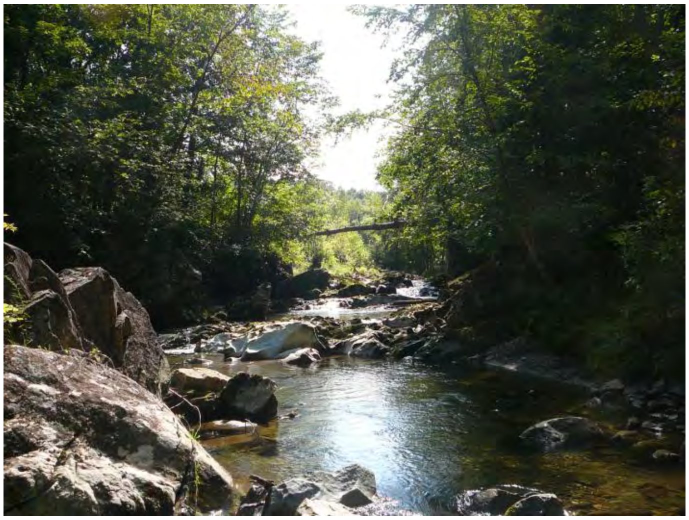
Upper Missisquoi River Corridor Plan
Missisquoi River Watershed
Orleans County, Vermont



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Prepared by:

Dori Barton
Ecologist
Aaron Worthley
Ecologist/GIS Analyst

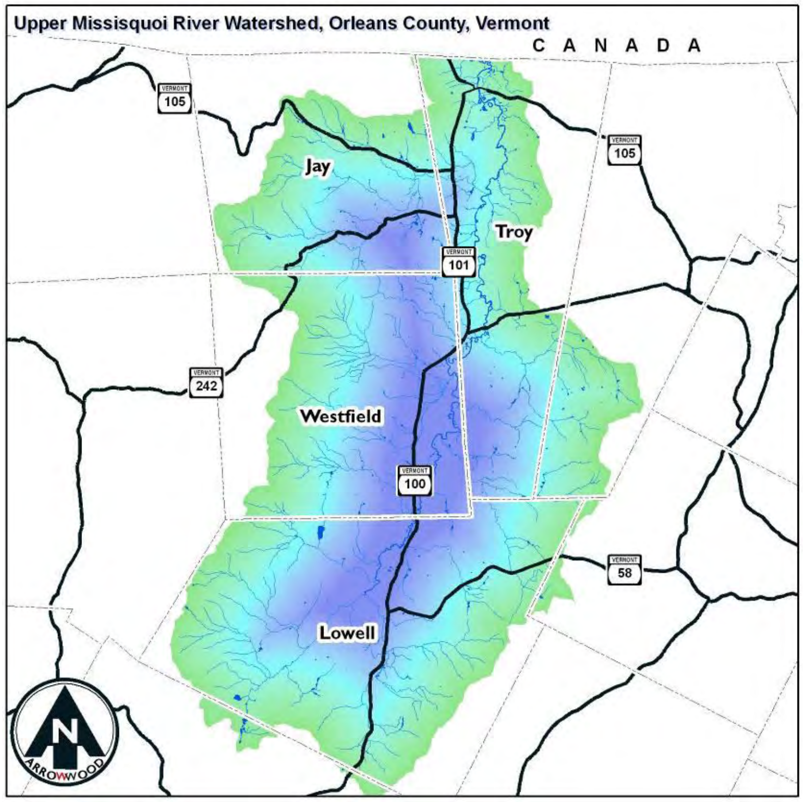
Prepared for:

Missisquoi River Basin Association and
Vermont River Management Program

ARROWWOOD ENVIRONMENTAL
950 BERT WHITE ROAD
HUNTINGTON, VT 05462
(802 434-7276 FAX: (802) 329-2253

Executive Summary

Missisquoi Bay drains 1,200 square miles of northwestern Vermont and southern Quebec. Almost sixty percent of the drainage area is in Vermont. Watershed origins include the towns of Lowell, Westfield, Troy and Jay. These towns through their town plans are committed to protecting, enhancing and improving the health of the Upper Missisquoi River Watershed.



Upper Missisquoi River Watershed Map

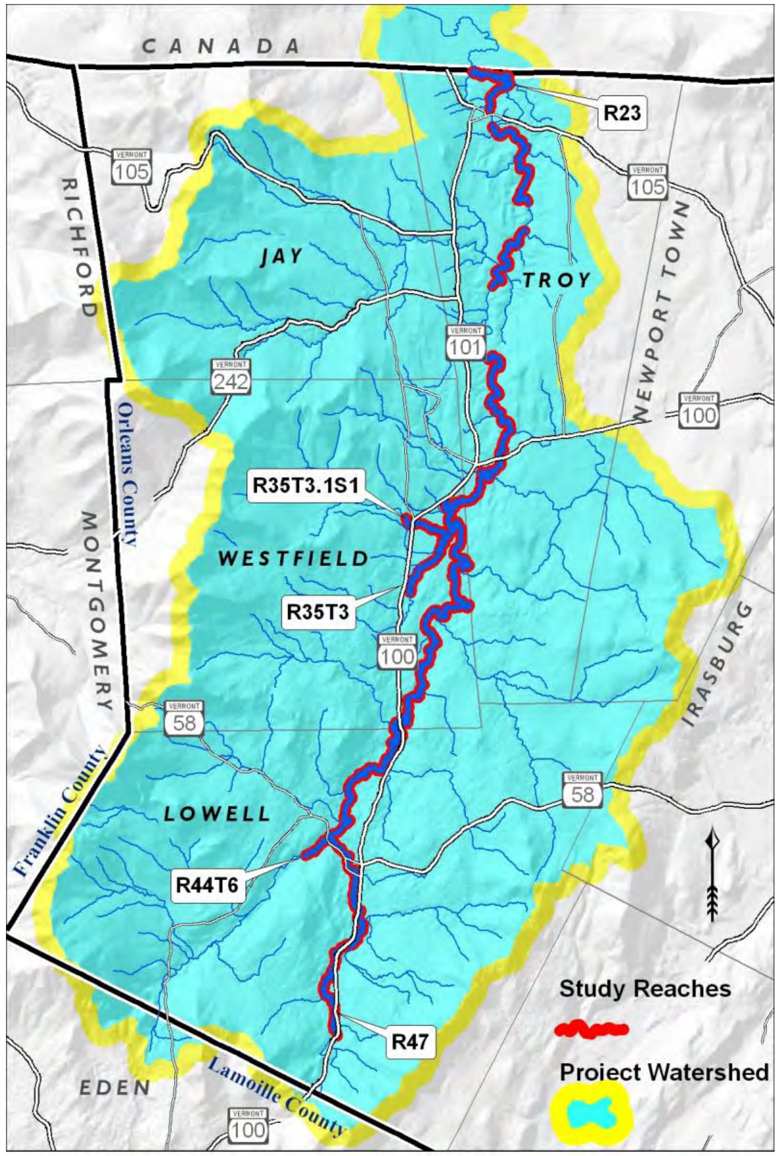
In May 2010, the Missisquoi River Basin Association (MRBA) extended a Request for Proposals for a Phase 2 Stream Geomorphic Assessment and River Corridor Plan for the Upper Missisquoi River Watershed. A Phase 1 Geomorphic Assessment was conducted by the Northeastern Vermont Development Association (NVDA) and Northwest Regional Planning Commission for the Upper Missisquoi River Watershed. Phase 2 Assessments were completed by Arrowwood Environmental in the summer of 2010. During the spring and summer of 2011, Arrowwood Environmental worked on the development of a community-based river corridor management plan for the Phase 2 assessed reaches of the Upper Missisquoi River Watershed.

The Corridor Plan focuses on stream reaches on the Upper Missisquoi River main stem and three of its tributaries. The study reaches are located on the following waters within the following towns:

Troy:	**Main Stem Reaches (R34, R33, R29, R28, R27, R25, R24, R23)**
Westfield:	**Main Stem Reaches (R35, R36, R37, R38, R40)**
	Taft Brook (R35T3.01)
	Mill Brook (R35T3.1S1.01)

Lowell: **Main Stem Reaches (R41, R42, R43, R44, R45, R46, R47)**
Burgess Brook (R44T6.01)

The upper Missisquoi River watershed has it's headwaters in the Lowell Mountains. The River commences its journey as a high elevation stream flowing through mountainous terrain in a narrowly confined valley. The River quickly departs the forest landscape, meandering through agricultural lands in a relatively broad valley about Route 100 through Lowell. Just west of the Village of Lowell, the River bends west through a series of confined valleys, picks up the flow of Burgess Brook, and continues its journey north meandering about Route 100 in another broad agricultural valley. As the River flows into Westfield it bends to the east and departs the Route 100 transportation corridor. It remains in a broad valley as it meanders about the Loop Road, picking up flows from Taft Brook and its tributaries, along the eastern boundary of Westfield. The River briefly reenters the Route 100 corridor as it crosses the Westfield town line into Troy. The River continues north about River Road in a generally broad agricultural valley. The last leg of the River's journey on its way to Canada is through a narrowly confined and forested valley setting. At the United States border the River discharges into a very broad valley which extends into Canada.



Upper Missisquoi River Subwatershed Map

Many land uses are incompatible with the meandering and ever-changing nature of rivers and streams. Rivers and streams are often straightened, armored, dredged, bermed, or encroached upon to protect property investments or to make floodplain available for other land uses. Channel straightening and bank armoring remove or alter natural meanders, while undersized bridges and culverts act as channel constrictions, forcing the stream to flow faster through a narrow area. These channel alterations directly affect the stream by increasing its slope and power, resulting in areas of bed and bank erosion.

Streams naturally exhibit erosion and deposition processes. When systems are not in equilibrium, the degree and rate of erosion may overwhelm the streams natural ability to transport sediment and natural depositional processes. Sedimentation and associated degradation of aquatic habitat are concerns in the Upper Missisquoi River and its tributaries. At the watershed scale, erosive materials present in upper side slopes of steep valley walls, alluvial soils on exposed streambanks, and bed materials contribute to a high sediment-load system. Geomorphic instability related to the downcutting (and loss of floodplain access) of several of the study reaches have resulted in adjustment processes that are manifested largely in redistribution of the sediment loads as the river tries to regain equilibrium and establish a new floodplain.

Watershed and reach scale stressors were evaluated for each study reach including hydrologic alterations, land use and land cover changes, sediment regime stressors, channel slope and depth modifiers, boundary conditions and riparian modifiers. Changes to sediment regime and reach sensitivity to future adjustments were also evaluated. Figures and Tables were created to allow for in-depth evaluation of how each of these stressors has contributed to the current condition of the study reaches, and how that differs from the expected reference (or equilibrium) condition. Restoration and conservation techniques were developed for each reach, and a comprehensive Preliminary Project Identification and Prioritization table was created to prioritize the identified restoration and conservation strategies.

The findings of the Upper Missisquoi River Corridor Plan are summarized as follows:

- Historically, the Upper Missisquoi River watershed acted as a sediment and nutrient attenuation zone, with incoming fine sediments from upstream stored on the floodplain, and inputs of coarse sediment essentially in balance and equal to outputs of coarse sediment.
- Many sections of the watershed still act as sediment and nutrient attenuation zones.
- Portions of the watershed have largely been transformed into a sediment and nutrient source and transport zone where floodplain access is limited and sediment and nutrients

are funneled through the system to downstream receiving waters, due to the historic and ongoing adjustment processes and stressors documented in the watershed.

- The highest priority projects developed for the watershed are those that attempt to restore the sediment and nutrient attenuation assets in areas that have been converted to transport zones.
- Other recommended project types include riparian buffer and corridor enhancement to filter out excess nutrients, help stabilize streambanks, restore wetlands, and provide shade and cover to improve aquatic habitat; and replacement of undersized bridges and culverts to reduce channel constrictions, restore normal flow patterns, and improve aquatic habitat.

This Corridor Plan encourages coordination of landowner and municipal efforts to approach restoration with an eye to watershed scale dynamics. The Missisquoi River Basin Association (MRBA) and local Conservation Commissions can play a critical role in coordinating restoration efforts, and this report aims to facilitate such coordination in a way that can help landowners understand the part their properties play within the context of the entire watershed.

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1.0 PROJECT OVERVIEW

In May 2010, the Missisquoi River Basin Association (MRBA) extended a Request for Proposals for a Phase 2 Stream Geomorphic Assessment and River Corridor Plan for the Upper Missisquoi River Watershed. A Phase 1 Geomorphic Assessment was conducted by the Northeastern Vermont Development Association (NVDA) and Northwest Regional Planning Commission (NRPC) for the Upper Missisquoi River Watershed. Phase 2 Assessments were completed by Arrowwood Environmental in the summer of 2010. During the spring and summer of 2011, Arrowwood Environmental worked on the development of a community-based river corridor management plan for the Phase 2 assessed reaches of the Upper Missisquoi River Watershed.

2.0 INTRODUCTION

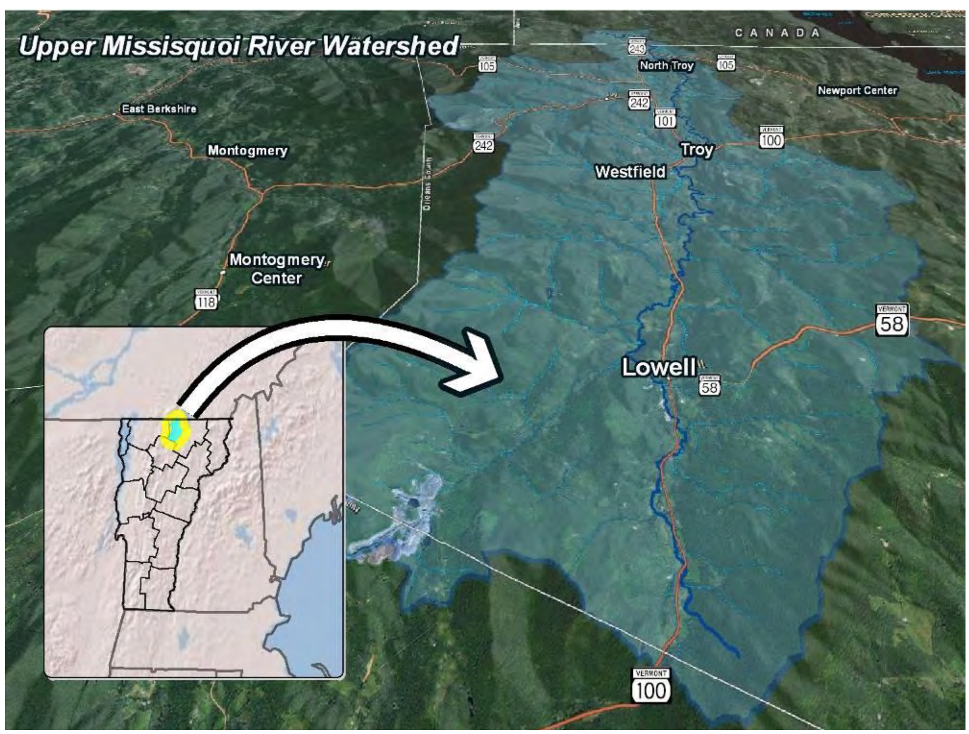


Figure 1. Upper Missisquoi River Watershed Map

The towns of Jay, Troy, Westfield and Lowell through their Conservation and Planning Commissions are committed to protecting, enhancing and improving the health of the Upper Missisquoi River and its tributaries. The following excerpts are from Town Plans and Zoning Regulations within the watershed, and serve to summarize the goals the towns have for the Upper Missisquoi and its watershed and also to identify strategies to accomplish those goals.

Jay Zoning Regulations (2010): The Town of Jay has identified the shorelines of surface waters as important resources. Development within 50’ of a shoreline must go through Conditional Use review.

Jay Town Plan (2010): The Town of Jay has identified the importance of preserving flood hazard areas. The Plan emphasizes enforcement of flood hazard regulations and that flood hazard areas should be reserved for agriculture, recreation, or other purposes, which do not significantly impair the land's natural ability to handle floodwaters.

Troy Town Plan (2008): The Town of Troy has identified both the Missisquoi River and its tributaries as contributors to myriad of interesting geological features including gorges, waterfalls, cascades, and swimming holes. The Plan establishes an intention to protect and manage Troy’s natural resources and biodiversity for the benefit of current and future generations. Strategies to accomplish these goals include encouraging residents to hook on to the new municipal sewer lines where possible and to investigate the designation of the Missisquoi River as a “Wild and Scenic River” under U.S. Parks Department.

Lowell Town Plan (2009): The Town of Lowell identifies the significance of its surface waters, including many miles of streams and river. The Plan emphasizes that these areas need to be protected from over development so as to maintain the current pristine status of these areas so that they will continue to provide the habitat necessary for the Town's plant and wildlife and the recreational benefits to the Town's residents.

Westfield Town Plan (2009): The Town of Westfield identifies threats to water quality including agricultural runoff and sediments washing into streams as a result of logging activities. The current Zoning Regulations provide a 50’ setback with a vegetated buffer strip along all waterways. The Plan emphasizes the need to maintain vegetated strips along shorelines of streams and the Missisquoi River in order to prevent bank erosion and collapse. The Plan also identifies the importance of the river flood plain for habitat for wildlife species that depend upon the water system for food, travel, and shelter.

Missisquoi River Basin Association: In addition to the local town governments, the Missisquoi River is watched over by the Missisquoi River Basin Association (MRBA). MRBA is dedicated to the restoration of the river, its tributaries and Missisquoi Bay. Their activities include field work to stabilize streambanks and planting trees in buffer areas, cleaning up trash along the river banks, cost sharing with farmers in a nutrient management program, and sampling for water quality.

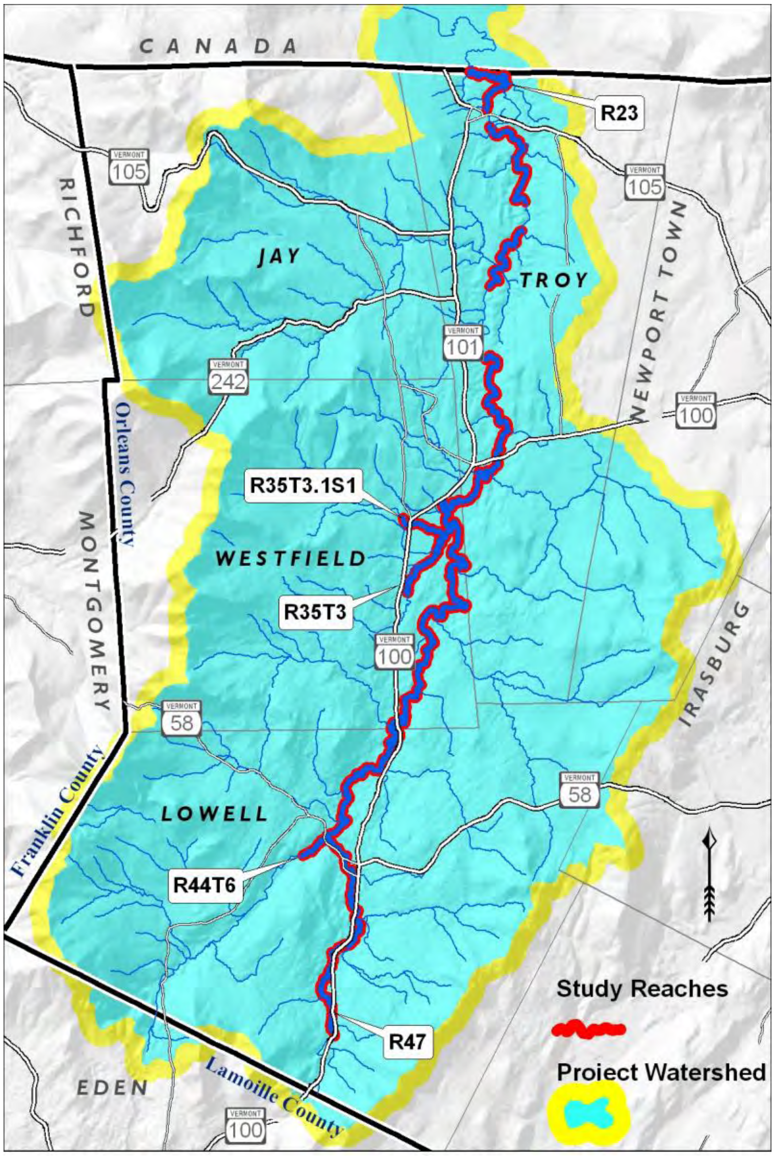
As part of their efforts, the MRBA was instrumental in obtaining a bill signed by the President (in March 2009) authorizing funding for a study to identify the "outstandingly remarkable values" of the Missisquoi and Trout Rivers. The study area covers the Missisquoi River from Enosburg Falls upstream (excluding the Canadian portion) to its headwaters in Lowell. Upon completion of the study, the decision to seek or not seek designation as a Wild and Scenic River would be made locally.

3.0 BACKGROUND WATERSHED INFORMATION AND GEOGRAPHIC SETTING

3.1 GEOGRAPHIC SETTING

Missisquoi Bay drains 1,200 square miles of northwestern Vermont and southern Quebec. Almost sixty percent of the drainage area is in Vermont. The headwaters of the Missisquoi River are in Lowell, Vermont. The Missisquoi River flows north into Quebec where the Missisquoi Nord joins the main stem at Highwater, Quebec. The Missisquoi River then returns to Vermont at East Richford and flows west to drain in Missisquoi Bay. In addition to draining the Missisquoi River's 88-mile course and its over 50-miles of tributaries (Black Creek, Trout River, the Tyler Branch, and Mud Creek), Missisquoi Bay also drains the Pike and Rock Rivers.

The current study focused on the Upper Missisquoi River Watershed, essentially from the headwaters in Lowell to the Canadian border. This watershed encompasses an area of approximately 140 square miles within the towns of Lowell, Westfield, Troy and Jay. For the purpose of geomorphic assessment and corridor planning, the Upper Missisquoi has been divided into 'reaches,' twenty-three of which fall within the scope of this River Corridor Plan. A reach is a section of stream with similar characteristics; this determination is primarily based on physical characteristics such as slope, sinuosity, dominant bed material, bed form, and valley confinement. The Corridor Plan focuses on stream reaches on the Upper Missisquoi River mainstem and three of its tributaries. The study reaches are located on the following waters within the following towns:



Troy:

Main Stem Reaches (R34, R33, R29, R28, R27, R25, R24, R23)

Westfield:
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Taft Brook
(R35T3.01)

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Lowell:
Main Stem Reaches (R41, R42, R43, R44, R45, R46, R47)

Burgess Brook
(R44T6.01)

Figure 2. Upper Missisquoi River Subwatershed Map

3.1.1 Land Use History and Current General Characteristics

The Upper Missisquoi River watershed is predominately a rural agricultural area. The dominant watershed land cover/land use along the main branch and tributaries of the River in the study area is forest with sub-dominant landuse consisting of fields and crops. The Missisquoi River provides, in its floodplain, farmers throughout the basin with prime agricultural farmland.

Increased development presence is seen in main stem sub-watersheds R34 and R35 (associated with the village of Troy); Mill Brook (associated with the village of Westfield) and main stem sub-watershed R44 (associated with the village of Lowell).

As with many rivers in Vermont, the Missisquoi River once was home to numerous grist and saw mills operated by early settlers. There are relicts of these structures still seen along the river today in the form of old foundations. The following photos provide a glimpse into the history of the watershed.

Figure 3. UVM Landscape Change Program, Photo ID LS04492_000. Back of photo reads: "Lowell Village, Missisquoi River, mostly destroyed in the flood of 1927. 1870-1927

Figure 4. UVM Landscape Change Program, LS04376_000. Circa 1907. Postcards shows view of Lowell village

Figure 4. UVM Landscape Change Program, LS04425_000. 1907-1915. Postcard shows view of J.H. Silsby Company

Figure 5. UVM Landscape Change Program, Photo ID LS00626_000. Circa 1907-1915. A caption at the top of the historic image reads, "Missisquoi River Near North Troy, Vt." The image shows a section of the river with a forested riparian zone.

3.2 GEOLOGIC SETTING

The Upper Missisquoi River watershed is located within the Northern Vermont Piedmont biophysical region. This region has a climate that is moderate-cooler and moister than the Champlain Valley and warmer and drier than the Green Mountains. The rocks of this region originated as marine sediments that were metamorphosed into schists, phyllites and crystalline limestones. These metamorphic rocks are generally calcareous. The region is also well known for its granite, an igneous rock. Granite quarries are common throughout the region. Millions of years of erosion have lowered and smoothed the former mountains of the region, creating the gentle hill and valley topography that is characteristic of today. The region includes portions of three major watersheds: Memphremagog, Lake Champlain, and Connecticut River. (Thompson and Sorenson, 2000)

The following table presents a summary of the geology and soils for the Upper Missisquoi River watershed from the reaches assessed as part of this Corridor Plan.

Table 1. Upper Missisquoi River Geology and Soils Summary for Phase 2 Assessed Reaches

Reach ID	Geologic materials			Valley side slopes		Soil Properties	
	Dominant	% Dom	Sub-Dominant	Left	Right	Erodibility	Erodibility (%)
R23	Alluvial	68	Ice-Contact	Hilly	Flat	B	49
R25	Alluvial	61	Ice-Contact	Steep	Steep	B	49
R27	Ice-Contact	50	Alluvial	Very Steep	Steep	A	49
R28	Glacial Lake	49	Alluvial	Very Steep	Steep	B	81
R29	Alluvial	65	Glacial Lake	Steep	Hilly	B	92
R33	Alluvial	65	Glacial Lake	Steep	Very Steep	B	64
R34	Alluvial	38	Till	Steep	Hilly	C	47
R35	Alluvial	60	Glacial Lake	Flat	Hilly	B	51
R35T3.01	Alluvial	60	Glacial Lake	Flat	Hilly	C	97
R35T3.1 S1.01	Glacial Lake	80	Alluvial	Hilly	Hilly	C	100
R36	Alluvial	90	Glacial Lake	Hilly	Hilly	B	95
R37	Alluvial	83	Till	Hilly	Steep	B	74
R38	Alluvial	67	Till	Steep	Very Steep	B	49
R40	Alluvial	74	Till	Hilly	Very Steep	B	76
R41	Alluvial	73	Glacial Lake	Hilly	Hilly	B	74
R42	Ice-Contact	43	Alluvial	Steep	Very Steep	A	43
43	Alluvial	71	Till	Hilly	Very Steep	B	58
R44	Till	55	Alluvial	Very Steep	Very Steep	C	59
R44T6.01	Till	52	Alluvial	Extremely Steep	Very Steep	B	62
R45	Ice-Contact	61	Alluvial	Very Steep	Steep	C	65
R46	Ice-Contact	100		Extremely Steep	Very Steep	A	57
R47	Ice-Contact	99	Till	Steep	Steep	B	51

3.3 FLUVIAL GEOMORPHIC SETTING

The Upper Missisquoi River watershed has it's headwaters in the Lowell Mountains. The River commences its journey as a high elevation stream flowing through mountainous terrain in a narrowly confined valley. The River quickly departs the forest landscape, meandering through agricultural lands in a relatively broad valley about Route 100 through Lowell. Just west of the Village of Lowell, the River bends west through a series of confined valleys, picks up the flow of Burgess Brook, and continues its journey north meandering about Route 100 in another broad agricultural valley. As the River flows into Westfield it bends to the east and departs the Route 100 transportation corridor. It remains in a broad valley as it meanders about the Loop Road, picking up flows from Taft Brook and its tributaries, along the eastern boundary of Westfield. The River briefly reenters the Route 100 corridor as it crosses the Westfield town line into Troy. The River continues north about River Road in a generally broad agricultural valley. The last leg of the River's journey on its way to Canada is through a narrowly confined and forested valley setting. At the United States border the River discharges into a very broad valley which extends into Canada.

The Upper Missisquoi River watershed was divided into 290 reaches during the Phase 1 assessment; 22 reaches had Phase 2 assessments completed. The reaches assessed in this study of the Upper Missisquoi River watershed are found in a variety of topographic terrains including very broad, gently sloping valleys and narrowly confined steep bedrock valleys. Variations in topography and slope influence the channel morphologies that would be expected under undisturbed (i.e. reference) conditions. Each reach was determined based upon physical characteristics such as slope, sinuosity, valley confinement, and hydrologic characteristics. The data collected in the Phase 1 assessments provide an overview of the general physical characteristics of a watershed. Maps, aerial pictures, and historic information are combined with field interpretations to produce reference stream typing, stream impact ratings, and provisional geomorphic condition evaluations (VANR Phase 1 Handbook, May 2009). Phase 1 data describe what one would expect the river system to look like in a natural state with no human influences.

Table 2 briefly summarizes the results of the Phase 1 assessment of the Phase 2 study reaches. Further detailed descriptions of the reaches, with associated Phase 1 and 2 observations, are found in Section 5 of this report along with individual reach maps depicting Phase 2 segment delineations in the attachment.

Table 2. Phase 1 Summary Data for Phase 2 Assessed Reaches

Reach ID	Drainage Area (sq mi)	Valley width (ft)	Valley Type	Channel width (ft)	Channel Slope (%)	Sinuosity	Reference Stream Type	Channel Bedform
R23	138	1624	VB	115	0.08	1.6	C	Dune-Ripple
R25	136	1217	VB	114	0.09	1.2	C	Dune-Ripple
R27	132	380	NW	75	0.21	1.2	C	Riffle-Pool
R28	131	691	BD	112	0.37	1.4	C	Riffle-Pool
R29	105	803	BD	101	0.27	1.3	C	Riffle-Pool
R33	102	752	BD	100	0.27	1.3	C	Dune-Ripple
R34	101	727	BD	100	0.43	1.2	C	Dune-Ripple
R35	89	1466	VB	94	0.10	1.8	C	Riffle-Pool
R35T3.01	13	1241	VB	40	0.21	1.5	E	Riffle-Pool
T35T3.1S1.01	5	1700	VB	27	1.69	1.2	C	Riffle-Pool
R36	68	781	BD	84	0.52	1.0	C	Riffle-Pool
R37	68	1110	VB	84	0.18	1.6	C	Riffle-Pool
R38	67	998	VB	83	0.03	1.2	C	Riffle-Pool
R40	52	680	BD	75	0.20	1.5	C	Riffle-Pool
R41	52	1685	VB	74	0.06	1.5	C	Riffle-Pool
R42	39	238	SC	66	0.73	1.0	C	Riffle-Pool
R43	33	650	VB	61	0.39	1.2	C	Riffle-Pool
R44	32	147	SC	60	1.16	1.1	C	Riffle-Pool
R44T6.01	17	277	BD	45	1.63	1.1	C	Riffle-Pool
R45	15	734	VB	43	0.77	1.2	C	Riffle-Pool
R46	7	200	BD	30	3.32	1.1	C	Riffle-Pool
R47	6	362	VB	29		1.2	C	Riffle-Pool

The most common reference stream type in the Upper Missisquoi River assessed reaches is the C stream type, riffle-pool system (Rosgen 1994) with well developed floodplains. The channels are dominated by gravel substrates. The C channels are generally lower gradient streams that are also slightly entrenched, but have moderate to high width-depth ratios. These streams are more often characterized by riffle-pool sequences (Rosgen 1994) dominated by gravel/cobble substrates. This channel type is typically found in broad alluvial valleys and is noted for its meandering nature. Channels have characteristic point bars and broad, well defined floodplains to reduce energy during flood events. The C stream type is dependent upon the stability of streambanks, and can be significantly altered and de-stabilized by changes in bank stability. (Rosgen and Sylvey, 1996)

This E channel type, assigned to Taft Brook (R35T3.01) is typically associated with low gradient and highly meandering channels, in broad valleys. These stream types are slightly entrenched with low width-depth ratios. The E stream type is considered a highly stable system, provided the floodplain and the low channel width/depth ratios are maintained. They are sensitive to disturbance and can rapidly adjust to other stream types in relatively short time periods. (Rosgen and Sylvey, 1996)

3.4 HYDROLOGY

The USGS maintains a stream gage on the Missisquoi River near North Troy, Vermont. The following graphs were taken from the USGS website. Of interest, is the seemingly higher mean daily discharge (recorded in cubic feet per second) and the higher average annual discharge (also recorded in cubic feet per second). Review of the daily discharge graph shows a higher frequency of discharge events in excess of the 2-year recurrence interval. Channel forming flows are thought to occur on an annual or semi-annual basis, generally referred to as the 2-year event. Increased flows, resulting in more frequent flooding, may result in a change in the channel width, which in turn can change the hydraulics of the channel and may lead to vertical channel adjustments (VDEC, 2009).

The National Weather Service has developed flood categories for the Missisquoi River at the North Troy gage based on historical data. The following flood categories and flood impact predictions have been determined:

<u>Major Flood Stage (12-13ft):</u> Large sections of Route 100 will be flooded, water will approach homes along River Road and Loop Road from Westfield to North Troy. Widespread flooding of

farmlands. Substantial flooding occurs with water over Loop Road and 3ft of water on Route 100 between Westfield and Newport.

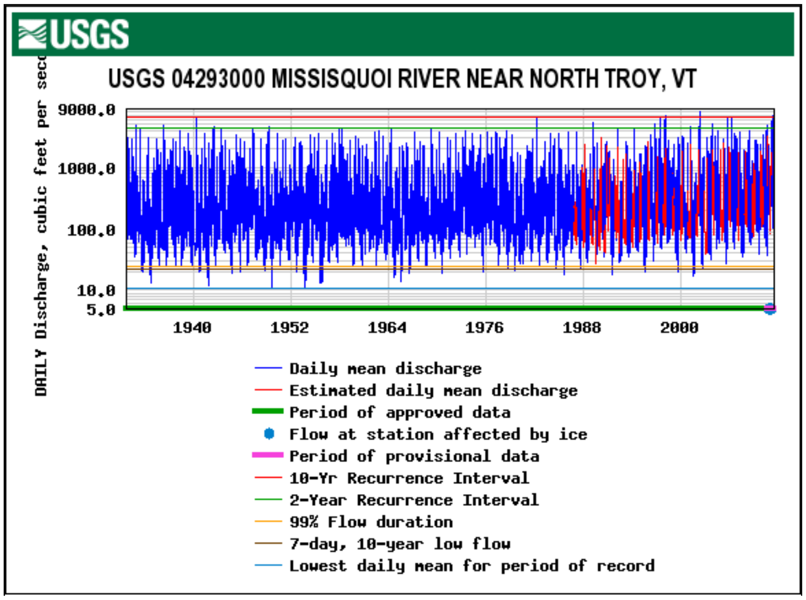


Figure 6. USGS gauge station at North Troy: Daily Discharge Graph- 8/22/1931 through 9/5/2011

Moderate Flood Stage (11ft): Water will inundate River Road between Troy and North Troy, as well as portions of Loop Road in Westfield and Troy. Water will cover portions of Route 100 near Troy and well upstream near Lowell. There will be widespread flooding of lowlands, fields, and pastures long the Missisquoi River from Lowell to North Troy.

Flood Stage (9ft): Water floods farmlands along the Missisquoi River from Lowell to North Troy. Low lying portions of Loop Road near Troy and Westfield will flood as well as portions of River Road from Troy to North Troy.

Action Stage (8ft): Water overflows onto farm lands. (National Weather Service: http://water.weather.gov/ahps2/hydrograph.php?wfo=btv&gage=ntyv1)

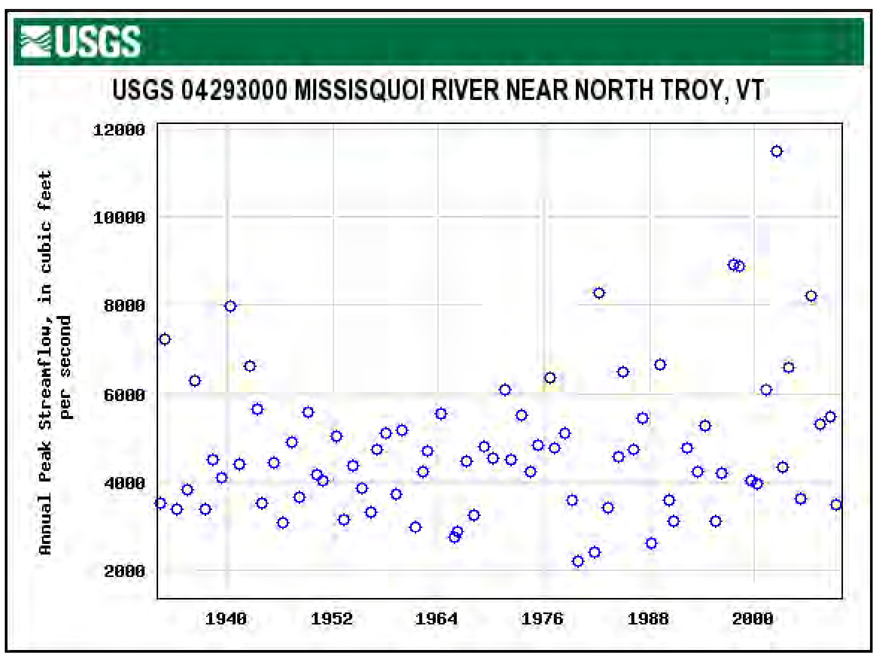


Figure 7. USGS gauge station at North Troy: Annual Peak Streamflow Graph- 8/22/1931 through 9/5/2011

On August 29, 2011, the remnants of Hurricane Irene ravaged Vermont. Record rainfall amounts covered the State resulting in historic flooding, particularly in Southern Vermont. The following graphs present the discharge amount and gage height on the Missisquoi River at the North Troy gage for the two months preceding the hurricane, for the actual storm event, and for the first days following the event. As can be seen from the graphs below, the August storm had more than a 100-yr recurrence interval with a 13.94' measured gage height. A spring storm event in April 2011 also resulted in major flood stage levels of 12.95'. Prior to these 2011 events, the last major flood stage events took place in 1997 with a level of 13.84' and 1982 with a level of 13.21' on the North Troy gage.

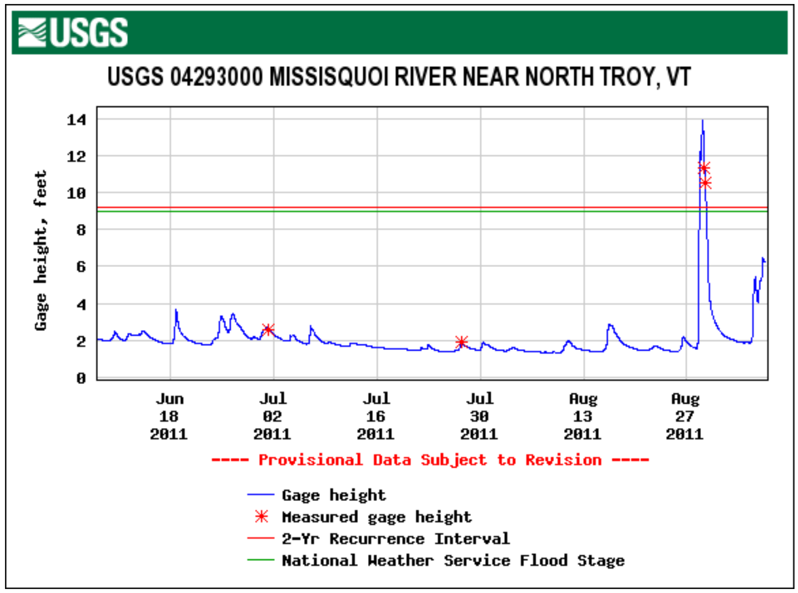


Figure 9. USGS gauge station at North Troy: Gauge height, summer 2011

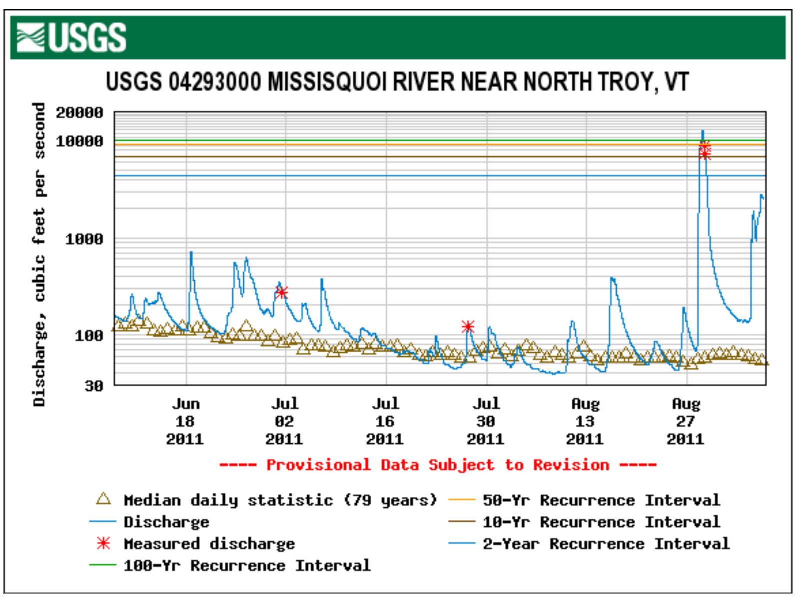


Figure 8. USGS gauge station at North Troy: Daily discharge, summer 2011

3.5 ECOLOGIC SETTING

The Upper Missisquoi River watershed occupies a diverse landscape position from an ecological standpoint. With headwaters rising from the Lowell Mountains, traveling down forested slopes, descending into flatlands dominated by broad floodplains, now functioning as agricultural land, and passing through growing village centers on its route north to Canada and eventually back into the United States and Lake Champlain.

3.5.1 DISTRIBUTION OF INSTREAM, RIPARIAN AND WETLAND HABITATS

Some 430 acres of wetland have been mapped in the Upper Missisquoi River watershed, and another 100 acres of soil likely to support wetlands exist. Many of these wetlands are located along the River and smaller stream valleys and are critical to providing floodwater retention. The Missisquoi River floodplain is a valuable stretch of habitat for wildlife species that depend upon the water system for food, travel, and shelter. These floodplain forests can also be home to several species of rare plants.

There are no major lakes or ponds within the watershed. Occasional small natural and man-made ponds are scattered throughout the watershed, but generally, the larger surface water features tend to be wetlands with varying levels of beaver influence.

3.5.2 AQUATIC LIFE

The Biomonitoring and Aquatic Studies Section of the Vermont Department of Environmental Conservation has conducted macroinvertebrate and/or fish biomonitoring assays in six locations on the Upper Missisquoi River. The following table provides a summary of the sampling results for the six locations.

Table 3: Biomonitoring Site Studies

Vermont Dept. of Environmental Conservation Biomonitoring and Aquatic Studies Section Ambient Biomonitoring Studies			
Site ID	Macroinvertebrate Community Assessment	Date Sampled	Fish Sampling Species Present (10/3/1991)
420000000774 (77.4 river mile)	NA	10/22/1986	Not sampled
420000000726 (72.6 river mile)	Very Good	9/8/2009	Not sampled
420000000745 (74.5 river mile)	Fair NA Good-Fair Good	10/7/1985 10/22/1986 9/16/1993 9/8/1999	Not sampled
420000000716 (71.6 river mile)	Good Good Good Good Very Good-Good Very Good	9/29/1988 10/3/1991 9/9/1992 9/7/1999 9/7/2004 9/8/2009	Blacknose Dace Bluntnose Minnow Brown Trout Common Shiner Lake Chub Longnose Dace Slimy Sculpin Tessellated Darter White Sucker
420000000745 (74.5 River mile)	NA NA NA NA	10/7/1985 10/22/1986 9/16/1993 9/8/1999	Not sampled
420000000731 (73.1 River Mile)	Very Good-Good	9/8/2009	Not sampled

In addition to State monitoring data, the Westfield Town Plan (2009) reports that the Missisquoi River, from the North Troy dam to Westfield Village has native populations of Brook, Rainbow, and Brown Trout. The Plan also indicates that Taft Brook has Brook Trout, and Mill Brook has native populations of both Brown and Brook Trout.

3.5.3 UNIQUE PLANT AND ANIMAL COMMUNITIES

The Nongame and Natural Heritage Program of the Vermont Department of Fish and Wildlife maintains a digital database of recorded/observed unique plant and animal communities throughout the State of Vermont. The following table provides a summary of the recorded species and communities within the river corridor of the Upper Missisquoi River study area.

Table 4: Vt. F&W RTE & Significant Natural Communities

Reach ID	RTE Species and/or Significant Natural Community Name
R25-R26	Dwarf Bilberry (*Vaccinium cespitosum*) Hyssop-leaved Fleabane (*Erigeron hyssopifolius*)
R34	Dwarf Bilberry (*Vaccinium cespitosum*)
R35	Great Laurel (*Rhododendron maximum*)
R38	Green Mountain Maidenhair-Fern (*Adiantum viridimontanum*) Large-leaved Sandwort (*Moehringia macrophylla*)
R40-R41	Serpentine Outcrop Green Mountain Maidenhair-Fern (*Adiantum viridimontanum*) Large-leaved Sandwort (*Moehringia macrophylla*)
R43-R44	Serpentine Outcrop Green Mountain Maidenhair-Fern (*Adiantum viridimontanum*) Aleutian Maidenhair-Fern (*Adiantum aleuticum*)
R44	Green Mountain Maidenhair-Fern (*Adiantum viridimontanum*) Large-leaved Sandwort (*Moehringia macrophylla*) Fragrant Fern (*Dryopteris fragrans*)

While deer wintering yards are not generally characterized as unique or rare, they are considered critical wildlife habitat. The Vermont Department of Fish and Wildlife developed a digital map of deer wintering habitat. Deer wintering habitat generally consists of south facing, conifer woods (i.e. Hemlock trees).

White-tailed deer are found throughout the Upper Missisquoi River watershed and there are roughly 4350 acres of mapped deer winter habitat within the watershed, which is most certainly an underestimate of the actual total. The majority of the mapped yards are located in the eastern portion of the study watershed in reaches R42, R43, R45, R46, R47, and R48. A significant amount of the mapped yards are located directly along the main stem of the Upper Missisquoi River. The presence of these mapped habitats indicates that the riparian buffers in these locations, when intact, serve not only an important function for the River but also for the wildlife in the surrounding area.

Some mammals likely present in the upland portions of the watershed include red and grey fox, coyote, fisher, bobcat, and many smaller mammals. In the wetlands and riparian zones, mink, river otter, beaver, and muskrat and others join the mix.

4.0 METHODS

4.1 FLUVIAL GEOMORPHIC AND HABITAT ASSESSMENT PROTOCOLS

4.1.1 PHASE 1 AND PHASE 2 ASSESSMENTS

In an effort to provide a sound basis for decision-making and project prioritization and implementation, the Vermont Agency of Natural Resources (VTANR) has developed protocols for conducting geomorphic assessments of rivers. The results of these assessments provide the scientific background to inform planning in a manner that incorporates an overall view of watershed dynamics as well as the reach-scale dynamics that have been a primary focal point of project planning in the past. Incorporating upstream and downstream dynamics in the planning process can help increase the effectiveness of implemented projects by addressing the sources of river instability that are largely responsible for erosion conflicts, increased sediment and nutrient loading, and reduced river habitat quality (VTANR, 2009). Trainings have been held to provide consultants, regional planning commissions, and watershed groups with the knowledge and tools necessary to make accurate and consistent assessments of Vermont's rivers.

The stream geomorphic assessments are divided into three phases. A Phase 1 assessment is a preliminary analysis of the condition of the stream through remote data sources such as aerial photographs, maps, and 'windshield survey' data collection. Phase 2 involves rapid assessment fieldwork to inform a more detailed analysis of what adjustment processes are taking place and predicting how the river will continue to evolve in the future. Phase 3 involves detailed fieldwork for the identification and implementation of management and restoration projects.

Phase I Stream Geomorphic Assessments were conducted by the Northeastern Vermont Development Association (NVDA) and Northwest Regional Planning Commission (NRPC) for the Upper Missisquoi River Watershed. The Phase 1 assessment team completed steps 1-7 of the Stream Geomorphic Assessment Phase 1 Protocols using the SGAT GIS extension. The Phase 1 assessments identified priority reaches for the Phase 2 assessments. The Phase 2 assessment completed steps 1-7 of the Stream Geomorphic Assessment Phase 2 Protocols using SGAT GIS extension. Phase 2 assessments were completed on twenty-two (22) reaches by Arrowwood Environmental in 2010.

4.2 QA/QC SUMMARY REPORT

Arrowwood Environmental (AE) conducted the Phase 2 assessment in compliance with the Vermont DEC River Management Program. The Phase 2 database (DMS) was submitted to Staci Pomeroy of the River Management Program for a QA review in January 2011. Photos were taken at each study cross-section and problem areas. Based on QA comments from Ms. Pomeroy, AE finalized the DMS database for the Upper Missisquoi River watershed in July 2011.

4.3 PHASE 2 RESULTS

The Phase 2 Rapid Stream Assessment is a detailed protocol for gathering data about the stream channel and riparian corridor. One of the products of the Phase 2 assessment is the determination of existing stream type. The stream type describes general physical characteristics of the channel and the fluvial processes going on in the assessed reach. Stream typing in the field provides an opportunity to verify the provisional reference stream type made during the Phase 1 assessment and to identify where the existing stream type has departed from the reference stream type. (VANR Phase 2 Handbook, May 2009)

Measurements of channel dimensions were made using a depth rod, a measuring tape, a hand-held tape ruler, and a hand level. Channel dimensions were measured at cross over (riffle) locations, and conducted at at least one cross-section per stream segment. The cross section data was entered in the Vermont Agency of Natural Resources, Phase 2 Stream Geomorphic Assessment Database.

Table 3 summarizes the existing channel conditions, including entrenchment ratio, width/depth ratio, incision ratio, sinuosity, sediment storage types, stream types, bed material and bed form for the Phase 2 study reaches.

Table 5. Upper Missisquoi River Phase 2 Channel Summary Data

Segment ID	Entrenchment Ratio	Width/ Depth Ratio	Incision Ratio	Sediment Storage Types	Phase 2 Stream Type	Bed Material	Bed Form
R23	7.72	35.41	1.0	Mid, Point, Side, Island	C	Sand	Dune-Ripple
R25-A	7.14	18.95	1.0	Point, Side	C	Sand	Dune-Ripple
R25-B	6.25	17.05	1.1	Mid, Point, Side, Diagonal	C	Gravel	Riffle-Pool
R27	2.21	33.33	1.3	Mid, Point, Island	C	Gravel	Riffle-Pool
R28	3.64	19.34	1.2	Mid, Point, Side, Diagonal, Delta	C	Gravel	Riffle-Pool
R29	14.34	17.02	1.1	Mid, Point, Side, Island	C	Gravel	Riffle-Pool
R33	9.15	18.78	1.1	Mid, Point, Island	C	Sand	Dune-Ripple
R34-A	7.18	19.96	1.0	Point, Side, Island	C	Gravel	Riffle-Pool
R34-B	NA	NA	NA	NA	NA	NA	NA
R34-C	NA	NA	NA	Mid	NA	NA	NA
R34-D	10.60	14.51	1.1	Mid, Point, Side, Delta, Island	C	Gravel	Dune-Ripple
R35-A	8.71	12.92	1.3	Mid, Point, Side, Diagonal	C	Sand	Riffle-Pool
R35-B	5.44	22.70	1.3	Mid, Point, Side, Diagonal, Island	C	Gravel	Riffle-Pool
R35 T3.01-A	64.06	7.73	1.4	Mid, Point, Side, Diagonal	E	Gravel	Riffle-Pool
R35 T3.01-B	43.18	8.03	1.5	Mid, Point, Side, Island	E	Sand	Riffle-Pool
R35T3.1 S1.01-A	12.38	21.14	1.0	Mid, Point, Side, Diagonal, Island	C	Gravel	Riffle-Pool
R35T3.1 S1.01-B	25.25	9.25	1.9	Side	E	Cobble	Step-Pool
R36	10.69	15.68	1.2	Mid, Side, Delta	C	Gravel	Riffle-Pool
R37-A	23.16	16.11	1.2	Mid, Point, Side, Diagonal	C	Gravel	Riffle-Pool
R37-B	6.99	26.34	1.0	Mid, Side, Delta	C	Gravel	Riffle-Pool
R38-A	5.17	14.40	1.1	Mid, Side, Delta	C	Gravel	Dune-Ripple
R38-B	9.05	24.63	1.2	Mid, Point, Side, Island	C	Gravel	Riffle-Pool
R40	9.88	19.06	1.3	Mid, Point, Side, Diagonal	C	Gravel	Riffle-Pool
R41	15.45	36.18	1.3	Mid, Point, Side, Diagonal, Island	C	Gravel	Riffle-Pool
R42	2.44	14.47	1.0	Mid, Point, Side, Diagonal, Delta	C	Gravel	Riffle-Pool

Segment ID	Entrenchment Ratio	Width/ Depth Ratio	Incision Ratio	Sediment Storage Types	Phase 2 Stream Type	Bed Material	Bed Form
R43	5.82	12.73	1.1	Mid, Point, Side, Diagonal	C	Gravel	Riffle-Pool
R44-A	5.82	12.73	1.1	Mid, Point, Side, Diagonal, Delta	C	Gravel	Riffle-Pool
R44-B	2.05	8.35	1.0	Mid, Point, Side, Delta, Island	G	Boulder	Step-Pool
R44-C	4.37	11.11	1.0	Point, Side	E	Gravel	Riffle-Pool
R44-D	2.11	12.05	1.8	Mid, Point, Side, Island	B	Cobble	Step-Pool
R44-E	NA	NA	NA	NA	C	Gravel	Riffle-Pool
R44 T6.01-A	6.00	16.67	1.0	Mid, Point, Side	C	Gravel	Riffle-Pool
R44 T6.01-B	1.30	22.07	1.2	Mid, Point, Side, Diagonal, Island	B	Cobble	Riffle-Pool
R45-A	6.83	18.44	1.0	Mid, Point, Side, Diagonal	C	Gravel	Riffle-Pool
R45-B	9.56	12.71	1.6	Point, Side, Diagonal	C	Gravel	Riffle-Pool
R45C	8.68	24.55	1.0	Mid, Point, Side, Diagonal, Delta, Island	C	Gravel	Riffle-Pool
R46	3.88	25.60	1.5	Mid, Point, Side	C	Gravel	Riffle-Pool
R47-A	4.89	15.86	1.2	Mid, Point, Side, Diagonal	C	Gravel	Riffle-Pool
R47-B	2.61	29.47	1.0	Mid, Point, Side, Diagonal, Delta	C	Gravel	Riffle-Pool

4.4 REACH DESCRIPTIONS

Observations and results made during the Phase 2 study are summarized below by reach number, and reach summary reports from the Phase 2 database are included in the attachment. Field measurements and locations of other features are overlaid on 2009 aerial photos (NAIP). Reach maps are included in the attachment and were created from available GPS data and field sketches.

4.4.1 REACH R23

Reach R23 is the most downstream reach of the Upper Missisquoi River included in the study area. The Upper Missisquoi flows north from R23 across the Canadian border. This reach is situated in a very broad valley with no encroachments identified within the river corridor. The reach is characterized as a shallow slope, wide, meandering channel with dune-ripple bedform. The streambanks are comprised of non-cohesive sands and silts with erosion present on most outside channel bends. The channel exhibits C type geometry with width to depth ratio (WDR) of 35.4 and entrenchment ratio (ER) of 7.7. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, no historic channel degradation and good access to its floodplain, the reach was assigned a Channel Evolution Model (CEM) Stage 1.

R23 Summary Data Missisquoi River	
Reach/Segment Length	10,130 ft
Valley Confinement	VB
Reference Stream Type/Bedform	C5 Dune-Ripple
Existing Stream Type/Bedform	C5 Dune-Ripple
Geomorphic Condition	Fair
Channel Evolution Stage	I
Adjustment Process	Planform/Widening
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors
Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

The habitat condition of the reach is only Fair due to poor bank canopy and bank vegetation, and poor riparian vegetation on the right bank. The reach has generally good buffers of greater than 100', with areas of poor buffers less than 25' restricted to agricultural settings. Located within an agricultural valley, there is no evidence of historic straightening or dredging. Three field ditches were identified as contributors of stormwater runoff to the channel. The reach has substantial large woody debris (LWD) distributed along its course (173 LWD/Mile) with one particularly large debris jam near the Canadian border. There are a fair number of deep pools along the reach (11 pools/mile) providing diversity in habitat conditions for aquatic fauna.

Figure 10. Erosion and poor buffers at the cross section

4.4.2 REACH R25

Reach R24 was not included in the current study due to impounded channel conditions from the North Troy dam. The next upstream reach (R25) was segmented due to change in confinement, substrate size, and channel dimensions.

R25-A

Reach segment R25-A begins approximately 1,100' upstream of the Rte 105 crossing, and extends upstream approximately 7,400'. This segment is situated in a broad valley with no encroachments identified within the river corridor. The segment is characterized as a shallow slope, wide, meandering channel with dune-ripple bedform. The streambanks are comprised of non-cohesive sands and silts with areas of erosion present. The channel exhibits C type geometry with width to depth ratio (WDR) of 18.9 and entrenchment ratio (ER) of 7.1. With a Rapid Geomorphic Assessment (RGA) condition rating of Good, no historic channel degradation and good access to its floodplain the reach was assigned a Channel Evolution Model (CEM) Stage 1.

R25-A Summary Data Missisquoi River	
Reach/Segment Length	**7,395 ft**
Valley Confinement	**BD**
Reference Stream Type/Bedform	**C5 Dune-Ripple**
Existing Stream Type/Bedform	**C5 Dune-Ripple**
Geomorphic Condition	**Good**
Channel Evolution Stage	**I**
Adjustment Process	**Widening/Planform Some Aggradation**
Habitat Condition	**Good**
Stream Sensitivity	**High**

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

Figure 11. Nice oxbow wetland

The habitat condition of the segment is rated Good with abundant large woody debris (59 LWD/Mile) with four debris jams, abundant and high quality wetlands adjacent to the channel, and good channel embeddedness. The segment is lacking pool habitat, and buffer widths and vegetation are poor along the right bank. Located within an agricultural valley, there is no evidence of historic straightening or dredging.

R25-B

R25-B Summary Data Missisquoi River	
Reach/Segment Length	5,311 ft
Valley Confinement	NW
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	I
Adjustment Process	Historic Degradation Current Widening/Planform
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

Subreach R25-B extends upstream of segment R25-A approximately 1 mile to the reach break. This subreach is situated in a narrow valley with road development and a section of berm within the river corridor. The subreach is characterized as a gentle sloped, wide, slightly meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands with significant areas of erosion and some rip rap present. The channel exhibits C type geometry with width to depth ratio (WDR) of 17 and entrenchment ratio (ER) of 6.3. The short section of berm was not characteristic of the reach and was not found to affect the incision ratio, which was 1.1 at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, no historic channel degradation or evidence of vertical instability and good access to its floodplain the reach was assigned a Channel Evolution Model (CEM) Stage 1.

The habitat condition of the subreach is only rated Fair due to the lack of pools, poorly formed riffles, and lack of depth-velocity patterns. There is also only fair bank vegetation, poor bank canopy, and poor riparian corridor vegetation on right bank. The subreach has good distribution of large woody debris (64 LWD/mile), with no debris jams present. There are generally good buffers of greater than 100'along the channel, with areas of poor buffers less than 25' restricted to agricultural settings. The riparian corridor is primarily forested with hay as a subdominant landuse. Located within an agricultural valley, there is no evidence of historic straightening or dredging. There is one animal crossing located at the downstream end of the subreach.

Figure 12. Old abutment

An old abutment located at the downstream end of the subreach serves as a channel constriction. The abutment constricts the normally 120' wide channel to a width of 75'.

4.4.3 REACH R27

Reach R26 was not assessed as part of this study due to bedrock gorge/waterfall conditions. This area is known as Big Falls. The next upstream reach is R27.

R27 Summary Data Missisquoi River	
Reach/Segment Length	2,839 ft
Valley Confinement	NW
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	IV
Adjustment Process	Historic Degradation Current Widening/Planform
Habitat Condition	Good
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

This is a short reach with two large islands at either end that split the river flow. The reach is situated in a narrow valley with no encroachments found in the river corridor. The reach is characterized as a gentle sloped, wide, meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands and mixed gravel with areas of erosion present. The channel exhibits C type geometry with width to depth ratio (WDR) of 33.3 and entrenchment ratio (ER) of 2.2. The incision ratio was measured as 1.3 at the cross section. There is one bedrock grade control just upstream of the R27S1.01 confluence. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, historic channel degradation and overwidening with reduced access to its floodplain, and current minor adjustments with a new floodplain developing at a lower elevation the reach was assigned a Channel Evolution Model (CEM) Stage IV.

The habitat condition of the reach is rated Good with abundant large woody debris (106 LWD/Mile) and 6 debris jams, good riffle coverage and formation, good refuge in low and high flows, and good buffer widths. Although the condition rating is Good, the channel is lacking in pools, has major evidence of sediment mobility and lack of sorting, fair channel embeddedness, and has poor bank vegetation and canopy cover. The riparian corridor is primarily forested with good buffers of greater than 150'along the channel.

Figure 13. Large pool upstream of island

4.4.4 REACH R28

R28 Summary Data	
Reach/Segment Length	3,251 ft
Valley Confinement	BD
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	III
Adjustment Process	Historic Degradation Current Widening/Planform
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors
Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

This is a short reach with a couple of good meanders. The channel is situated in a broad valley with development located within the river corridor. The reach is characterized as a gentle sloped, and wide channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands and gravel with areas of significant erosion and some rip rap present. The channel exhibits C type geometry with width to depth ratio (WDR) of 19.3 and entrenchment ratio (ER) of 3.6. The incision ratio was measured as 1.2 at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, historic channel degradation and reduced access to its floodplain, and current widening and planform changes, the reach was assigned a Channel Evolution Model (CEM) Stage III.

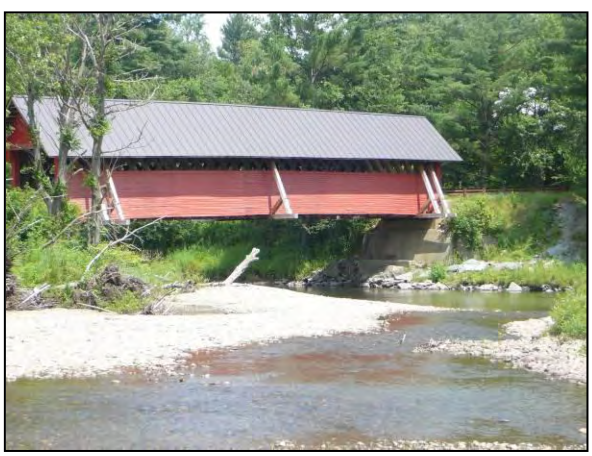


Figure 14. Covered bridge on Vielleux Road

The habitat condition of the reach is only rated Fair due to reduced amounts of large woody debris (48 LWD/Mile), fair channel embeddedness, small patches of algae, poor number of pools (<10 pools/mile), poor bank vegetation and bank canopy on the right bank, fair buffer widths and poor riparian corridor vegetation on the right bank. The reach has generally fair buffers of greater than 50’, with areas of poor buffers less than 25’ restricted to agricultural settings. Located in an agricultural valley with both forest and hay/pasture present, there is no evidence of historic channel straightening or dredging.

There is one undersized bridge just downstream of the R29 reach break. The bridge is associated with the Vielleux Road crossing and is only wide enough to support 77% of the bankfull flow event. Deposition was observed both above and below the structure with scour also observed below the structure.

4.4.5 REACH R29

Reach 29 is another short reach situated in a broad valley with a berm encroachment in the right river corridor. Channel flow is split at the upstream end of the reach by multiple islands. The reach is characterized as a gentle sloped, and wide channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands and silt with areas of erosion present. The channel exhibits C type geometry with width to depth ratio (WDR) of 17 and entrenchment ratio (ER) of 6.6. The incision ratio was measured as 1.1 at the cross section (with a human elevated incision ratio of 1.2 due to the berm). With a Rapid Geomorphic Assessment (RGA) condition rating of Good, no significant channel degradation or reduced access to its floodplain, and only minor current adjustments, the reach was assigned a Channel Evolution Model (CEM) Stage I.

The habitat condition of the reach is only Fair due to lack of pools, poor riffle coverage and formation, and poor depth/velocity patterns. There are high levels of bank erosion on the left bank with poor bank vegetation and bank canopy on both banks. The river corridor is has poor riparian and stream bank vegetation. The reach has generally poor buffers less than 25’ with a dominant corridor landuse of hay. While located in an agricultural valley, there is no evidence of historic channel straightening or dredging. One field ditch was observed as a contributor to stormwater runoff in the upstream portion of the reach

Figure 15. Erosion and poor buffers

R29 Summary Data Missisquoi River	
Reach/Segment Length	3,002 ft
Valley Confinement	BD
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Good
Channel Evolution Stage	I
Adjustment Process	Some Degradation/Planform Changes
Habitat Condition	Fair
Stream Sensitivity	High

Habitat Stressors

Invasive Plants
Dump Sites
Animal
Crossings
Dredging
Poor Stream Bank Vegetation
Algae
Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

4.4.6 REACH R33

Reaches R30, R31 and R32 were not assessed as part of this study generally due to bedrock gorge conditions at the upstream and downstream end of this stretch of river.

R33 Summary Data Missisquoi River	
Reach/Segment Length	5,240 ft
Valley Confinement	BD
Reference Stream Type/Bedform	C4 Dune-Ripple
Existing Stream Type/Bedform	C4 Dune-Ripple
Geomorphic Condition	Fair
Channel Evolution Stage	III
Adjustment Process	Historic Degradation Current Aggradation and Planform Changes
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal
Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

Reach R33 is situated in a broad valley with road development and a berm encroachment in the right river corridor. The river corridor is dominated by forest, wetlands, and hay. While located in an agricultural valley, there is no evidence of historic channel straightening or dredging. Channel flow is split at the downstream end of the reach by a large island. The reach is characterized as a gentle sloped, wide, and somewhat meandering channel with dune-ripple bedform. The streambanks are comprised of non-cohesive sands and silt with areas of erosion and some rip rap present. The channel exhibits C type geometry with width to depth ratio (WDR) of 18.8 and entrenchment ratio (ER) of 9.1. The incision ratio was measured as 1.1 at the cross section (with a human elevated incision ratio of 1.4 due to the berm). With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, historic channel degradation and loss of access to its floodplain, and current aggradation and planform changes underway, the reach was assigned a Channel Evolution Model (CEM) Stage III.

The habitat condition of the reach is only rated Fair due to lack of pools, poor riffle coverage, one depth-velocity pattern, small patches of algae on the substrate, finer deposition throughout the channel, poor and fair bank vegetation on the left and right bank, respectively, and poor bank canopy on both banks. There are poor buffer widths of less than 25’ and poor riparian vegetation on the right bank. There are two mapped mass failures in upstream reach R34-A which could be the source of additional sediment buildup in this reach. While the overall habitat condition is Fair, the reach has abundant large woody debris (89 LWD/Mile) with one debris jam, and refuge areas during both high and low flows.

Figure 16. Refuge area with nice vegetation

4.4.7 REACH R34

This reach was segmented and subreached for differences in valley width, bedform, grade controls, and flow status (impoundment).

R34-A

R34-A Summary Data Missisquoi River	
Reach/Segment Length	2,981 ft
Valley Confinement	BD
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Good
Channel Evolution Stage	I
Adjustment Process	Some Widening/Planform Changes
Habitat Condition	Fair
Stream Sensitivity	High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

Reach R34-A was identified as a subreach for its broad valley as compared to the narrower valleys of R34-B and R34-C. Within its river corridor, there is a berm encroachment along a significant distance of the right bank. While River Road is not contained within the river corridor, a ditch draining the road was mapped as a contributor to stormwater runoff in the subreach. The reach is characterized as a gentle sloped, wide, meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands and gravel with areas of erosion present. The channel exhibits C type geometry with width to depth ratio (WDR) of 20 and entrenchment ratio (ER) of 7.2. The incision ratio was measured as 1.0 at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Good, no significant historic channel degradation or loss of access to its floodplain, and only current minor adjustments underway, the subreach was assigned a Channel Evolution Model (CEM) Stage I.

The overall habitat condition rating is only Fair due to lack of large woody debris (44 LWD/Mile), lack of pools, small patches of algae on the substrate, poor bank vegetation on the right bank, poor canopy cover on both banks, poor buffer width on the right bank, generally poor riparian vegetation on both banks, and multiple mass failures on the left bank. The river corridor landuse is dominated by shrubs and forest on the left and by crops on the right. The right bank buffer width is predominately less than 25'. While located in an agricultural valley, there is no

Figure 17. Mass failure

evidence of historic channel straightening or dredging.

R34-B

R34-B Summary Data Missisquoi River	
Reach/Segment Length	1,001 ft
Valley Confinement	SC
Reference Stream Type/Bedform	NA
Existing Stream Type/Bedform	NA
Geomorphic Condition	NA
Channel Evolution Stage	NA
Adjustment Process	NA
Habitat Condition	NA
Stream Sensitivity	NA

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

Reach R34-B is identified as a subreach due to bedrock gorge conditions. No RGA or RHA were completed due to the bedrock gorge condition. The subreach is situated within a semi-confined valley and is characterized by a run of river dam at the upstream end which pours over a 38' waterfall. The stream banks are comprised of cohesive bedrock and boulder. There are good buffer widths of greater than 100' with good interspersion of vegetation cover present. The dominant corridor landuse is forest with some pasture in the right corridor. There are no encroachments present within the river corridor.

Figure 18. Bedrock falls

R34-C

R34-C Summary Data Missisquoi River	
Reach/Segment Length	1,383 ft
Valley Confinement	NW
Reference Stream Type/Bedform	NA
Existing Stream Type/Bedform	NA
Geomorphic Condition	NA
Channel Evolution Stage	NA
Adjustment Process	NA
Habitat Condition	NA
Stream Sensitivity	NA

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

Reach R34-C was segmented due to impounded channel conditions and valley width. Due to the impounded condition, no RGA or RHA were completed. This segment is impounded behind the large run of river dam in subreach R34-B. The segment is situated in a narrow valley with no encroachments identified in the river corridor. The reach is characterized as a gentle sloped, wide, and somewhat meandering channel with unknown bedform. The streambanks are comprised of non-cohesive sands. The segment has good buffer widths with good interspersion of vegetation on the banks. The dominant river corridor landuse is forest and shrub sapling.

There is one bridge acting as a floodprone constriction in this subreach. This relatively new bridge is associated with the River Road crossing and is 110' wide. There is an old abutment on the right bank just upstream of this bridge crossing. It is unknown at this time if the abutment is serving as a channel or floodprone constriction.

Figure 19. Old bridge abutment

R34-D

R34-D Summary Data Missisquoi River	
Reach/Segment Length	5,751 ft
Valley Confinement	BD
Reference Stream Type/Bedform	C4 Dune-Ripple
Existing Stream Type/Bedform	C4 Dune-Ripple
Geomorphic Condition	Good
Channel Evolution Stage	I
Adjustment Process	Minor Aggradation/Widening
Habitat Condition	Fair
Stream Sensitivity	High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

Reach R34-D was segmented due to valley width and bedform. This segment is situated in a broad valley with development encroachment within the river corridor. The reach is characterized as a gentle sloped, wide, and somewhat meandering channel with dune-ripple bedform. The channel stream flow is split at the downstream end of the segment by a large island. The streambanks are comprised of non-cohesive sands and silt with areas of erosion present. There is one bedrock grade control present on the right channel at the island. The channel exhibits C type geometry with width to depth ratio (WDR) of 14.5 and entrenchment ratio (ER) of 7.8. The incision ratio was measured as 1.1 at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Good, no significant historic channel degradation or loss of access to its floodplain, and only current minor adjustments underway, the segment was assigned a Channel Evolution Model (CEM) Stage I.

Figure 20. Channel at the cross section

The overall habitat condition of the segment is only rated Fair due to lack of pools, poor bank vegetation, poor bank canopy, and poor riparian vegetation. The invasive Japanese knotweed was identified on the island. While the habitat condition is generally fair, there are good buffer widths with a dominant corridor landuse of forest and abundant wetland resources along this segment. There is abundant large woody debris (87 LWD/Mile) with three debris jams.

There is one bridge in this segment associated with Rte 100. The bridge is adequately sized to support 140% of the bankfull flow event but is acting as a floodprone constriction. Scour was observed both above and below this structure.

4.4.8 REACH R35

This reach was segmented for differences in substrate size, bank height, and channel width.

R35-A

R35-A Summary Data Missisquoi River	
Reach/Segment Length	14,820 ft
Valley Confinement	VB
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C5 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	III
Adjustment Process	Historic Degradation Current Aggradation/Widening/ Planform Changes
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

Reach R35-A is a long segment situated in a very broad valley with road and development encroachment in the river corridor. The reach is characterized as a gentle sloped, wide, and meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands with significant areas of erosion present. The channel exhibits C type geometry with width to depth ratio (WDR) of 12.9 and entrenchment ratio (ER) of 8.7. The incision ratio was measured as 1.3 at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, historic channel degradation and reduced access to its floodplain, and current aggradation, widening, and planform adjustments underway, the segment was assigned a Channel Evolution Model (CEM) Stage III.

The overall habitat condition is only rated Fair due to lack of pools, poor riffle coverage and formation, poor bank vegetation, poor bank canopy, poor buffer widths, and poor riparian corridor vegetation. While the habitat condition is generally fair, there is abundant large woody debris (103 LWD/Mile) with three debris jams. The segment is located within an agricultural valley with the dominant corridor landuse being hay and crops. There is no evidence of channel alteration in the form of straightening or dredging. One field ditch was identified as a contributor of stormwater runoff to the channel.

Figure 21. Dump site (Project #R35A-2)

There is one bridge serving as a floodprone constriction. The bridge is associated with the Lane Road crossing and supports 121% of the bankfull flow event. Deposition was observed above the bridge. There is an old abutment acting as a channel and floodprone constriction just upstream of the Lane Road bridge. The abutment constricts the normally 78’ wide channel to a width of 35’.

R35-B

R35-B Summary Data Missisquoi River	
Reach/Segment Length	7,411 ft
Valley Confinement	VB
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Good
Channel Evolution Stage	IV
Adjustment Process	Historic Degradation Current Minor Widening/Planform
Habitat Condition	Fair
Stream Sensitivity	High

Habitat Stressors

- Invasive Plants
- Dump Sites
- Animal Crossings
- Dredging
- Poor Stream Bank Vegetation
- Algae Colonization

Reach Stressors

- Poor Buffers
- Erosion
- Mass Failures
- Encroachments
- Straightening
- Revetments
- Constrictions
- Rejuvenating
- Tributaries
- Dredging
- Stormwater inputs
- Headcuts

Reach R35-B was segmented for substrate size. Reach R35-B is situated in a very broad valley with road and development encroachment in the river corridor. The reach is characterized as a gentle sloped, wide, meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands with significant areas of erosion and some rip rap present. The channel exhibits C type geometry with width to depth ratio (WDR) of 22.7 and entrenchment ratio (ER) of 5.4. The incision ratio was measured as 1.3 at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Good, historic channel degradation and reduced access to its floodplain, and current minor adjustments underway, the segment was assigned a Channel Evolution Model (CEM) Stage IV.

Figure 22. Channel at the cross section

The overall habitat condition is only rated Fair due to lack of pools, fair riffle coverage, small patches of algae on the substrate, poor bank vegetation, poor bank canopy cover, poor buffer widths, and poor riparian vegetation. Stream buffers are generally less than 25' with the dominant corridor landuse hay and crop. While the habitat condition is generally fair, there is good supply of large woody debris (92 LWD/Mile) and one debris jam within this segment. The segment is situated in an agricultural valley, with no evidence of historic channel alteration in the form of straightening or dredging. One small irrigation withdrawal and one field ditch were mapped.

There is one undersized bridge serving as a channel constriction. The bridge is associated with a farm road at the downstream end of the segment and only supports 36% of the bankfull flow event. Scour was observed both above and below this structure.

Figure 23. Undersized farm bridge

4.4.9 REACH R35T3.01: TAFT BROOK TRIBUTARY

The Taft Brook tributary enters the Upper Missisquoi River just west of Lane Road. Reach R35T3.01 is the only reach of Taft Brook included in the study. The reach was segmented for differences in channel dimensions, bank height, and sinuosity.

R35T3.01-A

R35T3.01-A Summary Data Taft Brook	
Reach/Segment Length	1,688 ft
Valley Confinement	VB
Reference Stream Type/Bedform	E5 Riffle-Pool
Existing Stream Type/Bedform	E4 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	III
Adjustment Process	Historic Degradation Current Widening/Planform
Habitat Condition	Fair
Stream Sensitivity	Extreme

Habitat Stressors
Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors
Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

Reach R35T3.01-A is a short segment situated in a very broad valley with no identified river corridor encroachments. The segment is characterized as a gentle sloped, narrow, somewhat meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands with significant areas of erosion and some rip rap present. The channel exhibits E type geometry with width to depth ratio (WDR) of 7.7 and entrenchment ratio (ER) of 64.1. The incision ratio was measured as 1.4 at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, historic channel degradation and loss of access to its floodplain, and current widening and planform adjustments underway, the segment was assigned a Channel Evolution Model (CEM) Stage III.

Figure 24. Erosion of outside meander bend

The overall habitat condition is only rated Fair due to lack of large woody debris (6 LWD/Mile), large patches of substrate covered by dense algae, poor riffle coverage and formation, poor buffer widths generally less than 25', and poor riparian corridor vegetation. While the overall habitat condition is fair, there are a good number of deep pools (31 Pools/Mile) within the segment.

This segment is located within an agricultural valley with dominant landuse of hay and evidence of significant historic channel alteration. A length of approximately 900' was identified as historically straightened at the downstream end of the segment. Gravel extraction in association with maintenance of a stream ford is currently occurring at the upstream end of the segment. Two field ditch were identified as contributors of stormwater runoff to the segment just upstream and downstream of the Loop Road crossing.

Figure 25. Double Culvert associated with Loop Road crossing

There is one undersized double culvert crossing acting as both a channel and floodprone constriction. The culverts are associated with the Loop Road crossing and are only wide enough to support 94% of the bankfull flow event. Deposition was observed both upstream and downstream of this structure.

R35T3.01-B

Reach R35T3.01-B was segmented for differences in channel dimensions, bank height and width of floodprone area. This segment is situated in a very broad valley with no corridor encroachments. The segment is characterized as a gentle sloped, narrow, and meandering channel with riffle-pool bedform. There is a section impounded by beavers approximately 2,400' upstream of the segment break extending upstream to the Cemetery Road crossing. There are additional beaver dams within the last 1000' of the upstream end of the segment. The streambanks are comprised of non-cohesive sands with areas of erosion and rip-rap on both banks. The channel exhibits E type geometry with width to depth ratio (WDR) of 8.0 and entrenchment ratio (ER) of 43.2. The incision ratio was measured as 1.5 at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, historic channel degradation and loss of access to its floodplain, and current widening and planform adjustments underway, the segment was assigned a Channel Evolution Model (CEM) Stage III. The active nature of this segment is clearly evidenced by the twenty-nine mapped channel avulsions. The avulsions are primarily migrations of the outside meander bend. There is also a significant amount of sediment being stored in the form of mid, point, side and diagonal bars with 17, 32, 28 and 7 of these features mapped, respectively.

R35T3.01-B Summary Data
Taft Brook

Reach/Segment Length	**10,484 ft**
Valley Confinement	**VB**
Reference Stream Type/Bedform	**E5 Riffle-Pool**
Existing Stream Type/Bedform	**E5 Riffle-Pool**
Geomorphic Condition	**Fair**
Channel Evolution Stage	**III**
Adjustment Process	**Historic Degradation Current Widening/Planform**
Habitat Condition	**Fair**
Stream Sensitivity	**Extreme**

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

The overall habitat condition is fair due to lack of woody debris (47 LWD/Mile), fair riffle coverage and formation, large substrate patches covered by dense algae growth, poor bank vegetation, poor bank canopy, poor buffers, and poor riparian vegetation. The segment is located within an agricultural valley with evidence of historic channel alteration. The dominant buffer width is less than 25’ with dominant corridor land use of hay and crops. A total of five field ditches and one tile drain were identified as contributors of stormwater runoff to the channel. A number of animal crossings were identified upstream of the Cemetery Road crossing to the upstream reach break.

There is an undersized double culvert crossing acting as both a channel and floodprone constriction. These culverts are associated with the Cemetery Road crossing and are only wide enough to support 85% of the bankfull flow event. Deposition and scour were observed both above and below this structure.

Figure 26. Undersized double culverts at Cemetery Road crossing

4.4.10 REACH R35T3.1S1.01: MILL BROOK TRIBUTARY

The Mill Brook tributary enters the Taft Brook tributary just south of Lane and Loop Roads intersection. Reach R35T3.1S1.01 is the only reach of Mill Brook included in the study. The reach was segmented into subreaches for differences in substrate size, slope and bedform.

R35T3.1S1.01-A

R35T3.1S1.01-A Summary Data Mill Brook	
Reach/Segment Length	3,865 ft
Valley Confinement	VB
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	I
Adjustment Process	Planform/Aggradation/ Widening
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

Subreach R35T3.1S1.01-A is situated in a very broad valley with no encroachments identified within the river corridor. The segment is characterized as a gentle sloped, narrow, meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands and gravel with areas of erosion and rip-rap present on both banks. The channel exhibits C type geometry with width to depth ratio (WDR) of 21.1 and entrenchment ratio (ER) of 12.4. The incision ratio was measured as 1.0 at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, no historic channel degradation or loss of access to its floodplain, and current widening, aggradation and planform adjustments underway, the segment was assigned a Channel Evolution Model (CEM) Stage I. The active nature of this segment is clearly evidenced by the twenty-one mapped steep riffles, two floodchutes, one neck cutoff and four channel avulsions. It is likely that this material is sourced from the floodplain of the mainstem of the Upper Missisquoi River. While this subreach is very active as it cuts through this unconsolidated material, with obvious lateral instability, there is no evidence of historic channel evolution in the form of vertical instability.

Figure 27. Erosion and Poor Buffers

The overall habitat condition is only rated Fair due to lack of large woody debris (38 LWD/Mile), lack of pools, fair riffle coverage and formation, unconsolidated sediments underfoot, large substrate patches covered by dense algae growth, poor bank vegetation, poor bank canopy, poor buffer widths and poor riparian vegetation on the left bank. The buffer width is generally less than 25' with dominant river corridor landuse hay and pasture. This segment is located within an agricultural valley, but has no evidence of historical channel alteration in the form of straightening. There is evidence of active gravel extraction in the segment. Two tile drains were identified as contributors of stormwater runoff. A cattle crossing was identified approximately 800' upstream of the downstream subreach break.

R35T3.1S1.01-B

R35T3.1S1.01-B was identified as a subreach for changes in landuse, channel slope, stream type, and bedform. This subreach is situated in a very broad valley with development encroachment in the stream corridor. The segment is characterized as a sloped, narrow, and non-meandering channel with step-pool bedform. The streambanks are comprised of non-cohesive sands and gravel with areas of erosion and rip-rap present on both banks. The channel exhibits E type geometry with width to depth ratio (WDR) of 9.2 and entrenchment ratio (ER) of 25.3. Historic channel straightening and rip rap likely explain the reduced channel width resulting in an E type geometry instead of the expected C type. The incision ratio was measured as 1.9 at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, historic channel degradation and loss of access to its floodplain, and current channel stability (due to channel management activities), the segment was assigned a Channel Evolution Model (CEM) Stage II. Given the high level of encroachments and resulting channel management activities, it is unlikely that this subreach will move through the model of channel evolution. Vertical instability could still be an issue in this subreach and should be closely monitored.

R35T3.1S1.01-B Summary Data
Mill Brook

Reach/Segment Length	**1,651 ft**
Valley Confinement	**VB**
Reference Stream Type/Bedform	**C3 Step-Pool**
Existing Stream Type/Bedform	**E3 Step-Pool**
Geomorphic Condition	**Fair**
Channel Evolution Stage	**II**
Adjustment Process	**Historic Degradation and Planform Change**
Habitat Condition	**Fair**
Stream Sensitivity	**High**

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

The overall habitat condition is only rated Fair due to lack of large woody debris (9 LWD/Mile), lack of pools, poorly formed and incomplete steps, small patches of dense algae growth on the substrate, poor bank vegetation, poor bank canopy on the left bank, poor buffer widths, and poor riparian vegetation, and corridor encroachments. The buffer widths are generally less than 25’ with dominant river corridor landuse residential and hay. This subreach has a high level of development with evidence of historic channel straightening and current channel management in the form of revetments.

Figure 28. Channel management, corridor encroachments and channel constriction

There are a total of four bridges and culverts in this subreach, all serving as a floodprone constriction and three serving as channel constrictions. The following table provides a data summary for each structure.

Structure/Location	Bankfull Width Percentage	Channel Constriction	Floodprone Constriction	Problems
Bridge/Trail	163		x	Deposition below
Bridge/Trail	85	x	x	Deposition below
Triple Culvert/ Campground Drive	15	x	x	Scour above; scour below
Bridge/Rte 100	88	x	x	Deposition above and below; Scour above and below; poor alignment

Figure 29. Undersized Triple Culverts at Campground Drive

4.4.11 REACH R36

This short reach is situated in a broad valley with a berm encroachment in the river corridor on the left bank. The reach is characterized as a gentle slope, wide, and non-meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands with areas of erosion and some rip-rap present on the left bank. The channel exhibits C type geometry with width to depth ratio (WDR) of 15.7 and entrenchment ratio (ER) of 10.7. The incision ratio was measured as 1.2 at the cross section, with a human elevated ratio of 1.4 from the berm. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, historic channel degradation and loss of access to its floodplain, and current aggradation and widening underway, the segment was assigned a Channel Evolution Model (CEM) Stage III.

R36 Summary Data	
Reach/Segment Length	**1,721 ft**
Valley Confinement	**BD**
Reference Stream Type/Bedform	**C4 Riffle-Pool**
Existing Stream Type/Bedform	**C4 Riffle-Pool**
Geomorphic Condition	**Fair**
Channel Evolution Stage	**III**
Adjustment Process	**Historic Degradation Current Widening/Aggradation**
Habitat Condition	**Fair**
Stream Sensitivity	**Very High**

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

The overall habitat condition is rated only Fair due to lack of large woody debris (30 LWD/Mile), lack of pools (<10 Pools/Mile), lack of riffle coverage, small substrate patches covered by dense algae growth, poor bank canopy, poor buffer widths, and poor riparian vegetation. This reach is located within an agricultural setting with no evidence of historic channel straightening or dredging. The dominant corridor landuse is crop with riparian buffers generally less than 50'. One tile drain was identified as a source of stormwater runoff to the channel.

Figure 30. Nice undercut bank

4.4.12 REACH R37

Reach R37 was segmented for differences in valley width, channel dimensions, and corridor landuses.

R37-A

R37-A Summary Data Missisquoi River	
Reach/Segment Length	3,754 t
Valley Confinement	VB
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	III
Adjustment Process	Historic Degradation Current Widening/Planform
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

This segment is situated in a very broad valley with no encroachments in the river corridor. The segment is characterized as a gentle slope, wide, and meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands with areas of erosion and some rip-rap present on the right bank. The channel exhibits C type geometry with width to depth ratio (WDR) of 16.1 and entrenchment ratio (ER) of 23.2. The incision ratio was measured as 1.2 at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, historic channel degradation and loss of access to its floodplain, and current widening and planform change underway, the segment was assigned a Channel Evolution Model (CEM) Stage III. There is an active headcut on a floodchute east of the Loop Road crossing. The headcut is not in the main channel and is not typical of the reach segment.

Figure 31. Active headcut on floodchute

The overall habitat condition is only rated Fair due to lack of pools (<10 Pools/Mile), fair riffle coverage and formation, poor bank vegetation and canopy, small substrate patches covered by dense algae growth, poor buffers and poor riparian vegetation. This segment is located within an agricultural valley with a dominant corridor landuse of crops with bank buffers generally less than 25'. There is no evidence of historic channel straightening or dredging.

37-B

R37-B Summary Data Missisquoi River	
Reach/Segment Length	1,807 ft
Valley Confinement	BD
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Good
Channel Evolution Stage	I
Adjustment Process	Overwidened
Habitat Condition	Good
Stream Sensitivity	High

Habitat Stressors
- Invasive Plants
- Dump Sites
- Animal Crossings
- Dredging
- Poor Stream Bank Vegetation
- Algae Colonization

Reach Stressors
- Poor Buffers
- Erosion
- Mass Failures
- Encroachments
- Straightening
- Revetments
- Constrictions
- Rejuvenating Tributaries
- Dredging
- Stormwater inputs
- Headcuts

This segment is set in a broad valley with no encroachments in the river corridor. The segment is characterized as a gentle slope, wide, and meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands with areas of erosion and some rip-rap present on both banks. The channel exhibits C type geometry with width to depth ratio (WDR) of 26.3 and entrenchment ratio (ER) of 7.0. There is no evidence of incision with an incision ratio of 1.0 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Good, no historic channel degradation or loss of access to its floodplain, and only minor current adjustments, the segment was assigned a Channel Evolution Model (CEM) Stage I.

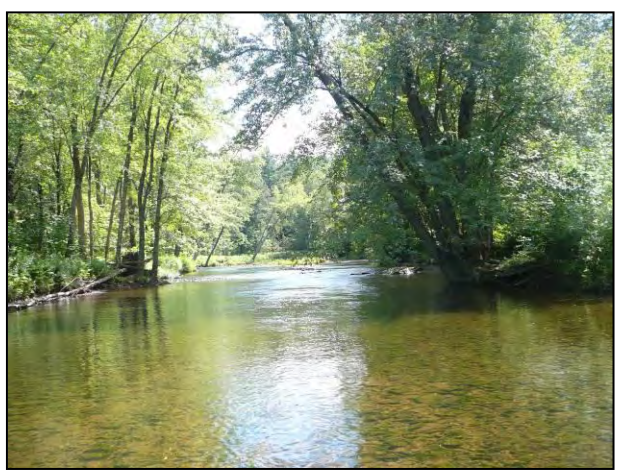


Figure 32. River channel at the cross section

This reach has a good width/depth ratio, but is likely overwidened at 98'. The expected channel width is likely closer to the Phase 1 predicted width of 83'.

The overall habitat condition of this segment is rated Good with good hydrologic conditions and connectivity, little erosion, good bank vegetation, good buffers and good riparian vegetation. There are some patches of substrate covered by dense algae growth and small sections where the buffer width is less than 25'. The dominant landuse in the river corridor is forest with a small area of pasture on the right bank. There is no evidence of historic channel straightening or dredging in this segment.

There is one undersized bridge in this segment serving as both a channel and floodprone constriction. The bridge is associated with the Loop Road crossing and is only wide enough to support 66 percent of the bankfull flow event. Scour was observed above this structure.

Figure 33. Undersized Loop Road Bridge

4.4.13 REACH R38

This reach was segmented for differences in valley width, bank height and buffer widths.

R38-A

This segment is situated in a broad valley with a berm encroachment in the river corridor on the right bank. The segment is characterized as a gentle slope, wide, and straightened channel with dune-ripple bedform. The streambanks are comprised of non-cohesive sands with significant areas of erosion and some rip-rap present on both banks. The channel exhibits C type geometry with width to depth ratio (WDR) of 14.4 and entrenchment ratio (ER) of 5.2. The incision ratio is 1.2 as measured at the cross section, with a human elevated incision ratio of 1.3. The berm was not found to affect floodplain access in this segment. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, no historic channel degradation or loss of access to its floodplain, and only minor current adjustments, the segment was assigned a Channel Evolution

Model (CEM) Stage I The channel has evidence of historic channel straightening which has affected the channel bedform. Given the space and opportunity, a riffle-pool system is likely to reestablish in this segment as is present in upstream segment R38-B and downstream segment R36-B.

R38-A Summary Data Missisquoi River	
Reach/Segment Length	3,199 ft
Valley Confinement	BD
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Dune-Ripple
Geomorphic Condition	Good
Channel Evolution Stage	I
Adjustment Process	Historically Straightened Currently Stable
Habitat Condition	Fair
Stream Sensitivity	High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

The overall habitat condition is only rated Fair due to lack of pools (<10 Pools/Mile), generally poor bank vegetation and canopy, and poor buffer width and poor riparian vegetation on the right bank. The dominant buffer width for the right bank is less than 25' with a dominant corridor landuse of hay. The dominant buffer width for the left bank is greater than 100' with forest as the dominant corridor landuse. While the overall habitat condition is only rated Fair, there is a diversity of habitat features present along the reach with an abundant supply of large woody debris (>200 LWD/Mile), two debris jams, and abundant wetlands adjacent to the channel. The channel also has access to a nice floodplain forest on the left bank.

Figure 34. Channel at the cross section

R38-B

R38-B Summary Data Missisquoi River	
Reach/Segment Length	9,541 ft
Valley Confinement	VB
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	I
Adjustment Process	Overwidened Minor Adjustments
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

This segment is situated in a very broad valley with no encroachments identified in the river corridor. The segment is characterized as a gentle slope, wide, and meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands with significant areas of erosion and some rip-rap present on both banks. The channel exhibits C type geometry with width to depth ratio (WDR) of 24.6 and entrenchment ratio (ER) of 9.0. The incision ratio is 1.2 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, no historic channel degradation or loss of access to its floodplain, and only minor current adjustments, the segment was assigned a Channel Evolution Model (CEM) Stage I. This reach has a good width/depth ratio, but is likely overwidened at 99.50'. The expected channel width is likely closer to the Phase 1 predicted width of 83'. This segment has had some laterally instability as evidenced by areas of significant erosion and resulting overwidening, but is not actively going through channel evolution at this time.

Figure 35. Erosion of an outside meander bend

The overall habitat condition for this segment is only rated Fair due to lack of pools (<10

Pools/Mile), poor stream bank vegetation and canopy cover, and poor riparian vegetation. This segment is located in an agricultural valley with dominant landuses of forest and pasture/hay. Multiple livestock crossings were observed along the length of this segment. The dominant buffer widths are generally greater than 50' with significant areas of less than 25' on both banks. There is no evidence of historic channel straightening or dredging. While the overall habitat condition is Fair, there is a diversity of habitat features present along the reach with an abundant supply of large woody debris (>150 LWD/Mile) and five debris jams. The channel also has access to a nice floodplain forest on the right bank.

There is one undersized bridge in this segment serving as both a channel and a floodprone constriction. The bridge is associated with a farm road and is wide enough to support 72 percent of the bankfull flow event. Deposition was observed below this structure. The 2009 NAIP shows the existing location of the bridge, which is approximately 215' downstream from the location indicated on the 2003 NAIP.

Figure 36. Undersized farm bridge

4.4.14 REACH R40

Reach R39 was not assessed in this current study due to bedrock gorge conditions.

R40 Summary Data Missisquoi River	
Reach/Segment Length	**4,458 ft**
Valley Confinement	**BD**
Reference Stream Type/Bedform	**C4 Riffle-Pool**
Existing Stream Type/Bedform	**C4 Riffle-Pool**
Geomorphic Condition	**Fair**
Channel Evolution Stage	**I**
Adjustment Process	**Overwidened/Stable**
Habitat Condition	**Fair**
Stream Sensitivity	**Very High**

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

Reach R40 is situated in a broad valley with no river corridor encroachments. The reach is characterized as a gentle slope, wide, and meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands with significant areas of erosion and some rip-rap present on the left bank. The channel exhibits C type geometry with width to depth ratio (WDR) of 19.1 and entrenchment ratio (ER) of 9.9. The incision ratio is 1.3 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, no historic channel degradation or loss of access to its floodplain, and only minor current adjustments, the segment was assigned a Channel Evolution Model (CEM) Stage I. This reach has a good width to depth ratio, but is likely overwidened at 81'. The expected channel width is likely closer to the Phase 1 predicted width of 75'. This segment has had some laterally instability as evidenced by areas of significant erosion and resulting overwidening, but is not actively going through channel evolution at this time.

The overall habitat condition is only rated Fair due to lack of riffle coverage, poor bank vegetation and canopy cover, and poor riparian vegetation. The dominant buffer width is generally greater than 50’ with small areas of less than 25’ present on both banks. This segment is located within an agricultural valley with dominant riparian corridor landuse of crop on the left and forest on the right bank. There is no evidence of historic channel straightening or dredging. While the overall habitat condition is fair, there is a diversity of habitat features present along the reach with an abundant supply of large woody debris (97 LWD/Mile), many deep pools, and abundant wetlands present adjacent to the channel.

Figure 37. Dump site

4.4.15 REACH R41

This long reach is situated in a very broad valley with both road and development encroachments in the river corridor. The segment is characterized as a gentle slope, wide, and meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands with significant areas of erosion and some rip-rap present on both banks. The channel exhibits C type geometry with width to depth ratio (WDR) of 36.2 and entrenchment ratio (ER) of 15.4. The incision ratio is 1.3 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, some historic channel degradation and reduced access to its floodplain, no current indications of vertical instability, and only minor current adjustments, the segment was assigned a Channel Evolution Model (CEM) Stage IV. This reach has a fair width to depth ratio, and is overwidened at 123'. The expected channel width is likely closer to the Phase 1 predicted width of 75'. The channel is unlikely to widen any further, but is still moving about laterally through its newly established floodplain. The prevailing condition is a wide, very active channel cutting back and forth across point and side bars (15 mid channel bars, 27 point bars and 25 side bars).

R41 Summary Data
Missisquoi River

Reach/Segment Length	**16,582 ft**
Valley Confinement	**VB**
Reference Stream Type/Bedform	**C4 Riffle-Pool**
Existing Stream Type/ Bedform	**C4 Riffle-Pool**
Geomorphic Condition	**Fair**
Channel Evolution Stage	**IV**
Adjustment Process	**Historic Degradation/ Overwidened**
Habitat Condition	**Fair**
Stream Sensitivity	**Very High**

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

The overall habitat condition is rated Fair due to lack of pools, generally poor stream bank vegetation, poor buffers on the right bank, and generally poor riparian vegetation. This reach sits in an agricultural setting with evidence of historic channel straightening and dredging. The dominant corridor landuse is hay with buffers less than 25’ on the right bank. The dominant buffer width on the left bank is greater than 100’ with significant areas of less than 25’ and a dominant landuse of pasture. There are multiple livestock crossings along this reach. Within this reach, a field ditch, a road ditch and a drain tile were identified as contributors of stormwater runoff to the channel. While the overall

Figure 38. Erosion of outside meander bend and poor buffer condition

condition of this reach is fair, there is a diversity of habitat features present along the reach with an abundant supply of large woody debris (184 LWD/Mile), ten debris jams, many deep pools, and abundant wetlands present adjacent to the channel.

There are four undersized structures in this reach each serving as channel and floodprone constrictions. The following table provides summary data for these structures.

Structure/Location	Bankfull Width Percentage	Channel Constriction	Floodprone Constriction	Problems
Bridge/Rte 100	75	X	X	None
Bridge/Farm Road	26	X	X	Scour above and below
Bridge/Trail	70	X	X	Deposition below
Old Abutment	20	X	X	None

Figure 39. Old abutment serving as a channel constriction

4.4.16 REACH R42

This short reach is situated within a semi-confined valley with no encroachments in the river corridor. The segment is characterized as a gentle slope, and meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands with areas of erosion and some rip-rap present on the left bank. The channel exhibits C type geometry with width to depth ratio (WDR) of 14.5 and entrenchment ratio (ER) of 2.4. The incision ratio is 1.0 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Good, no historic channel degradation or loss of access to its floodplain, and only minor current adjustments, the segment was assigned a Channel Evolution Model (CEM) Stage I.

R42 Summary Data Missisquoi River	
Reach/Segment Length	1,375 ft
Valley Confinement	SC
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Good
Channel Evolution Stage	I
Adjustment Process	Stable/Minor Adjustments
Habitat Condition	Fair
Stream Sensitivity	High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors
Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

Figure 40. Channel at the cross section

The overall habitat condition is only Fair due to lack of large woody debris (<50 LWD/Mile), lack of pools, and fair bank and riparian corridor vegetation. The buffer widths are generally greater than 100' with only short sections on the left bank of less than 25'. The dominant corridor landuse is forest, with an area of hay present on the left bank. There has been recent logging activity in the left corridor.

4.4.17 REACH R43

This reach is situated in a very broad valley with no encroachments within the river corridor. The segment is characterized as a gentle slope, and meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands with areas of erosion present. The channel exhibits C type geometry with width to depth ratio (WDR) of 12.7 and entrenchment ratio (ER) of 5.8. The incision ratio is 1.1 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, no significant historic channel degradation or loss of access to its floodplain, and only minor current adjustments, the segment was assigned a Channel Evolution Model (CEM) Stage I.

R43 Summary Data Missisquoi River	
Reach/Segment Length	2,545 ft
Valley Confinement	VB
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	I
Adjustment Process	Some Aggradation/Planform Changes
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal
Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

The overall habitat condition is only rated Fair due to lack of pools, poor bank vegetation on the left bank, and fair buffers and buffer vegetation on the left bank. The reach sits within an agricultural valley with no evidence of historic channel straightening or dredging. The dominant buffer width is generally greater than 50' with short sections on the left bank of less than 25'. The dominant landuse in the left corridor is hay and forest in the right. While the overall condition of this reach is fair, there is some diversity of habitat features present along the reach with an abundant supply of large woody debris (>100 LWD/Mile) in the channel.

Figure 41. Channel at cross section

4.4.18 REACH R44

This reach was segmented and sub-reached due to differences in valley width, channel dimensions, and substrate size.

R44-A

R44-A Summary Data Missisquoi River	
Reach/Segment Length	1,740 ft
Valley Confinement	BD
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Good
Channel Evolution Stage	I
Adjustment Process	Stable/Minor Adjustments
Habitat Condition	Fair
Stream Sensitivity	High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors
Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

This segment was identified as a subreach due to a broader valley width than present in the remainder of the reach. This subreach is situated in a broad valley with no encroachments in the river corridor. The subreach is characterized as a gentle slope, and meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands with areas of erosion and rip rap present on both banks. The channel exhibits C type geometry with width to depth ratio (WDR) of 12.7 and entrenchment ratio (ER) of 5.8. The incision ratio is 1.1 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Good, no significant historic channel degradation or loss of access to its floodplain, and only minor current adjustments, the segment was assigned a Channel Evolution Model (CEM) Stage I.

Figure 42. Mass Failure

The overall habitat condition is only rated Fair due to lack of large woody debris in the channel, poor riffle coverage and formation, poor bank vegetation and canopy on the left bank, fair buffer vegetation on the left bank and poor buffers on the right bank. The subreach is located within an agricultural valley with no evidence of historic channel straightening or dredging. The dominant corridor landuse is hay on the right bank with buffer widths generally less than 50'. The dominant corridor landuse is forest, with hay also present, on the left bank and buffer widths are generally greater than 50'. One livestock crossing was observed at the downstream end of this subreach.

R44-B

R44-B Summary Data
Missisquoi River

Reach/Segment Length	**1,202 ft**
Valley Confinement	**SC**
Reference Stream Type/Bedform	**G2 Step-Pool**
Existing Stream Type/Bedform	**G2 Step-Pool**
Geomorphic Condition	**Good**
Channel Evolution Stage	**I**
Adjustment Process	**Relatively Stable**
Habitat Condition	**Fair**
Stream Sensitivity	**High**

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

This segment has been identified as a subreach due to differences in valley width and stream type. This subreach is situated in a semi-confined valley with no encroachments in the river corridor. The subreach is characterized as a sloped, and slightly meandering channel with step-pool bedform. The streambanks are comprised of cohesive bedrock. The channel generally exhibits G type geometry with width to depth ratio (WDR) of 8.4 and entrenchment ratio (ER) of 5.8. This stream type does not match up well to the classification system. The existing condition best reflects the G stream type, although the entrenchment is greater than 1.4. Stream type G was selected as the closest fit. The incision ratio is 1.0 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Good, no significant historic channel degradation or loss of access to its floodplain, and relatively stable current condition, the subreach was

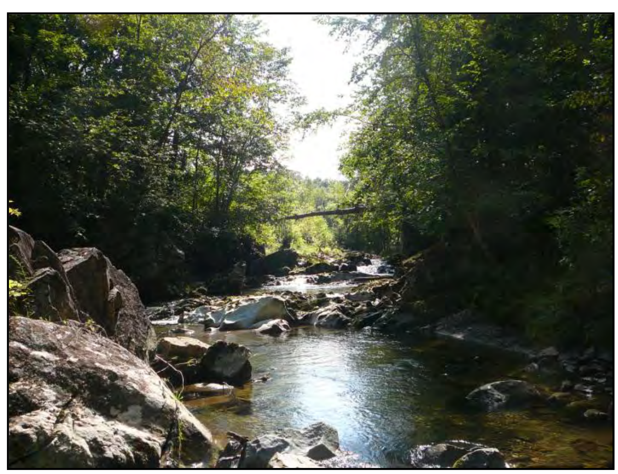


Figure 43. Nice step-pool sequence

assigned a Channel Evolution Model (CEM) Stage I. This is a confined stretch with ledge and boulders and very little floodplain.

The overall habitat condition is rated Fair due to poor large woody debris in larger size class, lack of pools, absence of CPOM in the channel, poor bank canopy, and fair riparian vegetation on the left bank. While the overall condition of this reach is fair, there is some diversity of habitat features present along the reach with an abundant supply of large woody debris of smaller size class (>300 LWD/Mile), some nice large pools, and a 37' waterfall approximately mid-segment. The dominant corridor landuse is forest with buffer widths greater than 100'.

R-44C

R44-C Summary Data Missisquoi River	
Reach/Segment Length	1,118 ft
Valley Confinement	SC
Reference Stream Type/Bedform	E4 Riffle-Pool
Existing Stream Type/Bedform	E4 Riffle-Pool
Geomorphic Condition	Good
Channel Evolution Stage	I
Adjustment Process	Minor Adjustments
Habitat Condition	Fair
Stream Sensitivity	High

Habitat Stressors
Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors
Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

This segment was identified as a subreach due to differences in valley width and stream type. This subreach is situated in a semi-confined valley with no identified encroachments in the river corridor. The subreach is characterized as a gently sloped, and meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sand and gravel with a small area of rip rap present on the left bank. The channel exhibits E type geometry with width to depth ratio (WDR) of 11.1 and entrenchment ratio (ER) of 4.4. The incision ratio is 1.0 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Good, no historic channel degradation or loss of access to its floodplain, and only current minor adjustments, the subreach was assigned a Channel Evolution Model (CEM) Stage I.

The overall habitat condition is only rated Fair due to lack of larger size woody debris, lack of pools, generally poor bank vegetation, fair canopy cover, poor buffer width on the right bank, and poor riparian corridor vegetation on both sides. While the overall condition of this reach is fair, there is some diversity of habitat features present along the reach with an abundant supply of large woody debris of smaller size class (>150 LWD/Mile) and some nice large pools along the channel. The dominant buffer width on the left bank is greater than 100' with a short section of less than 25'.

Figure 44. Undersized Hazen Notch Road Bridge

There is one undersized bridge serving as both a channel and floodprone constriction. The bridge is associated with the Hazen Notch Road crossing and is only wide enough to support 92 percent of the bankfull flow event. Deposition was observed above and scour above and below the structure.

R44-D

This segment has been identified as a subreach due to differences in valley width, stream type and bedform. This subreach is situated in a narrowly confined valley with development encroachments in the river corridor. There is ledge at the downstream subreach break acting as a grade control as well as is a large run of river dam acting as a grade control at the upstream subreach break. The subreach is characterized as a sloped, and slightly meandering channel with step-pool bedform. The streambanks are comprised of cohesive boulders on the left bank and non-cohesive sand and gravel on the right bank. There is a short section of erosion on the right bank and a short section of rip rap present on the left bank. The channel exhibits B type geometry with width to depth ratio (WDR) of 12.1 and entrenchment ratio (ER) of 2.1. The incision ratio is 1.8 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Good, historic channel degradation and loss of access to its floodplain, and only current minor adjustments, the subreach was assigned a Channel Evolution Model

(CEM) Stage IV. This is a relatively stable step-pool system in a narrowly confined bedrock valley.

R44-D Summary Data Missisquoi River	
Reach/Segment Length	988 ft
Valley Confinement	NC
Reference Stream Type/Bedform	B2 Step-Pool
Existing Stream Type/Bedform	B2 Step-Pool
Geomorphic Condition	Good
Channel Evolution Stage	IV
Adjustment Process	Historic Degradation Relatively Stable
Habitat Condition	Fair
Stream Sensitivity	High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors
Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

The overall habitat condition is only rated Fair due to lack of large woody debris (58 LWD/Mile), high embeddedness of the channel, generally poor bank vegetation, and poor stream buffers and riparian corridor vegetation. This stretch of river does have a number of deep pools providing important aquatic habitat. The dominant landuse in the riparian corridor is residential with areas of forest. The dominant buffer width is generally greater than 50' with a short section of buffer less than 25' on the left bank.

Figure 45. Large run-of-river dam

The large run-of-river dam at the upstream end of this segment has created impounded conditions in Segment E.

R44-E

R44-E Summary Data Missisquoi River	
Reach/Segment Length	370 ft
Valley Confinement	NA
Reference Stream Type/Bedform	NA
Existing Stream Type/Bedform	C Riffle-Pool Administrative Judgment
Geomorphic Condition	NA
Channel Evolution Stage	NA
Adjustment Process	NA
Habitat Condition	NA
Stream Sensitivity	NA

Habitat Stressors
Invasive Plants
Dump Sites
Animal
Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors
Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

This short segment was not assessed due to impoundment from the large run of river dam in subreach R44-D. The channel is situated in a narrow valley with development encroachment on the left bank. There is a section of poor buffer less than 25' on the left bank at the upstream end of the segment and a small stretch of erosion present on the right bank just upstream of the dam. The bank vegetation consists of shrubs and wetland vegetation on the right bank. The dominant buffer landuse on the right is forest, and residential on the left. Habitat and geomorphic condition ratings were not assigned.

4.4.19 REACH R44T6.01: BURGESS BRANCH TRIBUTARY

The Burgess Brook tributary enters the Upper Missisquoi River just west of Hazen Notch and Valley Roads intersection. Reach R44T6.01 is the only reach of Burgess Brook included in the study. The reach was segmented for differences in channel dimension and substrate size.

R44T6.01-A

R44T6.01-A Summary Data Burgess Branch	
Reach/Segment Length	1,650 ft
Valley Confinement	BD
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	I
Adjustment Process	Recent Channel Migrations/Lateral Instability
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors
Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

This segment is situated in a broad valley with no corridor encroachments. This segment is characterized as a gently sloped, and slightly meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands with areas of erosion and rip-rap present on both banks. The channel exhibits C type geometry with width to depth ratio (WDR) of 16.7 and entrenchment ratio (ER) of 6.0. The incision ratio is 1.0 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, no historic channel degradation or loss of access to its floodplain, the segment was assigned a Channel Evolution Model (CEM) Stage I. Recent channel migrations and active erosion on outside meander bends indicate that this segment of river is laterally unstable at this time. There is no evidence of historic vertical instability. The channel is still connected to its floodplain and unlikely to widen and develop a new lower floodplain. We may continue to see some lateral movement within the existing floodplain.

Figure 46. Bank erosion and poor buffer conditions

The overall habitat condition is Fair due to lack of large woody debris (44 LWD/Mile), high channel embeddedness, lack of pools, bank erosion on the right bank, fair bank vegetation, and poor buffer width and riparian corridor vegetation on the right bank. The buffer width on the right bank is generally less than 25’ while the left bank is generally greater than 100’ with a section of less than 25’ downstream of the Hazen Notch Road crossing. The dominant river corridor landuse is shrubs and forest on the left bank and hay on the right. There is one field ditch contributing stormwater runoff to the stream.

There is an undersized bridge acting as both a channel and floodprone constriction. The bridge is associated with the Hazen Notch Road crossing and is wide enough to support only 55 percent of the bankfull flow event. Deposition was observed above, and scour above and below the structure.

Figure 47. Undersized Hazen Notch Road bridge

R44T6.01-B

R44T6.01-B Summary Data Burgess Branch	
Reach/Segment Length	1,595 ft
Valley Confinement	SC
Reference Stream Type/Bedform	B3c Riffle-Pool
Existing Stream Type/Bedform	B3c Rifle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	IV
Adjustment Process	Historic Degradation Current Aggradation/Widening
Habitat Condition	Fair
Stream Sensitivity	High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

This segment was identified as a subreach due to differences in confinement, stream type, and substrate size. This subreach is situated in a semi-confined valley with no encroachments present in the river corridor. This subreach is characterized as a sloped, and slightly meandering channel with riffle-pool bedform. The streambanks are generally comprised of non-cohesive sand and gravel with minimal erosion. The channel exhibits B type geometry with width to depth ratio (WDR) of 22.1 and entrenchment ratio (ER) of 1.3. The incision ratio is 1.2 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, historic channel degradation and reduced access to its floodplain, and only current aggradation and some widening, the segment was assigned a Channel Evolution Model (CEM) Stage IV. This reach has a good width to depth ratio, but is overwidened at 81'. The expected channel width is likely closer to the Phase 1 predicted width of 45'. It is likely that with a minor to moderate level of historic incision and historic widening, that the "new" floodplain will develop at the current elevation.

Figure 48. Channel at cross section

The overall habitat condition is only rated Fair due to elevated stream embeddedness, lack of pools, poor riffle coverage, generally poor stream bank vegetation, and fair buffer vegetation. This stretch of stream does have an abundant amount of large woody debris (>200 LWD/Mile) providing habitat diversity in the channel. Small tributaries are depositing high gravel loads to the Brook with a likely source being stormwater runoff from Valley Road.

4.4.20 REACH R45

This reach was segmented for differences in channel dimensions, bank height and incision.

R45-A

This segment is situated in a very broad valley with road, development and berm encroachments in the river corridor. The valley width is only influenced by the Lower Village Road in the very lower portion of the segment. While a small change in valley width for that portion, it is still a very broad valley, and the remaining, 3,000+ ft of valley are not changed by the encroachment. This segment is located upstream of the larger run of river dam in R44-D. This segment is characterized as a sloped, and meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands and gravels with areas of erosion and rip rap present. The channel exhibits C type geometry with width to depth ratio (WDR) of 18.4 and entrenchment ratio (ER) of 6.8. The incision ratio is 1.0 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, no historic channel degradation or loss of access to its floodplain, and only current lateral migration, the segment was assigned a Channel Evolution Model (CEM) Stage I. The channel is still connected to its floodplain and unlikely to widen and develop a new lower floodplain. We may continue to see some lateral movement within the existing floodplain.

R45-A Summary Data Missisquoi River	
Reach/Segment Length	4,373 ft
Valley Confinement	VB
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	I
Adjustment Process	Aggradation/Planform Changes
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal
Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating
Tributaries
Dredging
Stormwater inputs
Headcuts

The overall habitat condition is only rated Fair due to elevated channel embeddedness, large substrate patches covered by dense algae growth, lack of pools and riffles, abundant mid-channel accumulation, poor bank vegetation, and fair buffer vegetation. This segment is located within an agricultural valley with no evidence of historic channel straightening or dredging. The dominant buffer width is generally greater than 100' with short sections of buffer less than 25' on both banks. The dominant corridor land use is forest and shrub on the left side and shrubs and hay on the right bank. Mid-channel accumulation is at least partly sourced by the multiple mass failures identified within this stretch of river. A field ditch was identified as a potential contributor to stormwater runoff in the channel.

Figure 49. Channel at cross section

There is an undersized bridge in this segment serving as both a channel and floodprone constriction at the Lower Village Road crossing. This structure supports 87% of the bankfull flow event. Deposition was observed above and below this structure.

Figure 50. Undersized Lower Village Road bridge

Figure 51. Undersized tube culvert

Figure 52. Channel after tube culvert removal

An undersized boiler tube culvert was removed with the assistance of Vermont Stream Alteration Engineer Chris Brunelle in the not too distant past. The culvert was located on the old gravel pit road and used to be used to access the pit. When the Town of Lowell took over the pit, the crossing was removed.

R45-B

This segment is situated in a very broad valley with development, road, and berm encroachments in the riparian corridor. There is a bedrock grade control in the form of ledge at the upstream segment R45-C break. This segment is characterized as a sloped, and meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands and gravels with areas of erosion and rip rap present. The channel exhibits C type geometry with width to depth ratio (WDR) of 12.7 and entrenchment ratio (ER) of 9.6. The incision ratio is 1.6 as measured at the cross section. There is a short section of berm on the right bank (continuous with the berm noted in R45-A) which is not representative of the segment. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, historic channel degradation and loss of access to its floodplain, and current widening and planform adjustment, the segment was assigned a Channel Evolution Model (CEM) Stage III.

R45-B Summary Data Missisquoi River	
Reach/Segment Length	1,601 ft
Valley Confinement	VB
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	III
Adjustment Process	Historic Degradation Current Widening/Planform
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors
Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

The overall habitat condition is only rated Fair due to lack of large woody debris (LWD/Mile), elevated channel embeddedness, major evidence of sediment mobility and lack of sorting, lack of pools and riffles, erosion on the right bank, fair bank vegetation, and poor buffers and riparian corridor vegetation on both sides. The dominant buffer width is less than 25' for both banks with dominant corridor landuse residential and hay.

Figure 53. Undersized Route 100 bridge

There is an undersized bridge at the Rte 100 crossing serving as both a channel and floodprone constriction. The bridge is wide enough to support 64 percent of the bankfull flow event. Scour was observed above and below this structure.

R45-C

R45-C Summary Data Missisquoi River	
Reach/Segment Length	4,702 ft
Valley Confinement	VB
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	I
Adjustment Process	Aggradation/Widening/ Planform Changes
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

This segment is situated in a very broad valley with road encroachment in the riparian corridor. This segment is characterized as a gently sloped, and meandering channel with riffle-pool bedform. The stream banks are comprised of non-cohesive sands and gravel with areas of erosion and rip rap present. The channel exhibits C type geometry with width to depth ratio (WDR) of 24.6 and entrenchment ratio (ER) of 8.7. The incision ratio is 1.0 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, no historic channel degradation or loss of access to its floodplain, and current aggradation, widening and planform adjustment underway, the segment was assigned a Channel Evolution Model (CEM) Stage I. Sediment is stored in numerous mid, point, side, diagonal, delta, and one island with fourteen floodchutes and six channel avulsions also identified. The channel in this segment is still connected to its floodplain on the right bank and unlikely to widen and develop a new lower floodplain. We may continue to see some lateral movement within the existing floodplain. The overall habitat rating is only rated Fair due to lack of pools and riffles, abundant mid-channel accumulation, and fair bank vegetation. The dominant buffer width is greater than 100’ with areas of poor buffer less than 25’ also present. The dominant corridor landuse is shrubs/sapling with hay and residential

Figure 54. Nice deep pool

subdominant on the left and right bank, respectively. There is evidence of historic channel straightening and gravel mining in the segment. While the overall habitat rating is fair, there are a number of deep pools in and abundant wetlands adjacent to the stream channel. Two field ditches were identified as potential sources of stormwater runoff to the channel. Two livestock crossings were also identified within this segment.

There are two undersized bridges serving as both channel and floodprone constrictions. The Rte 100 bridge is wide enough to support 98 percent of the bankful flow event. A number of problems were identified for this structure: deposition above and below, scour above, and overall poor alignment. The farm bridge is wide enough to support 73 percent of the bankfull storm event. Deposition was observed above this structure.

Figure 55. Undersized farm bridge

4.4.21 REACH R46

R46 Summary Data Missisquoi River	
Reach/Segment Length	3,160 ft
Valley Confinement	BD
Reference Stream Type/Bedform	C4b Riffle-Pool
Existing Stream Type/Bedform	C4b Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	IV
Adjustment Process	Historic Degradation/ Overwidened Current Aggradation/Planform
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

This short reach is situated in a broad valley with road and development encroachments in the riparian corridor. This segment is characterized as a sloped, and meandering channel with riffle-pool bedform. The streambanks are comprised of non-cohesive sands and gravels with areas of significant erosion and some rip rap present. The channel exhibits C type geometry with width to depth ratio (WDR) of 25.6 and entrenchment ratio (ER) of 3.9. The incision ratio is 1.5 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, historic channel degradation and loss of access to its floodplain, and current aggradation and planform adjustment underway, the segment was assigned a Channel Evolution Model (CEM) Stage IV. Historic channel management in the form of channel straightening and armoring resulted in degradation of the stream channel and loss of access to the floodplain. Current adjustments of aggradation and planform changes are underway to develop a new floodplain at the channel's current elevation. Sediment is being stored in multiple mid, point, side, and diagonal bars. The channel is overwidened at 65' compared to the predicted width of 34', but is unlikely to widen further at this stage of channel evolution.

The overall habitat condition is only rated Fair due to channel embeddedness, major evidence of sediment mobility and lack of sorting, most of the substrate covered by dense algae growth, lack of pools and riffles, bank erosion and poor bank vegetation on the right bank, and poor buffer widths and riparian corridor vegetation on the right bank. The dominant corridor landuses are forest and residential for the left and right banks, respectively. The dominant buffer widths are greater than 100' and less than 25' for the left and right banks, respectively. There are multiple mass failures within this segment, at least partly sourcing the observed mid-channel sediment accumulation.

Figure 56. Channel at cross section

There is an undersized bridge serving as both a channel and floodprone constriction at the Rickaby Road crossing. The bridge is wide enough to support 77 percent of the bankfull flow event. Deposition was observed above and below the structure, with scour also noted below.

Figure 57. Undersized Rickaby Road bridge

4.4.22 REACH R47

This reach was segmented for differences in channel dimensions, floodprone width, and valley confinement.

R47-A

R47-A Summary Data Missisquoi River	
Reach/Segment Length	1,921 ft
Valley Confinement	VB
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	IV
Adjustment Process	Historic Degradation Current Aggradation/ Planform
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors
Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors
Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

This segment is situated in a very broad valley with road and development encroachments in the river corridor. There is a ledge serving as a grade control at the upstream segment R47-B break. This segment is characterized as a gently sloped, and meandering channel with riffle-pool bedform. The stream banks are comprised of non-cohesive sands and gravels with areas of erosion and revetments present. The channel exhibits C type geometry with width to depth ratio (WDR) of 15.9 and entrenchment ratio (ER) of 4.9. The incision ratio is 1.2 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of Fair, historic channel degradation and reduced access to its floodplain, and current aggradation and planform adjustment underway, the segment was assigned a Channel Evolution Model (CEM) Stage IV. Historic channel management in the form of channel straightening and armoring resulted in degradation of the stream channel and reduced access to the floodplain. Current adjustments of aggradation and planform changes are underway to develop a new floodplain at the channel's current elevation. Sediment is being stored in multiple mid, point, side, and diagonal bars. The channel is overwidened at 46' compared to the predicted width of 29', but is unlikely to widen further at this stage of channel evolution.

Figure 58. Historically straightened section of channel

The overall habitat condition is only rated Fair due to lack of large woody debris, elevated channel embeddedness, most of substrate covered by dense algae growth, major evidence of sediment mobility and lack of sorting, lack of riffle coverage, poor bank vegetation, and poor buffer width and riparian corridor vegetation on the right bank. The dominant buffer width is generally greater than greater than 100' and less than 25' on the left and right banks, respectively. The dominant corridor landuses are forest on the left bank and hay and residential on the right bank. While the overall habitat condition is fair, there are a good number of deep pools creating important aquatic habitat in this segment. There is a road ditch and a tile drain serving as stormwater inputs to this segment.

Figure 59. Undersized Private Bridge on Pierce Road

There are two undersized bridges serving as both channel and floodprone constrictions. The private drive just upstream of the R46 reach break supports only 35% of the bankfull flow event and has both deposition and scour above the structure. The bridge at the 2nd private drive, on Pierce Road supports only 30% has deposition and scour both above and below the structure.

R47-B

R47-B Summary Data Missisquoi River	
Reach/Segment Length	6,225 ft
Valley Confinement	VB
Reference Stream Type/Bedform	C4 Riffle-Pool
Existing Stream Type/Bedform	C4 Riffle-Pool
Geomorphic Condition	Fair
Channel Evolution Stage	I
Adjustment Process	Widening/Planform Changes
Habitat Condition	Fair
Stream Sensitivity	Very High

Habitat Stressors

Invasive Plants
Dump Sites
Animal Crossings
Dredging
Poor Stream Bank Vegetation
Algae Colonization

Reach Stressors

Poor Buffers
Erosion
Mass Failures
Encroachments
Straightening
Revetments
Constrictions
Rejuvenating Tributaries
Dredging
Stormwater inputs
Headcuts

This segment is situated in a very broad valley with road encroachment in the riparian corridor. This segment is characterized as a gently sloped, and meandering channel with riffle-pool bedform. The stream banks are comprised on non-cohesive sands and gravel with areas of significant erosion and some rip rap present. The channel exhibits C type geometry with width to depth ratio (WDR) of 29.5 and entrenchment ratio (ER) of 2.6. The incision ratio is 1.0 as measured at the cross section. With a Rapid Geomorphic Assessment (RGA) condition rating of only Fair, no historic channel degradation or reduced access to its floodplain, and active widening and planform change underway, the segment was assigned a Channel Evolution Model (CEM) Stage I. Sediment is being stored in numerous mid, point, side, diagonal and delta bars with sixteen floodchutes and eighteen channel avulsions mapped.

Figure 60. Excavated channel Resulting in a Headcut

There is an active headcut in an agricultural setting at the upper end of this segment. The channel has been excavated in this area and the degradation feature is not typical for the reach. The area about the excavation has not incised at this time. The channel in this segment is still connected to its floodplain and unlikely to widen and develop a new lower floodplain. We may continue to see some lateral movement within the existing floodplain.

The overall habitat condition is only rated Fair due to lack of large woody debris (43 LWD/Mile), elevated channel embeddedness, major evidence of sediment mobility and lack of sorting, most of the substrate covered by dense algae growth, lack of riffle coverage, abundant mid-channel accumulation, bank erosion and poor bank vegetation, and poor buffer widths and riparian corridor vegetation. This segment is located within an agricultural valley with the dominant landuse pasture and hay. There is evidence of gravel mining of the channel and a livestock crossing was identified at the upstream end of the segment. The dominant buffer width on both banks is less than 25'. There is one mass failure, likely sourcing at least some of the increased mid-channel sediment deposits. Three field ditches and one road ditch were identified as contributors of stormwater runoff to the channel.

Figure 61. Channel at cross section

Figure 62. Undersized Cheney Road Bridge

There is an undersized box culvert and an undersized bridge both serving as channel and floodprone constrictions. The bridge associated with Cheney Road is wide enough to support only the 93 percent of the bankfull flow event. Several problems were noted about this bridge: deposition and scour above and below the structure as well as overall poor alignment.

The box culvert associated with Rte 100 is wide enough to support only 36 percent of the bankfull flow event. Deposition and scour were observed above and below this structure.

Figure 63. Undersized Rte 100 Box Culvert

5.0 DEPARTURE ANALYSIS AND STRESSOR IDENTIFICATION

The following sections summarize the results of the Phase 1 and 2 Stream Geomorphic Assessment data collection for the Upper Missisquoi River Watershed. Stressor, departure, and sensitivity maps are presented as a means to organize the data that has been collected and show the interaction of watershed and reach-scale dynamics. In addition, these maps should assist in identifying practical restoration and protection actions that can move the River and its tributaries towards a healthy equilibrium. Alterations to watershed-scale hydrologic and sediment regimes can greatly influence reach-scale dynamics, and if not considered adequately can undermine protection and restoration efforts at the reach level.

The data, tables, and maps described in Section 5 will be used to identify restoration and conservation techniques on a reach scale basis that meet the goals and objectives of reducing fluvial erosion hazards, increasing sediment and nutrient attenuation sites, and improving aquatic and riparian habitat.

5.1 DEPARTURE ANALYSIS

Section 5.1 summarizes watershed-scale stressors on the physical stability and habitat conditions of the River. Section 5.1 also characterizes reach-scale stressors.

5.1.1 HYDROLOGIC REGIME STRESSORS

The hydrologic regime involves the timing, volume, and duration of flow events throughout the year and over time; as addressed in this section, the regime is characterized by the input and manipulation of water at the watershed scale. When the hydrologic regime has been significantly changed, stream channels will respond by undergoing a series of channel adjustments. Where hydrologic modifications are persistent, the impacted stream will adjust morphologically (e.g., enlarging when stormwater peaks are consistently higher) and often result in significant changes in sediment loading and channel adjustments in downstream reaches (VTANR, 2009).

Natural land cover types (e.g. forests, wetlands) play important roles in watersheds by storing and filtering run-off, trapping sediment, reducing peak flood levels, and maintaining base flows during summer. Deforestation and urban and agricultural development increase rainwater runoff by decreasing the amount of natural vegetation to naturally filter water and sediment. Additionally, urban lands contain large amounts of impervious surfaces where stormwater will quickly run off into adjacent drainages rather than slowly percolate through the soil, resulting in higher peak flood levels with high nutrient and sediment inputs. These levels can trigger a channel to enlarge and incise due to consistently high stormwater runoff.

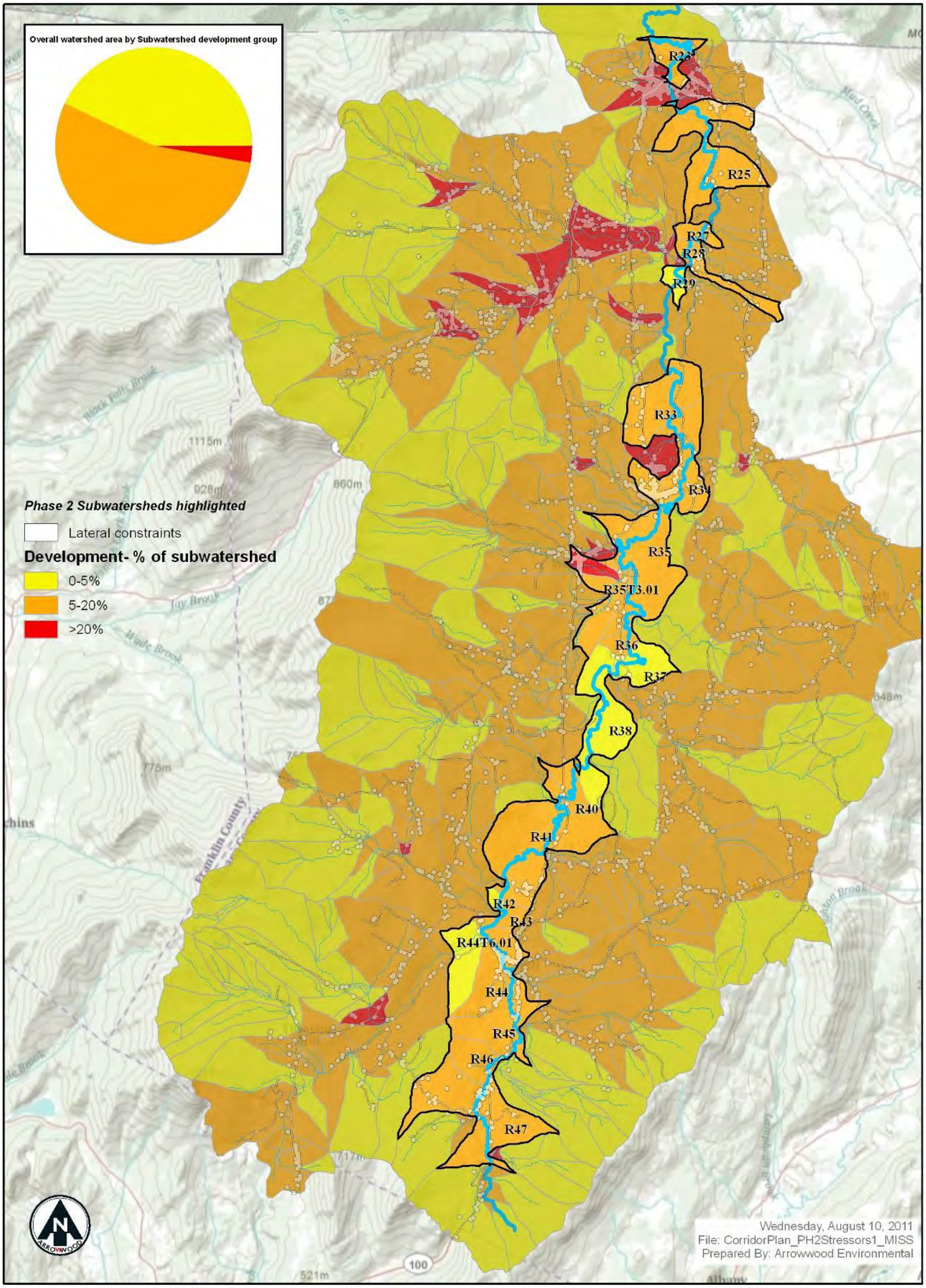


Figure 62. Developed Land within the Upper Missisquoi River Watershed

The Upper Missisquoi River Watershed has twenty-two subwatersheds where development is greater than 20% of the land area out of the overall two-hundred and ninety subwatersheds. Two of these subwatersheds are within the Phase 2 study area, R24 on the main stem and Taft Brook (R35T3.1S1.01). Reach R24 is the only mainstem reach with greater than 20% development of land area in the overall watershed, with development occurring primarily on the tributaries. Reach R24 encompasses the eastern portion of the town of North Troy, including North Pleasant Street, and areas of East Main Street, South Street, Hill Street, Main Street, Elkins Drive, Elm Street, and Blair Road. The subwatershed of the first reach of Mill Brook encompasses the town of Westfield, centered about Route 100 and North Hill Road. Both of these subwatersheds have a high level of residential and road development. Overall, the northwestern portion of the watershed has the most development per watershed area, with a high level of development within the subwatersheds of the Jay Branch.

The Upper Missisquoi River watershed study area is characterized by a combination of agricultural, forest and residential landuses. There is a significant agricultural presence within the valley of the Upper Missisquoi River with increasing residential development in the surrounding woodlands. Fifty-four of the subwatersheds of the Upper Missisquoi River have greater than 10% of their land area in cultivation. Of that fifty-four, eleven subwatersheds (R27, R28, R29, R33, R34, R35T3.01, R35T3.1S1.01, R36, R38, R40, and R45) occur in the Phase 2 study area. As the map below shows, there is a significant agricultural presence along the main stem of the Upper Missisquoi River.

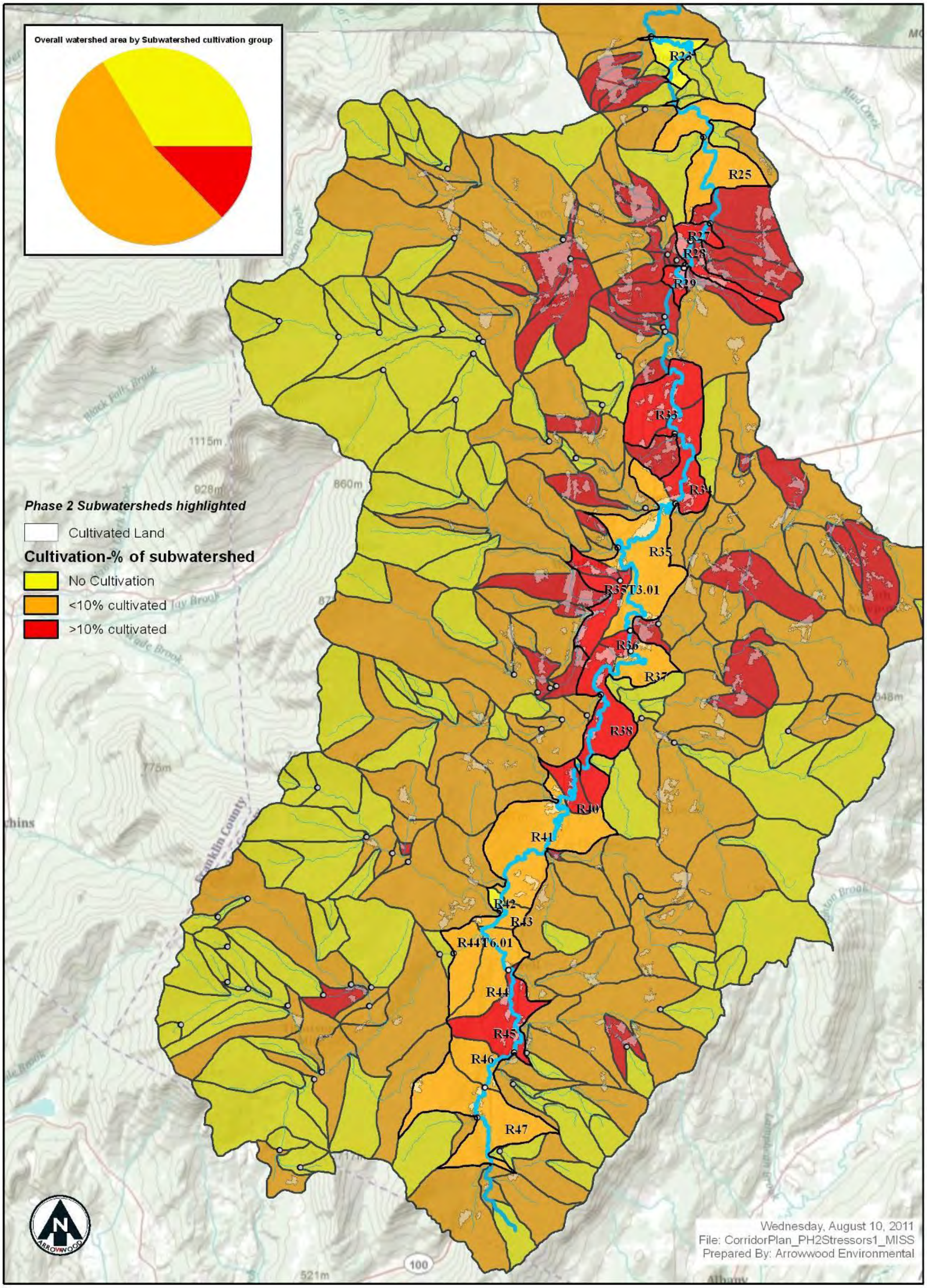


Figure 63. Cultivated Lands within the Upper Missisquoi River Watershed

Land use and land cover within the stream corridor is particularly important with respect to sediment deposition and erosion during annual flood events. Wetlands, ponds, and perennial vegetation moderate stormwater and sediment runoff, while impervious surfaces within urban areas and the exposed soils found in cropland have the potential to increase watershed inputs.

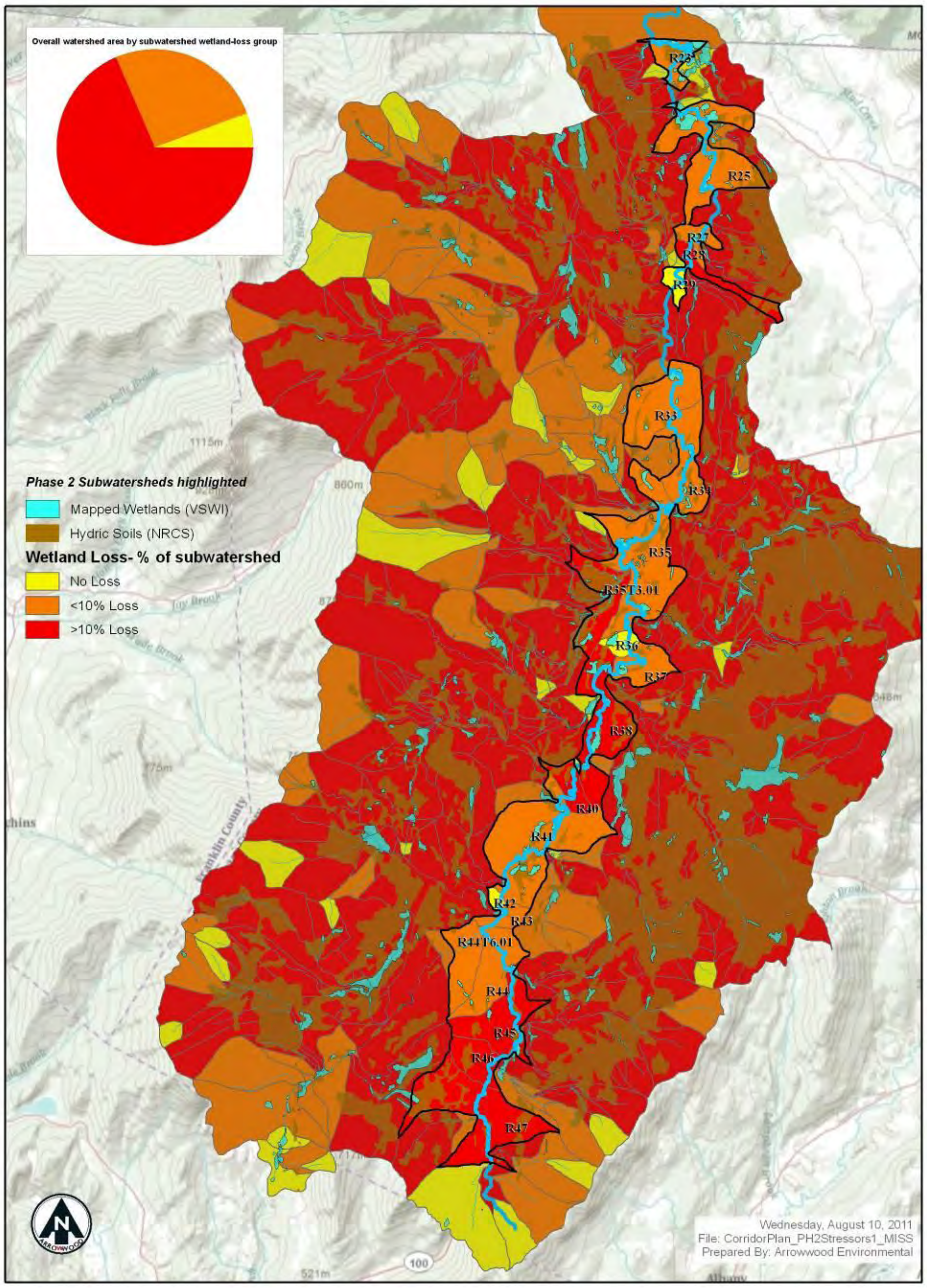


Figure 64. Wetland Losses within the Upper Missisquoi River Watershed

Analysis of hydric soils and existing agricultural and developed land uses indicates significant loss of wetland attenuation of precipitation inputs in the study watershed. Wetlands have been filled, ditched, diverted and otherwise manipulated resulting in a loss of hydrologic function.

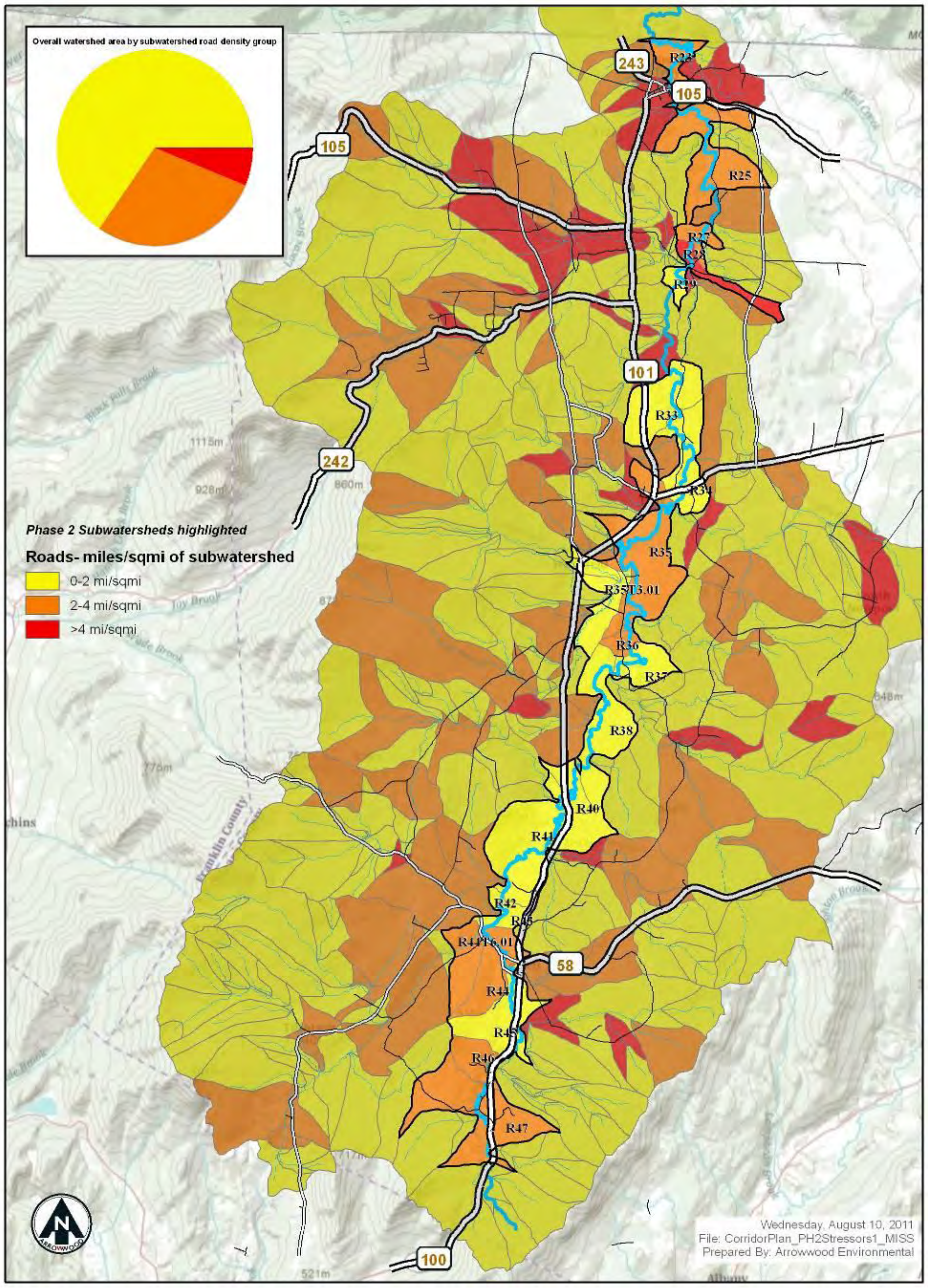


Figure 64. Road Density within the Upper Missisquoi River Watershed

Many of the roads and crop lands throughout the watershed have been ditched over time, contributing to intensified inputs to the River and its tributaries. Historical clearing (late 18th and 19th centuries) initially contributed to higher runoff of both water and sediment, which accumulated in the valleys. Additionally, removal of large woody debris from stream channels, likely related to use of the streams for agricultural uses, combined with road developments to change the rainfall-runoff regime in such a way that water inputs intensified through deposited sediments, and the watershed's hydrologic regime became more "flashy".

One of the most significant hydrologic stressors for the Upper Missisquoi River watershed, and the majority of Vermont, is the large scale deforestation that occurred in the 19th century. As the state was settled much of the forest was cut for timber and the land cleared for agriculture. Where today Vermont is approximately 80% forestland and 20% open, in the late 19th and early

20th century it was only 20% forested and 80% open. The effect of those land use changes are still being seen today. With much of the land cleared higher intensity flash floods were more common and carried with them a tremendous amount of sediment down into the valleys. This sediment built up in the river systems and raised the bed elevation of many streams.

5.1.2 SEDIMENT REGIME STRESSORS

Streams naturally exhibit erosion and deposition processes. When systems are not in equilibrium, the degree and rate of erosion may overwhelm the streams natural ability to transport sediment and natural depositional processes. Sedimentation and associated degradation of aquatic habitat are concerns in the Upper Missisquoi River and its tributaries. At the watershed scale, erosive materials present in upper side slopes of steep valley walls, alluvial soils on exposed streambanks, and bed materials contribute to a high sediment-load system. Geomorphic instability related to the downcutting (and loss of floodplain access) of some of the study reaches have resulted in adjustment processes that are manifested largely in redistribution of the sediment loads as the river tries to regain equilibrium and establish a new floodplain. Additional stressors in this system may include sheet and gully erosion on exposed soils of tilled croplands in the river corridor in particular, where ditching systems can transport these materials easily in runoff events.

Data collected in Phase 2 can be evaluated to determine whether the transport capacity of the channel has been exceeded, indicating a high sediment load. The stream deposition per mile (indicating the number of steep riffles, mid-channel bars, delta bars, flood chutes, avulsions, and braiding present per mile) and the erosion rating (indicating the percentage of the reach/segment length eroding), number of mass wasting or gullies per reach/segment, and presence of rejuvenating tributaries is used to determine which reaches/segments are experiencing increased sediment loads.

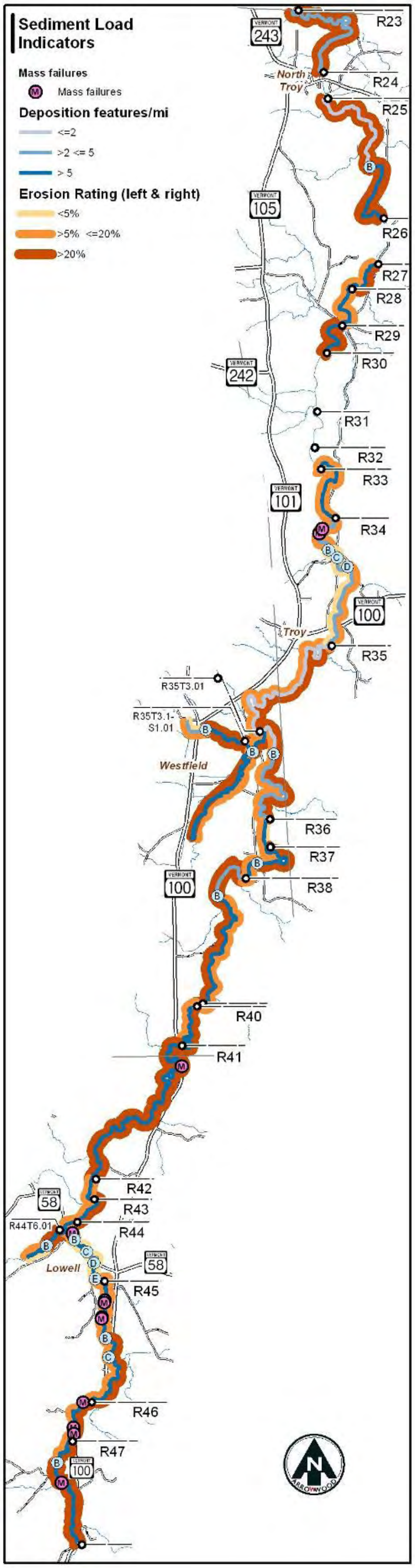


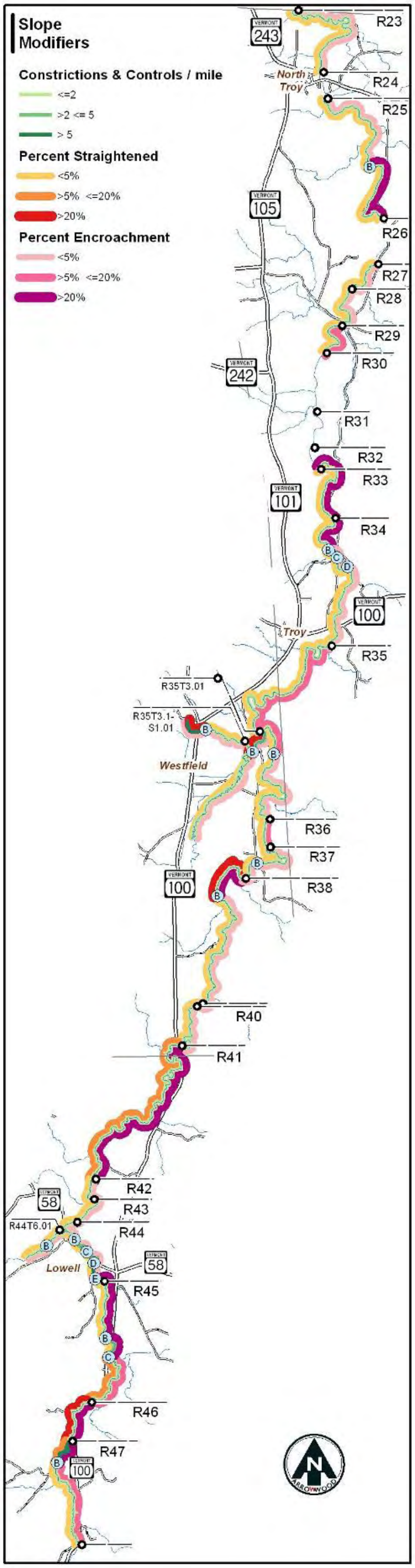
Figure 65. Sediment Load Stressors Map

5.1.3 REACH SCALE SEDIMENT REGIME STRESSORS

Watershed scale stressors provide a backdrop for understanding the timing and degree to which reach-scale modifications are contributing to field observed channel adjustments. Modifications to the valley, floodplain, and channel, as well as boundary (bank and bed) conditions, at the reach scale can change the hydraulic geometry, and thus change the way sediment is transported, sorted and distributed. Phase 1 and Phase 2 assessments provide semi-quantitative data-sets for examining stressors and their effects on sediment regime when channel hydraulic geometry is modified. (VTANR 2009)

Many land uses are incompatible with the meandering and ever-changing nature of rivers and streams. Rivers and streams are often straightened, armored, dredged, bermed, or otherwise encroached upon to protect property investments or to make floodplain available for other land uses. Channel straightening and bank armoring remove or alter natural meanders, while undersized bridges and culverts act as channel constrictions, forcing the stream to flow faster through a narrow area. These channel alterations directly affect the stream by increasing its slope and power, resulting in areas of bed and bank erosion.

In general, the high number of depositional features



per mile on several of the study reaches is a combination of deposits and channel bifurcations, indicating that the sediment carrying capacity of the channel has been exceeded. The presence of the deposits and channel bifurcations do not explain the source of the sediment. The Sediment Load Stressors Map (above) presents both the deposition features and erosion ratings, as well as locations of mass failures to better complete the picture. The map shows that upstream and in reach sections with high erosion ratings and presence of mass failures are likely sources for high depositional zones. This pattern commences at the most upstream study reach R47 and continues for the majority of the main stem. The study tributaries evidence the same pattern of high deposition likely sourced by high levels of bank erosion upstream and/or within the same segment.

5.1.4 CHANNEL SLOPE MODIFIERS

Results for Upper Missisquoi River indicate that primary stressors include select areas of extensive straightening of the channel, and select areas of corridor encroachments (including roads and development). Channel straightening can result in bed and bank erosion stemming from a measurable loss in floodplain access (i.e., increased incision), and play a significant role in enhancing sediment transport capacity as a result of the increased slope and depth at flood stage. With a significant increase in sediment load from upstream, the enhanced

Figure 67 . Slope Modifiers Map

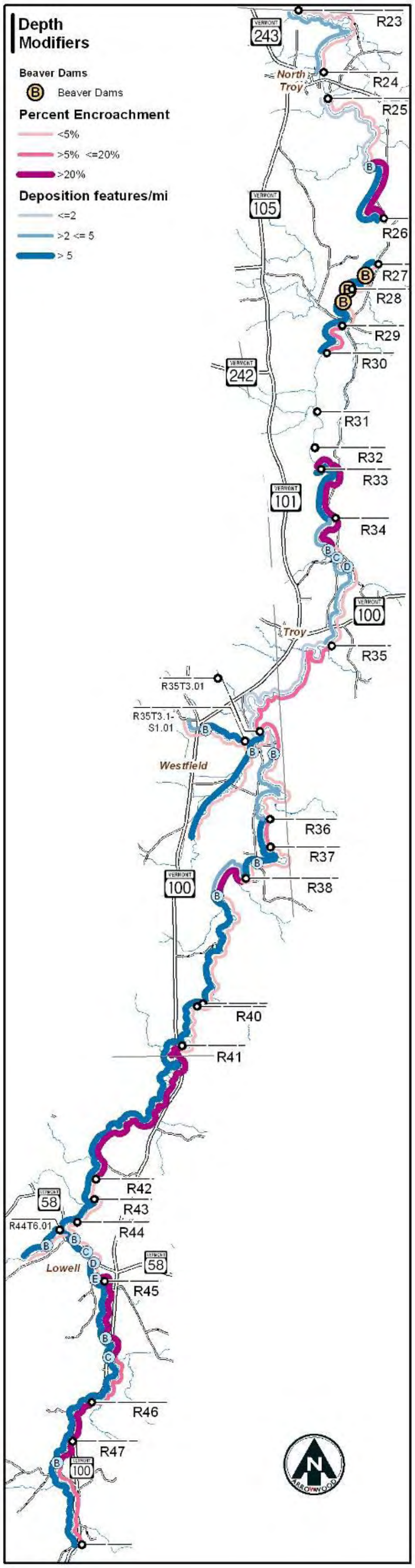
transport capacity can also result in stress to reaches downstream: instead of storing some of the increased load, the straightened reaches now convey sediment. Roads and development within the river corridor indirectly lead to an increased channel slope when structural measures are used to protect those encroachments.

There are eight natural grade controls, two dams and twenty-seven bridges/culverts within the study area serving to decrease channel slope and reduce stream power. Phase 2 data collection indicated that twenty-three of the bridges/culverts were inadequately sized to permit transport of both water and sediment (resulting in decreased slope in the reach). These structures are not adequately sized, resulting in upstream and downstream deposition and problems with scour about many of the structures.

The preceding map presents summary data collected during the Phase 2 assessment related to potential slope modifiers (increasers and decreasers) within the study reaches. Collectively, these modifications indicate the potential for increased erosion, possible incision, and decreased channel stability in some study reaches.

The Slope Modifiers Map shows (above) that several of the study reaches have been altered by historic channel straightening and encroachments, slope increasers. In particular, reaches R38A, R41, R45C, R46, R47A and R47B have all been altered by both historic straightening and encroachments. These reaches have also been identified as sediment load stressors for generally high erosion ratings and high number of depositional features per mile.

Constrictions and grade controls act as slope decreasers. Reaches R35T3.1S1.01B (three bridges and one culvert), R44D (one ledge grade control and a dam) and R47A (one ledge grade control and two bridges) have the highest number of constrictions and grade controls per mile in the study area. While the remaining reaches rate low overall for the number of constrictions and controls per mile, many have undersized bridges/culverts that act as localized slope decreasers in the vicinity of the structure with resulting impacts on sediment transport and deposition.



5.1.5 CHANNEL DEPTH MODIFIERS

Phase 2 data collection indicated high impact from corridor encroachments in several study segments, including R25B, R33, R34A, R38A, R41, R44E, R45A, R45B, R46 and R47A, which serves to reduce the effective width of the floodplain in these areas. Encroachments within the river corridor increase the depth of flood flows, and thus also increase stream power. Stream power is tempered in all of these segments by moderate to high sediment deposition per mile which creates the potential for more shallow depths during moderate flows. These reaches often contain other stressors affecting stream slope and depth. Due to generally high stream sensitivities, increased stress to these systems may result in rapid channel adjustments.

A good example of such a consequence of channel adjustments is seen in Reach R41. This reach has a history of channel straightening and corridor encroachment. The reach also has a high erosion rating, as well as high number of depositional features per mile. A combination of these stressors likely set about channel degradation and loss of floodplain access. Reach R41 subsequently experienced overwidening and is currently moving about laterally through its newly established floodplain. Other reaches

Figure 66. Depth Modifiers Map

have gone through a similar evolution, including R47A and R46, currently in a relatively stable condition. Reaches R33 and R45B have not completed the process of channel evolution and are still in the process of developing a new floodplain. Reaches R25B, R34A, and R45A have not been stressed to a point of starting channel evolution, but again, their high levels of sensitivity may result in rapid changes with any increased stress.

5.1.6 RIPARIAN BUFFER CONDITIONS

Stream boundaries include bed and banks, and are also affected by the condition of buffer vegetation in the riparian corridor. Root systems from woody vegetation help bind stream bank soils. The resistance of the channel boundary materials to the shear stress and stream power exerted, will, in large part, determine whether the channel will undergo adjustment. Riparian vegetation and human-placed bed and bank armoring are effective means of resisting erosion, although, armoring is considered a temporary condition. (VANR, River Corridor Planning Guide, 2010)

In general, the Upper Missisquoi River is described as a meandering, riffle-pool, gravel bottom system with a wide valley and broad floodplain. These stream systems are extremely susceptible to instability when natural vegetation is removed.

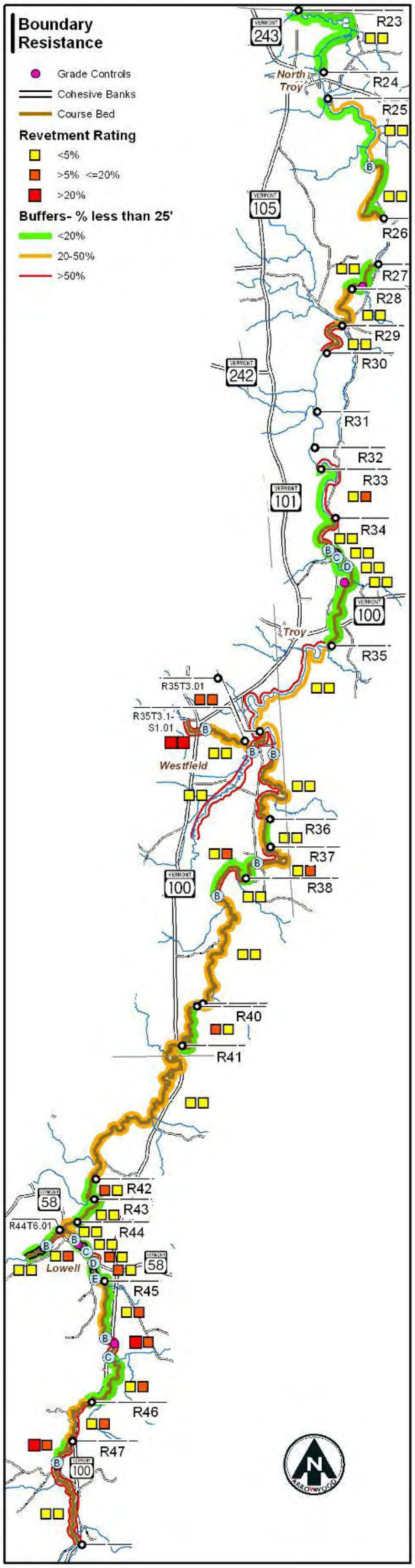


Figure 67. Boundary Resistance Map

Phase 2 data indicate that dominant buffer widths of greater than 25’ for both banks for more than 80% of the length of the reach occur on twelve of the Phase 2 assessed study segments (R23, R27, R34B, R34C, R34D, R37B, R42, R43, R44B, R44D, R4T6.01, and R45C). The remaining twenty-six assessed study segments had buffer widths of less than 25’ on at least one bank for more than 20% of the length of the segment. Of these same twenty-six segments, four also had a high revetment rating for one or both banks (R35T3.01A, R35T3.1S1.01B, R45B, and R47B). Poor buffer conditions in combination with generally non-cohesive bank conditions are likely contributing to the higher erosion rates seen in the majority of the study reaches.

The absence of vegetated buffers on the C and E stream type reaches within the project area can have a great affect on channel stability. When it is lacking, these channel types are highly sensitive to disturbance which may result in increased levels of streambank erosion and downcutting. These streams are highly sensitive to changes in sediment and stream flow. The Boundary Resistance Map presents the condition of the riparian buffers within the study reaches.

The primary hydrologic and sediment stressors in each assessed segment of the Upper Missisquoi River watershed are identified in Table 6 below.

Table 6. Upper Missisquoi River Stressors Identification table

	Watershed Input Stressors		Reach Modification Stressors	
River Segment **Stage of Channel Evolution; Geomorphic Condition; Stream Sensitivity**	**Hydrologic**	**Sediment Load**	**Stream Power**	**Boundary Resistance**
R23 CEM: I Fair Very High	*Increased Flows* Stormwater Inputs (3 field ditches) Moderate Wetland Loss Moderate Road Density Moderate Watershed Development	*Increased Load* Agricultural landuses in-reach Erosion Rating >20% (Lf&Rt banks)	*Decrease* Migration features Low slopes (channel/valley)	*Increase* 1 debris jam Good Buffers (both banks)
R25-A CEM: I Good High	*Increased Flows* Moderate Road Density Moderate Watershed Development	*Increased Load* Agricultural landuses in-reach Erosion Rating >20% (both banks)	*Decrease* Low slopes (channel/valley)	*Increase* Good Buffers (Lf bank) *Decrease* Bank Erosion (both banks)
R25-B CEM: 1 Fair Very High	*Increased Flows* Moderate Road Density Moderate Watershed Development Corridor Development	*Increased Load* Agricultural landuses in-reach Stream Ford or Animal Crossings High Deposition Features (>5/mile) Erosion Rating >20% (both banks)	*Increase* Corridor Encroachments (berm; roads) *Decrease* Migration features Low slopes (channel/valley) Constrictions-Old abutment	*Increase* Good Buffers (Rt bank) *Decrease* Bank Erosion (both banks)

	Watershed Input Stressors		Reach Modification Stressors	
River Segment **Stage of Channel Evolution; Geomorphic Condition; Stream Sensitivity**	**Hydrologic**	**Sediment Load**	**Stream Power**	**Boundary Resistance**
R27 CEM: IV Fair Very High	*Increased Flows* High Wetland Loss Upstream Moderate Road Density Moderate Watershed Development	*Increase Load* High Deposition Features (>5/mile) Erosion Rating >20% (Rt bank) *Decreased Load* Beaver activity reducing downstream load	*Decrease* Widening High Migration features Low slopes (channel/valley) Beaver activity	*Increase* Good Buffers (both banks) Beaver Activity *Decrease* Bank Erosion (Rt bank)
R28 CEM: III Fair Very High	*Increased Flows* Watershed Wetland Loss >10% Moderate Watershed Development Corridor Development	*Increased Load* Agricultural landuses in-reach Stream Ford or Animal Crossings High Deposition Features (>5/mile) *Decreased Load* Beaver activity reducing downstream load	*Increase* Corridor Encroachments (development) *Decrease* Constrictions-1 undersized bridge Migration features Low slopes (channel/valley) Beaver activity	*Increase* Beaver Activity
R29 CEM: 1 Good High	*Increased Flows* Stormwater Inputs (1 field ditch) Wetland Loss Upstream Watershed Wetland Loss >10% High Road Density Corridor Development	*Increased Load* Agricultural landuses in-reach High Deposition Features (>5/mile) Erosion Rating >20% (both banks)	*Increase* Corridor Encroachments (berm) *Decrease* Migration features Low slopes (channel/valley)	*Decrease* Poor Buffers (both banks) Bank Erosion (both banks)

	Watershed Input Stressors		Reach Modification Stressors	
River Segment **Stage of Channel Evolution; Geomorphic Condition; Stream Sensitivity**	**Hydrologic**	**Sediment Load**	**Stream Power**	**Boundary Resistance**
R33 CEM: III Fair Very High	*Increased Flows* Upstream Watershed Wetland Loss >10% Moderate Watershed Development Corridor Development	*Increased Load* Agricultural landuses in-reach High Deposition Features (>5/mile)	*Increase* Corridor Encroachments (berm; roads) *Decrease* Low slopes (channel/valley)	*Increase* 1 debris Jam Good Buffers (Lf Bank) *Decrease* Poor Buffers (Rt Bank) Revetments (Rt Bank)
R34-A CEM: 1 Good High	*Increased Flows* Stormwater Inputs (1 road ditch) Moderate Watershed Development Corridor Development	*Increased Load* Agricultural landuses in-reach Stream Ford or Animal Crossings Mass Failures	*Increase* Corridor Encroachments (berm) *Decrease* Migration features Low slopes (channel/valley)	*Increase* Good Buffers (Lf Bank) *Decrease* Poor Buffers (Rt Bank)
R34-B NA	*Increased Flows* Moderate Watershed Development	None	*Increase* High slopes in sections of bedrock grade controls and Dam	*Increase* Good Buffers (both banks)
R34-C NA	*Increased Flows* Moderate Watershed Development	*Increased Load* Agricultural landuses in-reach Large Run of River Dam	None	*Increase* Good Buffers (both banks)
R34-D CEM: 1 Good High	*Increased Flows* Moderate Watershed Development Corridor Development	*Increased Load* Agricultural landuses in-reach	*Increase* Corridor Encroachments (development) *Decrease* Constrictions-bedrock outcrops Low slopes (channel/valley)	*Increase* 3 debris dams Good Buffers (both banks)

	Watershed Input Stressors		Reach Modification Stressors	
River Segment **Stage of Channel Evolution; Geomorphic Condition; Stream Sensitivity**	**Hydrologic**	**Sediment Load**	**Stream Power**	**Boundary Resistance**
R35-A CEM: III Fair Very High	*Increased Flows* Stormwater Inputs (1 field ditch) Moderate Road Density Moderate Watershed Development Corridor Development	*Increased Load* Agricultural landuses in-reach Erosion Rating >20% (Rt bank)	*Increase* Corridor Encroachments (roads; development) *Decrease* Constrictions-Old abutment Low slopes (channel/valley)	*Increase* 3 debris dams *Decrease* Poor Buffers (both banks) Bank Erosion (Rt bank)
R35-B CEM: IV Good High	*Increased Flows* Stormwater Inputs (1 field ditch) Moderate Road Density Moderate Watershed Development Corridor Development	*Increased Load* Agricultural landuses in-reach Erosion Rating >20% (Rt bank)	*Increase* Corridor Encroachments (development) *Decrease* Constrictions-1 undersized bridge Low slopes (channel/valley)	*Increase* 1 debris jam *Decrease* Poor Buffers (both banks) Bank Erosion (Rt bank)
R35 T3.01-A CEM: III Fair Extreme	*Increased Flows* Watershed Wetland Loss >10% Stormwater Inputs (2 field ditches) Moderate Road Density Moderate Watershed Development	*Increased Load* Agricultural landuses in-reach Stream Ford or Animal Crossings High Deposition Features (>5/mile) Erosion Rating >20% (Rt bank)	*Increase* Straightening *Decrease* Constrictions-1 undersized culvert Migration features Low slopes (channel/valley)	*Decrease* Straightening Revetments (both banks) Poor Buffers (both banks) Bank Erosion (Rt bank)

	Watershed Input Stressors		Reach Modification Stressors	
River Segment **Stage of Channel Evolution; Geomorphic Condition; Stream Sensitivity**	**Hydrologic**	**Sediment Load**	**Stream Power**	**Boundary Resistance**
R35 T3.01-B CEM: III Fair Extreme	*Increased Flows* Watershed Wetland Loss >10% Stormwater Inputs (5 field ditches; 1 tile drain) Moderate Road Density Moderate Watershed Development	*Increased Load* Agricultural landuses in-reach Stream Ford or Animal Crossings High Deposition Features (>5/mile) Erosion Rating >20% (Lf bank) *Decreased Load* Beaver activity reducing downstream load	*Decrease* Beaver Activity Constrictions: 1 undersized culvert Migration features (37 features) Low slopes (channel/valley)	*Increase* 8 Beaver Dams, 2800 feet affected 4 debris dams *Decrease* Poor Buffers (both banks) Bank Erosion (Lf bank)
R35T3.1 S1.01-A CEM: I Fair Very High	*Increased Flows* Watershed Wetland Loss >10% Stormwater Inputs (2 tile drains) High Watershed Development	*Increased Load* Agricultural landuses in-reach Stream Ford or Animal Crossings High Deposition Features (>5/mile) Erosion Rating >20% (Both banks)	*Decrease* Migration features	*Decrease* Bank Erosion (both banks)

	Watershed Input Stressors		Reach Modification Stressors	
River Segment **Stage of Channel Evolution; Geomorphic Condition; Stream Sensitivity**	**Hydrologic**	**Sediment Load**	**Stream Power**	**Boundary Resistance**
R35T3.1 S1.01-B CEM: II Fair High	*Increased Flows* Watershed Wetland Loss >10% High Watershed Development Corridor Development	*Increased Load* Agricultural landuses in-reach	*Increase* Corridor Encroachments (development) Straightening *Decrease* Constrictions-2 undersized bridges;1 undersized culvert	*Decrease* Poor Buffers (both banks) Revetments (both banks) Straightening
R36 CEM: III Fair Very High	*Increased Flows* Stormwater Inputs (1 tile drain) Moderate Road Density Moderate Watershed Development Corridor Development	*Increased Load* Agricultural landuses in-reach High Deposition Features (>5/mile)	*Increase* Corridor Encroachments (berm) *Decrease* Migration features Low slopes (channel/valley)	*Increase* Good Buffers (Rt bank)
R37-A CEM: III Fair Very High	None	*Increased Load* Agricultural landuses in-reach Stream Ford or Animal Crossings High Deposition Features (>5/mile) Erosion Rating >20% (Rt bank)	*Decrease* Migration features Low slopes (channel/valley)	*Decrease* Poor Buffers (Lf bank) Bank Erosion (Rt bank) Revetments (Rt Bank)
R37-B CEM: I Good High	None	*Increase Load* High Deposition Features (>5/mile)	*Decrease* Constrictions-1 undersized bridge Migration features Low slopes (channel/valley)	*Increase* Good Buffers (both banks) *Decrease* Revetments (Rt Bank)

	Watershed Input Stressors		Reach Modification Stressors	
River Segment **Stage of Channel Evolution; Geomorphic Condition; Stream Sensitivity**	**Hydrologic**	**Sediment Load**	**Stream Power**	**Boundary Resistance**
R38-A CEM: I Good High	*Increased Flows* Watershed Wetland Loss >10% Corridor Development	*Increased Load* Agricultural landuses in-reach Erosion Rating >20% (both banks)	*Increase* Corridor Encroachments (berm) Straightening Decrease Low slopes (channel/valley)	*Increase* 2 debris jams Good Buffers (Lf Bank) *Decrease* Poor Buffers (Rt Bank) Straightening Bank Erosion (Both banks)
R38-B CEM: I Fair Very High	*Increased Flows* Watershed Wetland Loss >10%	*Increased Load* Agricultural landuses in-reach Stream Ford or Animal Crossings High Deposition Features (>5/mile) Erosion Rating >20% (Lf bank)	*Decrease* Widening High Migration features Low slopes (channel/valley) Constrictions: 1 undersized bridge	*Increase* 5 debris jams *Decrease* Bank Erosion (Lf bank)
R40 CEM: I Fair Very High	*Increased Flows* Moderate Wetland Loss High Wetland Loss Upstream Moderate Watershed Development	*Increased Load* Agricultural landuses in-reach High Deposition Features (>5/mile) Erosion Rating >20% (Rt bank)	*Decrease* Widening High Migration features Low slopes (channel/valley)	*Increase* Good Buffers (Rt Bank) *Decrease* Bank Erosion (Rt bank) Revetments (Lf bank)

	Watershed Input Stressors		Reach Modification Stressors	
River Segment **Stage of Channel Evolution; Geomorphic Condition; Stream Sensitivity**	**Hydrologic**	**Sediment Load**	**Stream Power**	**Boundary Resistance**
R41 CEM: IV Fair Very High	*Increased Flows* Stormwater Inputs (1 field ditch; 1 road ditch; 1 tile drain) Moderate Watershed Development Corridor Development	*Increased Load* Agricultural landuses in-reach Stream Ford or Animal Crossings Mass Failure High Deposition Features (>5/mile) Erosion Rating >20% (Both banks)	*Increase* Corridor Encroachments (roads; development) Straightening *Decrease* Constrictions-3 undersized bridges; Old abutment High Widening Migration features (25 features) Low slopes (channel/valley)	*Increase* 10 debris jams *Decrease* Straightening Bank Erosion (both banks)
R42 CEM: I Good High	None	*Increased Load* Agricultural landuses in-reach High Deposition Features (>5/mile)	*Decrease* Migration features Low slopes (channel/valley)	*Increase* Good Buffers (both banks) *Decrease* Revetments (Lf Bank)
R43 CEM: I Fair Very High	*Increased Flows* Moderate Watershed Development	*Increased Load* Agricultural landuses in-reach High Deposition Features (>5/mile) Erosion Rating >20% (Rt bank)	*Decrease* Migration features Low slopes (channel/valley)	*Increase* Good Buffers (both banks) *Decrease* Bank Erosion (Rt bank)

	Watershed Input Stressors		Reach Modification Stressors	
River Segment **Stage of Channel Evolution; Geomorphic Condition; Stream Sensitivity**	**Hydrologic**	**Sediment Load**	**Stream Power**	**Boundary Resistance**
R44-A CEM: I Good High	*Increased Flows* Moderate Road Density Moderate Watershed Development	*Increased Load* Agricultural landuses in-reach Stream Ford or Animal Crossings Mass Failure High Deposition Features (>5/mile)	*Decrease* Migration features Low slopes (channel/valley)	*Increase* 1 debris jam
R44-B CEM: I Good Low	*Increased Flows* Moderate Road Density Moderate Watershed Development	*Increased Load* High Deposition Features (>5/mile)	*Increase* High slopes in sections of bedrock grade controls	*Increase* Good Buffers (both banks)
R44-C CEM: I Good High	*Increased Flows* Moderate Road Density Moderate Watershed Development	None	*Decrease* Constrictions-1 undersized bridge Low slopes (channel/valley)	*Increase* Good Buffers (Lf bank) *Decrease* Revetments (Lf bank) Poor Buffers (Rt bank)
R44-D CEM: IV Good Moderate	*Increased Flows* Moderate Road Density Moderate Watershed Development Corridor Development	*Increased Load* Large Run of River Dam High Deposition Features (>5/mile)	*Increase* Corridor Encroachments (development) High slopes in sections of bedrock grade controls and dam	*Increase* Good Buffers (both banks) *Decrease* Revetments (Lf Bank)

	Watershed Input Stressors		Reach Modification Stressors	
River Segment **Stage of Channel Evolution; Geomorphic Condition; Stream Sensitivity**	**Hydrologic**	**Sediment Load**	**Stream Power**	**Boundary Resistance**
R44-E NA	*Increased Flows* Moderate Road Density Moderate Watershed Development	*Increased Load* High Deposition Features (>5/mile)		*Increase* Good Buffers (Lf bank) *Decrease* Revetments (Lf bank)
R44 T6.01-A CEM: I Fair Very High	*Increased Flows* Stormwater Inputs (1 field ditch) Moderate Road Density	*Increased Load* Agricultural landuses in-reach High Deposition Features (>5/mile) Erosion Rating >20% (both banks)	*Decrease* Constrictions-1 undersized bridge Migration features Low slopes (channel/valley)	*Increase* Good Buffers (Lf Bank) *Decrease* Poor Buffers (Rt Bank) Bank Erosion (both banks) Revetments (Rt Bank)
R44 T6.01-B CEM: IV Fair High	*Increased Flows* Moderate Road Density	*Increased Load* High Deposition Features (>5/mile)	*Decrease* Widening High Migration features	*Increase* Good Buffers (both banks)
R45-A CEM: I Fair Very High	*Increased Flows* Stormwater Inputs (1 field ditch) Watershed Wetland Loss >10% Moderate Watershed Development Corridor Development	*Increased Load* Agricultural landuses in-reach Stream Ford or Animal Crossings Mass Failures High Deposition Features (>5/mile)	*Increase* Corridor Encroachments (berm; roads) *Decrease* Constrictions-1 undersized bridge Migration features (14 features) Low slopes (channel/valley)	*Increase* 3 debris jams Good Buffers (Bank) *Decrease* Revetments (Rt Bank)

	Watershed Input Stressors		**Reach Modification Stressors**	
River Segment **Stage of Channel Evolution; Geomorphic Condition; Stream Sensitivity**	**Hydrologic**	**Sediment Load**	**Stream Power**	**Boundary Resistance**
R45-B CEM: III Fair Very High	*Increased Flows* Watershed Wetland Loss >10% Moderate Watershed Development Corridor Development	*Increased Load* Agricultural landuses in-reach High Deposition Features (>5/mile) Erosion Rating >20% (Rt bank)	*Increase* Corridor Encroachments (berm; roads; development) High slopes in sections of bedrock grade controls *Decrease* Constrictions-1 undersized bridge Migration features Low slopes (channel/valley)	*Decrease* Poor Buffers (both banks) Bank Erosion (Rt bank) Revetments (both banks)
R45-C CEM: I Fair Very High	*Increased Flows* Watershed Wetland Loss >10% Stormwater Inputs (2 field ditches) Corridor Development	*Increased Load* Agricultural landuses in-reach Stream Ford or Animal Crossings Erosion Rating >20% (Rt bank)	*Increase* Corridor Encroachments (roads) Straightening *Decrease* Constrictions-2 undersized bridges Widening High Migration features (20 features) Low slopes (channel/valley)	*Increase* Good Buffers (both banks) *Decrease* Straightening Bank Erosion (Rt bank) Revetments (Rt bank)

	Watershed Input Stressors		Reach Modification Stressors	
River Segment **Stage of Channel Evolution; Geomorphic Condition; Stream Sensitivity**	**Hydrologic**	**Sediment Load**	**Stream Power**	**Boundary Resistance**
R46 CEM: IV Fair Very High	*Increased Flows* Watershed Wetland Loss >10% Moderate Road Density Corridor Development	*Increased Load* Multiple Mass Failures High Deposition Features (>5/mile) Erosion Rating >20% (Rt bank)	*Increase* Corridor Encroachments (roads; development) Straightening *Decrease* Constrictions-1 undersized bridge Widening High Migration features	*Decrease* Poor Buffers (Rt Bank) Straightening Bank Erosion (Rt bank) Revetments (Rt Bank)
R47-A CEM: IV Fair Very High	*Increased Flows* Stormwater Inputs (1 road ditch; 1 tile drain) Watershed Wetland Loss >10% Corridor Development	*Increased Load* Agricultural landuses in-reach High Deposition Features (>5/mile) Erosion Rating >20% (Rt bank)	*Increase* Corridor Encroachments (roads; development) Straightening High slopes in sections of bedrock grade controls *Decrease* Constrictions-2 undersized bridges Migration features	*Increase* Good Buffers (Lf Bank) *Decrease* Poor Buffers (Rt Bank) Straightening Bank Erosion (Rt bank) Revetments (Both Banks)

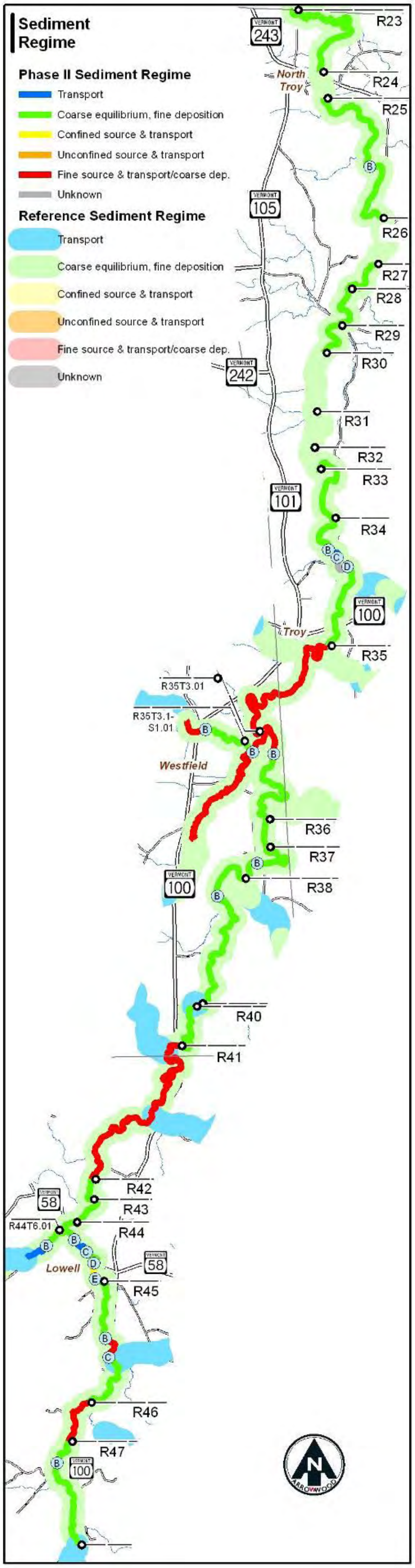
	Watershed Input Stressors		Reach Modification Stressors	
River Segment **Stage of Channel Evolution; Geomorphic Condition; Stream Sensitivity**	**Hydrologic**	**Sediment Load**	**Stream Power**	**Boundary Resistance**
R47-B CEM: I Fair Very High	*Increased Flows* Stormwater Inputs (3 field ditches; 1 road ditch) Watershed Wetland Loss >10% Corridor Development	*Increased Load* Agricultural landuses in-reach Stream Ford or Animal Crossings Mass Failure High Deposition Features (>5/mile) Erosion Rating >20% (Both banks)	*Increase* Corridor Encroachments (roads) High slopes in sections of bedrock grade controls *Decrease* Constrictions-1 undersized bridge; 1 undersized culvert Widening High Migration features (34 features) Low slopes (channel/valley)	*Decrease* Poor Buffers (Both banks) Bank Erosion (Both banks)

5.1.7 CONSTRAINTS TO SEDIMENT TRANSPORT AND ATTENUATION

Within a reach, the principals 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. Whether a project works with or against the physical processes at play in a watershed is primarily determined by examining the source, volumes, and attenuation of flood flows and sediment loads from one reach to the next within the stream network. If increasing 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 load or finds a way to attenuate the loads upstream (VTANR 2007).

Under reference conditions, the primary sediment regime of the Upper Missisquoi River would be one in which all reaches would provide for coarse particle equilibrium (in = out: stream power, which is produced as a result of channel gradient and hydraulic radius—is balanced by the sediment load, sediment size, and channel boundary resistance) and fine sediment deposition at annual flood flows. The lower segment (B) of reach R34 is in confined bedrock setting where the reference sediment regime is one of transport. The upper segment of the Burgess Brook tributary (R44T6.01B) and the lower segment (B) of R44 are also steep, confined settings where the reference sediment regime is one of transport. In a transport sediment regime, streams do not supply or store significant quantities of sediment. (VTANR 2010)

The existing sediment regime has been converted to one in which some reaches of the Upper Missisquoi now function as transport reaches, with coarse deposition occurring when stream power is reduced or sediment load exceeds the carrying capacity of the stream. Eight of the thirty-six assessed segments have been converted to either ‘Confined Source and Transport’ or ‘Fine Source and Transport & Coarse Deposition’ reaches. The remaining reaches are characterized by the reference sediment regime of ‘Coarse Equilibrium & Fine Deposition’ or ‘Transport’. Sediment and nutrient attenuation is occurring in those segments of the river where the channel has not lost access to its historic floodplain. The result of the conversion in segments is that sediment and nutrients are no longer retained in those areas of the watershed, but carried downstream to other reaches and receiving waters. These segments may experience erosion and supply both coarse and fine sediment due to little or no boundary resistance.



Sediment and nutrient attenuation is occurring in many of the study reaches (26 of the 37 assessed segments) because the channel has retained much of its floodplain access. It is critical to prevent the destabilization of the existing sediment regime in these segments so that sediments and nutrients continue to be retained in the watershed, and not carried downstream to Lake Champlain.

Much of the stream channel in the Upper Missisquoi River has a balanced sediment regime (in=out) with floodplain access. Stream sections with unbalanced sediment regimes and lack of access to historic floodplains will seek to re-establish equilibrium causing widening of channels and lateral migration until able to rebalance the power of the water in the channel with the amount of sediment being moved. Hence, it is important to identify areas where sediment and nutrients can be stored downstream of these reaches within the Upper Missisquoi River watershed.

Figure 68. Sediment Regime Map

Table 7. Sediment Regimes in the Upper Missisquoi River

Sediment Regime	Stage of Channel Evolution/Geomorphic Condition	Common Existing Stream Type	Delimiting criteria related to sediment supply, transport, and storage	Natural Valley Type
Transport	Stage I or V Good-Ref	A1, A2, B1, B2, G1, G2, G3, F1, F2, F3	Bedrock gorge= yes	NC, SC, NW
	Stage I or V	A3, B3, B4	Incision ratio <1.3	NC, SC, NW
Confined Source and Transport	Stage II-IV Fair-Good	A3,B3	Incision ratio >1.3	NC, SC, NW
	Stage II-IV Fair-Good	A4, A5, B4, B5	Incision ratio >1.3	Any Type
Fine Source and Transport & Coarse Deposition	Stage II-IV Fair-Poor	E3, E4, E5 C3, C4, C5, B3c, B4c, B5c, F3, F4, F5	Bank armor < 50% W/d > 30 Incision ratio $\geq$ 1.3	NW, BD, VB
	Stage II-IV Fair-Poor	D3, D4, D5	Bank armor < 50% Incision ratio $\geq$ 1.3	NW, BD, VB
Coarse Equilibrium (in = out) & Fine Deposition	Stage I or V Fair-Good-Ref	D3, D4, D5	Incision ratio < 1.3	NW, BD, VB
	Stage I or V Fair-Good-Ref	C2, C3, E3	W/d < 30 Incision ratio < 1.3	NW, BD, VB

Phase 2 work assessed all reaches of the Upper Missisquoi River as being at Stage I to IV of channel evolution (Table 7). Schumm (1977 and 1984) has described five stages of channel evolution (F-stage model) for reaches such as those found in the study area, where the stream has a bed and banks that are sufficiently erodible to be shaped by the stream over time, paraphrased from the SGA protocols (VTANR 2009, Appendix C) as follows:

I. Stable – in regime, reference to good condition. Insignificant to minimal adjustment; planform is moderate to highly sinuous.

II. Incision – Fair to poor condition, major to extreme channel degradation. High flow events are contained in the channel, and channel slope is typically increased.

III. Widening/Migration – Fair to poor condition, major to extreme widening and aggradation.

IV. Stabilizing – Fair to good condition, major reducing to minor aggradation, widening and planform adjustments

V. Stable – In regime, reference to good condition. Insignificant to minimal adjustment.

Table 8. Current Sediment Regimes in the Upper Missisquoi River Phase 2 Study Reaches

Segment ID/ Sediment Regime	Stage of Channel Evolution/Geomorphic Condition	Common Existing Stream Type	Delimiting criteria related to sediment supply, transport, and storage	Natural Valley Type
R23	Stage I: Fair	C5	Incision Ratio: 1.05 W/D Ratio: 35.4	VB
R25-A	Stage I: Fair	C5	Incision Ratio: 1.0 W/D Ratio: 18.95	BD
R25-B	Stage I: Fair	C4	Incision Ratio: 1.1 W/D Ratio: 17.0	NW
R27	Stage IV: Fair	C4	Incision Ratio: 1.27 W/D Ratio:33.3	NW
R28	Stage III: Fair	C4	Incision Ratio: 1.2 W/D Ratio: 19.3	BD
R29	Stage I: Good	C4	Incision Ratio: 1.1 W/D Ratio: 17.0 Incision Ratio HEF: 1.2	BD
R33	Stage III: Fair	C5	Incision Ratio: 1.1 W/D Ratio: 18.8	BD
R34-A	Stage I: Good	C4	Incision Ratio: 1.0 W/D Ratio: 12.9	BD
R34-B	NA	NA	Incision Ratio: NA W/D Ratio: NA	SC
R34-C	NA	NA	Incision Ratio: NA W/D Ratio: NA	NW
R34-D	Stage I: Good	C4	Incision Ratio: 1.1 W/D Ratio: 14.5	BD
R35-A	Stage III: Fair	C5	Incision Ratio: 1.3 W/D Ratio: 12.9	VB
R35-B	Stage IV: Good	C4	Incision Ratio: 1.3 W/D Ratio: 22.7	VB
R35 T3.01-A	Stage III: Fair	E4	Incision Ratio: 1.4 W/D Ratio: 7.7	VB
R35 T3.01-B	Stage III: Fair	E5	Incision Ratio: 1.5 W/D Ratio: 8.0	VB
R35T3.1 S1.01-A	Stage I: Fair	C4	Incision Ratio: 1.0 W/D Ratio: 21.1	VB
R35T3.1 S1.01-B	Stage II: Fair	E3	Incision Ratio: 1.9 W/D Ratio: 9.2	VB
R36	Stage III: Fair	C4	Incision Ratio: 1.2 W/D Ratio: 15.7 Incision Ratio HEF: 1.4	BD
R37-A	Stage III: Fair	C4	Incision Ratio: 1.2 W/D Ratio: 16.1	VB
R37-B	Stage I: Good	C4	Incision Ratio: 1.0 W/D Ratio: 26.3	BD
R38-A	Stage I : Good	C4	Incision Ratio: 1.1 W/D Ratio: 14.4 Incision Ratio HEF: 1.3	BD
R38-B	Stage I: Fair	C4	Incision Ratio: 1.2 W/D Ratio: 24.6	VB
R40	Stage I: Fair	C4	Incision Ratio: 1.3 W/D Ratio: 19.1	BD
R41	Stage IV: Fair	C4	Incision Ratio: 1.3 W/D Ratio: 36.2	VB

R42	Stage I: Good	C4	Incision Ratio: 1.0 W/D Ratio: 14.5	SC
R43	Stage I: Fair	C4	Incision Ratio: 1.1 W/D Ratio: 12.7	VB
R44-A	Stage I: Good	C4	Incision Ratio: 1.1 W/D Ratio: 12.7	BD
R44-B	Stage I: Good	G2	Incision Ratio: 1.0 W/D Ratio: 8.4	SC
R44-C	Stage I: Good	E4	Incision Ratio: 1.0 W/D Ratio: 11.1	SC
R44-D	Stage IV: Good	B3	Incision Ratio: 1.8 W/D Ratio: 12.1	NC
R44-E	NA	C4	Incision Ratio: NA W/D Ratio: NA	BD
R44 T6.01-A	Stage I: Fair	C4	Incision Ratio: 1.0 W/D Ratio: 16.7	BD
R44 T6.01-B	Stage IV: Fair	B3	Incision Ratio: 1.2 W/D Ratio: 22.1	SC
R45-A	Stage I: Fair	C4	Incision Ratio: 1.0 W/D Ratio: 18.4	VB
R45-B	Stage III: Fair	C4	Incision Ratio: 1.6 W/D Ratio: 12.7	VB
R45C	Stage I: Fair	C4	Incision Ratio: 1.0 W/D Ratio: 24.6	VB
R46	Stage IV: Fair	C4	Incision Ratio: 1.5 W/D Ratio: 25.6	BD
R47-A	Stage IV: Fair	C4	Incision Ratio: 1.2 W/D Ratio: 15.9	VB
R47-B	Stage I: Fair	C4	Incision Ratio: 1.0 W/D Ratio: 29.5	VB

Under the existing sediment regime, which includes limited floodplain access and increased stream power in eight of the assessed segments, erosion, widening, and lateral migration are likely to increase when sediment load exceeds carrying capacity in the Upper Missisquoi River watershed, until channel geometry changes sufficiently to decrease stream power in these segments.

The primary lateral constraints to stream processes identified in both Phase 1 and Phase 2 work on the Upper Missisquoi River are road and residential development encroachment in the river corridor, undersized bridges and culverts, and maintenance of highly-valued agricultural resources along the river corridor. Given the existing sediment transport regime and stage of channel evolution of reaches in the study area, likely entailing increased erosion and widening as the river attempts to reestablish equilibrium with the increased stream power, restoration of floodplain access would be a critical component in re-establishing a reference sediment regime. Identification of “attenuation assets” to accommodate high flows and sediment deposition would include areas where the river can be allowed to reestablish meanders (rather than being straightened) as well as access to the floodplain.

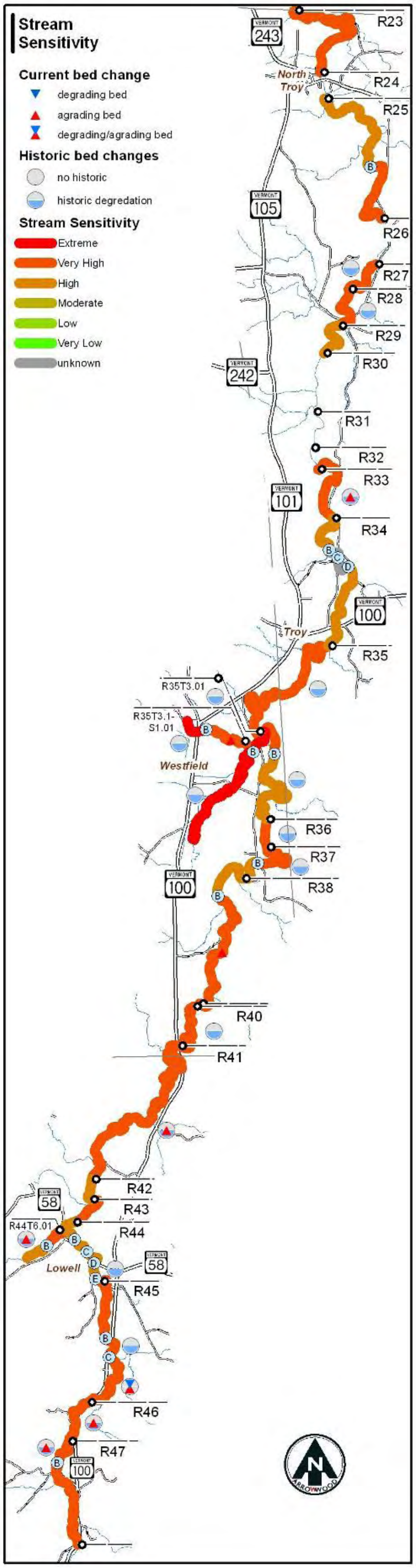
The following Departure Analysis Table indicates where stream segments are constrained from adjustment, converted to transport streams, and/or have existing or future potential as a place to attenuate sediment load. The table is used to identify priority reaches for river corridor conservation. The Table shows that the following segments of the Upper Missisquoi River have existing and future potential to be important attenuation assets within the watershed: R23, R25A, R27, R28, R29, R35B, R35T3.1S1.01A, R37A, R37B, R38B, R40, R42, R43, R44C, R44E, R45C, R47A and R47B.

Table 9. Departure Analysis Table

	Constraints		**Sediment Transport-Type Stream**		**Attenuation (storage type stream)**		
River Segment	Vertical	Lateral	Natural Transport Type	Converted by Human Constraints	Natural Deposition Zone	Increased Sediment Supply	Asset to Future Deposition
R23		Agriculture			X		X
R25-A		Agriculture			X		X
R25-B		Agriculture Old Abutment Roads Berm			X		
R27	Ledge				X		X
R28		Agriculture Development Undersized Bridge			X		X
R29		Agriculture Berm			X		X
R33		Agriculture Development Berm			X	X	
R34-A		Agriculture Berm Bridge (not undersized) Old Abutment			X		
R34-B	Waterfall ROR Dam		X				
R34-C		Agriculture Bridge (not undersized)			X		

	Constraints		Sediment Transport-Type Stream		Attenuation (storage type stream)		
River Segment	Vertical	Lateral	Natural Transport Type	Converted by Human Constraints	Natural Deposition Zone	Increased Sediment Supply	Asset to Future Deposition
R34-D	Ledge	Agriculture Development Bedrock Outcrops Bridge (not undersized)			X		
R35-A		Agriculture Roads Development Bridge (not undersized) Old Abutment		X	X		
R35-B		Agriculture Development Undersized Bridge			X		X
R35 T3.01-A		Agriculture Undersized Culvert		X	X		
R35 T3.01-B		Agriculture Undersized Culvert		X	X		
R35T3.1 S1.01-A		Agriculture			X		X
R35T3.1 S1.01-B		Agriculture Development 1 Bridge (not undersized) 2 Undersized Bridges 1 Undersized Culvert		X	X		
R36		Agriculture Berm			X		
R37-A		Agriculture			X		X
R37-B		Undersized Bridge			X		X
R38-A		Agriculture Berm			X		
R38-B		Agriculture Undersized Bridge			X		X
R40		Agriculture			X		X
R41		Agriculture Roads Development 3 Undersized Bridges Old Abutment		X	X	X	
R42		Agriculture			X		X

	Constraints		Sediment Transport-Type Stream		Attenuation (storage type stream)		
River Segment	Vertical	Lateral	Natural Transport Type	Converted by Human Constraints	Natural Deposition Zone	Increased Sediment Supply	Asset to Future Deposition
R43		Agriculture			X		X
R44-A		Agriculture			X		
R44-B	Waterfall		X				
R44-C		Undersized Bridge			X		X
R44-D	Ledge Dam	Development		X			
R44-E		Roads Development			X		X
R44 T6.01-A		Agriculture Undersized Bridge	X				
R44 T6.01-B					X	X	X
R45-A		Agriculture Roads Development Berm Undersized Bridge			X		
R45-B	Ledge	Agriculture Roads Development Berm Undersized Bridge		X	X		
R45-C		Agriculture Roads 2 Undersized Bridges			X	X	X
R46		Roads Development 1 Undersized Bridge		X	X	X	
R47-A	Ledge	Agriculture Roads Development 2 Undersized Bridges			X	X	X
R47-B	Ledge	Agriculture Roads Undersized Bridge Undersized Culvert			X		X



5.2 *SENSITIVITY ANALYSIS*

The preceding departure analysis identifies the watershed and reach scale stressors that help explain the sediment regime departure currently existing in several reaches of Upper Missisquoi River. Designing stream corridor protection and restoration projects that are compatible with channel evolution processes, and prioritizing them at the watershed scale, also requires an understanding of stream sensitivity.

Sensitivity refers to the likelihood that a stream will respond to a watershed or local disturbance or stressor, and an indication as to the potential rate of channel evolution (VTANR 2009, Phase 2 Step 7.7). While every stream changes in time, a sensitivity rating indicates that some streams, due to their setting and location within the watershed, are more likely to be in a state of change or adjustment (VTANR 2009, Phase 3 Step 6.2).

Alteration of sediment and flow regimes that have converted seven of the Upper Missisquoi River study reaches to an unconfined source and transport sediment regime and one to a confined source and transport sediment regime where the channel may experience erosion and supply both coarse or fine sediment during channel widening have led to conditions in which all stream segments are highly to extremely sensitive. These high levels of sensitivity may result in rapid

Figure 69. Stream Sensitivity Map

these systems.

6.0 PRELIMINARY PROJECT IDENTICATION AND PRIORITIZATION

The preceding departure and sensitivity analysis provides the watershed and reach scale background to guide prioritization and selection of projects in a manner that maximizes their effectiveness and reduces the likelihood of failure, specifically by assessing the underlying causes of channel instability. With the information from these maps and tables, a step-wise process has been conducted to identify the following actions, in order of priority, in a manner designed to facilitate restoration of the stream to equilibrium conditions (VTANR 2010):

Step 6.1. Protect River Corridors
Step 6.2. Plant Stream Buffers
Step 6.3. Stabilize Stream Banks
Step 6.4. Arrest head cuts and nick points
Step 6.5. Remove Berms and other constraints to flood and sediment load attenuation
Step 6.6. Remove/Replace Structures (e.g. undersized culverts, constrictions, low dams)
Step 6.7. Restore Incised Reaches
Step 6.8. Restore Aggraded Reaches

As indicated in Section 5.2 of this report, the high to extreme sensitivity of most of the reaches in the Upper Missisquoi River study area indicates that passive geomorphic projects is generally an appropriate management alternative. This places a very high priority, throughout the study area, on the first two items identified in the stepwise procedure above.

6.1 SITE-LEVEL PROJECT IDENTIFICATION

The site-level projects developed for the assessed reaches of the Upper Missisquoi River watershed are provided in Table 10 in the attachment. The project strategy and priority for each project are listed by project number and reach/segment. A total of one-hundred ten (110) projects were identified to promote the restoration or protection of channel stability and aquatic habitat. The table summarizes key information for each project, including the site stressors and constraints, project strategy, priority, and potential partners.

The project locations identified for the study area are included on reach maps in the attachment. The one-hundred ten (110) projects are further broken down by category as follows: Fifty-seven (57) active geomorphic restoration projects; fifty-three (53) passive geomorphic restoration projects. The Preliminary Project Identification and Prioritization Table 10 is provided in the attachment.

This Corridor Plan encourages coordination of landowner and municipal efforts to approach restoration with an eye to watershed scale dynamics. The Missisquoi River Basin Association and local conservation commissions can play a critical role in coordinating restoration efforts, and this report aims to facilitate such coordination in a way that can help landowners understand the part their properties play within the context of the entire watershed.

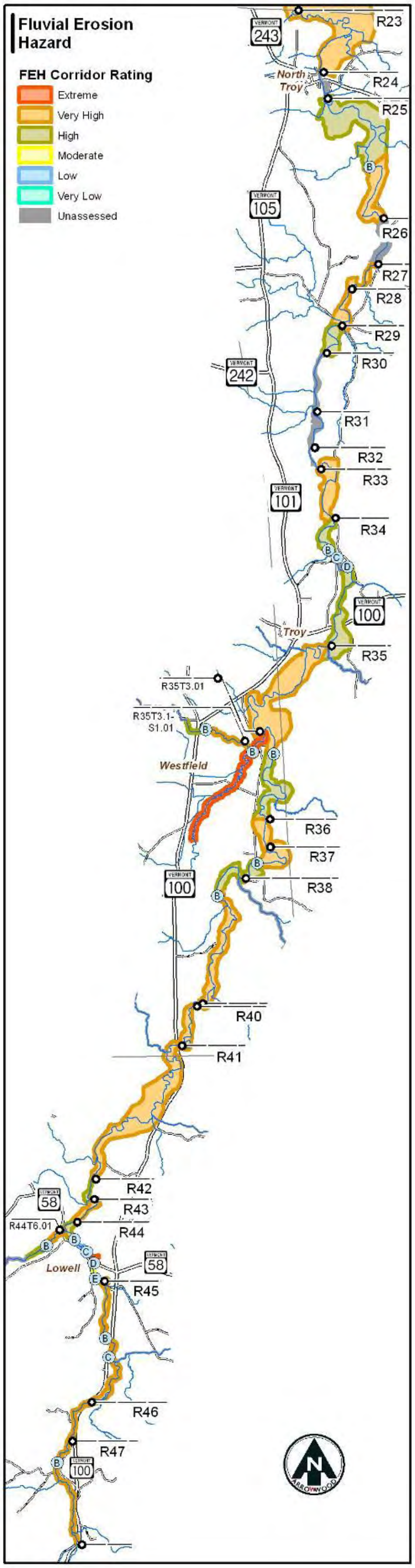
6.2 WATERSHED STRATEGIES

6.2.1 FLOODPLAIN AND RIVER CORRIDOR PLANNING AND PROTECTION

Several strategies can be used by state agencies and municipalities to reduce human conflicts with the river. The first strategy, planning and zoning to minimize future encroachment, includes tools such as participation in the National Flood Insurance Program, fluvial erosion hazard protection areas, and corridor-based zoning ordinances.

The towns of Jay, Troy, Westfield and Lowell all have local zoning regulations and a town plan. Each of the towns has identified in their respective town plan the significance of surface waters and intent to protect and manage these natural resources. The towns each participate in the National Flood Insurance Program, but have not established fluvial erosion hazard protection areas or corridor-based zoning ordinances.

The National Flood Insurance Program (NFIP) was created by Congress through the National Flood Insurance Act of 1968. It enables property owners in participating communities to purchase insurance protection against flood related losses (inundation hazards). The insurance provides an alternative to disaster assistance by covering damage repairs to buildings and their contents. Participation in the NFIP is based on an agreement between the Federal Government and local communities that states the Federal Government will make flood insurance available if a community adopts and enforces a floodplain management ordinance to reduce flood risks to



new construction in Special Flood Hazard Areas (SFHA). The SFHAs and other risk premium zones that affect participating communities are depicted on Flood Insurance Rate Maps. The Mitigation Division within the Federal Emergency Management Agency manages the NFIP, and oversees the floodplain management and mapping components of the Program (http://www.fema.gov/business/nfip/).

Mapping of Fluvial erosion hazard (FEH) protection areas uses the geomorphic data collected in Phases I and II to rate the erosion hazards in the zone along the Upper Missisquoi River based on the predicted movement of the river (http://www.anr.state.vt.us/ cleanandclear/rivstrm.htm). Mapping of FEH protection areas was completed for the Upper Missisquoi River by Arrowwood Environmental in the spring of 2011. The RMP has not yet conducted a formal QA review of the data and therefore, the map is still in draft form. Upon approval, the Upper Missisquoi River FEH Protection Areas map can be made available to the towns in the Project Area. In each town, corridor-based municipal zoning ordinances can be considered as a means to limit encroachment and landuse conflicts within the FEH zones identified.

Figure 72 . Draft FEH Protection Areas Map

6.2.2 BUFFER ESTABLISHMENT AND PROTECTION

Stream buffer planting is a high priority in sensitive reaches that are vertically stable. The study reaches of the Upper Missisquoi River are in Stages I, II, III, and IV of channel evolution, with the reaches in Stages II and III actively adjusting. Stream buffer plantings are generally recommended in all areas with less than 25' of naturally vegetated buffer. Due to the instability of reaches in Stage II and III of channel evolution, planting of vegetation on the immediate stream banks is not a high priority project. Plantings within the corridor, set back from the streambanks, are a high priority in these reaches. The reaches in Stage I and Stage IV are relatively stable with varying amounts of erosion and poor stream buffers. Planting of streambanks and buffers is a high priority in these reaches.

The following table presents the buffer projects which would likely be subsumed within and designed as part of a larger corridor protection and/or restoration project:

Table 11. Combination Buffer Planting and Corridor Conservation Projects

Reach ID	Stream Sensitivity	Stage of Channel Evolution/ Geomorphic Condition	Recommended Corridor Protection Project
R23	Very High	Stage I: Fair	Yes
R25-A	High	Stage I: Fair	Yes
R25-B	Very High	Stage I: Fair	Yes
R28	Very High	Stage III: Fair	Yes
R29	High	Stage I: Good	Yes
R35-B	High	Stage IV: Good	Yes
R35T3.1S1.01-A	Very High	Stage I: Fair	Yes
R38-B	Very High	Stage I: Fair	Yes
R40	Very High	Stage I: Fair	Yes
R42	High	Stage I: Good	Yes
R43	Very High	Stage I: Fair	Yes
R44-C	High	Stage I: Good	Yes
R44-E	NA	NA	Yes
R45C	Very High	Stage I: Fair	Yes
R46	Very High	Stage IV: Fair	Yes
R47-A	Very High	Stage IV: Fair	Yes
R47-B	Very High	Stage I: Fair	Yes

The following table presents the buffer projects within reaches likely to undergo planform change where plantings are recommended set back from the stream bank and within the river corridor:

Table 12. Buffer Planting Projects in Active Segments

Reach ID	Stream Sensitivity	Stage of Channel Evolution/ Geomorphic Condition
R28	Very High	Stage III: Fair
R33	Very High	Stage III: Fair
R35-A	Very High	Stage III: Fair
R35 T3.01-A	Extreme	Stage III: Fair
R35 T3.01-B	Extreme	Stage III: Fair
R35T3.1 S1.01-B	High	Stage II: Fair
R36	Very High	Stage III: Fair
R37-A	Very High	Stage III: Fair
R45-B	Very High	Stage III: Fair
R46	Very High	Stage IV: Fair

The following table presents buffer projects within reaches unlikely to undergo planform and prioritized projects based on stream sensitivity, opportunity to decrease sediment loading and opportunity to increase buffer connectivity. Ranking priority scale of low (1) to high (10):

Table 13. Priority Buffer Planting Projects in Stable Segments

Reach ID	Stream Sensitivity	Stage of Channel Evolution/ Geomorphic Condition	Sediment and Runoff Potential from Adjoining Landuses	Opportunity to Increase Buffer Connectivity	Project Ranking
R34-A	High	Stage I: Good	Mod	Mod	5
R34-D	High	Stage I: Good	High	High	4
R37-B	High	Stage I: Good	Low	Low	6
R38-A	High	Stage I : Good	Mod	Mod	6
R44-A	High	Stage I: Good	High	High	3
R44 T6.01-A	Very High	Stage I: Fair	Mod	Low	2
R45-A	Very High	Stage I: Fair	High	Mod	1

Locations of invasive plant species were inventoried and mapped for the study reaches. Locations of species populations identified during the field assessments are included on the attached reach maps. Invasive plant species removal and/or control are difficult tasks. There are various methods of control and possibly eradication including chemical treatments, biological and mechanical or manual removal. Any option likely involves multiple treatments over many years. This topic is included in the method of planting stream buffers because ideally the invasive species treatment would involve a step of planting native species in treatment areas. The Nature Conservancy and the Natural Resources Conservation Service are good resources for projects contemplating invasive species control and/or removal.

6.2.3 ROAD-STREAM CROSSING RETROFITS AND REPLACEMENTS

Bridges and culverts improperly sized at a stream crossing often modify natural channel dimensions and disrupt hydrology and sediment transport. Structures which are incompatible with stream geomorphology may fail due to excessive erosion around the structure and/or lead to disequilibrium in the reach. Undersized bridges and culverts can also prevent fish and wildlife movement resulting in loss of resident populations. A significant number of the bridges and culverts in the study reaches are currently undersized and causing various problems such as upstream deposition, excessive erosion, downstream bed degradation, and aquatic organism passage (AOP) problems. As these structures come up for replacement at the municipal level, it is important to resize them to accommodate the expected discharge and sediment loads and to place them in proper alignment with the stream channel. (VTANR, 2010)

Summary data for all structures in the study reaches was entered into the online DMS. In order to make use of the VTANR culvert screening tools for structure prioritization, Table 14 summarizes data collected for twenty-seven (27) crossings in the study reaches. There are twenty-three (23) undersized bridges and culverts in the study area serving as constrictions of the stream channel. The final column of the table includes a prioritization of structures for replacement or retrofit based on a review of the following three criteria: structure width in relation to bankfull channel width; aquatic organism passage (culverts only); and geomorphic compatibility (culverts only). Removing or replacing structures is a high priority for structures no longer in use or structures that contribute to a significant increase in erosion hazard or structures likely to result in channel avulsion during a storm event.

Table 14. Bridge and Culvert Summary Data Table

Segment ID	Town	Type	Road Name	Bankfull Width Percent	AOP Coarse Screen	AOP Geomorphic Compatibility	AOP Priority	Project Priority
R47B	Lowell	Culvert	Rte 100	36	**Reduced AOP**	**Mostly Incompatible**	**MLL**	**High**
R35T3.01 S1.01 B	Westfield	Culvert	Campground Dr.	15	**Reduced AOP**	**Mostly Incompatible**	**LLL**	**High**
R35T3.01B	Westfield	Culvert	Cemetery Rd	85	**Reduced AOP**	**Partially Compatible**	**HHM**	**High**
R35T3.01A	Westfield	Culvert	Loop Road	94	**Reduced AOP**	**Partially Compatible**	**HHM**	**Mod**
R35-A	Troy	Bridge	Lane Road	121	--	--	--	**Low**
R34-C	Troy	Bridge	River Road	NA	--	--	--	**Low**
R37-B	Westfield	Bridge	Loop Road	66	--	--	--	**Mod**
R44-C	Lowell	Bridge	Hazen Notch Road	92	--	--	--	**Mod**
R44T6.01-A	Lowell	Bridge	Hazen Notch Road	55	--	--	--	**High**
R45-A	Lowell	Bridge	Lower Village Road	87	--	--	--	**Mod**
R46	Lowell	Bridge	Rickaby Road	43	--	--	--	**High**
R47-B	Lowell	Bridge	Cheney Road	93	--	--	--	**High**
R28	Troy	Bridge	Vielleux Road	77	--	--	--	**Low**
R45-C	Lowell	Bridge	Rte 100	98	--	--	--	**Low**
R34-D	Troy	Bridge	Rte 100	140	--	--	--	**Low**
R35T3.1 S1.01-B	Westfield	Bridge	Rte 100	88	--	--	--	**High**
R41	Westfield	Bridge	Rte 100	75	--	--	--	**Mod**
R45-B	Lowell	Bridge	Rte 100	64	--	--	--	**High**
R41	Lowell	Bridge	Farm Road	26	--	--	--	**High**
R35T3.1 S1.01-B	Westfield	Bridge	Trail	163	--	--	--	**Low**
R41	Lowell	Bridge	Trail	70	--	--	--	**Mod**
R35T3.1 S1.01-B	Westfield	Bridge	Trail	85	--	--	--	**Low**
R45-C	Lowell	Bridge	Trail	73	--	--	--	**High**
R47-A	Lowell	Bridge	Private Drive	35	--	--	--	**High**
R38-B	Westfield	Bridge	Farm Road	72	--	--	--	**Mod**
R47-A	Lowell	Bridge	Pierce Road	30	--	--	--	**High**
R35-B	Troy	Bridge	Farm Road	36	--	--	--	**High**

Thirteen structures were identified during the Phase 2 field assessments as priority projects for repair or replacement. Evaluation of impacts of structure removal (including potential bank instability or channel bed elevation changes) upon corridor development and/or land use is recommended prior to project initiation. Structure locations are provided on the attached reach maps.

6.2.4 WETLAND RESTORATION

Wetlands have an important role in protecting the water quality of our rivers and lakes. Vermont has lost an estimated 35 percent of our wetlands since colonial times, with a corresponding decrease in water quality protection. However, in certain cases it is possible to restore impaired wetlands, bringing back their water quality protection function.

The following table provides a prioritization for potential wetland restoration projects within the Upper Missisquoi River study area. Within the table is presented the acres of potential wetland restoration area on a reach basis. This area was derived from the combination of hydric soils (NRCS soil survey data) and/or National Wetland Inventory mapped wetlands. Only reaches with greater than or equal to 1 acre of wetland restoration potential are included in the prioritization.

Table 15. Wetland Restoration Project Prioritization Table

Segment ID	Corridor Acreage	Potential Wetland Restoration Area (Acres)	Asset to Future Deposition	Project Ranking
R23	311.9	29	x	**1**
R25A	217.8	15	x	**2**
R25B	84.3	16		5
R27	20.0	4		7
R33	76.0	9		6
R34D	88.9	3		8
R36	31.3	4		7
R37B	20.9	3	x	3
R40	35.8	1	x	9
R42	8.1	3	x	3
R43	17.6	2	x	4
R44T6.01A	9.8	3		3
R44T6.01B	6.7	3	x	3
R46	12.4	2		9

As Table 13 shows, Reaches R23 and R25A have the greatest potential acreage identified for potential wetland restoration. Given the importance of these reaches as sediment and nutrient attenuation assets for the entire watershed, wetland restoration is both a watershed and reach priority for these reaches.

7.0 RECOMMENDATIONS FOR CORRIDOR PLAN UPDATES

It is recommended that periodic Upper Missisquoi River Corridor Plan updates be made, preferably at least every five years. These updates could include:

- Assessment of management strategies in light of project implementation
- Identification of additional reach and watershed scale management options
- Identification of public outreach and education efforts

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