

Waterbury, Vermont Middle Winooski River Corridor Plan

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Waterbury, Vermont

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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

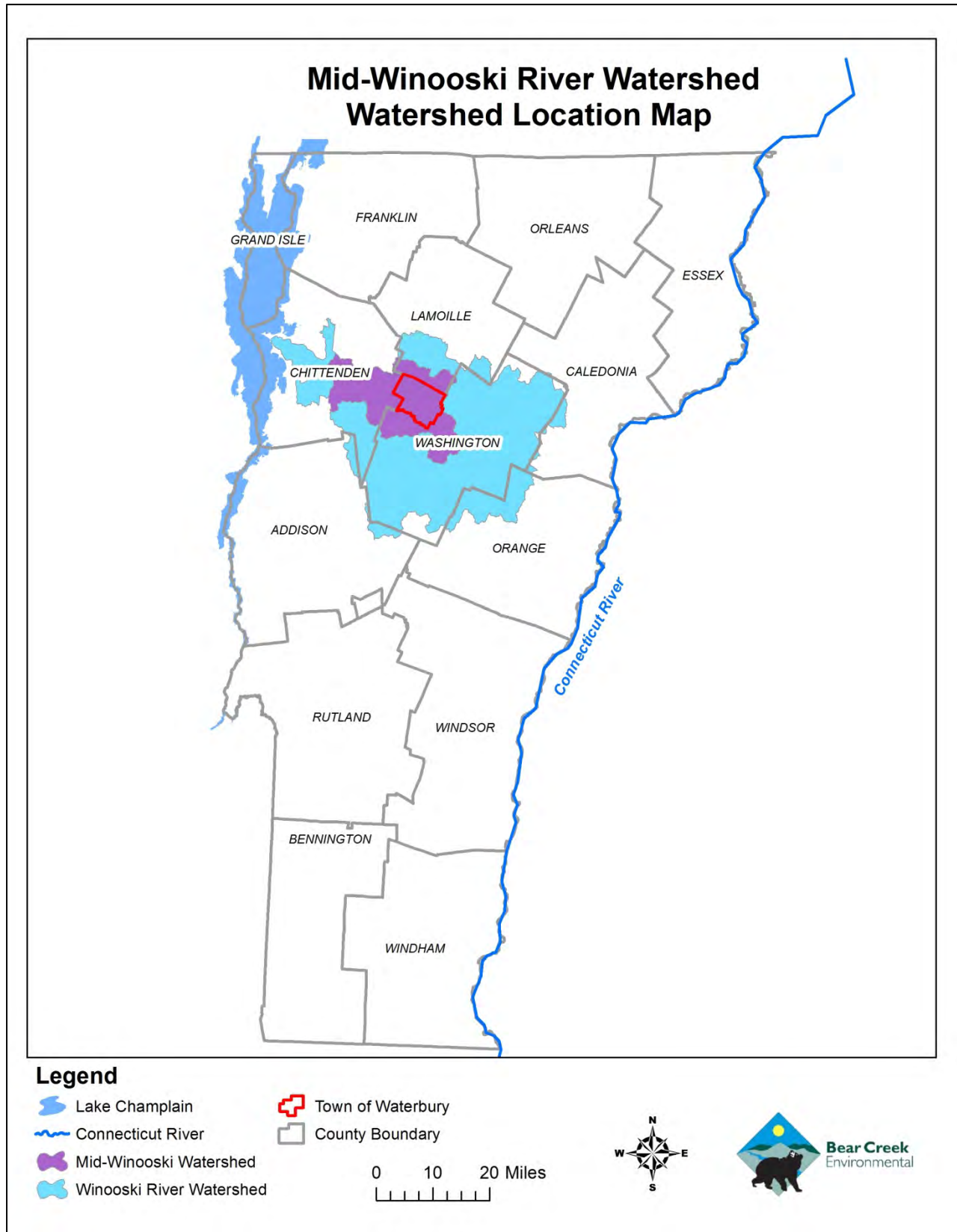


Figure 3.1. Watershed Location Map for the Mid-Winooski River watershed.

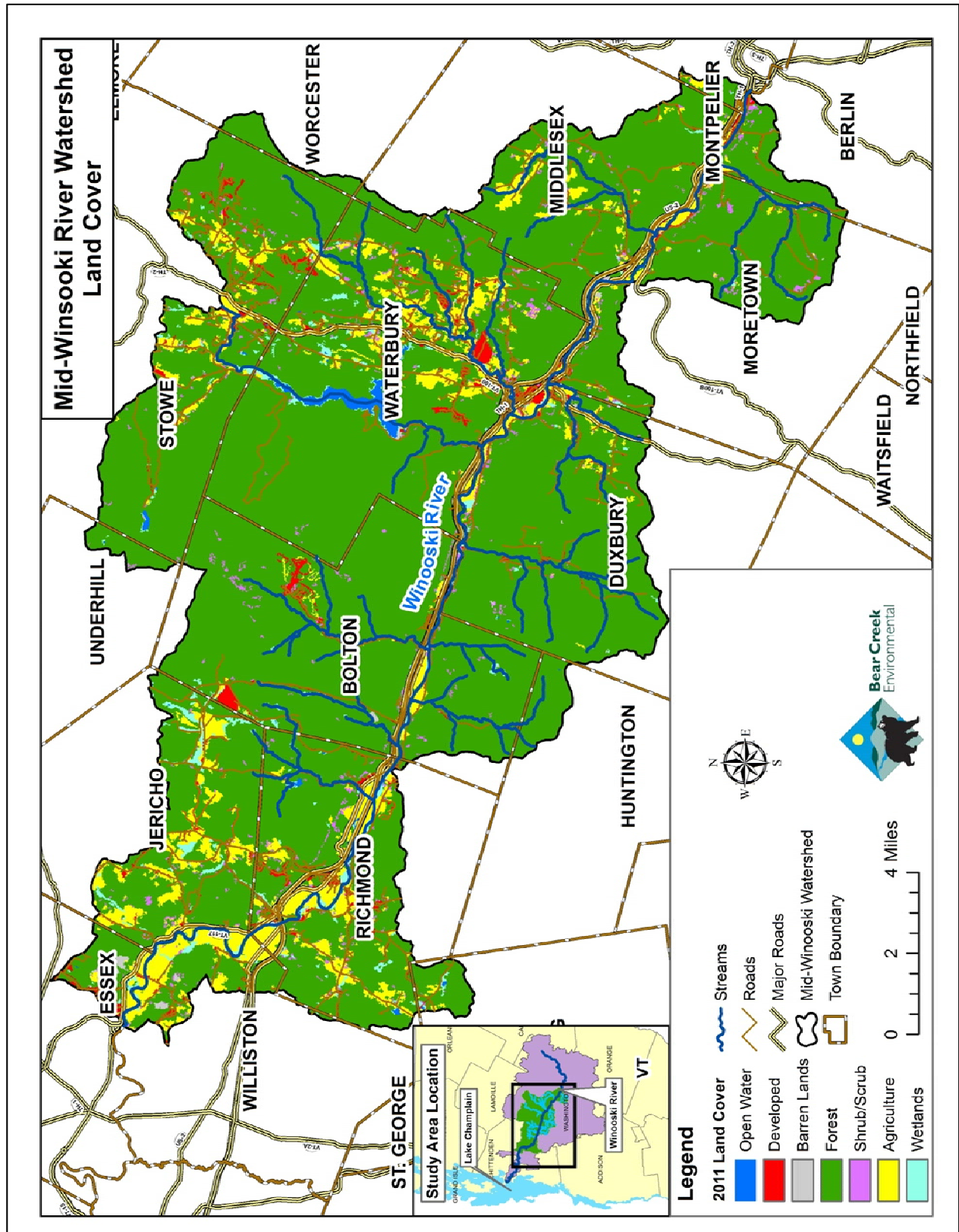


Figure 3.2. Land Cover Map for the Mid-Winooski watershed.

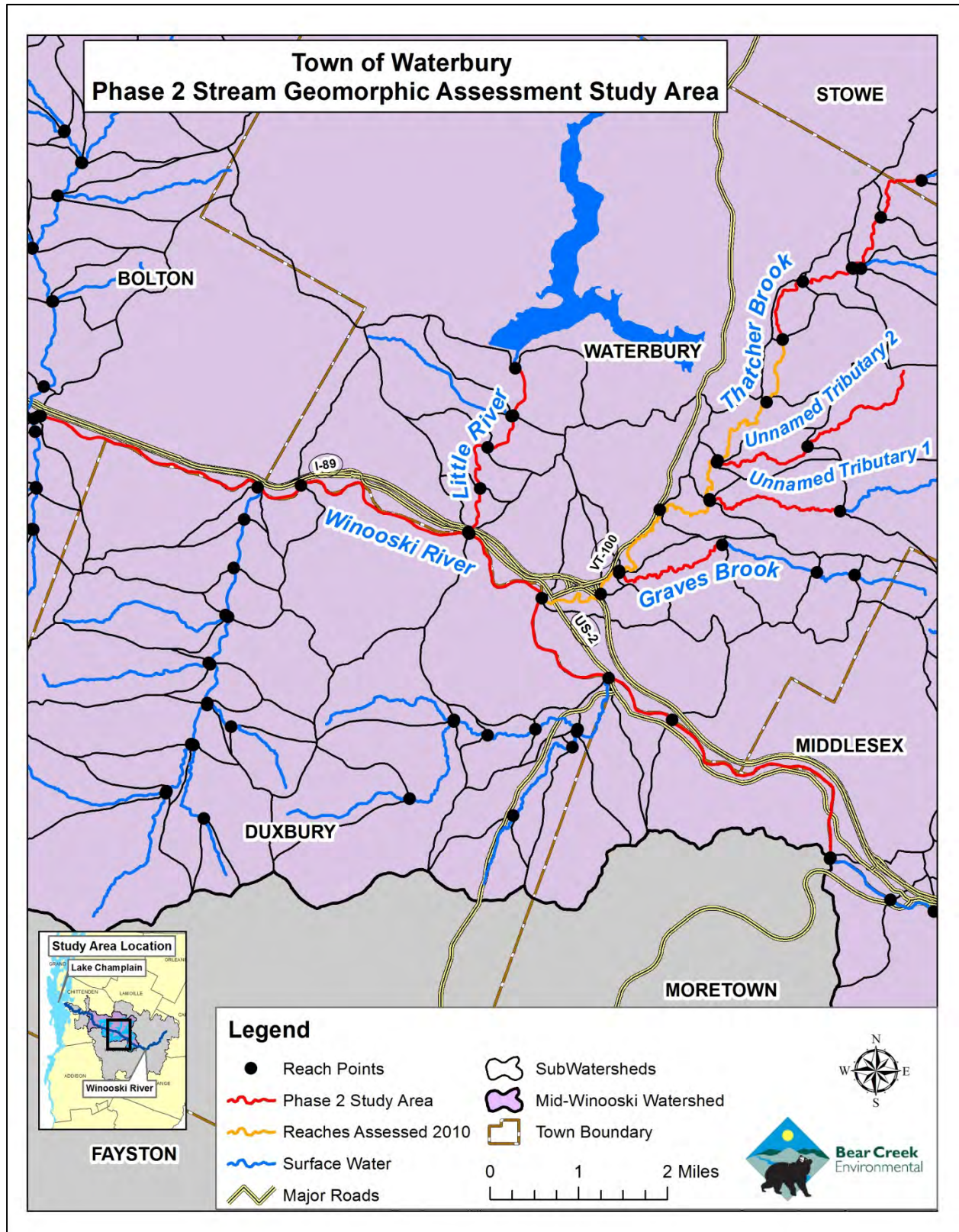


Figure 3.3. Mid-Winooski River watershed 2014 and 2010 stream geomorphic assessment study reaches.

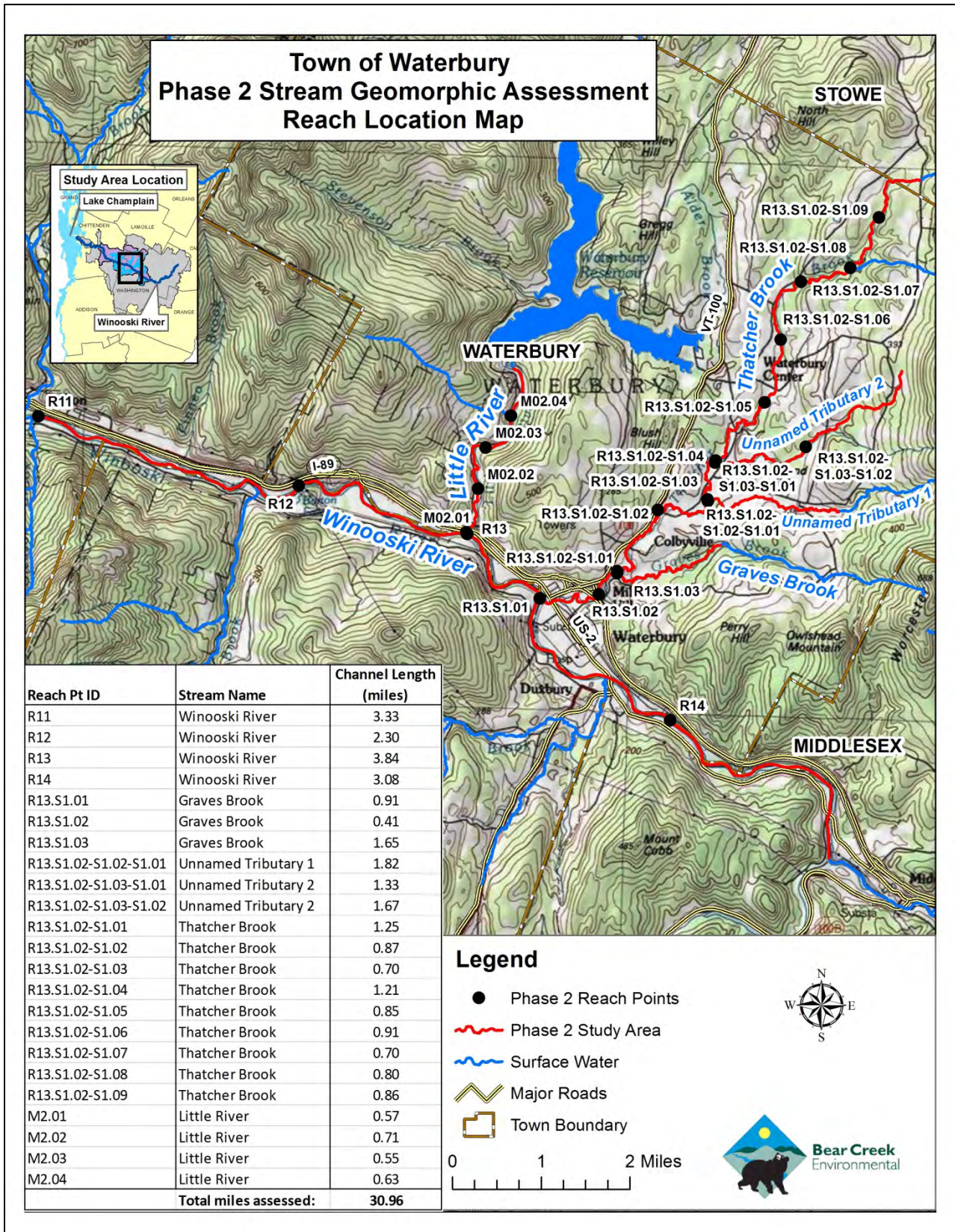


Figure 3.4. Mid-Winooski River watershed 2014 Phase 2 study reaches.

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.

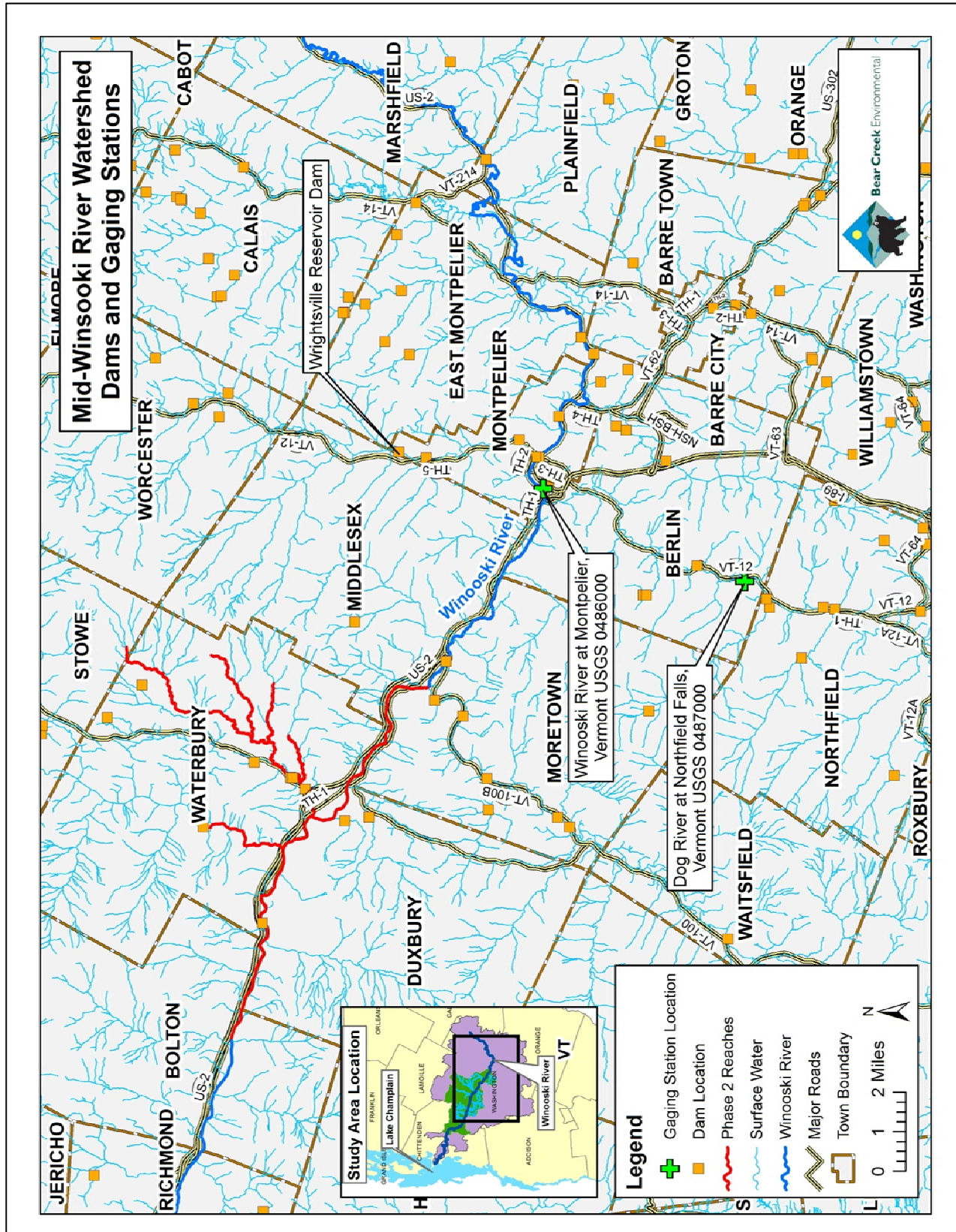


Figure 3.5. Gaging station and dam locations in relation to study area.

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).

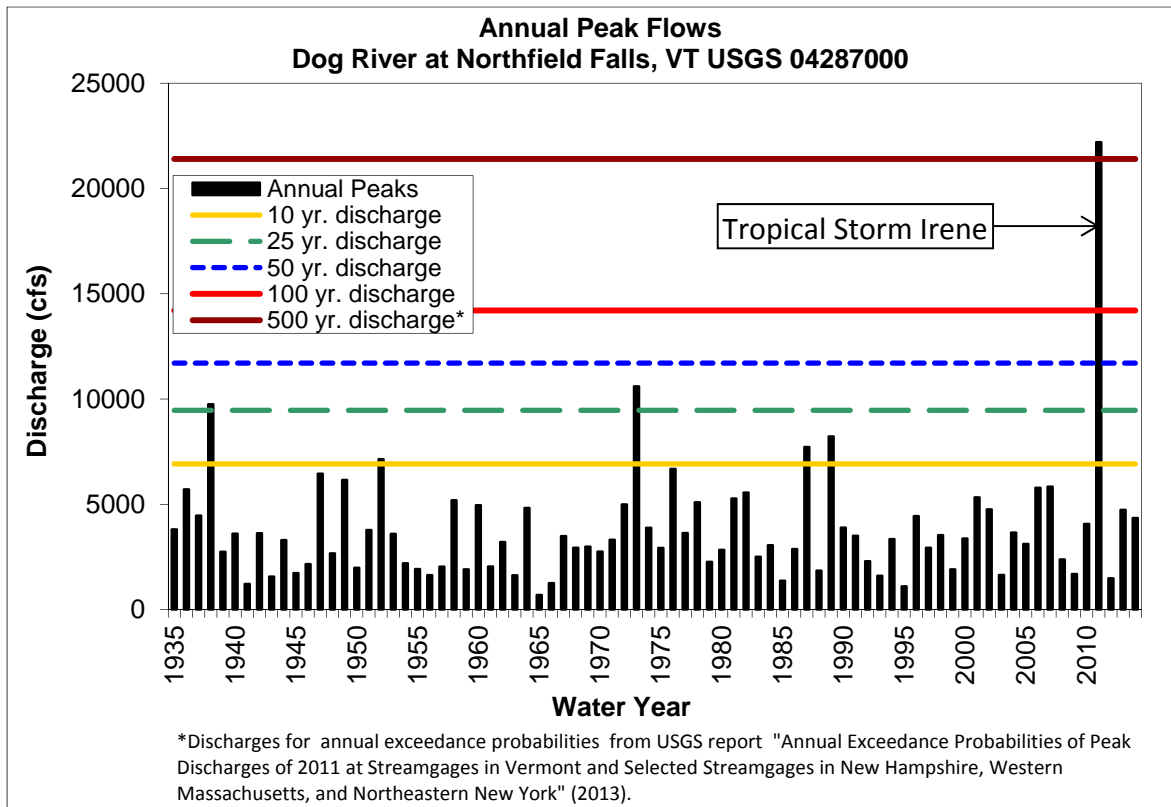


Figure 3.6. Annual Peak Flows for the Dog River at Northfield Falls, Vermont.

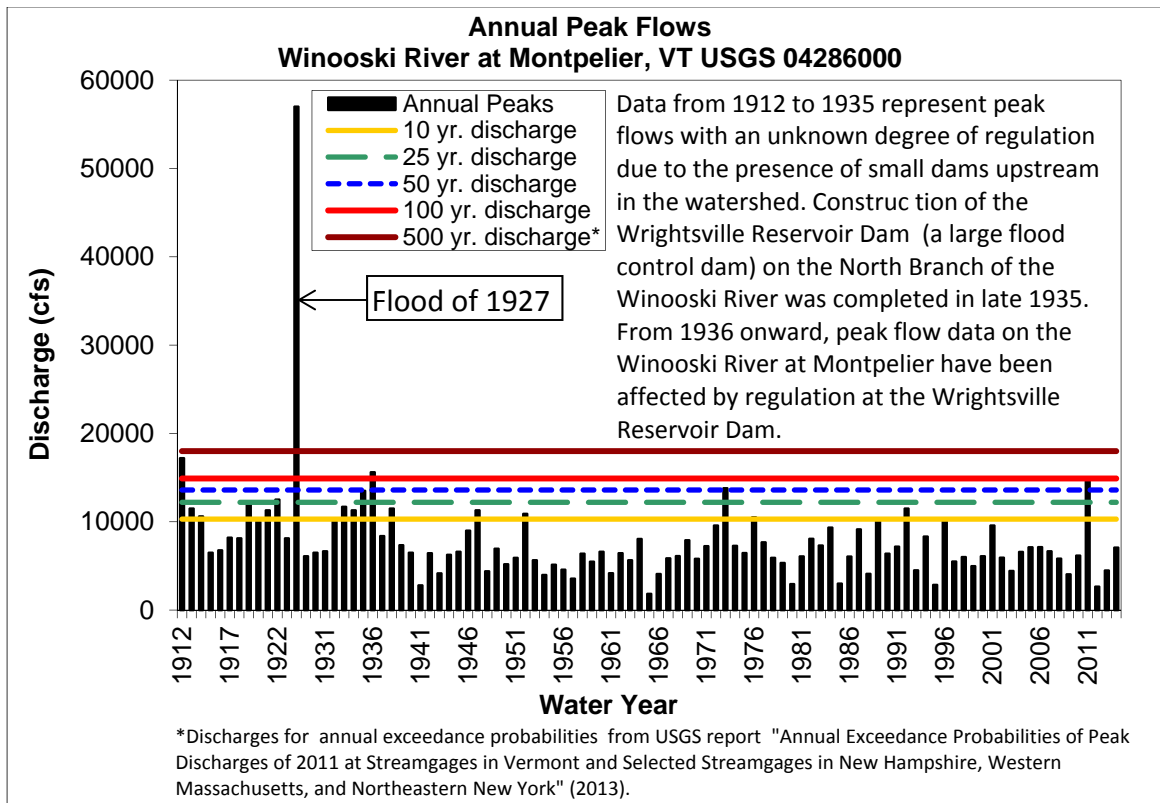


Figure 3.7. Annual Peak Flows for the Winooski River at Montpelier, Vermont.

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.

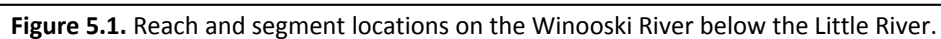
During the Phase 2 assessment, the 23 study reaches were broken into 53 segments based on detailed field observations. A segment is distinct in one or more of the following parameters: degree of floodplain encroachment or channel alteration, *grade control* occurrence (e.g. ledge), channel dimensions, 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



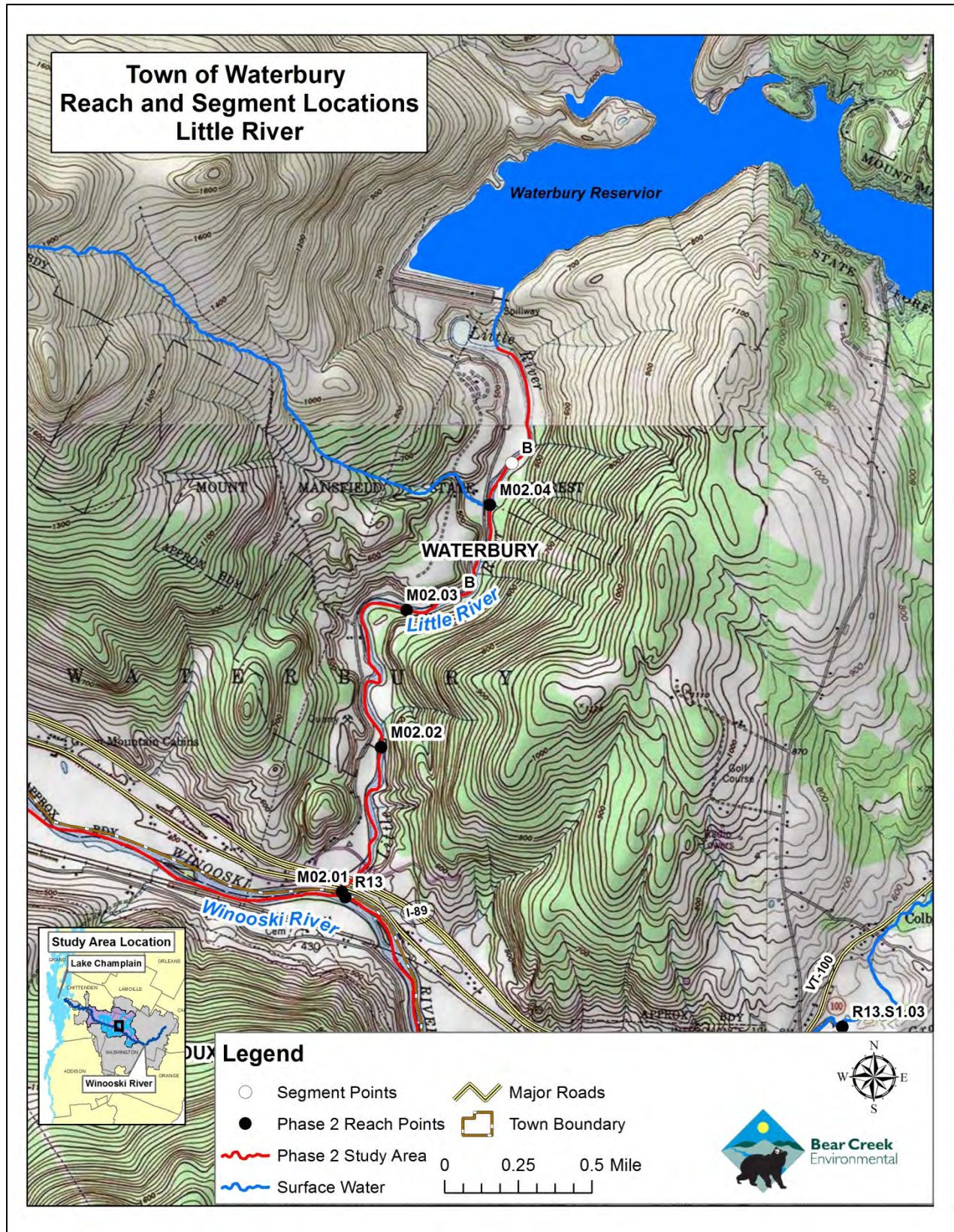
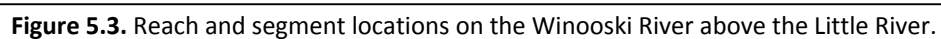
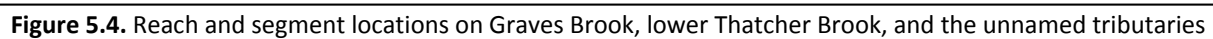
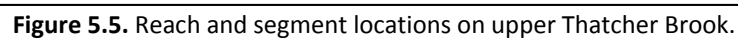


Figure 5.2. Reach and segment locations on the Little River.







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-I) - 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

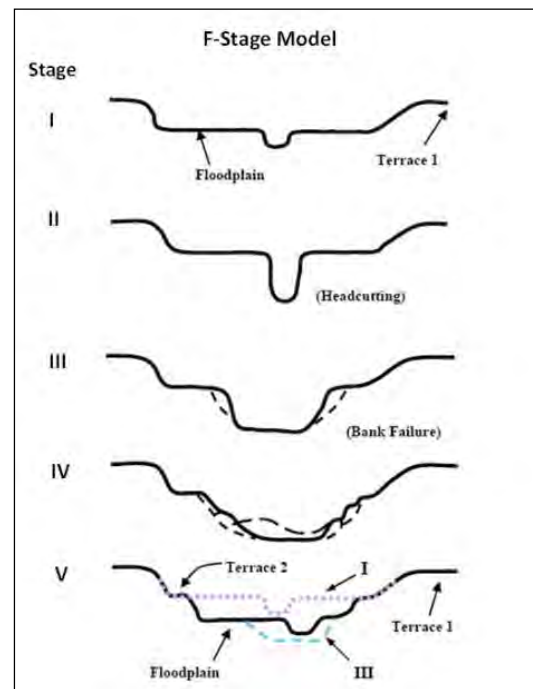


Figure 5.6 Typical channel evolution models for F-Stage (Vermont Agency of Natural Resources, 2009b)

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 Drainage Area: 112 sq. mi. Evolution Stage: F-III Sensitivity: Extreme	Confinement	Broad	Narrow
	Stream Type	C	F
	Entrenchment Ratio	> 2.2	1.1
	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.

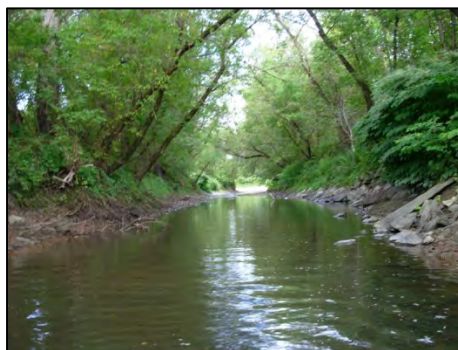


Figure 5.18. Graves Brook has a narrow and deep channel with abundant bank armoring in R13.S1.01-A.

R13.S1.01-A Data Summary		Reference	Existing
Length: 2,089 ft Drainage Area: 19 sq. mi. Evolution Stage: F-II Sensitivity: Extreme	Confinement	Very Broad	Very Broad
	Stream Type	C	E
	Entrenchment Ratio	> 2.2	3.4
	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 Drainage Area: 19 sq. mi. Evolution Stage: F-III Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	> 2.2	3.5
	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
Length: 986 ft Drainage Area: 18.3 sq. mi. Evolution Stage: N/A Sensitivity: N/A	Confinement	Semi-Confined	Semi-Confined
	Stream Type	B	N/A
	Entrenchment Ratio	1.4 – 2.2	N/A
	Incision Ratio	< 1.2	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 Drainage Area: 2.7 sq. mi. Evolution Stage: F-II Sensitivity: Extreme	Confinement	Very Broad	Very Broad
	Stream Type	C	E
	Entrenchment Ratio	> 2.2	9.6
	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 Drainage Area: 15.3 sq. mi. Evolution Stage: F-III Sensitivity: Extreme	Confinement	Very Broad	Very Broad
	Stream Type	E	E
	Entrenchment Ratio	>2.2	14.4
	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	Confinement	Semi-Confined	Semi-Confined
Drainage Area: 15.3 sq. mi.	Stream Type	B	N/A
Evolution Stage: N/A	Entrenchment Ratio	>2.2	N/A
Sensitivity: 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.

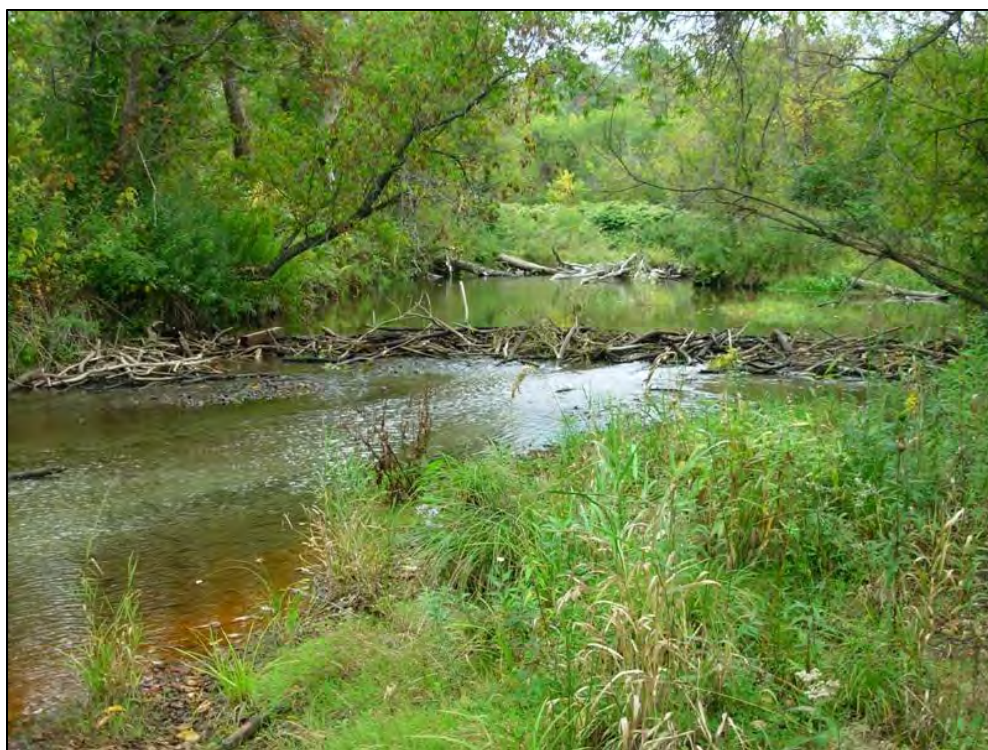


Figure 5.27. R13.S1.02-S1.01-C is a meandering wetland channel with current beaver activity.

R13.S1.02-S1.01-C Data Summary		Reference	Existing
Length: 1,953 ft Drainage Area: 15.3 sq. mi. Evolution Stage: D-IIc Sensitivity: Extreme	Confinement	Very Broad	Very Broad
	Stream Type	E	E
	Entrenchment Ratio	>2.2	13.9
	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 Drainage Area: 15.3 sq. mi. Evolution Stage: F-III Sensitivity: Very High	Confinement	Broad	Broad
	Stream Type	C	C
	Entrenchment Ratio	>2.2	6.9
	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 Drainage Area: 7.8 sq. mi. Evolution Stage: F-III Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	>2.2	11.9
	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 Drainage Area: 7.1 sq. mi. Evolution Stage: F-IV Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	>2.2	3.8
	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. .

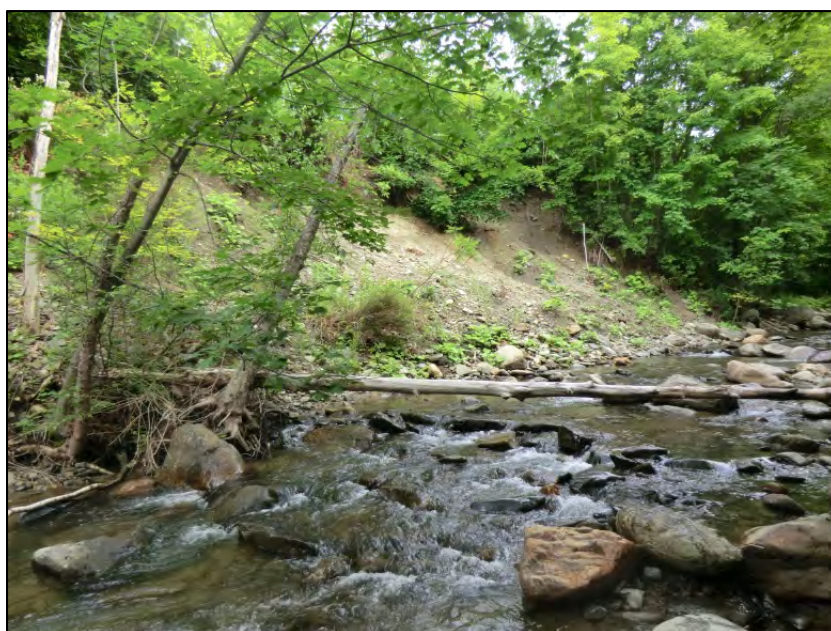


Figure 5.36. One of three mass failures in R13.S1.02-S1.06-A contributing sediment to the channel.

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.

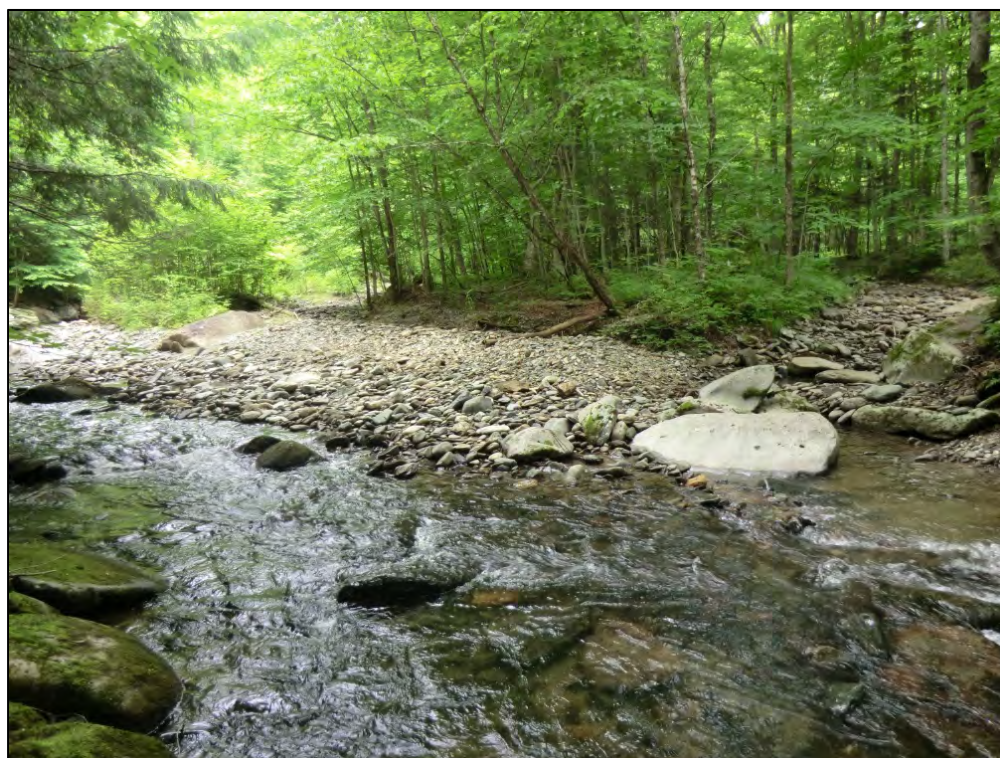


Figure 5.38. Large point bar where material from TSI may have been deposited.

R13.S1.02-S1.07 Data Summary		Reference	Existing
Length: 3,704 ft Drainage Area: 6 sq. mi. Evolution Stage: F-III Sensitivity: High	Confinement	Broad	Broad
	Stream Type	B	B
	Entrenchment Ratio	1.4 - 2.2	1.3
	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.

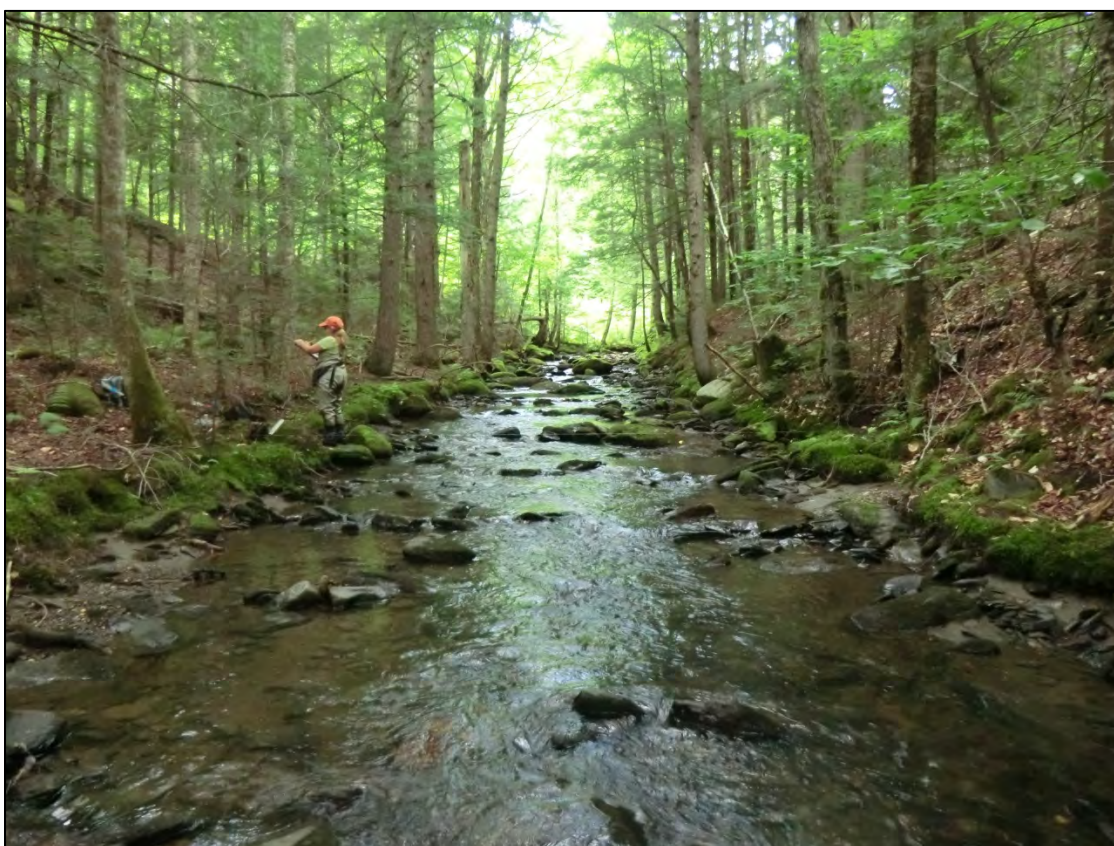


Figure 5.40. Mossy and stable stream banks in R13.S1.02-S1.08-B.

R13.S1.02-S1.08-B Data Summary		Reference	Existing
Length: 1,246 ft Drainage Area: 3.8 sq. mi. Evolution Stage: F-II Sensitivity: High	Confinement	Very Broad	Very Broad
	Stream Type	B	B
	Entrenchment Ratio	1.4 - 2.2	1.6
	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.

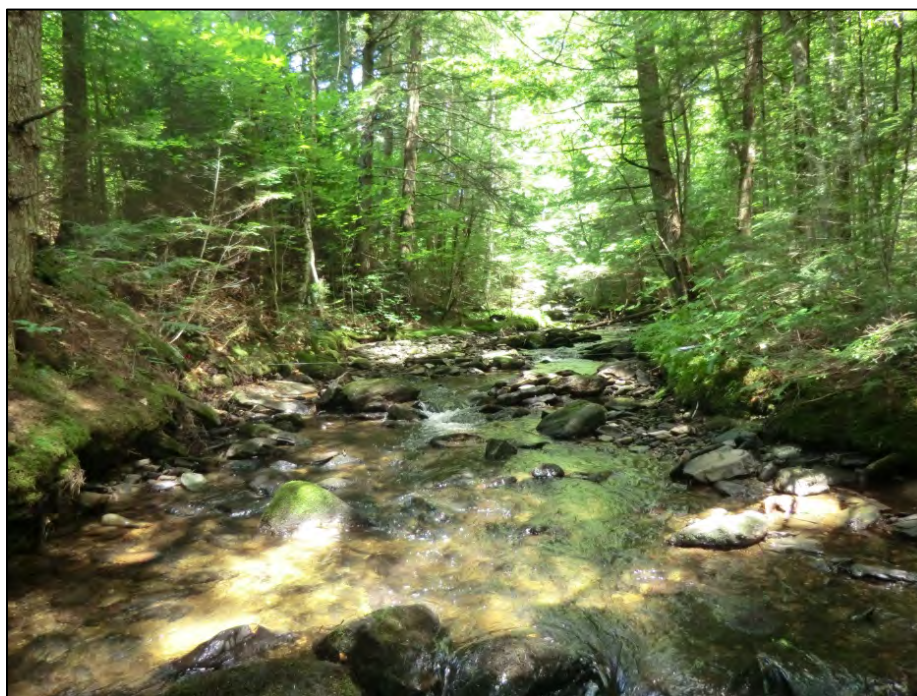


Figure 5.41. R13.S1.02-S1.09-A has well forested banks and buffers.

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
Length: 1,736 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	5.8
	Incision Ratio	< 1.2	1.3
	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.

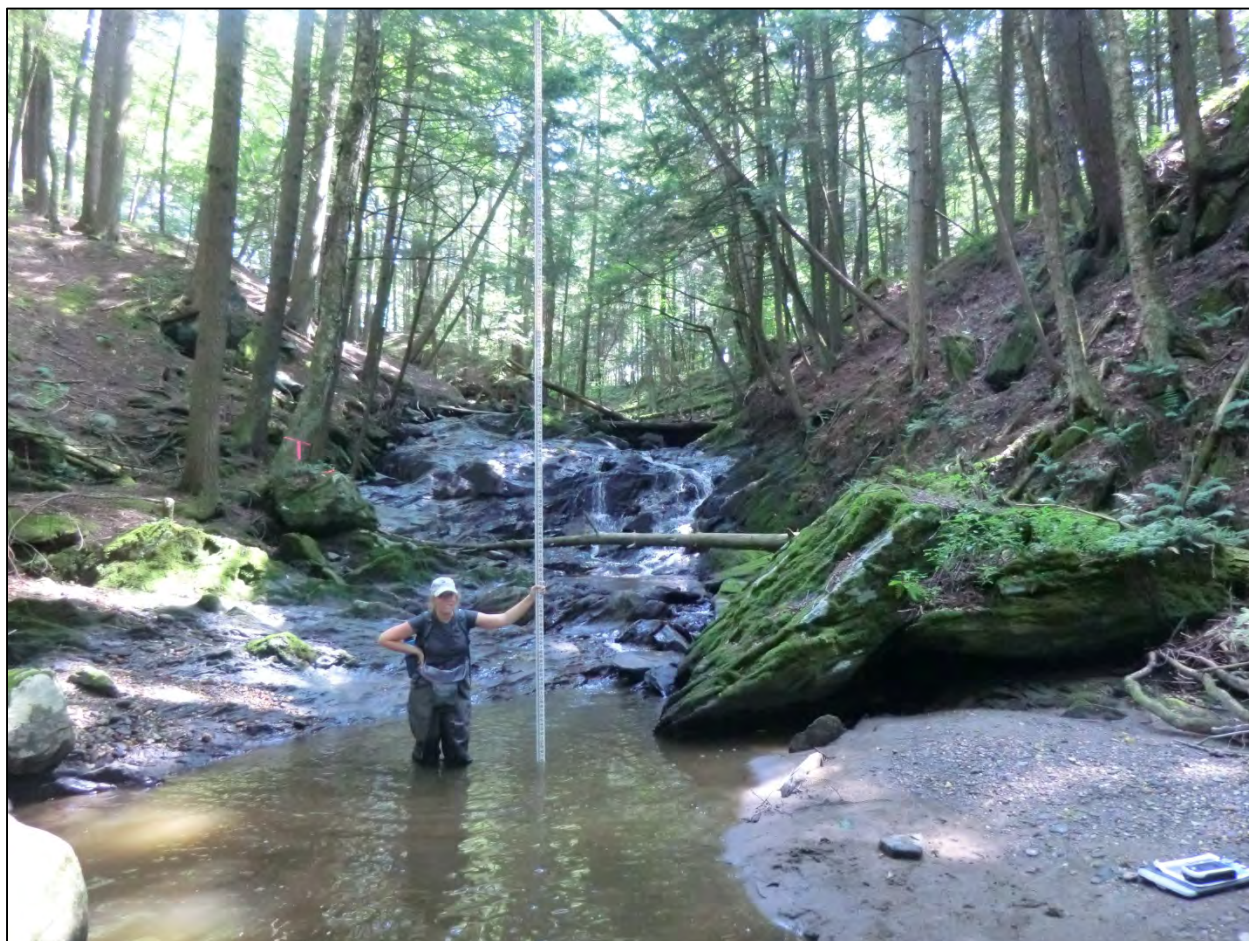


Figure 5.46. R13.S1.02-S1.02-S1.01-B is a bedrock gorge and was not fully assessed.

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.

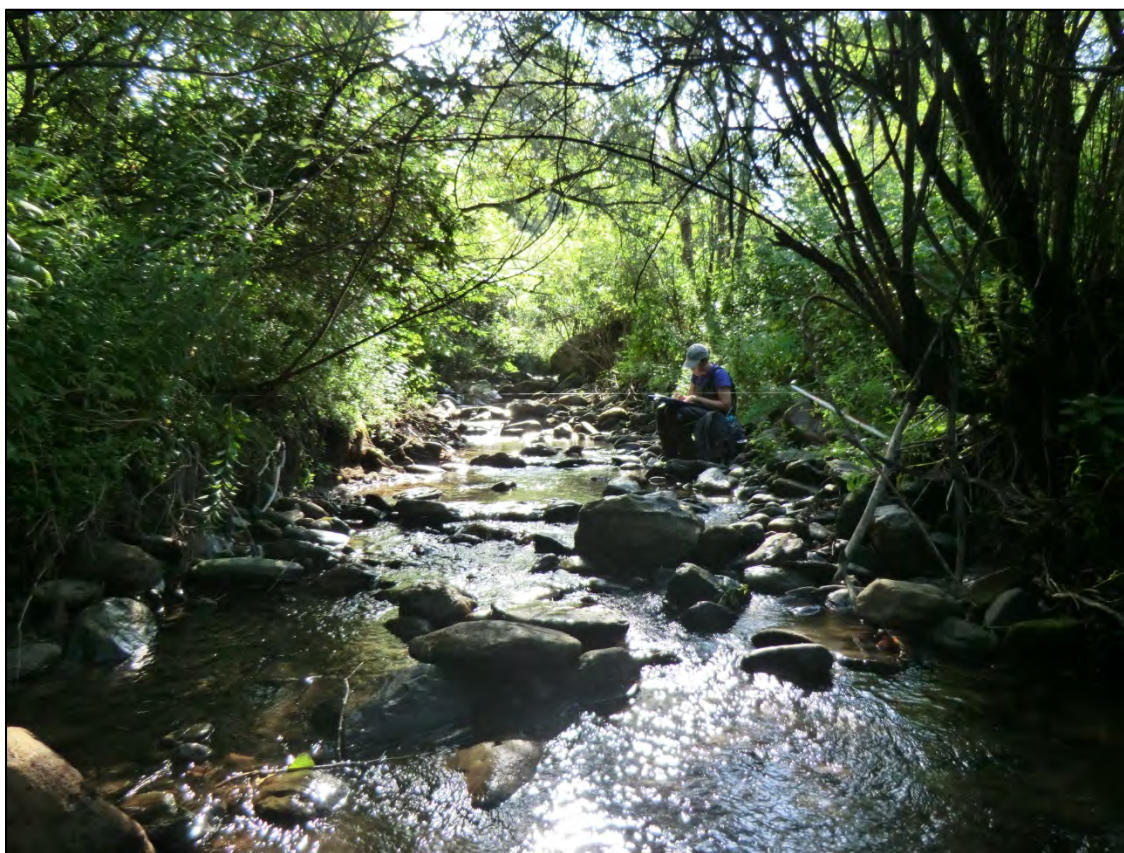


Figure 5.50. Segment F is a naturally narrow channel flowing through a shrubby wetland.

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.

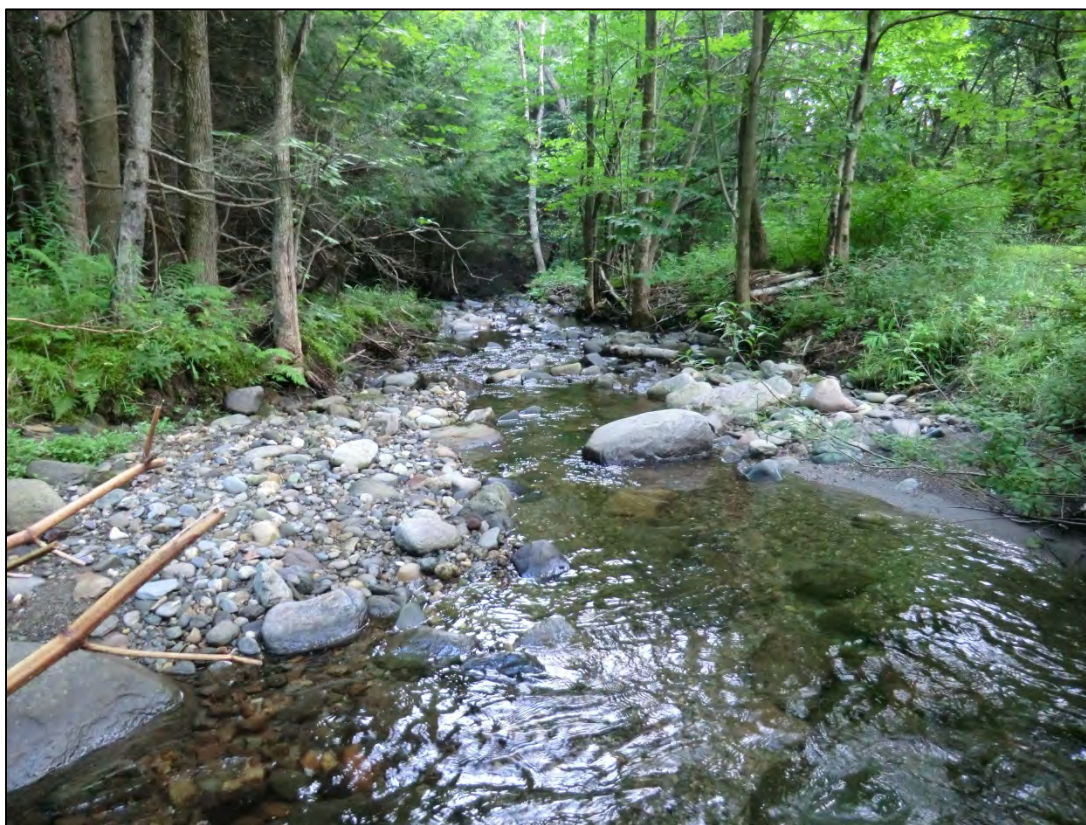


Figure 5.51. R13.S1.02-S1.02-S1.01-G flows through forested land and is stable and undisturbed.

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
Length: 1,162 ft Drainage Area: 2.3 sq. mi. Evolution Stage: F-I Sensitivity: High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	> 2.2	12.1
	Incision Ratio	< 1.2	1.0
	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.

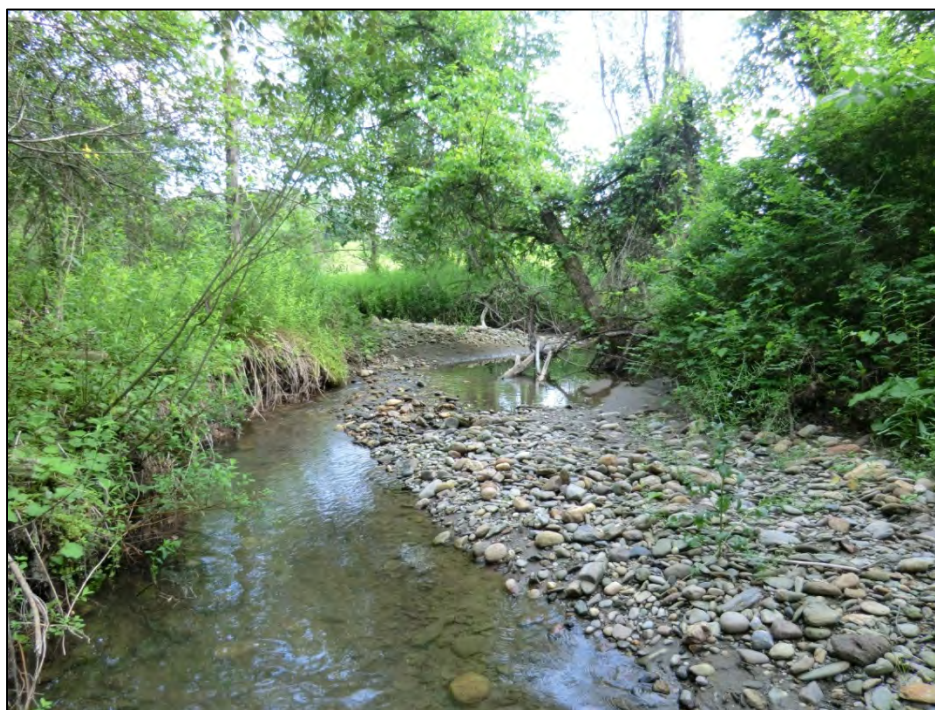


Figure 5.53. Aggradation is driving planform adjustment in R13.S1.02-S1.03-S1.01-B.

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.

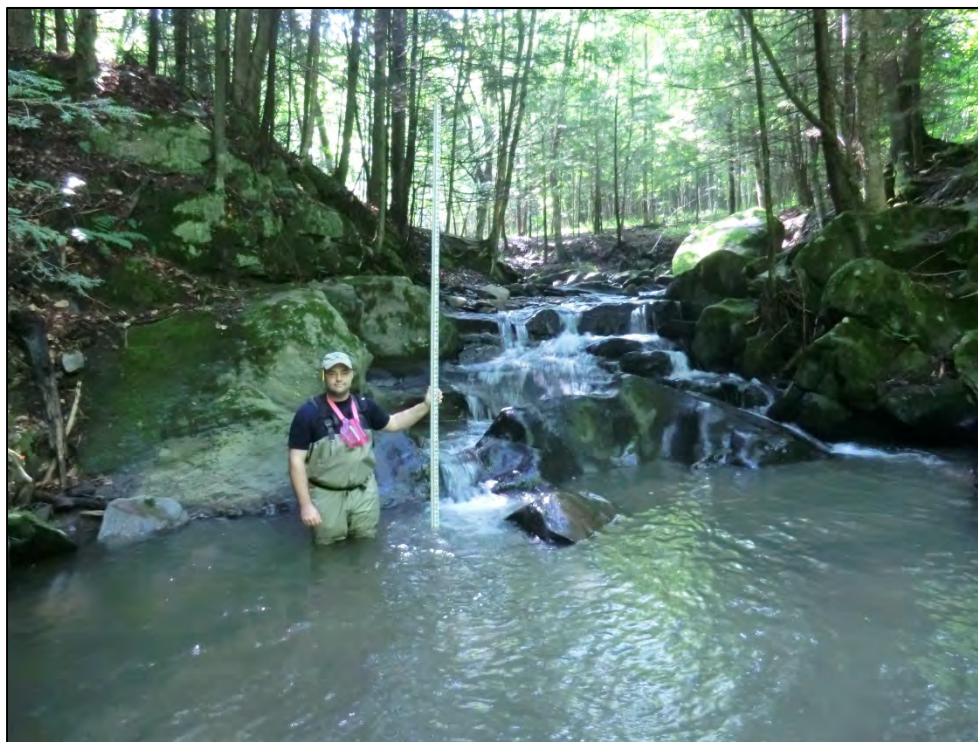


Figure 5.55. Bedrock outcrops are common in R13.S1.02-S1.03-S1.02-A and afford vertical stability to the channel.

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 Drainage Area: 1.8 sq. mi. Evolution Stage: F-II Sensitivity: High	Confinement	Very Broad	Very Broad
	Stream Type	C _b	C _b
	Entrenchment Ratio	> 2.2	5.0
	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
Length: 3,066 ft Drainage Area: 1.8 sq. mi. Evolution Stage: F-II Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C _b	B
	Entrenchment Ratio	> 2.2	1.9
	Incision Ratio	< 1.2	2.0
	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	<ul style="list-style-type: none"> ➤ 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	<ul style="list-style-type: none"> ➤ 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	<ul style="list-style-type: none"> ➤ 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	<ul style="list-style-type: none"> ➤ 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-Ottawquechee 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_apxgglossary.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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