Ompompanoosuc River Corridor Plan

West Fairlee to Thetford, Vermont

April 28, 2011

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Thetford Conservation Commission

Vermont Agency of Natural Resources

Ompompanoosuc River Watershed Council

White River Natural Resources Conservation District

Funding Provided by:

Upper Connecticut Mitigation and Enhancement Fund

Acknowledgments

Bear Creek Environmental, LLC (BCE) would like to acknowledge the individuals and groups who contributed their time and effort in the preparation of the Ompompanoosuc River Corridor plan for the section of the river from West Fairlee to Thetford. The Upper Connecticut Mitigation and Enhancement Fund provided funding for the project. Ben Copans, Sacha Pealer, and Gretchen Alexander of the Vermont Department of Environmental Conservation (DEC) provided technical guidance. The project had many partners including: the West Fairlee Conservation Commission (WFCC), the Thetford Conservation Commission (TCC), the Vermont Agency of Natural Resources, the Ompompanoosuc River Watershed Council (OWC), and the White River Natural Resources Conservation District.

BCE would also like to thank Ben Copans and Sacha Pealer (DEC); Corey Paye and members of the WFCC, Lilian Shen (TCC and OWC), Linda Matteson (OWC), and Sally Hull of Two Rivers-Ottauquechee Regional Planning Commission for providing comments on the draft Ompompanoosuc River Watershed Plan.

Ompompanoosuc River Mainstem in West Fairlee, Vermont

Ompompanoosuc River Corridor Plan
West Fairlee to Thetford, Vermont

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Ompompanoosuc River Corridor Plan
West Fairlee to Thetford, Vermont

EXECUTIVE SUMMARY

The River Corridor Planning effort in 2010-2011 of the upper Ompompanoosuc River and major tributaries is led by the West Fairlee Conservation Commission (grantee). Additional project partners include the Thetford Conservation Commission, the Ompompanoosuc River Watershed Council, the White River Natural Resources Conservation District (WNRCD) and the Vermont Agency of Natural Resources (VANR). The Vermont Department of Environmental Conservation (DEC) provided technical assistance for the project.

The 2010-2011 grant from the Upper Connecticut Mitigation and Enhancement Fund supported efforts to complete a Phase 2 Stream Geomorphic Assessment of the main stem of the Ompompanoosuc River from West Fairlee to Thetford, the lower portions of Blood Brook, Middle Brook, and Schoolhouse Brook. Approximately 14 miles of river were assessed in 2010. The Phase 2 information is the basis for the preparation of a River Corridor Plan (RCP). The primary objective of the RCP is to use stream geomorphic assessment data and habitat data to identify and prioritize river corridor protection and restoration projects within the Ompompanoosuc River watershed. The 2010 Phase 2 Assessment follows a Phase 1 Stream Geomorphic Assessment of the main stem of the Ompompanoosuc and tributaries that was completed in the spring of 2009 with support from a Clean and Clear Grant through the VANR. Additional funding is being sought by the Thetford Conservation Commission to complete a Phase 2 assessment of the lower Ompompanoosuc River main stem in Thetford and Norwich and the lower end of the West Branch in Thetford.

The Phase 2 assessment in 2010 was helpful in identifying major stressors to geomorphic stability in the Ompompanoosuc River watershed. One of the major problems in the watershed is channel straightening associated with the construction of roads and development as well as agricultural fields. In some cases, alteration of stream channels and floodplains has caused moderate to extreme channel degradation (i.e. lowering of the bed) resulting in sediment build up, channel widening and planform adjustment (lateral movement). There are four on-stream dams that are impeding the passage of aquatic organisms. High quality streamside buffers are lacking along the Ompompanoosuc River, Middle Brook and Blood Brook causing unstable streambanks and increased erosion. Livestock grazing in the riparian buffer of Blood Brook is also impacting bank stability and habitat.

As the river works toward a more stable equilibrium, the communities of West Fairlee and Thetford have the opportunity to provide long-term protection to the river corridor and encourage the reestablishment of floodplain vegetation and healthy instream habitat. At the reach and site level, potential restoration and protection projects that would be compatible with geomorphic adjustments and managing the stream toward equilibrium conditions were identified. A list of 29 potential restoration and conservation projects was developed during project identification including: river corridor and wetland protection through easements and conservation efforts, improving riparian buffers, evaluation of berm and dam removal, stormwater management, replacement of bridges and culverts, arresting active head cuts (incision), and improving stability of mass failures.

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Ompompanoosuc River Corridor Plan
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1.0 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.

1.1 Overview

This project focuses on the Ompompanoosuc River watershed in West Fairlee and Thetford, Vermont. Three *tributaries* (Blood Brook, Middle Brook and Schoolhouse Brook) and the main stem of the Ompompanoosuc were assessed using the Vermont Agency of Natural Resources Phase 2 Stream Geomorphic Assessment protocol during summer 2010 for a total of fourteen river miles. The Vermont River Management program has developed stream geomorphic assessment protocols that utilize the science of *fluvial geomorphology* (fluvial = water, geo = earth, and morphology = land shape). Fluvial geomorphology focuses on the processes and pressures operating on river systems.

1.2 River Corridor Planning Team

The river corridor planning team for the Ompompanoosuc River watershed is comprised of the West Fairlee Conservation Commission, the Thetford Conservation Commission, the Agency of Natural Resources, White River Natural Resources Conservation District, the Ompompanoosuc River Watershed Council, VANR, and landowners. This 2010/2011 planning effort is led by the West Fairlee Conservation Commission in close consultation with the Ompompanoosuc River Watershed Council. Funding for the project is provided through a grant from the Upper Connecticut Mitigation and Enhancement Fund. Sacha Pealer and Gretchen Alexander from the Vermont River Management Section of VANR provided a quality control/assurance review of the stream geomorphic assessment data and assisted with fieldwork. Ben Copans, DEC Watershed Coordinator, was instrumental in providing technical guidance to the grantee throughout this project.

1.3 Local Project Objectives

The stream geomorphic assessment data is 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. The study results are also important for

designing *restoration* and protection projects for the watershed. The 2010 proposal submitted to the Upper Connecticut Mitigation and Enhancement Fund by the West Fairlee Conservation Commission provides many reasons why the fourteen river miles were selected and prioritized for the Phase 2 study. The main stem of the Ompompanoosuc River from just below the Route 113 crossing in Thetford upstream to the West Fairlee/Vershire town boundary was included in the study because of interest in fluvial *erosion* hazard (FEH) zoning in Thetford and the potential for implementing projects in areas with active *planform* adjustment in both towns. The outlet to Lake Fairlee, which is the lower end of Blood Brook, was prioritized for inclusion in the project because its channel type has extreme *sensitivity*. This means the valley, *floodplain*, or condition of the channel has a high likelihood of responding to both natural and man induced disturbances. The Lake Fairlee outlet was also included in the study because it includes a potential project location owned by the Town of Thetford and managed by the Thetford Conservation Commission. Blood and Middle Brooks were prioritized for inclusion in the Phase 2 assessment due to lack of vegetative buffer and the potential to implement restoration and protection projects that reduce phosphorus loading to Lake Fairlee. The lowest section of Schoolhouse Brook was studied to better understand factors leading to active planform adjustment of the channel.

1.4 Goals of the Vermont River Management Program

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

2.0 BACKGROUND WATERSHED INFORMATION

2.1 Geographic Setting

2.1.1 Watershed Description

The Ompompanoosuc River is one of the major rivers in Vermont that drains 137 square miles into the Connecticut River (Figure 2.1). The portion of the watershed that was studied in 2010 lies within Orange and Windsor Counties and includes the following streams: Ompompanoosuc River main stem, Middle Brook, Blood Brook, Lake Fairlee Outlet, and Schoolhouse Brook. The Phase 2 study focused on the main stem of the Ompompanoosuc River primarily upstream of the confluence with Lake Fairlee outlet, Lake Fairlee outlet, the lower sections of Schoolhouse Brook, Middle Brook, and Blood Brook. The combined length of the stream channel assessed is 14 miles.

2.1.2 Political Jurisdictions

The Ompompanoosuc River watershed is located in the following towns within Orange and Windsor County: Vershire, West Fairlee, Fairlee, Thetford, Strafford, Norwich, Sharon, Chelsea, and Tunbridge. This project focused on the river channel and *riparian corridor* within the towns of West Fairlee and Thetford in Orange County.

2.1.3 Land Use

The 1992 land cover data was the only Geographic Information System (GIS) data available at the time of the Phase 1 assessment. The land cover data presented in the ANR's data management system is based on the 1992 layer. A more current land cover layer from 2002 was obtained from the Vermont Center for Geographic Information (VCGI) to present land use within the Ompompanoosuc River watershed for the river corridor plan. The 2002 land cover layer shows the Ompompanoosuc River Watershed is dominated by forested land (Figure 2.2). However, agriculture and developed land are sub-dominant land uses within the Ompompanoosuc Watershed. Developed areas are concentrated within the river corridor, especially near the mouth of the Ompompanoosuc River, adjacent to the Lake Fairlee outlet, and in the village center of West Fairlee.

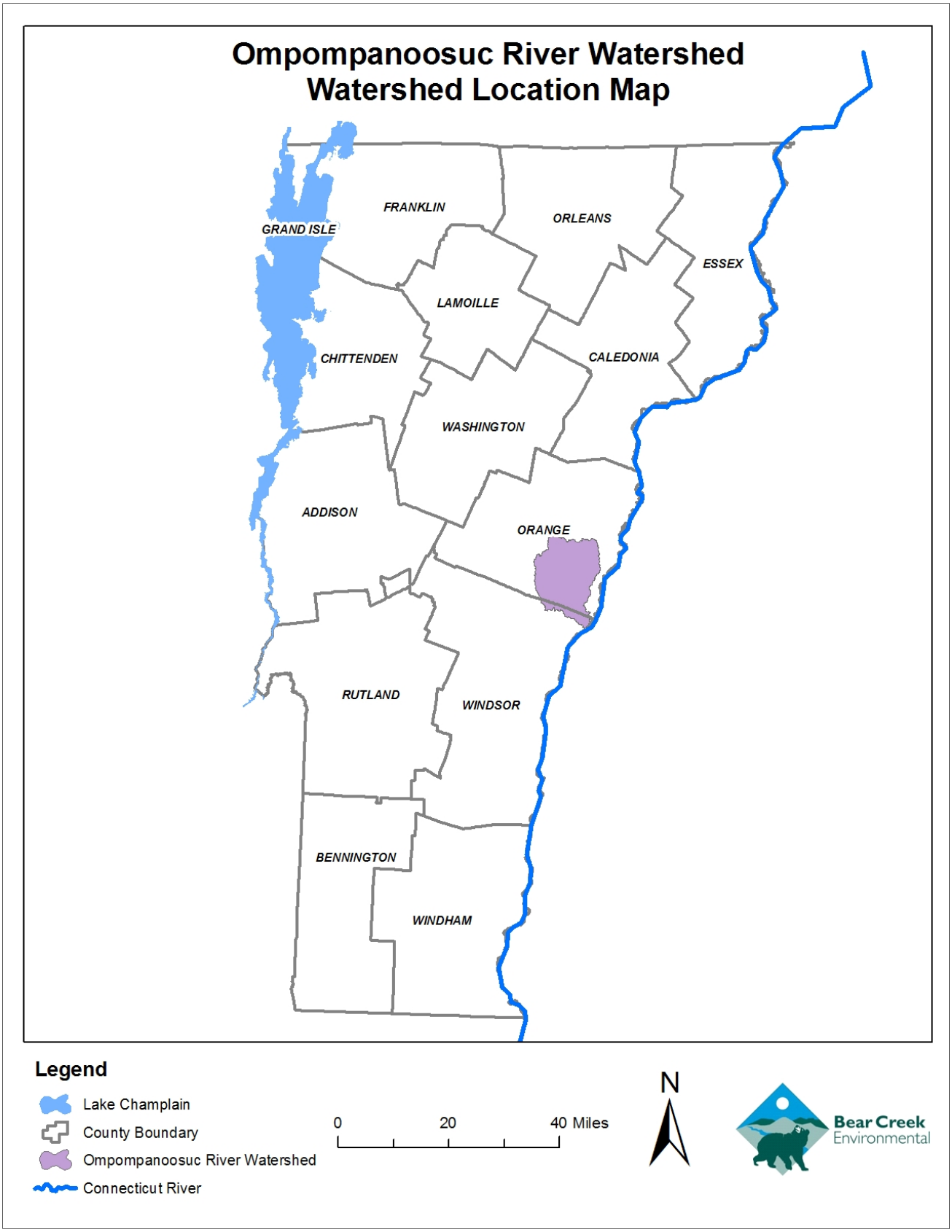

Figure 2.1. Watershed Location Map for Ompompanoosuc River Watershed

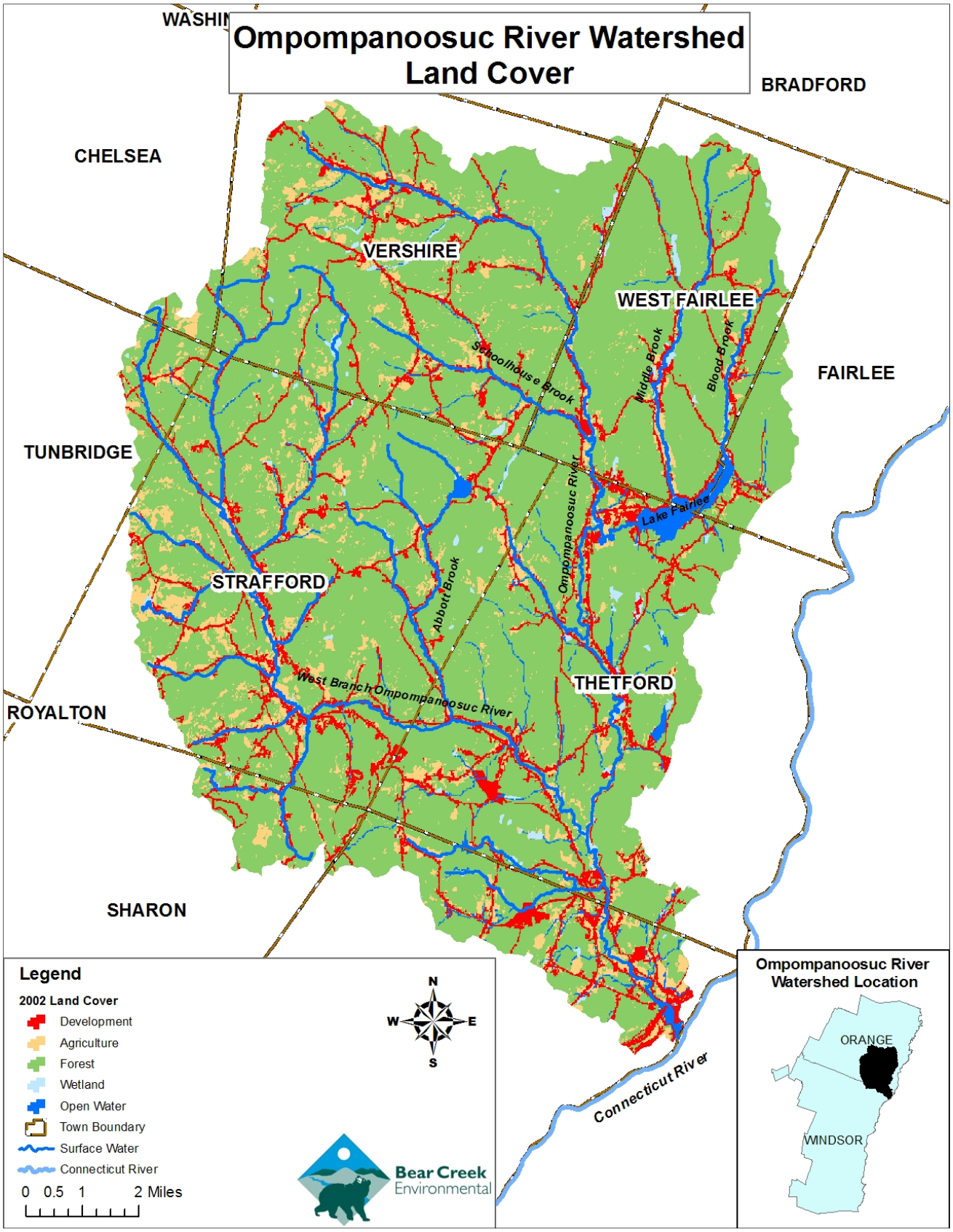

Figure 2.2. Land Cover and Land Use Map for the Ompompanoosuc River Watershed

2.2 Geologic Setting

The Ompompanoosuc River flows through a gentle *gradient* valley, except for the most upstream areas. Most of the main stem has a channel slope less than one percent. The greatest slopes are located in the most upstream areas, but are still all less than five percent on the main stem.

The Ompompanoosuc Watershed is located in the Connecticut Valley-Gaspe Basin Province, which contains thick sedimentary calcareous deposits (Doolan, 1996). The bedrock geology of this region is predominantly made up of metamorphosed sedimentary rocks and volcanic intrusions (Van Diver, 1987). This region was later worked by glaciation and now contains significant glacial drift deposits that have been downcut by the flowing rivers and streams (Van Diver, 1987).

Natural Resource Conservation Service (NRCS) soils information for the Ompompanoosuc watershed was acquired from the Vermont Center for Geographic Information. The dominant *surficial sediment*s (sediment deposits above bedrock) within the Ompompanoosuc valley are primarily glacial till, ice-contact deposits, and alluvium. Sub-dominant surficial sediments include glacial till, ice-contact deposits, alluvium, glacial lake, and other deposits.

2.3 Geomorphic Setting

The watershed was divided into 139 *reaches* for the Phase 1 assessment (Table 1). 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 2.3 represents the downstream end of the reach. Approximately one-third of the watershed received a Phase 1 assessment in 2004, with the remaining two-third of the watershed receiving a Phase 1 assessment in 2009 (Figure 2.3).

Previous Geomorphic Assessment Studies

A Phase 1 assessment of the West Branch of the Ompompanoosuc River (WBOR) watershed in Strafford was led by the Strafford Conservation Committee and was funded through a grant from the Upper Connecticut Mitigation and Enhancement Fund (New Hampshire Charitable Foundation). The 2004 Phase 1 study included 40 reaches (46 river miles) on the West Branch mainstem and the six major tributaries to the West Branch (Bear Creek Environmental, 2004). A Phase 1 Stream Geomorphic Assessment sponsored by the Thetford Conservation Commission was conducted of the main stem of the Ompompanoosuc and its major tributaries (Middle Brook, Blood Brook, Lake Fairlee Outlet, Barker Brook, Avery Brook, Schoolhouse Brook, Ompompanoosuc West Branch up to Abbott Brook, and Abbott Brook) in 2008 and 2009 (Bear Creek Environmental, 2009). During the 2008/2009 Phase 1 assessment, the remaining portion of the Ompompanoosuc River Watershed was divided into 99 reaches, encompassing roughly 73 miles of river channel.

Table 1. Stream Geomorphic Assessment Summary[1] Ompompanoosuc River Watershed				
Lead Organization	**Year**	**Phase**	**Channel Length (River Miles)**	**Number of Reaches**
Stafford Conservation Commission	2004	1	46	40
Thetford Conservation Commission	2009	1	73	99
Strafford Conservation Commission	2005	2	11	16
West Fairlee Conservation Commission	2010	2	14	15
[1]Refer to Figure 2.3 for location of study area.				

During 2004, the Strafford Conservation Commission with the assistance of BCE conducted stream crossing assessments of 29 bridges and 10 *culverts* in Phase 1 reaches in Strafford using the protocol developed by the Vermont DEC. The Strafford Conservation Commission also retained BCE to perform a Phase 2 Geomorphic Assessment of sixteen reaches (11 river miles) within the WBOR watershed during 2005 (Bear Creek Environmental, 2006a). The Phase 2 Strafford project was funded through a grant from the Upper Connecticut Mitigation and Enhancement Fund, and included the main stem starting at the Strafford/Thetford town line to just north of the Upper Village as well as the lower reaches of the major tributaries. A river corridor plan (Bear Creek Environmental, 2006b) was developed by the Strafford Conservation Commission in 2006 with funding from the Upper Connecticut Mitigation and Enhancement Fund. In partnership with the Vermont DEC, the Agency of Agriculture, Newton School, the White River Natural Resources Conservation District, and Bear Creek Environmental, the Strafford Conservation Commission has been focusing on project implementation and landowner outreach within the WBOR watershed in recent years (2007 through the present).

2010 Geomorphic Assessment Study

This 2011 report summarizes the 2010 Phase 2 study of the Ompompanoosuc River watershed, which focused on the Ompompanoosuc River main stem, Lake Fairlee outlet, and the lower reaches of Middle Brook, Blood Brook, and Schoolhouse Brook (Figure 2.3). The combined length of the stream reaches assessed during the Phase 2 study is approximately 14 miles (Figure 2.4) The 2010 Phase 2 study area includes 15 reaches.

Reaches were divided further into *segments* during the Phase 2 investigation based on changes in channel conditions. 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 15 Phase 2 reaches studied in 2010 were broken further into 31 segments based on field observations. Segments are labeled using letter notation (i.e. R15-A is the most downstream segment on reach 15). The most downstream segment within a reach is labeled "A", the second from the reach point is "B, etc.

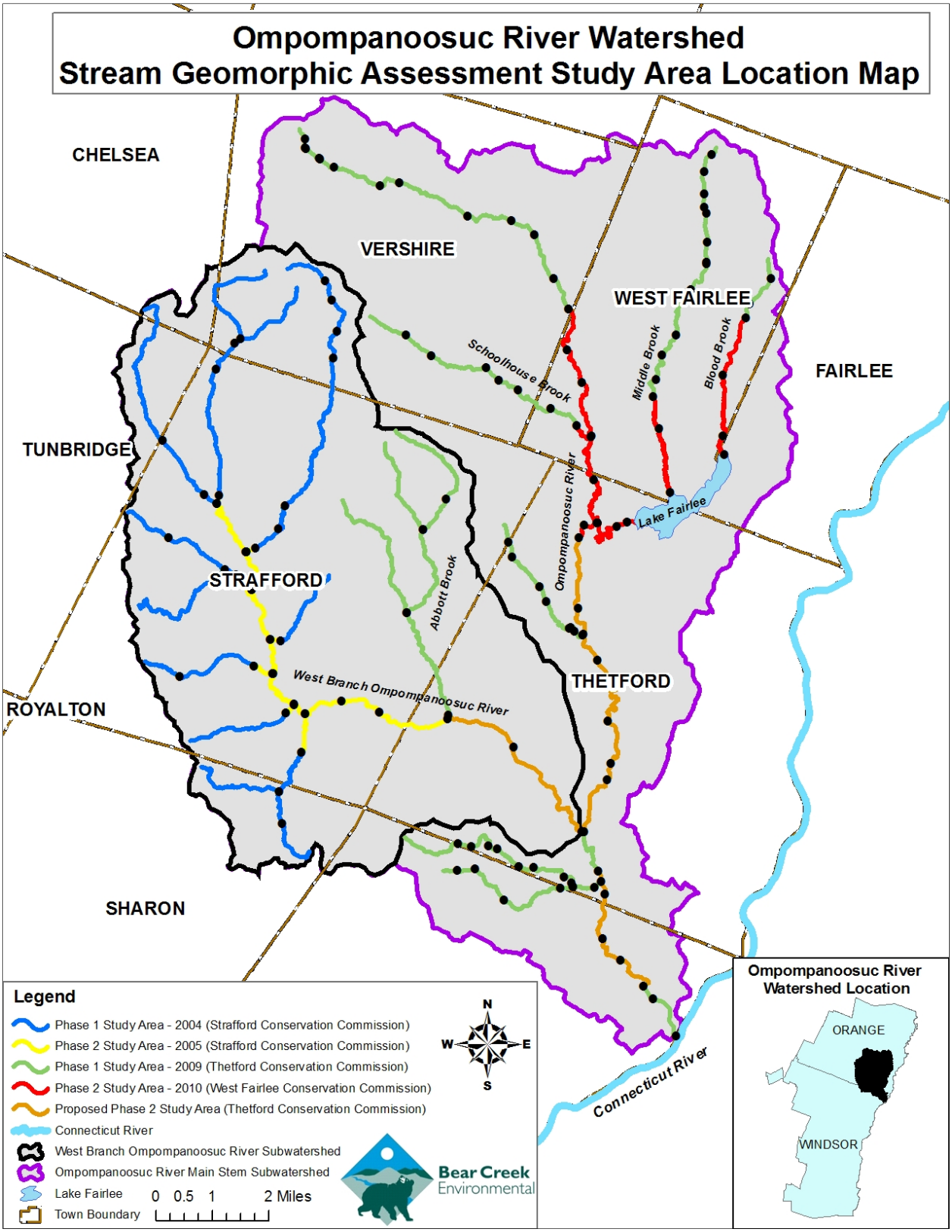

Figure 2.3. Ompompanoosuc River Stream Geomorphic Assessment Study Area

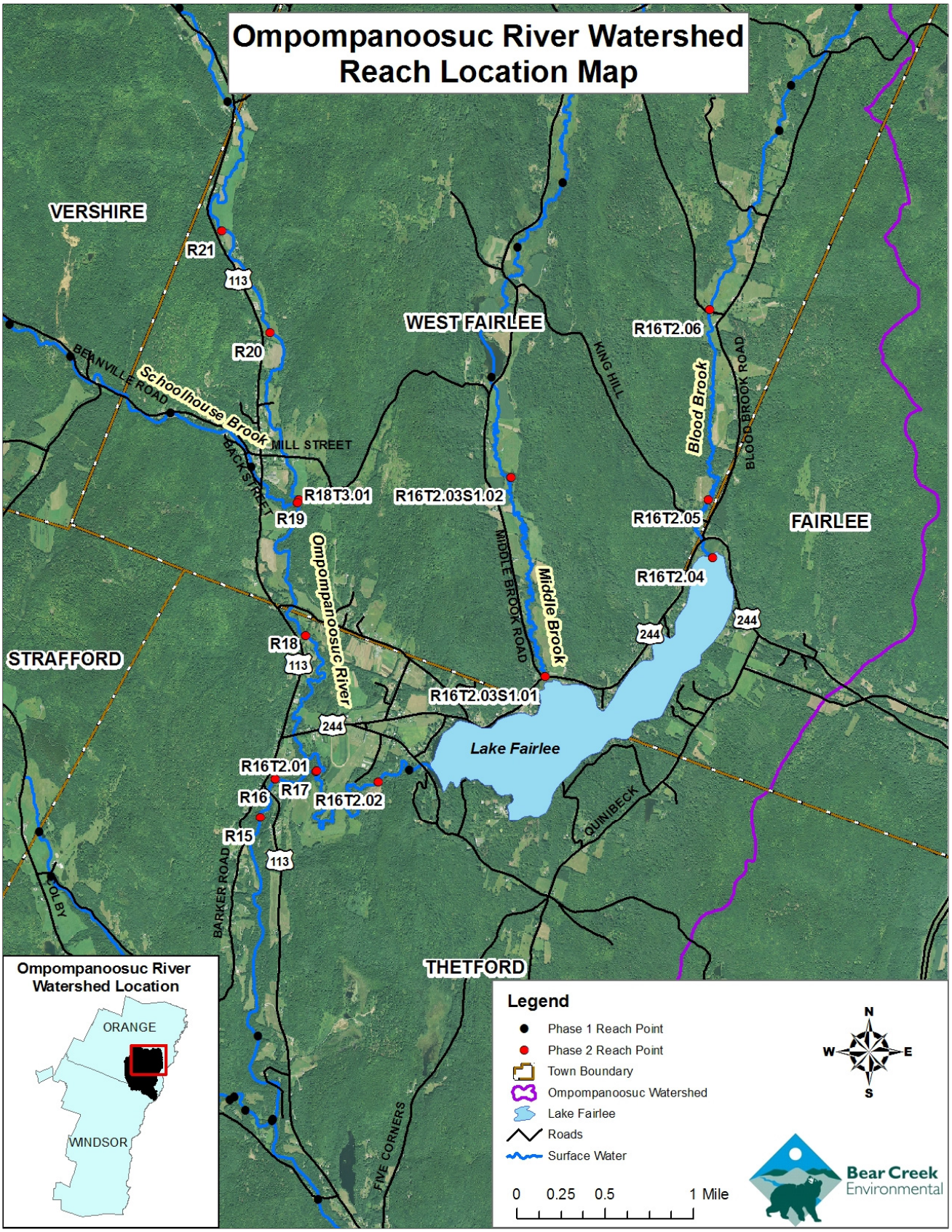

Figure 2.4. Ompompanoosuc River watershed Reach Location Map for 2010 Phase 2 Reaches

Reference stream types are also labeled with letter notation, and should not be confused with segment labels. The stream type letter refers to the degree of valley confinement (i.e. width of the floodplain), the valley slope and channel dimensions. Reference stream types are based on the 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, and/or watershed. Stream and valley characteristics including valley confinement, and slope were determined from digital USGS topographic maps. The reference reach characteristics were refined during the windshield survey and Phase 2 Assessment. Reference reach typing is based on both the Rosgen (1996) and the Montgomery and Buffington (1997) classification systems. Table 2 shows the typical characteristics used to determine reference stream types (Vermont Agency of Natural Resources, 2009a).

Table 2: 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[1]	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

The reference stream types for each assessed segment within the Ompompanoosuc River watershed are shown in Figure 2.5 and summarized below in Table 3. All of the reaches, with the exception of the upper reach on Blood Brook (R16T2.06), have moderate to gentle valley slopes (less than 2.0 percent). The upper reach on Blood Brook has an overall valley slope of between 2.0 – 3.0 %, falling into the moderate to steep category. There is a section of higher slope in this reach, which is located upstream of Godfrey Road. A waterfall is located in this area, and this drop in elevation is driving up the overall reach slope.

Most of the segments in the 2010 Phase 2 study area are either "C" channels or "E" channels by reference (Figure 2.5). Reference "C" channels have unconfined valleys with moderate to gentle

[1] "C" channels have a moderate to high width to depth ratio (>12), while "E" channels are narrow and have low width to depth ratios (<12)

valley slopes and moderate to high width to depth ratios and sinuosity. "E" channels have a very low width to depth ratio (i.e. narrow and deep) and flow through unconfined valleys with moderate to gentle slopes. Reference "E" stream types are often highly sinuous and have cohesive bank material associated with *lacustrine* (lake) *soils*.

All segments/reaches on the main stem of the Ompompanoosuc, except for R16 and R15-B, are "C" channels by reference. R16 has a reference stream type of "E". Segment R15-B is a bedrock gorge with multiple sections of ledge, which provide grade control. The reference stream type of R15-B is "B"; the floodplain is relatively narrow resulting in a moderately entrenched channel with a step-pool bedform.

The reach directly downstream from Lake Fairlee dam is a "C" channel by reference as well as the most downstream reach on Schoolhouse Brook and segment R16T2.06-C on Blood Brook. The remaining reaches on the tributaries, including the most downstream reach on Lake Fairlee Outlet, are all "E" channels by reference.

Table 3: Geomorphic Setting of 2010 Assessed Reaches

Stream	Reach ID	Reference Stream Type	Confinement	Valley Slope (%)	Bedform
Ompompanoosuc River	R15[2]	C/B	Narrow	0.21	Riffle-Pool
	R16	E	Broad	0.37	Dune-Ripple
	R17	C	Very Broad	0.45	Riffle-Pool
	R18	C	Very Broad	0.43	Riffle-Pool
	R19	C	Broad	0.74	Riffle-Pool
	R20	C	Very Broad	0.53	Riffle-Pool
	R21	C	Very Broad	0.66	Riffle-Pool
Lake Fairlee Outlet	R16T2.01	E	Broad	0.60	Dune-Ripple
	R16T2.02	C	Narrow	0.36	Dune-Ripple
Blood Brook	R16T2.04	E	Very Broad	0.73	Dune-Ripple
	R16T2.05	E	Very Broad	0.95	Riffle-Pool
	R16T2.06[3]	E/C	Very Broad	2.63	Riffle-Pool
Middle Brook	R16T2.03S1.01	E	Very Broad	0.17	Dune-Ripple
	R16T2.03S1.02	E	Very Broad	0.32	Dune-Ripple
Schoolhouse Brook	R18T3.01	C	Very Broad	1.60	Riffle-Pool

[2] Reach 15 was segmented due to having two different reference stream types. Segment 15-A is a "C" channel by reference, while segment 15-B is a "B" channel by reference.
[3] The majority of Segment R16T2.06 is an "E" channel by reference. Segment R16T2.06-C has a reference stream type of "C".

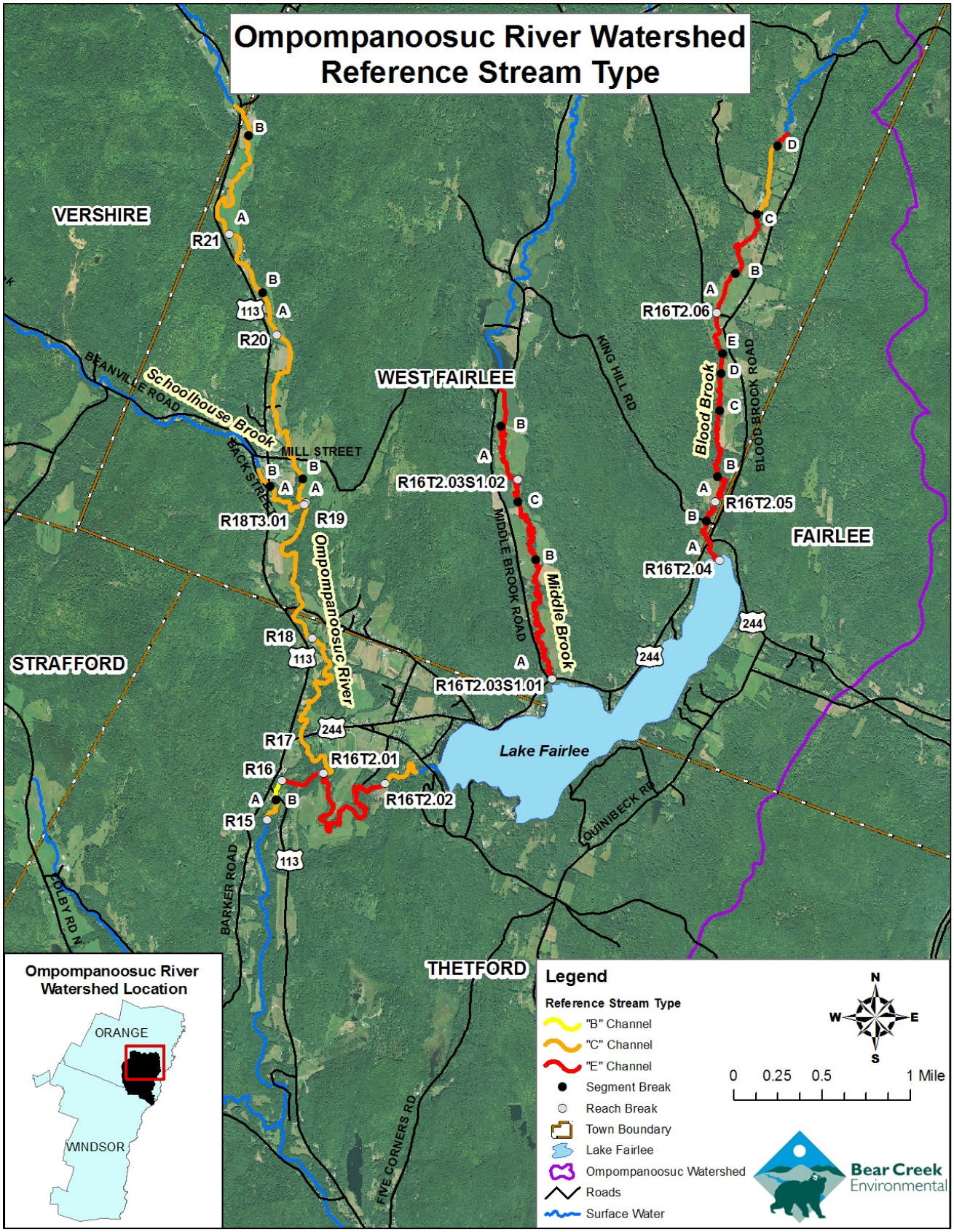

Figure 2.5. Reference Stream Type for Phase 2 Geomorphic Assessment

2.4 Hydrology

In order to better understand the flood history of the Ompompanoosuc River, long term data from the U.S. Department of the Interior, U.S. Geological Survey (USGS) were obtained (USGS 2010). The Ompompanoosuc River watershed has one USGS gage that is located immediately downstream from the Union Village Reservoir in Thetford, near the Orange and Windsor County lines. Daily discharge records are available for the Ompompanoosuc River at Union Village from September 1940 through September 1989. Daily mean flow values from 1989 to current are not published, and the reliability of low flows is variable. The partial-record station is maintained for purposes of flood control, and peak streamflow data are available for 1927 and 1941 through the current year. The gauge on the main stem of the Ompompanoosuc has been regulated by the Union Dam since 1949, and may also be influenced by the dam at Lake Fairlee. This influence changes the flow regime by holding back high flows, and releasing water when streamflows would normally be lower.

A nearby USGS gage on Ayers Brook at Randolph, Vermont was selected to better understand the flood history of the 2010 Phase 2 study area because of the influence of the Union dam on the hydrology. The drainage area at the Ayers Brook gauge is 31 square miles, and is a good match with the drainage area of the mainstem of the Ompompanoosuc River within the 2010 Phase 2 study area (18.6 to 53.1 square miles). Although the drainage area of the Ompompanoosuc is much larger at 137 square miles and the flow regime is influenced by the dam, it provides a good regional long term record.

Seventy years of record (1940-2009) are available for the Ayers Brook gauge. The long term record for Ayers Brook (Figure 2.6) shows the peak discharge for water year[4] 1949 is close to a ten year recurrence interval. The annual peak discharge for 1952 and 2007 were near a 25 year recurrence interval. Large precipitation events in June 1973 and June 1998 resulted in peak annual discharges that are the highest on record. The peak discharge for 1973 is close to the 50 year recurrence interval, while the highest instantaneous discharge in 1998 exceeded the 50 year event.

Of all the natural hazards experienced in Vermont, flooding is the most frequent, damaging, and costly. Over the last 50 years, flood recovery has cost Vermonters an average of 14 million dollars a year. During the period of 1995-1998 alone, flood losses in Vermont totaled nearly $57 Million. 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, 2006). The VANR (2006) 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).

[4] A water year is the twelve month period from October 1 through September 30.

According to Thetford Conservation Commission member Li Shen, there was a flash flood on August 5, 2003 on an unnamed tributary to the West Branch of the Ompompanoosuc that runs along Poor Farm Road in Thetford. This flash flood was the result of localized heavy rains and it caused the brook to cut a trench 8-10 feet deep across Tucker Hill Road. Culverts as well as parts of the road were washed away (Hookway, 2003). Residents in the area reported that a small stream normally 1.5 feet wide became as wide as 30 feet very quickly (Hookway, 2003). A washout on Sawnee Bean Road along Barker Brook in Thetford also occurred that day.

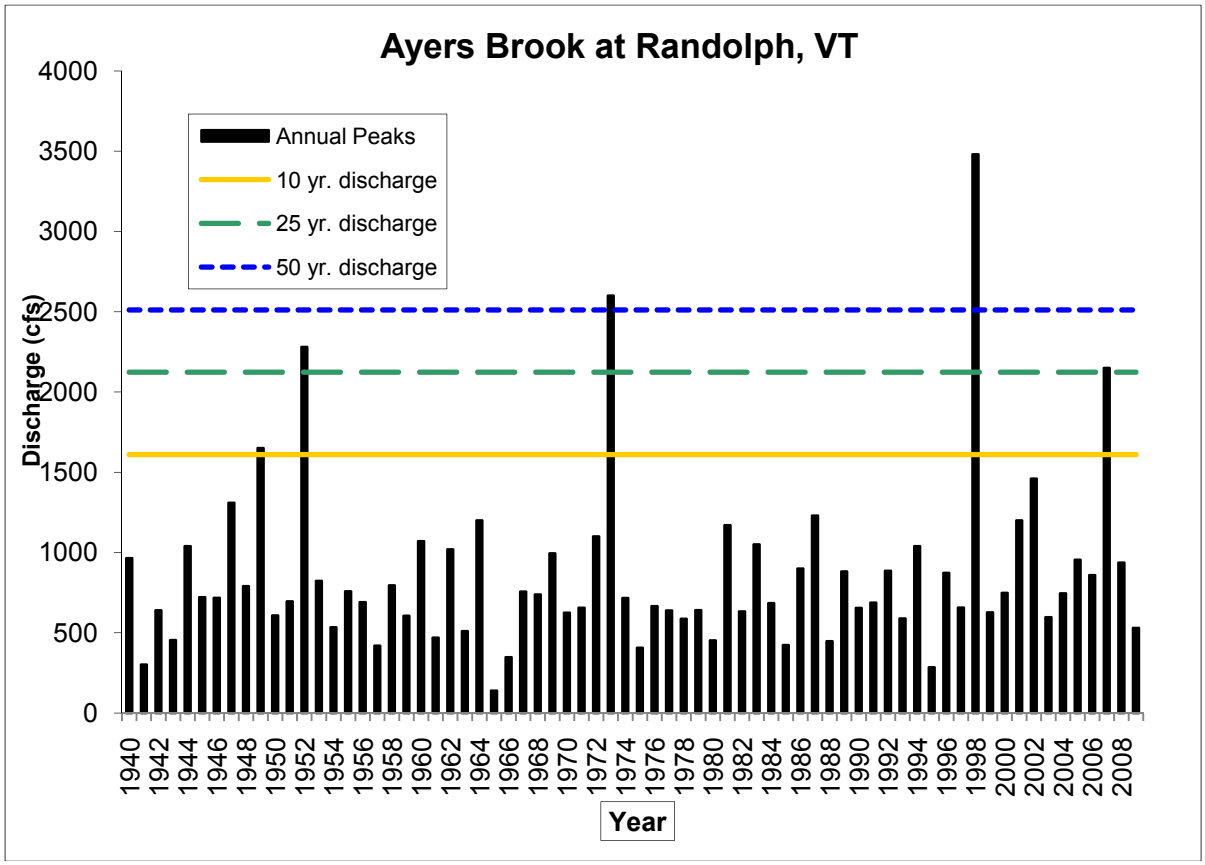

Figure 2.6. Flood frequency analysis for Ayers Brook at Randolph, Vermont

2.5 Ecological Setting

The Ompompanoosuc River watershed lies within both the Northern and Southern Vermont Piedmont biophysical regions (Figure 2.7). The 2010 Phase 2 study area (Upper Ompompanoosuc River main stem, Schoolhouse Brook, Middle Brook, and Lake Fairlee Outlet) is exclusively within the Northern Vermont Piedmont region. The Northern Vermont Piedmont region is characterized by Thompson and Sorenson (2000) as being hilly with numerous rivers. The majority of this region is within the Connecticut River watershed. The climate is moderate for Vermont, and is cooler and moister than the

Champlain valley, but warmer and drier than the Green Mountains or the Northern Highlands.

Northern hardwood forest is the dominant community in the Northern Piedmont biophysical region. Calcium rich bedrock plays an important role in the vegetation and community types in the region. The Vermont Significant Wetland Inventory GIS layer and hydric soils layer (mapped as intact wetland) provide important information about the distribution of wetland habitat within the Ompompanoosuc River watershed. Extensive areas of wetland habitat exist adjacent to Blood Brook, Middle Brook and the Ompompanoosuc River main stem near the junction of Route 113 and Route 244 in Thetford.

Deer wintering areas as identified by the Vermont Agency of Natural Resources are common in the floodplains of the Ompompanoosuc River main stem, Middle Brook and Blood Brook within the Phase 2 study area and along the floodplains of the lower Ompompanoosuc River mainstem in Thetford and Norwich as shown in Figure 2.7. According to Thompson and Sorenson (2000), white-tailed deer, beaver, coyote, fox, otter, mink, squirrels, and other rodent are common animals in the region. There are a number of wildlife management areas (WMA) within the Ompompanoosuc River watershed including: West Fairlee, Podunk, Kibling Hill, and Clover Hill. Other important public lands in the Ompompanoosuc River watershed are the Strafford Town Forest, the Thetford Town Forest, the Brushwood Community Forest and the Charles Downer State Forest in Sharon[5].

The Brushwood Community Forest sits within the Blood Brook watershed adjacent to the Bradford Town Forest (660 acres) and the Fairlee Town Forest (1,400 acres). The Town of West Fairlee has partnered with the Trust for Public Land (TPL) to conserve the Brushwood Community Forest, which could end up being as large as 1,200 acres. The goal of the project is to create a lasting resource for forestry, habitat for wildlife, and recreational trails. (Town of West Fairlee, Vermont, 2011).

[5] Charles Downer State Forest is located in the south west corner of the watershed and is not shown in Figure 2.7.

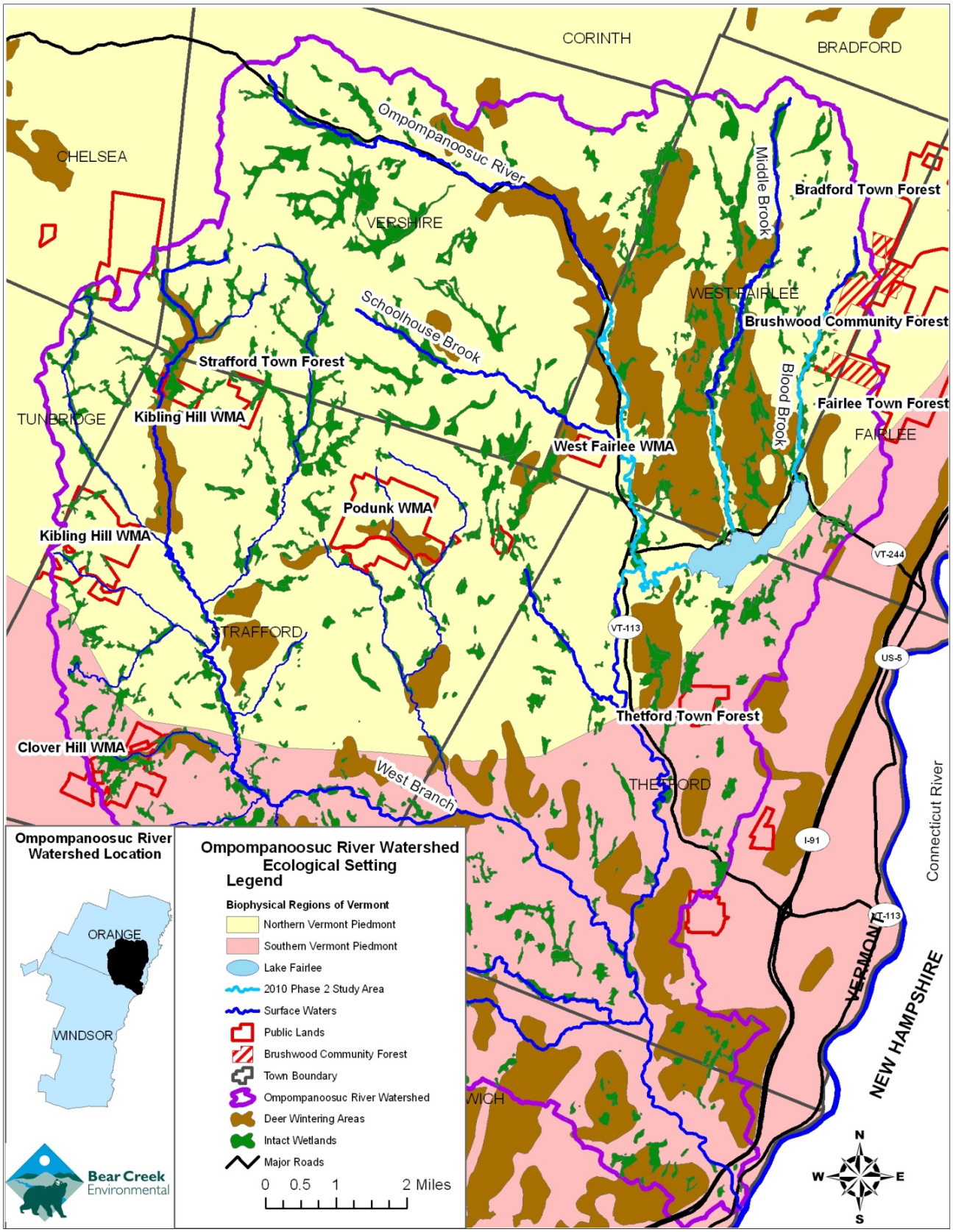

Figure 2.7. Ecological Setting of the Ompompanoosuc River Watershed

3.0 METHODS

This study of the Ompompanoosuc River watershed utilized state-of-the-art Stream Geomorphic Assessment (SGA) protocols developed by the Vermont Department of Environmental Conservation (DEC). The SGA protocols are intended to be used by resource managers, community watershed groups, municipalities and others to identify how changes to land use affect hydro-geomorphic processes at the landscape and reach scale, and how these changes alter the physical structure and biological habitat of rivers. 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.

A Phase 1 Assessment of the Ompompanoosuc River watershed was completed by BCE with the help of the Li Shen of the Thetford Conservation Commission during fall 2008.
The fieldwork for the Phase 2 assessment of the Ompompanoosuc River main stem, Blood Brook, Middle Brook, Schoolhouse Brook and the Lake Fairlee outlet reaches was completed in summer 2010. These field data were used to develop river restoration and protection projects presented in this report. Phase 3 surveys, for active restoration projects included in this report, may be required at some point in the near future for project design and permitting. A summary of the Phase 1 and 2 methodologies is provided in the following sections.

3.1 Phase 1 Methodology

The Phase 1 assessment followed procedures specified in the Vermont Stream Geomorphic Assessment Handbook Phase 1 (Vermont Agency of Natural Resources 2007), and used version 4.59 of the Stream Geomorphic Assessment Tool (SGAT) GIS 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.

3.2 Phase 2 Methodology

The Phase 2 assessment of the Ompompanoosuc River watershed followed procedures specified in the Vermont Stream Geomorphic Assessment Handbook Phase 2 (Vermont Agency of Natural Resources, 2009a), and used version 4.59 of the Stream Geomorphic Assessment Tool (SGAT) GIS extension to index impacts within each reach. SGAT is an ArcView extension. All assessment data were recorded on the Agency of Natural Resources Phase 2 data sheets, and were entered in to the VANR Stream Geomorphic Assessment Data Management System (DMS). The Phase 1 database was updated using the

field data from the Phase 2 assessment in fall of 2010. 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, 2009a). The study also used a new protocol developed by the Vermont Agency of Natural Resources (2008a) for conducting a rapid habitat assessment (RHA). The DEC River Management Program provided technical expertise and shared quality control/quality assurance responsibilities with BCE (refer to Section 3.4).

Reaches determined during Phase 1 were broken up further into segments for the Phase 2 geomorphic assessment as necessary. Topographic maps and orthophotos were used as a first cut in delineating segment breaks. The project team walked the entire length of the reach to confirm preliminary segment breaks determined when reviewing topographic maps and orthophotos. Attributes that were considered when determining segment breaks include: grade controls, changes in channel dimensions, changes in dominant bed material, slope, entrenchment or sinuosity, signs of planform changes, presence of beaver dams, and evidence of *aggradation* and *degradation*. The bankfull width and depth were measured occasionally along the reach to track changes in bankfull dimensions. Once segment breaks were determined, the Phase 2 field forms were completed accordingly.

BCE walked the entire length of each reach. Valley walls delineated by BCE during the Phase 1 assessment were verified in the field. Human caused changes in valley width due to permanent high embankments that serve as artificial valley walls were also mapped on field sketches with reference to topographic maps and/or orthophotographs. The field verified valley walls were used to evaluate Phase 2 confinement. Adjacent terraces and valley walls were evaluated in terms of their proximity to the channel. The location, total height and height above water surface were recorded for channel spanning grade controls, both natural and human constructed.

Channel dimensions and bed substrate composition were measured at one to three representative locations within each segment. The channel dimensions and substrate composition were recorded on the Cross-section Worksheet and summarized on the Rapid Stream Assessment Field Notes form under Step 2. Stream type was evaluated based on the channel dimension data, bed substrate composition results, and confirmed channel slope. Dominant bed forms were determined based on the criteria set forth in the most recent version of the Vermont Phase 2 SGA Handbook.

Stream banks were evaluated in terms of their typical slope and dominant texture. Areas of bank erosion, mass failures, and gullies were mapped and pertinent information regarding the height and length of such features was recorded. Areas lacking adequate riparian buffers (<25 feet) were mapped and notes were made about the types of vegetation comprising existing riparian buffers. River corridor encroachments including roads, railroads, improved paths, and development were mapped according to their locations, and the height of these encroachments was recorded. Notes were also taken concerning river corridor land use activities.

The locations of springs, seeps, small tributaries, adjacent wetlands, debris jams, beaver dams and channel constrictions were recorded and evaluated in terms of how they may be affecting channel flows. Locations of stormwater inputs from *urban runoff*, agricultural drainage and road ditching were noted to determine the extent of increased flow status during a storm event. Similarly, locations of flow regulations and water withdrawals were mapped to evaluate potential decreases in channel flows.

Depositional features were mapped to assess the sediment transport regime and storage capacity of the segment. Channel migration features were also mapped in order to determine the amount of channel planform adjustment the segment was undergoing. Sections of the stream where the channel does not appear to be following the natural path of the river and may have been straightened were noted, along with locations where material has been removed from the channel in order to assess the extent to which stream power and morphology have been altered. Steep *riffl*es and *head cut*s were mapped and used as indicators of active geomorphic processes.

RHA and RGA field forms were completed for the Phase 2 reaches that were governed by fluvial processes. 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.

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 were used to compare physical habitat condition between sites, streams, or watersheds, and they can also serve as a management tool in watershed planning.

For segments where the Vermont SGA protocols were not applicable, such as wetlands and bedrock gorges, general notes about geomorphic stability and quality were taken. Stream channels that were highly influenced by wetlands and could not be completely assessed according to the protocols were assigned a stream type and condition based on the field team's best judgment and observed Phase 2 field conditions.

Geomorphic Condition

Geomorphic condition is evaluated using four *adjustment processes*: channel degradation, channel aggradation, widening, and change in planform. 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. When the stream has lost access to its floodplain through channel degradation or floodplain encroachment, the stream flows contained in the channel will then erode the banks causing the channel to widen. Channel

widening may also occur when sediments overwhelm the stream channel and the erosive energy is concentrated into both banks.

Each adjustment process category is scored from 1 (poor) to 20 (excellent) based on the departure from reference condition for a particular valley setting (unconfined, confined, etc.). 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

Habitat Condition

There are eight parameter parameters that are scored during a Phase 2 assessment to determine habitat condition. These parameters are scored between 1 (poor) and 20 (excellent). The habitat parameters included in the rapid habitat assessment are as follows:

1. Woody Debris Cover
2. Bed Substrate Cover
3. Scour and Deposition Features
4. Channel Morphology
5. Hydrologic Characteristics
6. Connectivity
7. River Banks
8. Riparian Area

Similar to geomorphic condition there are four categories (reference, good, fair and poor) to describe the habitat condition. The habitat condition is indicative of the departure from reference habitat that would be expected for a particular bedform (e.g. riffle-pool, plane bed, etc.).

3.3 Bridge and Culvert

A bridge and culvert inventory and assessment was conducted as part of the Phase 2 assessment on all structures at stream crossings to determine if the structure was contributing to localized stream bank erosion, sedimentation, and reduced fish passage. The Agency of Natural Resources Bridge and Culvert protocols (Vermont Agency of Natural Resources, 2009b) were followed. Latitude and Longitude at each of the structures was determined using a Garmin Etrex Vista GPS unit. The assessment included photo documentation of the inlet, outlet, upstream, and downstream of each of the structures.

3.4 Quality Control/Quality Assurance Procedures

To assure a high level of confidence in the Phase 1 and 2 Stream Geomorphic Assessment data, strict quality assurance/quality control (QA/QC) procedures were followed. These

procedures involved automated and manual QC checks with the DEC River Management Program.

All the Phase 2 data were entered into the DMS and the Phase 1 data were updated. The Phase 1 DMS and ArcView shapefiles were updated based on the Phase 2 field assessment work during the Phase 2 QA/QC process. The DMS and the ArcView shapefiles for the Ompompanoosuc River Phase 2 study were submitted to Sacha Pealer of the VANR for a Quality Assurance review in December 2010.

3.5 River Corridor Plan

The Vermont Agency of Natural Resources River Corridor Planning Guide (2010a) was followed to generate a series of stressor maps, which are included in Appendix B. The stressor maps were created using indexed data from the Phase 1 and Phase 2 Stream Geomorphic Assessments along with existing data available from VCGI, including roads, buildings and driveways.

3.5.1 Stressor Maps

Stressor, departure and sensitivity maps are presented here as a means of displaying the effects of all significant physical processes occurring within the Ompompanoosuc River watershed that were observed during the Phase 1 and Phase 2 Stream Geomorphic Assessments. These maps also provide an indication of the degree to which the channel adjustment processes within the watershed have been altered, at both the watershed scale and the reach scale. The analysis of existing and historic departures from equilibrium conditions along a stream network allows for the prediction of future channel adjustments within the watershed. This is helpful in developing and prioritizing potential protection and restoration projects.

River corridor restoration and protection projects that are successful depend on a thorough understanding of the sources, volumes, and *attenuation* of flood flows and sediment loads within the stream network. If increased loads are transported through the network to a sensitive reach, where conflicts with human investments are creating a management expectation, little success can be expected unless the restoration design accommodates the increased sediment load or finds a way to attenuate the loads upstream. Modifications in watershed inputs in the form of peak flows or increased sediment can result in an imbalance of stream power and sediment in the channel. Changes in the shape of the channel may also lead to disequilibrium. Large channel adjustments, such as severe erosion and excessive deposition, are a result of this imbalance, and often continue until the channel reaches a state of equilibrium. (Vermont Agency of Natural Resources, 2010a)

Within a reach, the principles of stream equilibrium dictate that stream power and sediment will tend to distribute evenly over time (Leopold, 1994). Changes or modifications to watershed inputs and hydraulic geometry create disequilibrium and lead to an uneven distribution of power and sediment. Large channel adjustments observed

as dramatic erosion and deposition may be the result of this uneven distribution and may continue over the long term.

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, and 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). Examples of human-induced practices that contribute to stream instability include:

- Forest clearing
- *Channelization* and bank armoring
- Removal of woody riparian vegetation
- Floodplain encroachments
- Poor road maintenance and installation of infrastructure
- Loss of wetlands

Anthropogenic practices, such as increased areas of impervious surfaces and loss of wetlands, can increase peak discharges in a watershed resulting in a change in hydrologic regime. The hydrologic regime is the timing, volume, and duration of flow events throughout the year and over time and is characterized by the input and manipulation of water at the watershed scale. A Hydrologic Regime Map has been prepared to summarize the land uses influencing watershed hydrology. When the hydrologic regime has been significantly changed, stream channels will respond by undergoing a series of channel adjustments. The land use within the watershed plays a role in the hydrology of the receiving waters. The percentage of developed land and cropland within the watershed are factors which change a watershed's response to precipitation. The most common effect of developed land and cropland is increasing peak discharges and runoff by reducing infiltration and travel time (United States Department of Agriculture, 1986). Loss of significant wetland reduces the hydrologic attenuation of surface runoff at the reach and watershed scale. Wetland loss was mapped as the area where hydric soils (Natural Resources Conservation Service mapping) and National Wetland Inventory (NWI) mapped areas intersected with developed land or agricultural land uses in the watershed, with the remaining areas assumed to be intact wetland.

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 regime, and the specific morphology of the valley, floodplain, and stream. Bank erosion and mass failures are common sources of sediment to rivers and streams. Bank erosion is defined as "an area of raw and barren soil where the vegetation does not have the ability to hold the soil and/or the soil has slumped or fallen into the channel". Mass failures can occur when "a perennial stream erodes into or undercuts a high erodible landform, such as glacial lacustrine terrace" (Vermont Agency of Natural Resources, 2009a).

Many rivers throughout New England have been historically manipulated and straightened to maintain an unnaturally steep slope in a state of sediment transport, allowing for a short term sense of security from flooding and subsequent encroachment of infrastructure in the floodplain. In addition to historic alterations to channel slope in alluvial rivers, the lowering of stream beds (e.g. *dredging*) and the disconnection of floodplains (e.g. berming) has resulted in an increase in channel depth. Channel depths have typically increased through floodplain encroachment by roads and railroads and subsequent filling and armoring to construct and maintain this infrastructure. Increases in impervious cover have also led to the deepening and eventual widening of channels throughout developed areas of New England. A Channel Slope Modifiers Map has been prepared to summarize human alterations to channel and floodplain geometry.

The resistance of the channel boundary materials is important for understanding the sensitivity of a channel and for predicting when a channel will undergo adjustment from stressors in the watershed. There are a number of factors that can result in decreased boundary condition. One of the most important factors is the quality of the riparian buffer. Riparian buffers provide many benefits. Some of these benefits are protecting and enhancing water quality, providing fish and wildlife habitat, providing streamside shading, and providing root structure to prevent bank erosion. Woody vegetation is essential for holding the bank soils to provide resistance to stream bank erosion. These stream reaches which lack a high quality riparian buffer are at a significantly higher risk of experiencing high rates of lateral erosion. Riparian and Boundary Condition Maps have been prepared to show impacts along stream banks to the riparian buffer.

3.5.2 Departure Analysis

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, 2010a).

The "F" stage channel evolution model (Vermont Agency of Natural Resources, 2009a) is helpful for explaining the channel adjustment processes underway in the Ompompanoosuc River watershed. The "F" stage channel evolution model (i.e. Schumm 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 3.1 include:

- Stable (F-I) - 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

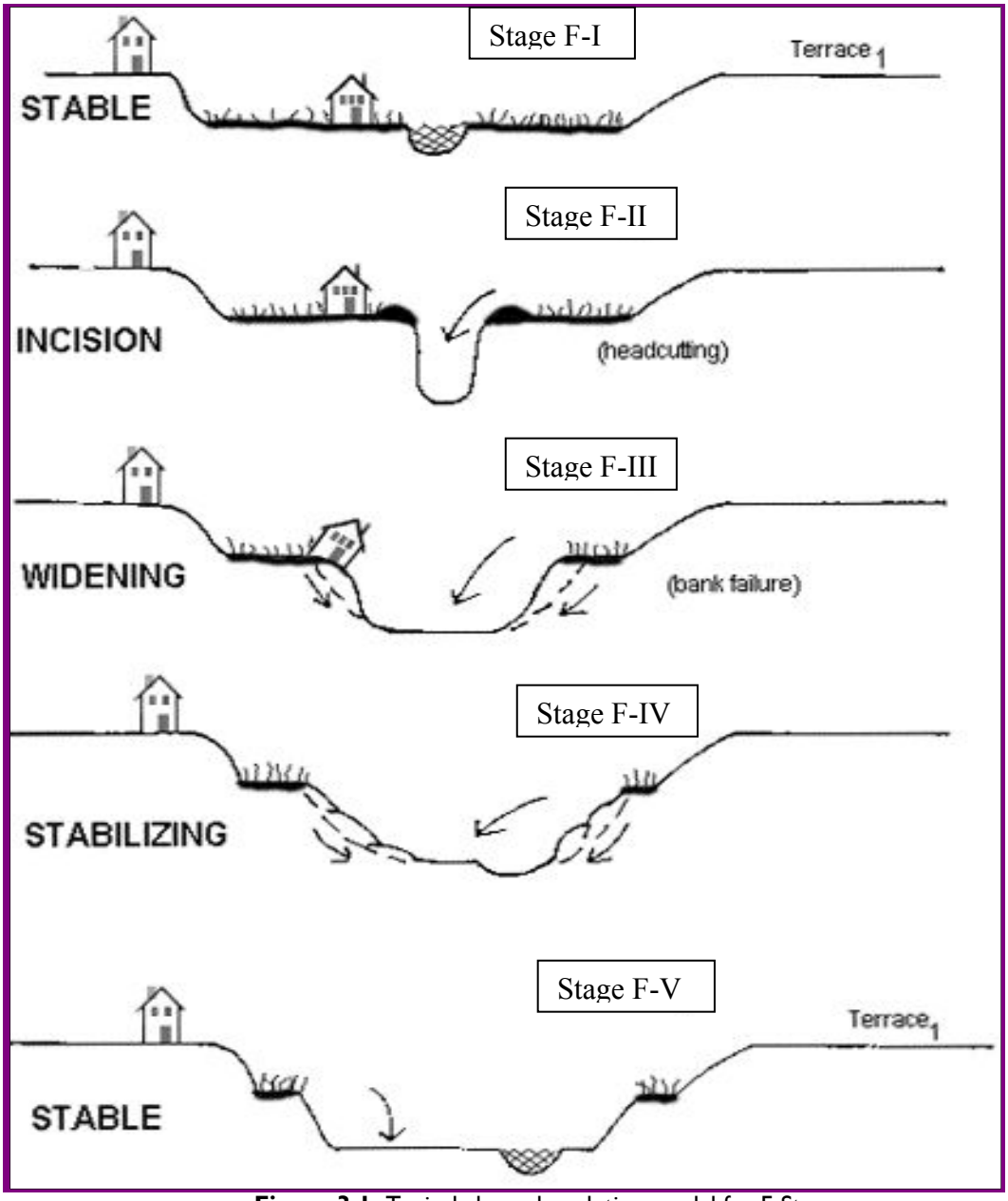

Figure 3.1. Typical channel evolution model for F-Stage
(used by permission of Mike Kline, VANR)

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 streambanks. 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 analysis of sediment regimes at the watershed scale is useful for summarizing the stressors affecting the equilibrium condition of river channels. Sediment regime mapping provides a context for understanding the sediment transport and channel evolution processes which govern changes in geometry and planform for river channels in a state of disequilibrium. Sediment Regime Maps have been prepared to show departure from reference conditions due to human alterations.

3.5.3 Sensitivity Analysis

Sensitivity ratings were assigned using the River Corridor Planning Guide Management Program (Vermont Agency of Natural Resources, 2010a). Stream sensitivity refers to the likelihood that a stream will respond to a watershed or local disturbance or stressor. Human activities such as: floodplain encroachment, channel straightening or armoring, changes in sediment or flow inputs, and/or disturbance of riparian vegetation may alter the natural adjustment rate of the channel. Streams that are actively adjusting through a lowering of the bed (degradation) or building up of the bed through sediment deposition (aggradation) are likely to have a heightened sensitivity. (Vermont Agency of Natural Resources, 2009a). Stream sensitivity is assigned based on the existing stream type and condition. For a particular stream type, a segment in "reference" or "good" condition has a lower sensitivity than a reach in "fair" condition. The highest sensitivity is assigned for segments in "poor" condition and reaches which have undergone a stream type departure.

Flow regime and floodplain constrictions affect the sensitivity of rivers and streams. Changes in land use and land cover that increase impervious cover, peak discharges, and/or the frequency of high flows will heighten a stream's sensitivity to change and adjustment. Confinement becomes a significant sensitivity concern when structures such as roads, railroads, and *berm*s significantly change the confinement ratio, reduce or restrict a stream's access to floodplain, and result in higher stream power during flood stage resulting in erosive velocities within the channel. A Stream Sensitivity and Adjustment Process Map was created to depict the various sensitivities of the reaches and to show whether degradation or aggradation are active adjustment processes.

4.0 RESULTS

4.1 Reach Descriptions

During the Phase 2 assessment, 15 reaches in the Ompompanoosuc River watershed were broken into 31 segments based on detailed field observations. Segment summary data are provided in Appendix A.

Ompompanoosuc River Main Stem

R15

The lowest Phase 2 reach of the Ompompanoosuc River main stem begins approximately 900 feet downstream of the Route 113 crossing in Post Mills and is 1,450 feet in length. The reach was broken into two segments during the Phase 2 assessment to account for differences in grade control and the existing valley confinement. The upper segment (R15-B) has multiple ledge grade controls and a breached dam at the upstream end. The lower segment (R15-A) lacks grade controls. Both segments have a narrow valley confinement by reference.

Segment R15-A is only about 800 feet in length. The upper end of the segment ends adjacent to the southern end of an abandoned mill building that was recently razed. A beaver dam (Figure 4.1) near the downstream end of the segment was impounding (Figure 4.2) all but the lower 200 feet of stream channel at the time of the Phase 2 assessment in early September 2010. The impounded conditions precluded a full rapid geomorphic assessment (RGA); however, an attempt was made to measure a cross section at the lower end of the segment to assist with determining a stream type. Buffers less than 25 feet in width are common along the east bank immediately upstream of the beaver dam. Given the active beaver activity, this would not be a good buffer planting location; however, a "no mow zone" to allow the vegetation to grow back would be beneficial. Overall, the geomorphic condition is "fair".

Figure 4.1 Beaver dam at lower end of R15-A

Figure 4.2 Impounded section of channel in R15-A

Segment R15-B is also a short segment and is only 640 feet in length. The segment starts at the southern extent of the old Mill Building and ends upstream at the Montague Rod and Reel Company's breached dam. Localized geomorphic instability is occurring within the vicinity of the Montague dam. While the dam is breached, it is still a significant channel constriction (Figures 4.3 and 4.4). The constriction width is six feet and is causing scouring below the structure. The dam is causing significant deposition of sediment above the structure as shown in Figure 4.5. The old bypass reach and rock walls on the west side of the dam are resulting in planform adjustment, such as the large island that is immediately downstream of the dam. According to Steve Bushman, Dam Safety Engineer with the Vermont Agency of Natural Resources, the Montague dam and the Lake Fairlee dam were used to generate power for the former mill on the main stem.

Figure 4.3 Constriction at dam in R15-B (Looking downstream)

Figure 4.4 Constriction at dam in R15-B (looking upstream)

The Route 113 Bridge is a second major channel constriction within segment R15-B. The span of the structure, measured from bedrock on the east side and concrete on the west bank is only 44 feet, compared with the reference bankfull width of 75 feet. Immediately downstream of the bridge, on the west bank is the old mill building that was razed.

A full rapid geomorphic assessment could not be completed in Segment R15-B due to the bedrock gorge with multiple ledge grade controls (Figure 4.6). The ledge grade controls are providing vertical stability within the reach by preventing the bed from incising.

Figure 4.5 Sediment deposition upstream of dam

Figure 4.6 One of many ledge grade controls in R15-B.

R16

Reach R16 begins where the grade controls in R15 end (upstream of the Montague dam) and continues about 1,400 feet to the confluence of the Lake Fairlee outlet (R16T2). The dominant bed substrate is sand, and silt/clay is present in the bed and along the banks (Figure 4.7). The bedform is dune-ripple. The channel is an "E" channel (deep and narrow) by reference, but has undergone a stream type departure to a "C" channel due to widening. Over 60 percent of R16 was indexed as straightened. In some sections, the channel appears to have been pushed up against the valley wall to make room for farm fields. Channel straightening is one factor that likely set the channel into an adjustment process. The increased energy from channel straightening has led to incision and subsequent channel widening and aggradation. The numerous diagonal and large side *bar* features and abundant fine sediment are indicative of aggradation (i.e. building up of sediment). The downstream dam in R15 is contributing to sediment build up in reach R16. The overall geomorphic condition is "fair".

The overall habitat condition in R16 is also "fair". Reach R16 scored in the reference category for woody debris cover, providing some cover for fish and aquatic organisms; however, there were no undercut banks noted in the entire reach. Stable undercut banks with overhanging vegetation are important for providing low velocity areas for fish to seek cover. Channel widening has led to moderate bank erosion. There are numerous *pool*s in R16, but deep pools (over 2.0 feet) are infrequent. Once again, channel widening may be impacting the quality of habitat, by making the channel over wide.

Figure 4.7 The bed substrate of reach 16 is dominated by sand.

R17

Reach R17 begins just upstream of the confluence with the Lake Fairlee outlet and continues until about 1,300 feet downstream of the Cross Road Bridge. The reach is set in a very broad valley with only minor human-caused change to the valley width from floodplain encroachments, such as houses. The channel exhibits "C" type morphology with a riffle-pool bedform. The valley slope is gentle and the channel substrate is fine, lending this reach to a subdominant bedform of dune-ripple. Clay was noted on the lower banks in some locations. Historic channel incision has led to extreme channel widening resulting in widespread bank erosion (Figure 4.8). The high frequency of debris jams and large bar features (Figure 4.9) are indicative of sediment buildup in the reach. There are two areas of mass failure in the reach that are contributing sediment to the channel. Planform adjustment (i.e. movement of the channel) is apparent from the extensive lateral bank erosion and active flood chutes. The channel is multiple thread in some locations. The overall geomorphic condition of reach R17 is "poor".

Figure 4.8 Extensive bank erosion in Reach R17

Figure 4.9 Large depositional features

The overall habitat condition of reach R17 is "fair". The active geomorphic adjustment processes are also impacting habitat. The extensive bank erosion made for very few stable undercuts to provide cover for fish. Large woody debris cover scored in the reference category with abundant wood and debris jams from all the downed trees. About one-quarter of both banks have narrow buffers of less than 25 feet in width. Although there are areas lacking woody vegetation, active planting projects in this reach are not recommended because of the active adjustment. Invasive plant species, such as Japanese barberry and knotweed are present. Pools are frequent and there is variety of pool types including habitat that is greater than three feet in depth. Other than downed trees that are providing habitat for fish, pools lack a diversity of cover (large boulders, undercut banks, and turbulent water).

R18

The lower end of reach R18 begins about 1,300 feet downstream of the Cross Road Bridge and continues upstream to the confluence with Schoolhouse Brook. Approximately 70 percent of this mile long reach appears to have been historically straightened. Historic incision has resulted in a stream type departure from a reference stream type of "C" with a vast floodplain to a "B" channel with a narrow floodplain. Reach 18 is undergoing active geomorphic adjustment, and alternates between areas that are widening and areas that are stabilizing and starting to build a juvenile floodplain at a lower elevation. Widening is causing significant bank erosion (Figure 4.10) and has led to a shallow channel, reducing available aquatic habitat and causing a buildup of sediment. The overall geomorphic condition is "poor". Recent gravel extraction (Figure 4.11) was noted at the downstream end of R18 at the time of the Phase 2 assessment in late August 2010.

Figure 4.10 Lack of buffer & extensive bank erosion **Figure 4.11** Recent gravel extraction location in R18

Reach R18 is gravel dominated and offers a mix of aquatic habitat. Scour of the gravel substrate results in frequent pools that have a diversity of depths and surface area. However, many of the pools are silted in and the fish cover is fair. The aggradation of gravel and finer materials has led to very large depositional features, mid channel accumulation and a buildup of fine sediment making the riffles less productive for aquatic insects. The bed substrate is mobile and soft underfoot. There are a number of undercut

banks in the reach, which provide habitat for fish. Some of these undercuts are roots that are providing a stable boundary, but many of the undercuts are unstable due to the considerable bank erosion. Logs and snags are providing hiding places for fish, and coarse particulate organic material is present in the channel and along the margins, providing a healthy energy supply for aquatic insects.

Both the east and west side of the channel in R18 have a dominant buffer width of greater than 100 feet; however, there are areas with buffers of 0-25 feet. Buffers less than 25 feet are associated with hay fields on the west bank and corn fields on the east bank. Approximately 20 percent of the west bank has buffers less than 25 feet. Japanese knotweed is an invasive plant species that was present on the near banks. High quality bank vegetation, such as alders and dogwoods, were noted to be growing in areas where the juvenile floodplain has developed. When considering all the habitat parameters, the habitat condition is "fair".

R19

Main stem reach R19 was segmented to account for differences in channel dimensions. The lower segment (R19-A) begins just upstream of the confluence with Schoolhouse Brook and continues for 925 feet to where there is no longer good floodplain access. The upper segment (R19-B) starts about 650 feet downstream of the Mill Street crossing and extends upstream about one-quarter mile past Slaughterhouse Road. Both segments are "C" channels by reference. Cross sections of the channel and floodplain measured during the Phase 2 assessment indicate historic incision has occurred within reach R19. Segment R19-A has an existing stream type of "C" and has undergone major channel incision. The upper segment R19-B has undergone extreme historic incision resulting in a stream type departure from a "C" channel to a "B" channel with a narrow floodplain.

Segment R19-A has been historically straightened for agricultural purposes (Figure 4.12). This channel straightening may have contributed to the historic incision that occurred. The Geer dam, located upstream in segment R19-B, may also have played a role in channel incision. Sediment is retained above the dam and the downstream reach has likely historically incised in response to the channel being sediment starved. The overall geomorphic condition of R19-A is "fair". There is moderate to high lateral bank erosion on the most outside bends, indicating planform adjustment is occurring. The primary adjustment processes are aggradation and channel widening. The channel is starting to transition from widening to stabilizing and building a juvenile floodplain in locations.

The lack of a high quality riparian buffer is one factor contributing to the "fair" habitat condition of R19-A. Approximately 80 percent of the east bank has buffer widths of less than 25 feet (Figure 4.13). The east bank has a riparian corridor that is primarily hay fields. The west bank has a dominant buffer width of greater than 100 feet and a sub-dominant buffer width of 51-100 feet. Forest is the primary land use in the western river corridor. Not surprisingly, 65 percent of the east bank has bank erosion compared with 25 percent of the west bank.

Figure 4.12 Historically straightened.

Figure 4.13 Lack of buffer along hay field

Segment R19-B is about a mile in length and contains five areas with ledge that are providing a natural grade control for the channel (Figure 4.14). The Geer dam, a man made grade control, was originally built to generate hydroelectric power (Figure 4.15). According to DEC records, the dam is no longer in service. The dam is holding back sediment, and is a barrier to aquatic organism passage. The dam has a total height of 6.7 feet, and it was 3.6 feet from the water surface to the top of the dam at the time of the Phase 2 assessment on July 28, 2010.

Figure 4.14 Ledge grade control above Geer dam

Figure 4.15 Geer dam in segment R19-B

Both at the lower and upper ends of segment 19-B, the channel appears to have been pushed up against the valley wall. The channel is held in a straightened path with riprap. About 20 percent of each bank has hard bank armoring (i.e. concrete) or riprap. In areas where riprap is not present, bank erosion is common. Nearly half of the west bank has buffers less than 25 feet. About 35 percent of the east bank has buffers in the range of 0-25 feet; however, the dominant buffer width on that side is greater than 100 feet. Figure 4.16 shows an area of bank, where trees were recently cut down and the bank was stabilized with riprap.

Figure 4.16 Newly installed riprap with trees cut along the bank in segment R19-B

R20

Reach R20 was segmented because of differences in depositional features (bars). The lower segment (R20-A) begins where the valley narrows upstream of West Fairlee Village and then continues about 1,400 feet to a private bridge. Segment R20-B picks up at the private bridge and extends about one-half mile to where the river runs close to Route 113. Segment R20-B is has more aggradation than the downstream segment, but diagonal bars are minor.

Segment R20-A was extensively straightened resulting in extreme channel incision and a stream type departure from a "C" channel to a "B" channel with a narrower floodplain. The channel has started to widen from the increased stream power of the straightened planform; but large trees along the bank and riprap are reducing further widening (Figure 4.17). About one-quarter of the channel length currently has riprap along the bank. Bank armoring may have been more extensive at one point, as the channel had outflanked the riprap in some locations with riprap now in the channel rather than along the bank. This segment appears to be acting as a sediment transport reach, with very little storage of sediment as bar features. The bed substrate is predominately gravel (50%) and cobbles (18%), and bedrock is present. Two ledge grade controls were observed at the lower end of the reach (Figure 4.18). The overall geomorphic condition is "fair".

The extensive channel straightening in R20-A has impacted aquatic habitat. The segment was devoid of refuge habitat for fish and other mobile aquatic organisms. Refuge areas act as retreats during stressful conditions, such as droughts, summer high temperatures, and high flow conditions. There were few undercut banks. A diversity of pools in terms of depth and size are present, but they lacked good cover (e.g. vegetative and debris cover, turbulence, and large substrate) for fish. The riparian buffer on the east bank is of higher

quality than the west bank. The dominant buffer width is greater than 100 feet; however, approximately one-third of the east bank has buffers less than 25 feet in width. The buffers on the west side are influenced by residential and commercial/industrial development along Route 113. Approximately three-quarters of the west bank have buffers less than 25 feet in width. The overall habitat condition of R20-A is "fair".

Figure 4.17 Straightened channel

Figure 4.18 Ledge grade control in R20-A

Segment R20-B has also been extensively straightened, leading to geomorphic instability and habitat degradation. The channel may have incised down to the elevation of three areas with channel spanning ledge that is at grade with the water surface under low flow conditions. The channel is a "C" by reference, and the cross section measurement indicated is near the cut-off between a "C" and a "B" channel. Route 113 is decreasing the available valley width. Even with this encroachment, the valley type is still broad. The channel evolution stage is best characterized as early widening. Historic channel degradation has caused widening and the channel is aggrading (filling in with sediment) through the presence of small diagonal bars. Upstream bank erosion and a mass failure (Figure 4.19) on the east side of the channel are sources of sediment in R20-B. Figure 4.20 shows bank erosion on the west bank and an old automobile near the upper end of R20-B, in the vicinity of Route 113. Riprap is preventing further planform adjustment and widening. The overall geomorphic condition is "fair".

Figure 4.19 Mass failure on east bank

Figure 4.20 Bank erosion and old automobile

The habitat in R20-B has been affected by the lack of *meanders* from channel straightening along almost the entire length of the segment. The dominant bedform is riffle-pool, but there are areas with plane bed bedform where pools are absent. Pools were noted to be partially filled with sediment in some locations, and riffle habitat scored in the fair category for embeddedness. Embeddedness is a measure of how filled in the interstitial spaces of the bed substrate are with fine sediment. These interstitial spaces are important habitat for aquatic insects that live in the river. The east bank has a fairly healthy buffer and is dominated by buffer widths of greater than 100 feet. There are a few short sections of buffers less than 25 feet in the vicinity of residential development. In contrast, the west bank is dominated (70%) by buffers less than 25 feet in width. The overall habitat condition of R20-B is "fair".

R21

The upper most reach that received a Phase 2 assessment on the Ompompanoosuc River mainstem in 2010 is reach R-21. R21 begins where the valley becomes wider and the river gets close to Route 113. The reach is just over one mile in length, with the downstream end of the reach in West Fairlee and the upstream end of the reach in Vershire (about 450 feet upstream of the West Fairlee/Vershire town line). R21 was segmented because of depositional features and different existing stream types. Both segments have reference stream types of "C". The lower segment (R21-A) has an existing stream type of "C", while R21-B has undergone a stream type departure from a "C" to an "F" channel. Bar features are more prevalent in R21-A than R21-B, and the upper segment is acting as a sediment transport section due to the lack of floodplain access.

Segment R21-A is 0.8 miles in length. Approximately 55 percent of the channel length has been straightened, primarily for agricultural purposes. The channel has incised historically as shown in the graph of the cross section below (Figure 4.21). The new bankfull elevation (depth where the water overtops the banks and spills out into the floodplain) is currently about two feet lower than the abandoned terrace (i.e. former floodplain before the channel incised). In this case, the channel is moving from the widening stage into the stabilizing stage of the channel evolution model. A very narrow juvenile floodplain (bankfull bench) is starting to develop on the right (west) bank. A bankfull bench, a flat area along the channel, forms at the elevation of the *bankfull discharge*. A bankfull discharge occurs about once every one to two years and is responsible for shaping river channels. The red line in the graph below shows the width of the floodprone area (an area whose extent is at an elevation twice the bankfull elevation) that would be accessed during a large flood event. The floodprone width of the cross section from R21-A is about 330 feet. The difference in the elevation of the abandoned terrace and the bankfull elevation is also illustrated in Figure 4.22.

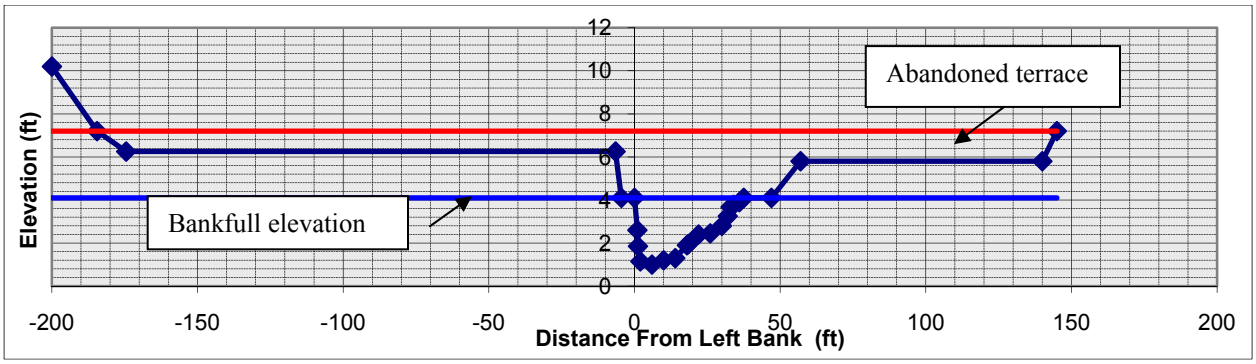

Figure 4.21 Channel cross section for segment R21-A (graph is vertically exaggerated for illustration purposes)

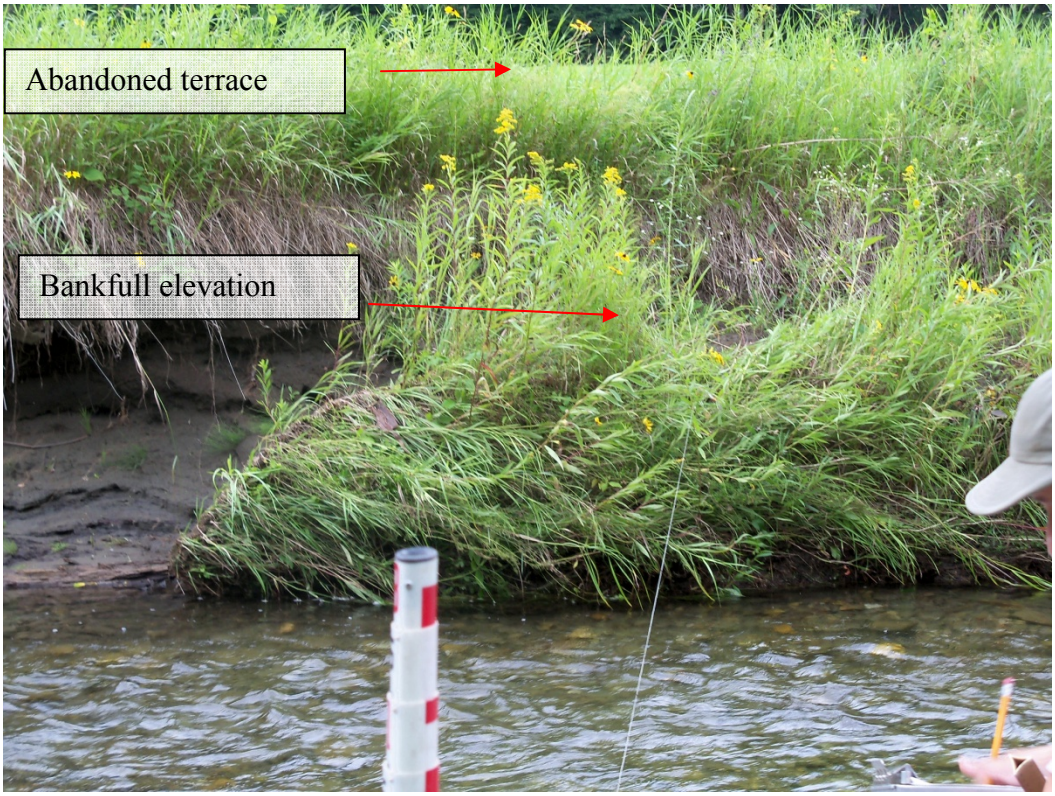

Figure 4.22 Cross section measurement in segment R21-A, showing incised channel.

Lack of vegetated buffers, high bank erosion, land use within the riparian corridor, and aggradation are all primary parameters that resulted in a habitat condition of "fair" in segment R21-A. Approximately 80 percent of the east bank and 50 percent of the west bank have buffers less than 25 feet in width. The dominant land use within the corridor is hay, with a subdominant land use of forest on the east side and residential on the west side near adjacent to Route 113. The lack of buffers is resulting in reduced woody debris recruitment, and the woody debris cover parameter was scored in the fair category. Aggradation of sediment in the channel is contributing to substrate embeddedness, and is reducing suitable habitat for colonization of aquatic insects in riffle habitat. Sources of sediment in segment R21-A include bank erosion and two mass failures.

Segment R21-B is a short segment of just over 1,000 feet in length near the West Fairlee/Vershire town line. Floodplain access is poor within this segment. As shown in Figure 4.23, the abandoned terrace is about 3.5 feet higher than bankfull. The floodprone width of this "F" channel is only 57 feet, and is much narrower than the floodprone width of the "C" channel shown in Figure 4.21. The channel in R21-B is just starting to go through a widening process. Trees on the bank and riprap are preventing the channel from widening further. There is virtually no floodplain available at a bankfull discharge, and the sediment is transported through rather than being deposited on the floodplain. The overall geomorphic condition of segment R21-B is "fair".

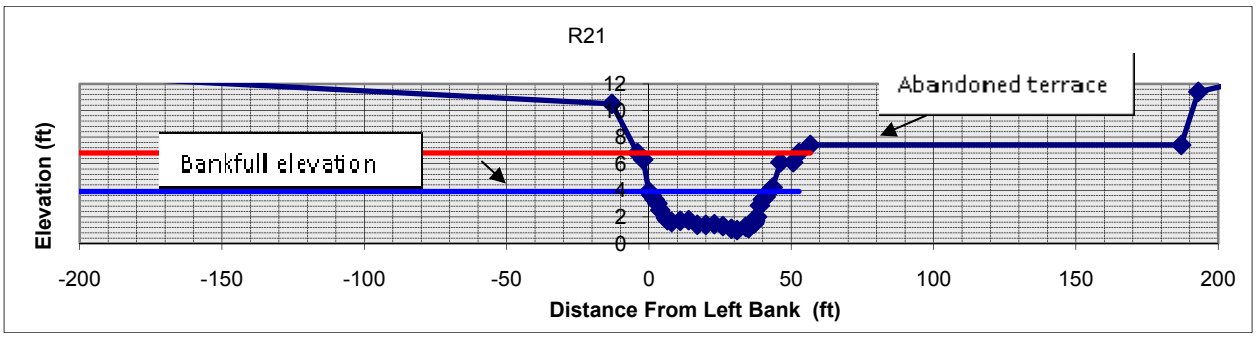

Figure 4.23 Channel cross section for segment R21-A (graph is vertically exaggerated for illustration purposes)

The overall habitat condition of R21-B is also "fair". The lack of wide, high quality riparian buffers and channel straightening are contributing to habitat degradation. Based on observations during the Phase 2 assessment, it is strongly suspected that the upper end of R21-B may have been straightened and windrowed. *Windrowing* is the pushing of gravel up from the stream bed onto the top of either bank as part of the straightening of a river. The entire length of segment R21-B has been straightened, and this has resulted in a loss of high quality pools. The number of pools per mile is within the expected range, but these pools lacked deep water habitat of over two feet, which is critical for adult trout and other resident fish species. Given the lack of buffer and the bank erosion, there are only a couple of places that have undercut banks with stable boundaries, such as roots (Figure 4.24). Hay fields are the dominant corridor land use on both sides of the channel, and buffers are generally less than 50 feet in width. Figure 4.25 shows a buffer planting project that was part of a Wildlife Habitat Incentives Program (WHIP) project about three years ago.

Figure 4.24 Stable undercut bank in segment R21-B

Figure 4.25 Planted buffer on east side of channel

Blood Brook
R16T2.01

The lower two reaches on Blood Brook are located downstream of the Lake Fairlee Dam and are referred to as Lake Fairlee outlet in this report. The most downstream reach (R16T2.01) is about 3,350 feet in length and is highly sinuous (i.e. has many meanders). *Sinuosity* is a measure of the channel length relative to the valley length. Reach R16T2.01 flows through a broad valley and has a reference and existing stream type of "E". The channel is narrow and deep. The channel slope is low gradient and sand dominates the substrate, making this a dune-ripple bedform. R16T2.01 is impounded by wetlands and beaver dams to the extent that a full Phase 2 assessment could not be completed (Figure 4.26). The dominant buffer width is greater than 100 feet, and there were no areas mapped with buffers less than 25 feet in width. Two mass failures, approximately 15 feet in height, are located on the south side of the channel.

Figure 4.26 Wetland impounded by beaver dam in reach R16T2.01 of the Lake Fairlee Outlet

R16T2.02

Reach R16T2.02 is 1,630 feet in length and is located immediately below Lake Fairlee. The channel flows through a narrow valley. The dam at the upstream end of the reach has impacted flows and held back sediment in the reach. The reach is only slightly incised, and is at the low end of the "good" range for geomorphic condition. The dominant substrate is sand, and the bedform is dune-ripple. The reference and existing stream type are "C". Aggradation, widening, and planform adjustment are currently only minor processes. Trees are falling in the near bank indicating some widening is taking place.

The habitat condition for R16T2.02 is at the high end of the "fair" range. Woody debris cover was outstanding, with logs and debris jams creating cover (Figure 4.27). Coarse particulate organic material (CPOM), which is an important source of food and cover for aquatic insects, was present both in the margins and channel. There is a high percentage of silt (30%) making the substrate less suitable for the colonization by water quality sensitive species and for trout reproduction. Connectivity of habitat scored low, because of the man-made obstruction (Lake Fairlee Dam). The dam is fourteen feet in height and is creating a system obstruction for movement of fish and other aquatic species (Figures 4.28 and 4.29).

Figure 4.27 Debris jam at reach break between R16T2.02 and R16T2.01

Figure 4.28 Lake Fairlee Dam from downstream

Figure 4.29 Looking upstream at natural ledge & Dam

R16T2.03

Lake Fairlee (R16T2.03) was not assessed because it is currently not a riverine (fluvial) system.

R16T2.04

The reach above Lake Fairlee, R16T2.04 was split into two segments during the Phase 2 assessment to account for differences in channel dimensions**.** Lack of landowner permission for access was a second reason for segmenting.

R16T2.04-A is a wetland from upstream of Lake Fairlee to above the Route 244 crossing (Figure 4.30). The upper end of the segment, below King Hill Road, had a defined channel (Figure 4.31), but access to the stream was not possible because of lack of landowner permission for access. The entire length of the segment from Lake Fairlee to King Hill Road is about 1,760 feet. The dominant buffer width on each side is greater than 100 feet; however, there are areas with buffers less than 100 feet in the vicinity of the road crossing.

Figure 4.30 Wetland below Route 244 crossing

Figure 4.31 Below Kings Hill Road in R16T2.04

The upper most segment in reach R16T2.04 begins at the King Hill Road crossing and continues upstream about 1,000 feet. The reference and existing channel type is "E". The

substrate is dominated by sand, and the bedform is dune-ripple. The sinuosity is high, with many meanders within the reach.

There are no corridor encroachments (roads, development, improved paths, railroads, etc.) in R16T2.04-B. Impacts to this segment are predominately from active livestock grazing in the riparian corridor. The livestock are causing bank erosion and are trampling the vegetation in the buffer (Figure 4.32). The channel has undergone historic incision and is currently widening. There is moderate to high erosion at the base of both banks in the riffle section, and moderate lateral bank erosion on the outside bends. About one-half the length of both banks has active erosion. Alders on the near bank are providing root structure to hold the soil and reduce further channel widening. The overall geomorphic condition is "fair".

Figure 4.32 Animal crossing and eroded bank

The overall habitat condition in segment R16T2.04-B falls at the low end of the "good" range. The pasture adjacent to the channel has introduced some invasive species, such as Japanese barberry and honeysuckle. In areas that have not been disturbed, alders are providing high quality bank vegetation and good root structure (Figure 4.33). There are very few undercut banks because of the extensive bank erosion. Figure 4.34 shows an undercut bank that is providing cover for resident species. Coarse particulate organic material that is important for food and cover for aquatic insects is common in both the channel and margins. The buffer is reverting back to trees and shrubs in some locations and at some point could provide higher recruitment of large woody debris, which is currently in low supply.

Figure 4.33 Alders providing good root structure

Figure 4.34 Undercut bank providing good cover

R16T2.05

Reach R16T2.05 is approximately 1.5 miles in length. The reach starts about 1,000 feet upstream of the King Hill Road crossing and ends at Marsh Hill Road. R16T2.05 was broken into five segments during the Phase 2 assessment. The lower three segments are mapped in the Vermont Significant Wetland Inventory as palustrine wetland.

The lowest segment in R16T2.05-A is 1,500 feet in length. Most of the segment has a dune-ripple bedform, but the upper portion is riffle-pool. The channel has historically incised resulting in a stream type departure from a reference "E" channel to a "C" channel. The overall geomorphic condition is on the low end of the "fair" range. In terms of the channel evolution model, the channel has undergone widening and is currently stabilizing. Moderate to high scour and erosion at the base of both banks and the very high width to depth ratio (i.e. channel is wide and shallow) indicate widening is a major process. There is moderate to high lateral bank erosion on most outside bends and *flood chutes* are crossing the inside of meander bends indicating planform adjustment is a significant process. Aggradation is also evident from the filling of pools with sediment and the large number of *point bar*s that are present. Point bars typically are not found in channels with a reference stream type of "E" because the channel is narrow and deep and able to transport the sediment through the system.

The habitat of segment R16T2.05-A is "fair". The stream banks have been impacted by livestock grazing. About 40 percent of the east bank and 60 percent of the west bank have eroded. There are isolated areas (about 10% of the length of the channel) with buffers less than 25 feet in width. Japanese barberry and honey suckle are invasive species that are common in the riparian corridor (Figure 4.35). There is limited habitat diversity in the straightened section in the middle of the reach in the vicinity of a residence.

Figure 4.35 Lack of buffer along the near bank and invasive plant species in the background in R16T2.05-A

Similar to the downstream segment, R16T2.05-B also represents a stream type departure from an "E" channel by reference to a "C" channel. Two cross sections were measured in segment R16T2.05-B to capture the range of floodplain access. The more incised cross section is representative of the overall segment, and the overall geomorphic condition is "fair". Segment B is about one-half mile in length and starts where the west buffer becomes more wooded and continues to a beaver dam. The east side of the channel runs along a field in the upper half of the segment, resulting in about 540 feet with buffers less than 25 feet on that side (Figure 4.36) .

Despite the lack of large trees along the bank on the east side of the channel, there were a number of places where small debris jams formed offering cover for aquatic species (Figure 4.37). The pools lack cover other than large woody debris and coarse particulate organic material. The overall habitat score is in the upper range of "fair" and just missed the "good" category. River Banks (east side of channel) and Riparian Area (east side of channel) were the only habitat parameters that did not score in the good range.

Figure 4.36 Lack of buffer along east side of channel

Figure 4.37 Habitat debris jam in R16T2.05-B

A large beaver dam at the lower end of R16T2.05-C is impounding the channel (Figure 4.38). Two smaller beaver dams were in place near the upper end of segment C at the time of the Phase 2 assessment. A full Phase 2 assessment could not be completed due to the extent of the impounded flow. Segment C is in good condition with dominant buffer widths of greater than 100 feet. Hay fields are in the eastern corridor, and the subdominant buffer width on the east side is 51-100 feet. The reference channel type is "E" and the valley type is very broad.

Figure 4.38 Large beaver dam at downstream end of R16T2.05-C

Segment R16T2.05-D is 610 feet in length, and starts where the wetland vegetation ends at the top of segment C and continues upstream until there is no property access near a horse pasture. Segment D appears to have been extensively straightened at some point in the past, and likely incised as a result of this channel modification. Riprap from historic channel straightening is evident along small sections of the bank, but is also in the channel. The channel is currently in the widening stage of the channel evolutions model (Figure 4.39), and is starting to regain some sinuosity. The moderate to high lateral bank erosion and the presence of flood chutes and *islands* indicate planform adjustment is a major process. The overall geomorphic condition is "fair".

The straightened planform and the narrow buffer on the east side of the channel are factors that are affecting habitat in segment R16T2.05-D. There are frequent pools, but only one pool was over two feet in depth. The lack of sinuosity in the segment is responsible for the marginal pool depths; typically, deep pools form on the outside of meander bends. Small minnows were observed in pool habitat. About 50 percent of both banks are eroded. Pasture is in the east riparian corridor, and buffers are narrow on the east side with the dominant buffer width of less than 25 feet. The west side of the channel has a forested buffer. The habitat condition is "fair".

Figure 4.39 Bank erosion indicative of channel widening in segment R16T2.05-D

A full Phase 2 assessment of the most upstream portion of R16T2.05 (segment E) could not be completed because of lack of landowner permission. Segment E is about 1,500 feet in length. Riprap is evident along both sides of the channel at the downstream end; the lower 230 feet of the segment has been straightened (Figure 4.40). The upper 550 feet of the segment has also been straightened, and what appears to be an old mill building is located along the east bank in the most upstream part of the segment (Figure 4.41). The channel in most of this segment flows through a horse pasture with nearly 75 percent of the channel length having buffers less than 25 feet in width.

Figure 4.40 Straightened channel in R16T2.05-E

Figure 4.41 Old mill building on east bank

R16T2.06

The most upstream reach assessed on Blood Brook (R16T2.06) was split into four segments during the Phase 2 assessment to account for a variety of factors including banks and buffers, grade control, channel dimensions, and wetland habitat. The total length of reach R16T2.06 is 1.2 miles.

The most downstream segment, R16T2.06-A, starts at Marsh Hill Road and goes upstream about one-half mile through a horse pasture with buffers less than 25 feet along the entire length (Figure 4.42). This segment likely was a wetland historically that has been altered for agricultural use. The dominant bedform is riffle-pool, although there are some areas with plane bed features that lack defined pools. The dominant bed substrate is gravel. Silt and clay are cohesive bank material on the lower bank, while the upper bank is non-cohesive and consists primarily of sand. The channel has a reference and existing stream type of "E", but lacks the high sinuosity that is typical of this type of channel. The channel currently has a straightened planform either due to active head cuts (Figure 4.43) or historic and present channel management practices, such as straightening and armoring or dredging. Six active head cuts were mapped during the Phase 2 assessment, which is a sign of active incision. The overall geomorphic condition is at the low end of the "fair" range. In addition to having extreme active incision through the presence of numerous head cuts, the channel is actively widening due to lack of floodplain access. There is bank erosion along 60 percent of both banks. Horses are adding to the bank erosion, by causing localized disturbance at animal fords (Figures 4.44 and 4.45).

Figure 4.42 Low sinuosity in segment R16T2.06-A

Figure 4.43 Head cut or knickpoint

Figure 4.44 Disturbed soil at animal ford

Figure 4.45 Trampled stream banks from horses

The habitat condition of R16T2.06-A also scored at the low end of the "fair" range. Woody debris cover, River Banks and Riparian Area all scored in the poor category. Despite the "fair" habitat condition, brook trout and blacknose dace were observed. Frogs were also present in this segment. Pools are frequent, yet depths greater than 2 feet are

not common. Undercut banks are numerous within the segment, and overhanging shrubs and herbaceous vegetation provide cover for aquatic species. Some of the undercut banks are unstable due to the significant bank erosion.

Segment R16T2.06-B begins above the horse pasture, where the banks and buffers become wooded, and continues upstream about one-half mile to a pedestrian bridge, located downstream of the Godfrey Road crossing. A pond visible in the 2008 imagery is not an onstream pond. The channel flows around the pond. The reference and existing stream type for segment B is "E". The bedform is riffle-pool and the dominant bed material is gravel. The valley is very broad. Over half of R16T2.06-B has a straightened planform, and there are active head cuts both downstream and upstream of the pond. Extreme active incision has led to channel widening and significant bank erosion. About 75 percent of both banks are eroded. The geomorphic condition is "fair".

Wetlands are extensive in the riparian buffer and corridor (Figure 4.46). The high quality buffers are contributing to the habitat condition of "good", although the habitat score was at the low end of the range. The dominant buffer width on each side of the channel is 100 feet, and there is less than 200 feet of channel length with buffers less than 25 feet on the east bank. The subdominant buffer width on the west bank is 26-50 feet. All of the habitat parameters were rated in the good category with the exception of Channel Morphology. Channel morphology was rated fair because of the channel straightening (Figure 4.47) and the limited floodplain access.

Figure 4.46 Wetlands in buffer and corridor

Figure 4.47 Channel straightening and bank armoring

Segment R16T2.06-C starts at the pedestrian bridge, located just downstream of the Godfrey Road crossing, and continues upstream just under one-half mile to a wetland. The geomorphic and habitat setting of segment C is much different than the "E" channels in segments A and B. There are multiple grade controls in R16T2.06-C, including three areas of ledge and a waterfall below Godfrey Road that is shown in Figure 4.48. The valley is still very broad. A cross section measured in the middle of the reach indicates the channel is not incised. Figure 4.49 shows the channel at the cross section location in segment C. Both the existing and reference stream type is "C". The channel is in the first stage of the channel evolution model (F-I or stable). The geomorphic condition is "good".

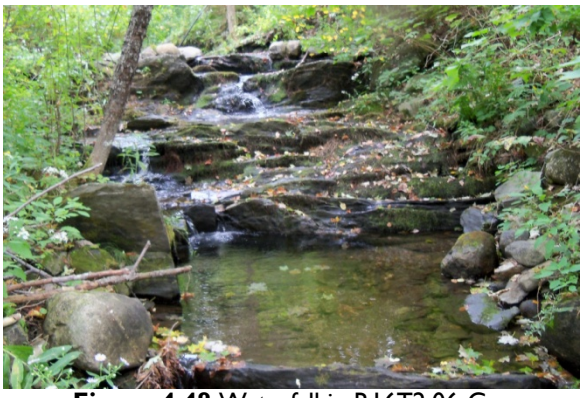

Figure 4.48 Waterfall in R16T2.06-C

Figure 4.49 Typical channel in R16T2.06-C

The habitat condition of R16T2.06-C is also "good", although the score is at the low end of the range. All of habitat parameters scored in the good category with the exception of connectivity. The waterfall and the Godfrey Road culvert are likely an obstruction for some aquatic species. The Godfrey Road culvert is discussed in further detail in sections 4.5 and 6.2. In general, the water depth in segment C is shallow. There are frequent pools, but none of the pools exceeded two feet in depth at the time of the assessment.

A full Phase 2 assessment of R16T2.06-D, the most upstream segment of Blood Brook, could not be completed because the channel is small and in a wetland setting (Figure 4.50). The valley is very wide and the buffers are expansive.

Figure 4.50 Wetland in segment R16T2.06-D

Middle Brook

R16T2.03S1.01

The lowest reach on Middle Brook was split into three segments during the Phase 2 assessment to break out sections that are impounded by wetlands or beaver dams. Segment R16T2.03S1.01-A begins above Lake Fairlee (Figure 4.51) and continues just over one mile to upstream of a farm bridge, where the channel is no longer impounded. Figure 4.52 shows the upper end of the impounded section, immediately below the farm bridge. The channel in segment A is impounded from flow which backs up from Lake Fairlee and from beaver dams. Much of the riparian corridor is included as palustrine wetland in the Vermont Significant Wetland Inventory Geographic Information System (GIS) layer. The dominant buffer width is greater than 100 feet in width. There is only a short section (approximately 200 feet in length) of channel near the top of Segment A that has buffers less than 25 feet. This narrow buffer is associated with a hay field and a farm bridge.

Figure 4.51 Wetland upstream of Lake Fairlee

Figure 4.52 Impounded channel below farm bridge

R16T2.03S1.01-B is about 3,400 feet in length and starts just upstream of a farm bridge and continues to just upstream of Cross Rivendell Trail Bridge, where there is a beaver dam. This middle segment is located in between two areas of beaver dam influence. The channel has a high sinuosity, and is located in a very broad valley. The dominant substrate material is sand. The primary bedform is dune-ripple; however, there are some short sections that are riffle-pool. The reference and existing stream type is "E". Some minor historic incision has occurred resulting in geomorphic adjustment. Moderate to high scour and erosion at the base of both banks in riffles is a sign of channel widening. Large point bars inside of meander bends indicate aggradation is a major process. Flood chutes have developed into point bars, and two recent channel *avulsions* indicate extreme planform change. Extensive lateral bank erosion on most outside bends is also a sign of significant planform adjustment. The adjustments that are occurring indicate the channel is in the stabilizing stage of the channel evolution model.

The habitat condition for Reach R16T2.03S1.01-B is "good". The dominant buffer width within the reach is over 100 feet on the east side and 51-100 feet on the west side. Buffers less than 25 feet are subdominant and occur in the area immediately downstream of the Cross Road Trail (Figure 4.53). The presence of frequent pools with a variety of depths and surface area are offering suitable depth cover for fish and other aquatic species. Pools with depths greater than three feet are common within segment B. There are a number of low flow and high flow refuge areas, where aquatic species can retreat during stressful conditions. Large woody debris cover is excellent (Figure 4.54), and there are many undercut banks.

Figure 4.53 Lack of buffer and bank erosion

Figure 4.54 Large woody debris cover

The most upstream segment in R16T2.03S1.01-C starts above the Cross Rivendell Trail Bridge and continues about 1,000 feet upstream. The channel is impounded by a beaver dam at the downstream end of the segment (Figure 4.55). Riparian buffers are narrow in segment C along the west bank with a dominant buffer width of 0-25 feet. The east bank, however, is forested and the dominant buffer width is greater than 100 feet. There is a short area in the middle of the segment adjacent to a crop field, where the buffer is 51 to 100 feet. Crop is the dominant land use within the western corridor, while forest is dominant in the eastern corridor.

Figure 4.55 Beaver dam impounding flow in reach R16T2.03S1.01-C of Middle Brook

R16T2.03S1.02

The next reach on Middle Brook begins about 1.2 miles from the junction of Middle Brook Road and Route 244. The reach was split into two segments to account for differences in sinuosity. Segment A, the most downstream segment, has a high sinuosity (i.e. long channel length compared with valley length), with the exception of a short section of straightened channel at the bottom of the segment. The upper segment (B) has a low sinuosity and a straightened planform.

Segment R16T2.03S1.02-A is about 2750 feet in length. The channel has a reference and existing and stream type of "E". The dominant substrate material is sand. The bedform is predominantly dune-ripple, yet some portions have distinct riffles and pools. The downstream end of the segment (last 350 feet) is impounded by a beaver dam. Segment A is in "fair" geomorphic condition, and is undergoing major adjustment processes in terms of aggradation, widening, and planform change. The wetland adjacent to the channel on the west side is about one foot higher than the bankfull elevation. An active head cut in clay soils (Figures 4.56 and 4.57) was observed on a small drainage that enters the channel from the west side in the middle of the segment. It is not clear whether the channel historically incised in this segment. Nonetheless, given the extent of the aggradation, widening, and planform adjustment that is occurring, the channel appears to be in the stabilizing stage of the channel evolution model. There is a well defined floodplain on both sides of the channel. Based on the inspection of orthophotos, the channel has moved laterally over time. Planform adjustment is evident in the field from the moderate to high lateral bank erosion on most outside bands, *neck cutoffs* (places where the channel crosses and cuts off a meander), active flood chutes crossing inside of meander bends, and islands. There are numerous bars, which are uncharacteristic of the reference "E" channel. These bars are indicative of aggradation within the channel. Channel widening has occurred, and approximately seventy percent of both banks are eroded (Figure 4.58 and 4.59).

Figure 4.56 Active head cut in clay soils in swale

Figure 4.57 Incised drainage swale

Figure 4.58 Bank erosion and lack of buffer

Figure 4.59 Bank slumping and typical channel

The active geomorphic processes occurring in R16T2.03S1.02-A is also impacting habitat. The overall habitat condition is "fair". There are few stable undercut banks, most likely due to the extreme bank erosion and the lack of large woody vegetation along the near bank. Woody debris cover is in the fair category due to lack of large woody debris. Most of the woody material is small, and coarse particulate material is in good supply and is present in the channel and along the margins. About one-third of the reach has buffers less than 25 feet in width. Hay fields are the dominant corridor land use on the east side of the channel, while wetland is dominant in the buffer on the west side. The subdominant land use on the west side is pasture. Wetlands in the corridor on the west side are providing out of channel refuge areas (such as the shown in Figure 4.60) that provide safety for aquatic species during high flow events.

Figure 4.60 High flow refuge area in wetland

R16T2.03S1.02-B is approximately 1,600 feet in length. The upper end of segment B ends at Middle Brook Dam. Segment B is straightened along its entire length, and riprap maintains this straightened planform in the section between the dam and Middle Brook Road. There

is also evidence of patches of riprap below Middle Brook Road (Figure 4.61), suggesting the entire channel may have been riprapped at one point to maintain a straightened planform for maximum use of agricultural fields. The channel is currently in the widening stage of the channel evolution stage, where it is free from riprap. The geomorphic condition is "fair". Aggradation is minor except for large *mid channel bars* upstream of an undersized culvert crossing on Middlebrook Road.

Figure 4.61 Outflanked riprap in R16T2.03S1.02-B

The overall habitat condition for R16T2.03S1.02-B is "fair" and is primarily related to the straightened planform and lack of buffer (Figure 4.62). A number of habitat parameters scored in the fair or poor range including River Banks and Riparian Area. Large woody debris important for cover for fish is almost absent in the segment and coarse particulate material vital for food and habitat for aquatic insects is limited both in the channel and along the margins. This resulted in a score for Woody Debris Cover in the poor range. Channel Morphology scored in the fair range because of the moderate channel incision and the extent of the channel straightening. The Middle Brook Dam is acting as a system obstruction in the reach for movement of aquatic species, and this factor reduced the Connectivity score.

Figure 4.62 Bank erosion and lack of buffer along straightened channel

Schoolhouse Brook (Tributary 3 to Ompompanoosuc River)
R18T3.01

The Phase 2 assessment included one reach on Schoolhouse Brook. Reach R18T3.01 starts at the confluence with the Ompompanoosuc River main stem and continues to about 450 feet below the Back Street crossing. The reach was broken into two segments to capture differences in grade control, channel dimensions, depositional features, and channel evolution.

The most downstream segment (R18T3.01-A) has a reference and existing stream type of "C". The segment is about 1,700 feet in length. The dominant bed substrate is cobble, and bedform is riffle-pool. The channel flows through a very broad valley, and has moderate to high sinuosity. As shown in the graph of a cross section (Figure 4.63), there is a well defined abandoned terrace on the right (west side) of the channel, which may be the recently abandoned floodplain. If this is the case, the channel has historically incised by 2.5 feet (or the *bankfull channel depth*). Historic channel incision has led to extreme planform adjustment and considerable widening and aggradation. The geomorphic condition is "poor". The channel has started to build a juvenile floodplain at a lower elevation than the abandoned terrace.

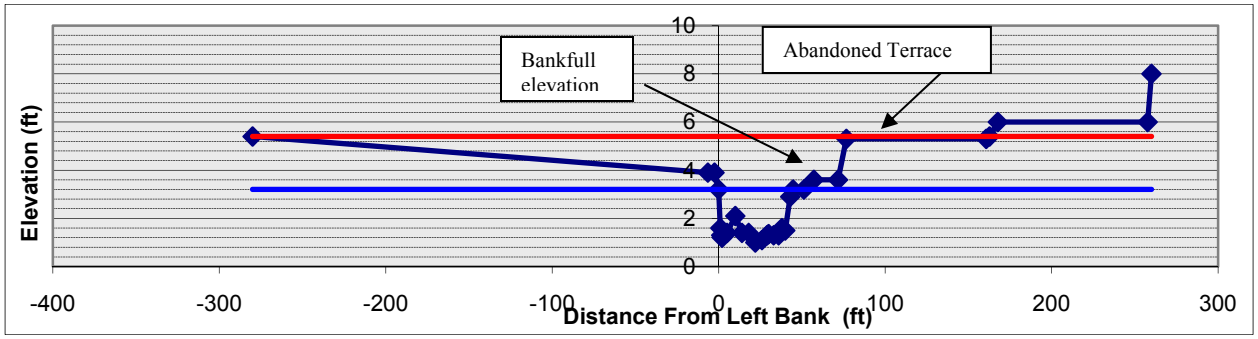

Figure 4.63 Graph of channel cross section for segment R18T3.01-A
(The graph is vertically exaggerated for illustration purposes.)

Despite the active geomorphic adjustment, the habitat scored at the high end of the "fair" range. The habitat parameter Scour and Deposition Features was mixed in terms of scoring. Scour (pool habitat) was ranked high, while deposition (bars) was ranked low. The frequency and diversity of pool sizes are providing excellent deep water habitat cover for fish. Boulders and large woody debris in the pools are contributing to pool cover (Figure 4.64). Large depositional features, such as mid channel bars, are present in the channel (Figure 4.65). Fine deposition in the channel may clog the voids between cobbles and coarse gravel, thereby impairing spawning habitat for trout, shelter for young trout, and habitat for aquatic insects. The dominant buffer width is greater than 100 feet on both sides, and trees on the near bank are providing organic material that is an important source of food for aquatic insects and other aquatic species. There are numerous undercut banks with suitable water depths to provide bank cover for fish (4.66).

Figure 4.64 Large pool providing habitat for fish

Figure 4.65 Large depositional features reduce habitat

Figure 4.66 Tree root is providing a stable undercut bank

Segment B on the lowest reach of Schoolhouse Brook begins just downstream of the Route 113 crossing and continues upstream 625 feet. The segment has been extensively straightened and there is large rock or hard bank armoring present along 245 feet of the west bank and 155 feet of the east bank. There is some evidence of berms along the east bank that are likely from windrowing. The channel was likely dredged following a major flood event and the material was placed along the east bank to protect adjacent yards and buildings off of Route 113. The channel is encroached upon by Back Street on the west bank. A rock wall or old abutment is also located on the east bank (Figure 4.67). Back Street sits high above the channel, and it is possible that there was some placement of fill on the west bank that is associated with the residential development. The channel has incised resulting in a stream type departure from a reference "C" channel to a "B" channel with reduced floodplain. The geomorphic condition is "fair". The channel is in the incised stage of the channel evolution model, and appears to be locked in place by large boulders along the bank toe and berms. There are very few depositional features in segment B; the channel has become a sediment transport reach because of the straightened planform (Figure 4.68). There are two channel spanning ledge grade control areas that guard against future channel incision.

Figure 4.67 Rock wall or old abutment on east bank

Figure 4.68 Straightened planform

Habitat diversity is lacking in segment R18T3.01-B. The dominant bedform is *planebed*, and this is a departure from the reference bedform of riffle-pool. In other words, the channel lacks discrete bed features (such as pools, riffles, and point bars) and may have long stretches of featureless bed. Pools are present, but there was only one pool that exceeded two feet in depth in the segment at the time of the Phase 2 survey in August 2010. There are a number of stormwater inputs (road ditches on the east side and a pipe on the west side) that are increasing peak flows during a storm event and adding fine sediment to the channel. This fine sediment degrades habitat for aquatic insects, fish, and other aquatic species.

4.2 Geomorphic Summary

The existing stream types for each assessed reach/segment are included in Figure 4.69. There are a few segments where the existing stream type differs from the reference stream type or a stream type departure has taken place (refer back to Figure 2.5). 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. A stream type departure occurred on Middle Brook in R16T2.03S1.02-B where an "E" channel was converted to a "C" channel due to widening. On Blood Brook, segments R16T2.05-A and R16T2.05-B changed from "E" channels to "C" channels most likely due to aggradation and widening, respectively. Reach R16 on the main stem of the Ompompanoosuc (immediately downstream of the confluence with the Lake Fairlee outlet) was also altered from an "E" channel to a "C" channel due to channel widening.

There were some reaches/segments that departed from a "C" channel to a "B" channel. "B" channels have moderate to steep slopes and have narrower floodplain than "C" channels. These reaches/segments include: R18 (main stem on Thetford/West Fairlee town line, R18T3.01-B (Schoolhouse Brook), R19-B (main stem in vicinity of Mill Street), and R20-A. The cross section for segment R15-A (downstream of Route 113) indicated there may have been a stream type departure from a "C" channel to a "B" channel; however most of the segment was impounded and there were poor bankfull features in the riffle at the downstream end. In segment R21-B (main stem at West Fairlee/Vershire town line), a

stream type departure from a reference "C" channel to an "F" channel has occurred. An "F" channel has moderate to high width to depth ratio, a gentle slope, and is even more entrenched than a "B" channel. Historic incision is the cause for the stream type departure in reaches/segments R15-A, R18, R19-B, R20-A, R21-B, and R18T3.01-B. Route 113 and Back Street encroach upon the river corridors of the main stem and Schoolhouse Brook (R18T3), respectively. These encroachments have resulted in a loss of floodplain access, which has led to channel incision.

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, 2010a).

Many of the reaches studied in the Ompompanoosuc River 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. All three adjustment processes, aggradation, widening and planform migration as a result of historic degradation within the channel are common in the Ompompanoosuc River watershed. Tables 3a and 3b below summarize the channel evolution of each study reach/segment and the primary adjustment processes that are occurring in the Ompompanoosuc River mainstem and tributaries, respectively. A narrative and illustration of the F stage channel evolution model is provided in Section 3.52 for reference.

The Ompompanoosuc River is predominately at stage III (widening) or IV (stabilizing) of the "F-stage" channel evolution model. In all reaches/segments except one, the channel has undergone historic degradation or is actively degrading. Many of the cross sections on Phase 2 study reaches were found to be incised, with thirteen reaches/segments having moderate (1.4-2.0) incision ratios. Four reaches/segments had incision ratios greater than 2.0 and were therefore considered having severe degradation. Two segments, R16T2.06-A and R16T2.06-B on Blood Brook between Marsh Hill Road and Godfrey Road are actively degrading as evidenced by the presence of head cuts.

Along many of the segments, the system is actively adjusting to this lower bed elevation by moving laterally and widening in order to create a new floodplain at a lower elevation. This widening and planform adjustment is leading to another adjustment process, aggradation. Aggradation, widening and planform adjustment are major in most reaches/segments with some experiencing severe adjustment processes. Aggradation in the Ompompanoosuc River study area seems to be a combination of *endogenous* sediment that is created as the stream widens and erodes its banks to reestablish a new floodplain as well as from *exogenous* sources such as gravel roads and land clearing. Unvegetated mid-channel bars, point bars, side bars, and flood chutes confirm the Ompompanoosuc River is undergoing extensive lateral migration. One segment, R16T2.06-C, above Godfrey Road on Blood Brook, was found to be in stage I of the "F-stage" channel evolution model, wherein no major adjustment processes were noted and the channel has not historically incised.

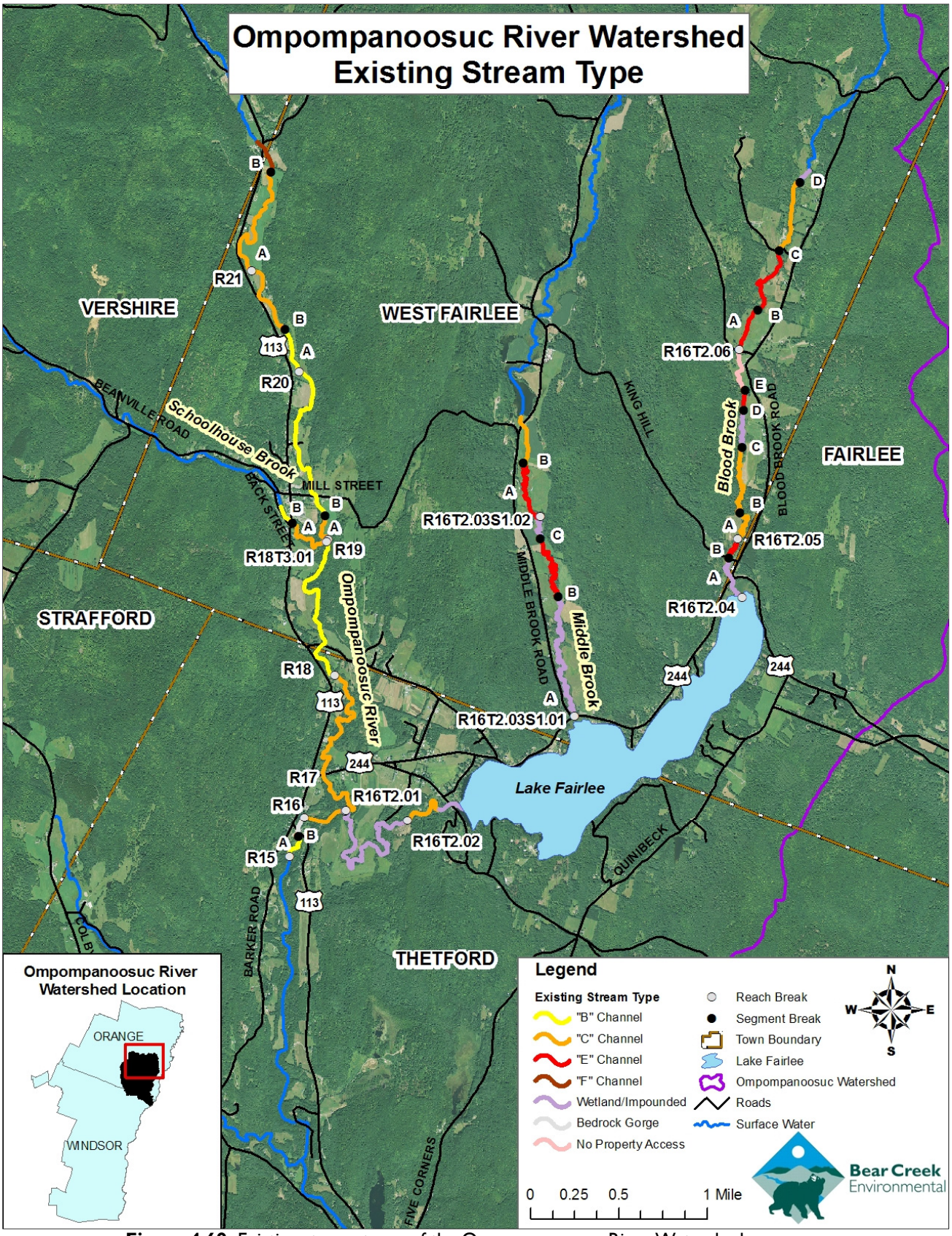

Figure 4.69. Existing stream types of the Ompompanoosuc River Watershed

Table 3a. Stream Type and Channel Evolution Stage
Ompompanoosuc River Main Stem

Segment Number	Entr. Ratio	Width to Depth Ratio	Reference Stream Type	Incision Ratio	Existing Stream Type	Channel Evolution Stage	Active Adjustment Process
Ompompanoosuc River							
R15-A	1.40	17.2	C4	2.20	B4c	NA[1]	NA[1]
R15-B	Bedrock Gorge						
R16	5.23	15.8	E5	1.31	C5	F-III Widening	**Aggradation Widening Planform**
R17	10.7	18.2	C5	1.70	C5	F-IV Stabilizing	**Aggradation Widening Planform**
R18	1.77	36.2	C4	2.77	B4c	F-IV Stabilizing	**Aggradation Widening Planform**
R19-A	3.41	20.6	C4	1.94	C4	F-III Widening	**Aggradation Widening** Planform
R19-B	1.42	17.3	C4	2.59	B4c	F-III Widening	**Aggradation Widening Planform**
R20-A	1.60	19.9	C4	1.92	B4c	F-III Widening	**Widening** Planform
R20-B	2.07	18.7	C4	1.77	C4	F-III Widening	Aggradation **Widening** Planform
R21-A	8.79	19.2	C4	1.55	C4	F-III Widening	**Aggradation Widening Planform**
R21-B	1.34	20.2	C4	2.21	F3	F-III Widening	Aggradation **Widening** Planform

[1] A cross section was done on this segment, but a full assessment was not done since most of the segment was affected by beaver dams. The cross section in segment R15-A may not be representative of the entire segment.

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 a stream type departure

Table 3b. Stream Type and Channel Evolution Stage
Tributaries of the Ompompanoosuc River

Segment Number	Entr. Ratio	Width to Depth Ratio	Reference Stream Type	Incision Ratio	Existing Stream Type	Channel Evolution Stage	Active Adjustment Process
Lake Fairlee Outlet							
R16T2.01	Impounded by Beaver Dam						
R16T2.02	2.65	16.7	C5	1.21	C5	F-III Widening	Aggradation Widening Planform
Blood Brook							
R16T2.04-A	Wetland						
R16T2.04-B	51.34	6.26	E5	1.52	E5	F-III Widening	**Widening** Planform
R16T2.05-A	8.75	22.6	E5	1.77	C5	F-IV	**Aggradation Widening Planform**
R16T2.05-B	8.60	18.6	E5	1.83	C5	F-III Widening	**Aggradation Widening Planform**
R16T2.05-C	Wetland						
R16T2.05-D	10.4	7.54	E4	1.44	E4	F-III Widening	Aggradation **Widening Planform**
R16T2.05-E	No Property Access						
R16T2.06-A	30.9	5.53	E4	1.60	E4	F-II Incising	**Degradation** Aggradation **Widening Planform**
R16T2.06-B	22.8	10.0	E4	1.56	E4	F-II Incising	**Degradation** Aggradation **Widening** Planform
R16T2.06-C	5.23	11.6	C4b	1.00	C4b	F-I Stable	Aggradation Planform
R16T2.06-D	Wetland						
Middle Brook							
R16T2.03S1.01-A	Wetland						
R16T2.03S1.01-B	9.10	11.7	E5	1.35	E5	F-IV Stabilizing	**Aggradation Widening Planform**
R16T2.03S1.01-C	Impounded by Beaver Dam						
R16T2.03S1.02-A	11.9	11.2	E5	1.32	E5	F-IV Stabilizing	**Aggradation Widening Planform**

Table 3b. Stream Type and Channel Evolution Stage Tributaries of the Ompompanoosuc River							
Segment Number	**Entr. Ratio**	**Width to Depth Ratio**	**Reference Stream Type**	**Incision Ratio**	**Existing Stream Type**	**Channel Evolution Stage**	**Active Adjustment Process**
R16T2.03S1.02-B	9.74	13.0	E5	1.54	C5	F-III Widening	Aggradation **Widening** **Planform**
Schoolhouse Brook							
R18T3.01-A	9.91	26.8	C3	1.95	C3	F-IV Stabilizing	**Aggradation** **Widening** **Planform**
R18T3.01-B	2.12	20.5	C3	1.76	B3c	F-II Incised	Aggradation Widening Planform
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 a stream type departure							

4.3 Geomorphic Condition

The existing geomorphic condition is depicted in Figure 4.70. Geomorphic condition is determined based on the degree (if any) of channel degradation, aggradation, widening and planform adjustment. These terms are defined in the glossary and in section 3.2.

Except for four reaches/segments, the assessed segments and reaches in the Ompompanoosuc River watershed were found to be in "fair" geomorphic condition. Two assessed reaches/segments (R16T2.06-C and R16T2.02) are in "good" geomorphic condition. R16T2.06-C is located in the *headwaters* of Blood Brook, and R16T2.02 is immediately downstream of Lake Fairlee. The remaining two reaches/segments (R17 and R18) are in "poor" condition. R17 and R18 are on the main stem of the Ompompanoosuc River, immediately above the confluence of the Lake Fairlee outlet.

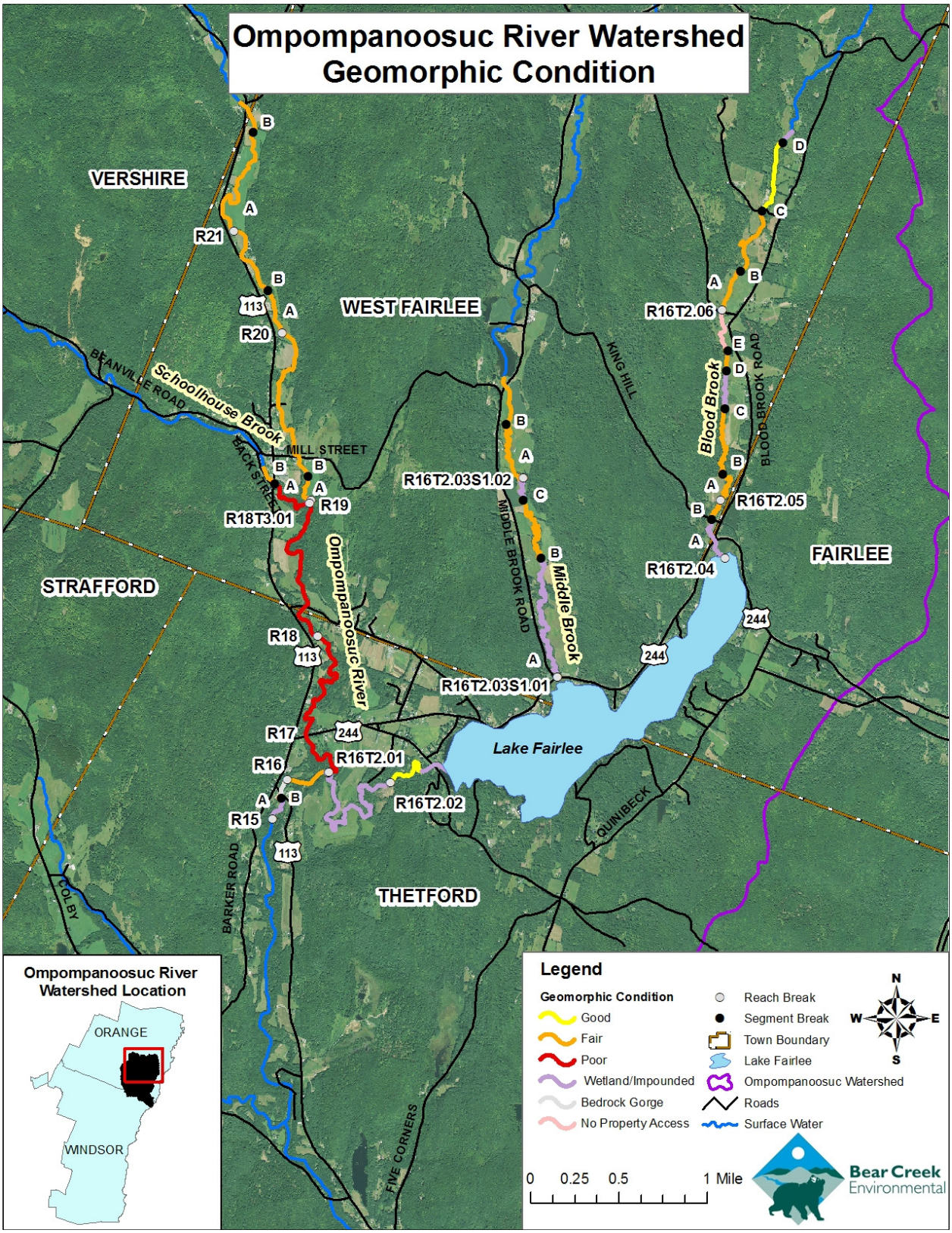

Figure 4.70. Phase 2 Geomorphic Condition of the Ompompanoosuc River Watershed

4.3 Habitat Condition

The score for each habitat parameter and the overall habitat score is provided on pages 98 and 99 of Appendix A. For most of the reaches/segments included in the 2010 Phase 2 study area, the habitat condition is "fair". All of reaches/segments on the main stem of the Ompompanoosuc River received a habitat score of "fair", as shown in Figure 4.74. Of the thirteen segments that were assessed on tributaries to the Ompompanoosuc River, nine of the reaches (70%) have overall habitat scores of "fair". A photo showing an example of "fair" habitat is provided in Figure 4.71.

Three segments on Blood Brook have a habitat score of good; however, these scores are on the cut-off between "good" and "fair". The three Blood Brook segments include: R16T2.04-B (above the King Hill Road crossing), R16T2.06-B (starting one-half mile above the Marsh Hill crossing to just downstream of Godfrey Road), R16T2.06-C (from immediately below Godfrey Road to wetland in headwaters). Segment R16T2.03S1.01-B on Middle Brook has a habitat score squarely in the "good" range. R16T2.03S1.01-B is located in the vicinity of Cross Rivendell Trail Bridge, situated between two areas of beaver dam influence. Examples of areas with good habitat are provided in Figures 4.72 and 4.73.

Figure 4.71. Segment R18 rated "fair" for habitat. The segment lacked large woody debris, riparian vegetation and was shallow and wide where the channel had been historically straightened.

Figure 4.72. Segment R16T2.03S1.01-B on Middle Brook had high quality habitat including excellent woody debris cover, deep pools, undercut banks, and trees in the buffer.

Figure 4.73. Large woody debris creating cover in Reach 17

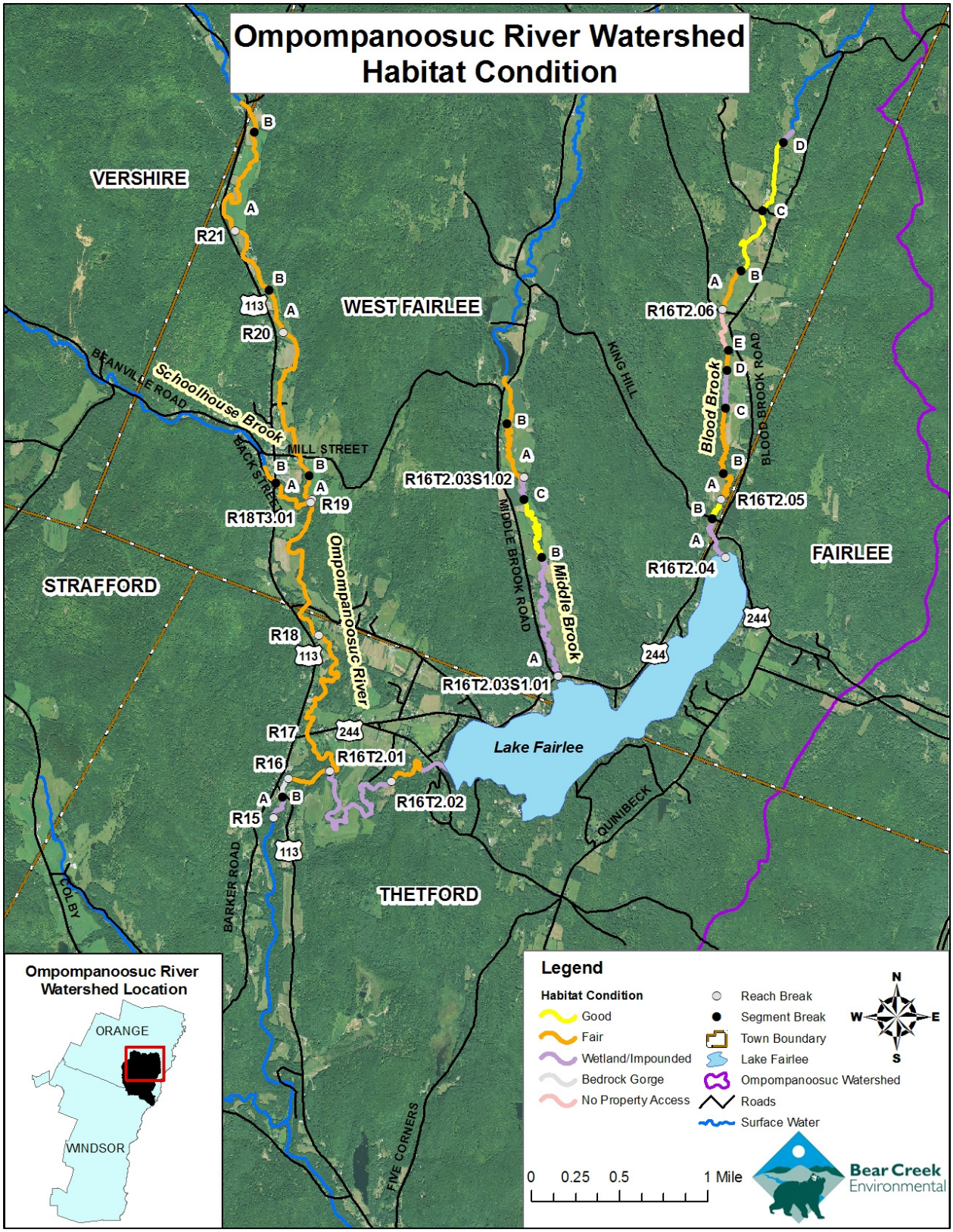

Figure 4.74. Phase 2 Habitat Condition of the Ompompanoosuc River Watershed

4.4 Comparison of Geomorphic and Habitat Condition

Tables 4a and 4b below show a comparison of the habitat condition based on the Rapid Habitat Assessment (RHA) and the geomorphic condition based on the Rapid Geomorphic Assessment (RGA).

For 14 of the 22 assessed reaches/segments, both the habitat and the geomorphic condition received a "fair" rating. Three reaches (R17, R18, and R18T3.01-A) had a rating of "fair" for habitat and "poor" for the geomorphic condition. Reach R16T2.02 had a rating of "fair" for habitat but "good" for geomorphic condition, and four reaches/segments (R16T2.04-B, R16T2.06-B, and R16T2.03S1.01-B,) had a rating of "good" for habitat but "fair" for geomorphic condition. The best ratings were observed in segment R16T2.06-C where both the habitat and geomorphic condition were rated "good.

Reaches/segments that have been straightened or had floodplain alterations can lack diversity in habitat features. Many sections of the Ompompanoosuc and its tributaries have been straightened, especially along Route 113. These reaches/segments along with some others had major intrusion into their river corridor from roads or berms, and many segments had inadequate riparian buffers due to historic and/or recent land clearing. Overall, the habitat score was similar to the geomorphic score, implying that the ecological health of the Ompompanoosuc River is closely related to the geomorphic condition of the stream.

Table 4a. Comparison of Habitat and Geomorphic Scores and Condition for Phase 2 Reaches on the Ompompanoosuc River Main Stem

Segment Number	Habitat Score (Percentage)[1]	Geomorphic Score (Percentage)[1]	Rating Habitat Condition	Rating Geomorphic Condition
Ompompanoosuc River				
R15-A	Not Assessed – Beaver Dam			
R15-B	Not Assessed – Bedrock Gorge			
R16	61	45	Fair	Fair
R17	52	23	Fair	Poor
R18	54	30	Fair	Poor
R19-A	51	43	Fair	Fair
R19-B	52	35	Fair	Fair
R20-A	56	54	Fair	Fair
R20-B	54	51	Fair	Fair
R21-A	49	39	Fair	Fair
R21-B	49	48	Fair	Fair

[1]Scores as a Percentage
Reference: 85-100 – no departure from reference
Good: 65-84 – minor departure from reference
Fair: 35-64 – major departure from reference
Poor: 0-34 – severe or extreme departure from reference

Table 4b. Comparison of RHA and RGA for Phase 2 Reaches Tributaries of the Ompompanoosuc River

Segment Number	Habitat Score (Percentage)[1]	Geomorphic Score (Percentage)[1]	Rating Habitat Condition	Rating Geomorphic Condition
Lake Fairlee Outlet				
R16T2.01	Not Assessed – Beaver Dam			
R16T2.02	63	66	Fair	Good
Blood Brook				
R16T2.04-A	Not Assessed – Wetland			
R16T2.04-B	65	60	Good	Fair
R16T2.05-A	60	38	Fair	Fair
R16T2.05-B	64	39	Fair	Fair
R16T2.05-C	Not Assessed – Wetland			
R16T2.05-D	58	44	Fair	Fair
R16T2.05-E	Not Assessed – No Property Access			
R16T2.06-A	43	40	Fair	Fair
R16T2.06-B	66	49	Good	Fair
R16T2.06-C	66	74	Good	Good
R16T2.06-D	Not Assessed – Wetland			
Middle Brook				
R16T2.03S1.01-A	Not Assessed – Wetland			
R16T2.03S1.01-B	73	40	Good	Fair
R16T2.03S1.01-C	Not Assessed – Beaver Dam			
R16T2.03S1.02-A	56	45	Fair	Fair
R16T2.03S1.02-B	42	46	Fair	Fair
Schoolhouse Brook				
R18T3.01-A	63	31	Fair	Poor
R18T3.01-B	43	61	Fair	Fair

[1]Scores as a Percentage
Reference: 85-100 – no departure from reference
Good: 65-84 – minor departure from reference
Fair: 35-64 – major departure from reference
Poor: 0-34 – severe or extreme departure from reference

4.5 Bridge and Culvert Assessment

There are a total of 20 bridge crossings and four culvert crossings on reaches assessed for Phase 2 in the Ompompanoosuc River Watershed (Figure 4.78). Thirteen of these stream crossings are on public roads. A bridge and culvert assessment using the VANR protocol was conducted on all structures that crossed stream channels in the Phase 2 study area. Four crossings were not evaluated: two which cross wetlands and two others that cross the inlet and the outlet of Lake Fairlee. A list of resources for towns regarding funding, planning and design for replacement and retrofit of stream crossings is available on the Vermont River Management and the Vermont Department of Fish and Wildlife's web sites:
http://www.vtwaterquality.org/rivers/htm/rv_EducationalResources.htm
http://www.vtfishandwildlife.com/library.cfm?libbase_=Reports_and_Documents

Table 5 summarizes the data collected for bridges within the Phase 2 study reach. The final column of Table 5 includes a prioritization of structures for replacement or retrofit. The geomorphic compatibility and AOP screening tools, photographs and Phase 2 constriction notes were used to prioritize structures for replacement/retrofit. One of three priorities for replacement was assigned (low, moderate or high). The following criteria explain the priority level assigned to each structure:

High Priority: Structures with spans of approximately 50 percent of the bankfull width or less, which are significantly impeding natural sediment transport. Culverts that are impeding the passage of aquatic organisms are automatically placed in the high priority category (e.g. *free fall outlet*).

Moderate Priority: Structures with spans less than 50 percent the bankfull width that are not causing significant geomorphic instability and structures with spans greater than 50 percent that are causing instability. Culverts that are resulting in reduced aquatic organism passage (e.g. do not have material throughout the structure or have a cascade outfall) result in at least moderate priority.

Low Priority: Stream crossing structures that are not included in either of the two categories above.

<u>High Priority for Replacement</u>

Based on the culvert screening tool, the Marsh Hill Road and Godfrey Road culverts on Blood Brook do not allow aquatic organism passage including adult salmonids (trout). For this reason, the Marsh Hill Road and Godfrey Road culverts have been assigned a high priority for replacement. Both culverts are undersized relative to the bankfull channel width. The Marsh Hill Road culvert has a width that is 63 percent of the bankfull width and the Godfrey Road culvert's width is 51 percent of the bankfull width.

Three structures crossing Middle Brook have also been assigned a high priority for replacement. Two of these structures are bridges that have a span less than 50 percent the bankfull width. The Middle Brook Road culvert is also undersized. The percent bankfull

width at the crossing is only 44 percent, and the structure was given a rating of mostly incompatible using the geomorphic compatibility tool. There is a large mid-channel bar upstream of the culvert and a large scour hole below, indicating the structure is causing a localized problem in terms of sediment transport and stream equilibrium. The lack of a natural substrate on the bottom of the culvert is potentially reducing aquatic organism passage (Figure 4.77).

Figure 4.77. Reduced aquatic organism passage and geomorphic incompatibility at Middle Brook Road Culvert

Moderate Priority for Replacement

Three bridges and one culvert were assigned a moderate priority for replacement. Two of the structures are bridges that have spans greater than 50 percent the bankfull channel width that are causing geomorphic instability. The Slaughterhouse Road Bridge in R19-B is 62 percent of the bankfull channel with and has scour above and below the crossing. A farm bridge, just upstream of Lake Fairlee on Middle Brook, has rock blocks that are falling into the channel. The percent bankfull channel width is only 54 percent. There is scour above and below the structure.

The Route 244 Bridge in R17 of the main stem has a span that is 148 percent of the bankfull channel width; however, a center pier is causing alignment problems and sediment accumulation on the east side of the channel (Figure 4.75). This aggradation is reducing the effective width to pass sediment and water during a bankfull event. The bridge is not likely to be replaced in the near future because of its size (span is 81 feet). The Route 244 Bridge has been assigned a priority of moderate rather than NR (not recommended at this time) to acknowledge this issue; it is recommended that geomorphic compatibility be considered if the bridge were to be replaced in the future.

The Route 244 crossing on Blood Brook consists of three small culverts ranging between 6 and 6.5 feet in width (Figure 4.76). The culvert bottoms are steel corrugated pipe; the pipes do not have a natural stream bed with sediment and are reducing aquatic organism passage. For this reason the Route 244 crossing was assigned a moderate priority for replacement.

Figure 4.75. Center pier of Route 244 Bridge

Figure 4.76. Three culverts at Route 244 Crossing

Lower Priority Structures

Five bridges were identified as low priority because the spans are between 50 and 100 percent of the bankfull channel width and the structures do not appear to be causing significant geomorphic instability. Two bridges that cross the Ompompanoosuc River (Cross Road and Mill Street), five bridges that cross Blood Brook (King Hill Road, Snowmobile bridge, and three pedestrian bridges), and the Route 113 Bridge over Schoolhouse Brook have structure spans greater than 100 percent of the bankfull channel width and are not recommended for replacement at this time.

The remaining five bridges were assigned a low priority due to having a span between 50 percent and100 percent of the bankfull width, and did not appear to be causing significant geomorphic instability.

Table 5
Ompompanoosuc River Watershed
Stream Crossing Summary

Reach/ Segment Number	Road Name	Structure Type	Percent Bankfull Channel Width[1]	Aquatic Organism Passage (AOP)	Geomorphic Compatibility	Phase 2 Constriction Notes	Priority for Replacement or Retrofit
R15-B Main stem	Route 113	Bridge	81[2]	NA	NA	Deposition below	Low
R17 Main Stem	Route 244	Bridge	148[2,3]	NA	NA	Deposition above and below, pier is causing alignment problem	Moderate
R18 Main stem	Cross Road	Bridge	130[2]	NA	NA	Deposition above and below, scour above and below, alignment	NR[4]
R18T3.01-B Schoolhouse Brook	Route 113	Bridge	140[2]	NA	NA	Deposition above and below, scour above, alignment	NR
R19-B Main stem	Mill Street	Bridge	136[2]	NA	NA	Scour above, alignment	NR
R19-B Main stem	Slaughterhouse Road	Bridge	62[2]	NA	NA	Scour above and below	Moderate
R20-A Main stem	Private bridge	Bridge	91[2]	NA	NA	None	Low
R20-B Main stem	Private bridge	Bridge	70[2]	NA	NA	Deposition above	Low
R20-B Main stem	Private bridge	Bridge	99[2]	NA	NA	None	Low
R21-B Main stem	Route 113	Bridge	59[2]	NA	NA	None	Low
R16T2.04-A Blood Brook	Route 244	Culvert	170[2]	Reduced AOP	Fully Compatible	Scour below	Moderate
R16T2.04-B Blood Brook	King Hill Road	Bridge	107[2]	NA	NA	Deposition above and below, scour above and below	NR

Table 5
Ompompanoosuc River Watershed
Stream Crossing Summary

Reach/ Segment Number	Road Name	Structure Type	Percent Bankfull Channel Width[1]	Aquatic Organism Passage (AOP)	Geomorphic Compatibility	Phase 2 Constriction Notes	Priority for Replacement or Retrofit
R16T2.05-C Blood Brook	Wooden bridge	Bridge	NE[5]	NA	NA	None	NR
R16T2.05-E Blood Brook	Marsh Hill Road	Culvert	63[2]	No AOP Including Adult Salmonids	Partially Compatible	Scour above	High
R16T2.06-B Blood Brook	Snowmobile bridge	Bridge	148[2]	NA	NA	Deposition above, scour below	NR
R16T2.06-B Blood Brook	Pedestrian bridge	Bridge	136[2]	NA	NA	Deposition above	NR
R16T2.06-C Blood Brook	Pedestrian bridge	Bridge	136[2]	NA	NA	Deposition below	NR
R16T2.06-C Blood Brook	Pedestrian bridge	Bridge	118[2]	NA	NA	Deposition above and below	NR
R16T2.06-C Blood Brook	Godfrey Road	Culvert	51[2]	No AOP Including Adult Salmonids	Partially Compatible	None	High
R16T2.03S1.01-A Middle Brook	Pedestrian bridge	Bridge	NE[5]	NA	NA	None	NR
R16T2.03S1.01-A Middle Brook	Farm bridge	Bridge	54[2]	NA	NA	Deposition above, scour above	Moderate
R16T2.03S1.01-B Middle Brook	Cross Rivendell Trail	Bridge	47[2]	NA	NA	Scour above and below	High
R16T2.03S1.02-A Middle Brook	Pedestrian Bridge	Bridge	42[2]	NA	NA	Deposition above, scour above	High
R16T2.03S1.02-B Middle Brook	Middle Brook Road	Culvert	44[2]	Reduced AOP	Mostly Incompatible	Deposition above, scour below	High

[1]Shaded for bankfull width percentage less than 50%
[2]Percent bankfull width measured in the field during Phase 2 Assessment
[3] Used total span of bridge for percent bankfull; effective width during a bankfull event is actually lower (36 feet) and is the distance between the center pier and west bank rip-rap; sediment has accumulated in between pier and east bank rip-rap to form a large side bar
[4] NR = Not recommended for replacement
[5] NE = Not evaluated; crosses wetland

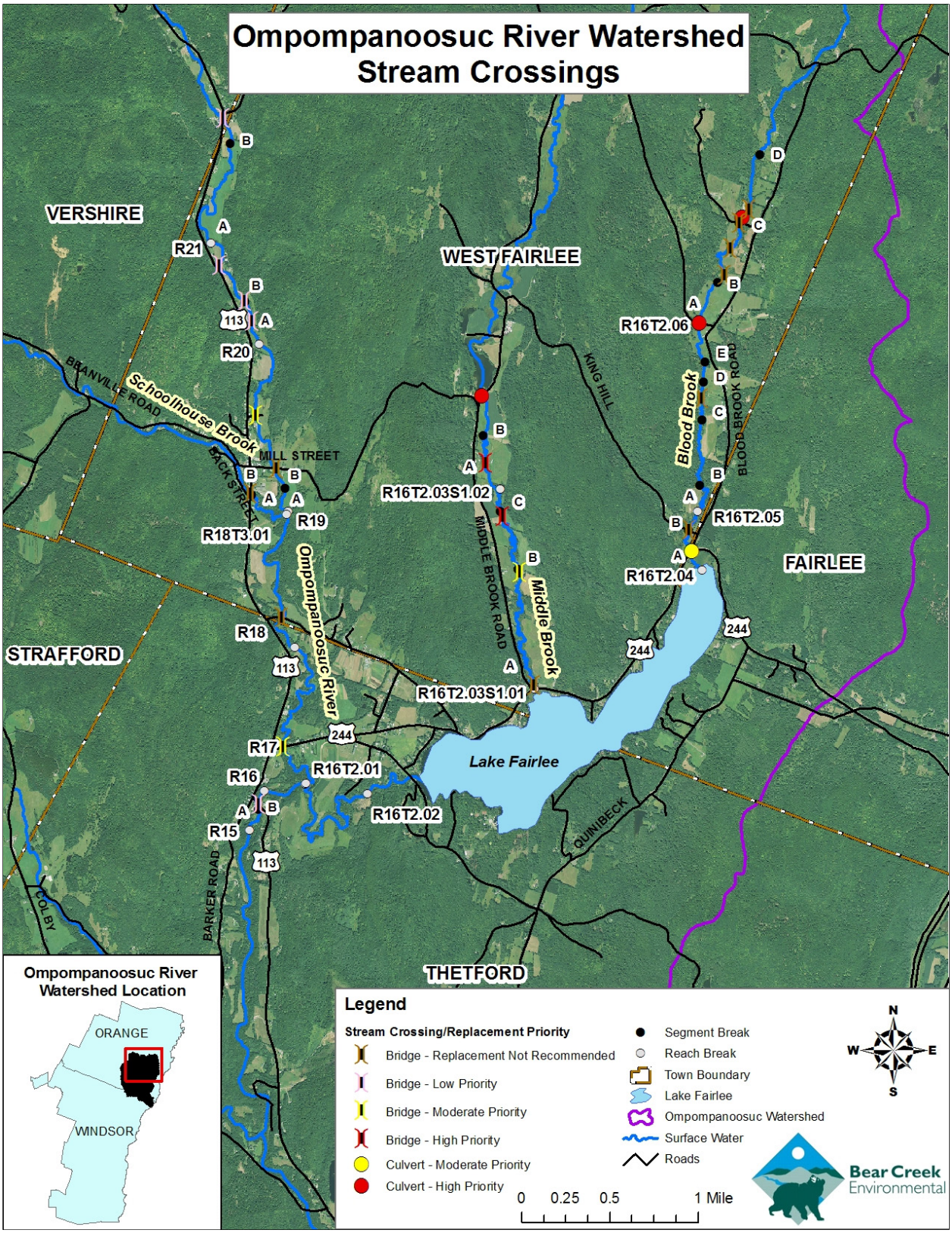

Figure 4.78. Stream Crossings within the Ompompanoosuc River Watershed

5.0 Stressor, Departure and Sensitivity Analysis

5.1 Stressor Identification

5.1.1 Hydrologic Regime Stressors

The dominant watershed land cover/land use within the Ompompanoosuc River watershed is forest. The impact rating for watershed land cover/land use was low (between 2% and 10% is crop and/or developed areas). Analysis of hydric soils located where current land uses are agricultural or developed areas indicates some loss of wetland attenuation (Appendix B, Page 1).

The Ompompanoosuc River watershed has a moderate network of roads as shown in Appendix B, Page 1. Extensive road networks can contribute significantly to increased flows within a river resulting both from increased runoff and stormwater ditching. According to Foreman and Alexander (1998), increased peak flows in streams may be evident at road densities of 3.2 miles/square mile. Subwatersheds with road densities of greater than 3.2 miles/square mile account for about 4.2 percent of the Ompompanoosuc River watershed. The highest road densities within the Phase 2 area are found in the subwatersheds of reaches R15 and R16T2.02, where development is denser.

5.1.2 Sediment Regime Stressors

Bank erosion and mass failures contribute significant sediment inputs within the Ompompanoosuc River watershed. Bank erosion mapped during the Phase 2 study totals approximately seven percent on both the east and west banks of the assessed segments/reaches. Fifteen mass wasting sites were mapped during the Phase 2 assessment. The total length of mass failures on the Ompompanoosuc River Phase 2 reaches/segments is about 790 feet.

Depositional features per mile can indicate areas of deposition and planform adjustment. Steep riffles, mid-channel bars, *delta bar*s, flood chutes, avulsions and braiding are parameters that can indicate deposition or planform adjustment. These features do not necessarily explain the sources of sediment, but they are common in areas where the sediment transport capacity of the channel has been exceeded (Vermont Agency of Natural Resources, 2010a). Channel migration features (avulsions and flood chutes) show areas of significant planform adjustment. There are 211 channel migration features within the segments/reaches assessed for Phase 2. All but two of the Phase 2 segments assessed have a high number (greater than 5) of depositional features per mile. Segments R20-A and R16T2.04-B were the only segments with a low (less than 2) number of depositional features per mile.

The bank erosion and the prevalence of mass failures illustrate the Ompompanoosuc River is providing a source of sediment input. This is resulting in the channel being

overwhelmed by sediment and exceeding the sediment transport capability as observed by the numerous depositional features per mile.

5.1.3 Channel Modifiers

Channel straightening, floodplain encroachment, and berms and roads can increase the slope of a channel resulting in increased stream power. Increases in stream power (shown in red or orange on Page 2 of Appendix B) can initiate streambed erosion resulting in incision. The most extensive areas of channel straightening and floodplain encroachment (both development and adjacent roads) along the Ompompanoosuc River main stem are mostly upstream of the Thetford/West Fairlee town line. In this section of the river (R18 through R21), approximately 75 percent of the channel has been straightened. The Ompompanoosuc River main stem channel has also been straightened below the Lake Fairlee outlet in the Post Mills area. From about the West Fairlee/Thetford Town line to below Post Mills (R15-R17), about 25 percent of the main stem has been straightened. This straightening is concentrated below the Lake Fairlee outlet in the Post Mills area, and is also associated with the channel being pushed up against the valley wall to make room for agricultural fields. The majority of the channel straightening on Middle Brook and Blood Brook has occurred where the river has been straightened for agricultural fields. Straightening percentages for Blood Brook above the Lake Fairlee outlet and Middle Brook within the Phase 2 study areas are estimated to be 29 percent and 17 percent, respectively. Straightening also occurred to accommodate roads and development. One example of this is Schoolhouse Brook in West Fairlee, which has been extensively straightened (48 percent) due to the proximity of Back Street and Beanville Road. The extensive areas with increases in stream power due to channel and floodplain alteration explain the channel adjustment that is occurring within the watershed.

Grade controls (waterfalls and ledge) and natural and manmade dams and constrictions (such as bridges and culverts) constrict flows or raise the bed elevation. Backwater conditions and sediment deposition typically reduce channel slope and stream power (Vermont Agency of Natural Resources, 2010a). Localized areas where slope decreases are expected in the Ompompanoosuc River watershed are shown in blue and green in Appendix B, Page 2.

5.1.4 Boundary Conditions and Riparian Modifiers

The Ompompanoosuc River Phase 2 study area has been broken into four maps to provide riparian and boundary condition information at a useful scale. These maps are provided on Pages 3 through 6 of Appendix B. Parameters which are indicative of a decrease in boundary resistance are shown in white with x's (bank armoring) and orange (erosion) on Pages 3-6 of Appendix B. While bank armoring may temporarily increase the boundary resistance, it is indicative of where the stream power has resulted in bank erosion or widening of the channel. Extensive bank armoring may increase the stream power, resulting in downstream bank erosion. Areas where woody debris, bed substrate and plant material were removed from the channel also result in

decreased boundary resistance. A summary of bank erosion totals mapped during the Phase 2 assessment is provided below.

- Mainstem in West Fairlee (R18-R21) – 46%
- Mainstem in Thetford (R15-R17) – 36%
- Blood Brook – 37%
- Lake Fairlee Outlet – 5%
- Middle Brook – 29%
- Schoolhouse Brook – 33%

Woody vegetation is essential for holding the bank soils to provide resistance to streambank erosion. There are many locations along the Ompompanoosuc River and its tributaries where there is little or no buffer as defined by buffers less than 25 feet in width. Many of these areas are in close proximity to roads or developed areas and are not suitable for buffer plantings. These stream reaches which lack a high quality riparian buffer are at a significantly higher risk of experiencing high rates of lateral erosion.

Important factors that result in an increase in boundary resistance are included on Pages 3-6 of Appendix B with blue/aqua colored symbols and brown symbols for dams. Natural and man-made grade controls increase the resistance of the bed to erosion. There were several locations where natural grade controls (ledge) are present on the Ompompanoosuc River main stem in West Fairlee and in Thetford where Route 113 crosses. Man-made grade controls such as dams are present on the main stem just upstream from the Route 113 crossing in Post Mills and just downstream of the Slaughterhouse Road crossing. There are two other dams in the Phase 2 study area: one at Lake Fairlee and one on Middle Brook just upstream of the Middle Brook Road crossing. The cohesiveness of the lower bank materials is another factor that is considered in evaluating boundary condition. Cohesive bank material can increase the boundary resistance. The only reaches with cohesive material on the lower bank are on the Ompompanoosuc main stem in Thetford (R16 and R17) and one segment on Blood Brook just upstream of Marsh Hill Road (R16T2.06-A).

5.2 Departure Analysis

The reference sediment regime map (Appendix B, Page 7) shows the Phase 1 reference stream sediment conditions for each reach within the stream network. In the reference condition, streams use available floodplain access as a means to store sediment within the watershed. Thirty out of the 31 reaches/segments of the Phase 2 study area 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 channel boundary resistance. The remaining segment (R15-B) has *Transport* as its reference sediment regime. *Transport* channels are steep, dominated by bedrock and boulder/cobble substrates, and are typically in confined valleys. Transport channels do not supply appreciable quantities of sediments to downstream reaches. These

channels have confining valleys 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 some reach segments. All departures were derived from the DMS according to the sediment regime criteria established by the Vermont Agency of Natural Resources (2010a). Existing sediment regimes have not been established for reaches that were not assessed during the phase 2 stream geomorphic assessment. Nineteen reaches/segments that were *Coarse Equilibrium (in=out) & Fine Deposition* by reference have been converted to *Fine Source and Transport & Coarse Deposition* sediment regimes based on the Phase 2 Stream Geomorphic Assessment data (Appendix B, Page 8). This means that most fine sediment entering the stream is transported through without being deposited as a result of channel incision and reduced floodplain access. Additionally, coarse sediment storage is increased due to increased load along with lower transport capacity. One segment on Schoolhouse Brook was converted from *Coarse Equilibrium (in=out) & Fine Deposition* to *Unconfined Source & Transport*. This regime type describes incised channels that have been straightened and armored more than 50 percent and are therefore no longer a significant sediment supply due to the boundary resistance of the armoring (Vermont Agency of Natural Resources, 2010a). Channel management practices such as straightening and encroachment have resulted in this sediment regime change.

The existing sediment regime for the Ompompanoosuc River watershed includes reduced floodplain access, increased stream power, reduced boundary resistance, and lateral constraints, such as roads, at various locations throughout the stream network. 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, 2010a).

5.3 Sensitivity Analysis

Page 9 in Appendix B is a map presenting the stream sensitivity, generalized according to stream type and condition as per the VANR protocol, and current adjustments for each reach segment in the Ompompanoosuc River watershed. Eleven of the twenty-two segments (about half) that received a full Phase 2 assessment had stream sensitivities of very high. Seven segments/reaches received a sensitivity rating of extreme due to their stream type and condition. Reaches with a stream type of "E" in fair condition have an extreme sensitivity. Two segments on Middle Brook (R16T2.03S1.01-B and R16T2.03S1.02-A) are "E" streams in fair condition and therefore have an extreme sensitivity. On Blood Brook, four segments (R16T2.04-B, R16T2.05-D, R16T2.06-A and R16T2.06-B) are also "E" streams in fair condition and therefore have extreme sensitivity. Only one segment on the Ompompanoosuc River main stem (R21-B) has extreme sensitivity due to its stream type departure from a "C" channel to an "F" channel. This stream type departure is attributed to historic incision and floodplain encroachment. The four remaining segments/reaches

have a high sensitivity and are located on Schoolhouse Brook (R18T3.01-A and R18T3.01-B), Lake Fairlee Outlet (R16T2.02), and Blood Brook (R16T2.06-C).

Major aggradation adjustment processes are displayed on the corridor where they were found to be actively occurring and not evaluated as historic. Aggradation is a current major active process for many segments/reaches on the Ompompanoosuc River main stem, Schoolhouse Brook, Middle Brook and Blood Brook. Two reaches/segments on Blood Brook (R16T2.06-A and R16T2.06-B) were found to have degradation as an active process as was evident from active head cuts. These segments are located between the Marsh Hill Road and Godfrey Road crossings.

6.0 PRELIMINARY PROJECT IDENTIFICATION AND PRIORITIZATION

The departure and sensitivity analyses presented in Section 5.0 of this report provide beneficial background for selecting potential projects that will effectively help the channel return to equilibrium conditions by assessing limiting factors and by identifying underlying causes of channel instability. 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, Passive Geomorphic Restoration, and Conservation.

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 are 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 the ideal results. Active riparian buffer revegetation and long-term protection of a river corridor is also essential to this alternative.

Conservation is an option to consider when stream conditions are generally good and nearing a state of dynamic equilibrium. Typically, conservation is applied to minimally disturbed stream reaches where river structure and function and vegetation associations are relatively intact.

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

- ANR River Corridor Easement Program (RCE)
- Ecosystem Restoration Program (formally called Clean and Clear)
- Conservation Reserve Enhance Program (CREP)
- Trees for Streams (TFS)
- Environmental Quality Incentives Program (EQUIP)

- Wildlife Habitat Incentives Program (WHIP)
- Wetland Reserve Program (WRP)
- Upper Connecticut River Mitigation and Enhancement Fund (UCMEF)

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, formally 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, and 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 the US Partners for Fish and Wildlife. Examples of the practice costs include fencing, livestock 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 to work with local partners and landowners to restore native streamside vegetation along river banks.

Environmental Quality Incentives Program

EQUIP 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.

Upper Connecticut River Mitigation and Enhancement Fund

Restoration, protection and enhancement of the river, wetlands, and shore lands within the upper Connecticut River watershed are supported by funds from the Upper Connecticut River Mitigation and Enhancement Fund. The upper Connecticut River is defined as the watershed upstream of the confluence of the White River and the Connecticut River (White River Junction and West Lebanon, NH). Small grants (up to $5000) and large grants (greater than $5000) are awarded based on evaluation criteria and priority for funding.

6.1 Watershed-Level Opportunities

Fluvial Erosion Hazard Zone

Of all types of natural hazards experienced in Vermont, flash flooding represents the most frequent disaster mode and has resulted in by far the greatest magnitude of damage suffered by private property and public infrastructure. While inundation-related flood loss is a significant component of flood disasters, the predominant mode of damage is associated with the dynamic, and oftentimes catastrophic, physical adjustment of stream channel dimensions and location during storm events due to bed and bank erosion, debris and ice jams, structural failures, flow diversion, or flow modification by man-made structures. These channel adjustments and their devastating consequences have frequently been documented wherein such adjustments are related to historic channel management activities, floodplain encroachments, adjacent land use practices and/or changes to watershed hydrology associated with land use and drainage.

The purpose of defining Fluvial Erosion Hazard Zones is to prevent increases in man-made conflicts that can result from development in identified fluvial erosion hazard areas; minimize property loss and damage due to fluvial erosion; and prohibit land uses and development in fluvial erosion hazard areas that pose a danger to health and safety.
The basis of a Fluvial Erosion Hazard Zone is a defined river corridor 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 FEH overlay districts on the municipal level are recommended by the Vermont River Management Program (2010a) to improve stream stability, reduce flood losses, and enhance public safety. Additional information about FEH zones is available at (http://www.anr.state.vt.us/dec//waterq/rivers/docs/rv_vtfehqa.pdf).

Stormwater

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. Improved stormwater management in the Ompompanoosuc River watershed is recommended to minimize the effects of stormwater runoff.

6.2 Site Level Opportunities

Site specific projects were identified and prioritized using the criteria outlined by the VANR in Chapter 6 of the river corridor planning guide– Preliminary Identification and Prioritization (Vermont Agency of Natural Resources 2010a). This planning guide is intended to aid in the development of projects that protect and restore river equilibrium. Tables 6 through 10, located at the end of Section 6.3, provide information for each project, including the project strategy, technical feasibility, priority and general cost. Maps and photos of the potential projects sites are included in Appendix C. The tables and maps are broken down by stream and town. The project tables are cross referenced to the maps in the heading of each table. A total of 29 projects were identified to promote the restoration or protection of channel stability and aquatic habitat in the Ompompanoosuc River watershed 2010 Phase 2 study area. The projects are summarized below:

Ompompanoosuc River Main Stem and Lake Fairlee Outlet
(Refer to Appendix C, Map 1 and Tables 6 and 7)

1. **Passive Restoration** by establishing no mow zone on east side of main stem channel in Post Mills downstream of old mill building;
2. **Active Restoration** by removing remnant rock wall and parking lot along old mill building in Post Mills and improving floodplain access on main stem;
3. **Stormwater Management** along Route 113 in Post Mills;
4. **Active Restoration** by removing Montague Rod and Reel dam to allow natural transport of sediment and ecological connectivity;
5. **Active Restoration** by redesigning footpath on main stem downstream of Lake Fairlee Outlet to allow floodplain access;
6. **Conservation** of river corridor and wetlands through corridor easement and/or Wetlands Reserve Program on Lake Fairlee outlet upstream of Post Mills Natural Area;
7. **Active Restoration** of mass failure on east side of main stem upstream of confluence with Lake Fairlee Outlet through use of bioengineering techniques;
8. **Passive Restoration** by planting native trees and shrubs on west side of main stem upstream of Cross Road Bridge in West Fairlee.

Ompompanoosuc River Main Stem and Schoolhouse Brook
(Refer to Appendix C, Map 2 and Table 8)

1. **Passive Restoration** by protecting river corridor and planting native vegetation along east bank of main stem upstream of confluence with Schoolhouse Brook;
2. **Stormwater Management** of runoff from Back Street and Route 113 in the vicinity of Schoolhouse Brook;
3. **Active Restoration** by improving floodplain access along Schoolhouse Brook in the vicinity of Route 113 and Back Street;
4. **Active Restoration** by removing Geer dam to allow natural transport of sediment and ecological connectivity;
5. **Passive Restoration** by planting riparian buffer on west side of main stem channel in vicinity of logging operation;

6. **Passive Restoration** by planting riparian buffer on west side of the main stem along beach area in front of residence on Route 113.
7. **Passive Restoration** by protecting river corridor and planting native vegetation along main stem downstream of Route 113 Crossing in West Fairlee.

Middle Brook
(Refer to Appendix C, Map 3 and Table 9)

1. **Passive Restoration** by protecting river corridor and wetland through easement and/or Wetlands Reserve Program;
2. **Active Restoration** through removal of old abutment upstream of farm bridge;
3. **Passive Restoration** by protecting river corridor and planting native vegetation in the buffer between farm bridge and Cross Rivendell Trail Bridge;
4. **Active Restoration** by replacing undersized Cross Rivendell Trail Bridge;
5. **Active Restoration** by replacing undersized pedestrian bridge;
6. **Passive Restoration** by protecting river corridor
7. **Active Restoration** by replacing undersized Middle Brook culvert with a structure that improves sediment transport and improves fish passage;
8. **Active Restoration** by removing Middle Brook dam to allow natural transport of sediment and ecological connectivity.

Blood Brook above Lake Fairlee
(Refer to Appendix C, Map 4 and Table 10)

1. **Passive Restoration** by protecting river corridor and providing livestock exclusion in riparian buffer above King Hill Road;
2. **Stream Clean up** along east side of Blood Brook to remove glass bottles, cans, and other trash;
3. **Active Restoration** by replacing Marsh Hill culvert with a larger sized structure that improves aquatic organism passage;
4. **Passive/Active Restoration** to protect river corridor, exclude livestock, improve riparian buffer and arrest active head cuts upstream of Marsh Hill Road;
5. **Passive/Active Restoration** to protect river corridor and arrest head cuts;
6. **Active Restoration** by replacing Godfrey Road culvert with a structure that accommodates the bankfull width and improves aquatic organism passage.

6.3 Next Steps

There are many opportunities to restore the Ompompanoosuc River watershed to a stable condition. Types of reach level and site level projects that have been identified in this plan include river corridor and wetland protection, streamside plantings, evaluating berm and dam removal, improving stormwater management, and arresting active head cuts. On the watershed level, the development and implementation of fluvial erosion hazard zones is recommended to avoid conflicts regarding land use and to save money spent on flood damage and river maintenance. The towns of West Fairlee and Thetford could pursue the opportunity to work with the Vermont River Management Program to develop fluvial erosion hazard zones for the land surrounding the Ompompanoosuc River main stem,

Blood Brook, Middle Brook and Schoolhouse Brook. The following are recommendations for next steps:

1. Outreach to private landowners and the public about the plan and potential restoration and protection opportunities.
2. Meetings to be held with project partners and landowners to prioritize projects and discuss implementation.
3. Apply to funding sources for implementation grants.
4. Implementation of priority projects with project partners and landowners.
5. Reapply for funding to complete Phase 2 assessment of additional priority reaches in Thetford and Norwich;
6. Complete Phase 2 assessment of reaches in Thetford and Norwich, and prepare a river corridor plan for these areas.

For additional information about fluvial erosion hazard (FEH) zones or project development, please contact the Vermont River Management Program or your local conservation commission.

Table 6. Ompompanoosuc River Main Stem and Blood Brook below Lake Fairlee (Lake Fairlee Outlet) - Map 1
Site Level Opportunities for Restoration and Protection
Thetford, Vermont

Project # Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Technical Feasibility and Priority	Other Social Benefits	Costs	Potential Partners/ Programs
#1 Along Route 113 just downstream of Route 113 bridge in Post Mills R15-A	Passive Restoration	There is no buffer along the stream in between the channel and Route 113.	Not a preferred planting site due to beaver activity. Establish no mow zone to help minimize impact from lack of buffer or plant trees and install beaver guards.	Low priority	Improved habitat and water quality	Low cost	Landowners, TCC, OWC, WRNRCD, VANR TFS, WHIP
#2 Just downstream from Route 113 crossing in Post Mills R15	Active Restoration	An old parking lot and rock wall is located within riparian corridor where old mill building was located.	Remove rock wall and pavement to re-establish floodplain access and plant trees where necessary.	High priority	Improved habitat and geomorphic stability. Conversion of impervious surfaces to vegetated river banks to reduce stormwater runoff.	High cost of removal of materials, cost of planting	VANR, Town of Thetford, TCC, landowner, WRNRCD, OWC TFS, Clean & Clear
#3 Route 113 crossing R15-B	Stormwater Management	Stormwater drainage off of Route 113 is causing excess stormwater to enter the Ompompanoosuc River.	The review of the stormwater management plan for this area is recommended	Moderate priority	Improve water quality	Unknown	VANR, Town of Thetford Clean & Clear
#4 Dam just upstream of Route 113 crossing in Post Mills R15-B	Active Restoration	The Montague Rod and Reel dam just upstream from the Route 113 crossing is causing significant deposition above the structure.	Alternatives analysis for dam removal	High priority	Improved habitat and geomorphic stability and Aquatic Organism Passage (AOP).	High cost of analysis and possible dam removal	VANR, Town of Thetford, TCC, UCMEF
#5 Just downstream of confluence with Lake Fairlee outlet R16	Active Restoration	A 440 foot berm is located along an elevated path within the floodplain and inside corridor of reach R16.	Evaluate different alternatives to improve floodplain access through berm removal. Path could be redesigned for access during non flood stages or removed entirely.	Moderate priority	Improved habitat and geomorphic stability	Cost of analysis and possible berm removal	Town of Thetford, VANR, TCC, landowner Clean & Clear

Table 6. Ompompanoosuc River Main Stem and Blood Brook below Lake Fairlee (Lake Fairlee Outlet) - Map 1
Site Level Opportunities for Restoration and Protection
Thetford, Vermont

Project # Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Technical Feasibility and Priority	Other Social Benefits	Costs	Potential Partners/ Programs
#6 Just upstream of confluence with Ompompanoosuc River R16T2.01	Passive Restoration	Beaver dams have created impounded areas and wetlands in downstream section of Lake Fairlee outlet. As part of a grant agreement between the Town of Thetford and the Upper Valley Land Trust, 100 acres has been placed into a conservation easement to protect scenic and conserve undeveloped spaces near Lake Fairlee and Post Mills.	Protect river corridor and wetlands through easements upstream of conserved area owned by the Town of Thetford; No structures in corridor	Low priority	Conserve sediment and flood attenuation of wetlands; Improved habitat and water quality	Cost of easement	Town of Thetford, VANR, TCC, landowners, WRP, land trust RCE, WRP
#7 Approximately 0.15 miles upstream of confluence with Lake Fairlee Outlet R17	Active Restoration	A mass failure on the east side of the Ompompanoosuc River is introducing sediment to the channel.	Investigate improving stability of mass failure using bioengineering techniques.	Low priority	Improved habitat and geomorphic stability	High cost to design and implement a project to stabilize the mass failure	Town of Thetford, VANR, TCC, landowners

Table 7. Ompompanoosuc River Main Stem - Map 1
Site Level Opportunities for Restoration and Protection
West Fairlee, Vermont

Project # Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Technical Feasibility and Priority	Other Social Benefits	Costs	Potential Partners/ Programs
#8 Upstream of Thetford/West Fairlee town line and Cross Road bridge. R18	Passive Restoration	Reach is incised but there are areas of juvenile floodplain development. Lack of adequate buffer along west side of channel.	Stream plantings along field.	Low priority - incised	Improved habitat and water quality	Cost of plantings	VANR, WFCC, Town of West Fairlee, landowners TFS, UCMEF

Table 8. Ompompanoosuc River Main Stem and Schoolhouse Brook - Map 2
Site Level Opportunities for Restoration and Protection
West Fairlee, Vermont

Project # Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Technical Feasibility and Priority	Other Social Benefits	Costs	Potential Partners/ Programs
#1 Upstream of confluence with Schoolhouse Brook R19-A	Passive Restoration	Lack of buffer where hay fields border east bank. Reach is mostly incised, but this section is in an area with floodplain access. Extensive bank erosion.	Protect river corridor through easement and/or CREP. Streamside plantings along farm fields as part of possible CREP project.	High priority; hayed along river in narrow valley. Fields are small and buffer plantings may cause a land use constraint.	Improved habitat and water quality	Cost of plantings and corridor easement	Landowners, WRNRCD, WFCC, CREP, land trust, ANR TFS, CREP, ANR RCE
#2 Along Back Street and Route 113 R18T3.01-B	Stormwater Management	Stormwater drainage off of Back street and Route 113 is causing excess stormwater to enter the main stem and Schoolhouse Brook.	The review of the stormwater management plan for this area is recommended.	Moderate priority	Improve water quality	Unknown	V ANR, Town of West Fairlee, landowner Clean &Clear
#3 Near confluence of Schoolhouse Brook and first tributary R18T3.01-B	Active Restoration	There are a number of channel modifications and floodplain encroachments that are reducing floodplain access. These include a berm, windrowed sections and a rock wall.	Evaluate different alternatives to improve floodplain access	Moderate priority; feasibility for this project may be limited due to location of houses in floodprone area.	Improved habitat and geomorphic stability	Cost of analysis and possible berm removal	Town of West Fairlee, VANR, WFCC, OWC, landowner Clean &Clear
#4 Dam just downstream of Slaughterhouse Road crossing R19-B	Active Restoration	The Geer dam just downstream from the Slaughterhouse Road crossing is impeding fish passage and the transport of sediment	Alternatives analysis for dam removal and associated channel constrictions.	High priority	Improved habitat and geomorphic stability and Aquatic Organism Passage (AOP).	Cost of analysis and high cost of removal	VANR, Town of West Fairlee, WFCC, private landowner UCMEF
#5 Along logging operation field on west bank R19-B	Passive Restoration	Lack of buffer along field. This includes areas where trees have been cut on the bank and has been recently riprapped.	Stream plantings along field	High priority	Improved habitat and water quality	Cost of plantings	VANR, Town of West Fairlee, WFCC, OWC, landowner, WRNRCD TFS; CREP

Table 8. Ompompanoosuc River Main Stem and Schoolhouse Brook - Map 2
Site Level Opportunities for Restoration and Protection
West Fairlee, Vermont

Project # Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Technical Feasibility and Priority	Other Social Benefits	Costs	Potential Partners/ Programs
#6 Along beach area in front of residence on Route 113 approximately ¼ mile upstream of dam at Slaughterhouse Road R20-B	Passive Restoration	Residential lawn where there is no buffer. Does not appear to be incised as in the rest of the segment.	Stream plantings along residential lawn.	High priority	Improved habitat and water quality	Cost of plantings	VANR, Town of West Fairlee, WFCC, OWC, WRNRCD, landowner TFS
#7 From 0.15 miles downstream of Route 113 Bridge to ¾ mile downstream of Route 113 Bridge R21-A and R21-B	Passive Restoration	Lack of adequate buffer along both banks where there are no trees in fields.	Protect river corridor through easement and/or CREP. Stream plantings in hay fields with no trees along bank. Plant far away from bank since stream channel is currently widening.	Low priority – widening	Improved habitat and water quality	Cost of plantings	VANR, WFCC, Town of West Fairlee, landowners, land trust CREP, Clean & Clear, WHIP, TFS, RCE

Table 9. Middle Brook – Map 3
Site Level Opportunities for Restoration and Protection
West Fairlee, Vermont

Project # Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Technical Feasibility and Priority	Other Social Benefits	Costs	Potential Partners/ Programs
#1 From Lake Fairlee to approximately ¾ mile upstream along Middle Brook Road R16T2.03S1.01-A	Passive Restoration	Backwater from Lake Fairlee and beaver dams have created impounded areas and wetlands in downstream section of Middle Brook	Protect river corridor and wetlands through easements	Low priority	Conserve sediment and flood attenuation of wetlands; Improved habitat and water quality	Cost of easement	Town of West Fairlee, VANR, WFCC RCE, WRP
#2 Approximately 0.10	Active Restoration	An old abutment and a beaver dam that has been built into it are	Remove old abutment	Low priority; may cause more damage than	Improved habitat and geomorphic stability	High cost of removal	VANR, Town of West Fairlee, WFCC

Table 9. Middle Brook – Map 3
Site Level Opportunities for Restoration and Protection
West Fairlee, Vermont

Project # Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Technical Feasibility and Priority	Other Social Benefits	Costs	Potential Partners/ Programs
miles upstream of farm bridge and top of wetland area R16T2.03S1.01-B		causing braiding and significant planform adjustment within channel.		benefit by removing structure surrounded by sensitive wetland habitat			Clean & Clear
#3 From just downstream of farm bridge where impounded water ends to just upstream of Cross Rivendell Trail Bridge R16T2.03S1.01-B	Passive Restoration	Agricultural fields along channel. Lack of adequate buffer along hay field on east bank on the outside bend of a large meander. Channel is widening so plant far away from channel.	Protect river corridor through easement and/or CREP. Stream plantings along hay field.	High priority	Improved habitat and water quality	Cost of plantings and easement	VANR, Town of West Fairlee, WFCC, landowner, land trust CREP, RCE, TFS
#4 Cross Rivendell Trail Bridge R16T2.03S1.01-B	Active Restoration	The bridge crossing at the Cross Rivendell Trail is undersized. The structure is causing scour above and below.	Replace with a structure that accommodates at least the bankfull channel width	High priority	Improved habitat and geomorphic stability	High cost of replacement	VANR, Town of West Fairlee, WFCC, landowner
#5 Pedestrian Bridge R16T2.03S1.02-A	Active Restoration	A pedestrian bridge crossing is undersized. The structure is causing deposition and scour above.	Replace with a structure that accommodates at least the bankfull channel width	High priority	Improved habitat and geomorphic stability	High cost of replacement	VANR, Town of West Fairlee, WFCC, landowner
#6 From top of wetland to Middle Brook Road crossing R16T2.03S1.02-A & R16T2.03S1.02-B	Passive Restoration	Agricultural fields along channel. Lack of adequate buffer along hay field on east bank on the outside bends of meanders. 45 trees/shrubs were planted on inside of meander bends as part of TFS Programs in Fall 2010.	Protect river corridor through easement and/or CREP. Plant additional trees on outside of meander bends along hay fields, if feasible.	High priority	Improved habitat and water quality	Cost of plantings and easement	VANR, Town of West Fairlee, WFCC, WRNRCD, landowner, land trust ANR corridor easement, CREP, TFS

Table 9. Middle Brook – Map 3
Site Level Opportunities for Restoration and Protection
West Fairlee, Vermont

Project # Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Technical Feasibility and Priority	Other Social Benefits	Costs	Potential Partners/ Programs
#7 Middle Brook Road Culvert R16T2.03S1.02-B	Active Restoration	A culvert is undersized. The structure is causing deposition above and scour below.	Replace with a structure that accommodates at least the bankfull channel width and improves AOP.	High priority	Improved habitat and geomorphic stability	High cost of replacement	VANR, Town of West Fairlee, WFCC
#8 Dam upstream from Middle Brook Road crossing R16T2.03S1.02-B	Active Restoration	A dam just upstream from the Middle Brook Road crossing reducing fish passage.	Remove dam and associated channel constrictions.	High priority	Improved habitat and geomorphic stability and Aquatic Organism Passage (AOP).	High cost of removal	VANR, Town of West Fairlee, WFCC, private landowner UCMEF

Table 10. Blood Brook above Lake Fairlee – Map 4
Site Level Opportunities for Restoration and Protection
West Fairlee, Vermont

Project # Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Technical Feasibility and Priority	Other Social Benefits	Costs	Potential Partners/ Programs
#1 From King Hill Road crossing to wetland R16T2.04-B, R16T2.05-A and R16T2.05-B	Passive Restoration	Cow pasture is located within riparian corridor causing erosion on stream banks and cow manure along banks.	Protect river corridor through easement and/or CREP. Exclude livestock from stream channel and banks.	High priority	Improved habitat and water quality	Cost of easement, fencing and watering alternative for cows	VANR, Town of West Fairlee, WFCC, landowner,, land trust CREP, EQUIP, RCE
#2 Approximately 0.10 miles downstream from wetland R16T2.05-B	Stream Clean up	A variety of trash (glass bottles, old sink, cans, steel) is located on the eastern stream bank.	Trash clean-up along eastern stream bank	Moderate priority	Improved habitat and water quality	Cost of trash removal	VANR, Town of West Fairlee, WFCC, landowner

Table 10. Blood Brook above Lake Fairlee – Map 4
Site Level Opportunities for Restoration and Protection
West Fairlee, Vermont

Project # Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Technical Feasibility and Priority	Other Social Benefits	Costs	Potential Partners/ Programs
#3 Marsh Hill Road Culvert R16T2.05-E	Active Restoration	A culvert is significantly undersized. The structure is causing scour above and there is no AOP including adult salmonids.	Replace with a structure that accommodates at least the bankfull channel width and AOP.	High priority	Improved habitat and geomorphic stability	High cost of replacement	VANR, Town of West Fairlee, WFCC, landowner
#4 From Marsh Hill Road crossing to where horse pasture ends R16T2.06-A	Passive /Active Restoration	Horses graze within riparian corridor and have access to stream causing erosion along banks and manure input into stream. Reach is actively degrading as seen by numerous head cuts. Most of segment lacks adequate buffer. Channel is widening so plant away from bank.	Protect river corridor through easement and/or CREP. Streamside plantings. Exclude livestock from stream channel and banks. Arrest head cuts. Consider improving planform using natural channel design.	High priority	Improved habitat and water quality	Cost of easement, plantings, fencing and watering alternative for horses	VANR, Town of West Fairlee, WFCC, landowner, land trust CREP, RCE, EQUIP, TFS, WHIP, WRP, UCMEF
#5 From where horse pasture ends to Godfrey Road crossing R16T2.06-B	Passive /Active Restoration	Stream flows through forested area and then enters straightened section. Segment is actively degrading as shown by head cuts.	Protect river corridor through easement .Arrest head cuts.	High priority	Improved habitat, water quality, and geomorphic stability	Cost of easement and labor and materials to arrest head cuts	VANR, Town of West Fairlee, WFCC, landowner, land trust ANR CE, Clean & Clear
#6 Godfrey Road Culvert R16T2.06-C	Active Restoration	A culvert is undersized. There is no AOP including adult salmonids.	Replace with a structure that accommodates at least the bankfull channel width and AOP.	High priority	Improved habitat and geomorphic stability	High cost of replacement	VANR, Town of West Fairlee, WFCC

7.0 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, 2004, 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 raising 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.

Attenuation of flows–dissipation of energy against the bed and banks of a river or reduction of high flows. This can be accomplished by the river overflowing its banks onto the floodplain or through storage in wetlands. Natural and manmade dams can also act to attenuate flows.

Attenuation of sediment – reduction in amount of sediment being transported downstream by river overflowing its banks onto the floodplain and the sediment settling out.

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 streambank 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.

Bedform– stream classification system developed by Montgomery and Buffington (1997) to describe streams of different settings, bed material and gradients. The bedforms in order of decreasing gradient are: cascades, step-pool, planebed, riffle-pool, and dune-ripple.

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

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

Cascade outfall – The invert of the culvert is above the stream bed surface and the flow spills out of the culvert onto a steep section or riprap or stream bed.

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 mainstem 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).

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.

Dune-ripple - Usually associated with low gradient and highly sinuous channels. Dominated by sand-sized substrates. Typically undulating bed does not establish distinct pools and riffles.

Endogenous – material (sediment) that is coming from within the stream channel and banks.

Erosion – 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.

Exogenous – material (sediment) that is coming from outside of the stream channel and banks. The source of this material is often from stormwater runoff.

Free fall outlet – The invert (bottom) of the culvert outlet is above the stream bed surface and the flow spills vertically out of the culvert down to the water surface (i.e. perched).

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

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 knick point at the leading edge of a gully

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

Knickpoint – Location in a river or channel where there is a sharp change in channel slope

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.

Neck cutoff – The result of two meanders migrating towards one another and the neck of land between them is about to be cutoff. If this neck of land is cut off, a channel avulsion occurs.

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

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

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

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

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

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

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

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

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

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

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

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

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

Sinuosity – Channel length divided by the valley length.

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.

Surficial sediment/geology – Sediment that lies on top of bedrock.

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

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 – Pushing gravel up from the stream bed onto the top of either bank as part of the channel straightening of a river.

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