.03-S1.02-B	Shaw Mansion Road	100000000512181	7/17 = 41	Culvert bottom rusted. Headwall failing and scour around culvert. Aggradation above and large scour pool below.	1	2	2	3 Mild Bend	0	**8**	Mostly Incompatible	Reduced AOP	**High** (Significantly undersized, scour and deposition)
R13.S1.02-S1.03-S1.02-C	Ripley Road	100000000612181	6.5/17 = 38	Culvert bottom rusted. Four foot high cascade over riprap causing a potential AOP barrier. Deposition above and scour below.	1	3	2	5 Naturally Straight	0	**11**	Partially Compatible	Reduced AOP	**High** (Significantly undersized; cascade potential AOP issue)
R13.S1.02-S1.03-S1.02-E	Private Trail	700000000412183	NA	Culvert located at outlet of human-made pond in wetland therefore not applicable for bankfull assessment. Stream channel begins below culvert. Scour below.	NA	5	5	2 Channelized Straight	4	**16**	Mostly Compatible	Reduced AOP	Low (Pond outlet pipe)
R13.S1.02-S1.03-S1.02-E	Private Trail	700000000512183	3.5/17 = 21	Double culvert, one 1.5 feet wide and one 2 feet wide due to being slightly crushed.	0	5	2	5 Naturally Straight	4	**16**	Mostly Compatible	Reduced AOP	Moderate (Significantly undersized, low slope)

[1]The structure ID is the identification number provided by the 2010 "TransStructures_TRANSTRUC" shapefile from the Vermont Center for Geographic Information, unless no number was available. In this case the SGAID is provided.
[2]Percent Bankfull Channel Width percentages are calculated based on the reference channel width for each reach. The percentage is calculated by dividing the culvert width by the reference channel width.

Town of Waterbury
Bridge & Culvert Assessments
Winooski River and Little River



Legend

- Bridge
- Culvert
- Segment Point
- Phase 2 Reach Point
- Phase 2 Study Area
- Surface Water
- Roads
- Major Roads
- Town Boundary

The ID numbers are provided by the 2010 “TransStructures_TRANSTRUC”shapefile from the Vermont Center for Geographic Information, unless no number was available. The SgaID (State of Vermont Data Management System) was used if no “TransStructures_TRANSTRUC” information was available.

Geomorphic Compatibility Rating for bridges is adapted from the Vermont Culvert Geomorphic Compatibility Screening Tool (Milone and MacBroom, Inc. 2008).

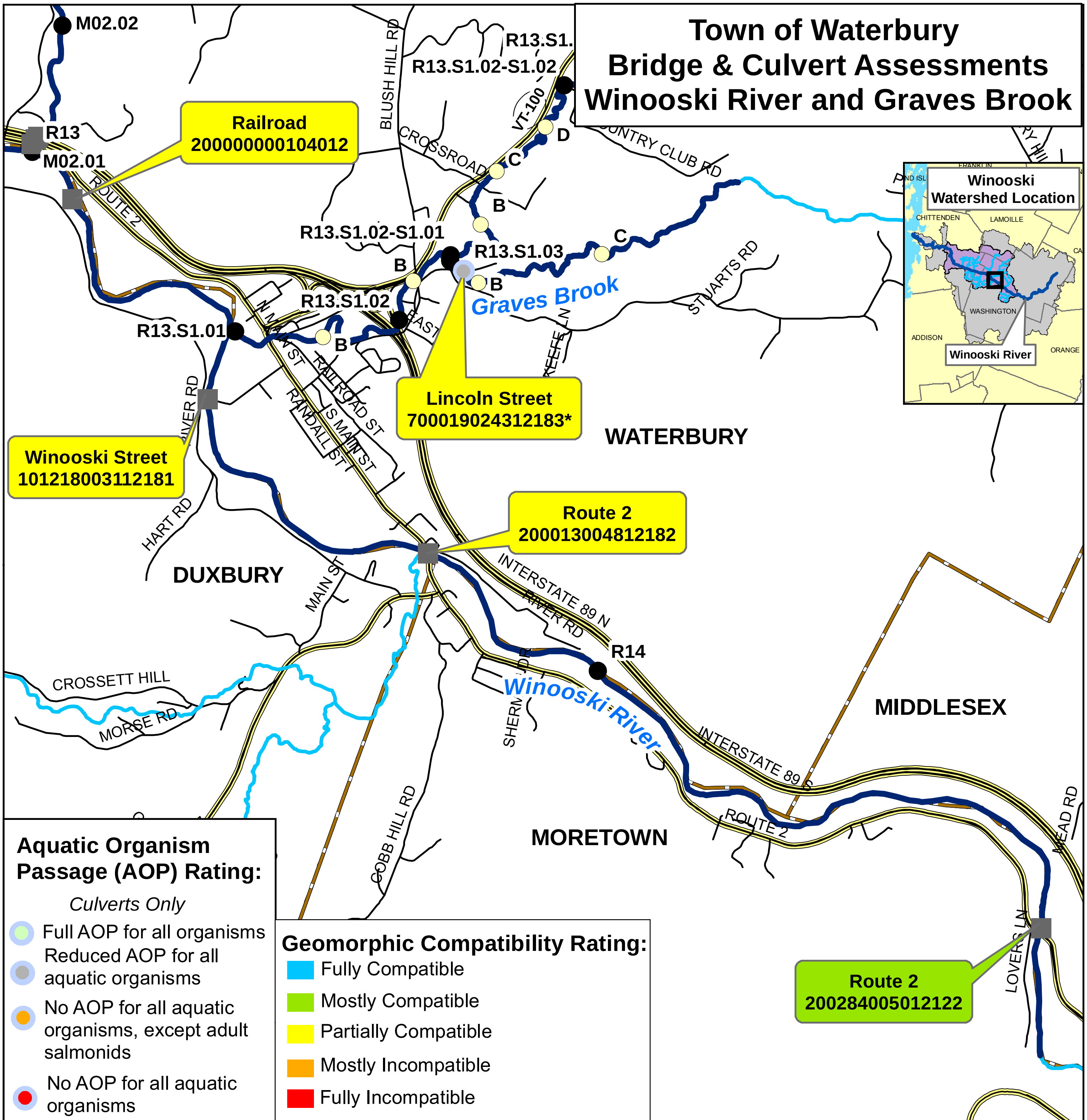
Aquatic Organism Passage Rating for culverts is from the Vermont Culvert Aquatic Organism Passage Screening Tool (Milone and MacBroom, 2009).

*Structure is recommended for replacement.

N W E S

0 0.5 1 Mile

Bear Creek Environmental



Legend

- Bridge
- Culvert
- Segment Point
- Phase 2 Reach Point
- Phase 2 Study Area
- Surface Water
- Roads
- Major Roads
- Town Boundary

The ID numbers are provided by the 2010 “TransStructures_TRANSTRUC”shapefile from the Vermont Center for Geographic Information, unless no number was available. The SgaID (State of Vermont Data Management System) was used if no “TransStructures_TRANSTRUC” information was available.

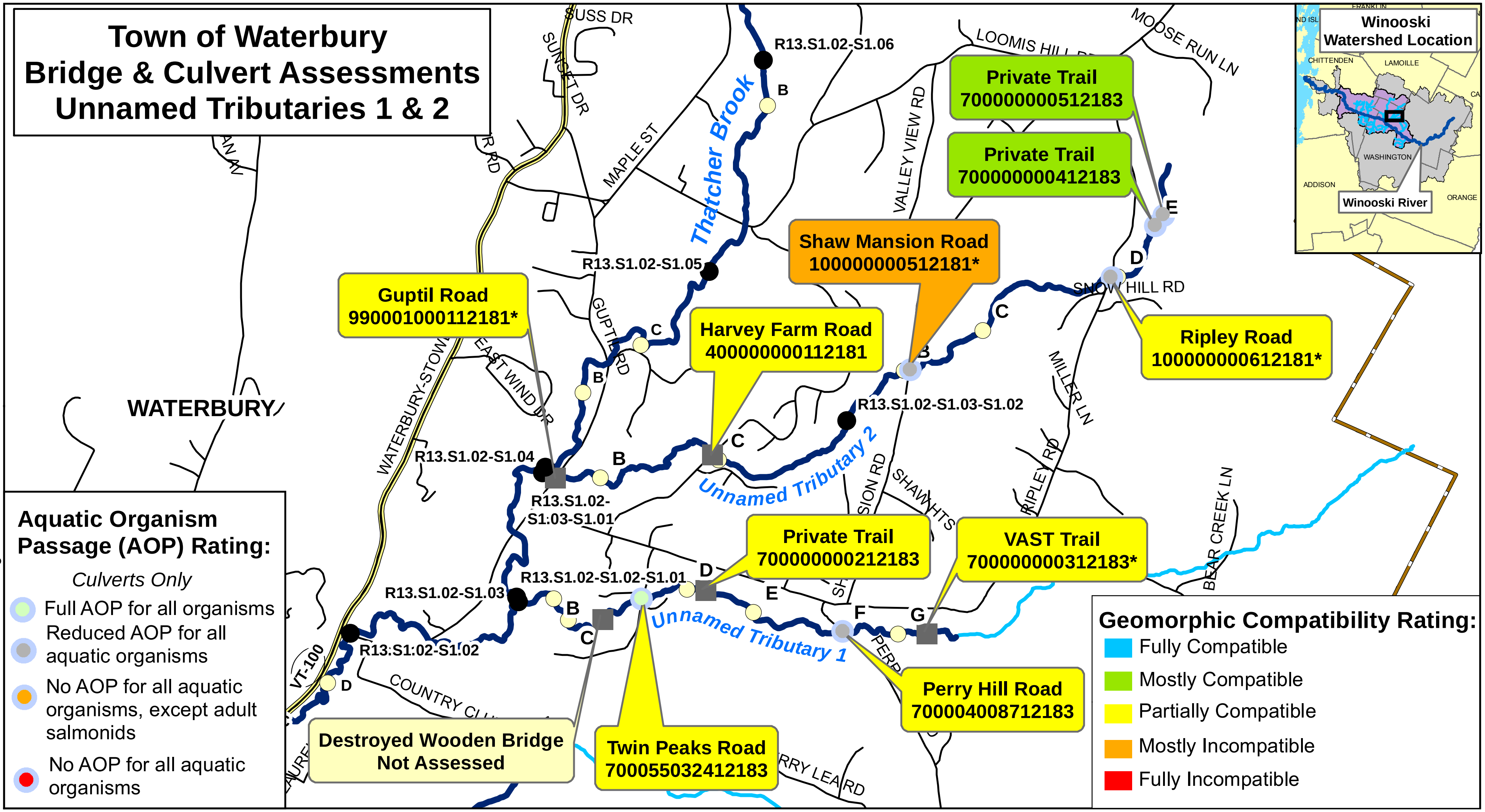
Geomorphic Compatibility Rating for bridges is adapted from the Vermont Culvert Geomorphic Compatibility Screening Tool (Milone and MacBroom, Inc. 2008).

Aquatic Organism Passage Rating for culverts is from the Vermont Culvert Aquatic Organism Passage Screening Tool (Milone and MacBroom, 2009).

*Structure is recommended for replacement.

0 0.5 1 Mile

Bear Creek Environmental



Legend

- Bridge
- Culvert
- Segment Point
- Phase 2 Reach Point
- Town Boundary
- Phase 2 Study Area
- Surface Water
- Roads
- Major Roads

The ID numbers are provided by the 2010 "TransStructures_TRANSTRUC"shapefile from the Vermont Center for Geographic Information, unless no number was available. The SgaID (State of Vermont Data Management System) was used if no "TransStructures_TRANSTRUC" information was available.

Geomorphic Compatibility Rating for bridges is adapted from the Vermont Culvert Geomorphic Compatibility Screening Tool (Milone and MacBroom, Inc. 2008).

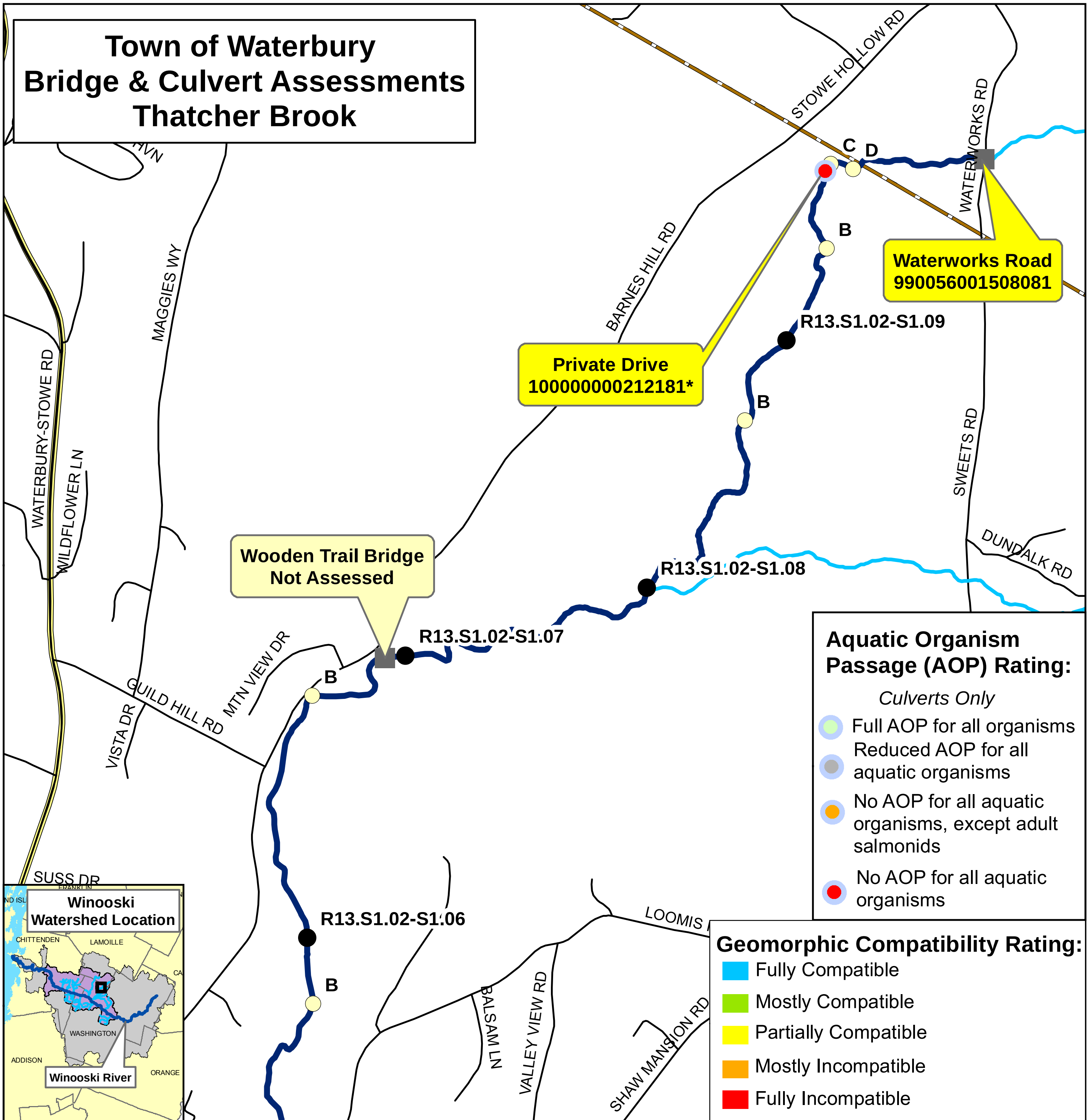
Aquatic Organism Passage Rating for culverts is from the Vermont Culvert Aquatic Organism Passage Screening Tool (Milone and MacBroom, 2009).

*Structure is recommended for replacement.

0 0.5 1 Mile

Bear Creek Environmental

Town of Waterbury
Bridge & Culvert Assessments
Thatcher Brook



Legend

- Bridge
- Culvert
- Segment Point
- Phase 2 Reach Point
- Phase 2 Study Area
- Surface Water
- Roads
- Major Roads
- Town Boundary

The ID numbers are provided by the 2010 "TransStructures_TRANSTRUC"shapefile from the Vermont Center for Geographic Information, unless no number was available. The SgaID (State of Vermont Data Management System) was used if no "TransStructures_TRANSTRUC" information was available.

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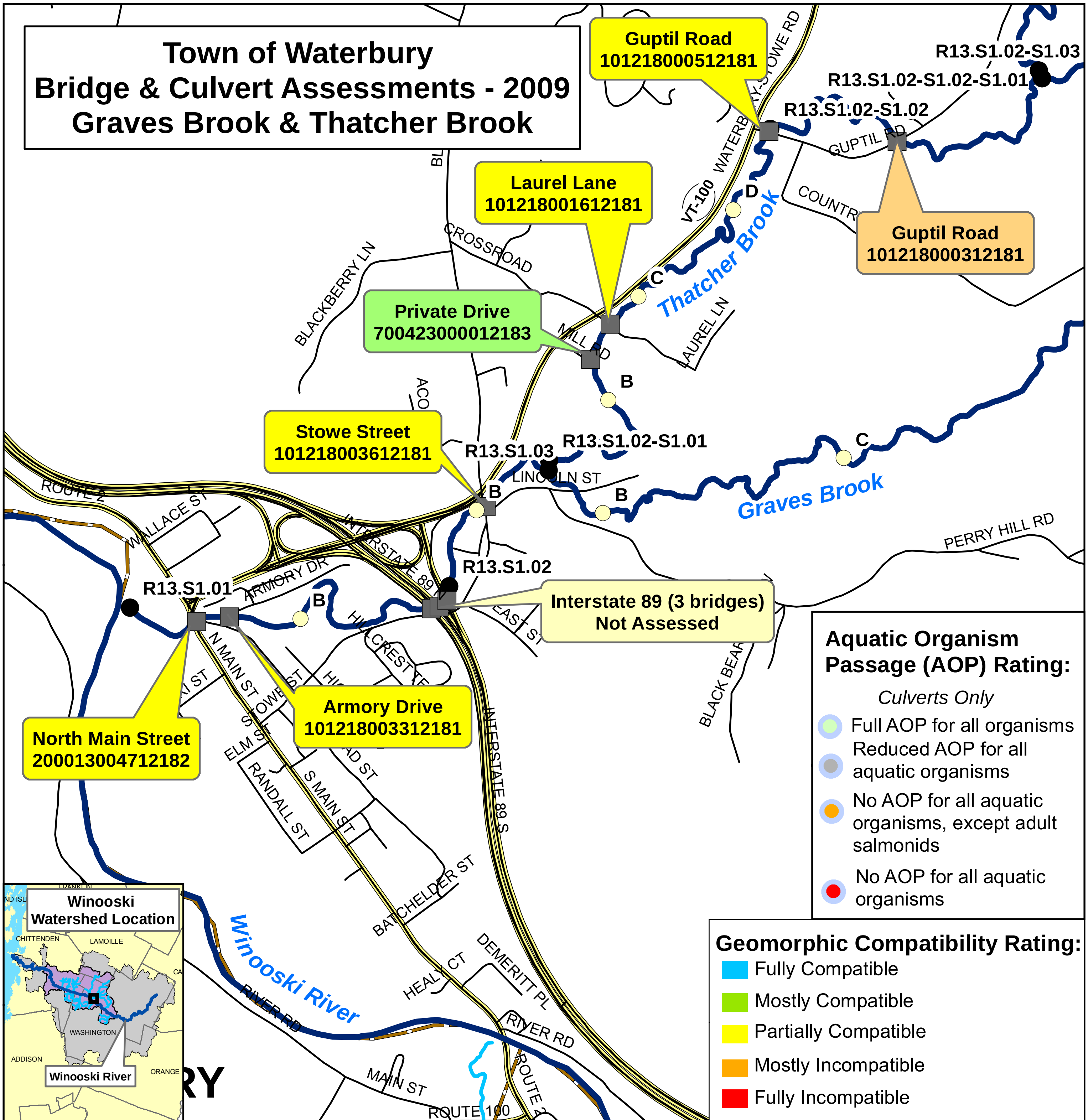
*Structure is recommended for replacement.

N W E S

0 0.25 0.5 Mile

Bear Creek Environmental



Legend

- Bridge
- Segment Point
- Phase 2 Reach Point
- Phase 2 Study Area
- Surface Water
- Roads
- Major Roads
- Town Boundary

The ID numbers are provided by the 2010 “TransStructures_TRANSTRUC”shapefile from the Vermont Center for Geographic Information, unless no number was available. The SgaID (State of Vermont Data Management System) was used if no “TransStructures_TRANSTRUC” information was available.

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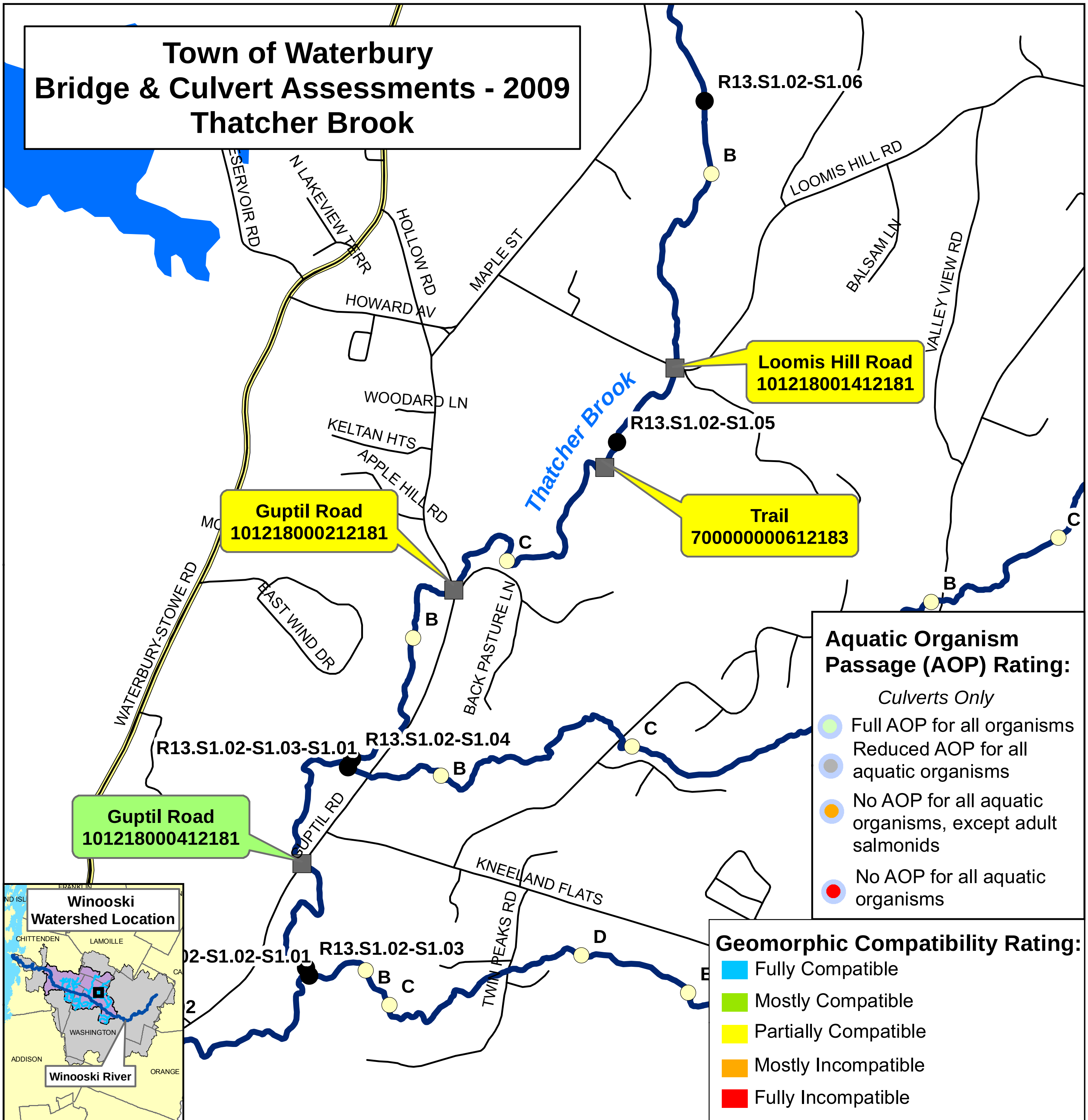
*Structure is recommended for replacement.

0 0.25 0.5 Mile

Bear Creek Environmental



Legend

- Bridge
- Segment Point
- Phase 2 Reach Point
- Phase 2 Study Area
- Surface Water
- Roads
- Major Roads
- Town Boundary

The ID numbers are provided by the 2010 "TransStructures_TRANSTRUC"shapefile from the Vermont Center for Geographic Information, unless no number was available. The SgaID (State of Vermont Data Management System) was used if no "TransStructures_TRANSTRUC" information was available.

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*Structure is recommended for replacement.

N W E S

0 0.25 0.5 Mile

Bear Creek Environmental

APPENDIX C

Post-Flood Update

Bear Creek Environmental, LLC
149 State Street, Suite 3 / Montpelier, VT 05602
Phone: (802) 223-5140 / Web: www.BearCreekEnvironmental.com

POST-FLOOD UPDATE SECTION

1.0 INTRODUCTION

In late August of 2011, Vermont was hit hard by Tropical Storm Irene (TSI). Heavy rain totaled over seven inches in areas over the course of one day. The immense downpours caused raging floodwaters to tear through Vermont's streams, devastating people and infrastructure throughout central and southern Vermont. In some areas, TSI flooding approached historic flood levels, while in other areas, the storm greatly exceeded them. Over 500 miles of state roads were damaged as a result of TSI, in addition to over 2000 segments of municipal roads. In total, approximately 500 bridges were damaged or destroyed, as well as almost 1,000 culverts. Approximately 1,500 residences were significantly damaged or destroyed as a result of flooding, as well as state, municipal, and commercial buildings (VANR 2012).
Flooding associated with Tropical Storm Irene (TSI) in late August 2011 greatly impacted Waterbury, Vermont. Due to very high stream flows from TSI, the channels of Graves and Thatcher Brook may have experienced major changes. In order to observe any changes in channel geometry, Bear Creek Environmental (BCE) looked at pre-TSI geomorphic data and aerial imagery and compared it to post TSI measurements and observations.

2.0 PRE- AND POST-TSI CHANNEL CONDITIONS

Phase 2 Stream Geomorphic Assessment data were collected on the lower reaches of Graves Brook and Thatcher Brook in 2009 by Redstart Consulting under contract with the Central Vermont Regional Planning Commission (CVRPC). Bear Creek Environmental, LLC (BCE) and the Central Vermont Regional Planning Commission resurveyed cross sections during 2014 that had been measured by Redstart Consulting in 2009 to assess whether there were major changes in channel geometry due to flooding or post TSI floodworks (i.e. stream channel modification). Wherever possible, BCE placed cross sections at the same locations as in 2009. In addition, BCE conducted a review of aerial imagery to determine visible changes in channel course between 2009 and 2013 – pre- and post-Irene.

National Agricultural Inventory Project (NAIP) 2009 imagery data were used to digitize the pre-TSI stream channel location for lower Graves Brook and Thatcher Brook. The digitized stream layer from 2009 was then overlain on Vermont Center for Geographic Information imagery from spring 2013 in ArcGIS to observe changes from 2009 to 2013. Figures 1 and 2 below show examples of changes observed along Thatcher Brook between 2009 and 2013. The results of the comparison of channel planform from 2009 and 2013 showed two areas where the channel had avulsed in the following segments: R13.S1.02-S1.04-A and R13.S1.02-S1.05-A (Figure 3). Google Earth Imagery dated 12/30/2011 was observed to pinpoint when the channel avulsions may have occurred. In both locations, Google Earth Imagery revealed that these avulsions occurred between 2009 and the end of 2011, most likely during TSI. Meander migrations occurred in 18 locations along the channel meanders between 2009 and 2013.

Figure 1. Side by side comparison of a location along Thatcher Brook where meander migration (purple dots) occurred likely as a result of TSI (2009 imagery on left, 2013 on right).

Figure 2. Side by side comparison of a location along Thatcher Brook where channel avulsion occurred as a result of TSI (2009 imagery on left, 2013 on right).

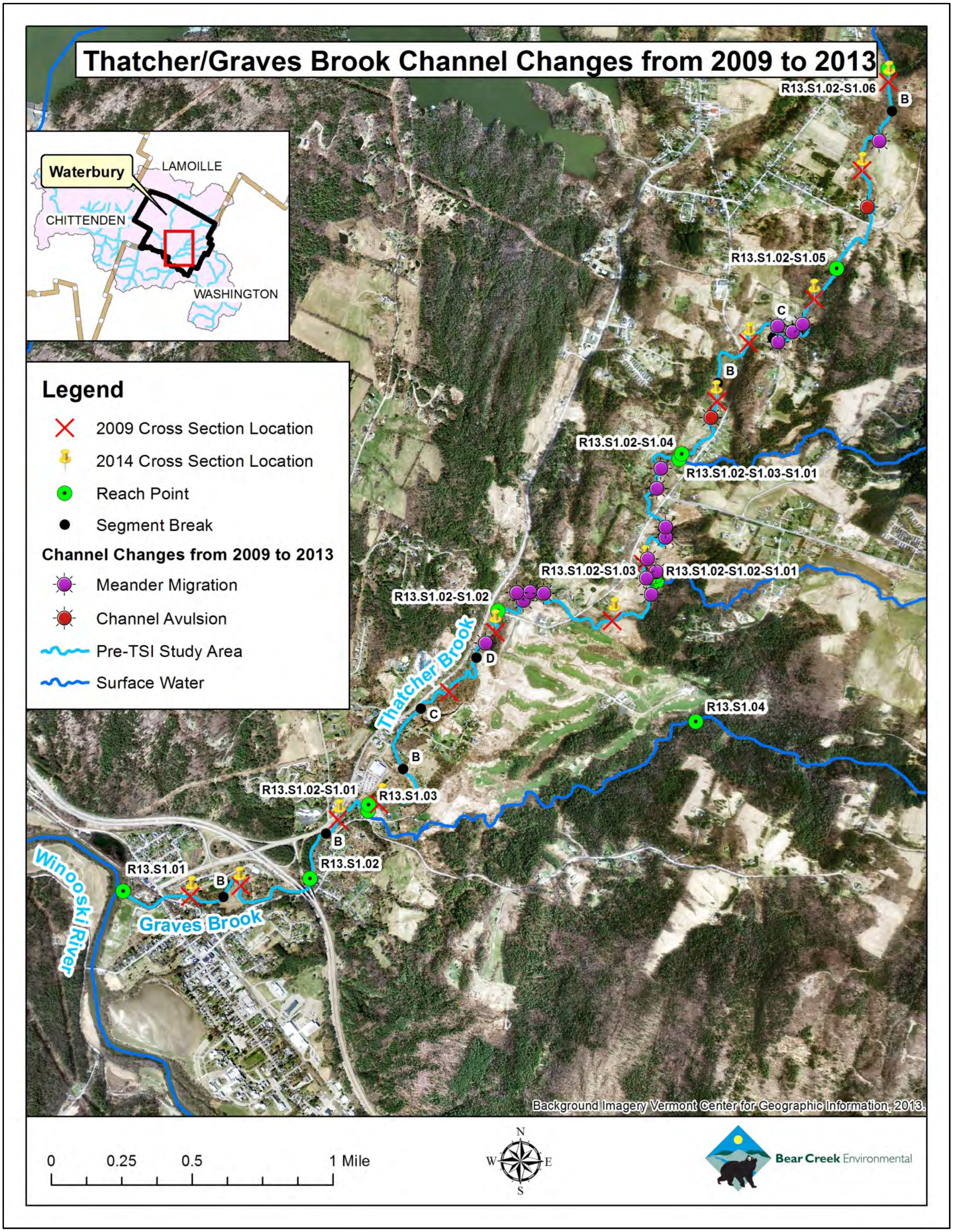


Figure 3. Channel changes in Thatcher and Graves Brook from 2009 to 2013.

Thatcher Brook flows through extensive wetland complexes in Waterbury Center as it meanders toward the confluence with Graves Brook just northeast of Waterbury Village. This area is extremely important for the attenuation of floodwaters and sediment and likely alleviates flooding and fluvial erosion downstream in the densely populated village. Figures 4 and 5 show wetlands along Thatcher Brook storing floodwaters during a high flow event in April of 2014.

Figure 4. Floodwater attenuation in wetlands along Thatcher Brook.

Figure 5. Water disperses energy out onto the floodplain in many areas along Thatcher Brook.

During the 2009 stream geomorphic assessment of Thatcher and Graves Brook, a total of thirteen cross sections within fifteen segments was measured by Redstart Consulting. BCE resurveyed twelve of these thirteen cross sections in 2014. A cross section was not measured in segment R13.S1.02-S1.01-C in 2014 due an impoundment created by a beaver dam within the vicinity of the 2009 cross section location. No cross sections were measured within segments R13.S1.02-A and R13.S1.02-S1.01-B in either 2009 or 2014, because these segments are classified as bedrock gorges. The following graphs and tables display both similarities and differences between the 2009 and 2014 cross sections. Parameters in the tables explain the changes, if any, in the morphology of the stream channels. Some parameters are more significant indicators of adjustment than others. For instance, a greater incision ratio in 2014 suggests that the channel has cut down into its bed. An increase in the width to depth ratio is an indication that the channel may have widened.

Graves Brook

R13.S1.01-A

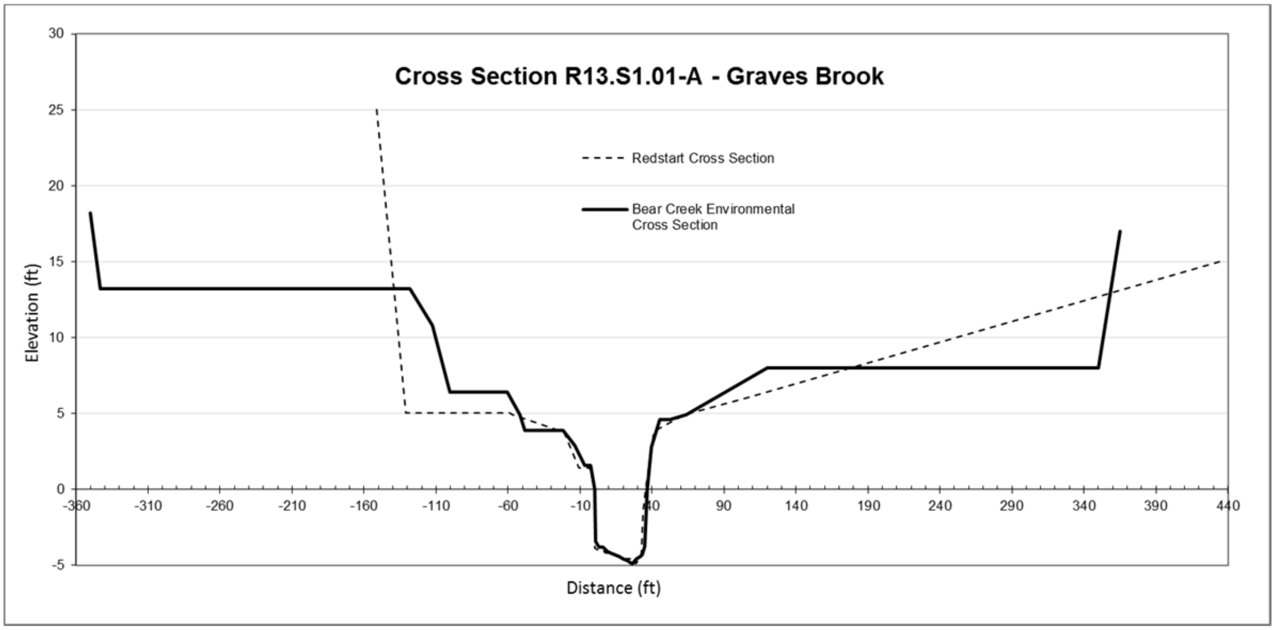


Figure 6. 2009 and 2014 Cross sections done by Redstart and BCE, respectively in Segment R13.S1.01-A.

Table 1: Comparison of 2009 and 2014 Cross Sections at R13.S1.01-A					
River Scientist Team	**Cross Sectional Area**	**Bankfull Width**	**W/D Ratio**	**Entrenchment Ratio**	**Incision Ratio**
Redstart (2009)	146.8	35.3	8.5	3.39	1.8
BCE (2014)	151.4	36.6	8.8	3.17	1.8
Percent change	3.1%	3.7%	3.5%	-6.5%	0%
Comments: Cross sections very similar. No significant change due to TSI. Left valley wall differs due to 2014 cross section extending to railroad bed. 2009 cross section ended at road. Bedform in 2014 was more of a run and not a riffle.					

Figure 7. Cross section R13.S1.01-A in 2009 (left) and in 2014 (right)

R13.S1.01-B

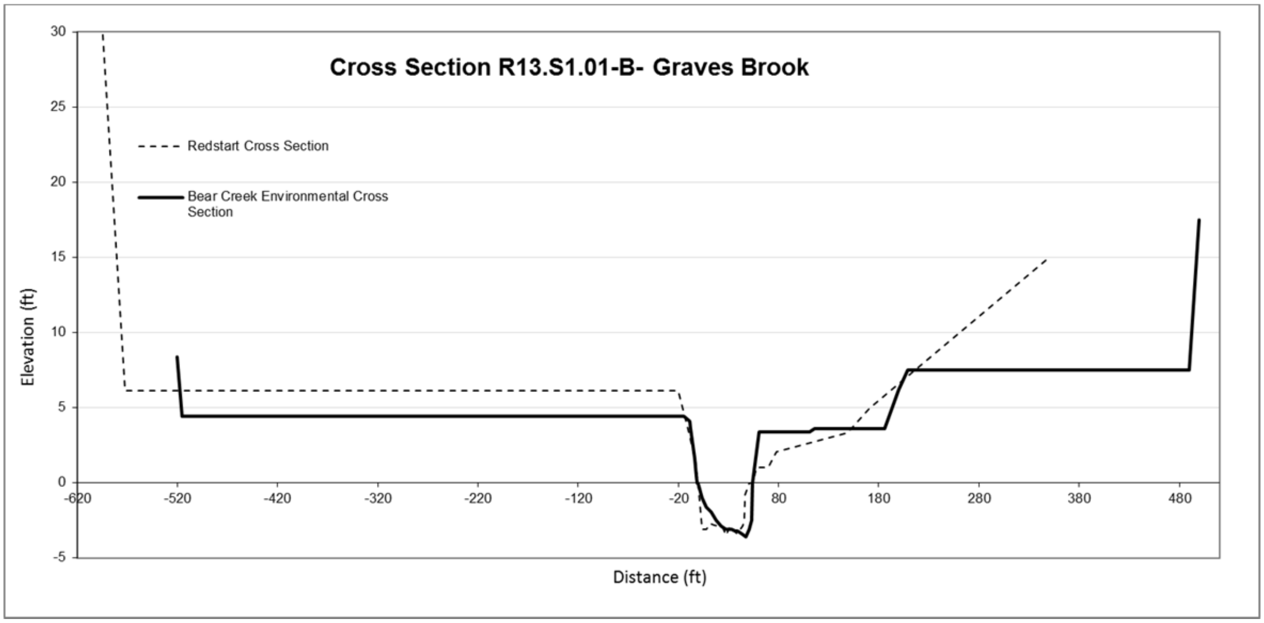


Figure 8. 2009 and 2014 Cross sections done by Redstart and BCE, respectively in Segment R13.S1.01-B.

Table 2: Comparison of 2009 and 2014 Cross Sections at R13.S1.01-B					
River Scientist Team	**Cross Sectional Area**	**Bankfull Width**	**W/D Ratio**	**Entrenchment Ratio**	**Incision Ratio**
Redstart (2009)	135	50.8	19.1	2.96	1.6
BCE (2014)	138	54.3	21.4	2.27	1.9
Percent change	2.2%	6.9%	12.0%	-23.3%	18.8%
Comments: 2009 cross section location is now a pool. 2014 cross section was surveyed just upstream (about 35 feet) of 2009 cross section location, which may account for the difference in left terrace elevation. Channel has slightly widened. No more undercut on left bank and left bank has slumped. More aggradational in 2014 possibly due to TSI (See Figure 9).					

Figure 9. Cross section R13.S1.01-B in 2009 (left) and in 2014 (right)

R13.S1.02-B

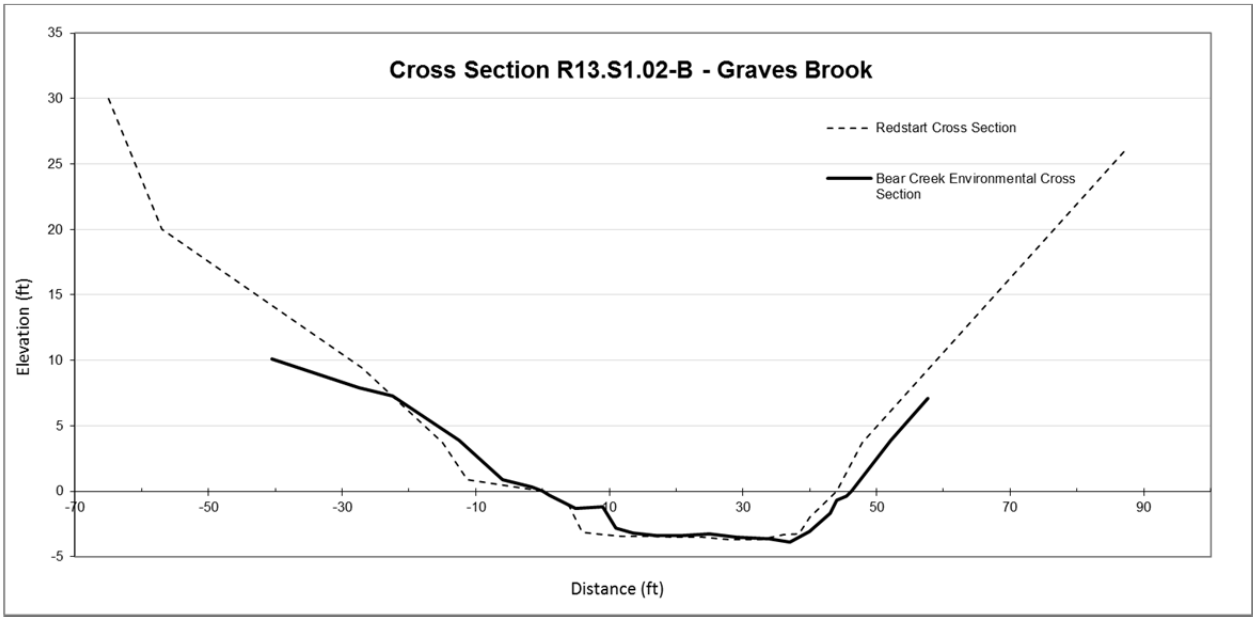


Figure 10. 2009 & 2014 Cross sections done by Redstart and BCE, respectively in Segment R13.S1.02-B.

Table 3: Comparison of 2009 and 2014 Cross Sections at R13.S1.02-B					
River Scientist Team	**Cross Sectional Area**	**Bankfull Width**	**W/D Ratio**	**Entrenchment Ratio**	**Incision Ratio**
Redstart (2009)	127.6	44.0	15.2	1.43	3.5
BCE (2014)	120.9	46.2	17.7	1.40	3.0
Percent change	-5.3%	5.0%	16.4%	-2.1%	-14.3%
Comments: Cross sections very similar from 2009 to 2014. Channel may have widened based on increased w/d ratio.					

Figure 11. Cross section R13.S1.02-B in 2009 (left) and in 2014 (right)

Thatcher Brook

R13.S1.02-S1.01-A

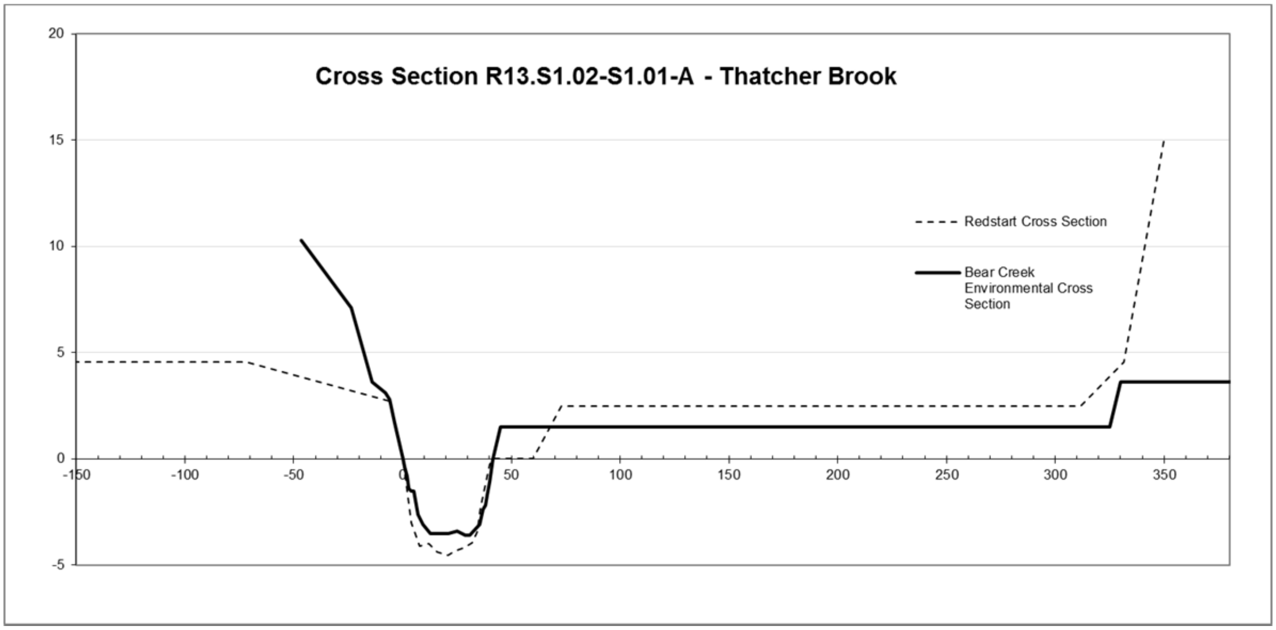


Figure 12. 2009 and 2014 Cross sections done by Redstart and BCE in Segment R13.S1.02-S1.01-A.

Table 4: Comparison of 2009 and 2014 Cross Sections at R13.S1.02-S1.01-A					
River Scientist Team	**Cross Sectional Area**	**Bankfull Width**	**W/D Ratio**	**Entrenchment Ratio**	**Incision Ratio**
Redstart (2009)	141.2	41.6	12.3	9.7	1.55
BCE (2014)	116.4	41.6	14.9	8.3	1.42
Percent change	-17.6%	0%	21.1%	-14.4%	-8.4%
Comments: Cross sectional area for 2014 was lower than 2009, but consistent with upstream cross sectional areas. Cross section in 2014 was measured just 45 feet upstream of 2009 cross section due to bank slump in 2009 location (indicating channel widening). This resulted in different valley widths. Bankfull width in 2014 cross section was the same as 2009 cross section. Width to depth ratio in 2014 showed "C" stream type.					

Figure 13. Cross section R13.S1.02-S1.01-A in 2009 (left) and in 2014 (right)

R13.S1.02-S1.01-D

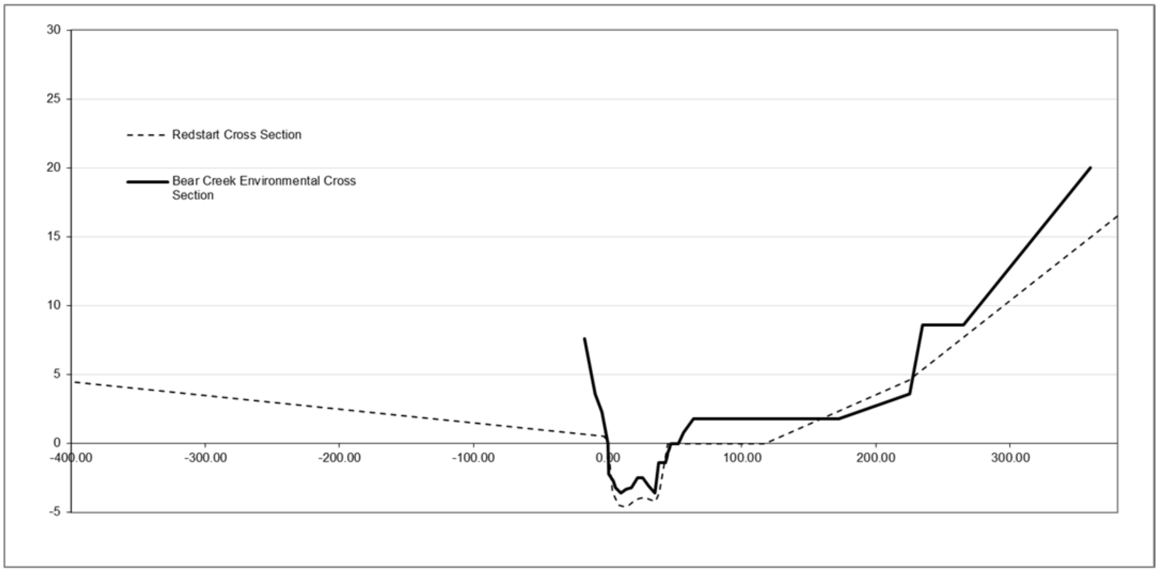


Figure 14. 2009 and 2014 Cross sections done by Redstart and BCE, respectively in Segment R13.S1.02-S1.01-D.

Table 5: Comparison of 2009 and 2014 Cross Sections at R13.S1.02-S1.01-D					
River Scientist Team	**Cross Sectional Area**	**Bankfull Width**	**W/D Ratio**	**Entrenchment Ratio**	**Incision Ratio**
Redstart (2009)	95.9	37.4	14.6	6.9	1.5
BCE (2014)	121.7	47.1	18.3	5.0	1.5
Percent change	26.9%	25.9%	25.3%	-27.5%	0%
Comments: Cross sectional area was higher in 2014 than 2009. The 2014 cross section was measured just upstream (about 20 feet) of the 2009 cross section due to channel changes. The fallen tree and large pool were present in the 2009 location (Figure 15). Channel may have experienced widening based on increased w/d ratio.					

Figure 15. Looking upstream at cross section R13.S1.02-S1.01-D in 2009 (left) and 2014 (right).

R13.S1.02-S1.02

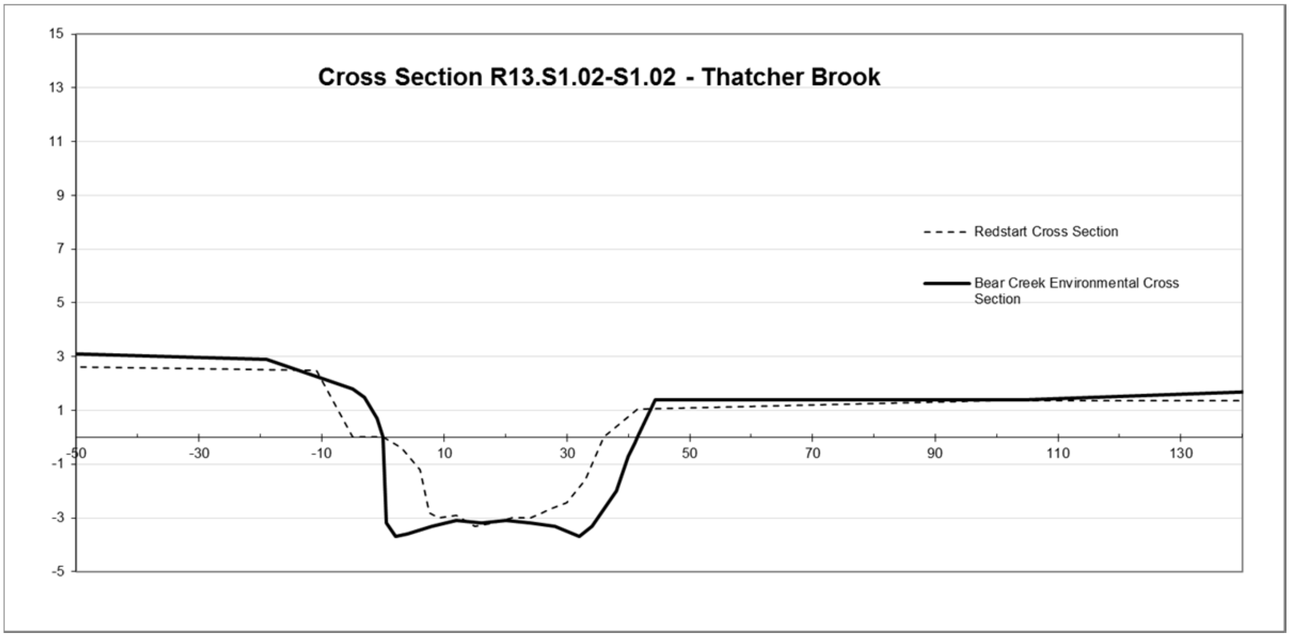


Figure 16. 2009 & 2014 Cross sections done by Redstart and BCE, respectively in Segment R13.S1.02-S1.02.

Table 6: Comparison of 2009 and 2014 Cross Sections at R13.S1.02-S1.02					
River Scientist Team	**Cross Sectional Area**	**Bankfull Width**	**W/D Ratio**	**Entrenchment Ratio**	**Incision Ratio**
Redstart (2009)	81.2	36	15.9	18.1	1.3
BCE (2014)	125.5	41.4	13.7	12.8	1.4
Percent change	54.6%	15.0%	-13.8%	-29.3%	7.7%
Comments: Cross sectional area for 2014 was higher than 2009. Depositional features in 2014 were larger than in 2009, and new debris noted in channel in 2014; both most likely due to TSI (See Figure 17). Both teams noted that bankfull was hard to find in the field. Redstart used a “low new bench” for determining the bankfull elevation, while Bear Creek used the tree line. This likely accounts for differences in the bankfull cross sectional areas measured.					

Figure 17. Cross section R13.S1.02-S1.02 in 2009 (left) and 2014 (right).

R13.S1.02-S1.03

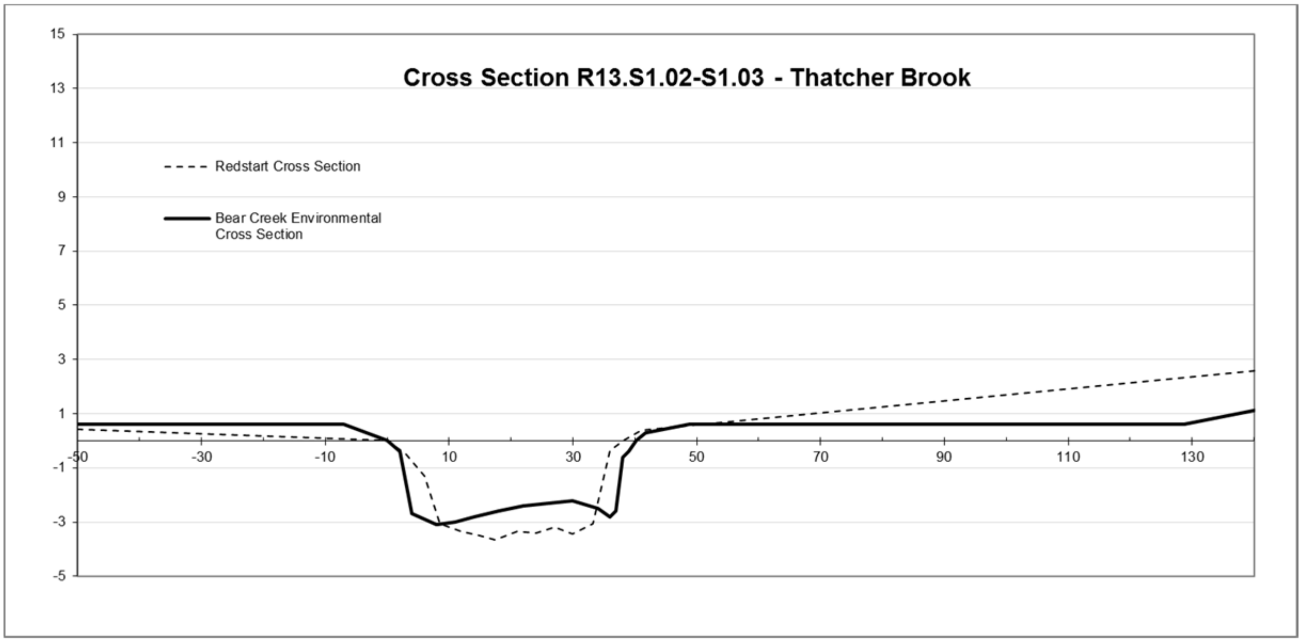


Figure 18. 2009 and 2014 Cross sections done by Redstart and BCE, respectively in Segment R13.S1.02-S1.03.

Table 7: Comparison of 2009 and 2014 Cross Sections at R13.S1.02-S1.03					
River Scientist Team	**Cross Sectional Area**	**Bankfull Width**	**W/D Ratio**	**Entrenchment Ratio**	**Incision Ratio**
Redstart (2009)	97.1	38.2	15.0	16.5	1.0
BCE (2014)	91.9	40.2	17.6	14.3	1.1
Percent change	-5.4%	5.2%	17.3%	-13.3%	10%
Comments: 2014 cross section was surveyed just downstream (about 40 feet) of 2009 cross section due to new beaver dam. Channel still has good floodplain access. More aggradational than in 2009 (Figure 19).					


Figure 19. Cross section R13.S1.02-S1.03 in 2009 (left) where there is now a beaver dam and in 2014 (right) – more aggradational.

R13.S1.02-S1.04-A

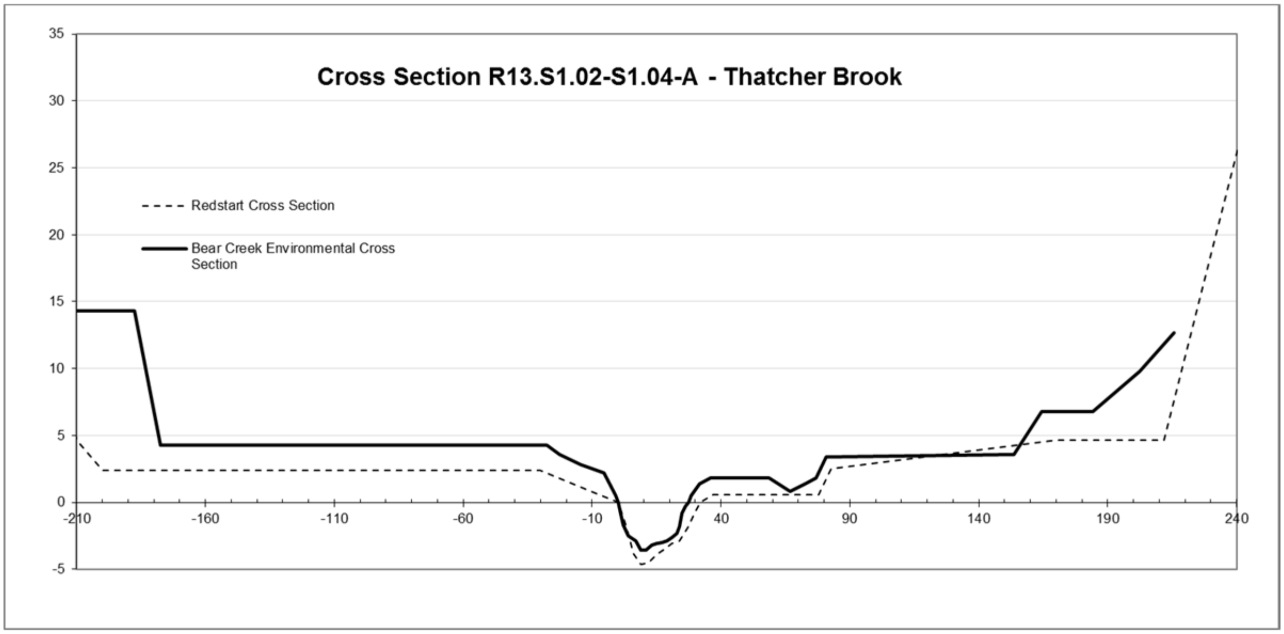


Figure 20. 2009 and 2014 Cross sections measured by Redstart and BCE, respectively in Segment R13.S1.02-S1.04-A.

Table 8: Comparison of 2009 and 2014 Cross Sections at R13.S1.02-S1.04-A					
River Scientist Team	**Cross Sectional Area**	**Bankfull Width**	**W/D Ratio**	**Entrenchment Ratio**	**Incision Ratio**
Redstart (2009)	91.4	31.9	11.1	11.9	1.5
BCE (2014)	67.4	27.3	11.1	6.5	1.9
Percent change	-26.3%	-14.4%	0%	-45.4%	21.1%
Comments: Cross sectional area lower in 2014 than 2009, but consistent with upstream cross sectional areas measured in 2014.					


Figure 21. Cross section R13.S1.02-S1.04-A in 2009 (left) and 2014 (right).

R13.S1.02-S1.04-B

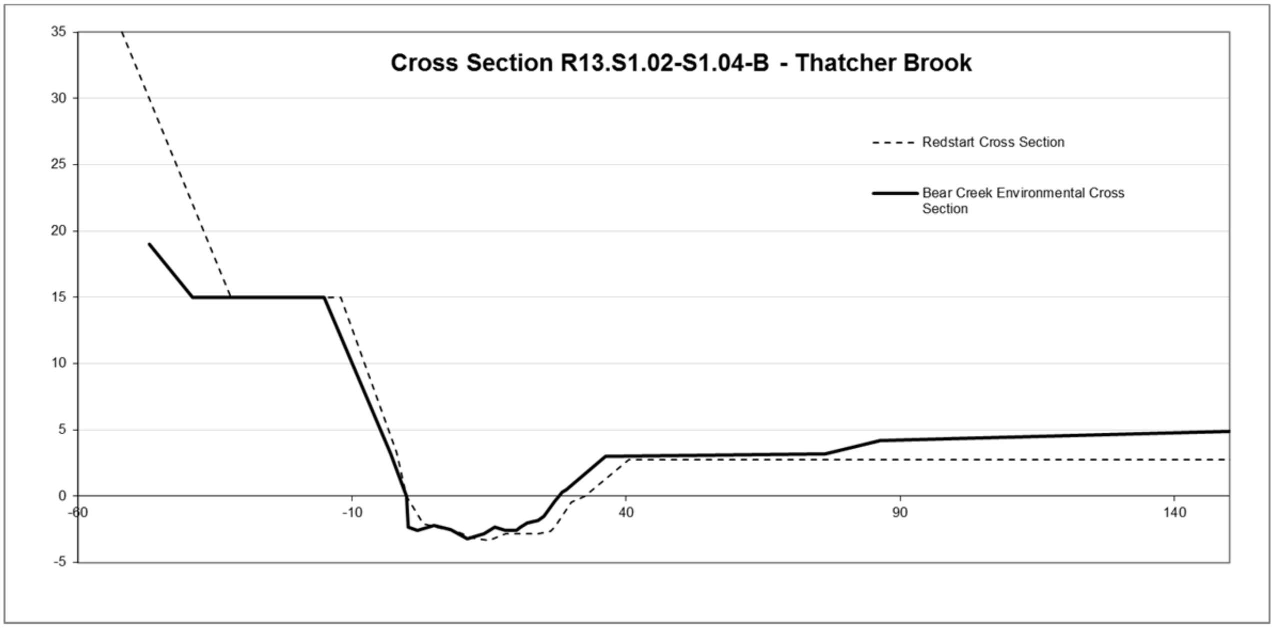


Figure 22. 2009 and 2014 Cross sections done by Redstart and BCE, respectively in Segment R13.S1.02-S1.04-B.

Table 9: Comparison of 2009 and 2014 Cross Sections at R13.S1.02-S1.04-B					
River Scientist Team	**Cross Sectional Area**	**Bankfull Width**	**W/D Ratio**	**Entrenchment Ratio**	**Incision Ratio**
Redstart (2009)	74.8	32.5	14.1	8.5	1.8
BCE (2014)	63.7	27.8	12.1	2.9	1.9
Percent change	-14.8%	-14.5%	-14.2%	-65.9%	5.6%
Comments: Cross sections similar. No significant changes from TSI except for some fallen debris from left bank.					

Figure 23. Cross section R13.S1.02-S1.04-B in 2009 (left) and 2014 (right).

R13.S1.02-S1.04-C

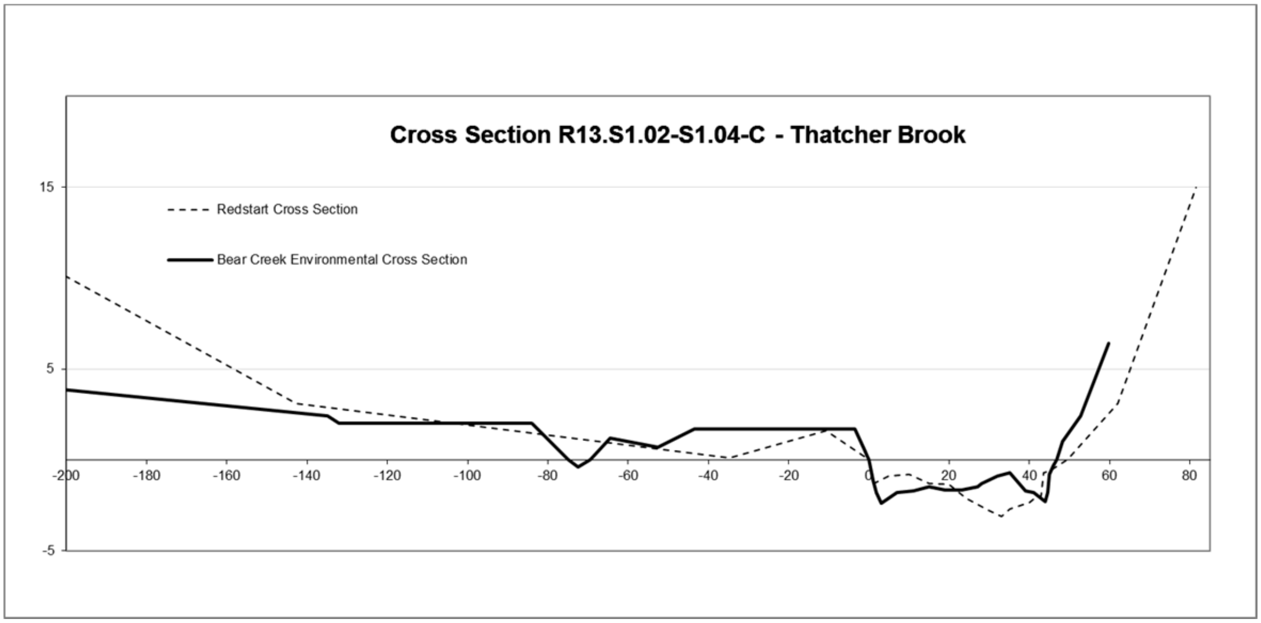


Figure 24. 2009 and 2014 Cross sections done by Redstart and BCE, respectively in Segment R13.S1.02-S1.04-C.

Table 10: Comparison of 2009 and 2014 Cross Sections at R13.S1.02-S1.04-C					
River Scientist Team	**Cross Sectional Area**	**Bankfull Width**	**W/D Ratio**	**Entrenchment Ratio**	**Incision Ratio**
Redstart (2009)	79.0	49.4	30.9	4.1	1.5
BCE (2014)	71.5	52.3	38.3	3.6	1.7
Percent change	-9.5%	5.9%	23.9%	-12.2%	13.3%
Comments: Left side of channel deeper in 2014. Flood chute observed in left floodplain in 2014. Bar shifted from left to right in channel.					

Figure 25. Cross section R13.S1.02-S1.04-C in 2009 (left) and 2014 (right).

R13.S1.02-S1.05-A

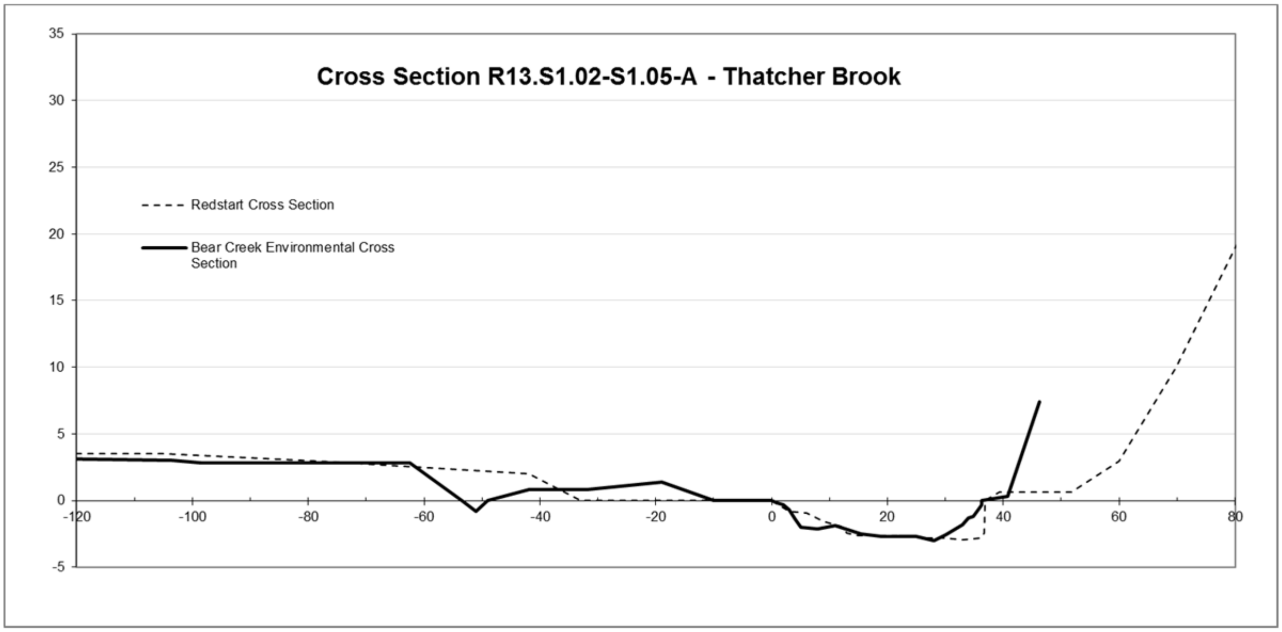


Figure 26. 2009 and 2014 Cross sections done by Redstart and BCE, respectively in Segment R13.S1.02-S1.05-A.

Table 11: Comparison of 2009 and 2014 Cross Sections at R13.S1.02-S1.05-A					
River Scientist Team	**Cross Sectional Area**	**Bankfull Width**	**W/D Ratio**	**Entrenchment Ratio**	**Incision Ratio**
Redstart (2009)	79.3	36.8	17.1	3.8	1.7
BCE (2014)	77.1	40.8	21.6	3.5	2.0
Percent change	-2.8%	10.9%	26.3%	-7.9%	15%
Comments: Cross sections were similar in 2009 and 2014. Flood chute observed in 2014 in left floodplain. 2014 cross section measured slightly downstream of 2009 cross section affecting the valley width. More aggradational and slightly wider in 2014 than 2009.					

Figure 27. Cross section R13.S1.02-S1.05-A in 2009 (left) and 2014 (right)-more aggradational.

R13.S1.02-S1.05-B

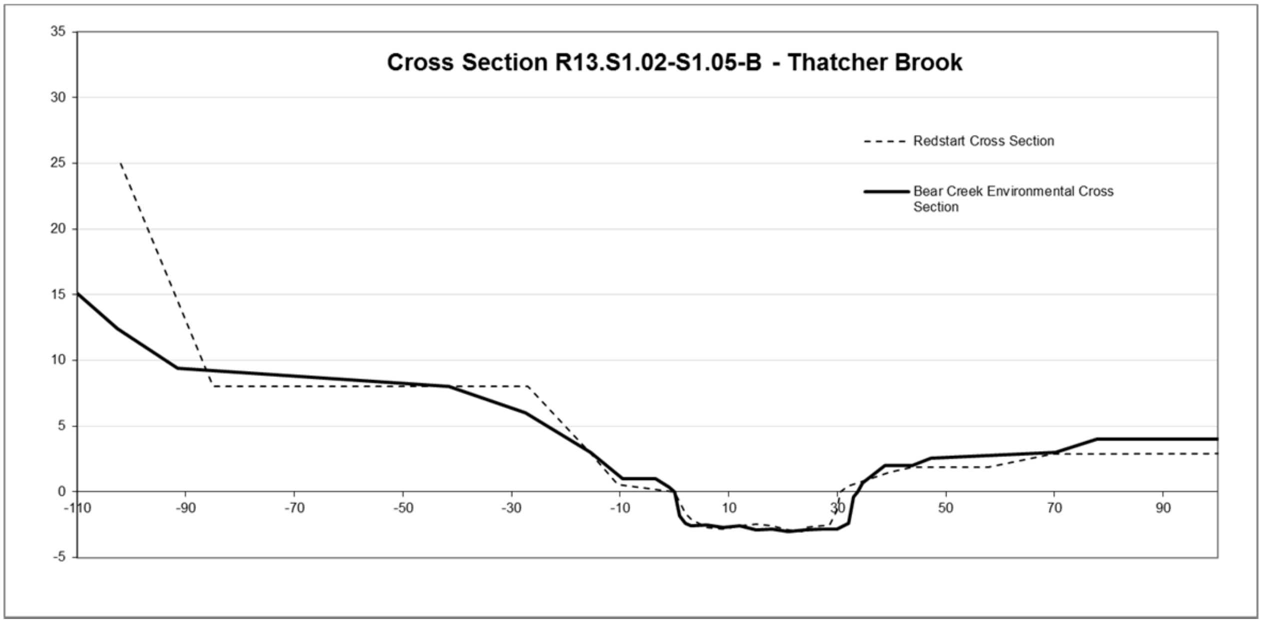


Figure 28. 2009 and 2014 Cross sections done by Redstart and BCE, respectively in Segment R13.S1.02-S1.05-B.

Table 12: Comparison of 2009 and 2014 Cross Sections at R13.S1.02-S1.05-B					
River Scientist Team	**Cross Sectional Area**	**Bankfull Width**	**W/D Ratio**	**Entrenchment Ratio**	**Incision Ratio**
Redstart (2009)	74.3	30.5	12.5	6.7	1.6
BCE (2014)	86.9	33.7	13.1	2.5	1.9
Percent change	17%	10.5%	4.8%	-62.7%	15.8%
Comments: Cross sections were similar in 2009 and 2014. More aggradational in 2014 than in 2009 most likely due to TSI (See Figure 29).					

Figure 29. Cross section in Segment R13.S1.02-S1.05-B in 2009 (left) and 2014 (right).

3.0 CONCLUSION

The orthophoto review and cross section analyses are useful in determining if channel dimensions were altered by flooding and to indicate where the channel has changed its planform over time. These analyses will help to inform restoration and protection alternatives in the river corridor plan. Channel avulsions observed from the orthophoto analysis were most likely a direct result of Tropical Storm Irene (TSI). Meander migrations between 2009 and 2013 were also most likely accelerated by the increased flows and aggradation from the floodwaters of TSI. The cross section surveys suggest that in general, the influence of TSI on Thatcher and lower Graves Brook was limited to localized areas of increased aggradation and some widening. Channel degradation has not appeared to have been increased as a result of TSI. The cross section surveys from 2009 to 2014 differed somewhat, but overall they were rather consistent and did not show any major change aside from increased aggradation and localized widening.

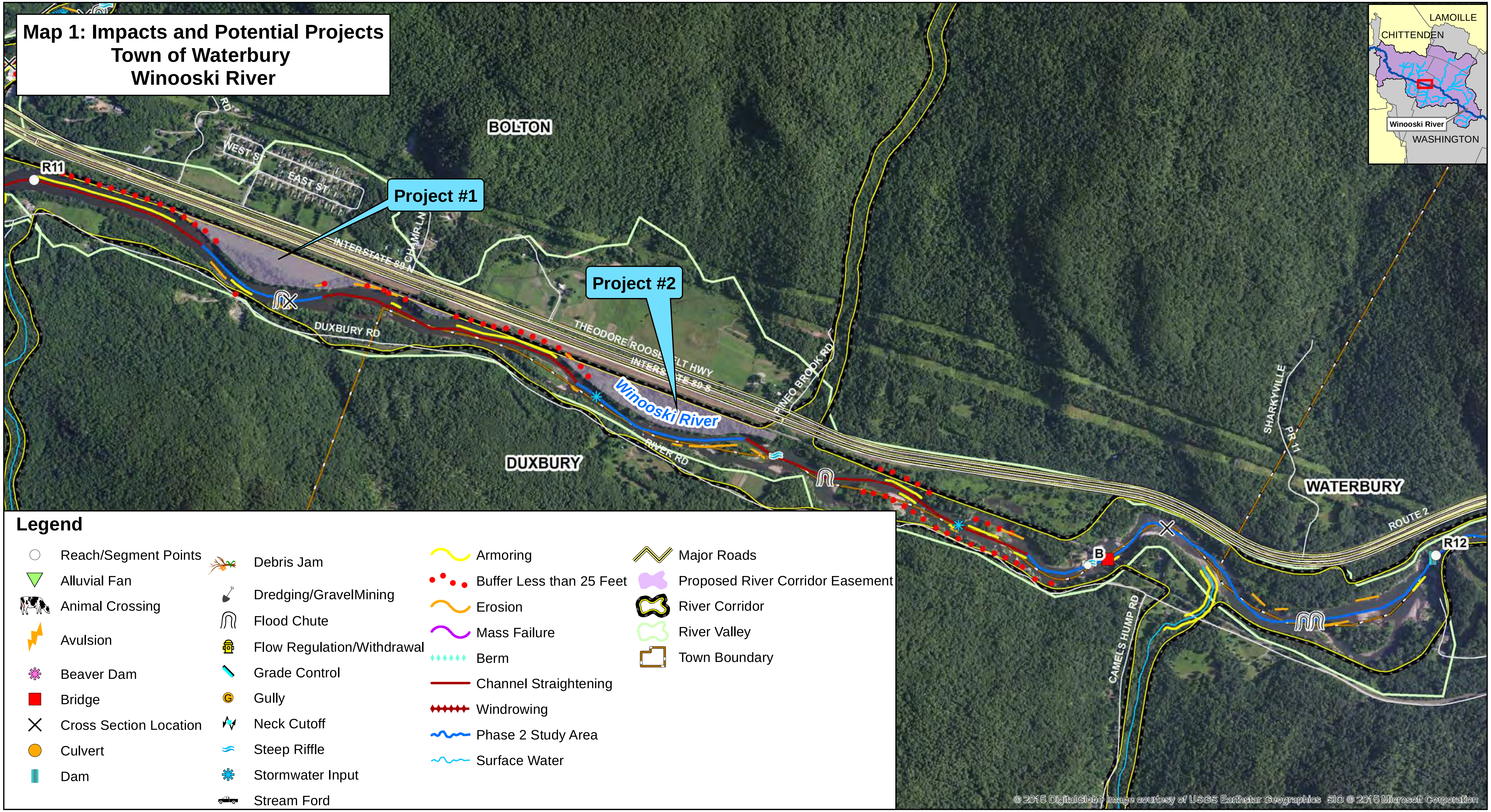
Thatcher and Graves Brook overall have very good floodplain access and extensive adjacent wetlands. During Tropical Storm Irene, it is likely that a large amount of floodwaters and sediment accessed these floodplains and adjacent wetlands, reducing the energy within the stream channels of Thatcher Brook and Graves Brook. This storage of floodwaters and reduction of in-channel energy during TSI caused a reduction in erosive forces that could have caused the stream channels to downcut, widen, aggrade, and change planform much more drastically than was observed if these floodplains and wetlands had not been intact. This post-flood study has demonstrated the immense importance of accessible floodplains and adjacent wetlands in mitigating stream impacts and adjustment during high flow events. It is critically important to protect and preserve the floodplains and wetlands along Thatcher and Graves Brook to retain their floodwater and sediment attenuation capacities.

4.0 REFERENCES

Vermont Agency of Natural Resources. 2012. Climate Change Team. Tropical Storm Irene. Accessed January 7, 2013 and available at http://www.anr.state.vt.us/anr/climatechange/irenebythenumbers.html.

APPENDIX D

Potential Project Locations & Descriptions



Background is Bing Imagery

Projects:
1. River Corridor or Conservation Easement
2. River Corridor or Conservation Easement

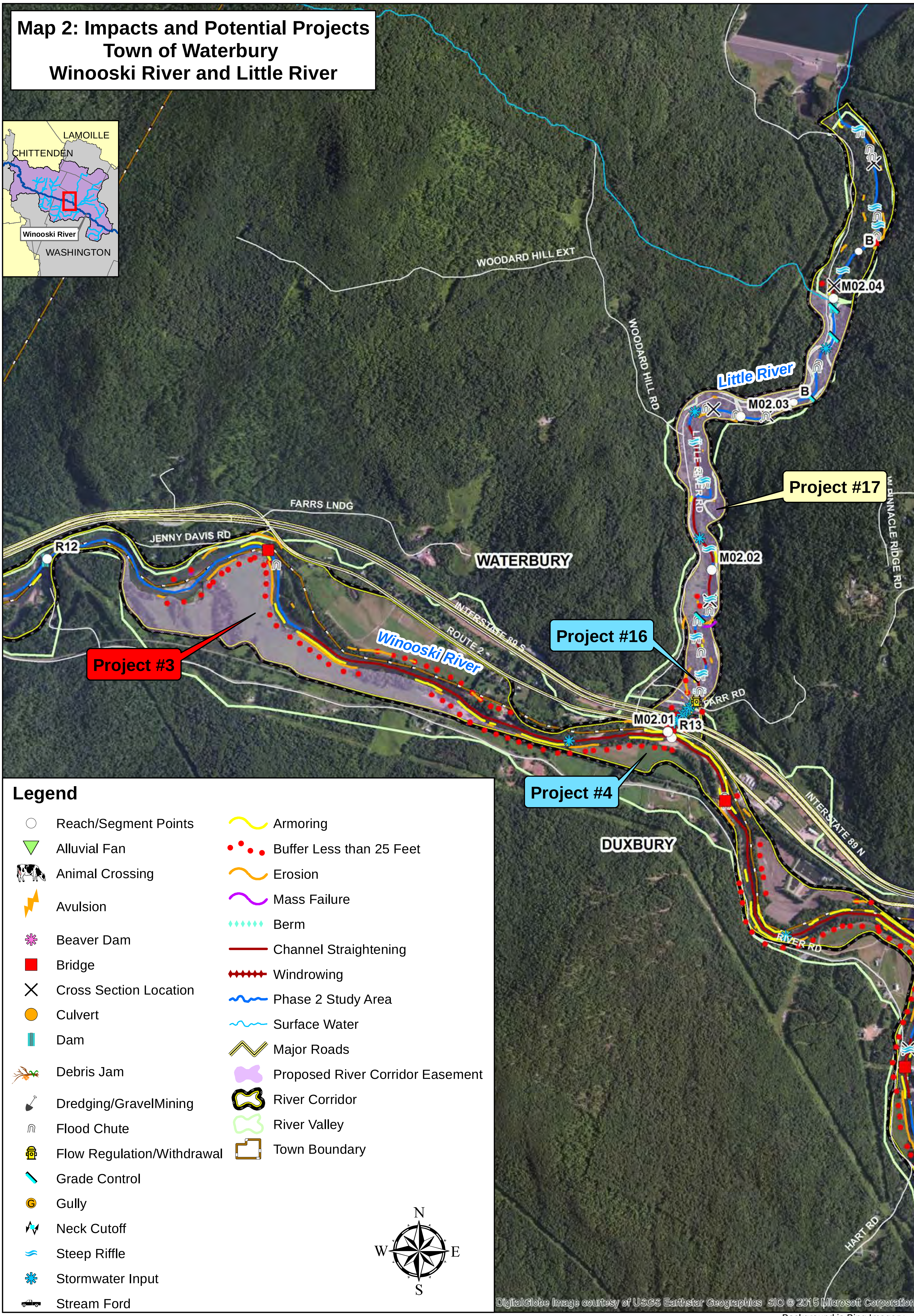
Project Priority:
- Low
- Moderate
- High

0 1,000 2,000 Feet

1 inch = 1,000 feet

Bear Creek Environmental

Map 2: Impacts and Potential Projects
Town of Waterbury
Winooski River and Little River



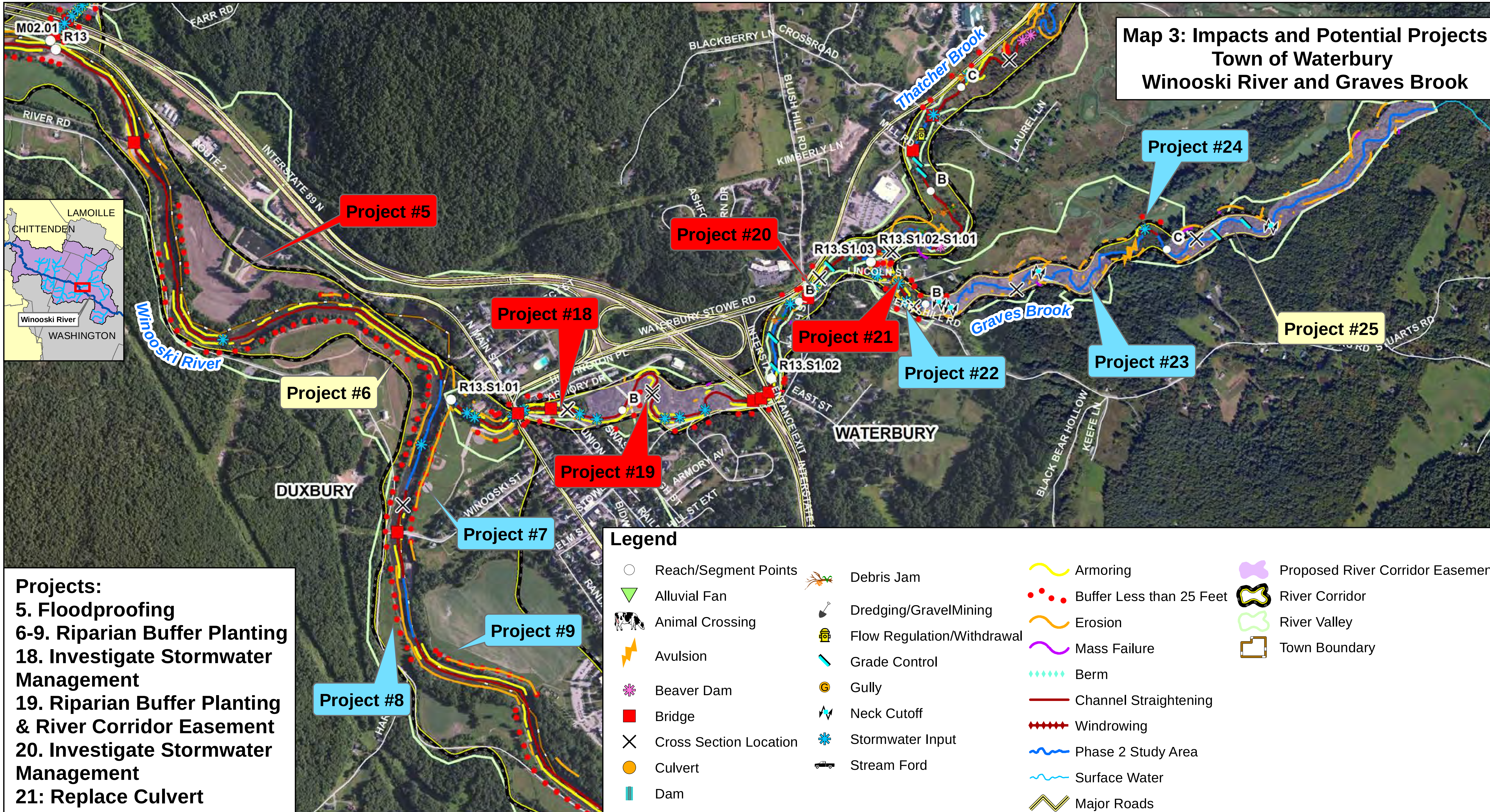
Background is Bing Imagery

Projects:
3. Riparian Buffer Planting & River Corridor Easement
4. Riparian Buffer Planting
16. Create Floodplain
17. River Corridor or Conservation Easement (Eastern Side)

Project Priority:
- Low
- Moderate
- High

0 1,500 3,000 Feet

Map 3: Impacts and Potential Projects
Town of Waterbury
Winooski River and Graves Brook



Projects:
5. Floodproofing
6-9. Riparian Buffer Planting
18. Investigate Stormwater Management
19. Riparian Buffer Planting & River Corridor Easement
20. Investigate Stormwater Management
21: Replace Culvert
22. Riparian Buffer Planting
23. River Corridor or Conservation Easement
24. Riparian Buffer Planting
25. River Corridor or Conservation Easement

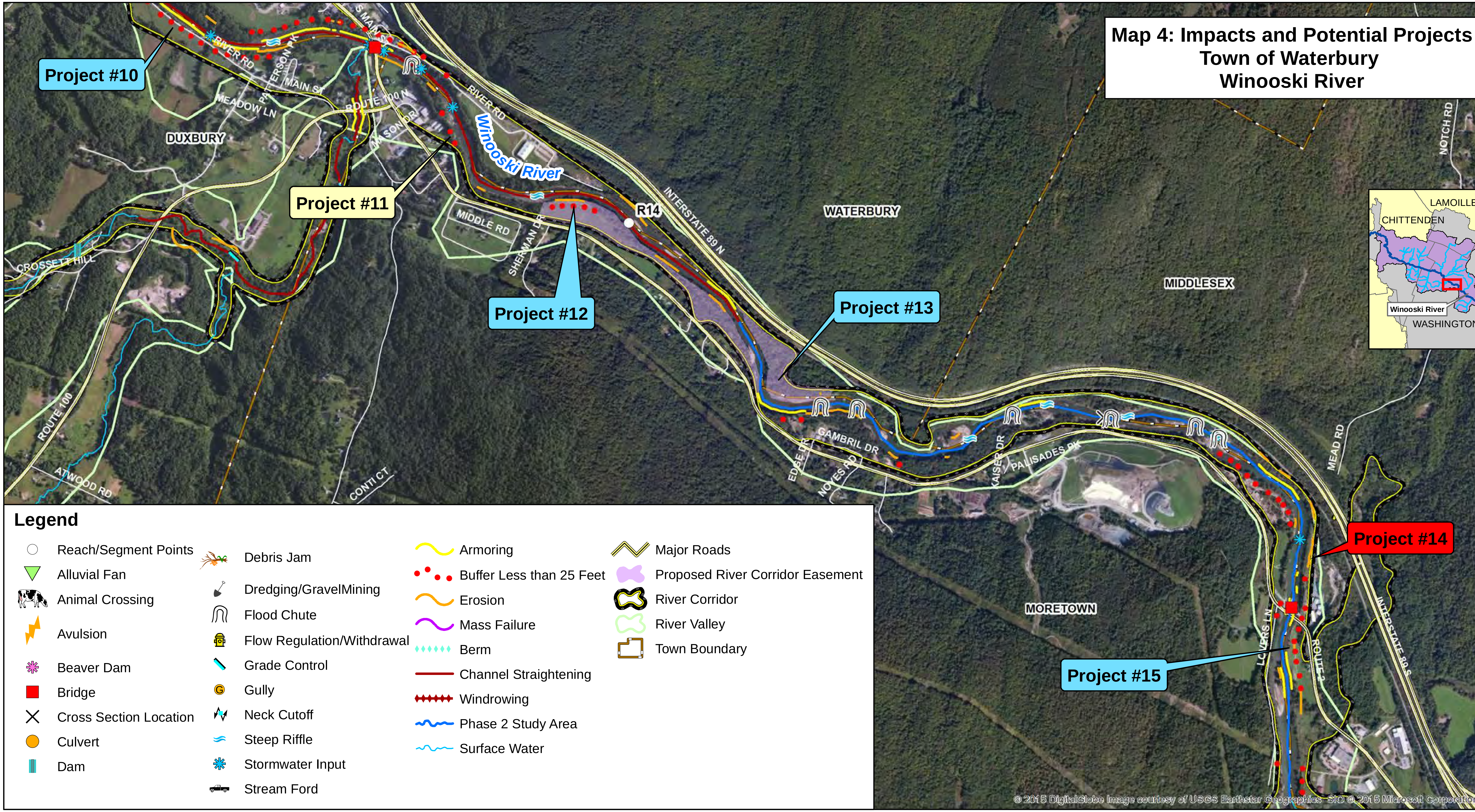
Project Priority:
- Low
- Moderate
- High

N E S W

0 1,000 2,000 Feet

Background is Bing Imagery

Bear Creek Environmental



Projects:

10. Lower or Relocate Road

11. & 12. Riparian Buffer Planting

13. River Corridor or Conservation Easement

14. Relocate Storage of Gravel and Sand

15. Riparian Buffer Planting

Project Priority:

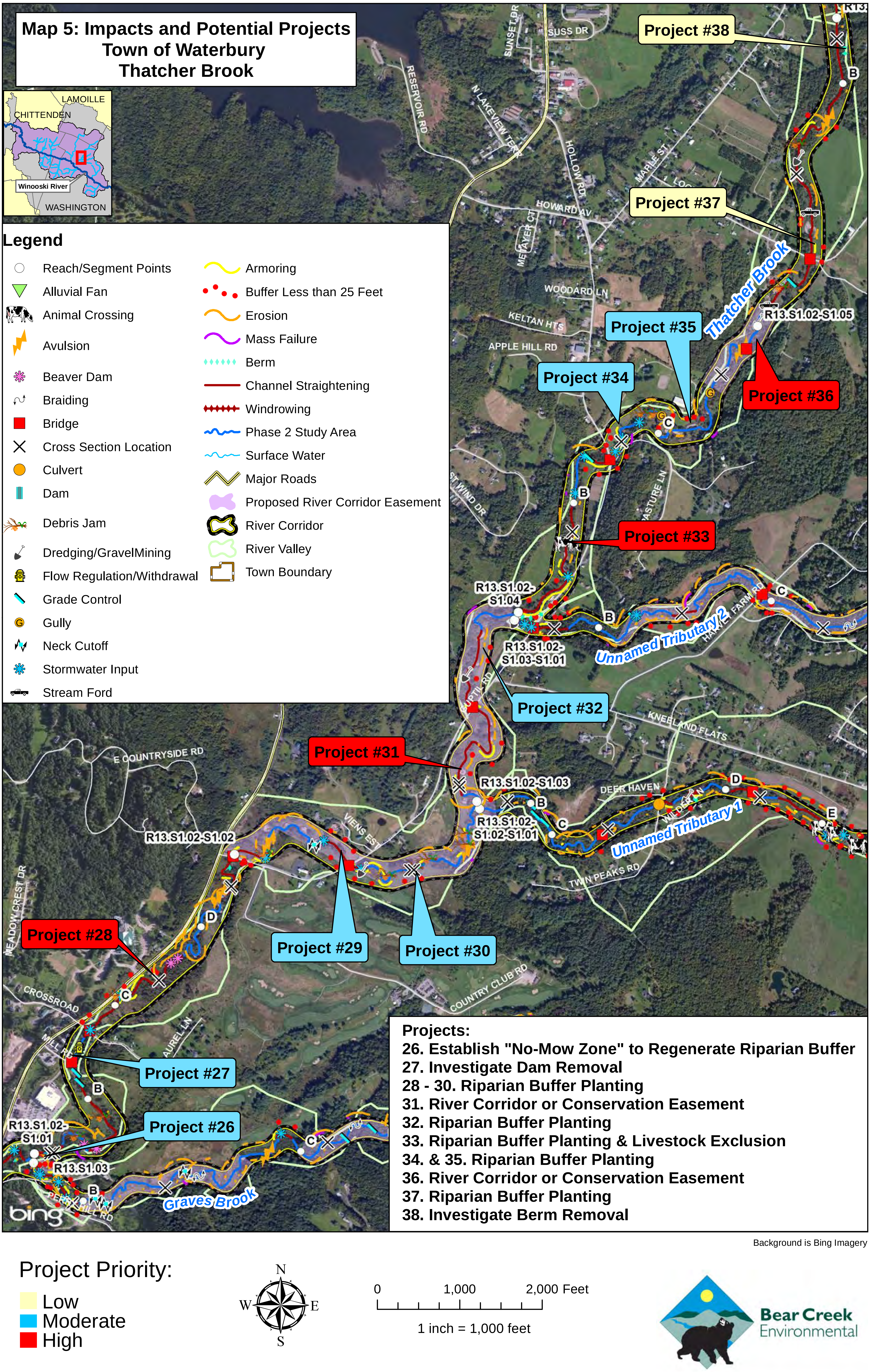
- Low
- Moderate
- High

N W E S

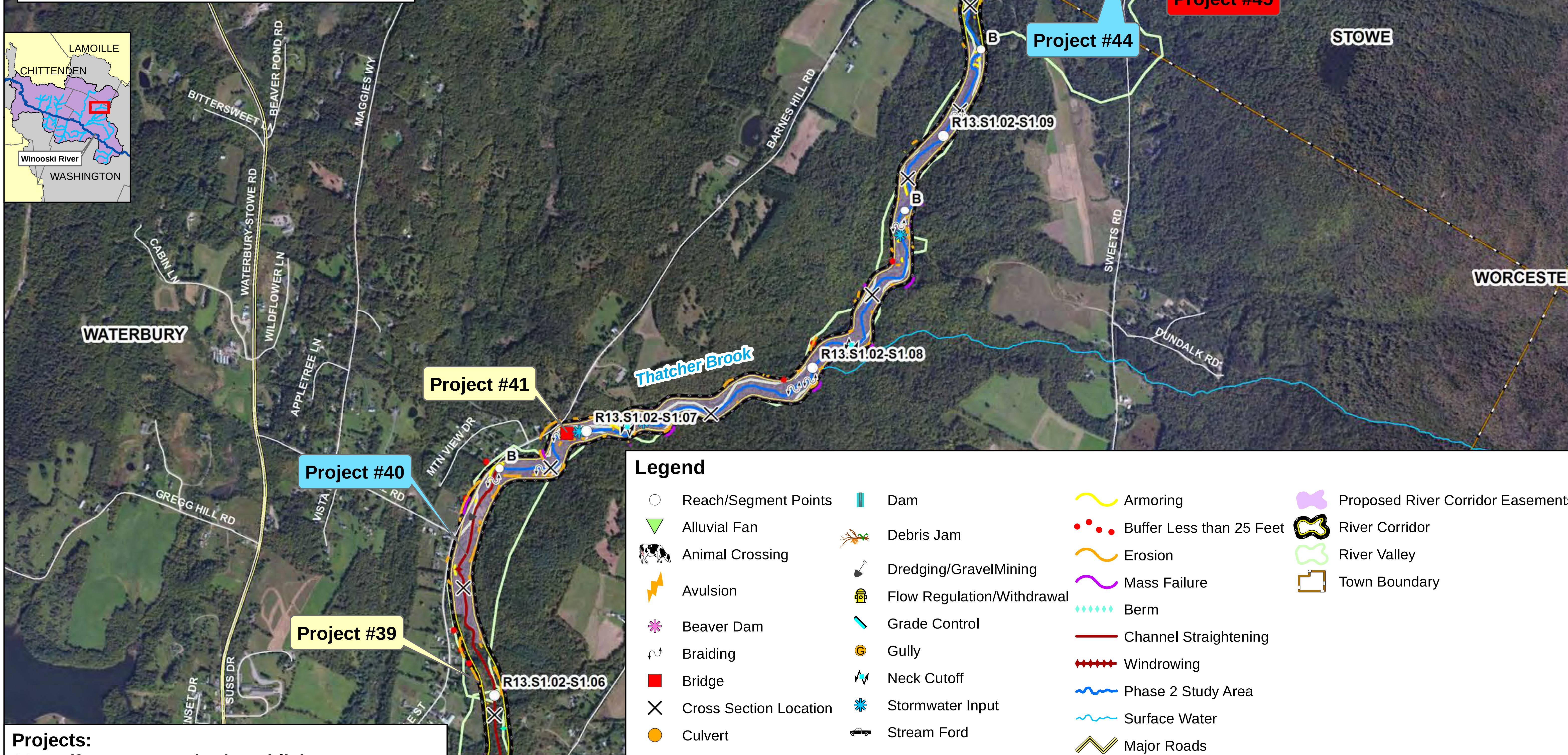
0 1,300 2,600 Feet

Background is Bing Imagery

Bear Creek Environmental


Map 5: Impacts and Potential Projects
Town of Waterbury
Thatcher Brook
LAMOILLE
CHITTENDEN
Winooski River
WASHINGTON
Legend
Reach/Segment Points
Alluvial Fan
Animal Crossing
Avulsion
Beaver Dam
Braiding
Bridge
Cross Section Location
Culvert
Dam
Debris Jam
Dredging/GravelMining
Flow Regulation/Withdrawal
Grade Control
Gully
Neck Cutoff
Stormwater Input
Stream Ford
Armoring
Buffer Less than 25 Feet
Erosion
Mass Failure
Berm
Channel Straightening
Windrowing
Phase 2 Study Area
Surface Water
Major Roads
Proposed River Corridor Easement
River Corridor
River Valley
Town Boundary
Project #38
Project #37
Project #35
Project #34
Project #36
Project #33
Project #32
Project #31
Project #29
Project #30
Project #28
Project #27
Project #26
Thatcher Brook
Unnamed Tributary 2
Unnamed Tributary 1
Graves Brook
R13.S1.02-S1.05
R13.S1.02-S1.04
R13.S1.02-S1.03-S1.01
R13.S1.02-S1.03
R13.S1.02-S1.02-S1.01
R13.S1.02-S1.02
R13.S1.02-S1.01
R13.S1.03
SUSS DR
RESERVOIR RD
N LAKEVIEW TER
HOLLOW RD
HOWARD AV
WOODARD LN
KELTAN HTS
APPLE HILL RD
KNEELAND FLATS
DEER HAVEN
TWIN PEAKS RD
COUNTRY CLUB RD
E COUNTRYSIDE RD
CROSSROAD
AUREL LN
Projects:
26. Establish "No-Mow Zone" to Regenerate Riparian Buffer
27. Investigate Dam Removal
28 - 30. Riparian Buffer Planting
31. River Corridor or Conservation Easement
32. Riparian Buffer Planting
33. Riparian Buffer Planting & Livestock Exclusion
34. & 35. Riparian Buffer Planting
36. River Corridor or Conservation Easement
37. Riparian Buffer Planting
38. Investigate Berm Removal
Background is Bing Imagery
Project Priority:
Low
Moderate
High
N
W
E
S
0
1,000
2,000 Feet
1 inch = 1,000 feet
Bear Creek Environmental

Map 6: Impacts and Potential Projects
Town of Waterbury
Thatcher Brook



Projects:

39. Buffer Regeneration/Establish No-Mow Zone
40. Riparian Corridor or Conservation Easement
41. Remove Old Wooden Bridge
42. Replace Culvert
43. Remove Old Wooden Bridge
44. Return or Remove Windrowed Material
45. Restore Streamflow

Project Priority:

- Low
- Moderate
- High

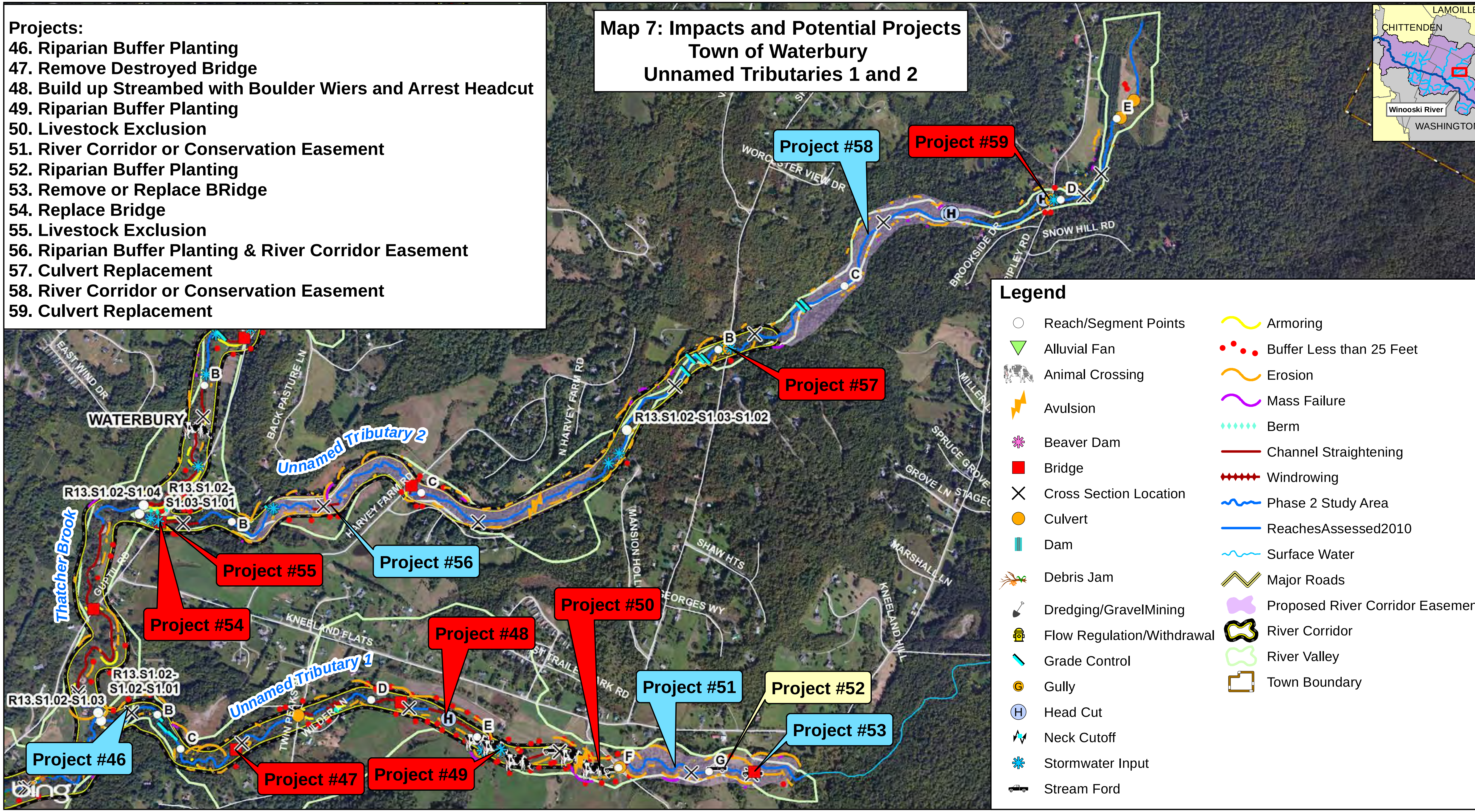
N W E S

0 1,250 2,500 Feet

1 inch = 1,250 feet

Background is Bing Imagery

Bear Creek Environmental



Background is Bing Imagery

Project Priority:
- Low
- Moderate
- High

N S W E

0 1,000 2,000 Feet

1 inch = 1,000 feet

Bear Creek Environmental

Mid-Winooski River Watershed - Waterbury Area - Restoration & Protection Projects
Waterbury, Vermont
Central Vermont Regional Planning Commission
May 1, 2015

Legend

● Effective ◒ Limited ○ Ineffective

Project Number Segment	Project Category	Project Type	Stream Name	Town	Project Location	Priority	OBJECTIVES: Improves or Protects Habitat[1]	Improves Water Quality[2]	Improves Long-term Channel Stability[3]	Protects Infrastructure, and Property[4]	Comments
Project #1 R11-A (Refer to Map 1)	Floodplain Improvement and Conservation	River Corridor or Conservation Easement	Winooski River	Bolton	On northern bank of river approximately 3,000 feet upstream of Joiner Brook confluence	Moderate	●	◒	●	◒	A 13 acre parcel is located on the inside of a slight meander bend between the river and the railroad/I-89. About half of the parcel has well-formed floodplain forest, while half is mowed for some purpose - likely agriculture. Project may be eligible for CREP.
Project #2 R11-A (Refer to Map 1)	Floodplain Improvement and Conservation	River Corridor or Conservation Easement	Winooski River	Bolton	On northern bank of river across river from 6097 River Road	Moderate	●	◒	●	◒	A 12.3 acre parcel on an inside bend has a well forested buffer - silver maple floodplain forest.
Project #3 R12 (Refer to Map 2)	Floodplain Improvement and Conservation	Riparian Buffer Planting and River Corridor Easement	Winooski River	Duxbury	Just upstream of Bolton Falls Dam on southern bank of the river	**High**	●	●	●	◒	Agricultural fields exist along the river and riparian buffer is lacking for about 4,500 feet. This is an important area for floodwater and sediment storage due to dam backwatering. One of two landowners indicated project interest. Project may be eligible for CREP.
Project #4 R12 & R13 (Refer to Map 2)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Winooski River	Duxbury	Just across Winooski River from confluence of Little River	Moderate	●	●	●	◒	Buffer is lacking on southern bank due to agricultural fields. Project could be eligible for CREP.
Project #5 R13 (Refer to Map 3)	Public Safety Improvement	Floodproofing	Winooski River	Waterbury	At the Waterbury Wastewater Treatment Facility	**High**	◒	●	○	●	The Waterbury Wastewater Treatment Facility is located in between the Winooski River and the New England Central Railroad/Route 2. It sustained major damage due to inundation during Irene. The facility could be floodproofed to reduce future damages and prevent future discharges of wastewater to the river.
Project #6 R13 (Refer to Map 3)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Winooski River	Duxbury	At the Harvey Farm on River Road just northwest of Waterbury Village	Low	◒	◒	◒	○	Riparian buffer is lacking for about 2,500 feet due to the presence of agricultural fields at the Harvey Farm. The bank is high in this location and land use conflicts may present challenges for implementation. This is the location of a proposed floodplain creation project (CVRPC and Milone & MacBroom).
Project #7 R13 (Refer to Map 3)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Winooski River	Waterbury	At Rowe Fields	Moderate	◒	●	◒	○	Buffer is lacking on east bank of river for about 1,500 feet due to town recreational fields. Town could designate a wider "no mow" zone, but land use conflicts may present challenges for implementation.
Project #8 R13 (Refer to Map 3)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Winooski River	Duxbury	On western bank just upstream of Winooski Street bridge	Moderate	◒	●	●	○	1,000 foot stretch is lacking riparian buffer, likely due to an agricultural field. The bank is eroding. Project could be eligible for CREP.
Project #9 R13 (Refer to Map 3)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Winooski River	Waterbury	On eastern bank at state-owned Randall Meadow	Moderate	◒	●	●	○	Buffer is lacking for approximately 1,300 feet due to presence of agricultural field. State-owned land.

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[2] Reduces sedimentation and phosphorus levels
[3] Moves the channel toward equilibrium where the water and sediment are in balance
[4] Reduces risk of flooding and erosion hazard

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Project #10 R13 (Refer to Map 4)	Floodplain Improvement and Conservation	Lower or Relocate Road	Winooski River	Duxbury	River Road across the river from the state office complex	Moderate	◓	○	●	●	Town of Duxbury raised River Road after Irene to prevent future inundation, but cut off large undeveloped floodplain. Lowering the dirt road or relocating it farther away from the river against the valley wall would reconnect the floodplain.
Project #11 R13 (Refer to Map 4)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Winooski River	Moretown	Just south of Extra Room Storage facility	Low	●	●	◓	○	Buffer is lacking on west bank of river for about 200 feet due to landowner's lawn. This would be a small planting area and the bank is not currently eroding, making it a low priority project.
Project #12 R13 (Refer to Map 4)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Winooski River	Moretown	On southern bank of river just downstream of reach break between R13 and R14	Moderate	●	●	◓	○	Buffer is lacking for 800 feet due to corn field. Project could be eligible for CREP.
Project #13 R14 (Refer to Map 4)	Floodplain Improvement and Conservation	River Corridor or Conservation Easement	Winooski River	Moretown	On both banks of river in vicinity of 1327 Route 2	Moderate	●	◓	◓	◓	The river has good floodplain access in this area, most of which is well forested. A section of this area is a corn field, which may be eligible for CREP. One of three landowners is interested in projects.
Project #14 R14 (Refer to Map 4)	Floodplain Improvement and Conservation	Relocate Storage of Gravel and Sand	Winooski River	Middlesex	At VTrans Middlesex Garage	**High**	●	●	○	◓	Large gravel and sand piles are stored on eastern bank of the Winooski River. These piles are likely contributing sediment to the river during rain and snowmelt events and could be claimed by the river during flooding.
Project #15 R14 (Refer to Map 4)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Winooski River	Middlesex	Just upstream of Route 2 Bridge near VTrans garage on eastern bank	Moderate	●	●	◓	○	Buffer is lacking on eastern bank for nearly 1,300 feet due to the presence of a corn field. Project may be eligible for CREP.
Project #16 M2.01 (Refer to Map 2)	Floodplain Improvement and Conservation	Create Floodplain	Little River	Waterbury	On western bank of river approximately 350 feet upstream of former Farr Road crossing	Moderate	◓	◓	●	●	This section has incised and lost floodplain access. Two parcels (one 3 acres and one 2 acres) on the western bank of the river. High banks with abundant erosion. Dwellings outside of river corridor. Further investigation is needed.
Project #17 M2.01, M2.02, M2.02-A, and M2.03-B (Refer to Map 2)	Floodplain Improvement and Conservation	River Corridor or Conservation Easement	Little River	Waterbury	Eastern side of river corridor throughout segments	Low	◓	◓	●	◓	One large forested tract of land (276 acres) on eastern side of river. Land on western side and some on eastern side already protected as part of Mount Mansfield State Forest.
Project #18 R13.S1.01-A & B (Refer to Map 3)	Stream Channel Improvement and Restoration	Investigate Stormwater Management	Graves Brook	Waterbury	From the mouth of Graves Brook to the I-89 bridges	**High**	●	●	●	○	There are at least 14 stormwater inputs to Graves Brook in reach one. The Winooski River Basin Plan identifies Graves Brook as an impaired surface water due to sedimentation from surrounding development. Stormwater inputs add flow and sediment to the channel during precipitation/ snowmelt. Project would involve investigating and improving stormwater management on Lower Graves Brook.

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[4] Reduces risk of flooding and erosion hazard

Mid-Winooski River Watershed - Waterbury Area - Restoration & Protection Projects
Waterbury, Vermont
Central Vermont Regional Planning Commission
May 1, 2015

Legend: ● Effective | ◓ Limited | ○ Ineffective

Project Number Segment	Project Category	Project Type	Stream Name	Town	Project Location	Priority	OBJECTIVES: Improves or Protects Habitat[1]	OBJECTIVES: Improves Water Quality[2]	OBJECTIVES: Improves Long-term Channel Stability[3]	OBJECTIVES: Protects Infrastructure, and Property[4]	Comments
Project #19 R13.S1.01-B (Refer to Map 3)	Floodplain Improvement and Conservation	Riparian Buffer Planting and River Corridor Easement	Graves Brook	Waterbury	Southern bank on inside of bend between Armory Road and I-89 bridges	**High**	Effective	Effective	Limited	Ineffective	Buffer is lacking for almost 400 feet on southern bank of brook. Landowner is interested in planting and conservation projects.
Project #20 R13.S1.01-B (Refer to Map 3)	Stream Channel Improvement and Restoration	Investigate Stormwater Management	Graves Brook	Waterbury	From just below Stowe Street Bridge to confluence of Thatcher Brook	**High**	Effective	Effective	Limited	Ineffective	There are at least 7 stormwater inputs in this short stretch of Graves Brook. Investigating stormwater management and improvement could reduce sediment loading to the Brook.
Project #21 R13.S1.03-A (Refer to Map 3)	Structure Replacement/ Removal	Replace Culvert	Graves Brook	Waterbury	At Lincoln Street crossing	**High**	Limited	Ineffective	Effective	Effective	Structure is significantly undersized and has poor alignment. Riprap is falling into streambed. If culvert gets blocked, stream could flood nearby homes, road, and park and ride.
Project #22 R13.S1.03-A (Refer to Map 3)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Graves Brook	Waterbury	Just upstream of Lincoln Street crossing on southern bank.	Moderate	Effective	Effective	Limited	Limited	Buffer is minimal on southern bank due to landowner's lawns. Some trees are present, but planting more in buffer would help to stabilize bank. Homes are nearby that could be threatened by further bank erosion.
Project #23 R13.S1.03-B (Refer to Map 3)	Floodplain Improvement and Conservation	River Corridor or Conservation Easement	Graves Brook	Waterbury	Both southern and northern sides of channel along segment approximately 2,700 feet upstream of segment break.	Moderate	Effective	Limited	Effective	Ineffective	101 acre parcel potentially vulnerable to future river corridor development. Areas of beaver dam impoundment that could be protected as wetlands.
Project #24 R13.S1.03-B (Refer to Map 3)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Graves Brook	Waterbury	At edge of golf course green on northern bank at upstream end of segment	Moderate	Effective	Effective	Effective	Ineffective	No buffer for approximately 200 feet in vicinity of golf course green. Riprap has been placed at downstream end to protect stream bank. Channel is undergoing major adjustment.
Project #25 R13.S1.03-C (Refer to Map 3)	Floodplain Improvement and Conservation	River Corridor or Conservation Easement	Graves Brook	Waterbury	Both southern and northern sides of channel along length of segment.	Low	Effective	Limited	Effective	Ineffective	One large forested parcel (330 acres) with no development currently in corridor for segment.
Project #26 R13.S1.02-S1.01-A (Refer to Map 5)	Floodplain Improvement and Conservation	Establish "No Mow Zone" to Regenerate Riparian Buffer	Thatcher Brook	Waterbury	At the Waterbury Park and Ride	Moderate	Effective	Effective	Limited	Limited	A short stretch on the southern bank of Thatcher Brook is lacking a buffer due to mowing around the park and ride. A "no mow" zone could be established to allow buffer regeneration.
Project #27 R13.S1.02-S1.01-B (Refer to Map 5)	Structure Replacement/ Removal	Investigate Dam Removal	Thatcher Brook	Waterbury	Historic Dams at Mill Road	Moderate	Effective	Ineffective	Limited	Limited	Two historic dams exist that may be creating a barrier for aquatic organism passage. The lower dam has been breached, but the upper one is fully intact. Removing the dams could improve habitat connectivity, but degree of current AOP is uncertain. More investigation needed.
Project #28 R13.S1.02-S1.01-C (Refer to Map 5)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Thatcher Brook	Waterbury	At 1320 Route 100	**High**	Effective	Effective	Effective	Limited	Riparian buffer is lacking along northern bank for about 200 feet due to a landowner's lawn. Landowner indicated interest in potential projects and is concerned about bank erosion on their property. Planting a buffer could help stabilize the bank.

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Mid-Winooski River Watershed - Waterbury Area - Restoration & Protection Projects
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Project Number Segment	Project Category	Project Type	Stream Name	Town	Project Location	Priority	OBJECTIVES: Improves or Protects Habitat[1]	OBJECTIVES: Improves Water Quality[2]	OBJECTIVES: Improves Long-term Channel Stability[3]	OBJECTIVES: Protects Infrastructure, and Property[4]	Comments
Project #29 R13.S1.02-S1.02 (Refer to Map 5)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Thatcher Brook	Waterbury	Just downstream of upstream Guptil Road Bridge on north bank	Moderate	●	●	◓	○	Riparian buffer is lacking for about 450 feet along the north side of Thatcher Brook due to what appears to be a crop field. Project could be eligible for CREP.
Project #30 R13.S1.02-S1.02 (Refer to Map 5)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Thatcher Brook	Waterbury	On pasture land north of golf course	Moderate	●	●	◓	○	About 250 feet on the south bank are lacking a riparian buffer. Land use is unknown.
Project #31 R13.S1.02-S1.02 & R13.S1.02-S1.03 (Refer to Map 5)	Floodplain Improvement and Conservation	River Corridor or Conservation Easement	Thatcher Brook	Waterbury	Between the lower Guptil Road Bridge and confluence of Unnamed Tributary 2 to Thatcher Brook	**High**	●	●	●	◓	This section of the brook is extremely dynamic and contains abundant adjacent wetlands. It is very important for the storage of floodwaters and sediment and is currently undeveloped. Several large parcels.
Project #32 R13.S1.02-S1.03 (Refer to Map 5)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Thatcher Brook	Waterbury	Directly west of the intersection of Kneeland Flats Road and Guptil Road	Moderate	●	●	◓	○	About 250 feet on the east bank of the brook are lacking adequate riparian vegetation. This area appears to be used as both a residential lawn and an agricultural field. Project may be eligible for CREP.
Project #33 R13.S1.02-S1.04-A (Refer to Map 5)	Floodplain Improvement and Conservation	Riparian Buffer Planting and Livestock Exclusion	Thatcher Brook	Waterbury	Along western bank upstream of confluence with Unnamed Tributary 2 at 1211 Guptil Road	**High**	●	●	●	◓	Lack of buffer along pasture and horse crossing in this section. Abundant armoring preventing widening in places. Channel is widening where riprap is not located. Project may be eligible for CREP.
Project #34 R13.S1.02-S1.04-B (Refer to Map 5)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Thatcher Brook	Waterbury	Along western bank upstream of Guptil Road Bridge at 1526 Guptil Road	Moderate	●	◓	●	◓	Lack of buffer along lawn/pasture along northwestern bank. Channel is widening where armoring is not in place. Project may be eligible for CREP.
Project #35 R13.S1.02-S1.04-C (Refer to Map 5)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Thatcher Brook	Waterbury	Along northern bank at 1530 Guptil Road	Moderate	●	◓	●	◓	Lack of buffer along lawn/pasture on northern side of channel. Channel is adjusting and building new floodplain.
Project #36 R13.S1.02-S1.04-C & R13-S1.02-S1.05-A (Refer to Map 5)	Floodplain Improvement and Conservation	River Corridor or Conservation Easement	Thatcher Brook	Waterbury	Eastern side of parcels at 1842 Guptil Road and 116 Maple Street	**High**	●	○	●	○	Two parcels 70 acres in total of well forested riparian corridors.
Project #37 R13.S1.02-S1.05-A (Refer to Map 5)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Thatcher Brook	Waterbury	Approximately 1,500 feet upstream of Loomis Hill Road Bridge	Low	●	◓	●	◓	Lack of buffer in some locations along agricultural fields. Channel in major adjustment. Possible CREP project.
Project #38 R13.S1.02-S1.05-B (Refer to Map 5)	Stream Channel Improvement and Restoration	Investigate Berm Removal	Thatcher Brook	Waterbury	Approximately 2,700 feet upstream of Loomis Hill Road Bridge	Low	●	○	●	○	Historic berm most likely caused by previous windrowing preventing floodplain access on eastern bank. Well forested and removal of berm would not cause flood risks.

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Project #39 R13.S1.02-S1.06-A (Refer to Map 6)	Floodplain Improvement and Conservation	Buffer regeneration/Establish no mow zone	Thatcher Brook	Waterbury	At downstream end of reach in between stream and 646 Maple Street	Low	●	◓	●	○	13 acre parcel with former hay field/pasture. Buffer is currently regenerating and stream would benefit from further removal of vegetation.
Project #40 R13.S1.02-S1.06-A & B, R13.S1.02-S1.07, R13.S1.02-S1.08-A & B, R13.S1.02-S1.09-A (Refer to Map 6)	Floodplain Improvement and Conservation	River Corridor or Conservation Easement	Thatcher Brook	Waterbury	From across 901 Maple Street to just above segment break for R13.S1.02-S1.09-B at 1842 Barnes Hill Road.	Moderate	●	◓	●	○	Nine landowners along a stretch of Thatcher Brook 2.5 miles long. One parcel is landlocked with 8 acres and another town owned lot is 12 acres. All other parcels are large (85-308 acres). Well forested buffer for the most part.
Project #41 R13.S1.02-S1.06-B (Refer to Map 6)	Structure Replacement/ Removal	Remove Bridge	Thatcher Brook	Waterbury	Across from 371 Barnes Hill Road	Low	◓	○	◓	○	Old wooden trail bridge with no abutments. Low clearance and in unstable condition.
Project #42 R13.S1.02-S1.09-B (Refer to Map 6)	Structure Replacement/ Removal	Replace Culvert	Thatcher Brook	Waterbury	At private drive crossing near 1930 Barnes Hill Road	**High**	●	◓	●	●	Flow downstream of wetland is split into two channels that go through three culverts. Culverts are very undersized and there is no aquatic organism passage. Beaver dam upstream. Replace with adequately sized structure with no freefall drop.
Project #43 R13.S1.02-S1.09-D (Refer to Map 6)	Structure Replacement/ Removal	Remove Bridge	Thatcher Brook	Waterbury	Approximately 900 feet downstream of Waterworks Road crossing	**Low**	◓	○	◓	○	Old wooden trail bridge with no abutments. Low clearance and in unstable condition.
Project #44 R13.S1.02-S1.09-D (Refer to Map 6)	Stream Channel Improvement and Restoration	Return or Remove Windrowed Material/Remove berm	Thatcher Brook	Waterbury	Just downstream of Waterworks Road Bridge on southern bank	Moderate	◓	○	●	○	Material was windrowed and piled on southern bank creating a berm. The berm is not protecting anything on the southern bank. Remove material from berm to reestablish floodplain connection. Channel is undergoing major adjustment.
Project #45 R13.S1.02-S1.09-D (Refer to Map 6)	Stream Channel Improvement and Restoration	Restore flow to stream channel	Thatcher Brook	Waterbury	In vicinity of Waterworks Road crossing	**High**	●	●	○	○	Lack of flow during times of water withdrawal are leaving the stream bed dry.
Project #46 R13.S1.02-S1.02-S1.01-A (Refer to Map 7)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Unnamed Tributary 1 to Thatcher Brook	Waterbury	On northern bank just upstream of confluence with Thatcher Brook	Moderate	●	●	◓	○	Riparian buffer is lacking for about 250 feet on the northern side of the stream due to the presence of a field and walking path. Project may be eligible for CREP. Alternatively, a "no mow" zone could be established and allow for natural buffer regeneration. Project could continue along the edge of the field, which also borders R13.S1.02-S1.03 of Thatcher Brook.
Project #47 R13.S1.02-S1.02-S1.01-C (Refer to Map 7)	Structure Replacement/ Removal	Remove Destroyed Bridge	Unnamed Tributary 1 to Thatcher Brook	Waterbury	On VAST trail about 900 feet downstream of culvert under Twin Peaks Road	**High**	●	◓	●	◓	There is a destroyed snowmobile bridge (iron and wood) causing sediment and debris accumulation in the stream channel. The bridge could affect water quality and channel stability, and could wash downstream and cause damage to infrastructure/property if not removed.

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● Effective ◓ Limited ○ Ineffective

Project Number Segment	Project Category	Project Type	Stream Name	Town	Project Location	Priority	OBJECTIVES: Improves or Protects Habitat[1]	Improves Water Quality[2]	Improves Long-term Channel Stability[3]	Protects Infrastructure, and Property[4]	Comments
Project #48 R13.S1.02-S1.02-S1.01-D (Refer to Map 7)	Stream Channel Improvement and Restoration	Build Up Streambed with Boulder Weirs and Arrest Headcut	Unnamed Tributary 1 to Thatcher Brook	Waterbury	At Green Mountain Garlic Farm	**High**	◓	◓	●	◓	Stream channel is cutting down to glacial till and threatens good floodplain access upstream. Landowners indicated that they wanted help with the bank erosion and channel downcutting.
Project #49 R13.S1.02-S1.02-S1.01-D & E (Refer to Map 7)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Unnamed Tributary 1 to Thatcher Brook	Waterbury	On both banks from about 900 feet upstream of Twin Peaks Road crossing to Perry Hill Road Crossing	**High**	●	●	●	○	Riparian buffer is lacking on both banks for all of segments C and D due to crop fields and pasture land. Banks are unstable due to lacking vegetation. Project may be eligible for CREP. Landowner interest in projects is present.
Project #50 R13.S1.02-S1.02-S1.01-E (Refer to Map 7)	Stream Channel Improvement and Restoration	Livestock Exclusion	Unnamed Tributary 1 to Thatcher Brook	Waterbury	For about 1,500 feet of stream channel immediately downstream of Perry Hill Road crossing	**High**	●	●	●	○	Grazing animals have access to the stream throughout all of segment E, which is causing geomorphic instability and water quality problems. There are at least 8 locations where animals can cross/ access the stream. Algae growth in the channel is abundant below this section (but not above), suggesting that agricultural practices here could be causing nutrient enrichment.
Project #51 R13.S1.02-S1.02-S1.01-F & G (Refer to Map 7)	Floodplain Improvement and Conservation	River Corridor or Conservation Easement	Unnamed Tributary 1 to Thatcher Brook	Waterbury	Upstream of Perry Hill Road crossing	Moderate	●	◓	●	◓	This section of the brook is largely undisturbed and is an important area for floodwater and sediment storage. A section of this area is a wetland complex. Mostly forested land. Parcels are not very large, but one landowner is interested in projects.
Project #52 R13.S1.02-S1.02-S1.01-G (Refer to Map 7)	Floodplain Improvement and Conservation	Riparian Buffer Planting	Unnamed Tributary 1 to Thatcher Brook	Waterbury	About 1,300 feet upstream of Perry Hill Road crossing	Low	●	●	◓	○	Riparian buffer is lacking on northern bank for approximately 150 feet due to an agricultural field. Project may be eligible for CREP, but is a small planting area.
Project #53 R13.S1.02-S1.02-S1.01-G (Refer to Map 7)	Structure Replacement/ Removal	Remove or Replace Bridge	Unnamed Tributary 1 to Thatcher Brook	Waterbury	On VAST trail about 1,800 feet upstream of Perry Hill Road crossing	Moderate	◓	○	●	●	A snowmobile bridge on the VAST trail is in poor condition and is partially collapsing. The bridge is a safety issue if it is currently in use, and if it is not in use, it should be removed as it is undersized and failing.
Project #54 R13.S1.02-S1.03-S1.01-A (Refer to Map 7)	Structure Replacement/ Removal	Replace Bridge	Unnamed Tributary 2 to Thatcher Brook	Waterbury	Bridge on Guptil Road almost 800 feet northeast of intersection with Kneeland Flats Road	**High**	◓	○	●	●	Bridge is slightly undersized and is in poor condition. Riprap around the bridge has all fallen into the stream and a large amount of sediment has accumulated beneath the bridge, causing it to have a very low clearance. It could be easily overtopped and damaged during high flows.
Project #55 R13.S1.02-S1.03-S1.01-A (Refer to Map 7)	Stream Channel Improvement and Restoration	Livestock Exclusion	Unnamed Tributary 2 to Thatcher Brook	Waterbury	Just upstream of Guptil Road Bridge	**High**	●	●	●	○	Upstream of the Guptil Road Bridge, there is pasture land for cows, which appear to have free access to the stream. Excluding these cows would eliminate localized geomorphic instability and improve water quality.

[1] Enhances or protects aquatic or riparian habitat
[2] Reduces sedimentation and phosphorus levels
[3] Moves the channel toward equilibrium where the water and sediment are in balance
[4] Reduces risk of flooding and erosion hazard

Mid-Winooski River Watershed - Waterbury Area - Restoration & Protection Projects
Waterbury, Vermont
Central Vermont Regional Planning Commission
May 1, 2015

Legend: ● Effective ◓ Limited ○ Ineffective

Project Number Segment	Project Category	Project Type	Stream Name	Town	Project Location	Priority	OBJECTIVES: Improves or Protects Habitat[1]	Improves Water Quality[2]	Improves Long-term Channel Stability[3]	Protects Infrastructure, and Property[4]	Comments
Project #56 R13.S1.02-S1.03-S1.01-B & C (Refer to Map 7)	Floodplain Improvement and Conservation	Riparian Buffer Planting and River Corridor Easement	Unnamed Tributary 2 to Thatcher Brook	Waterbury	Between Guptil Road and Harvey Farm Road	Moderate	●	●	●	◓	Riparian buffer is lacking on south bank for 325 feet due to an agricultural field. Aside from this, the stream is undisturbed and has good floodplain access here. It is undergoing major adjustment. One large parcel. Project may be eligible for CREP.
Project #57 R13.S1.02-S1.03-S1.02-C (Refer to Map 7)	Structure Replacement/ Removal	Culvert Replacement	Unnamed Tributary 2 to Thatcher Brook	Waterbury	Culvert under Shaw Mansion Road	**High**	●	◓	●	●	This culvert is significantly undersized and rusty. The culvert was washed out during Irene, causing road damage, and could wash out again due to its very small size.
Project #58 R13.S1.02-S1.03-S1.02-B & C (Refer to Map 7)	Floodplain Improvement and Conservation	River Corridor or Conservation Easement	Unnamed Tributary 2 to Thatcher Brook	Waterbury	Between Shaw Mansion Road and Ripley Road	Moderate	●	◓	◓	◓	One large parcel (55 acres) is suggested for river corridor or conservation easement. There is no development present in the parcel and the stream is actively adjusting in this area.
Project #59 R13.S1.02-S1.03-S1.02-C (Refer to Map 7)	Structure Replacement/ Removal	Culvert Replacement	Unnamed Tributary 2 to Thatcher Brook	Waterbury	Culvert under Ripley Road	**High**	●	◓	●	●	This culvert is severely undersized and creates a barrier to aquatic organism passage due to the drop at its outlet.

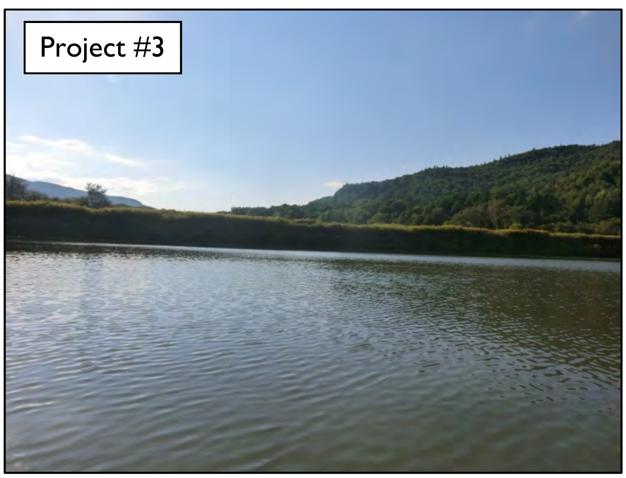
[1] Enhances or protects aquatic or riparian habitat
[2] Reduces sedimentation and phosphorus levels
[3] Moves the channel toward equilibrium where the water and sediment are in balance
[4] Reduces risk of flooding and erosion hazard


Project #1

No photo for Project #5


Project #2


Project #6


Project #3

No photo for Project #7


Project #4


Project #8

Project #9

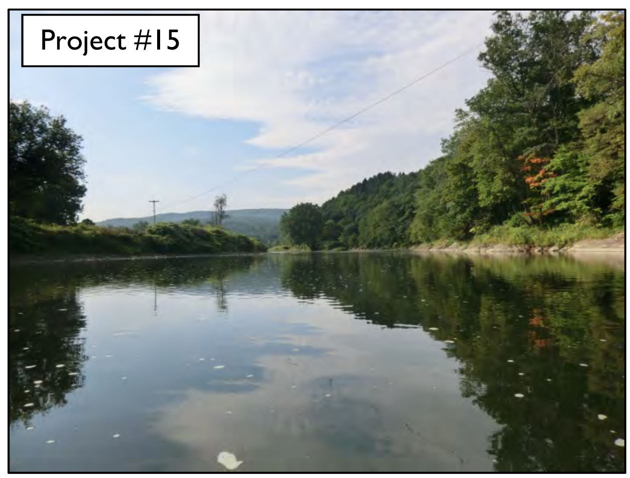
Project #10

Project #11

Project #12

Project #13

Project #14



Project #15

Project #16


Project #17


Project #18


Project #19

No photo for Project #20


Project #21


Project #22


Project #23


Project #24


Project #25

No photo for Project #29


Project #26


Project #30


Project #27


Project #31

No photo for Project #28

No photo for Project #32


Project #33


Project #34


Projects #35


Project #36


Project #37


Project #38


Project #39


Project #40


Project #41


Project #42


Project #43


Project #44


Project #45


Project #46


Project #47


Project #48


Project #49


Project #50


Project #51


Project #52


Project #53


Project #54


Project #55


Project #56


Project #57


Project #58


Project #59