Wardsboro Brook Watershed Corridor Plan

Wardsboro & Jamaica, Vermont

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1.0 EXECUTIVE SUMMARY

A stream geomorphic assessment of Wardsboro Brook was conducted by Bear Creek Environmental, LLC (BCE) under the direction of the Windham Regional Commission (WRC) and the Vermont Agency of Natural Resources (VANR) during the summer of 2013. 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 towns of Wardsboro and Jamaica experienced major flooding in August 2011 as a result of Tropical Storm Irene (TSI) and subsequent damage and destruction of infrastructure. As part of the long term plan to mitigate the impact of flooding, the Windham Regional Commission secured state funding to complete a Phase 2 stream geomorphic assessment of the Wardsboro Brook watershed. The stream geomorphic assessment data will be used to help focus stream restoration and protection activities within the watershed and assist the towns of Wardsboro and Jamaica with flood resiliency planning.

Wardsboro Brook and one tributary, Dover Brook, were divided into seven reaches for the assessment. The study encompassed approximately 11 miles of stream channel, and was helpful in identifying major stressors to geomorphic stability in the Wardsboro Brook watershed. The primary problems relating to geomorphic stability and habitat condition in the watershed are channel straightening and corridor encroachment associated with the existence of roads, and post flood channel management practices. Extensive windrowing and channel work post-TSI has exacerbated these issues and disconnected the brook from its floodplain in many areas. Encroachments and channel work have limited floodplain access and caused moderate to extreme channel degradation (lowering of the bed) resulting in sediment build up, channel widening, and planform adjustment (lateral movement). There are approximately 8.7 miles, or about 80 percent, of Warsdboro Brook in the study area, that run parallel to Route 100. In some places, the high road embankment is restricting floodplain access. Mass failures (i.e., landslides) are common along Wardsboro Brook and are contributing sediment and downed trees to the channel. In many places, post-Irene channel work, which often focused on excavating stream channels and creating berms, did more damage to the streams than the storm itself. TSI has emphasized the importance of adequately planning for emergency situations, as well as regulating post-emergency recovery efforts.

A list of 29 potential restoration and conservation projects was developed during project identification. Types of projects include: returning material that was excavated and piled on the bank (i.e., windrowing) to the channel, river corridor protection through easements, improving riparian buffers, bridge and culvert replacements, and arresting of headcuts. Detailed surveys for active restoration projects may be required at some point in the near future for project design and permitting.

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 Wardsboro Brook watershed in Wardsboro and Jamaica, Vermont. The main stem of Wardsboro Brook and Dover Brook were assessed using the Vermont Agency of Natural Resources Phase 2 Stream Geomorphic Assessment protocol during the summer of 2013 for a total of 10.8 river miles. The Vermont River Management 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 Wardsboro Brook watershed is comprised of Bear Creek Environmental (BCE), the Windham Regional Commission (WRC), the Connecticut River Watershed Council (CRWC), and the Vermont Agency of Natural Resources (VANR). The 2013 study was funded through The State of Vermont Ecosystem Restoration Program under contract to the Windham Regional Commission. Shannon Pytlik from the Vermont River Management Program of VANR provided a quality control/assurance review of the stream geomorphic assessment data.

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. The Windham Regional 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 r*estoration* and protection projects outlined in this corridor plan.

The Water Quality Management Plan (WQMP) for Basin 11 (West River, Williams River, and Saxtons River) (Vermont Agency of Natural Resources, 2008a) specifies the goal of proactively managing streams through identification and prioritization of stream restoration projects that will bring channels back to equilibrium conditions. Specifically, the WQMP includes recommendations to conduct Phase 2 geomorphic assessments in the Wardsboro Brook watershed. According to the Plan, two of the main impacts in this basin are thermal modification and sediment inputs to the streams as a result of human activities, such as river corridor encroachment. River corridor encroachments can lead to a lack of high quality *riparian buffers*, bank erosion, excessive sediment, flow alterations, and storm water runoff.

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 Wardsboro Brook 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 Rivers 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

Wardsboro Brook is a tributary to the West River, one of the major rivers in Vermont that drains into the Connecticut River (Figure 3.1). The 13.5-mile long stream drains approximately 35 square miles of land. Generally flowing from west to east, Wardsboro Brook originates in Stratton, Vermont, just south of Stratton Mountain, and flows through the towns of Wardsboro and Jamaica, Vermont where it empties into the West River. From its source in the *headwaters* of the Green Mountains, Wardsboro Brook flows southeast through confined areas in its valley in Stratton and to the valley floor in Wardsboro where it generally flows through a broad valley until it reaches the confluence of the West River. As the river flows from Stratton to the West River, Wardsboro Brook is influenced by several tributaries.

3.1.2 Political Jurisdictions

The Wardsboro Brook watershed is located in Windham County in the following towns:

- Town of Stratton
- Town of Wardsboro
- Town of Jamaica.

The 2013 Phase 2 assessments focused on the river channel and *riparian corridor* within these towns.

3.1.3 Land-Use

A land cover layer (2002) was obtained from the Vermont Center for Geographic Information (VCGI) to present land-use within the Wardsboro Brook watershed for the river corridor plan. The 2002 land cover data indicates that the watershed is 83% forested, 9% urban, and 3% agricultural (Figure 3.2). While the Wardsboro Brook watershed is dominated by forested land, developed and agricultural land are sub-dominant land-uses. Developed areas are concentrated along roads and in the vicinity of downtown Wardsboro (Wardsboro Center) and West Wardsboro.

3.2 Geologic Setting

The upper part of Wardsboro Brook originates in Stratton with a steep valley slope of 4.5%. As the stream drops out of the uplands and flows east, the slope decreases to a low gradient (1.5%) before the channel enters a steep, confined portion of the valley where the slope increases to 4.2%. When the brook enters the town of Wardsboro, the valley slope drops to a moderate gradient (1.5-2.5%), that persists over the stream's course through Jamaica to its confluence with the West River. The study area on Dover Brook above its confluence with Wardsboro Brook has a very steep slope of 5.5 percent.

The Wardsboro Brook watershed is located in the Green Mountain physiographic region, which is characterized by a large anticline or upfold that extends from southern to northern Vermont. The watershed is located primarily within the Green Mountain Massif (Somerset Reservoir Granite Formation), the Rowe Schist Formation, and the Hoosac Formation. The Green Mountain Massif, present in the western part of the watershed, is dominated by Precambrian metamorphic gneiss. Specifically, granite and augen gneiss are prevalent in this portion of the watershed. The Rowe Schist Formation and the Hoosac Formation were both formed during the Upper Precambrian and Lower Cambrian periods. Phyllite, schist, amphibolite, and gneiss are present in the Rowe Schist Formation within the Wardsboro Brook watershed. Amphibolite, schist, granofels, and greenstone comprise the majority of the Hoosac Formation in the study area (Bedrock Geologic Map of Vermont, USGS, 2011).

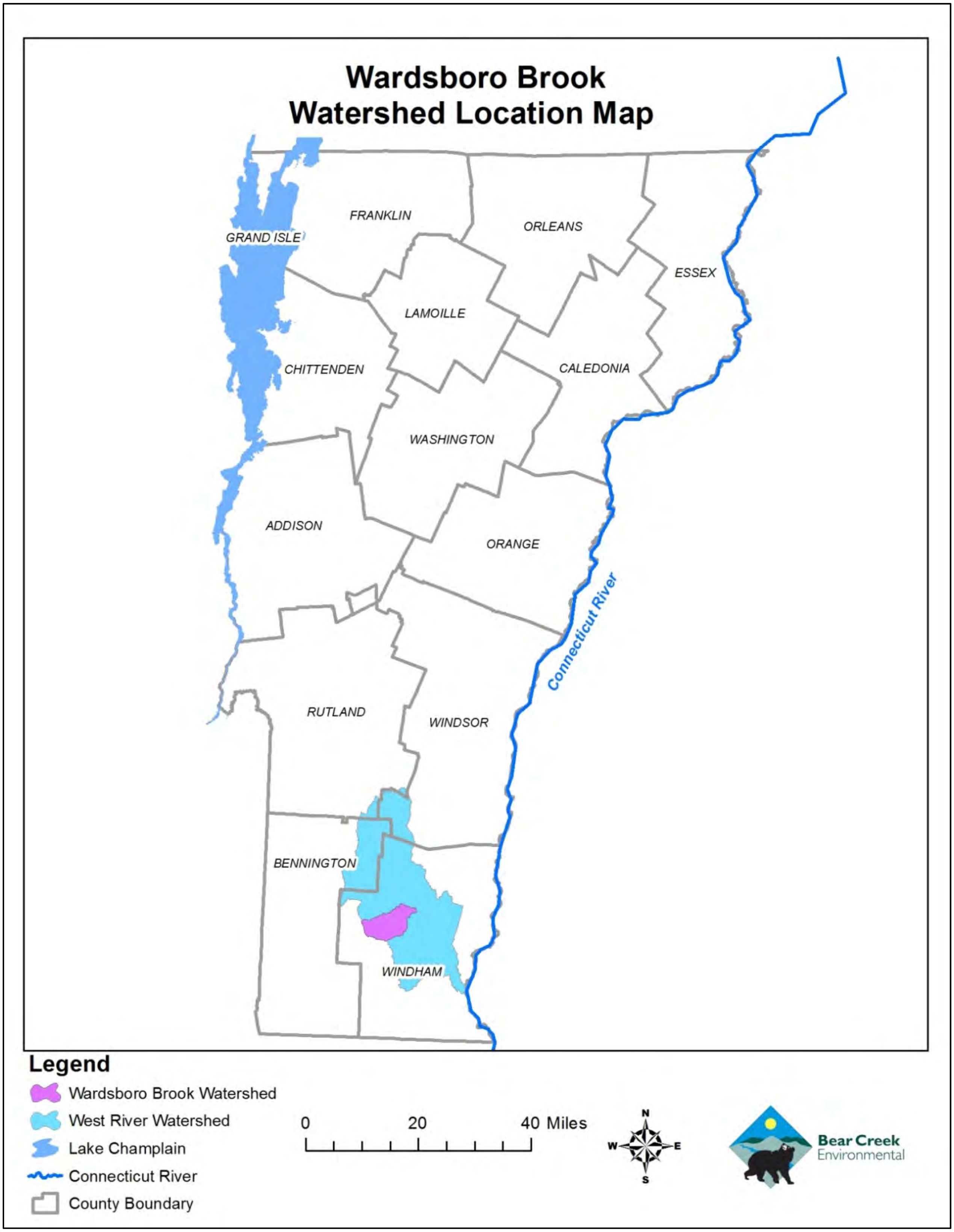

Figure 3.1. Watershed Location Map for Wardsboro Brook watershed.

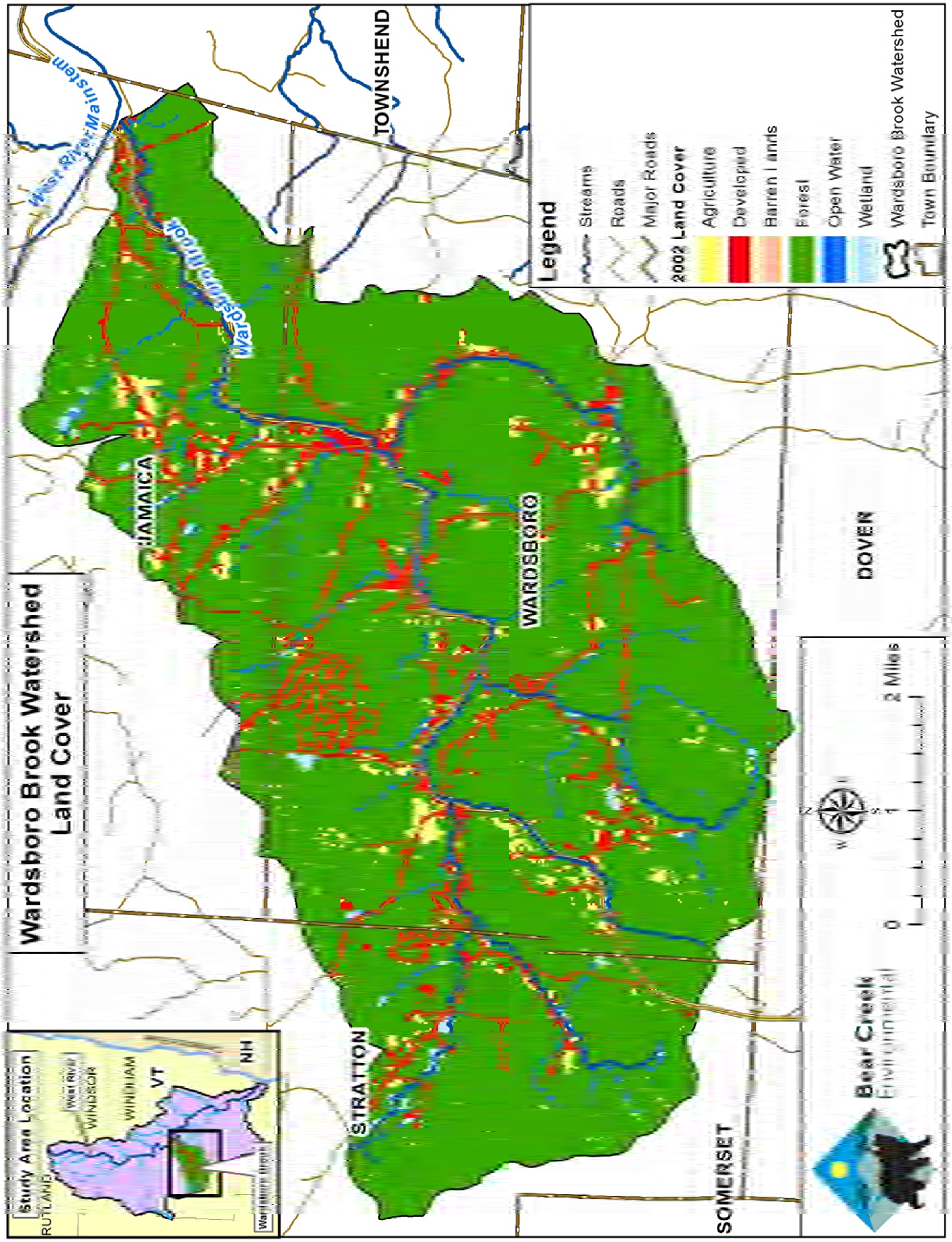

Figure 3.2. Land Cover Map for the Wardsboro Brook watershed.

3.3 Geomorphic Setting

A Phase 1 assessment of the Wardsboro Brook watershed was completed in 2007 as part of the West River study conducted by Michael Batcher, consultant to the Windham County Natural Resources Conservation District. The Phase 1 assessment included breaking the watershed into twenty-four *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. Each point in Figure 3.3 represents the downstream end of the reach. This report summarizes the 2013 Phase 2 study of Wardsboro Brook and one tributary (Dover Brook). The combined length of the seven stream reaches assessed during the Phase 2 study is approximately 11 miles (Figure 3.4).

3.4 Hydrology

In late August 0f 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 were damaged as a result of TSI, in addition to over 2000 segments of municipal roads. In total, approximately 500 bridges were damaged or destroyed, as well as almost 1,000 culverts. Approximately 1,500 residences were significantly damaged or destroyed as a result of flooding, as well as state, municipal, and commercial buildings (VANR 2012b). Wardsboro Brook was severely impacted by flooding from Tropical Storm Irene as well as instream channel work following the flood. In the Wardsboro Brook watershed, six bridges and five homes suffered significant damage or were completely destroyed as a result of high streamflows from Tropical Storm Irene (Windham Regional Commission 2013). Pages 1 and 2 in Appendix A show Irene-related damage within the study area. Studying the flood history of Wardsboro Brook can aid in the understanding of flood damage during TSI and possible flood risks for the future.

In order to better understand the flood history of Wardsboro Brook, long-term data from the U.S. Department of the Interior, U.S. Geological Survey (USGS), were obtained (USGS 2014). There are no USGS *gaging stations* in the Wardsboro Brook watershed, but peak flow data from two nearby stations were reviewed. The station on the Saxton's River at Saxton's River, Vermont has a drainage area of 72.2 square miles, and the station on a tributary to a West River tributary near Jamaica, Vermont has a drainage area of 0.9 square miles. The Wardsboro Brook watershed has a drainage area of 35.2 square miles. Although the drainage areas of these stations are different from that of Wardsboro Brook, their peak flow data shows the magnitude of difference in stream flows as a result of Tropical Storm Irene in August 2011. Figure 3.5 shows a map of the locations of these two stations in relation to the Wardsboro Brook watershed.

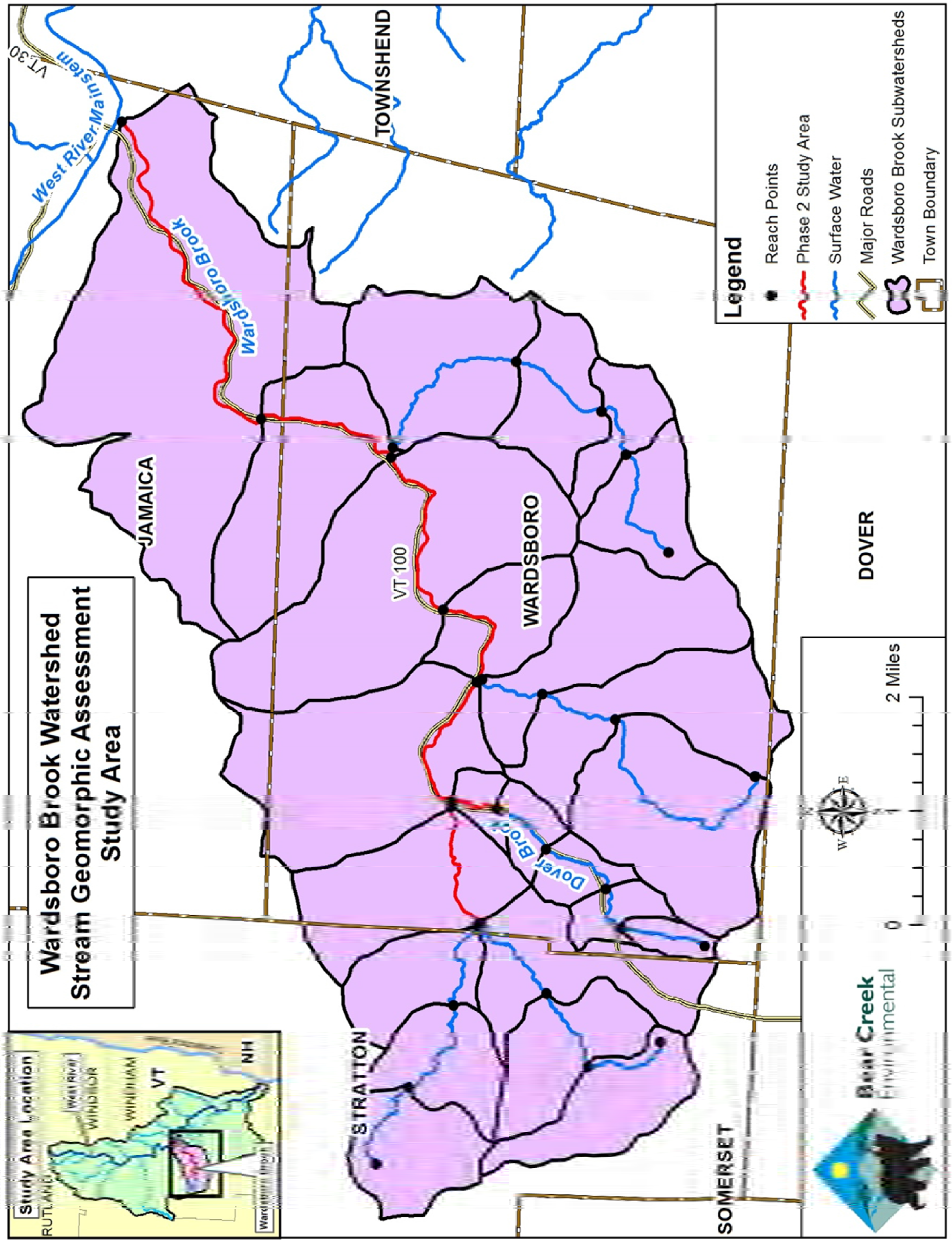

Figure 3.3. Wardsboro Brook Stream Geomorphic Assessment Study Area.

Reach Pt ID	Stream Name	Channel Length (miles)
T8.01	Wardsboro Brook	3.54
T8.02	Wardsboro Brook	1.34
T8.03	Wardsboro Brook	1.75
T8.04	Wardsboro Brook	1.02
T8.05	Wardsboro Brook	1.40
T8.06	Wardsboro Brook	1.28
T8.S3.01	Dover Brook	0.48
	Total Miles Assessed	**10.81**

Figure 3.4. Reach Location Map for Wardsboro Brook watershed.

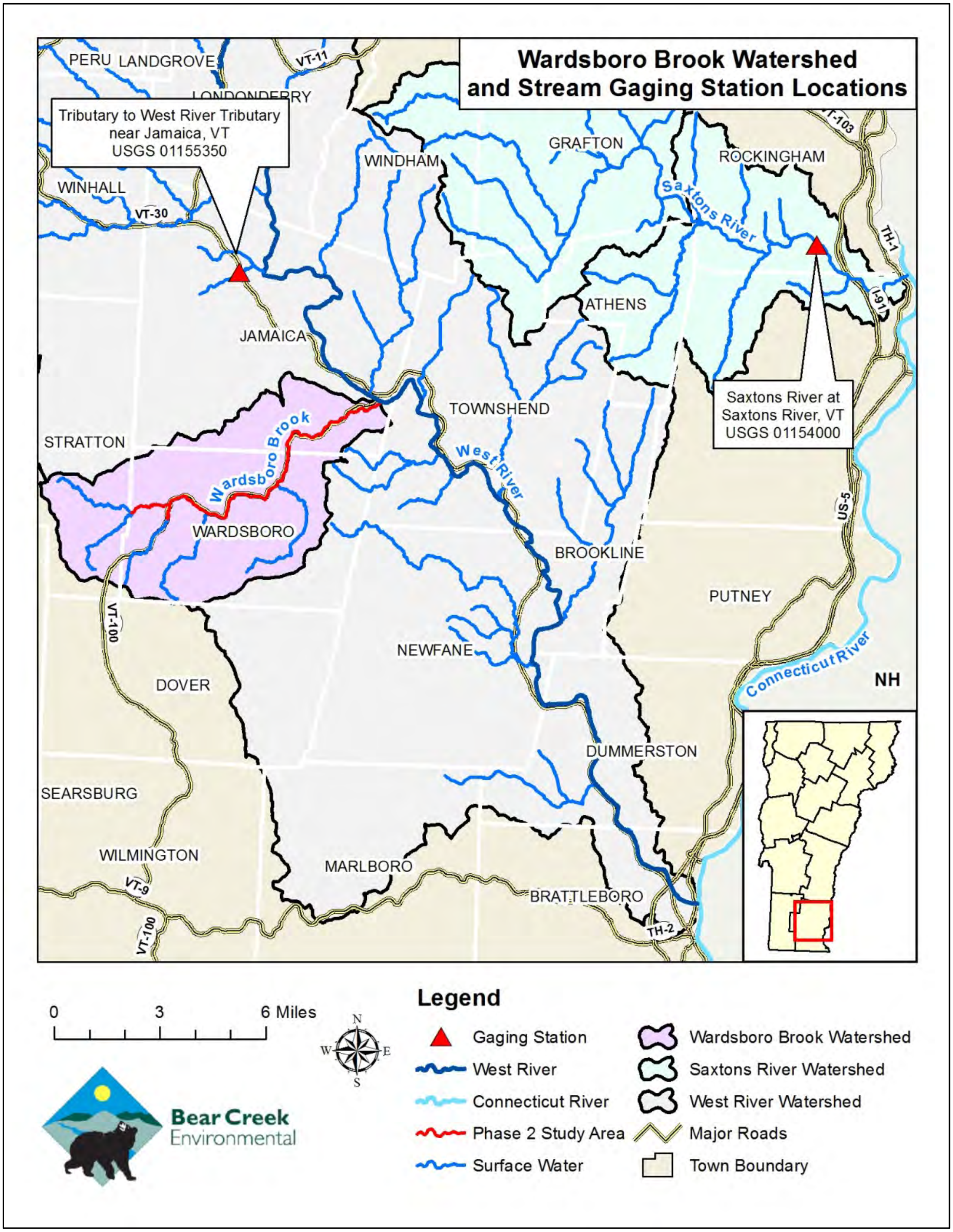

Figure 3.5. Gaging station locations in relation to study area.

Peak discharge records are available for the Tributary to the West River Tributary near Jamaica, Vermont from 1964 through 1978 and 1999 through 2012 (Figure 3.6) (USGS 2014). Flood events higher than the 50 year recurrence interval did not occur in this watershed from Tropical Storm Irene as they did in 1973. However in August of 2011, Tropical Storm Irene resulted in an increase of approximately five times the peak streamflow from the previous water year.

Peak discharge records are also available for the Saxtons River at Saxtons River, Vermont from 1941 through 1982 and 2002 through 2012 (Figure 3.7) (USGS 2014). Tropical Storm Irene resulted in peak streamflow higher than the 100 year recurrence interval, which approached the 500 year return interval. This peak streamflow value is the highest on record for the Saxtons River at Saxtons River, VT gaging station.

For Tropical Storm Irene, flood levels for many areas in Vermont equaled or approached the historic flood of 1927 (Vermont Agency of Natural Resources, 2012b). In the aftermath of TSI, emergency flood recovery work involved stream channel excavation where infrastructure damage occurred. Throughout central and southern Vermont, stream channels were dug out, and channel materials piled on the banks in a process known as *windrowing.* This and other channel work has largely degraded aquatic habitat in Wardsboro and Dover Brooks, and has created geomorphic instability that puts these stream channels at high risk of causing significant damage to infrastructure during large storms in the future.

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) attribute 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).

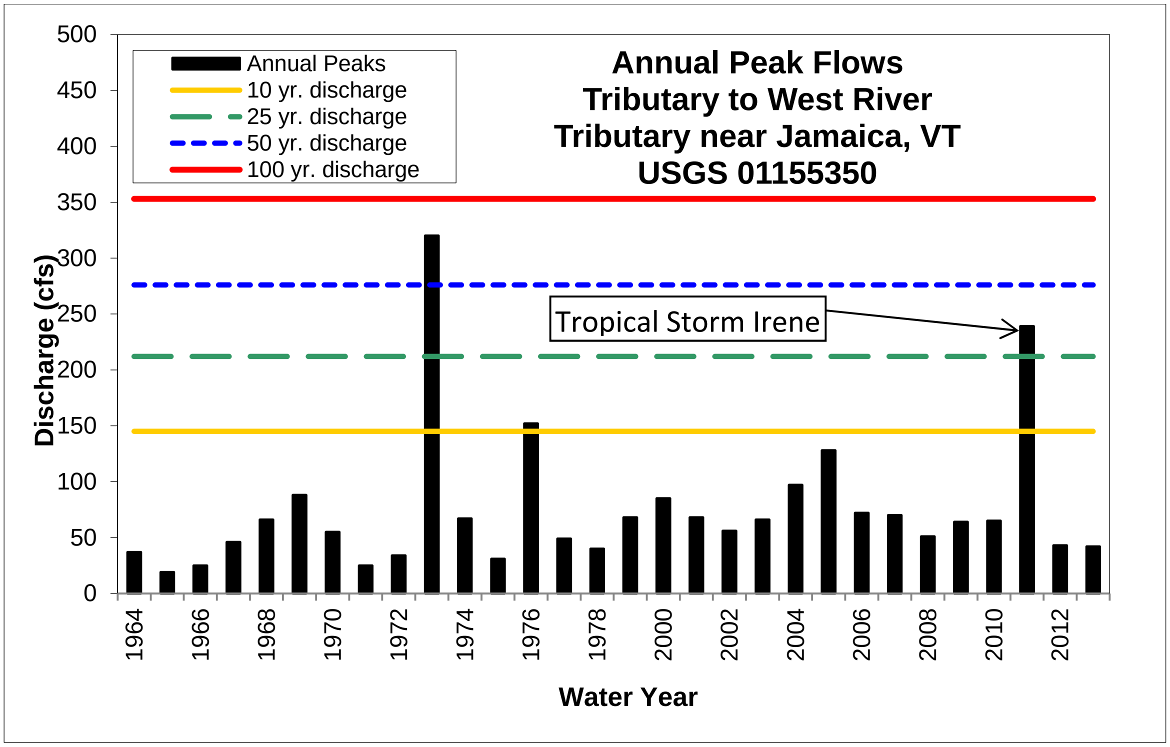

Figure 3.6. Annual Peak Flows for the Tributary to West River Tributary near Jamaica, Vermont.

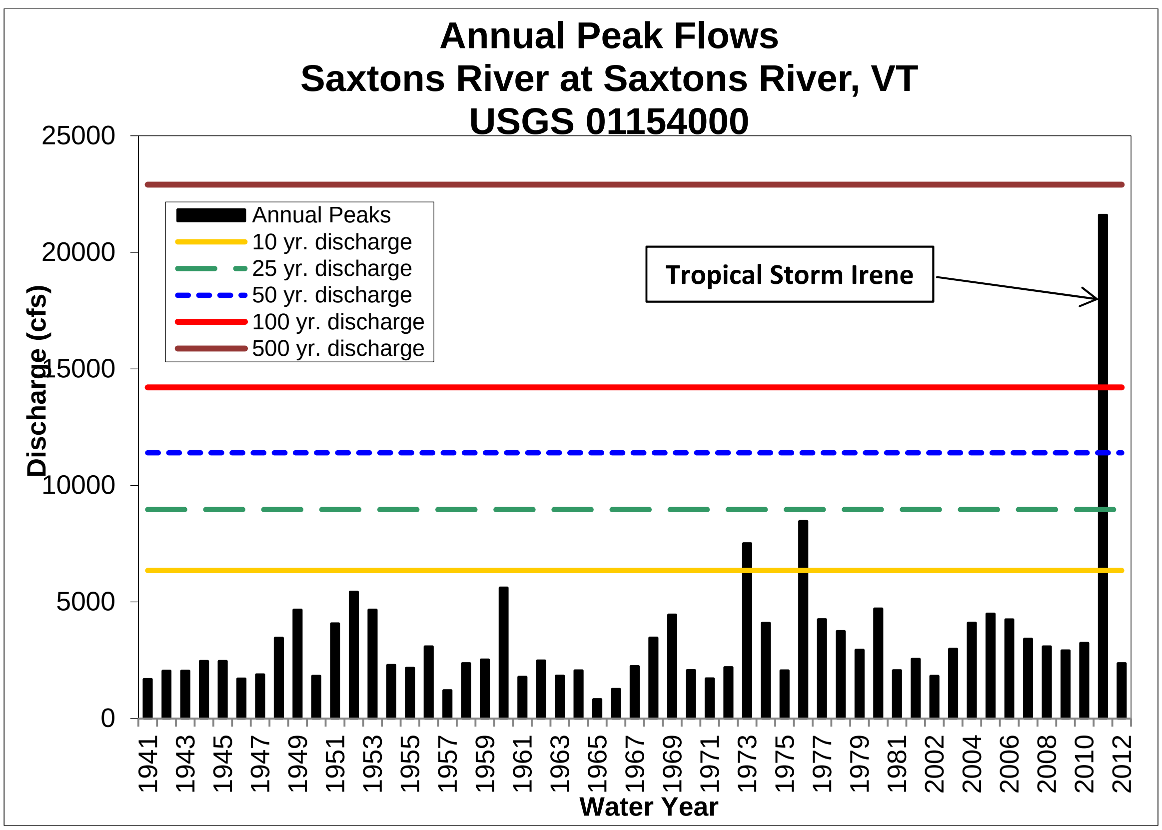

Figure 3.7. Annual Peak Flows for the Saxtons River at Saxtons River, Vermont.

3.5 Ecological Setting

The Wardsboro Brook watershed lies within the Southern Green Mountains biophysical region. This region is characterized by Thompson and Sorenson (2000) as being a combination of high peaks, high plateau, and steep cliffs on the western border while the eastern side is low foothills. The climate is cool during the summer months and the elevation leads to a high average annual precipitation (Thompson and Sorenson, 2000). The typical zonation of forests 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 Vermont Significant Wetland Inventory (VSWI) GIS layer provides important information about the distribution of wetland habitat within the Wardsboro Brook watershed (Appendix A, page 3). There are relatively few wetlands within the watershed according to the VSWI layer. The majority of these wetlands are located in the western section of the watershed, in the headwaters of Wardsboro Brook. According to Thompson and Sorenson (2000), the Southern Green Mountains contain excellent wildlife habitat. Mammals found here include black 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 Bicknell’s’ thrush (Thompson and Sorenson, 2000).

Deer wintering areas are present within the Wardsboro Brook watershed, especially in the northern portion of the watershed. These important wildlife areas abut reaches T8.01, T8.03, and T8.06. Green Mountain National Forest land is also present within the watershed, located in the most southern and western parts. The Wardsboro Town Forest is located along Tributary 1 to Wardsboro Brook. Core habitat, areas that are at least 100 meters from a zone of human disturbance, is abundant in the Wardsboro Brook watershed as shown on page 3 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, 2007), and used version 4.59 of the Stream Geomorphic Assessment Tool (SGAT). SGAT is an ArcView 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 of the Wardsboro Brook watershed followed procedures specified in the Vermont Stream Geomorphic Assessment (SGA) Phase 2 Handbook (Vermont Agency of Natural Resources, 2009b), and used version 10.0 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, 2008a; 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 BCE. These procedures involved a thorough in-house review of all data, which took place during January 2014. The Project Team conducted the assessment according to the approved Quality Assurance procedures specified in the Phase 2 handbook. Shannon Pytlik of the State of Vermont Watershed Management Division conducted a QA/QC review of the data collected by Bear Creek Environmental (BCE) for the Wardsboro Brook during March 2014.

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 VTANR 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 by BCE 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

One culvert was 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 culverts are scored using the screening tool. 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
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 assessed reaches in the Wardsboro Brook watershed. All reaches assessed for Phase 2 in the Wardsboro Brook 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. The reference confinement of the assessed portion of Wardsboro Brook and Dover Brook ranges from Very Broad to Broad on average. All reaches have a reference bedform of *riffle-pool*. The reference reach characteristics were refined during the Phase 2 Assessment.

During the Phase 2 assessment, the seven assessed reaches were broken into 16 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. (Figures 5.1 and 5.2). The existing stream type is based on channel dimensions measured during the Phase 2 assessment. A map of the reference and existing stream type for each assessed reach/segment is included on page 4 of Appendix A.

Some of the segments in the 2013 assessment have the same reference and existing stream type. However, the existing stream type differs from the reference stream type in twelve of the 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 which 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 2013 Assessed Reaches					
Stream	**Reach ID**	**Reference Stream Type**	**Reference Confinement**	**Valley Slope (%)**	**Bedform**
Wardsboro Brook	T8.01	C	Broad	2.0	Riffle-Pool
	T8.02	C	Broad	1.6	Riffle-Pool
	T8.03	C	Very Broad	1.7	Riffle-Pool
	T8.04	C	Very Broad	1.7	Riffle-Pool
	T8.05	C	Very Broad	2.4	Riffle-Pool
	T8.06	C	Very Broad	2.0	Riffle-Pool
Dover Brook	T8.S3.01	C	Very Broad	5.6	Riffle-Pool

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

A map of the existing geomorphic condition for each segment is depicted on page 5 of 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 Wardsboro Brook watershed, nine of sixteen segments are in "poor" geomorphic condition and seven are in "fair" condition. None of the assessment reaches are in "good" or "reference" condition. The current geomorphic conditions are a result of several factors. Following Tropical Storm Irene, many streams within the Wardsboro Brook watershed were windrowed and their channels excavated to protect infrastructure from future flooding. This windrowing, in combination with other factors such as corridor encroachments, has caused Wardsboro and Dover Brooks to lose access to the majority of their floodplains. Corridor encroachments within the watershed are also causing changes in valley type. Mass failures, erosion, and aggradation were all exacerbated by TSI, and are contributing to the unstable geomorphic condition of many assessment reaches.

Figure 5.1. Reach and segment locations for the Wardsboro Brook watershed in Jamaica and Wardsboro, Vermont.

Figure 5.2. Reach and segment locations for the Wardsboro Brook watershed in Wardsboro, Vermont.

5.1.3 Habitat Condition

The habitat condition for each segment within the Wardsboro 2013 study area is presented on page 5 of Appendix A. Two segments in the study are in "good" habitat condition and are located in an area where the brook flows away from Rt. 100 and into forested areas (T8.01-B and T8.06-B). 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. Fourteen segments are in "fair" habitat condition (T8.01-A, T8.01-C, T8.01-D, T8.02-A, T8.02-B, T8.02-C, T8.03, T8.04, T8.05-A, T8.05-B, T8.05-C, T8.06-A, T8.06-C, and T8.S3.01). Segments are in "fair" habitat condition mainly as a result of corridor encroachments, poor bank and buffer vegetation, erosion and revetments, channel straightening, and windrowing. Many of the segments in "fair" habitat condition exhibit a habitat stream type departure to a *plane bed*, featureless channel.

The map on page 5 in Appendix A includes both the geomorphic and habitat condition maps side by side. Overall, the habitat and geomorphic conditions were similar, implying that the ecological health of the Wardsboro Brook watershed is related to the geomorphic condition of the stream.

As shown in Table 1 (Appendix A, pages 8 through 9), many of the segments have high width to depth ratios. This can be attributed to the geomorphic process of channel widening. The aggradation as a result of the increased flows from TSI in 2011 has likely led to the high width to depth ratios observed in the assessed reaches. 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. Also, the widespread channel excavation that occurred in the Wardsboro Brook watershed post-TSI has created very incised, largely featureless channels.

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 Wardsboro Brook watershed include:

- Channelization and bank armoring
- Removal of woody riparian vegetation
- Floodplain encroachments
- Post-Irene channel work

These anthropogenic practices have altered the balance between water and sediment discharges within the Wardsboro Brook 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. A sediment regime map depicting the reference and existing sediment regimes can be found on page 6 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).

Of the 16 assessed segments, 14 of the segments have a reference sediment regime of Coarse Equilibrium & Fine Deposition (*Equilibrium*). *Equilibrium* channels are unconfined on at least one side, and they transport and deposit sediment in equilibrium, wherein the stream power is balanced by the sediment load, sediment size, and boundary resistance. Two segments have transport as their dominant reference sediment regime. *Transport* channels are typically in confined valleys, and do not supply appreciable quantities of sediment to downstream reaches. These channels have confining valley walls with limited sediment storage capacity due to both channel slope and entrenchment (Vermont Agency of Natural Resources, 2010a).

Changes in hydrology (such as development and agriculture within the riparian corridor) and sediment storage within the watershed have altered the reference sediment regime types for many segments in the Wardsboro Brook watershed. The majority of the segments have undergone a transformation from a reference sediment regime of Coarse Equilibrium & Fine Transport or Transport to a departure sediment regime (Appendix A, page 6). Tropical Storm Irene, as well as post-flood channel work, further altered the sediment regimes in the study reaches. 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 these anthropogenic practices and changes in sediment regimes 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 Wardsboro Brook watershed. In many areas, the placement of VT Route 100 has significantly changed the river's valley width, floodplain access, and its ability to meander. The floods that came through the area during TSI in August, 2011 have resulted in significant aggradation and planform change, which has been exacerbated by post-TSI channel excavation and widespread windrowing.

The reach condition ratings of the Wardsboro Brook watershed indicate that most of the reaches/segments are actively or have historically undergone a process of major geomorphic adjustment. Many of the reaches studied in the Wardsboro Brook watershed are undergoing a channel evolution process in response to large scale changes in its sediment, slope, and/or discharge associated with the human influences on the watershed and impacts from flooding.

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 Wardsboro Brook watershed. The "F" stage channel evolution model 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 5.2 include:

- Stable (F-1) - a pre-disturbance period
- Incision (F-II) – channel degradation (head cutting)
- 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

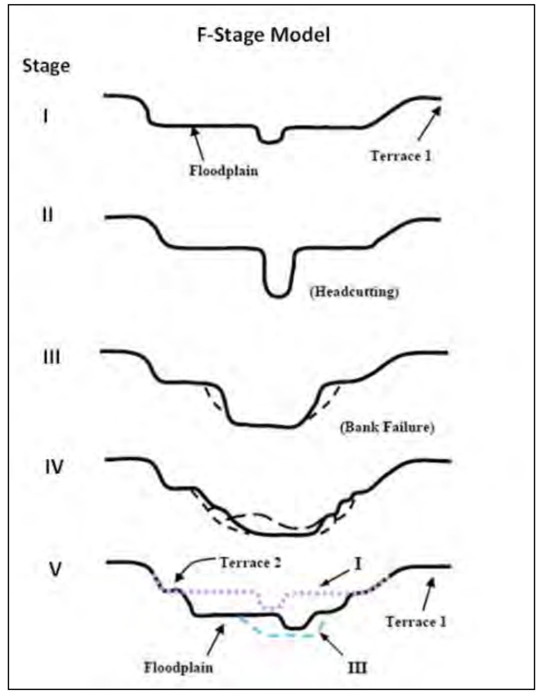

Figure 5.3 Typical channel evolution models for F-Stage (Vermont Agency of Natural Resources, 2009b)

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.

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 8 through 9 of Appendix A. In terms of the channel evolution model, none of the assessed segments are in stage I of the "F-stage" channel evolution model, indicating that all segments have undergone a channel incision process. One segment (T8.05-C) is in stage II of the "F-stage" channel evolution model. It has lost floodplain access due to straightening and windrowing, and may stay locked into stage II due to extensive revetments and corridor encroachments.

Nine of sixteen segments are in stage III of the "F-stage" channel evolution model. Most of these segments have undergone severe historic incision. The placement of VT Route 100 likely led to this incision and the subsequent loss of floodplain access, which has been exacerbated by TSI and post-TSI channel work. In stage F-III, the entrenched channel begins to widen and migrate laterally through bank erosion caused by the increased stream power.

Six 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 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.

5.1.6 Stream Sensitivity

A stream sensitivity rating was determined based on existing stream type, dominant sediment size, and geomorphic condition. Stream sensitivity ratings help identify the likelihood that a segment will undergo vertical and lateral adjustments driven by natural or human-induced fluvial processes (ANR, 2010a). The sensitivity ratings are as follows: Very Low, Low, Moderate, High, Very High, and Extreme. All assessed reaches in the Wardsboro Brook watershed had a minimum sensitivity of High because most segments are undergoing major or extreme channel adjustments. Eight segments are assigned a rating of Extreme, four are Very High, and four are High. A map showing stream sensitivities is found on page 7 of Appendix A.

5.2 Reach/Segment Descriptions

A description of each segment is provided in this section along with a list of recommendations for restoration and protection strategies. The segments are listed from downstream to upstream. 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/dataEntry.aspx?pid=120.

Proposed project locations are provided on maps on in Appendix C. Further recommended project detail tables and photos are also provided 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.

Wardsboro Brook

T8.01

The most downstream reach on Wardsboro Brook was split into four segments to account for changes in channel dimensions and planform. The reference confinement is broad as the river valley opens up to the West River valley. Two segments, B and D, have semi-confined river valleys by reference, and one segment, C, has been converted from a broad valley to a narrow valley due to human influences such as the placement of Rt. 100.

T8.01A

This segment begins at the confluence with the West River and continues approximately 900 feet upstream until the valley narrows. This segment is an *alluvial fan*, where the channel slope drops and the valley opens up as Wardsboro Brook meets the West River. Floodplain access is limited throughout the segment and bedform has been lost. A riffle-pool channel by reference has been converted to featureless plane-bed channel in this segment, as seen in Figure 5.4. This segment is in **fair** geomorphic condition, with major historic degradation, major recent widening, and significant bar formation. The segment is also in **fair** habitat condition due to lack of diverse habitat features and floodplain access, as well as impacted buffers. There is one stream crossing in this segment (Eaton Road), but it is not a channel constriction.

Figure 5.4. Lack of riffle-pool bedform and habitat features in T8.01A.

T8.01-A Data Summary		Reference	Existing
Length: 905 ft Drainage Area: 35 sq. mi. Evolution Stage: F-III Sensitivity: Very High	Confinement	Broad	Broad
	Stream Type	C	F
	Entrenchment Ratio	> 2.2	1.1
	Incision Ratio	< 1.2	2.2
	Dominant Bed Material	Cobble	Gravel
	Dominant Bedform	Riffle-Pool	Plane Bed
Major Stressors:	**Bank Erosion, Poor Bank Vegetation, Invasive Plants, Revetments**		

T8.01-B

This segment begins where the valley becomes more confined and continues upstream for a half mile until the valley opens up again. It is characterized by a semi-confined valley and a step-pool bed form. At the upstream end of the segment, the brook was straightened along Old Route 8, which led to a loss of bedform and conversion to a plane bed channel in this area. Overall, this segment retains a variety of habitat features, including large pools, refuge areas, undercut banks, and forested buffers. However, erosion and mass failures are common throughout the segment, and are contributing sediment to the brook. This segment is in stage F-IV of the evolution process, and is building a juvenile floodplain through large bar formation. This aggradation and change in channel planform places the segment in **fair** geomorphic condition. This segment is in **good** habitat condition due to its step-pool bedform, refuge areas, undercut banks, and riparian buffers, some of which are shown in Figure 5.5.

Figure 5.5. Good habitat features characteristic of segment.

T8.01-B Data Summary		Reference	Existing
Length: 2,670 ft Drainage Area: 35 sq. mi. Evolution Stage: F-IV Sensitivity: High	Confinement	Semi-confined	Semi-confined
	Stream Type	B	B
	Entrenchment Ratio	1.4 – 2.2	2.0
	Incision Ratio	< 1.2	1.3
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Step-Pool	Step-Pool
Major Stressors:	**Bank Erosion, Channel Straightening, Revetments, Encroachments**		

T8.01-C

This segment begins where the valley opens up and continues upstream about 2.5 miles until the valley narrows again. It is characterized by extreme historic incision, which has led to a stream type departure, and has resulted in a loss of floodplain access throughout the segment. In this area, the brook was significantly impacted by TSI and post-flood channel work. Erosion is prevalent along both banks throughout the segment, and mass failures, which were likely caused or exacerbated by TSI, are frequent along the north bank. This portion of the brook runs along Rt. 100 S and the channel has been straightened and armored along the road. Windrowing and dredging are present in this segment, particularly in areas where the brook is close to the road. Due to these channel alterations, corridor encroachments, and loss of riparian buffer, this segment was placed in **fair** habitat condition. The channel has undergone extreme widening, and is in active planform adjustment, as evidenced by continuous erosion, mass failures, and large flood chutes behind very large bars. Due to these factors, this segment is in **poor** geomorphic condition. An example of the frequent mass failures present in this segment is shown in Figure 5.6.

Figure 5.6. One of many mass failures present in this segment.

T8.01-C Data Summary		Reference	Existing
Length: 13,216ft Drainage Area: 35 sq. mi. Evolution Stage: F-IV Sensitivity: Extreme	Confinement	Broad	Narrow
	Stream Type	C	F
	Entrenchment Ratio	> 2.2	1.1
	Incision Ratio	< 1.2	2.4
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Riffle-Pool	Riffle Pool
Major Stressors:	**Erosion, Mass Failures, Windrowing, Encroachments, Channel Straightening, Revetments, Poor Buffers**		

T8.01-D

This segment begins where the valley becomes more confined and continues upstream for 1,900 feet to the reach break. The river valley in T8.01-D is semi-confined and the stream channel has undergone major historic and recent degradation. Over half of the reach was straightened along Rt. 100 during its construction. There are two active headcuts present within the segment, as well as some bank armoring and erosion. The brook is currently building a juvenile floodplain as evidenced by very large bars throughout the segment. Planform change is minor in the segment at this time, placing it in **fair** geomorphic condition. T8.01-D is also in **fair** habitat condition due to a lack of large woody debris (LWD) and poor buffers.

Figure 5.7. Very large bars are forming a juvenile floodplain in T8.01-D.

T8.01-D Data Summary		**Reference**	**Existing**
Length: 1,900ft Drainage Area: 35 sq. mi. Evolution Stage: F-IV 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	2.3
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Riffle-Pool	Riffle Pool
Major Stressors:	**Channel Straightening, Encroachments, Headcuts, Erosion, Revetments, Poor Buffers, Invasive Plants**		

T8.02

This reach was split into three segments to account for changes in confinement and existing stream types. Rt. 100 significantly impacts valley confinement in this reach and recent windrowing is present throughout.

T8.02-A

The most downstream segment in T8.02 begins immediately downstream of the Rt. 100 bridge near Pot Luck Lane and continues upstream for almost 2,000 feet to where the stream channel becomes more entrenched. This segment has extensive straightening with windrowing along Rt. 100. The channel historically incised due to the road encroachment. Despite this straightening and channel excavation, the channel has widened significantly and is undergoing major aggradation. This aggradation is developing into a juvenile floodplain. Due to these major and extreme geomorphic processes that are occurring in T8.02-A, the segment is in **poor** geomorphic condition. The segment lacks large woody debris, refuge areas, and undisturbed riparian buffers, placing it in **fair** habitat condition.

Figure 5.8. Large bar characteristic of T8.02-A.

T8.02-A Data Summary		Reference	Existing
	Confinement	Broad	Narrow
Length: 1,900 ft	Stream Type	C	B_C
Drainage Area: 29 sq. mi.	Entrenchment Ratio	> 2.2	1.5
Evolution Stage: F-IV	Incision Ratio	< 1.2	1.9
Sensitivity: High	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Channel Straightening, Windrowing, Encroachments, Invasive Plants**		

T8.02-B
This segment begins just downstream of the intersection of Rt. 100 with Peters Road and ends just upstream of the South Wardsboro Road stream crossing. The valley is broad and has been altered due to the presence of Rt. 100. The segment overall has a riffle-pool bedform, but plane bed is sub dominant where the stream has been straightened along the road. Rip rap is common along the north bank on Rt. 100 road embankments. Historic incision has resulted in a loss of floodplain and a stream type departure. One potential active headcut is present in the segment, and the stream may continue to incise. The stream channel is actively widening. Due to these factors, segment T8.02-B is in **poor** geomorphic condition. Because of the loss of bedform within straightened sections of the segment and the majorly impacted riparian buffer, the segment is in **fair** habitat condition.

Figure 5.9. Impacted buffer where segment T8.02-B has been straightened along Rt. 100.

T8.02-B Data Summary		Reference	Existing
Length: 3,630 ft	Confinement	Very Broad	Broad
Drainage Area: 29 sq. mi.	Stream Type	C	F
Evolution Stage: F-III	Entrenchment Ratio	> 2.2	1.1
Sensitivity: Extreme	Incision Ratio	< 1.2	2.2
	Dominant Bed Material	Cobble	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Encroachments, Channel Straightening, Revetments, Erosion, Headcut, Poor Buffers**		

T8.02-C

This segment begins just upstream of the South Wardsboro Road bridge where the valley walls open and continues upstream to Mitch Avenue. In this segment, the valley is broad, but a stream type departure has occurred, creating a plane bed channel with limited floodplain access. The entire segment has been straightened and windrowed, and revetments and Japanese knotweed are abundant. The riparian buffers are impacted throughout the segment. Due to all of the aforementioned factors, this segment is in **fair** habitat condition. Historic straightening along Rt. 100 has led to historic incision, and recent windrowing has furthered this channel degradation. The channel has widened toward the bottom of the segment and is beginning to form a juvenile floodplain. Overall, the segment is in **poor** geomorphic condition.

Figure 5.10. Location of three buyouts in T8.02-C

T8.02-C Data Summary		**Reference**	**Existing**
Length: 1,525 ft Drainage Area: 29 sq. mi. Evolution Stage: F-III Sensitivity: Extreme	Confinement	Broad	Broad
	Stream Type	C	F
	Entrenchment Ratio	> 2.2	1.3
	Incision Ratio	< 1.2	2.8
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Riffle-Pool	Plane Bed
Major Stressors:	**Windrowing, Channel Straightening, Revetments, Encroachments, Invasive Plants**		

T8.03

This reach was not split into any segments. T8.03 has a very broad valley by reference, however due to the encroachment of Rt. 100, the existing channel confinement is broad. T8.03 begins where Mitch Avenue enters the river corridor, and continues upstream approximately 9,200 feet where it ends between the Gilfeather Road and Lower Podunk Road stream crossings. Over 75% of this reach has been straightened and windrowed, creating a featureless, plane bed stream channel. Major historic incision led to a stream type departure, and current bed degradation is evidenced by the presence of a headcut in this reach. Massive bars are present, which are likely a result of aggradation that occurred during TSI. Large flood chutes and a channel avulsion were also formed during TSI as the brook underwent major planform adjustment. Erosion is common along the south bank and rip rap along the north. Two large mass failures are present along the south bank. Post-TSI flood work appears to have been aimed at repositioning the stream within its significantly widened channel. This reach is highly geomorphically unstable, resulting in its **poor** geomorphic condition. The reach also has very few features that create good aquatic habitat, so it has been placed in the **fair** category for habitat condition.

Figure 5.11. Post-TSI channel work to reposition flow in an over-widened channel.

T8.03 Data Summary		**Reference**	**Existing**
Length: 9,231 ft Drainage Area: 23 sq. mi. Evolution Stage: F-III Sensitivity: Extreme	Confinement	Very Broad	Broad
	Stream Type	C	F
	Entrenchment Ratio	> 2.2	1.3
	Incision Ratio	< 1.2	1.7
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Riffle-Pool	Plane Bed
Major Stressors:	**Channel Straightening, Windrowing, Encroachments, Headcut, Poor Buffers, Erosion, Revetments, Mass Failures, Stormwater Inputs**		

T8.04

This reach was not split into any segments during assessment. T8.04 begins approximately 3,000 feet upstream of the Gilfeather Road stream crossing and continues just over one mile upstream to where Waite Brook enters Wardsboro Brook just above Lower Podunk Road. This reach has a very broad valley by reference, but Rt. 100 has caused a change in confinement to a narrow valley. The stream in this reach was historically straightened along the road and incised. Recent and historic channel straightening spans over half of the reach, of which a large portion was windrowed post-TSI. This has contributed to a loss of bedform and conversion from riffle-pool to plane bed. Rip rap is common along Rt. 100 on the north bank and erosion on the south bank. There are two headcuts in this reach and one channel avulsion that likely occurred during TSI. Due to the aggradation and planform adjustment that occurred during TSI and is continuing to occur, this reach is in **poor** geomorphic condition. The loss of bedform that has occurred in this reach has also created **fair** habitat conditions.

Figure 5.12. Channel avulsion with active headcut and erosion.

T8.04 Data Summary		**Reference**	**Existing**
Length: 5,411 ft Drainage Area: 19 sq. mi. Evolution Stage: F-III Sensitivity: Extreme	Confinement	Broad	Narrow
	Stream Type	C	F
	Entrenchment Ratio	> 2.2	1.2
	Incision Ratio	< 1.2	3.2
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Riffle-Pool	Plane Bed
Major Stressors:	**Channel Straightening, Windrowing, Headcuts, Encroachments, Revetments, Poor Buffers, Erosion, Invasive Plants**		

T8.05

This reach was split into three segments during the assessment to account for differences in channel dimensions, planform, corridor encroachment, and depositional features.

T8.05-A

The downstream-most segment begins just upstream of the Lower Podunk Road stream crossing and continues upstream for almost 2,500 feet to where the stream is no longer straightened along Rt. 100. This segment is characterized by major historic and recent incision due partly to a large sediment plug immediately upstream, creating a sediment starved segment. A headcut is present at the top of this segment below the sediment plug. Bank erosion is abundant throughout T8-05A, which is causing many trees to fall into the stream, providing large woody debris. A small amount of windrowing occurred around a house in this segment, but overall, channel straightening has not been significant. There are no revetments present in this segment, but due to flood damage during Irene, it is in **poor** geomorphic condition. The segment is in **fair** habitat condition due to the instability of its banks and flood-damaged channel morphology.

Figure 5.13. Headcut below sediment plug and high stream banks in T8.05-A.

T8.05-A Data Summary		**Reference**	**Existing**
	Confinement	Very Broad	Broad
Length: 2,440 ft	Stream Type	C_b	B
Drainage Area: 12 sq. mi.	Entrenchment Ratio	> 2.2	1.7
Evolution Stage: F-III	Incision Ratio	< 1.2	4.2
Sensitivity: Extreme	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Erosion, Headcut, Mass Failure, Poor Bank Vegetation, Encroachments**		

T8.05-B

This segment continues upstream for 1,700 feet, meandering away from Rt. 100, and ends where the brook is straightened along the road again. This segment has lower banks than much of the brook and the channel can access its floodplain. It is highly depositional, with aggradation and planform change acting as the major processes in its evolution. The channel is slightly incised and has one avulsion. It is in **fair** geomorphic condition due to these factors, but it has room to adjust without corridor encroachment from Rt. 100. The upstream-most portion of the segment was altered during post-TSI channel work to divert flow away from a house on the north bank using windrowing. There is also a large sediment plug at the downstream end of the segment that is contributing to aggradation. T8.05-B is also in **fair** habitat condition due to its lack of such habitat features as LWD, deep pools, and refuge areas.

Figure 5.14. Major aggradation and floodplain access in T8.05-B.

T8.05-B Data Summary		**Reference**	**Existing**
Length: 1,706 ft Drainage Area: 12 sq. mi. Evolution Stage: F-IV Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C_b	C
	Entrenchment Ratio	> 2.2	2.6
	Incision Ratio	< 1.2	1.5
	Dominant Bed Material	Cobble	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Windrowing, Encroachments, Poor Buffers, Erosion**		

T8.05-C

This segment begins where Rt. 100 encroaches upon the brook again and continues upstream for just over 3,200 feet to where Dover Brook enters Wardsboro Brook. T8.05-C is characterized by extensive channel straightening and bank armoring along Rt. 100, which has caused extreme historic incision. The channel has been recently windrowed in many places, activating further channel degradation. There is evidence that the channel widened slightly and adjusted laterally during TSI, however it is currently locked into place by extensive straightening and rip rap. Reference riffle-pool bedform has been lost and replaced with a featureless plane bed channel. Because of these factors, this segment is in **poor** geomorphic condition. Minimal buffers, coupled with a lack of diverse bed features, LWD, and refuge create **fair** habitat conditions in this segment.

Figure 5.15. A straight, featureless channel with poor buffers dominates in T8.05-C.

T8.05-C Data Summary		Reference	Existing
Length: 3,258 ft Drainage Area: 12 sq. mi. Evolution Stage: F-II Sensitivity: Extreme	Confinement	Very Broad	Broad
	Stream Type	C_b	F_b
	Entrenchment Ratio	> 2.2	1.4
	Incision Ratio	< 1.2	4.2
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Riffle-Pool	Plane Bed
Major Stressors:	**Channel Straightening, Revetments, Encroachments, Poor Buffers, Windrowing**		

T8.06

This reach was split into three segments during assessment based primarily on channel dimensions and river corridor encroachments.

T8.06-A

The most downstream segment in T8.06 begins just above the Rt. 100 crossing near Dover Brook and continues upstream for 2,200 feet until just below the Temple Road stream crossing. This segment is characterized by extreme historic and recent channel degradation, as evidenced by a high incision ratio and two active headcuts. This channel degradation has led to an overall loss of channel bedform and a conversion of a riffle-pool stream to plane bed. Rip rap and erosion are both minimal in the segment, and channel straightening is not present. Due to the channel degradation present in this segment, it is in **fair** geomorphic condition. This segment lacked LWD and refuge areas, also placing it in **fair** habitat condition.

Figure 5.16. One of two active headcuts in T8.06-A.

T8.06-A Data Summary		**Reference**	**Existing**
Length: 2,208 ft	Confinement	Very Broad	Very Broad
Drainage Area: 8 sq. mi.	Stream Type	C	B_c
Evolution Stage: F-III	Entrenchment Ratio	> 2.2	1.8
Sensitivity: High	Incision Ratio	< 1.2	1.8
	Dominant Bed Material	Gravel	Cobble
	Dominant Bedform	Riffle-Pool	Plane Bed
Major Stressors:	**Headcuts, Mass Failure, Encroachment**		

T8.06-B

This segment begins just below the Temple Road stream crossing and continues upstream for 2,300 feet to where the brook becomes straightened along Stratton-Arlington Road. T8.06-B is characterized by good floodplain access and abundant depositional features. This segment appears to have undergone aggradation and major planform adjustment during TSI, as evidenced by multiple channel avulsions. Incision in this segment is minor, though one headcut is present. Straightening and post-TSI windrowing are minimal. Due to the planform adjustment that is occurring in this segment, it is in **fair** geomorphic condition. There are many debris jams creating plunge pools and avulsions, providing a diversity of habitat features. For this reason, the segment is in **good** habitat condition.

Figure 5.17. Debris jam creating plunge pool for good habitat conditions in T8.06-B.

T8.06-B Data Summary		Reference	Existing
Length: 2,369 ft Drainage Area: 8 sq. mi. Evolution Stage: F-IV Sensitivity: Very High	Confinement	Very Broad	Very Broad
	Stream Type	C	C
	Entrenchment Ratio	> 2.2	3.4
	Incision Ratio	< 1.2	1.3
	Dominant Bed Material	Gravel	Gravel
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Poor Buffers, Revetments, Encroachments, Channel Straightening**		

T8.06-C

This segment begins where Wardsboro Brook is straightened along Stratton-Arlington Road and continues 2,100 feet upstream to the reach break above the Boardman Loop bridge. This segment is has been straightened and rip rapped along Stratton-Arlington Road for nearly all of its extent. This straightening and armoring led to historic channel incision and loss of floodplain access for the entirety of the segment. The channel has largely lost its bed features and was converted from a riffle-pool bedform to plane bed. Channel widening and planform adjustment are limited by the boundary conditions within this segment. Buffers are also in poor condition due to road and development encroachments. Overall, the segment is in **fair** geomorphic condition, as there is evidence of recent channel alteration, channel aggradation, widening, or planform adjustment. Due to its lack of bed features, LWD, refuge, and riparian buffers, T8.06-C is in **fair** habitat condition.

Figure 5.18. Straightened and rip rapped along the road, T8.06-C has been converted to a plane bed bedform.

T8.06-C Data Summary		Reference	Existing
Length: 2,182 ft	Confinement	Very Broad	Very Broad
Drainage Area: 8 sq. mi.	Stream Type	C	F
Evolution Stage: F-III	Entrenchment Ratio	>2.2	1.3
Sensitivity: Very High	Incision Ratio	< 1.2	2.0
	Dominant Bed Material	Gravel	Cobble
	Dominant Bedform	Riffle-Pool	Plane Bed
Major Stressors:	**Channel Straightening, Encroachments, Revetments, Poor Buffers, Stormwater Inputs**		

Dover Brook

T8.S3.01

This reach on Dover Brook, a tributary to Wardsboro Brook, was not divided into segments during assessment. The reach begins at the confluence with Wardsboro Brook and continues upstream for 2,500 feet, ending below the Rt. 100 crossing. T8.S3.01 was historically straightened and armored along Rt. 100. The stream has largely lost access to its floodplain and has majorly incised. This reach appears to have aggraded and undergone planform change during TSI, as evidenced by one channel avulsion and five mass failures in this short reach. Post-TSI channel work is present in the form of windrowing in areas where Dover Brook runs along Rt. 100 and private residences. The buffers in this reach are highly impacted by the road and development on both sides of the brook. Erosion is also common in this reach in areas where the banks are not armored or windrowed, indicating slight widening where boundary conditions do not prevent it. Due to the stream's extreme historic degradation and boundary conditions preventing adjustment, this reach is in **poor** geomorphic condition. T8.S3.01 has a very weak riffle-pool bedform and lacks a diversity of bed features. There is also little LWD and few refuge areas, although canopy cover overall is good for the reach. Due to these factors, the reach is in **fair** habitat condition. There is one bridge and one culvert in T8.S3.01; the culvert poses a potential barrier to aquatic organism passage.

Figure 5.19. Windrowing and corridor encroachment of Rt. 100 common in T8.S3.01.

T8.S3.01 Data Summary		Reference	Existing
Length: 2,531 ft Drainage Area: 1.4 sq. mi. Evolution Stage: F-III Sensitivity: Extreme	Confinement	Very Broad	Very Broad
	Stream Type	C_b	F_b
	Entrenchment Ratio	> 2.2	1.4
	Incision Ratio	< 1.2	2.6
	Dominant Bed Material	Cobble	Cobble
	Dominant Bedform	Riffle-Pool	Riffle-Pool
Major Stressors:	**Channel Straightening, Encroachments, Windrowing, Mass Failures, Stormwater Inputs, Poor Buffers, Revetments**		

5.3 Stream Crossings

Tables 6 and 7 in Appendix B summarize the data collected for the assessed structures within the Phase 2 study area. The map on page 6 in Appendix B shows the location and geomorphic compatibility rating of each structure. Of the 10 bridges and culverts assessed, one was determined to be "mostly incompatible," six were "partially compatible," and three were "mostly compatible." This information can be used by municipalities and the Vermont Agency of Transportation to prioritize bridge replacements. Information from the Phase 2 stream geomorphic assessment and bridge and culvert assessments can be used to inform Jamaica and Wardsboro of which stream crossings are contributing to localized instability.

Stream crossings that have been recommended for replacement are in T8.05-C and T8.06-B of Wardsboro Brook and T8.S3.01 of Dover Brook. The following parameters factored into the recommendations and their priority for replacement: flood damage, geomorphic compatibility, and condition of structure. All structures are bridges except for one in T8.S3.01, which is a culvert under Rt. 100 and Cross Road.

The downstream-most crossing recommended for replacement was a Rt. 100 bridge in T8.05-C. Significant scour around the structure occurred during TSI and the bridge could have been undermined during the next major flow event. The bridge ranked mostly compatible; however, due to its poor condition (cracked abutments, rusting beams, and deteriorating decking) and the potential for the bridge to be undermined, it was recommended for replacement with a moderate priority. According to John Bennett of the Windham Regional Commission, this bridge was replaced by the Vermont Agency of Transportation during 2014.

Figure 5.20. Deteriorating decking and rusting beams **of** Rt. 100 bridge in segment T8.05-C.

The bridge on Temple Road in segment T8.06-B is ranked as mostly incompatible and is recommended for replacement. This bridge has poor alignment, abutment scour, and was likely overtopped during TSI. Channel avulsions are present directly upstream of the structure.

Figure 5.21. Temple Road bridge in segment T8.06-B recommended for replacement.

On reach T8.S3.01 of Dover Brook, the most downstream crossing recommended for replacement is the box culvert under Rt. 100 and Cross Road. It is recommended for replacement due to its poor alignment with the channel, reduced aquatic organism passage (AOP), and scour around the structure. Under typical low flows, the depth of water in the culvert is very shallow and it contains no sediment, which could create a barrier for fish and other wildlife.

Figure 5.22. Poor alignment of Dover Brook culvert under Rt. 100 and Cross Rd.

Farther upstream in T8.S3.01, a private driveway bridge is recommended for replacement with a low priority. This structure is a slight channel constriction, and has scour around its footers and failing rip rap.

Figure 5.23. Private driveway bridge in T8.S3.01 recommended for replacement.

6.0 PRELIMINARY PROJECT IDENTIFICATION AND PRIORITIZATION

6.1 Reach Level and Site Specific Opportunities

The stream reaches evaluated in this study present a variety of planning and management strategies which can be classified under one of the following categories: Active Geomorphic Restoration and Passive Geomorphic Restoration.

Active Geomorphic Restoration implies the management of rivers to a state of geomorphic equilibrium through active, physical alteration of the channel and/or floodplain. Often this approach involves the removal or reduction of human constructed constraints or the construction of *meanders*, floodplains or stable banks. Active riparian buffer revegetation and long-term protection of a river corridor is essential to this alternative.

Passive Geomorphic Restoration allows rivers to return to a state of geomorphic equilibrium by removing factors adversely impacting the river and subsequently using the river's own energy and watershed inputs to re-establish its meanders, floodplains and equilibrium conditions. In many cases, passive restoration projects may require varying degrees of active measures to achieve ideal results. Active riparian buffer revegetation and long-term protection of a river corridor are also essential to this alternative.

6.1.1 Project Identification

Wardsboro Brook Mainstem

Reach T8.01
(Refer to Appendix C, Maps 1 and 2 and Tables 1 and 2)

1. **Passive Restoration** by protecting the river corridor at the alluvial fan where Wardsboro Brook meets the West River;
2. **Active Restoration** by returning windrowed material to the stream channel and removing a 5 foot berm that is restricting floodplain access where the brook runs along Old Rt. 8;
3. **Passive Restoration** by protecting the river corridor between the brook and Rt. 100 where active planform adjustment is occurring;
4. **Passive & Active Restoration** by planting native trees and shrubs in a lawn just above the Rt. 100 stream crossing in T8.01-C, and returning windrowed material to the stream channel;
5. **Active Restoration** by returning windrowed material to the stream channel and removing a 4 foot berm that is restricting access to a forested floodplain;
6. **Active Restoration** by investigating channel alteration and options to replace material that was dredged out of the brook after TSI near the top of T8.01-C;
7. **Passive Restoration** by protecting the river corridor at the top of T8.01-C and bottom of T8.01-B where the brook flows away from Rt. 100;
8. **Active restoration** by arresting two active headcuts in T8.01-D.

Reach T8.02
(Refer to Appendix C, Maps 3 and 4 and Tables 3 and 4)

9. **Active Restoration** by returning windrowed material to the stream channel just upstream of the Rt. 100 crossing;
10. **Passive Restoration** by protecting the river corridor along Rt. 100 where the floodplain is forested;
11. **Active Restoration** by arresting an active headcut below the South Wardsboro Rd stream crossing;
12. **Passive Restoration** by protecting the river corridor at the location of three FEMA buyouts along the brook in the center of Wardsboro;
13. **Active Restoration** by removing a berm and returning windrowed material to the channel from the three-buyout location upstream into T8.03.

Reach T8.03
(Refer to Appendix C, Map 5 and Table 5)

14. **Active & Passive Restoration** by returning windrowed material to the stream channel and protecting the river corridor throughout the middle portion of the reach;
15. **Passive Restoration** by planting native tree and shrub species in a lawn on the south bank of the brook;
16. **Active Restoration** by arresting a headcut and returning windrowed material to the channel at the top of T8.03.

Reach T8.04
(Refer to Appendix C, Map 6 and Table 6)

17. **Active Restoration** by returning windrowed material to the stream channel and removing a berm that is restricting floodplain access toward the bottom of the reach;
18. **Passive Restoration** by protecting the river corridor at the location of a major channel avulsion and reducing future flood risks with the acquisition of several at-risk houses through FEMA;
19. **Active Restoration** by arresting an active headcut at the top of the reach;

Reach T8.05
(Refer to Appendix C, Map 6 and Table 6)

20. **Active Restoration** by returning windrowed material to the stream channel and arresting a major headcut that is threatening floodplain access at the break between segments A & B;
21. **Passive Restoration** by planting vegetation along a grass lawn at the top of segment B;
22. **Passive Restoration** by protecting the river corridor throughout segment B where there is good floodplain access;
23. **Active Restoration** by returning windrowed material to the channel along Rt. 100 and removing a berm at the B/C segment break.

Reach T8.06
(Refer to Appendix C, Map 8 and Table 8)

24. **Active Restoration** by arresting a headcut in segment A that is threatening good floodplain access in B;
25. **Passive Restoration** by planting native tree and shrub species along a field just downstream of Temple Rd. and protecting the river corridor where there is good floodplain access and good in-stream habitat;
26. **Passive Restoration** by planting native trees and shrubs in a field just upstream of the Temple Rd. crossing to enhance the good habitat in this area;
27. **Active Restoration** by returning windrowed material to the stream channel in segment B to improve floodplain access.

Dover Brook

Reach T8.S3.01
(Refer to Appendix C, Map 7 and Table 7)

28. **Active Restoration** by replacing the box culvert under Rt. 100 and Cross Rd with a structure that has better channel alignment, sediment continuity, and aquatic organism passage;
29. **Active & Passive Restoration** by returning windrowed material to the stream channel to improve floodplain access, planting native trees and shrubs on both sides of the brook where lawns create poor buffers, and protecting the river corridor through an easement spanning one large parcel.

6.1.2 Program Descriptions

There are a number of federal, state, and local programs available for river restoration and protection. These programs are as follows:

- ANR River Corridor Easement Program (RCE)
- Ecosystem Restoration Program (formerly called Clean & Clear)
- Conservation Reserve Enhance Program (CREP)
- Trees for Streams (TFS)
- Environmental Quality Incentives Program (EQIP)
- Wildlife Habitat Incentives Program (WHIP)
- Wetland Reserve Program (WRP)
- Connecticut River Watershed Council (CRWC)

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.

Connecticut River Watershed Council
Restoration, protection, and enhancement of the river, wetlands, and shore lands within the Connecticut River watershed are supported by funds from the Connecticut River Watershed Council (CRWC). Typical projects include guiding development, preventing erosion, restoring stream passage, and making sure hydropower and industrial permits are aligned to protect natural heritage for future generations.

6.2 Watershed-Level Opportunities

There are a number of watershed-level opportunities available to improve the geomorphic stability and water quality of the Wardsboro Brook watershed. Watershed opportunities include the development and adoption of River Corridors and improved stormwater treatment.

River Corridors
The purpose of defining 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. 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 the lateral extent of the river meanders, called the meander belt width, which is governed by valley landforms, *surficial geology*, and the length and slope requirements of the river channel. The width of the corridor is also governed by the stream type and *sensitivity* of the stream. River corridors, as defined by the Vermont Agency of Natural Resources (2008b), are intended to provide landowners, land-use planners, and river managers with a meander belt width which would accommodate the meanders and slope of a balanced or equilibrium channel, which when achieved, would serve to maximize channel stability and minimize fluvial erosion hazards. Information collected during the Phase 2 Assessment including reach sensitivity, reach condition, and stream type is used to develop these zones. The development of river corridor overlay districts on the municipal level are recommended by the Vermont River Management Program (2010b) to improve stream stability, reduce flood losses, and enhance public safety. Additional information about river corridors is available at (http://www.anr.state.vt.us/dec/waterq/rivers/docs/rv_vtfehqa.pdf).

Stormwater Management
Stormwater runoff rates are of particular concern in urbanized and agricultural watersheds because stormwater runs off from impervious surfaces rather than naturally infiltrating the soil. The cumulative effect of the increased frequency, volume, and rate of stormwater runoff results in increases in wash-off pollutant loading to streams and destabilization of stream channels. Improving stormwater management and construction practices in the Wardsboro Brook watershed is recommended to reduce siltation of critical aquatic habitat and improve geomorphic stability. An added benefit of stormwater management is the reduction of peak flows in the channel.

6.3 Next Steps

There are many opportunities to restore the Wardsboro Brook watershed to a more stable condition. Types of reach and site level projects that have been identified in this plan include returning excavated material to the stream channel, removing berms, arresting headcuts, planting in the riparian zone, protecting the river corridor, and replacing stream crossing structures. These projects combine in a strategy to recover from Tropical Storm Irene and post-flood channel work through improving flood resiliency in the watershed. Further, the development and implementation of river corridors 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:

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

For additional information about river corridors or project development, please contact the Vermont River Management Program or the Windham Regional Commission.

7.0 LIST OF ACRONYMS AND GLOSSARY OF TERMS

List of Acronyms

BCE – Bear Creek Environmental, LLC
CREP – Conservation Reserve Enhancement Program
CRWC – Connecticut River Watershed Council
EQIP – Environmental Quality Incentives Program
ERP – Ecosystem Restoration Program
GIS – Geographic Information System
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
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
WRC – Windham Regional Commission
WRP – Wetland Reserve Program

Glossary of Terms

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

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

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

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

Alluvial Soils – Soil deposits from rivers.

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

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

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

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

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

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

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

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

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

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.

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.

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 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.

Head Cut – Sudden change in elevation or knickpoint at the leading edge of a gully

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.

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.

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 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.

Windrowing – The process of excavating a stream channel and piling channel materials on the banks to create berms and prevent flood waters from reaching the adjacent floodplain.

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Vermont Agency of Natural Resources. 2010a. Vermont Agency of Natural Resources River Corridor Planning Guide to Identify and Develop River Corridor Protection and Restoration Projects. DEC River Management Program. Waterbury, Vermont.

Vermont Agency of Natural Resources. 2010b. Municipal Guide to Fluvial Erosion Hazard Mitigation. DEC River Management Program. Waterbury, Vermont

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

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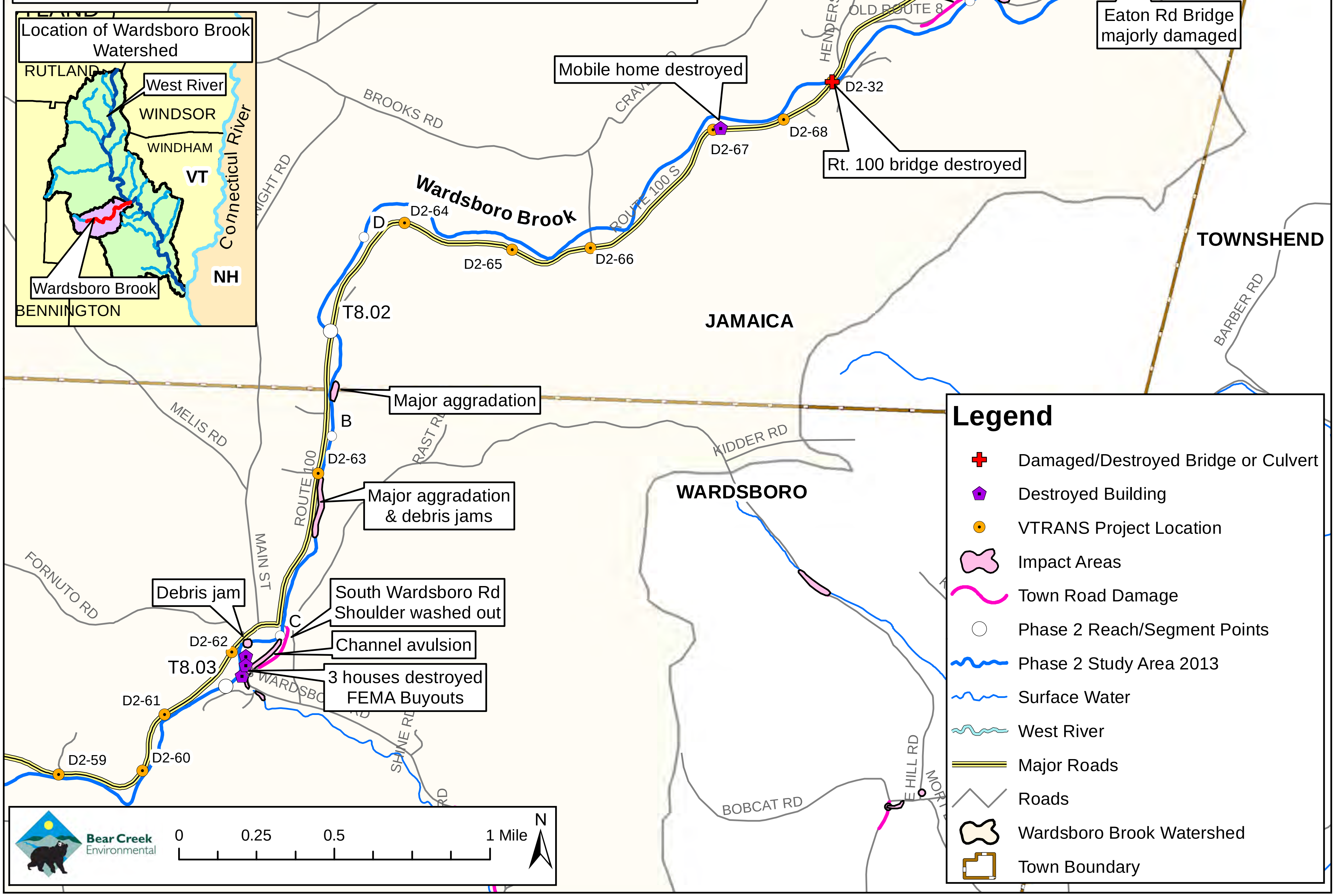
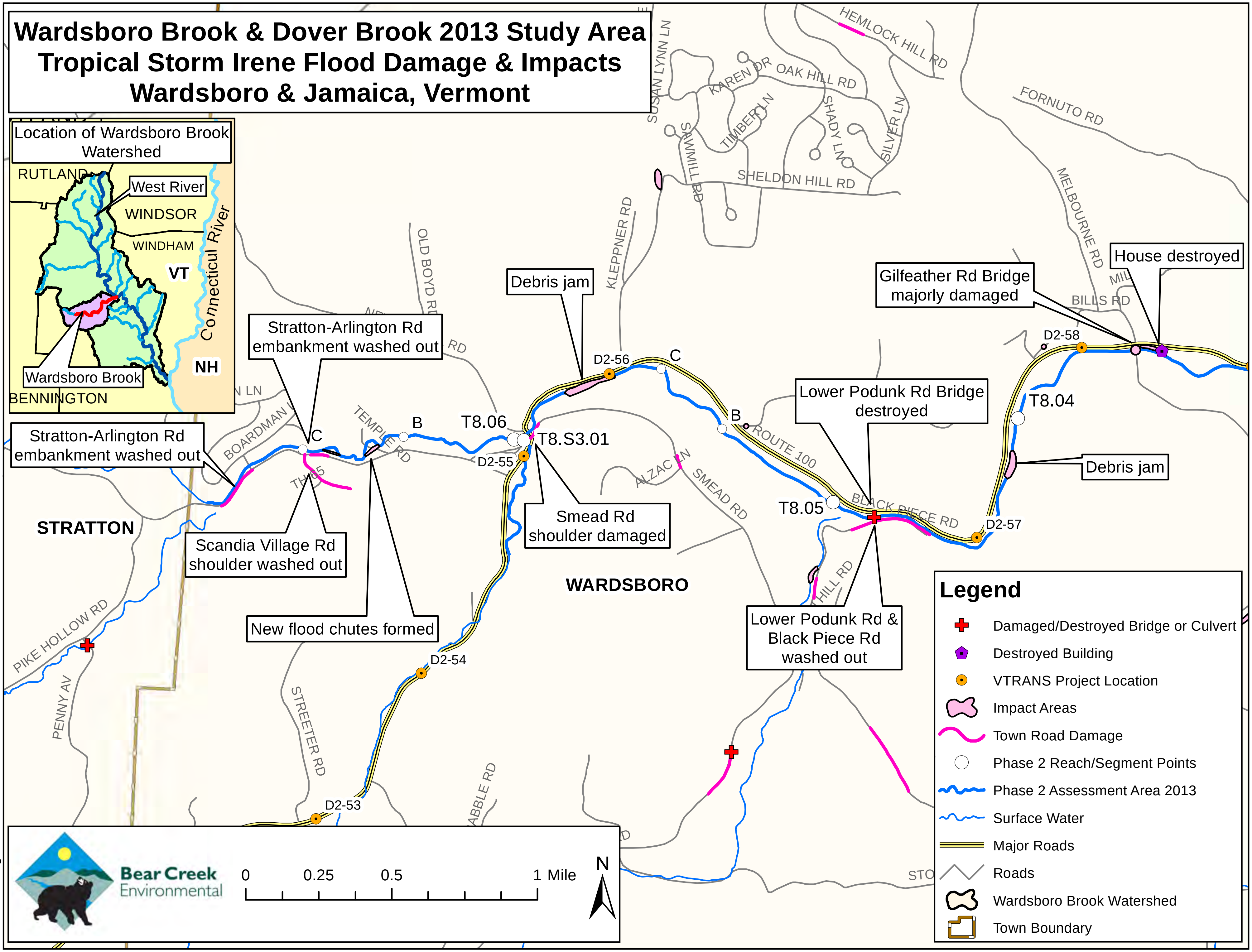
APPENDIX A

Maps

Wardsboro Brook & Dover Brook 2013 Study Area
Tropical Storm Irene Flood Damage & Impacts
Wardsboro & Jamaica, Vermont

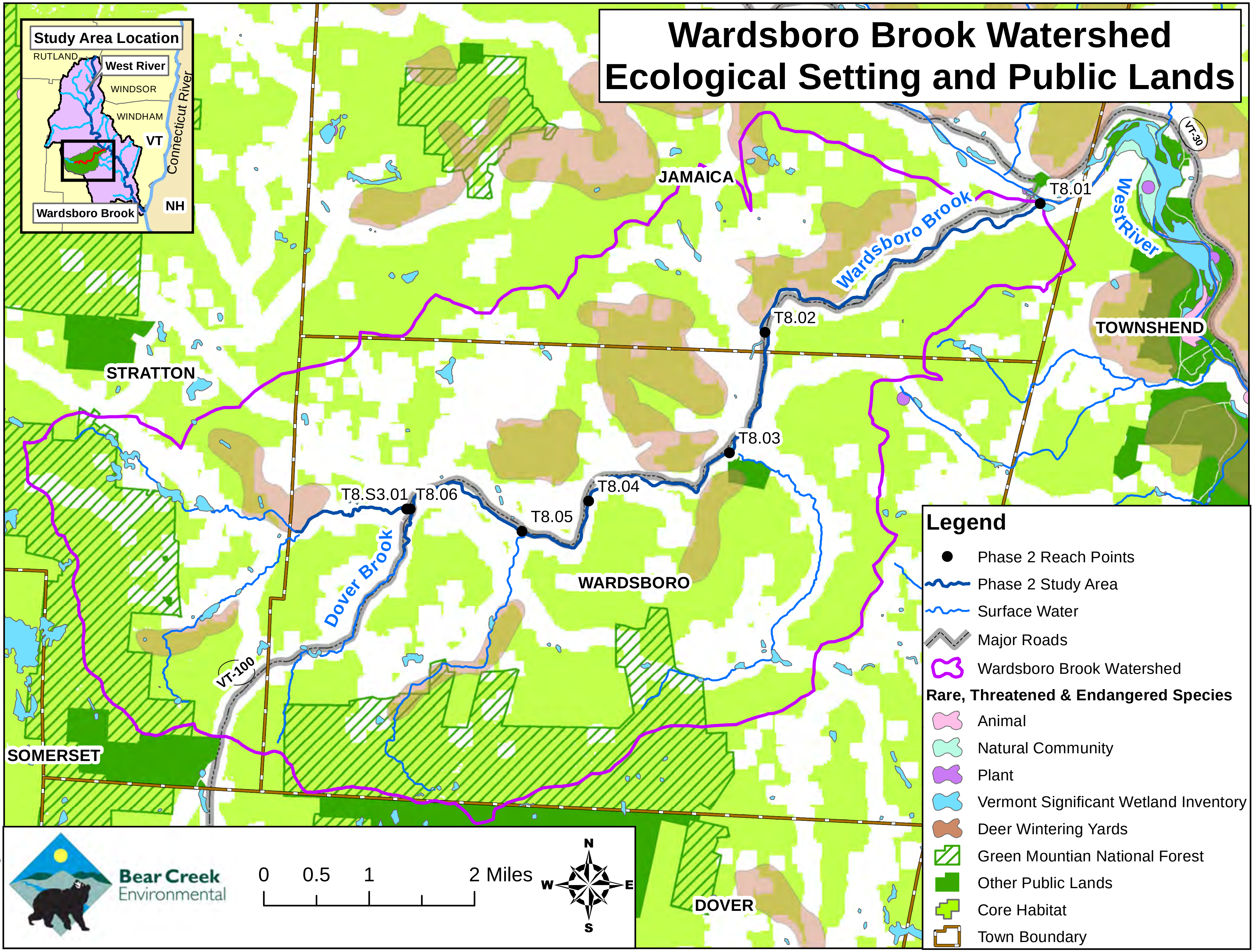


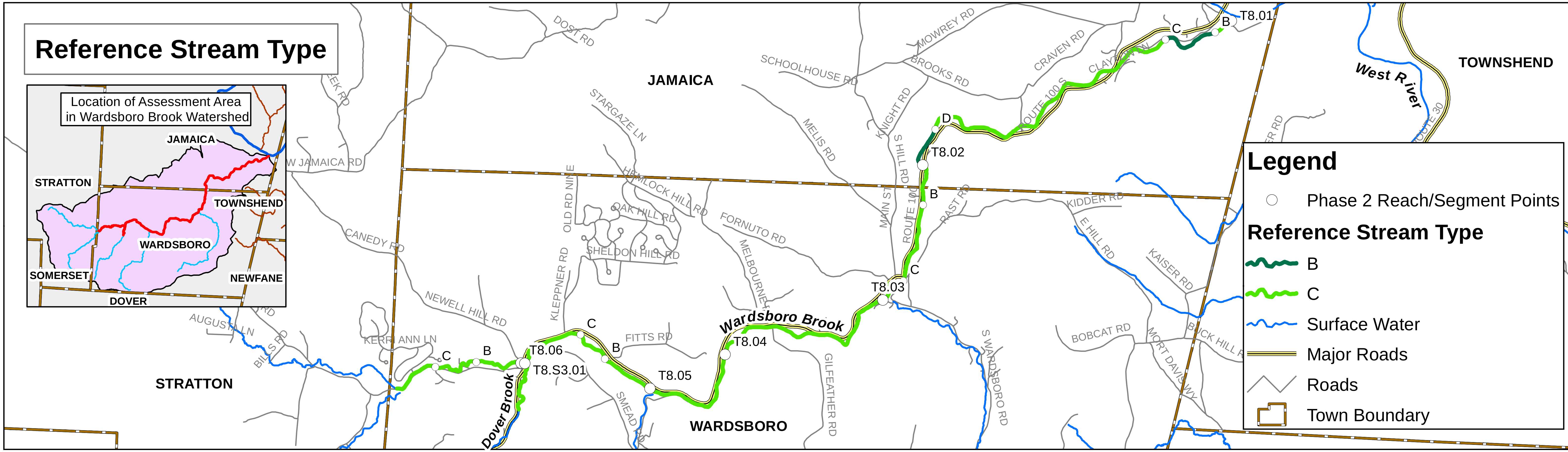
Data provided by the Windham Regional Commission and Vermont Agency of Transportation. Road damage data are not comprehensive and reflect information collected during a time of crisis.

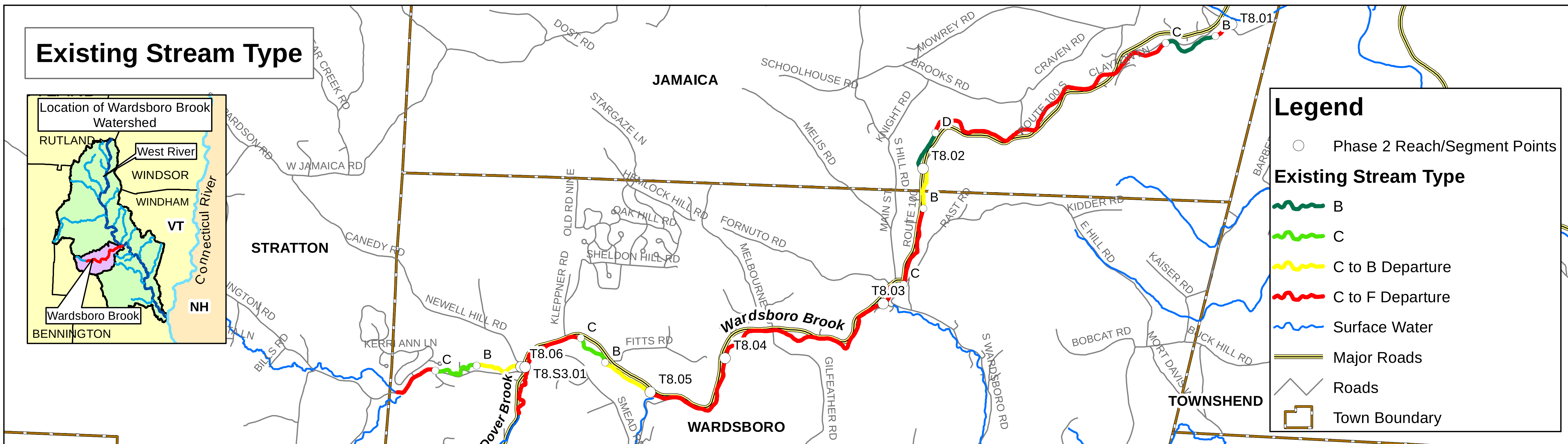


Data provided by the Windham Regional Commission and Vermont Agency of Transportation. Road damage data are not comprehensive and reflect information collected during a time of crisis.

Wardsboro Brook Watershed Ecological Setting and Public Lands

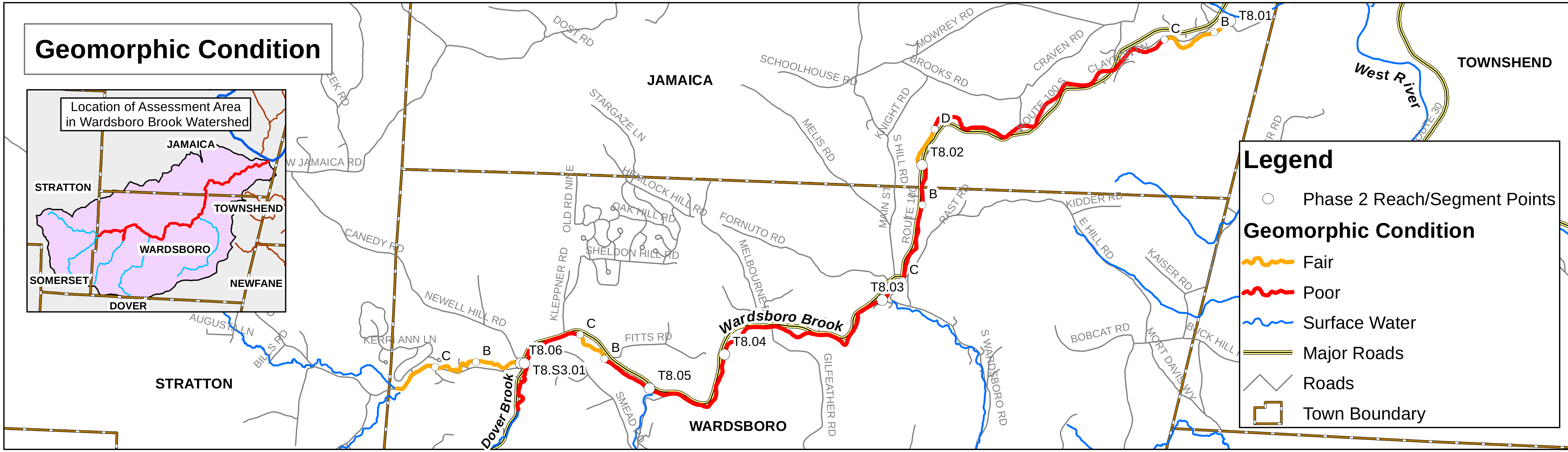


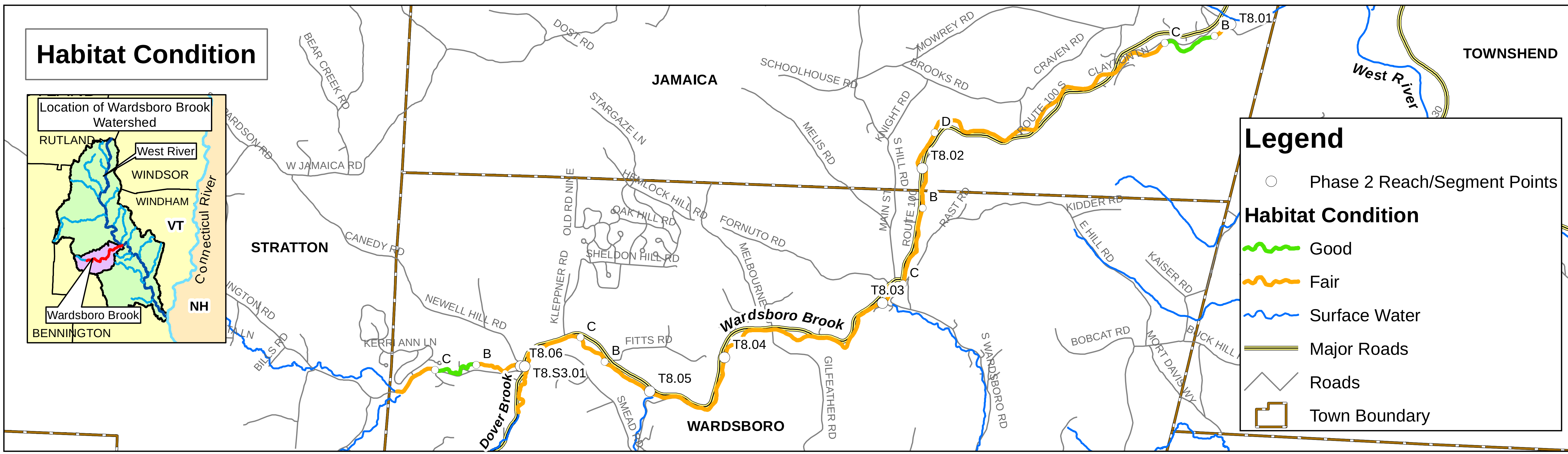




Wardsboro Brook & Dover Brook
Stream Type - Wardsboro & Jamaica, Vermont

Bear Creek Environmental



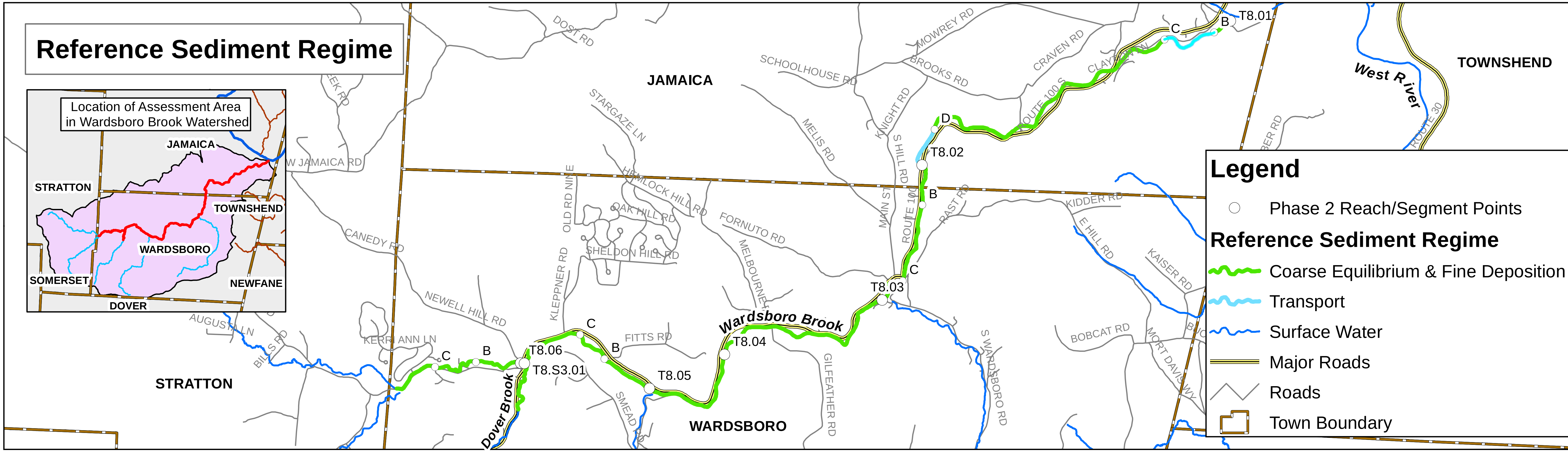


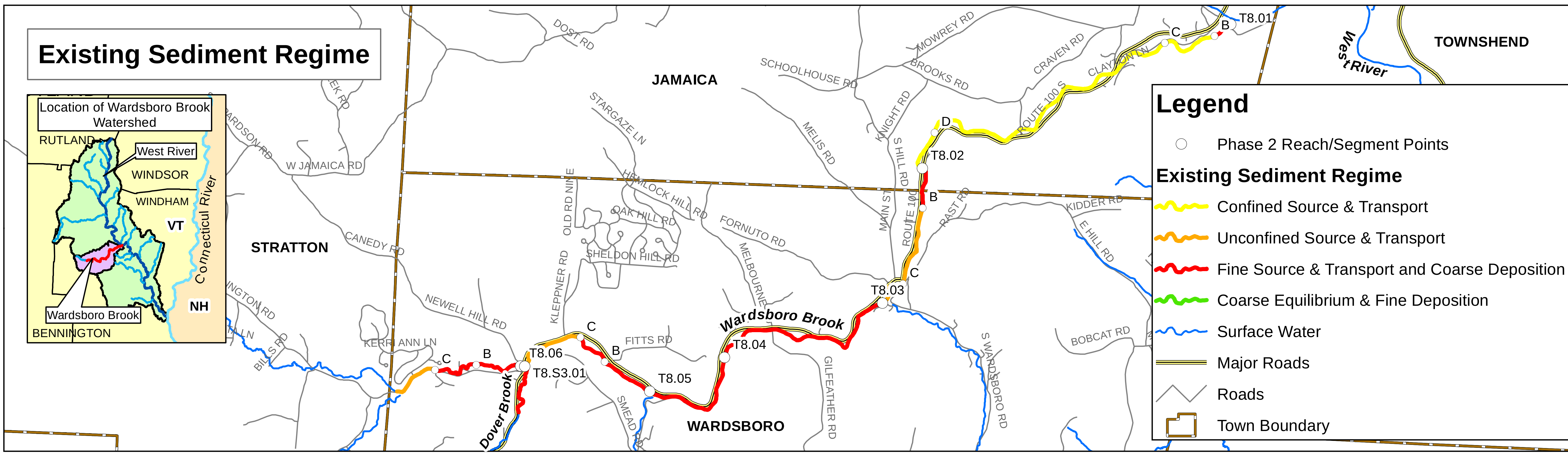
Wardsboro Brook & Dover Brook
Stream Condition - Wardsboro & Jamaica, Vermont

N W E S

0 0.5 1 2 Miles

Bear Creek Environmental





Wardsboro Brook & Dover Brook
Sediment Regimes - Wardsboro & Jamaica, Vermont

N W E S

0 0.5 1 2 Miles

Bear Creek Environmental

Wardsboro Brook & Dover Brook
Stream Sensitivity - Wardsboro & Jamaica, Vermont

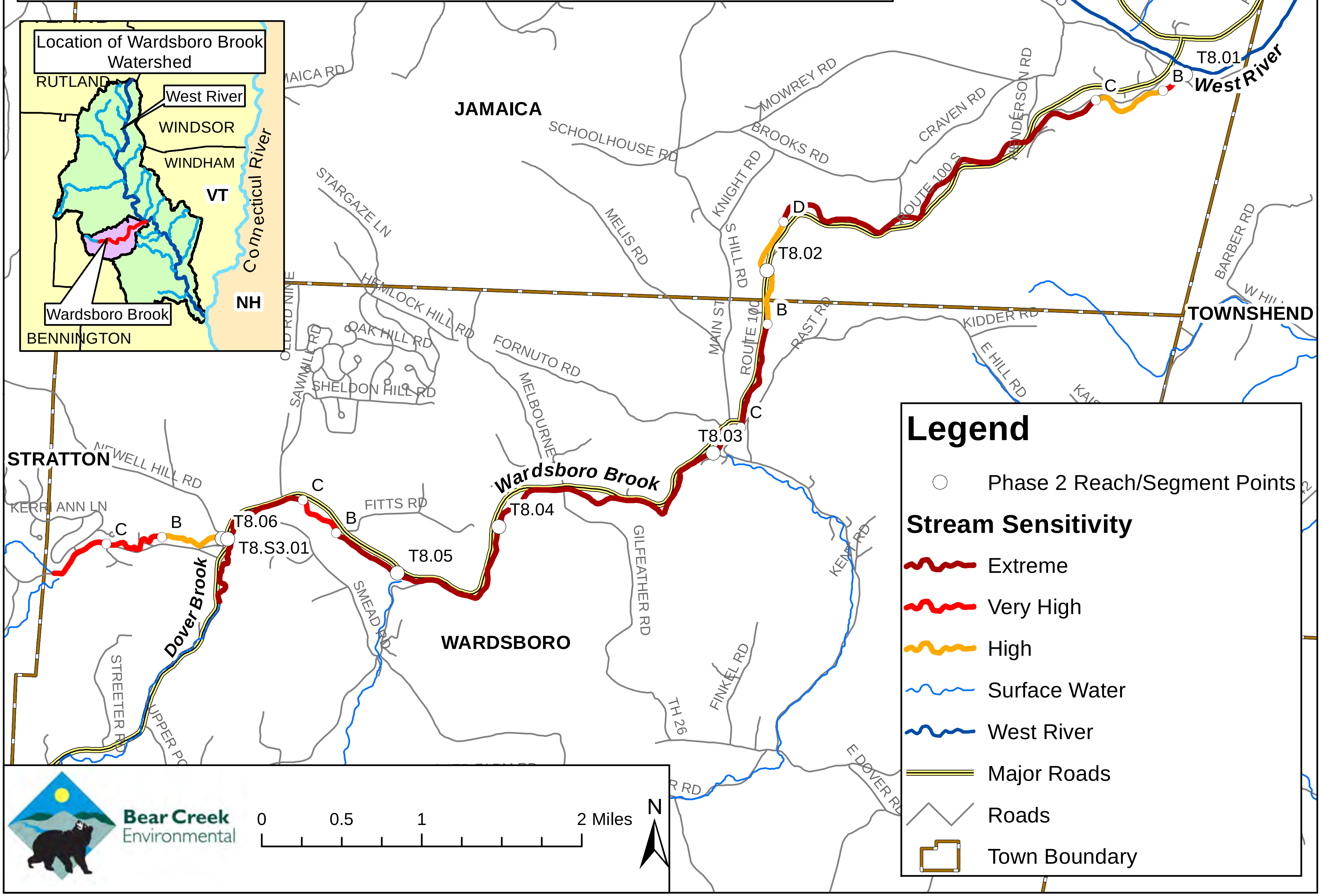


Table 1. Stream Type and Channel Evolution Stage Summary
Wardsboro Brook Watershed

Segment Number	Entrenchment Ratio	Width to Depth Ratio	Reference Stream Type	Incision Ratio	Existing Stream Type	Channel Evolution Stage	Active Adjustment Process
Wardsboro Brook Mainstem							
T8.01-A	1.1	46.1	C	2.2	F	F-III	**Incision** **Aggradation** **Widening** Planform
T8.01-B	2.0	33.5	B	1.3	B	F-IV	Incision **Aggradation** **Widening** **Planform**
T8.01-C	1.1	100.5	C	2.4	F	F-IV	**Incision** **Aggradation** **Widening** **Planform**
T8.01-D	1.4	35.2	B_c	2.3	B_c	F-IV	**Incision** **Aggradation** **Widening** Planform
T8.02-A	1.5	46.4	C	1.9	B_c	F-IV	**Incision** **Aggradation** **Widening** **Planform**
T8.02-B	1.1	52.2	C	2.2	F	F-III	**Incision** **Aggradation** **Widening** **Planform**
T8.02-C	1.3	41.8	C	2.8	F	F-III	**Incision** **Aggradation** **Widening** **Planform**
T8.03	1.3	62.7	C	1.7	F	F-III	**Incision** **Aggradation** **Widening** **Planform**
T8.04	1.2	39.5	C	3.2	F	F-III	**Incision** **Aggradation** **Widening** **Planform**

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

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

Table 1. Stream Type and Channel Evolution Stage Summary Wardsboro Brook Watershed							
Segment Number	**Entrenchment Ratio**	**Width to Depth Ratio**	**Reference Stream Type**	**Incision Ratio**	**Existing Stream Type**	**Channel Evolution Stage**	**Active Adjustment Process**
T8.05-A	1.7	20.6	C_b	4.2	B	F-III	**Incision** Aggradation **Widening** Planform
T8.05-B	2.6	52.6	C_b	1.5	C	F-IV	**Incision** **Aggradation** **Widening** **Planform**
T8.05-C	1.4	16.5	C_b	4.2	F_b	F-II	**Incision** Aggradation **Widening** Planform
T8.06-A	1.8	22.1	C	1.8	B_c	F-III	**Incision** Aggradation Widening Planform
T8.06-B	3.4	21.4	C	1.3	C	F-IV	Incision **Aggradation** Widening **Planform**
T8.06-C	1.3	21.9	C	2.0	F	F-III	**Incision** Aggradation Widening Planform
Dover Brook							
T8.S3.01	1.4	18.8	C_b	2.6	F_b	F-III	**Incision** **Aggradation** **Widening** **Planform**

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

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

APPENDIX B

Bridge & Culvert Assessment Data

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

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

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

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

Table 3. Scoring Table
Vermont Culvert Geomorphic Compatibility Screen Tool (Milone & MacBroom, 2008)

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

Table 4. Geomorphic Compatibility Rating Results
Vermont Culvert Geomorphic Compatibility Screen Tool (Milone & MacBroom, 2008)

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

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

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

Table 6. Wardsboro Brook Bridge Assessment (2013)
Geomorphic Compatibility

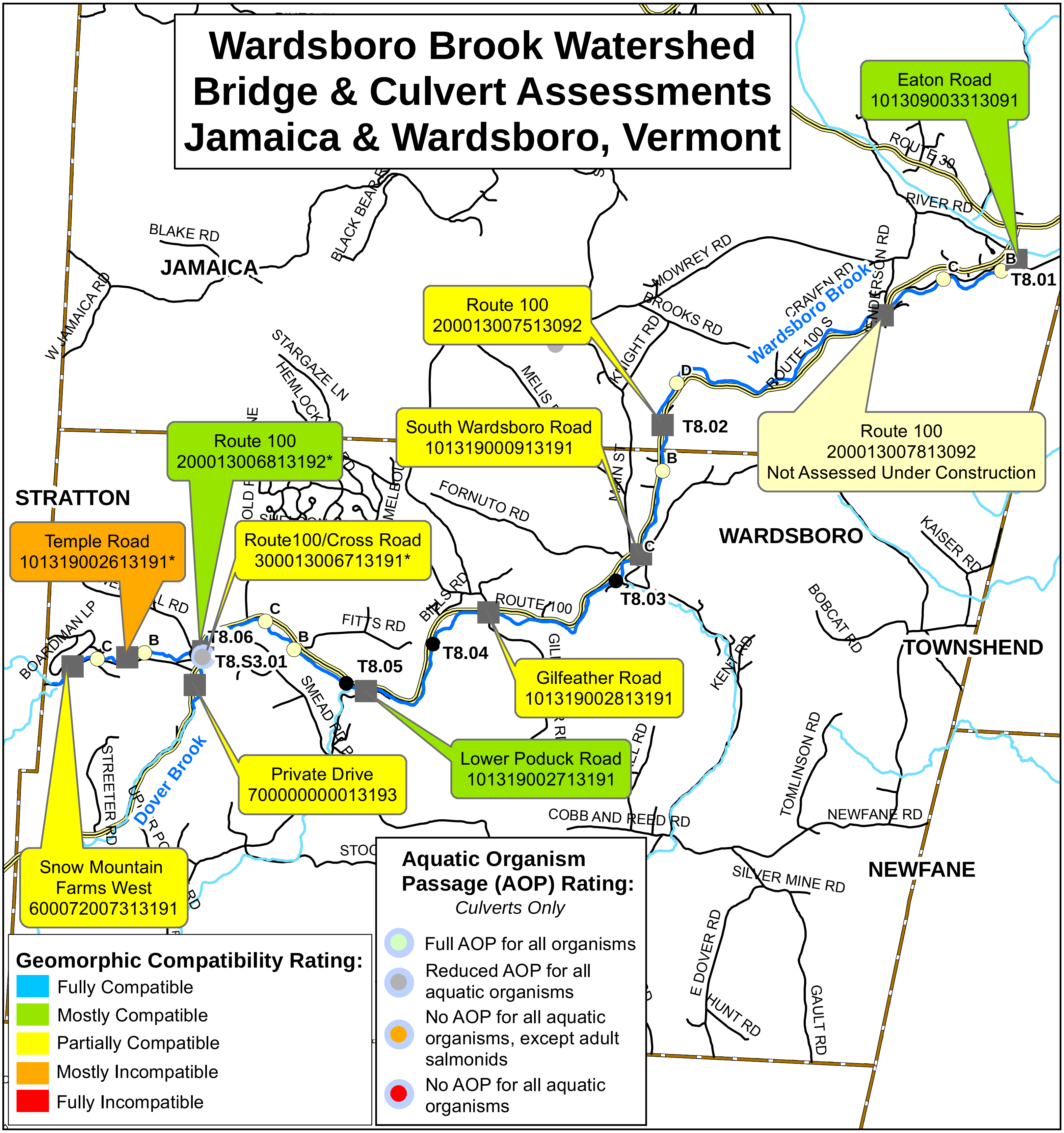
Reach/ Segment Number	Town	Road Name	Structure ID[1]	Percent Bankfull Channel Constriction Width[2]	Phase 2 Notes	Scoring						Priority for Replacement
						% Bankfull Width[3]	Sediment Continuity	Approach Angle	Erosion & Armoring	Total Score	Geomorphic Compatibility	
T8.01-A	Jamaica	Eaton Road	101309003313091	90/62.9 = 143	Not a channel constriction but a floodprone constriction. Deposition above and below. Elevation of downstream deposits >1/2 bankfull. Scour above.	5	4	5 Naturally Straight	0	**14**	Mostly Compatible	Not recommended for replacement
T8.02-A	Jamaica	Route 100	200013007513092	105/57.6 = 182	Not a channel constriction but a floodprone constriction. Scour below. Two piers within span. Eastern pier has some woody debris. Bedrock on eastern bank under bridge.	5	4	0 Sharp Bend	3	**12**	Partially Compatible	Not recommended for replacement
T8.02-B	Wardsboro	South Wardsboro Road	101319000913191	63/57.6 = 109	Not a channel constriction but a floodprone constriction. Riprap is new – post TSI. The entire upstream eastern bank eroded and reconstructed. Poor alignment. Bedrock upstream and in structure.	4	4	0 Sharp Bend	3	**11**	Partially Compatible	Not recommended for replacement
T8.03	Wardsboro	Gilfeather Road	101319002813191	60/51.7 = 116	Not a channel constriction but a floodprone constriction. Bridges is brand new but not open at the time of assessment. Survey was done on the new bridge as the old one will be removed. Damage from TSI – significant erosion to the western bank downstream of bridge.	4	4	2 Channelized Straight	1	**11**	Partially Compatible	Not recommended for replacement (Newly constructed)
T8.04	Wardsboro	Lower Podunk Road	101319002713191	66/47.5 = 139	Not a channel constriction but a floodprone constriction. Bridge withstood TSI but scoured the upstream and downstream eastern bank significantly. Re-riprapped but according to Selectboard chair Peter Sebastian, it was a surficial job. Stream was moved back to the west to its original location.	4	4	3 Mild Bend	3	**14**	Mostly Compatible	Not recommended for replacement
T8.05-C	Wardsboro	Route 100	200013006813192	39/39.2 = 99	Scour above and below. Bridge in poor condition - beams rusting and corroding; decking deteriorating, abutments cracked. Armoring is new and post TSI. Potential scour of structure, which is buried under riprap.	3	5	3 Mild Bend	3	**14**	Mostly Compatible	Moderate (Poor condition)
T8.S3.01	Wardsboro	Private Drive	700000000013193	13/15.2 = 86	"F" channel with major scour upstream and downstream of structure. Some rock work appears to have been done post TSI. Some boulders in riprap falling into channel.	3	4	3 Mild Bend	0	**10**	Partially Compatible	Low (Scour around footers and failing riprap)
T8.06-B	Wardsboro	Temple Road	101319002613191	54/32.5 = 166	Structure to private residence. Evidence of overtopping during TSI. Channel avulsion just upstream of structure. Poor alignment and scour of eastern abutment. Depositional features >1/2 bankfull elevation upstream, downstream and within structure.	5	3	0 Sharp Bend	0	**8**	Mostly Incompatible	Moderate (Geomorphic incompatibility; Poor alignment; overtopped during TSI)
T8.06-C	Wardsboro	Snow Mountain Farms West	600072007313191	28/32.5 = 86	Old bridge was washed out. New bridge under construction. New bridge assessed. Riprap was out of place but not labeled as failing as construction was not yet complete.	3	3	3 Mild Bend	2	**11**	Partially Compatible	Not recommended for replacement (Newly constructed)

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

Table 7. Wardsboro Brook Culvert Assessment (2013) Geomorphic Compatibility and Aquatic Organism Passage (AOP)															
Reach/ Segment Number	**Town**	**Road Name**	**Structure Type and ID[1]**	**Percent Bankfull Channel Width[2]**	**Phase 2 Notes**	**Scoring** (Geomorphic Compatibility - Milone & MacBroom, 2008; AOP – Milone & MacBroom, 2009)									**Priority for Replacement**
						% Bankfull Width	**Sediment Continuity**	**Slope**	**Approach Angle**	**Erosion & Armoring**	**Total Score**	**Geomorphic Compatibility**	**AOP**		
T8.S3.01	Wardsboro	Route100/ Cross Road	300013006713191	14/15.2 = 92	Culvert goes across two roads. Concrete box culvert with poor alignment and depositional features upstream greater than ½ bankfull elevation. Scour above around the culvert and the wingwalls. Deteriorating top of culvert.	3	1	5	0 Sharp Bend	0	**9**	Partially Compatible	Reduced AOP		Moderate (Scour and poor alignment)

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

Wardsboro Brook Watershed Bridge & Culvert Assessments Jamaica & Wardsboro, Vermont



Legend

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

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

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

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

0 0.5 1 Miles

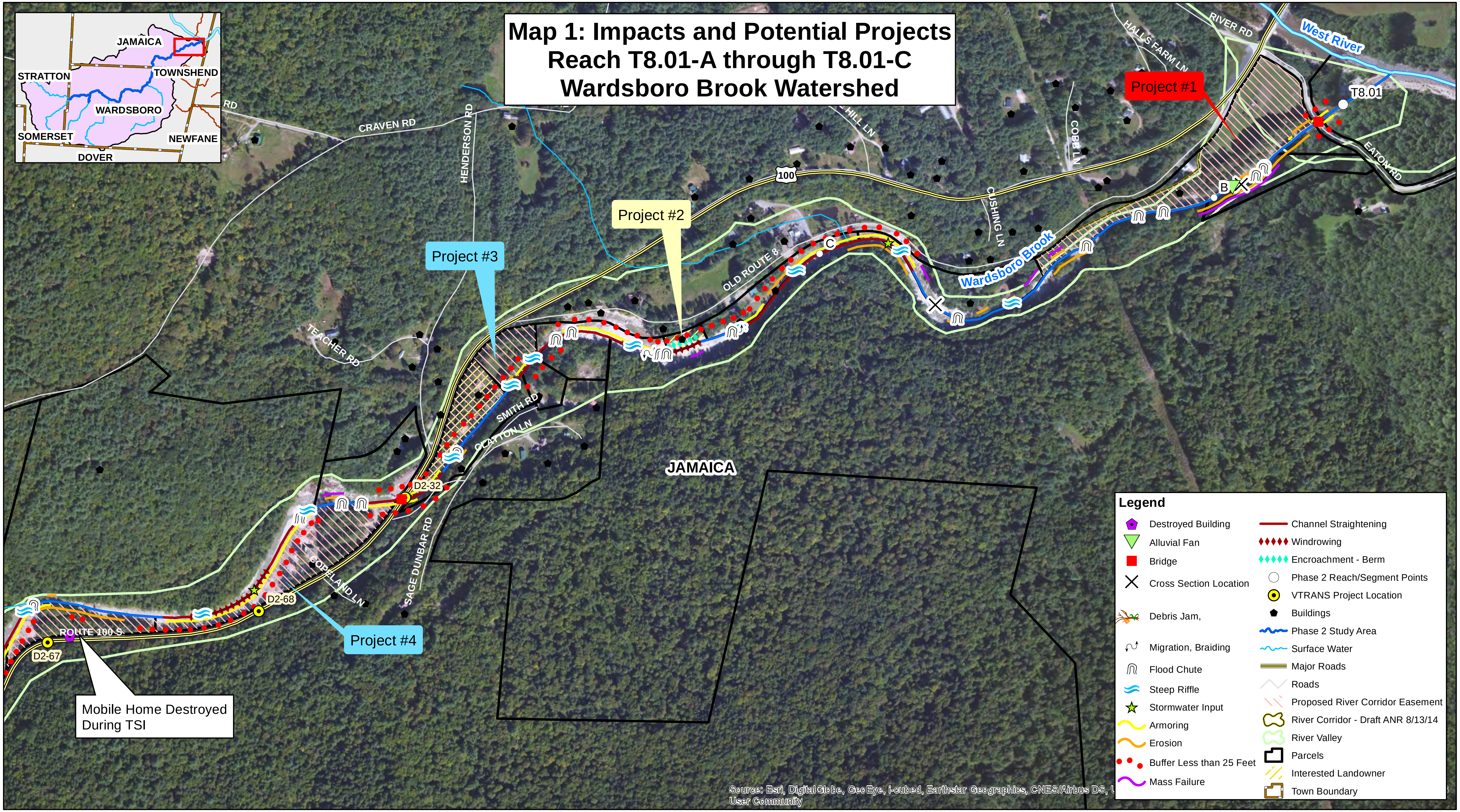
N W E S

*Structure is recommended for replacement.

Bear Creek Environmental

APPENDIX C

Potential Project Locations & Descriptions



Background is World Imagery

Projects:

1. River Corridor Easement
2. Return Windrowed Material to Channel
3. River Corridor Easement
4. Streamside Plantings & Return Windrowed Material to Channel

Project Priority:

- Low
- Moderate
- High

N

0 500 1,000 2,000 Feet

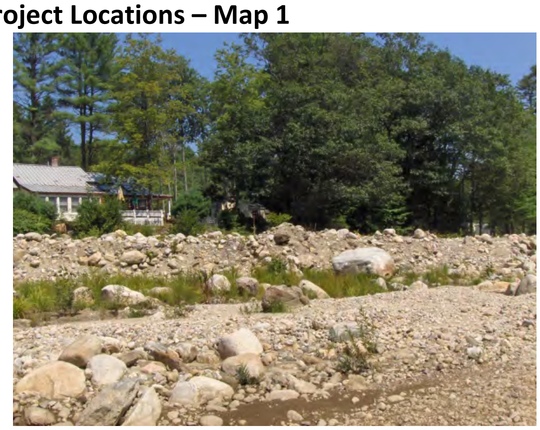
1 inch = 500 feet

Bear Creek Environmental

Table 1. Wardsboro Brook Main Stem Map 1: T8.01-A through T8.01-C Site Level Opportunities for Restoration and Protection Jamaica, Vermont						
Project # Segment	**Type of Project**	**Site Description Including Stressors and Constraints**	**Project or Strategy Description**	**Technical Feasibility and Priority**	**Benefits**	**Potential Partners/ Programs**
Project #1 T8.01-A	Passive Restoration	Alluvial fan present just above confluence with West River in a broad valley. Channel has been pushed up against the valley wall and is incised.	**River Corridor Easement**	High Priority (alluvial fan)	Improved habitat and water quality	Landowner, WRC, VANR RCE
Project #2 T8.01-C	Active Restoration	Channel was windrowed & excavated after TSI and a five foot berm was built to protect a house along the north bank of the brook.	**Return Windrowed Material to Channel/ Remove Berm**	Low Priority (Berm is protecting house from floodwaters; landowner will likely not want to remove)	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR
Project #3 T8.01-C	Passive Restoration	Valley is broad but brook is confined by Rt. 100 on one side. Active planform adjustment is occurring where possible.	**River Corridor Easement**	Moderate Priority (interested landowner & abandoned parcel w/ building destroyed during TSI)	Improved habitat and water quality	Landowners, WRC, VANR, Town of Jamaica RCE
Project #4 T8.01-C	Passive & Active Restoration	Channel was windrowed & excavated after TSI, creating a severely incised, unstable channel. Also, the buffer is poor due to a landowner's lawn.	**Streamside Plantings & Return Windrowed Material to Channel**	Moderate Priority	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR

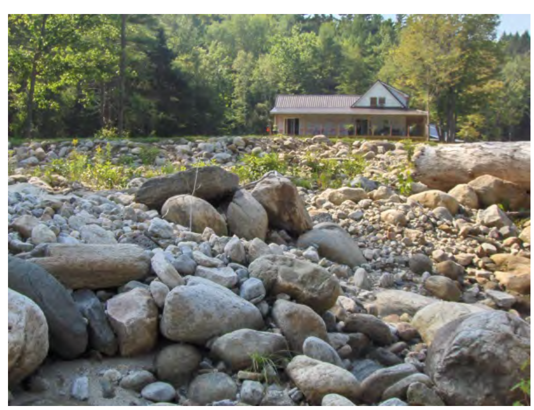
Photos of Proposed Project Locations – Map 1

Project #1 – River Corridor Easement



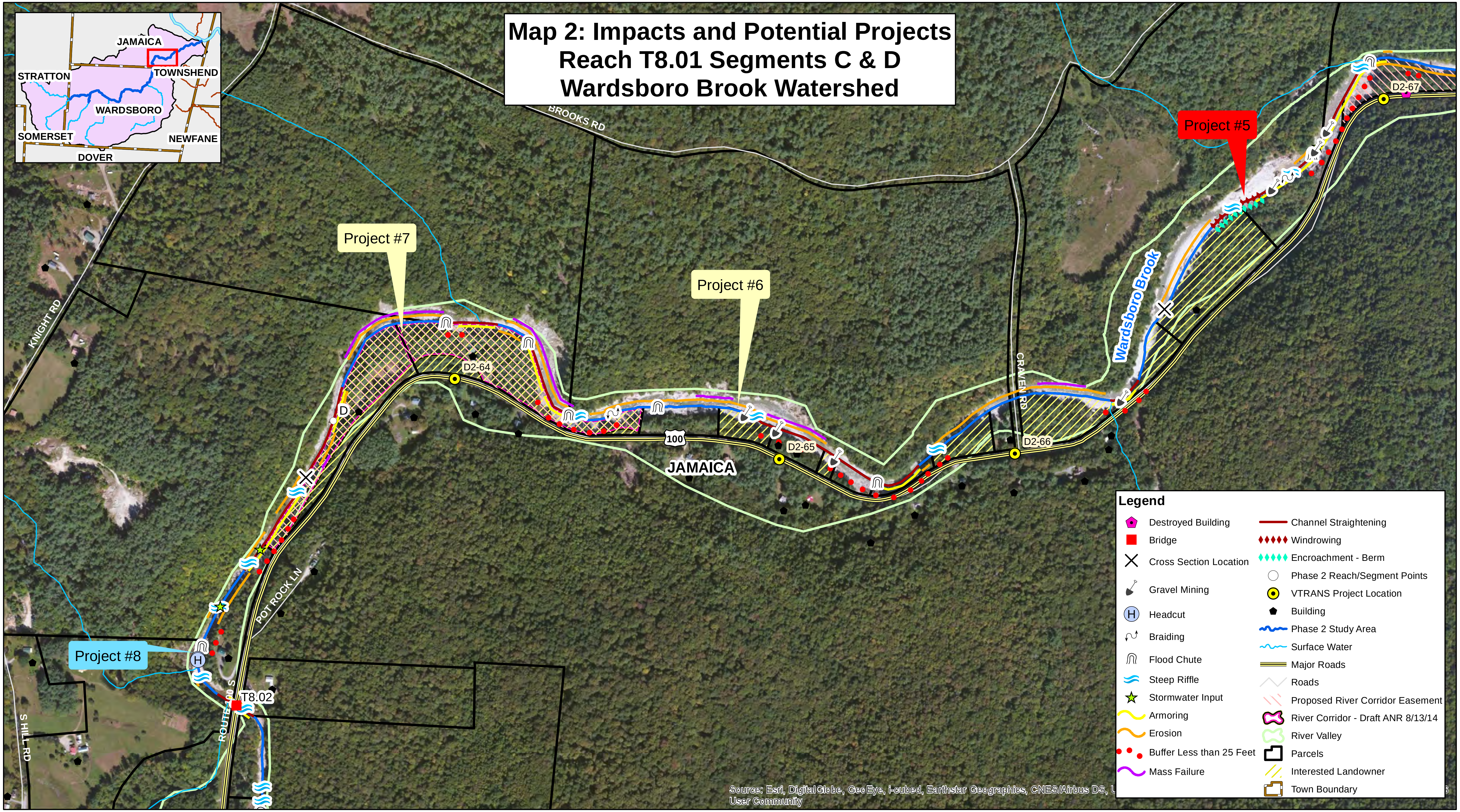
Project #2 – Return Windrowed Material/ Remove Berm

Project #3 – River Corridor Easement



Project #4 – Streamside Plantings & Return Windrowed Material

Map 2: Impacts and Potential Projects Reach T8.01 Segments C & D Wardsboro Brook Watershed



Background is World Imagery

Projects:

5. Return Windrowed Material to Channel
6. Investigate Channel Alteration & Options to Replace Dredged Material
7. River Corridor Easement
8. Arrest Headcuts

Project Priority:

- Low
- Moderate
- High

N

0 500 1,000 2,000 Feet

1 inch = 500 feet

Bear Creek Environmental

Table 2. Wardsboro Brook Main Stem Map 2: T8.01-C through T8.01-D Site Level Opportunities for Restoration and Protection Jamaica, Vermont						
Project # Segment	**Type of Project**	**Site Description Including Stressors and Constraints**	**Project or Strategy Description**	**Technical Feasibility and Priority**	**Benefits**	**Potential Partners/ Programs**
Project #5 T8.01-C	Active Restoration	A four foot berm, which was built in the 1970s, exists but is not protecting any infrastructure.	**Return Windrowed Material to Channel/ Remove Berm**	High Priority (Berm is not protecting infrastructure; floodplain is wooded)	Improved geomorphic stability, habitat, and water quality; attenuation of floodwaters & sediment	Landowners, WRC, VANR
Project #6 T8.01-C	Active Restoration	Channel was heavily dredged and gravel mined post-TSI, lowering the streambed significantly. The brook is trapped between the valley wall and Rt. 100 in this area.	**Investigate Channel Alteration & Options to Replace Dredged Material**	Low Priority (Interested landowner, but not much available floodplain)	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR, Town of Jamaica
Project #7 T8.01-C & D	Passive Restoration	Valley is broad and planform adjustment is occurring.	**River Corridor Easement**	Low Priority (two houses within corridor, banks are very high)	Improved habitat and water quality	Landowners, WRC, VANR RCE
Project #8 T8.01-D	Active Restoration	Channel was historically straightened along Rt. 100 in a semi-confined valley. Two active headcuts are moving upstream through significant deposition.	**Arrest Headcuts**	Moderate Priority	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR

Photos of Proposed Project Locations – Map 2

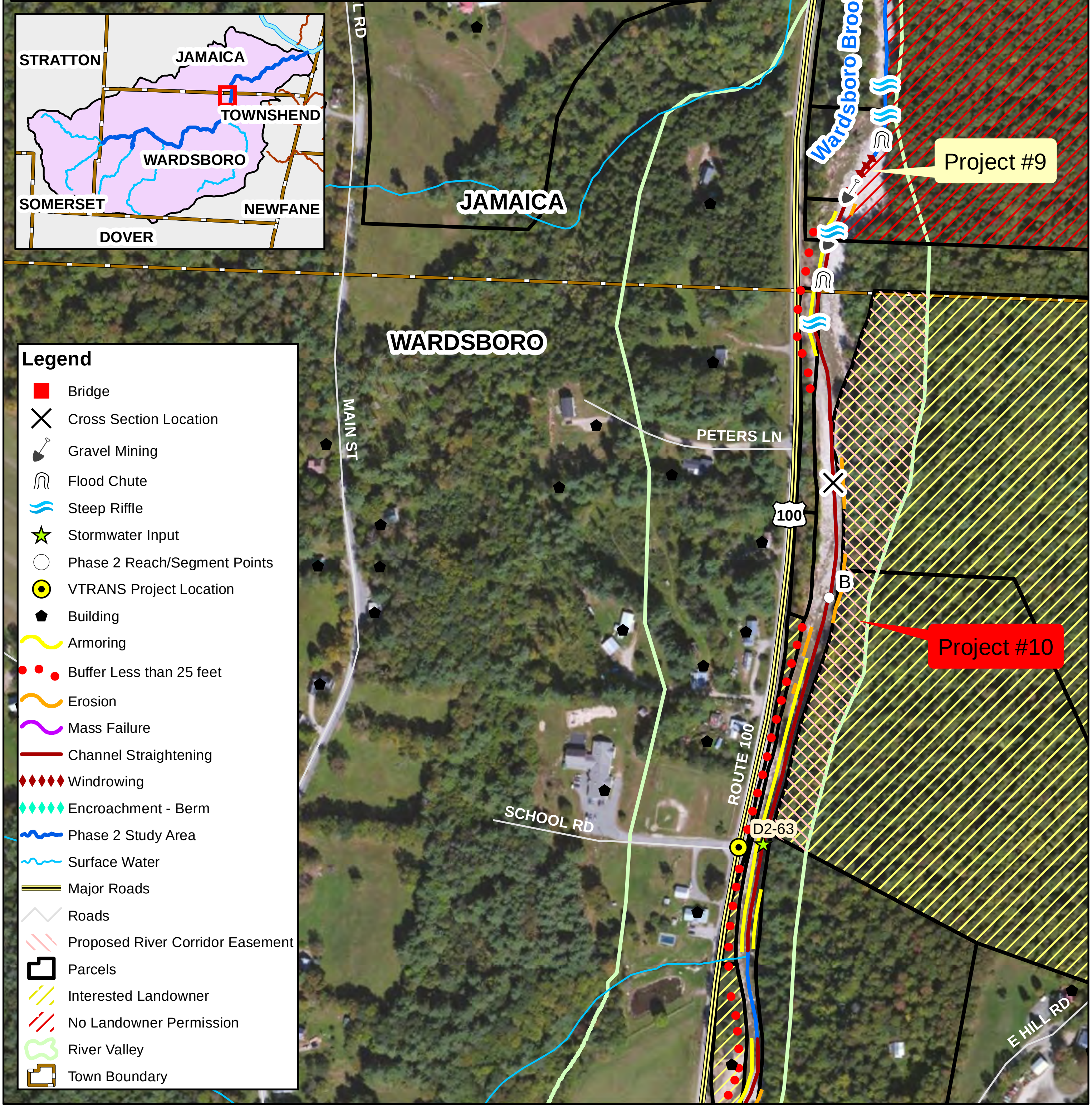
Project #5 – Return Windrowed Material/ Remove Berm

Project #6 – Investigate Channel Alteration

Project #7 – River Corridor Easement

Project #8 – Arrest Headcuts

Map 3: Impacts and Potential Projects
Reach T8.02-A through T8.02-B
Wardsboro Brook Watershed



Background is World Imagery

Projects:

9. Return Windrowed Material to Channel
10. River Corridor Easement

Project Priority:

- Low
- Moderate
- High

N

0 87.5175 350 Feet

1 inch = 350 feet

Bear Creek Environmental

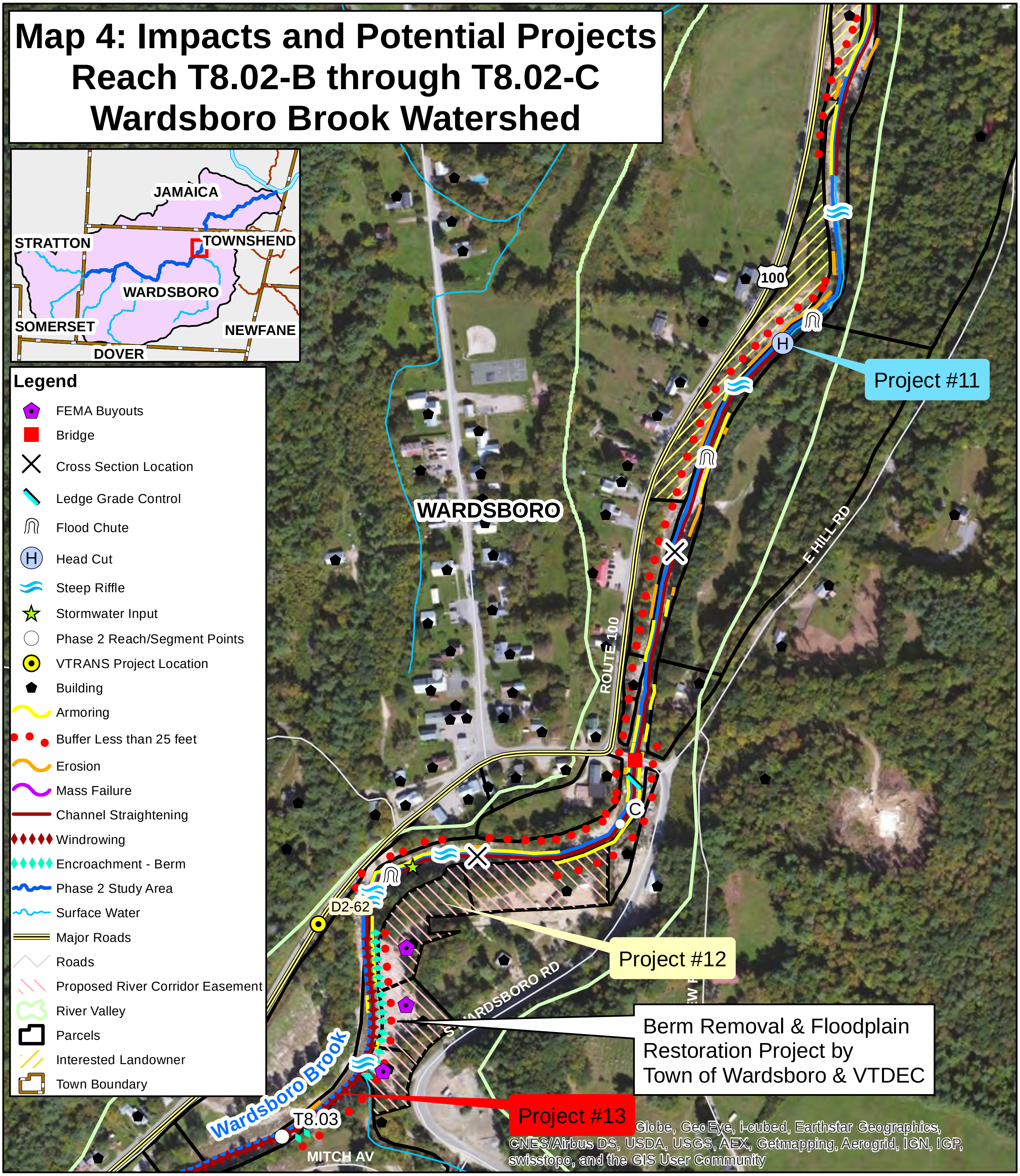
Table 3. Wardsboro Brook Main Stem Map 3: T8.02-A through T8.02-B Site Level Opportunities for Restoration and Protection Jamaica & Wardsboro, Vermont						
Project # Segment	**Type of Project**	**Site Description Including Stressors and Constraints**	**Project or Strategy Description**	**Technical Feasibility and Priority**	**Benefits**	**Potential Partners/Programs**
Project #9 T8.02-A	Active Restoration	Channel was dredged, gravel mined, and windrowed post-TSI.	**Return Windrowed Material to Channel**	Low Priority (no landowner permission on one side of brook)	Improved habitat, water quality, and geomorphic stability	Landowners, WRC, VANR
Project #10 T8.02-A & B	Passive Restoration	Some floodplain access exists along eastern bank of river. Interested landowner owns a significant tract of land.	**River Corridor Easement**	High Priority	Improved habitat and water quality	Landowners, WRC, VANR RCE

Photos of Proposed Project Locations – Map 3

Project #9 – Return Windrowed Material to Channel

Project #10 – River Corridor Easement

Map 4: Impacts and Potential Projects
Reach T8.02-B through T8.02-C
Wardsboro Brook Watershed



Background is World Imagery

Projects:

11. Arrest Headcut
12. River Corridor Easement
13. Return Windrowed Material to Channel

Project Priority:

- Low
- Moderate
- High

N

0 87.5175 350 Feet

1 inch = 350 feet

Bear Creek Environmental

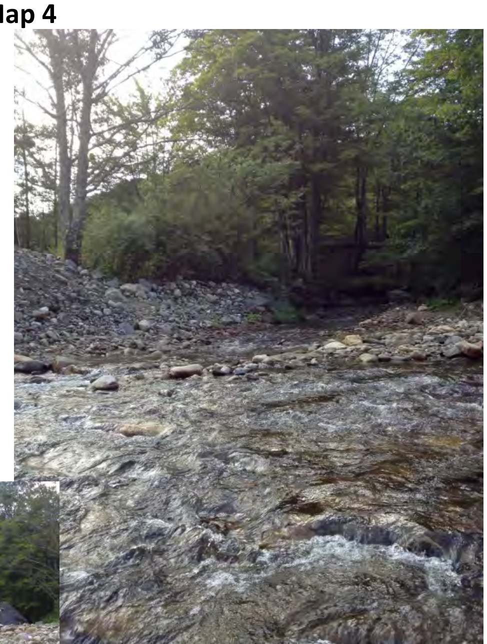
Table 4. Wardsboro Brook Main Stem
Map 4: T8.02-B through T8.02-C
Site Level Opportunities for Restoration and Protection
Wardsboro, Vermont

Project # Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Technical Feasibility and Priority	Benefits	Potential Partners/ Programs
Project #11 T8.02-B	Active Restoration	Channel has historically incised severely due to the placement of Rt. 100. One active headcut present in the segment may continue the process of incision.	**Arrest Headcut**	Moderate Priority	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR
Project #12 T8.02-C	Passive Restoration	Three homes were destroyed along the brook during TSI. These homes are now FEMA buyouts & a restoration project at the site has been designed by Todd Menees of VTDEC to remove a berm & rip rap and create a floodplain bench.	**River Corridor Easement**	Low Priority (Town of Wardsboro project at location of 3 FEMA buyouts; development already restricted on buyout properties)	Improved geomorphic stability, habitat, and water quality	Town of Wardsboro, VTDEC, WRC RCE
Project #13 T8.02-C & T8.03	Active Restoration	Just upstream of the floodplain bench project site, the windrowing continues. This windrowing could be returned to the brook at the same time the floodplain bench is constructed.	**Return Windrowed Material to Channel**	High Priority (same location as town project)	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR, Town of Wardsboro

Photos of Proposed Project Locations – Map 4

Project #11 – Arrest Headcut

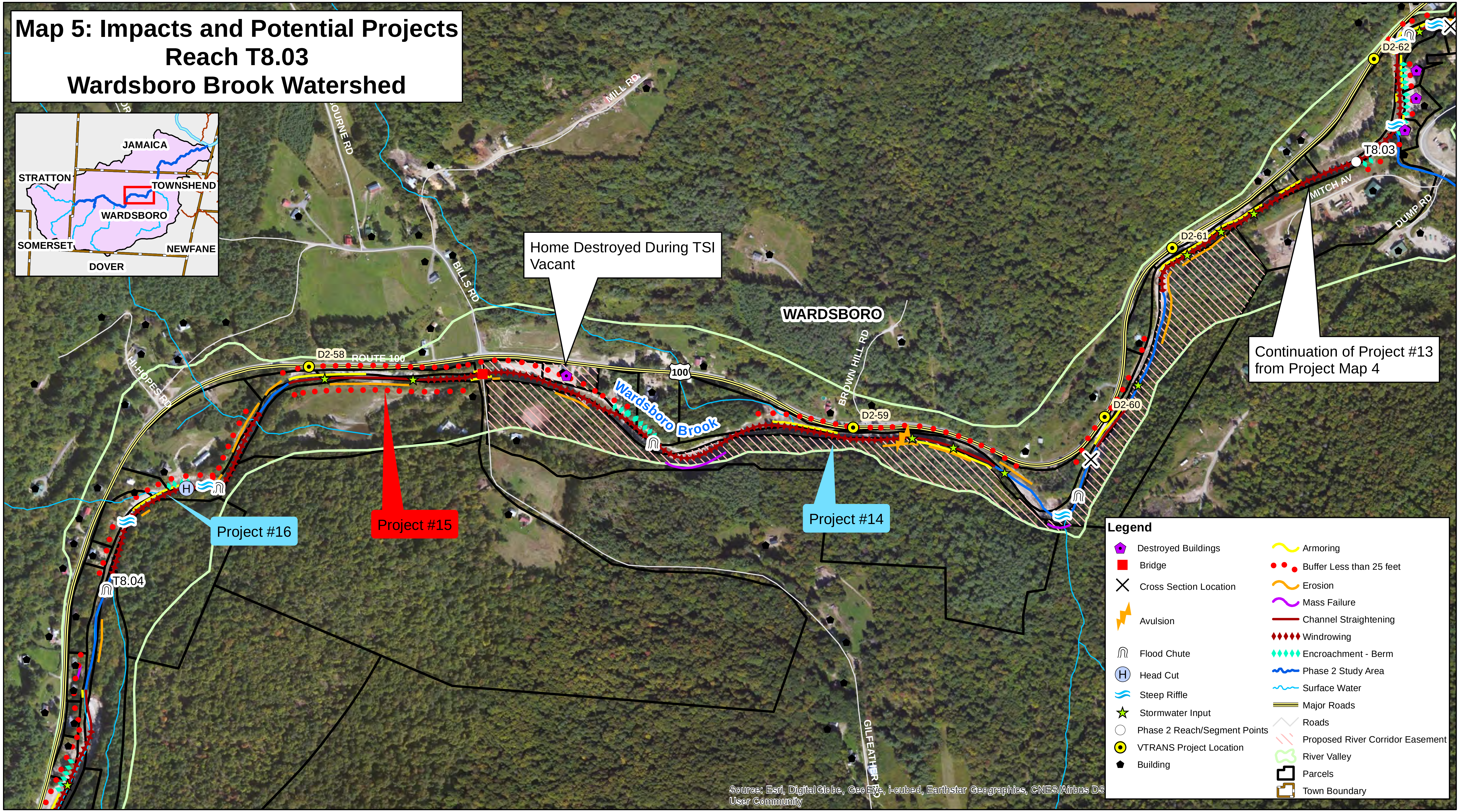
Project #13 – Return Windrowed Material



Project #12 – River Corridor Easement

FEMA buyout in T8.02-C

Map 5: Impacts and Potential Projects
Reach T8.03
Wardsboro Brook Watershed



Background is World Imagery

Projects:

14. Return Windrowed Material to Channel & River Corridor Easement
15. Streamside Plantings
16. Arrest Headcut & Return Windrowed Material to Channel

Project Priority:

- Low
- Moderate
- High

N

0 — 500 — 1,000 — 2,000 Feet

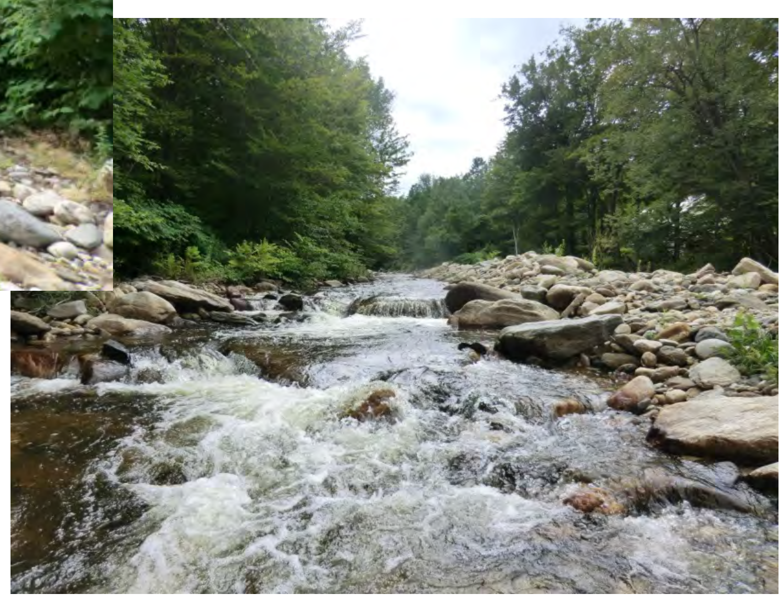
1 inch = 500 feet

Bear Creek Environmental

Table 5. Wardsboro Brook Main Stem Map 5: T8.03 Site Level Opportunities for Restoration and Protection Wardsboro, Vermont						
Project # Segment	**Type of Project**	**Site Description Including Stressors and Constraints**	**Project or Strategy Description**	**Technical Feasibility and Priority**	**Benefits**	**Potential Partners/ Programs**
Project #14 T8.03	Active & Passive Restoration	Channel has severely incised due to Rt. 100 and recent windrowing post-TSI. The stream is moving laterally as it adjusts planform.	**Return Windrowed Material to Channel & River Corridor Easement**	Moderate Priority	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR RCE
Project #15 T8.03	Passive Restoration	This section of the brook has poor buffers due to Rt. 100 on one side and a private lawn on the other. The lawn is large, but the stream banks are fairly high.	**Streamside Plantings**	High Priority (Large planting area, visible from Rt. 100)	Improved habitat and water quality	Landowner, WRC TFS
Project #16 T8.03	Active Restoration	Stream channel was excavated & windrowed post-TSI, creating a three foot berm on the north bank. There are houses along the bank. The channel is also actively headcutting.	**Arrest Headcut & Return Windrowed Material to Channel**	Moderate Priority (Berm is protecting house from flooding)	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR

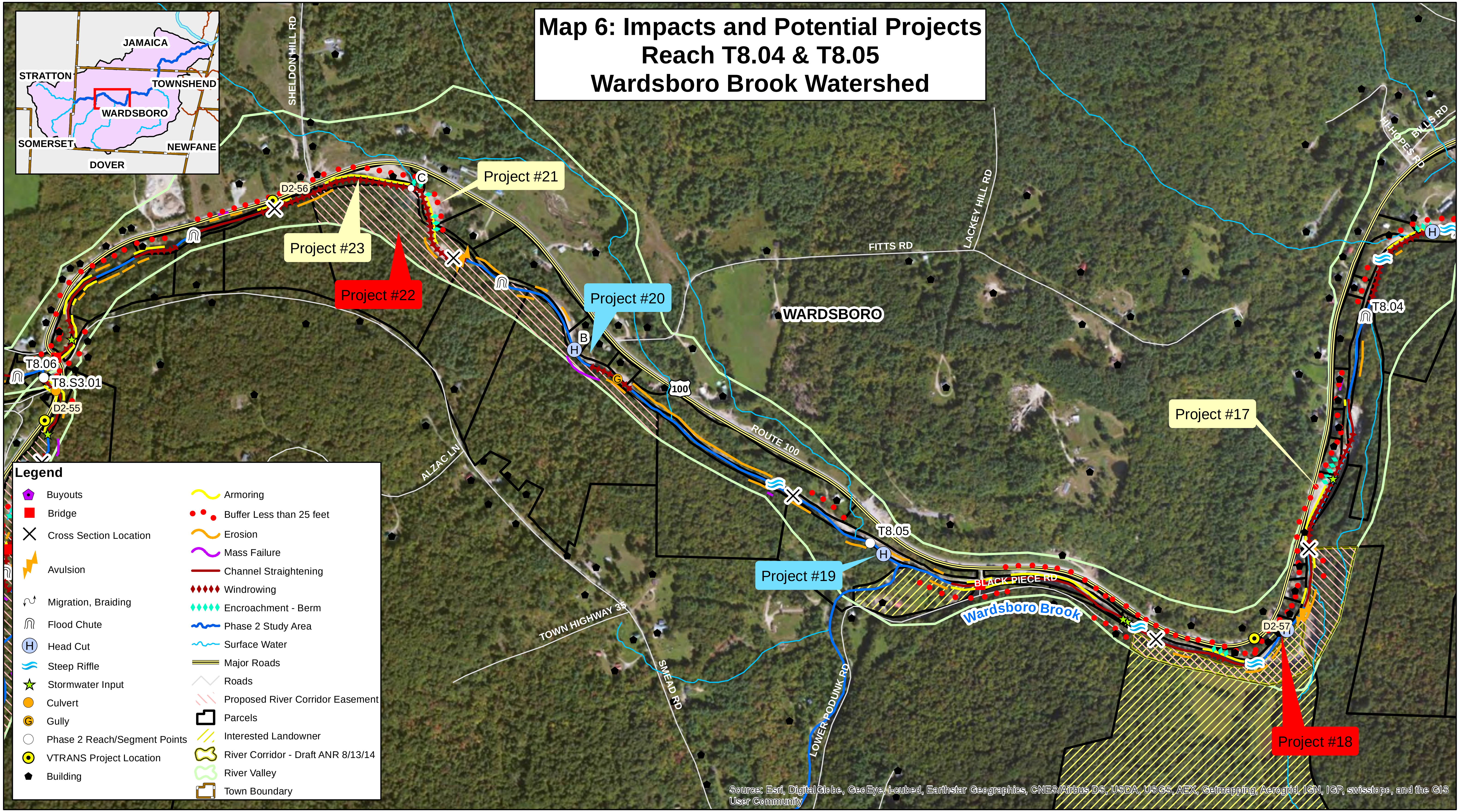
Photos of Proposed Project Locations – Map 5
(No photo for Project #15)

Project #14 – Return Windrowed Material & River Corridor Easement



Project #16 – Arrest Headcut & Return Windrowed Material to Channel

Map 6: Impacts and Potential Projects
Reach T8.04 & T8.05
Wardsboro Brook Watershed



Projects:

17. Return Windrowed Material to Channel
18. River Corridor Easement & Flood Mitigation
19. Arrest Headcut
20. Return Windrowed Material to Channel & Arrest Headcut
21. Streamside Plantings
22. River Corridor Easement
23. Return Windrowed Material to Channel

Project Priority:

- Low
- Moderate
- High

N

0 500 1,000 2,000 Feet

1 inch = 600 feet

Background is World Imagery

Bear Creek Environmental

Table 6. Wardsboro Brook Main Stem Map 6: T8.04 through T8.05 Site Level Opportunities for Restoration and Protection Wardsboro, Vermont						
Project # Segment	**Type of Project**	**Site Description Including Stressors and Constraints**	**Project or Strategy Description**	**Technical Feasibility and Priority**	**Benefits**	**Potential Partners/ Programs**
Project #17 T8.04	Active Restoration	Channel was excavated & windrowed post-TSI, which is restricting floodplain access. A two foot berm was created that is protecting a house from flooding.	**Return Windrowed Material to Channel**	Low Priority (Berm is protecting a house)	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR
Project #18 T8.04	Passive Restoration	The channel is undergoing major planform change in this area. A major channel avulsion occurred during TSI. Future changes in the course of the river in this location put several houses on the west bank at risk of severe damage/destruction. Acquisition of these homes through FEMA could reduce future flood damage.	**River Corridor Easement & Flood Mitigation**	High Priority (Interested landowners, at risk homes)	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR, Town of Wardsboro, FEMA RCE
Project #19 T8.04	Active Restoration	Stream channel was historically straightened and is actively headcutting.	**Arrest Headcut**	Moderate Priority	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR
Project #20 T8.05-A	Active Restoration	Above this segment, there is a large sediment plug, which has caused a major headcut at the top of the segment. Headcut may move upstream into area with good floodplain access. Sediment plug has led to a sediment-starved segment that has incised. Post-TSI windrowing has exacerbated these impacts.	**Return Windrowed Material to Channel & Arrest Headcut**	Moderate Priority	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR
Project #21 T8.05-B	Passive Restoration	Riparian buffer is poor on one side due to private lawn. Not a large area for planting & bank is windrowed.	**Streamside Plantings**	Low Priority	Improved habitat and water quality	Landowner, WRC TFS
Project #22 T8.05-B & C	Passive Restoration	Channel is undergoing active planform adjustment. Segment has good floodplain access.	**River Corridor Easement**	High Priority (one of the only segments in study area with good floodplain access)	Improved geomorphic stability, habitat, and water quality	Landowners, WRC RCE
Project #23 T8.05-B & C	Active Restoration	Channel was excavated & windrowed post-TSI along Rt. 100 and two houses, restricting floodplain access and creating a 4 foot berm. Berm is protecting a house.	**Return Windrowed Material to Channel**	Low Priority (Berm protecting a house)	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR

Photos of Proposed Project Locations – Map 6
(No photo for Project #23)

Project #17 – Return Windrowed Material

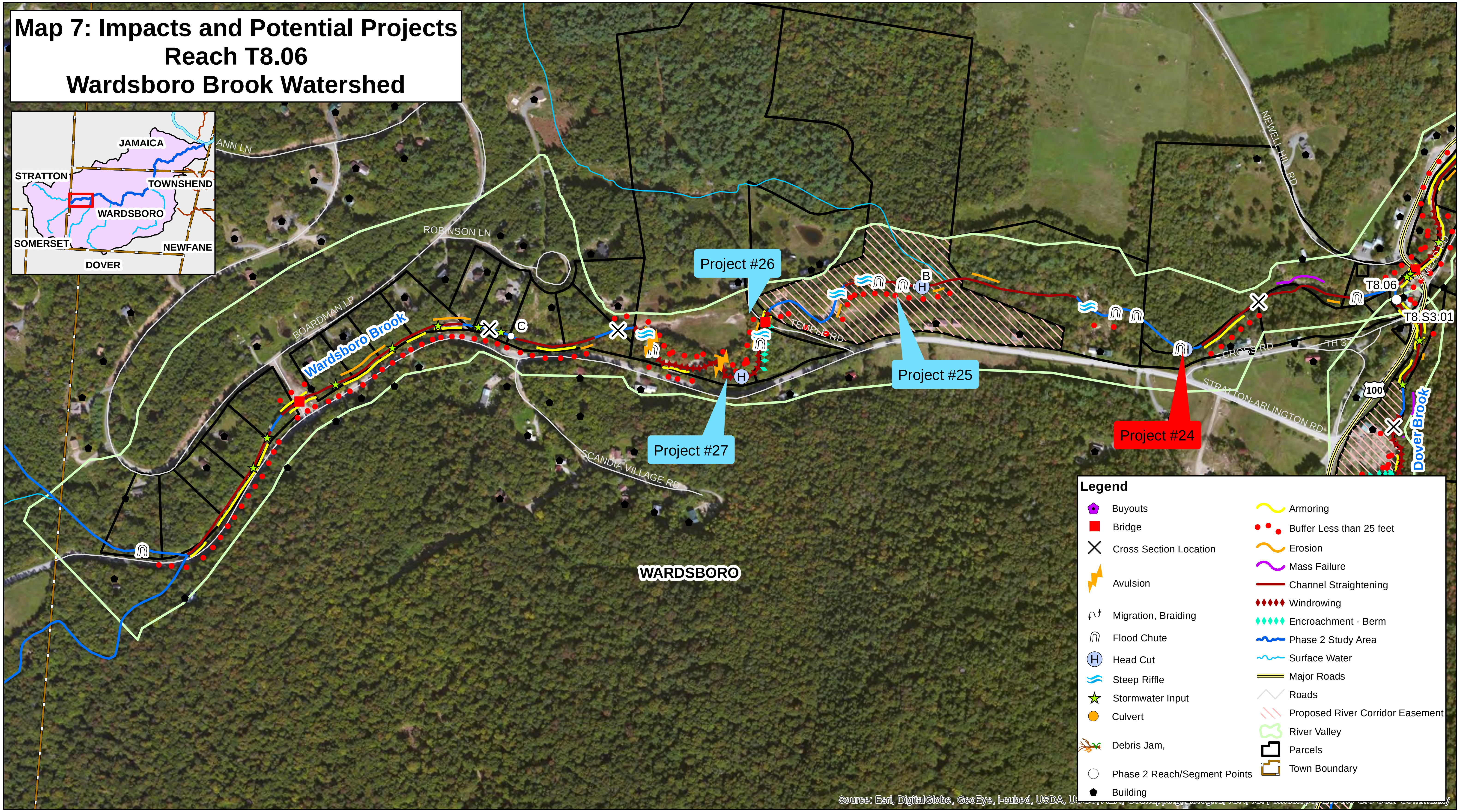
Project #18 – River Corridor Easement & Flood Mitigation

Project #19 – Arrest Headcut

Project #20 – Return Windrowed Material & Arrest Headcut

Project #21 – Streamside Plantings

Project #22 – River Corridor Easement



Background is World Imagery

Projects:

24. Arrest Headcut
25. Streamside Plantings & River Corridor Easement
26. Streamside Plantings
27. Return Windrowed Material to Channel

Project Priority:

- Low
- Moderate
- High

N

0 500 1,000 2,000 Feet

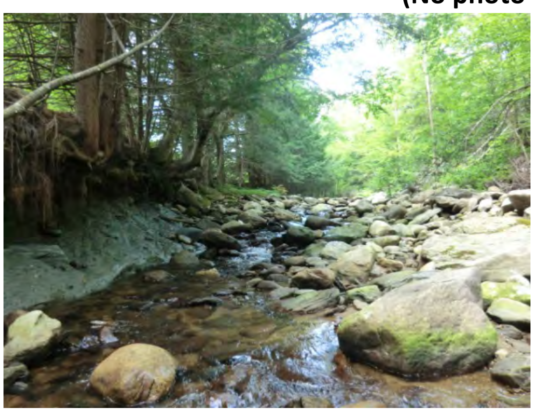
1 inch = 400 feet

Bear Creek Environmental

Table 7. Wardsboro Brook Main Stem Map 7: T8.06 Site Level Opportunities for Restoration and Protection Wardsboro, Vermont						
Project # Segment	**Type of Project**	**Site Description Including Stressors and Constraints**	**Project or Strategy Description**	**Technical Feasibility and Priority**	**Benefits**	**Potential Partners/ Programs**
Project #24 T8.06-A	Active Restoration	Channel historically incised and active headcut is present.	**Arrest Headcut**	High Priority	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR
Project #25 T8.06-B	Passive Restoration	Channel has good floodplain access and good habitat, but buffer is lacking on the south bank.	**Streamside Plantings & River Corridor Easement**	Moderate Priority	Improved habitat and water quality; attenuation of floodwaters and sediment	Landowners, WRC RCE, TFS
Project #26 T8.06-B	Passive Restoration	Channel has good floodplain access and good habitat, but buffer is lacking on the north bank.	**Streamside Plantings**	Moderate Priority (potential ag field)	Improved habitat and water quality	Landowner, WRC TFS
Project #27 T8.06-B	Active Restoration	Channel was windrowed & excavated after TSI below bridge. No buildings are along the banks in this area.	**Return Windrowed Material to Channel**	Moderate Priority	Improved geomorphic stability, habitat, and water quality	Landowners, WRC, VANR

Photos of Proposed Project Locations – Map 7
(No photo for Project #26)

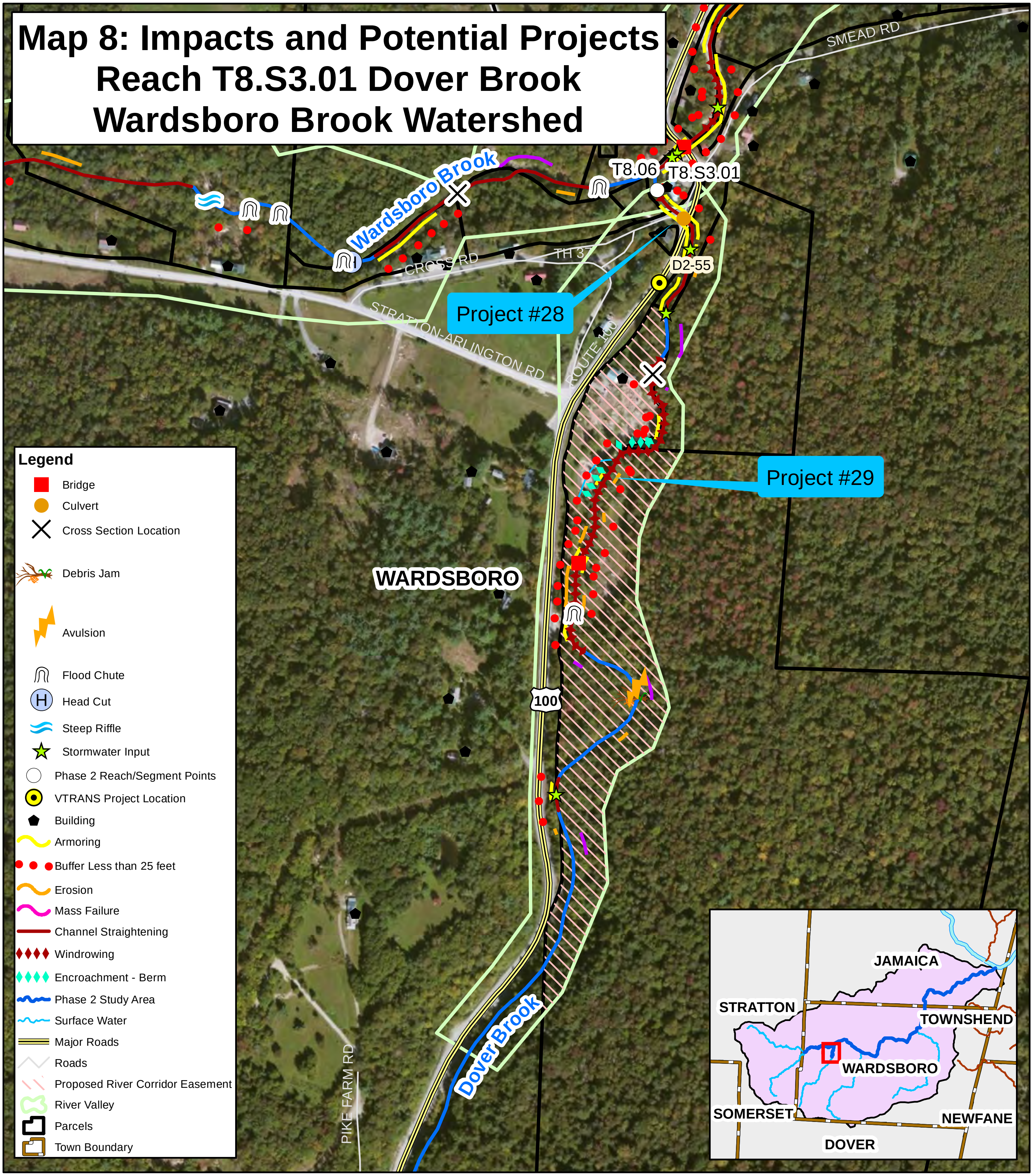
Project #24 – Arrest Headcut



Project #25 – Streamside Plantings & River Corridor Easement

Project #27 – Return Windrowed Material to Channel

Map 8: Impacts and Potential Projects
Reach T8.S3.01 Dover Brook
Wardsboro Brook Watershed



Background is World Imagery

Projects:

28. Culvert Retrofit
29. Return Windrowed Material to Channel, Streamside Plantings, & River Corridor Easement

Project Priority:

- Low
- Moderate
- High

N

0 100 200 400 Feet

1 inch = 400 feet

Bear Creek Environmental

Table 8. Dover Brook Map 8: T8.S3.01 Site Level Opportunities for Restoration and Protection Wardsboro, Vermont						
Project # Segment	**Type of Project**	**Site Description Including Stressors and Constraints**	**Project or Strategy Description**	**Technical Feasibility and Priority**	**Benefits**	**Potential Partners/ Programs**
Project #28 T8.S3.01	Active Restoration	The culvert under Rt. 100 and Cross Rd is very poorly aligned with the stream. It is also a potential barrier to AOP under low flows.	**Culvert Retrofit**	Moderate Priority	Improved habitat, geomorphic stability, and AOP	Town of Wardsboro, VANR, WRC
Project #29 T8.S3.01	Active & Passive Restoration	One very large parcel spans almost entire reach. Channel undergoing major planform adjustment. Areas are severely incised due to historic straightening and recent channel windrowing (post-TSI). Buffers are poor in lower half of reach. Planting opportunity exists on two private lawns. Property owner owns dog boarding and training business and boards over 20 dogs in yard.	**Return Windrowed Material to Channel, Streamside Plantings, River Corridor Easement**	Moderate Priority (Berm protects dogs; dogs occupy lawn)	Improved habitat and water quality	Landowner, WRC, VANR RCE, TFS

Photos of Proposed Project Locations – Map 8

Project #28 – Culvert Retrofit

Project #29 – Return Windrowed Material, Streamside Plantings, River Corridor Easement