Restoring Water Quality in the Lake Memphremagog Basin: River Corridor Plan for the Barton and Johns Rivers

Photo: Johns River at Lake Memphremagog, late summer 2008

Melissa Dyer
December 19, 2008

NorthWoods Stewardship Center

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NorthWoods Stewardship Center at a Glance

The NorthWoods Stewardship Center is a multi-disciplinary organization with a mission to foster long-term stewardship of human and natural communities. Through education and action, the Center strives to improve the region's natural resources while cultivating new generations of land stewards.

Founded in 1989 as the Vermont Leadership Center, the organization began by offering educational programs to local schools from its wooded site in the heart of Vermont's Northeast Kingdom. In 1995, the Vermont Leadership Center received its 501(c)(3) non-profit status and broadened its scope of service to three program areas: Education, Ecosystem Management and Conservation Service. In 2004, the Center changed its name to the NorthWoods Stewardship Center to better reflect its multidisciplinary programs as well as its multi-state service area. Today, NorthWoods is a dynamic organization that serves Northern Forest communities through environmental education, land management, conservation science, conservation service, and outdoor recreation programs.

NorthWoods is rooted in education, and NorthWoods' Education programs offer local and regional youth a wide array of hands-on learning experiences specifically designed to teach participants a land ethic and empower them with the knowledge and motivation necessary to take responsible action on behalf of themselves, their communities, and the natural world.

Through its Land Management offerings, NorthWoods is in a unique position to demonstrate and teach sustainable land management to landowners and land managers throughout the Northern Forest region.

Our Conservation Science efforts use research and monitoring to increase our understanding of humans and the natural environment in the Northern Forest by evaluating the health of Northern Forest ecosystems and assessing the impacts of local and regional human activities on these magnificent ecosystems.

The NorthWoods Conservation Corps represents our steadfast commitment to the next generation of land stewards. The Corps utilizes hands-on conservation work as a tool for teaching young people about the human and natural communities in which they live while working on projects that protect the environment, improve recreational opportunities, and ultimately strengthen our local communities.

Finally, through Outdoor Recreation, NorthWoods seeks to bring people in closer contact with the wonders of their natural environment while enjoying hikes through the woods, paddling down the Clyde River, or skiing or snowshoeing through the snowy woods.

Today NorthWoods Stewardship Center is broadening our reach from local to regional communities while continuing the programs that we do best: learning stewardship through ecological research and monitoring; teaching stewardship through educational and recreational offerings for students of all ages; and doing stewardship through demonstration forestry, landowner assistance, and the NorthWoods Conservation Corps. For further information on NorthWoods Stewardship Center, visit our website at www.northwoodscenter.org.

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River Corridor Plan for the Barton and Johns Rivers

Final Report for the 2007-2008 River Corridor Grant

Melissa Dyer
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fostering stewardship of human and natural communities

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1. Summary

The Barton and Johns River Stream Geomorphic Assessments are part of an on-going partnership between the NorthWoods Stewardship Center and the State of Vermont to identify non-point source pollution in the four main Vermont tributaries draining into Lake Memphremagog. A significant amount of water quality degradation stems from the over-nutrification of streams and lakes which is driven in large part by river instability. Beyond water quality degradation, river instability and accompanying river channel erosion, or adjustment, results in greater damage to public and private property during high flow events. This river corridor plan organizes and interprets the geomorphic assessment data to identify factors driving river instability and the means of mitigating those factors.

River stability and water quality are influenced by inputs from the surrounding watershed as well as the health of the river itself. For this reason, we have assessed land uses in the Barton and Johns Watersheds in addition to conducting detailed mapping and studies of the rivers themselves. In the Barton River Watershed, we have completed Phase 1 Stream Geomorphic Assessments on the entire Barton and Willoughby Rivers; from these, we completed 26.6 miles of Phase 2 field assessments. In the Johns River Watershed, we have completed Phase 1 assessments on 5.8 miles of the Johns River and one un-named tributary; from these, 4.6 miles received Phase 2 assessments.

Along the Barton River, a majority of the river corridor and the adjacent watershed lands are in high agricultural and urban land use. Nearly half (48%) of the study reaches are in some stage of channel evolution (mostly stage III). These reaches are reacting to a combination of historic events such as deforestation and the emptying of Runaway Pond, alterations to the stream channel, and current land use practices. Of the Barton River reaches which received Phase 2 assessments, approximately 28% are in reference condition, 35% are in good condition, and 37% are in fair condition.

In the case of the Willoughby River, portions of the corridor and adjacent watersheds contain high agricultural and urban land uses, but overall uses are lower than along the Barton River. Here, geomorphic conditions along most reaches are largely determined by natural large sediment inputs from valley side slopes adjacent to the stream corridor. Only one portion is undergoing major lateral adjustments; the remainder of the reaches are in stable condition. Approximately 92% of the assessed reaches are in good condition and 8% are in poor condition.

The Johns River corridor, in contrast to that of the Barton River, is only minimally impacted by urban and agricultural land uses with only a few exceptions. Channel alterations are uncommon as well. Much of the river is surrounded by wetlands which help deter farming and development. Agricultural and urban land uses within the entire watershed, however, are much higher than those found in the Memphremagog Watershed as a whole. These land uses likely explain the high sediment and nutrient levels afflicting this tributary. All reaches are stable; approximately 77% are in reference condition and 23% are in good condition.

Next Steps:

Our waterways are treasured resources which harbor important habitats, provide a multitude of recreational opportunities, and are extremely susceptible to degradation caused by watershed and channel alterations. To protect these resources, there is a need to ensure that reaches in reference condition are protected from future degradation while working to restore degraded reaches. Rivers are most stable when they can adjust to changes in average annual flow and average annual sediment loading associated with changing climate and land uses. Such adjustment occurs in the form of lateral migration which, by increasing or decreasing channel length, maintains a relatively constant stream power over time. When channels are prevented from adjusting laterally the stream power fluctuates wildly over time and constraining elements such as rip-rap, bridges, culverts, and roads are eventually destroyed by river erosion.

In 2009-2010, NorthWoods Stewardship Center will begin assessment work along the Black River while working to develop restoration and protection projects by reaching out to landowners throughout the Barton, Black, Clyde, and Johns Watersheds. Our outreach campaign will include educating local communities and landowners about the condition of the river and the various programs that help cover costs of protecting river corridors from encroachments that would ultimately lead to attempts to control the river and prevent it from moving. Programs such as the Conservation Reserve Enhancement Program (CREP), the Wildlife Habitat Incentives Program (WHIP), the Environmental Quality Incentives Program (EQIP), and Fluvial Erosion Hazard Management can all be utilized to protect river corridors, thereby maintaining river stability and water quality.

2. INTRODUCTION

2.1 PROJECT BACKGROUND AND MEMPHREMAGOG WATERSHED DESCRIPTION

This project continues our efforts to identify water quality threats within the Lake Memphremagog Basin, with the goal of prioritizing and implementing watershed protection and restoration projects. Lake Memphremagog is located in the Northeast Kingdom of Vermont and the Eastern Townships of Quebec. Most of the lake lies in Quebec, while about 71% of the lake's watershed is located in Vermont. The southern portion of the lake is fed by three major tributaries (Barton, Black, and Clyde Rivers) located in Vermont and one smaller tributary that straddles the Vermont/Quebec border (Johns River). These tributaries drain north into Lake Memphremagog, which flows into the St. Francis River before ultimately flowing into the St. Lawrence River.

Though a valued resource for recreation, drinking water, aquatic habitat, and other values, Lake Memphremagog currently faces a number of threats to water quality. Concern over sediment and nutrient inputs and the resulting eutrophication have motivated groups on both sides of the border to address non-point sources of pollution throughout the watershed. Blue-green algae (cyanobacteria) blooms, which are caused by high nutrient inputs, are a concern and can lead to beach closures. Lake Memphremagog and South Bay are listed by the State of Vermont as impaired surface waters needing a total maximum daily load (TMDL) due to high phosphorus levels, nutrient enrichment, and excessive algal growth (State of Vermont 2006a).

During 2005 and 2006, the NorthWoods Stewardship Center sampled water quality in the four Vermont tributaries (Gerhardt 2005, Dyer and Gerhardt 2007) for nitrogen, phosphorus, and sediment (Figure 1). While all watersheds contained areas of elevated phosphorus and sediment levels, the results indicate that water quality was poorest in the Johns River, intermediate in the Barton and Black Rivers, and best in the Clyde River. These levels originate from many point and non-point sources located throughout the Lake Memphremagog Watershed.

Non-point sources consist of multiple, diffuse pollution sources originating from many areas within the watershed and from a variety of landscapes. Precipitation flows over and through these landscapes carrying sediment, nutrients, and other contaminants into nearby waterways. Examples of non-point sources include agricultural fields, construction sites, roads, urban stormwater, mining, waste disposal, streambank erosion, atmospheric deposition, and septic systems. Even natural land cover types such as forests can be significant contributors of non-point source pollution, particularly when improper logging practices are used.

In 2006, we began a multi-year effort to identify sources of sediment in major tributaries within the Memphremagog Watershed, starting with Stream Geomorphic Assessments of the Clyde River Watershed. This study highlighted many areas throughout the watershed that are in excellent condition and that may require protection to preserve water quality and riparian habitat. The study also revealed areas which lack riparian vegetation and may require restoration.

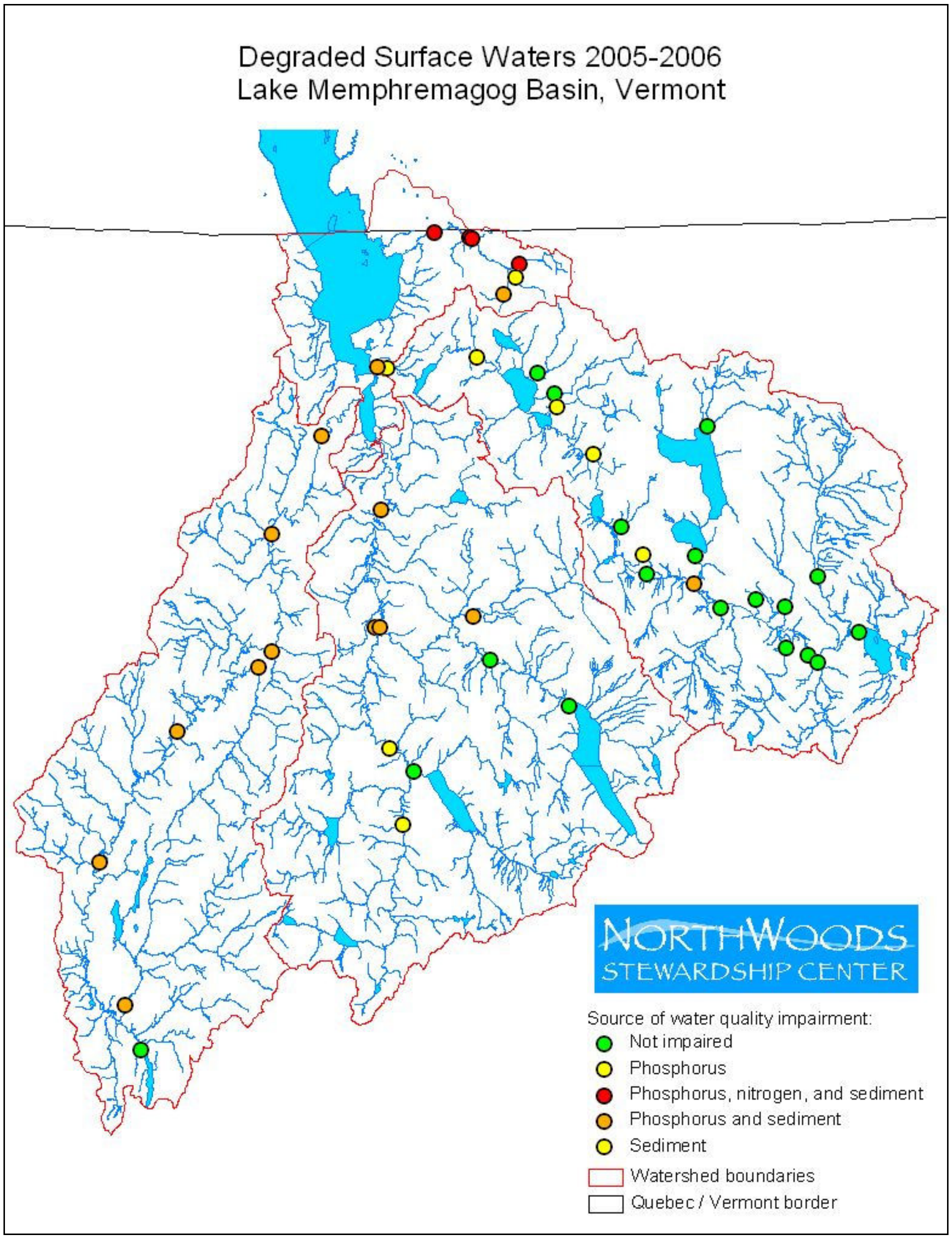


Figure 1. *Summary of water quality results for the four main Vermont tributaries to Lake Memphremagog, 2005-2006. Starting clockwise from the top are the John's, Clyde, Barton, and Black River Watersheds.*

2.2 PROJECT GOALS

The goal of the project described in this report was to identify sources of nutrients and sediment into the Barton and Johns Rivers and several of their tributaries by assessing the current health and stability of these waterways. For two years, NorthWoods Stewardship Center sampled water quality in tributaries throughout the Memphremagog Watershed, including the Barton and Johns River Watersheds (Gerhardt 2005, Dyer and Gerhardt 2007). These efforts identified areas of sediment and nutrient enrichment throughout the watershed. While the Clyde River contained low nutrient levels overall, levels in the remaining tributaries were significantly higher, particularly the Johns River. To address these nutrient inputs, we are continuing a multi-year project aimed at identifying specific sources of these nutrients.

Following protocols developed by the Vermont Agency of Natural Resources (ANR) River Management Program, we conducted Phase 1 and 2 Assessments on three tributaries to Lake Memphremagog. Phase 1 assessments were initial evaluations of the river corridor and its watershed using aerial photographs, topographic maps, and GIS databases. The Phase 2 assessments involved detailed fields surveys and measurements of selected reaches while wading or canoeing. From 2005-2007, we studied the Clyde River and several of its tributaries. From 2007-2008, we studied the Barton and Johns Rivers and several of their tributaries. The data gathered from these assessments has allowed an understanding of the overall condition and stability of the tributaries draining into Lake Memphremagog, their roles in delivering nutrients and sediment to the lake, and the degree to which humans have impacted their riparian habitats. This information will later be used to address and educate individual watershed communities and landowners about potential river restoration and protection projects aimed at increasing river stability and improving water quality and aquatic habitat.

3. METHODS

3.1 PHASE 1 ASSESSMENTS

The Stream Geomorphic Assessments were completed using protocols established by the Vermont Agency of Natural Resources (Vermont ANR; State of Vermont 2007b). The Phase 1 assessments were preliminary evaluations of selected reaches and sub-watersheds through three types of sources: remote sensing, other survey datasets, and brief “windshield” surveys. Most of the Phase 1 Assessment was completed using ArcView 3.2 (ESRI, Redlands, California) with the following data layers (additional details about the data collected and their sources are found in Appendix A):

<u>Remote Sensing Data:</u>
1:24,000 USGS topographic maps (1988)
1:62,500 USGS topographic maps (1925, 1953)
1:5,000 Aerial orthophotographs (1962, 1999)
1:80,000 Infrared aerial photographs (1977)
1:5,000 Vermont Hydrography Data Set
Land use – land cover maps (1990s)

<u>Existing Survey Data:</u>
NRCS digital soil survey maps (2005)
Vermont Significant Wetland Inventory maps (2006)
National Wetlands Inventory maps (1975-1978)

All streams within the Barton and Johns River Watersheds represented in the Vermont Hydrography Data Set (VHD) were divided into individual reaches and sub-watersheds (Figure 3). We then used the Stream Geomorphic

Assessment Tool (SGAT), a GIS extension developed by the Vermont ANR, to automatically associate all existing survey data with each individual sub-watershed. The data associated with each sub-watershed included the following:

Reach number and length
Valley length and width
Soil properties
Stream corridor land cover / land use
Watershed size
Geologic materials
Sub-watershed land cover / land use

Through evaluation of new and old topographic maps and aerial photographs as well as brief field visits, we described the following stream conditions:

Stream type / stream bed material
Valley side slopes
Stream migration
Meander belt width and wavelength
Presence of alluvial fans
Ground water inputs
Depositional features

In addition, we collected data describing human-caused modifications to the streams and their corridors:

Grade controls (dams)
Channel straightening
Bridges and culverts
Dredging / gravel mining history
Land use
Riparian buffer width
Floodplain encroachments
Development

All data were entered and archived in the Vermont ANR Data Management System (DMS) database. The DMS integrated all of the data and assigned impact ratings to each reach based on the degree of channel and floodplain modifications, and the degree to which the streams appeared to be responding to these modifications. These ratings were summed to calculate the overall reach condition rating, predicted adjustment scores, and reach sensitivities. These data sets were reviewed by River Management staff and any needed changes were noted in the DMS. The complete DMS datasets are available to the public at https://anrnode.anr.state.vt.us/ssl/sga/security/frmLogin.cfm.

Due to the nature of the stream geomorphic data collection process, several Phase 1 parameters were not evaluated on the more remote streams. In some instances a reach was not accessible from a road; in other instances only a small portion of a reach was viewable. Examples of such parameters included channel bedform, bed material, and ice and debris jam potential. In these instances NE (not evaluated) was written in the appropriate field in this report and in the DMS.

3.2 PHASE 2 ASSESSMENTS

The Phase 2 assessments consisted of in-depth mapping and evaluation of selected reaches and involved wading or canoeing entire reaches. Reaches were selected based on results of the Phase 1 assessment, with preference towards reaches that could potentially benefit from restoration or protection projects. The data collected included sketch maps, photographs, channel and floodplain measurements to document the condition of the stream itself and its adjacent floodplain. The following features were measured and mapped in the field:

Bank erosion
Channel straightening
Bank armoring
Floodplain development
Bridges and culverts
Floodplain encroachments
Riparian buffer width
Beaver dams
Debris jams
Stormwater inputs
Stream migration
Grade controls
Channel cross-sections
Pebble counts

Stream health was rated based on the stream's geomorphic and habitat conditions. These ratings were based on the field measurements listed above and upon other characteristics, including sediment deposition and erosion patterns, channel evolution stage, and degree of floodplain access. All of these features were mapped with the SGAT extension and are presented in the following pages of this report. Like the Phase 1 data, the complete Phase 2 datasets are available to the public in the DMS database.

3.3 QA/QC SUMMARY

This project was completed in accordance with an approved Quality Assurance Project Plan developed in conjunction with River Management Program (RMP) staff. As part of this plan, all GIS layers and data entered into the DMS were checked through the appropriate Quality Assurance procedures specified in the Stream Geomorphic Assessment Protocol Handbook (State of Vermont 2007b). In addition, DMS data were checked for blank fields and conflicting Phase 1 and Phase 2 data by NorthWoods' staff and RMP staff.

PART I
BARTON RIVER

4. BACKGROUND WATERSHED INFORMATION

4.1 GEOGRAPHIC SETTING

4.1.1 Barton River Watershed Description

The Barton River drains an area of approximately 164 mi^2, extending from its headwaters in the Town of Glover to its mouth at Lake Memphremagog's South Bay in Coventry (Figure 2). The watershed contains one large tributary watershed, the Willoughby River (62 mi^2), which drains from Lake Willoughby in the Town of Westmore and enters the Barton River in Orleans Village. Most lakes occur in the upper part of the watershed, including Lake Willoughby (1864 acres), Crystal Lake (772 acres), Parker Lake (253 acres), and Shadow Lake (217 acres).

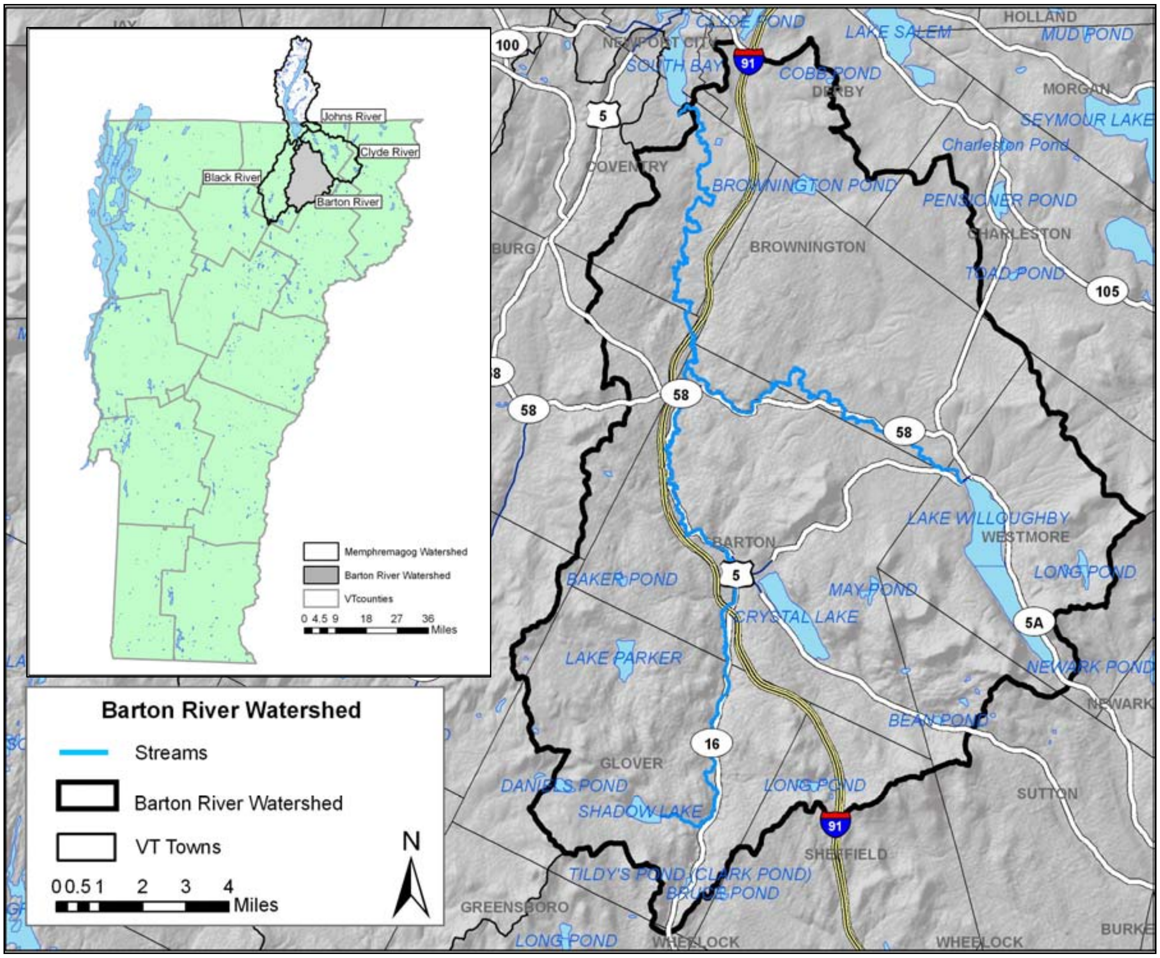


Figure 2. Map of the Barton River Watershed, one of the four principal Vermont tributaries to Lake Memphremagog (see inset).

4.1.2 Political Jurisdictions

The Barton River Watershed lies within Orleans and Caledonia counties in northeastern Vermont, and includes all or portions of the towns of Barton, Brownington, Charleston, Coventry, Derby, Glover, Irasburg, Sheffield, Sutton, and Westmore. The mainstem originates from Tildy's Pond in Glover; then travels north through the villages of Glover, Barton, and Orleans before emptying into Lake Memphremagog's South Bay (Figure 2). The river also passes through two state Wildlife Management Areas: 2.2 miles of the river flows through Willoughby Falls Wildlife Management Area in Orleans and 6.0 miles flow through South Bay Wildlife Management Area in Coventry.

4.1.3 Land Use History

Long before European settlement, the Barton River Watershed was inhabited by small population of Native Americans belonging to the broad eastern Abenaki cultural group, with established villages near Crystal Lake and Lake Willoughby. Both Native Americans and European settlers had utilized the Barton River as a transportation route to Montreal before the building of the railroad in the mid-1800s. The confluence of the Barton and Willoughby Rivers was an important junction along the route (Young 1998). After European settlement, numerous mills were built along the Barton River in Orleans and at Willoughby Falls. While a few mills were washed out in the 1927 floods, visible evidence of these sites remains on the Barton River.

Among the more dramatic events in the watershed's history was the emptying of Runaway Pond, formerly known as Long Pond, in 1810. Runaway Pond was located at the northeast corner of the Lamoille River Watershed in southern Glover. An outlet was located on its southern edge which drained into the Lamoille River. On June 6 a crew went to this pond to excavate a channel on its northern edge in order to provide additional flows to power a mill located on the Barton River. Suddenly the sand along the northern edge gave way, emptying the entire pond into the Barton River in a matter of minutes. Bridges and mills were destroyed, trees uprooted, and landowners found their fields covered in mud, log piles, and boulders up to ten feet deep (Young 1998). Today the former Runaway Pond is a meadow with a small stream flowing through it that is now the source of the Barton River.

4.2 GEOLOGIC SETTING

The majority of the Barton River Watershed lies within the Northern Vermont Piedmont biophysical region, with some portions in the vicinity of Crystal and Willoughby Lakes falling within the Northeastern Highlands. Elevations in the watershed range from 700 feet at Lake Memphremagog's South Bay to 3,315 feet at Bald Mountain in Westmore. The region is dominated by rolling hills, numerous lakes and ponds, and large wetlands in the vicinity of South Bay.

Much of the Barton River flows through an area formerly occupied by proglacial Lake Memphremagog, whose shoreline 12,000 years ago was approximately 300 feet higher than the current lake level (Stewart and MacClintock 1969). Glacial lake deposits of silt and clay dominate this valley. While the majority of the region's soils are derived from metamorphosed calcium-rich bedrock of the Waits River Formation, there are numerous erosion-resistant granitic areas which form many of the higher mountains, particularly in the Crystal and Willoughby Lakes areas.

4.3 GEOMORPHIC SETTING

4.3.1 Description and Mapped Location of the Assessed Reaches

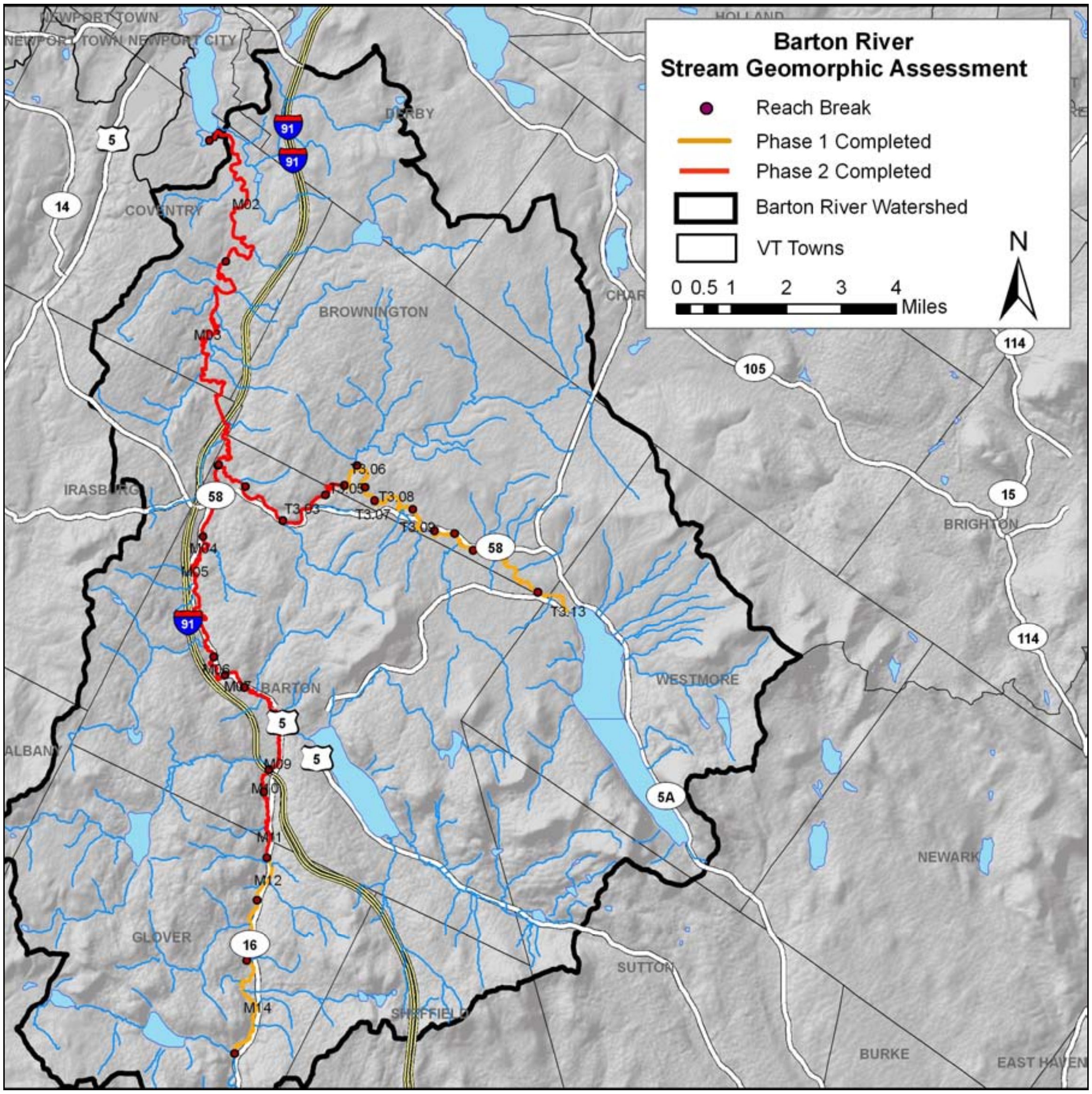


Figure 3. *Assessed and numbered reaches in the Barton River Watershed. Phase 1 Assessments (yellow and red) were completed on 27 reaches and totaled 40.5 river miles; Phase 2 Assessments (red only) were completed on 14 reaches (totaling 26.6 river miles).*

The Barton River and most of its tributaries were divided into 425 reaches and subwatersheds using topographic maps and aerial photographs. Reaches on the Barton River mainstem were defined as part of a Phase 1 Assessment completed in 2004 by Greg Hennemuth of Lake Region Union High School. Each reach represents a section of stream with physical attributes that distinguish it from reaches immediately upstream and downstream. These attributes include valley width, valley slope, channel width, and sinuosity. The Barton River Phase 1 assessments were updated to current protocol standards and Phase 1 assessments were completed on the Willoughby River mainstem - a total of 27 reaches. Fourteen of these reaches received Phase 2 Assessments: the Barton River was assessed from the village of Glover to South Bay and the Willoughby River was assessed from the Center Road crossing in Brownington to its confluence with the Barton River in Orleans (Figure 3).

4.3.2 Longitudinal Profile, Alluvial Fans, and Natural Grade Controls

From its origin at Tildy's Pond in Glover (Reach M15), the Barton River begins as a slow, meandering stream traveling through narrow forested valleys, occasional farm fields, and alder wetlands, and at times splitting into multiple small channels. At 3.8 miles from its origin, the river changes to a steeper and more confined channel as it travels through forests and the village of Glover, dropping 326ft in elevation in the next 2.1 miles.

Downstream of Glover (Reach M11), river flows are slowed as it travels through a very broad valley of pastures, hayfields, and occasional forested stretches. The river flows over one bedrock ledge near the I-91 bridge before resuming its course through fields and the village of Barton. From Reach M11 through reach M08, the river drops only 20ft over 4.5 miles.

After the river crosses Route 5 downstream of Barton (Reach M07), its slope quickly increases as it cascades over numerous bedrock ledges and waterfalls in its confined, bedrock-dominated valley. After passing under two railroad bridges, dropping 40' in 0.55 miles, the valley widens and the river passes over several more ledges before the velocity and slope lessen at the next Route 5 crossing (Reach M05).

The Barton River then transitions again to a sandy-bottomed meandering river, travelling through crop and hay fields for the next 3.5 miles. At Reach M04, the Barton travels through Orleans Village, then quickly transitions to a steeper and confined channel just downstream of the villages. After cascading over several ledges, the river slope decreases as it meets the Willoughby River (T3) in a very broad, sandy valley.

From its confluence with the Willoughby River, the Barton becomes a slow, flatwater river for the next 11.9 miles, traveling through a very broad valley through old fields and floodplain forests before entering Lake Memphremagog's South Bay in Coventry (Reach M02).

4.3.3 Valley and Reference Stream Data

Using topographic maps and windshield surveys, data were collected to describe the valley setting for each reach, which determines the type of stream found there (Table 1). Stream types were assigned based on the Rosgen stream classification system (Appendix B). For example, C and E stream types were found in the wider valleys throughout the watershed (Figure 4), where the river deposits sediments on the adjacent floodplain. These stream types were found in river reaches with 0-2% slopes, and were the majority of stream types found along both the Barton and Willoughby Rivers. Faster, cascading B stream types were found in the confined valleys in a few locations in the watershed, where channel slopes exceeded 2%. Here sediment transport was the dominant regime, and these sediments are later deposited in the broad floodplains traversed along the way to the river's mouth at Lake Memphremagog.

Table 1. Valley and channel characteristics for the main stem of the Barton River (reaches M02-M11) and the Willoughby River (reaches T3.01-T3.13)

Reach	Channel Width (ft)	Channel Slope (%)	Sinuosity	Valley Type	Reference Stream Type*	Reference Stream Bedform*
M02	64	0.03	1.56	Very Broad	E	Dune-Ripple
M03	58	0.03	1.7	Very Broad	E	Dune-Ripple
M04	55	0.5	1.02	Semi-Confined	E	Dune-Ripple
M05	66	0.33	1.5	Very Broad	C	Riffle-Pool
M06	58	0.11	1	Narrow	C	Riffle-Pool
M07	54	1.36	1	Narrowly Confined	B	Bedrock
M08	51	0	1.46	Very Broad	C	Dune-Ripple
M09	44	0.42	1.14	Very Broad	E	Riffle-Pool
M10	56	0	1.1	Narrow	C	Riffle-Pool
M11	37	0.24	1.22	Very Broad	E	Riffle-Pool
M12	50	1.63	1.06	Very Broad	C	Riffle-Pool
M13	47	3.82	1.04	Broad	B	Step-Pool
M14	42	0.21	1.27	Very Broad	C	Riffle-Pool
M15	21	0	1.07	Very Broad	C	Dune-Ripple
T3.01	65	0.47	1.19	Very Broad	C	Riffle-Pool
T3.02	74	1.29	1.11	Broad	C	Riffle-Pool
T3.03	55	1.56	1.07	Semi-Confined	C	Riffle-Pool
T3.04	55	1.05	1.52	Semi-Confined	C	Plane Bed
T3.05	77.3	1.13	1.19	Semi-Confined	B	Riffle-Pool
T3.06	63.3	1.02	1.19	Semi-Confined	C	Riffle-Pool
T3.07	63.1	0	1	Semi-Confined	C	Riffle-Pool
T3.08	63	0.84	1.4	Semi-Confined	C	Riffle-Pool
T3.09	61.8	1.33	1	Narrow	C	Riffle-Pool
T3.10	60.5	0.7	1	Narrow	C	Riffle-Pool
T3.11	60.3	0	1.18	Very Broad	C	Riffle-Pool
T3.12	55.7	0.19	1.34	Very Broad	C	Riffle-Pool
T3.13	50.9	0	1.07	Very Broad	C	Dune-Ripple

*** See Appendix B for stream type descriptions**

Figure 4: *Most of the Barton River lies in a broad alluvial valley with C and E stream types (left), but portions cascade down confined valleys with B stream types (right).*

5. RESULTS AND DISCUSSION

5.1 IDENTIFICATION OF HYDROLOGIC AND SEDIMENT REGIME STRESSORS IN THE WATERSHED

5.1.1 Hydrologic Regime Stressors

Land Cover / Land Use

Natural land cover types (e.g. forests and 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 and snowmelt runoff by decreasing the amount of natural vegetation available to naturally filter water and sediment. Urban lands also contain impervious surfaces which quickly shed stormwater into adjacent drainages rather than slowly percolating it through the soil. The result is higher peak flood levels as well as high nutrient and sediment inputs. Consistently high stormwater runoff can cause a channel to enlarge, erode, and incise to accommodate high flows.

The southern and eastern fringes of the Barton River Watershed are mostly forested, particularly in the more mountainous Willoughby and Crystal Lake sub-watersheds (Figure 5). Today natural vegetation covers 70.8% of land in the watershed (Table 2). Agricultural land uses are spread evenly throughout the remainder of the watershed and comprise 16.9% of the land cover. Urban lands (including roads) comprise 5.5% of the watershed and are concentrated in four villages, all located along rivers: Barton and Orleans along the Barton River and Brownington and Evansville along the Willoughby River.

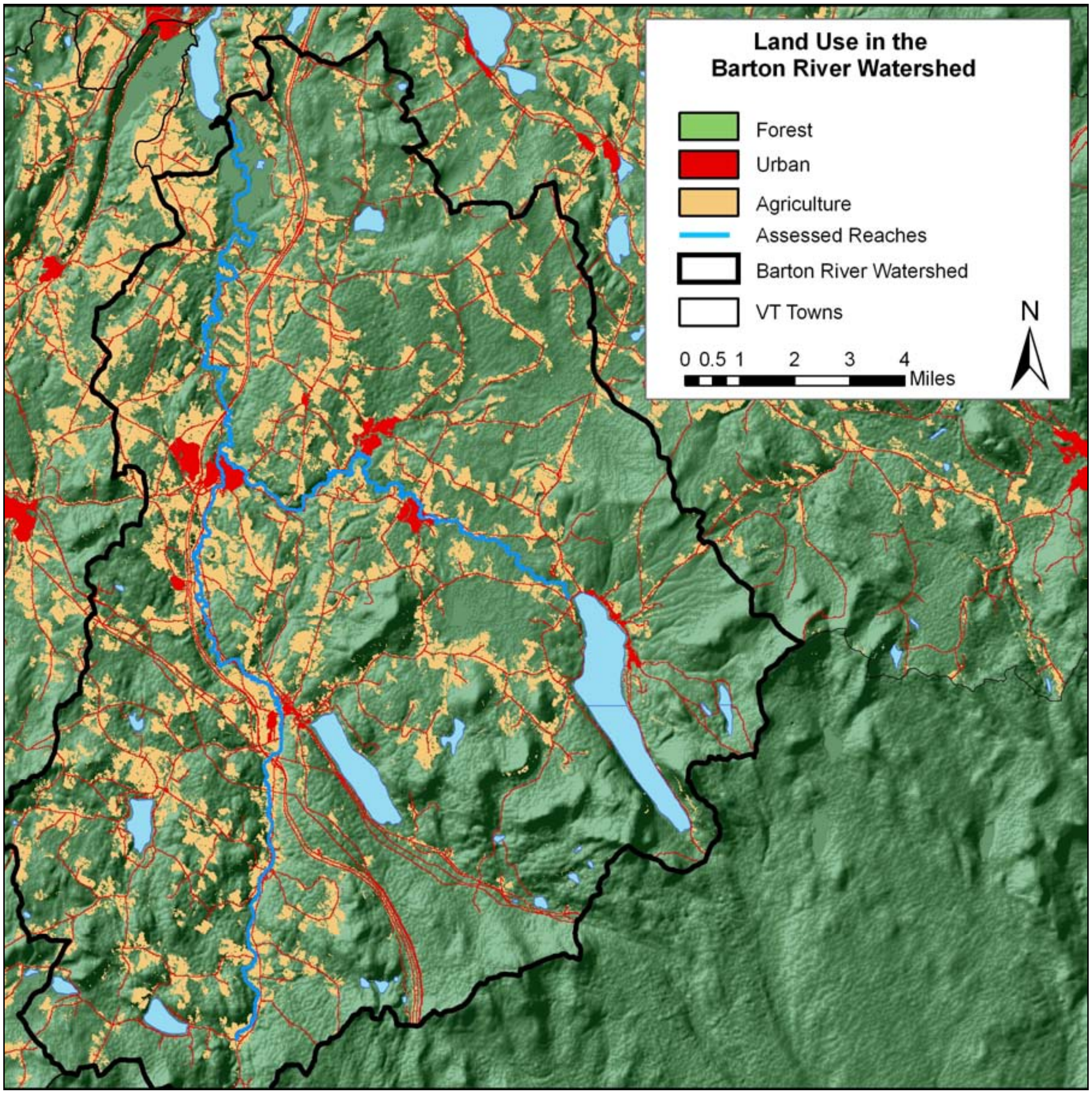


Figure 5. *Land Use in the Barton River Watershed, showing forested land, agricultural land (uses include hay, crops, and pasture) and urban land (includes residential, industrial, transportation, and commercial uses).*

Table 2. Summary of Land Uses in the Barton River Watershed

Land Use	Percentage of Watershed	
Broadleaf forest (generally deciduous)	24.0%	Forested or brush: 67.3%
Mixed coniferous-broadleaf forest	21.8%	
Coniferous forest (generally evergreen)	21.4%	
Brush or transitional between open and forested	0.2%	
Forested wetland	2.6%	Wetland: 3.5%
Non-forested wetland	0.9%	
Hay/rotation/permanent pasture	8.9%	Agriculture: 16.9%
Row crops (not including orchards and berries)	8.0%	
Other agricultural land	<0.1%	
Transportation, communication, and utilities	4.5%	Urban: 5.5%
Residential	1.0%	
Industrial	<0.1%	
Commercial, services, and institutional	<0.1%	
Outdoor and other urban and built-up land	<0.1%	
Water	6.8%	Other: 6.8%
Barren land	<0.1%	

Stormwater Inputs, Road Densities, and Urban Land Cover

Stormwater inputs were documented during the Phase 2 assessments in order to determine whether a reach may be responding to periodic high water flows during rain events. Examples of stormwater discharges include field and road ditches, tile drains, and urban stormwater inputs. These features move water quickly away from land surfaces and into stream channels. Reaches receiving many stormwater inputs may erode and enlarge to accommodate those sudden high flows. Stormwater inputs were infrequently encountered along the Barton and Willougby Rivers. The majority were found in reaches which passed through Orleans Village, which had a maximum of 11 inputs per river-mile. Many were also found in and around Barton Village (Figure 6).

Both gravel and paved roads affect the watershed like urban lands. All are impervious surfaces which shed water quickly into drainages rather than allowing it to slowly percolate through the soil, resulting in higher flows during precipitation events. Road densities were calculated based on the number of miles per area (in square miles). Values ranged from 0 miles/square mile to 23 miles/square mile. The highest densities exist around Orleans Village and around Barton to a lesser extent.

Cumulatively, urban land uses cover 5.5% of the watershed, however urban lands often occur in higher densities within stream corridors. Most of the Upper Willoughby reaches are undeveloped though development increases as one travels downstream (Figure 6). The opposite is true for the Barton River, where corridor development is highest in the middle and upper reaches and lowest in the twelve miles before the river enters Lake Memphremagog.

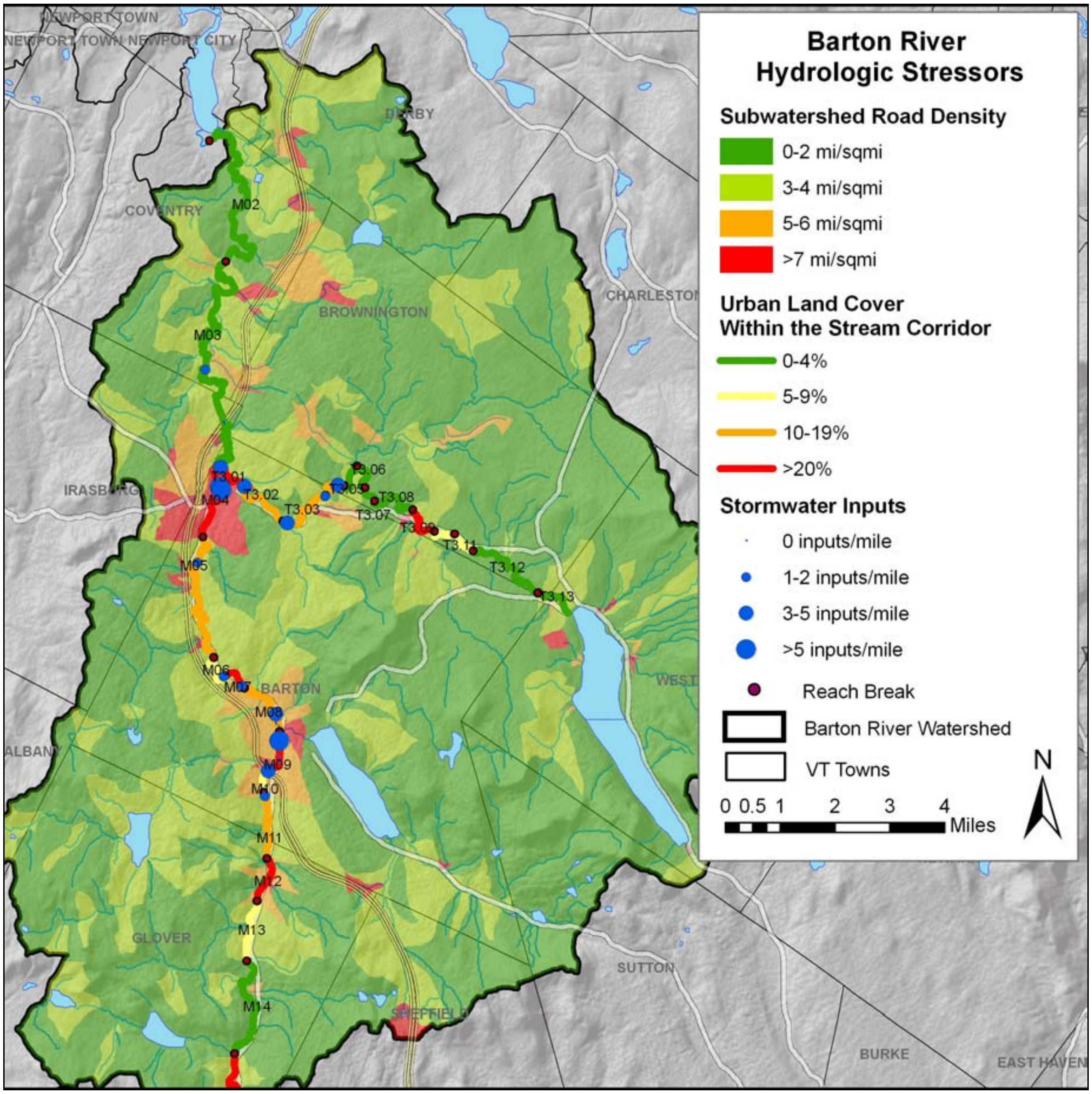


Figure 6. *Hydrologic stressors in the Barton River Watershed.*

5.1.2 Sediment Regime Stressors

Channel Slope Modifiers

Many land uses conflict with the meandering and ever-changing nature of rivers. Rivers and streams are often straightened, dredged, and bermed to protect property investments or to make floodplains available for other land uses. Channel straightening and bank armoring remove or alter natural meanders, forcing the stream to flow faster through a narrow area. Similar results can occur when river sediments are dredged from the stream bed. These channel alterations directly affect the stream by increasing its slope and power, resulting in a higher sediment transport capacity. Many rivers in Vermont have incised (eroded the stream bed) because of these alterations, further increasing the river's power during high flows.

Floodplain encroachments such as roads, railroads, and berms exist as raised surfaces that cut off sections of floodplain that were normally utilized by the stream to migrate and deposit flood-related sediment. A stream that has access to a wide floodplain is also able to dissipate more energy when the floodwaters spread out over a large area, which decreases flood damage to downstream areas. Encroachments were mapped if they fell within the stream corridor, even if they did not occur immediately adjacent to a stream. This is because streams move and meander over time; a stream that is currently near but not immediately against a floodplain encroachment could migrate closer in the future, especially if that stream is rapidly adjusting to a stressor.

Figure 7 shows slope modifiers found along the Barton and Willoughby Rivers. Collectively, these modifications indicate the potential for increased erosion, channel incision, and decreased channel stability. Clear evidence of dredging and gravel mining was not found on either river, however one instance of bar scalping (removal of sediment from a gravel bar) was found on the Willoughby River. Channel straightening occurred only on the Barton River, totaling to about 10% of the river's length. Three reaches were highly impacted by straightening, with straightened lengths ranging from 24-47% of the reach lengths. Most instances of straightening were adjacent to the railroad, including several long portions with cut-off meander bends to accommodate the railroad tracks. Floodplain encroachments occurred along both rivers, but like the channel straightening, occurred mainly along the Barton River.

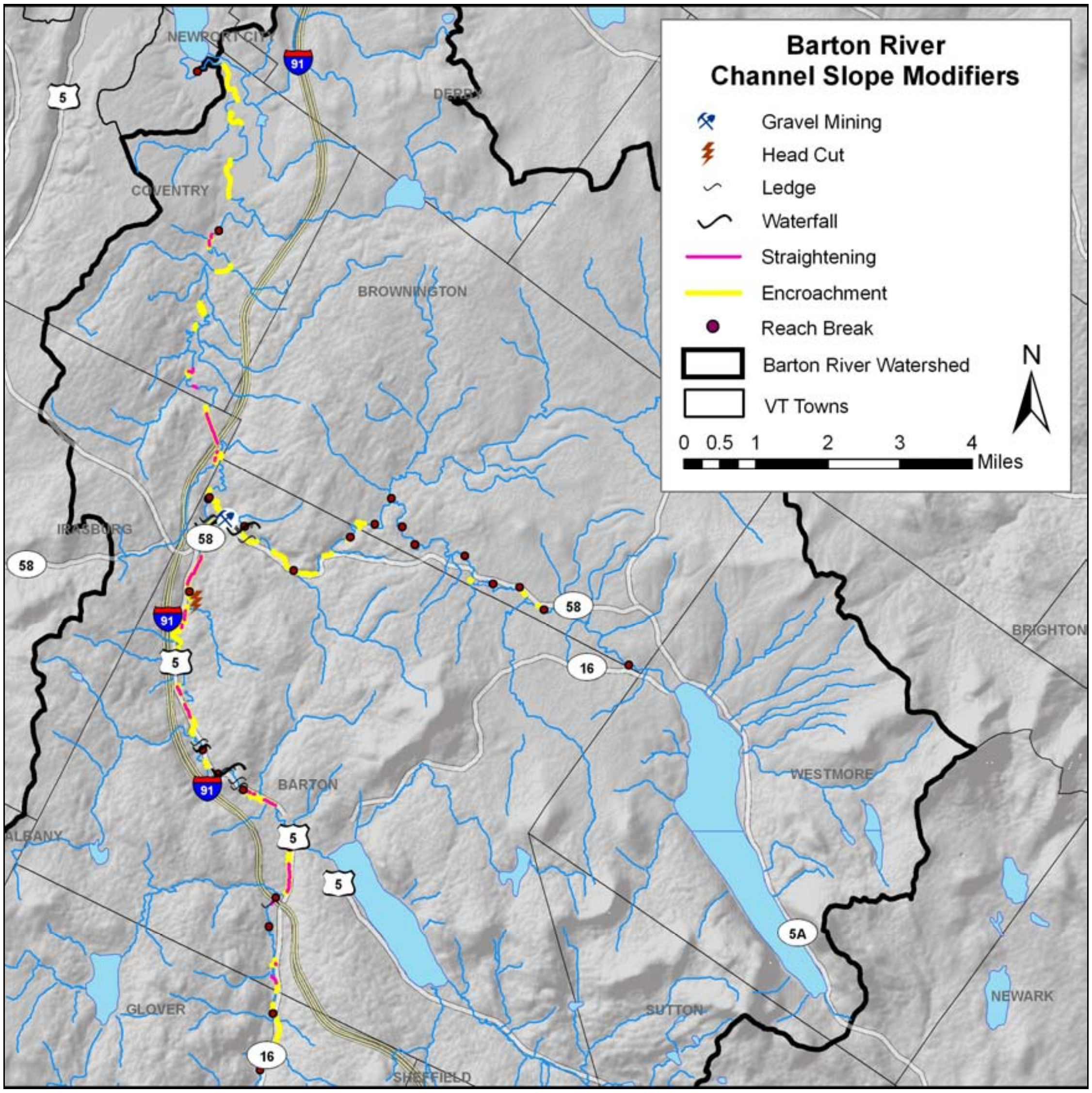


Figure 7. *Slope modifiers in the Barton River Watershed, including floodplain encroachments (berms, roads, and railroads) channel straightening, natural grade controls, head cuts, and gravel mining.*

Sediment Load Indicators

Streams naturally erode, move, and deposit sediment. Erosion occurs on the outer bank of meander bends, where the water flows fastest and contains the most energy. The sediment is then deposited on point bars along the inner bank, where the current is slowest. This process is a natural part of stream evolution as it responds to varying flow levels and sediment inputs over time, and results in the maintenance of relatively moderate stream power and resulting channel erosion.

In the absence of human influences average flow levels and sediment inputs vary little over time and the erosion process is quite slow, although some streams located on alluvial fans or at the base of very steep valleys are naturally more dynamic. Streams that exhibit excessive adjustments in the form of lateral and vertical migration (such as avulsions, neck cut-offs, channel widening and incision) and widespread erosion are likely to be responding to a variety of stream channel or watershed stressors disturbing the sediment regime.

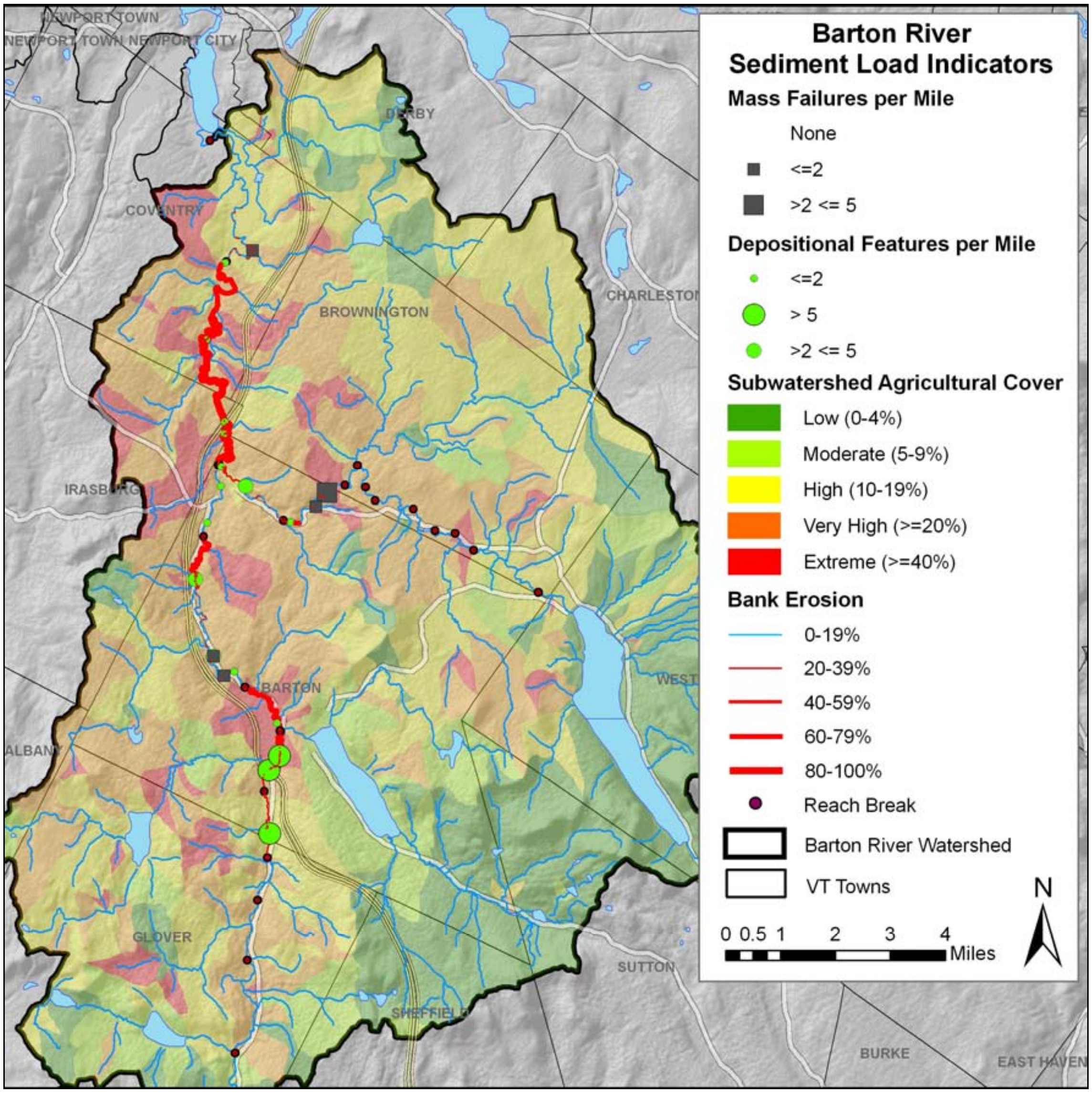


Figure 8. *Sediment load indicators in the Barton River Watershed. Mass failures, bank erosion, and depositional features are for Phase 2 Reaches only.*

Indicators and sources of the sediment load within the Barton River watershed are displayed in Figure 8. Bank erosion has been displayed for all assessed Phase 2 reaches and was common throughout the Barton River with the exception of South Bay WMA (Reach M02). Erosion was uncommon on the Willoughby River, except in the Willoughby Falls WMA and some isolated areas upstream. Mass failures, which occur when a river erodes a hillside, are large sources of sediment and are displayed in Figure 8 as normalized values for each stream reach (number of features per river-mile). They were very commonly observed along the Willoughby River, and smaller failures were occasionally observed on the Barton River. These large sediment sources may explain the dynamic nature of the Willoughby River observed just upstream of its confluence with the Barton River. Given that these sediment sources will remain active over the long term, continued adjustment of the Lower Willoughby should be expected to continue.

Agricultural land use is an important source of sediment on a watershed scale and is depicted as the percentage of land devoted to crop, hay, pasture, and other agricultural uses. Most of the sub-watersheds along both the Barton and Willoughby Rivers have over 20% of their land coverage in agricultural use. Depositional features and channel adjustments that indicate a high sediment load are also displayed, including steep riffles, mid-channel bars, flood chutes, and avulsions. These features are displayed as normalized values for each stream reach. Most were observed on the Barton River upstream of the Crystal Lake outlet in Barton Village (Reaches M09, M10, M11), upstream of Orleans Village (Reach M05A), and the lower reach of the Willoughby River (Reach T3.01).

5.1.3 Channel Constrictions and Stream Crossings

Bridges and culverts that are narrower than the stream channel width may exacerbate channel stability by causing excessive deposition upstream of the structure and increasing stream velocity and erosive energy downstream of the structure. This often results in localized areas of sediment deposition, erosion, fish passage problems, and ice and debris jams. In some cases, the stream crossing may increase the risk of flooding and property damage by forcing the river to flow around or over the bridge during high flows.

Table 3 shows the widths of all bridges, culverts, and old abutments measured in the Phase 2 assessments. Of the 41 structures listed, only 20 were as wide as the stream channel. The remaining 21 bridges and old abutments functioned as channel constrictions, altering the channel slope and flow hydraulics, and in many cases creating localized areas of erosion, scour pools and sediment deposition. In some instances, the stream was no longer aligned with the constriction due to channel migration in the vicinity of the undersized structure. These are areas where the stream could undermine the bridges during high flows; these are also areas where floodwaters could flow over and around the bridge.

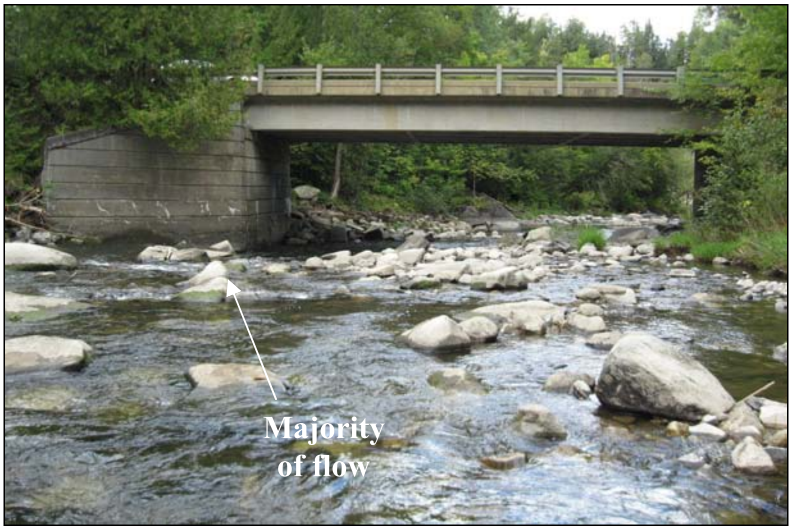


Figure 9: *Example of sediment deposition upstream of bridge on Willoughby River Reach T3.*

Table 3. Channel and floodplain constrictions found during Phase 2 assessments of the Barton and Willoughby Rivers.

Reach	Road Name	Type	Structure Span (ft)	Channel Width (ft)	% of Stream Width	Floodplain Constriction?	Length of River Affected (ft)	Comments/ Problem Associated With Bridge
M02	Railroad	Bridge	94	64	147	Yes	120	Scour downstream
M02	Coventry Station Rd.	Bridge	90	64	141	Yes	30	Half of right footer exposed, scour pool below bridge
M03A	Private	Old Abutment	48	61	79	No	40	Very minor scour upstream and downstream of abutment
M03B	Railroad	Bridge	117	65	180	Yes	75	Alignment issues
M03C	Webster Rd.	Bridge	75	55	136	No	80	Some scour upstream and downstream
M03C	River Rd.	Bridge	75	55	136	No	160	Mid-channel bar upstream
M03C	Railroad	Bridge	48	55	87	Yes	50	Scour and very sharp bend upstream
M03C	I-91	Bridge	156	55	284	No	70	Bridge is very wide, but one of its support structures is basically the left bank. Some minor scour
M03C	I-91	Bridge	135	55	245	No	70	Bridge is wide, but one of its support structures is basically the left bank. Some minor scour upstream
M03D	Maple St.	Bridge	66	71	93	Yes	100	Deposition upstream, scour upstream
M04B	Ethan Allen Plant	Bridge	68	48	142	Yes	0	None
M04B	Ethan Allen Plant	Bridge	63	48	131	Yes	35	Small scour pool below
M04B	Railroad	Bridge	66	48	138	No	50	River flowing against right footer
M04B	Railroad Ave.	Bridge	84	48	175	Yes	100	Scour pool downstream
M04B	Railroad	Bridge	80	48	167	Yes	90	Located at river bend, scour pool upstream
M04B	Ethan Allen Plant	Rip-rap constriction	25	48	52	No	250	Rip-rap along both banks in straightened section, very large pool downstream, very high banks downstream
M04B	Snowmobile bridge	Bridge	36	48	75	Yes	288	Old abutment below bridge causing constriction and upstream/downstream scour
M05A	Souliere Ln.	Bridge	45	59	76	Yes	70	Deposition downstream. Clearance is low; river flowed up against bridge in spring 2008
M05A	Boudreau Ln.	Bridge	45	59	76	Yes	100	Some scour upstream and downstream
M05A	Railroad	Bridge	69	59	117	Yes	60	Meander cut-off probable immediately upstream of bridge. Mid-channel bar downstream.
M05B	May Farm Rd.	Bridge	80	77	104	Yes	0	None
M05B	Heath Ln.	Bridge	45	77	58	Yes	120	Some scour upstream and downstream

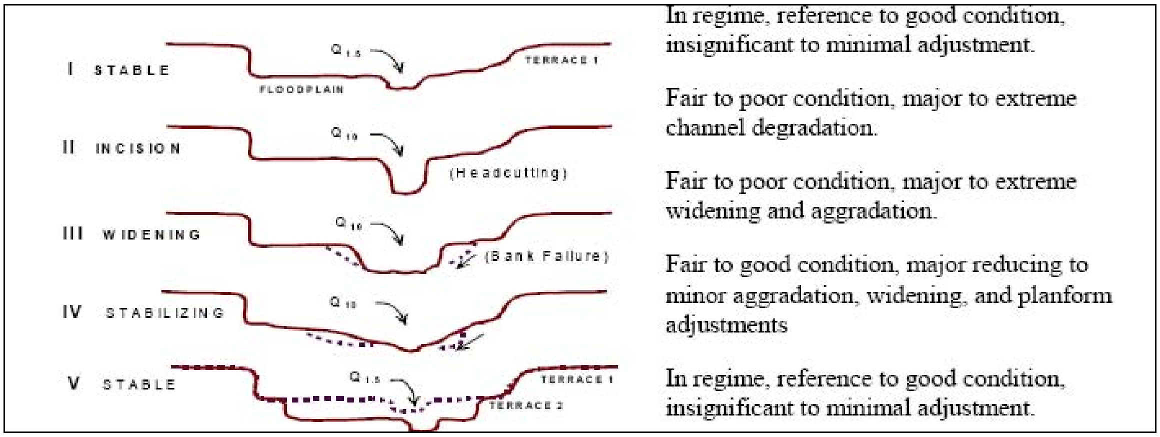
Reach	Road Name	Type	Structure Span (ft)	Channel Width (ft)	% of Stream Width	Floodplain Constriction?	Length of River Affected (ft)	Comments/ Problem Associated With Bridge
M05B	Route 5	Bridge	66	77	86	Yes	0	None
M05B	Private	Bridge	48	77	62	Yes	0	Bridge is being undermined by river, but is not affecting it. In ledge section
M06	Route 5	Bridge	87	77	113	Yes	0	None
M07	Railroad	Bridge	25	54	46	Yes	0	Located in bedrock area, but may be fish passage issue
M07	Railroad	Bridge	25	54	46	Yes	120	Large pool downstream
M07	Route 5	Bridge	36	54	67	Yes	200	Large scour pool upstream and scour downstream
M08	Private	Bridge	75	51	147	No	0	None
M08	Elm St.	Bridge	53	51	104	Yes	265	Mucky pool upstream, pool downstream
M09	Roaring Brook Rd	Bridge	34	44	77	Yes	100	Mid-channel bar downstream, some scour upstream
M09	Private	Old Abutment	25	44	57	No	100	Some deposition upstream, scour downstream
M10	I-91	Bridge	36	55	65	Yes	250	Some deposition downstream. River straightened to accommodate bridge
M11	Private	Old Abutment	20	37	54	No	0	None
M11	Private	Covered Bridge	33	37	89	No	150	Scour pools upstream and downstream, river makes sharp bend upstream
M11	Private	Bridge	36	37	97	Yes	150	Mid-channel deposit upstream, scour downstream, known ice jam location
M11	Private	Old Abutment	42	37	114	No	60	Steep riffle upstream, pooling downstream
M11	Fulton Ln.	Bridge	34	37	94	Yes	35	Mid-channel deposit downstream
T3.01B	East St.	Bridge	105	77	136	No	0	None
T3.03A	Churchill Rd.	Bridge	90	65	138	Yes	0	None
T3.04	Center Rd.	Bridge	50	55	91	Yes	300	Steep aggradation of large boulders upstream; majority of river flow hits left abutment. High incised banks downstream.

5.2 CURRENT GEOMORPHIC CONDITIONS

5.2.1 Geomorphic Condition Ratings and Channel Evolution Stage

Since European settlement, watersheds and stream channels have undergone extensive modifications such as deforestation, development, channel straightening, and bank armoring. These actions function to increase peak flow levels, increase stream power, and decrease sediment storage. This has led to decreased floodplain function and increased erosion and flood damage. When stream channels or floodplains are modified, the stream adjusts to maintain equilibrium with its flows and sediment loads.

There are five stages in channel evolution depicted in Figure 10. Streams in stable or equilibrium condition are in Stage I. These streams are in reference or good condition and have the ability to regularly flood in order to disperse sediment and energy. Reaches in fair or poor condition are currently evolving to regain stability; these streams will be in various stages of channel evolution. Streams in Stage II have incised and may have lost the ability to access their floodplains. These reaches have increased power, increased ability to erode, and decreased ability to store sediment within the reach. Instead, much of the sediment may be sent downstream to affect downstream reaches or lakes. In Stages III and IV, the stream is widening and migrating as it re-establishes meanders and a new floodplain at a lower elevation. Erosion may be severe at these stages as the stream attempts to re-establish equilibrium. Finally, Stage V represents a new equilibrium and a re-established floodplain at a lower elevation.



In regime, reference to good condition, insignificant to minimal adjustment.

Fair to poor condition, major to extreme channel degradation.

Fair to poor condition, major to extreme widening and aggradation.

Fair to good condition, major reducing to minor aggradation, widening, and planform adjustments

In regime, reference to good condition, insignificant to minimal adjustment.

Figure 10. *Channel evolution processes (State of Vermont 2007b); Stages I and V represent equilibrium conditions, and Stages II, III, and IV represent the channel degradation, widening, aggradation, and planform adjustments occurring as the stream adjusts to regain equilibrium.*

Figure 11 depicts the stream geomorphic conditions found throughout the Barton River Watershed as found in the Phase 1 and Phase 2 Stream Geomorphic Assessments. Current channel evolution stages are also shown for Phase 2 reaches. Based on the intensity of channel and floodplain modifications, as well as the overall stream condition observed during the field assessments, reach conditions are defined as reference, good, fair, or poor. Vermont ANR Stream Geomorphic Assessment Protocols describe these conditions as follows (State of Vermont 2007b):

> “**In Regime: A stream reach in *reference and good* condition that** is in dynamic equilibrium which may involve localized, *insignificant to minimal change* to its shape or location while maintaining the fluvial processes and functions of its watershed over time and within the range of natural variability.
>
> **In Adjustment: A stream reach in *fair* condition that** has experienced *major change* in channel form and fluvial processes outside the expected range of natural variability; and may be poised for additional adjustment with future flooding or changes in watershed inputs that could change the stream type.
>
> **Active Adjustment and Stream Type Departure: A stream reach in *poor* condition that** is experiencing extreme adjustment outside the expected range of natural variability for the reference stream type; likely exhibiting a new stream type; and is expected to continue to adjust, either evolving back to the historic reference stream type or to a new stream type consistent with watershed inputs and boundary conditions.”

Along the Barton River, 28% of assessed reaches are in reference condition, 35% are in good condition, and 37% are in fair condition (Figure 11). Most reaches are either in Stage I or Stage III of channel evolution; those in Stage III are incised and reacting to modifications to the channel and watershed. Along the Willoughby River, 92% of assessed reaches are in good condition and 8% are in poor condition. All reaches are in Stage I of channel evolution except for a single Stage III segment. Man-made stressors to the Willoughby River watershed are minimal, but the river does receive large sediment inputs from multiple mass failure sites.

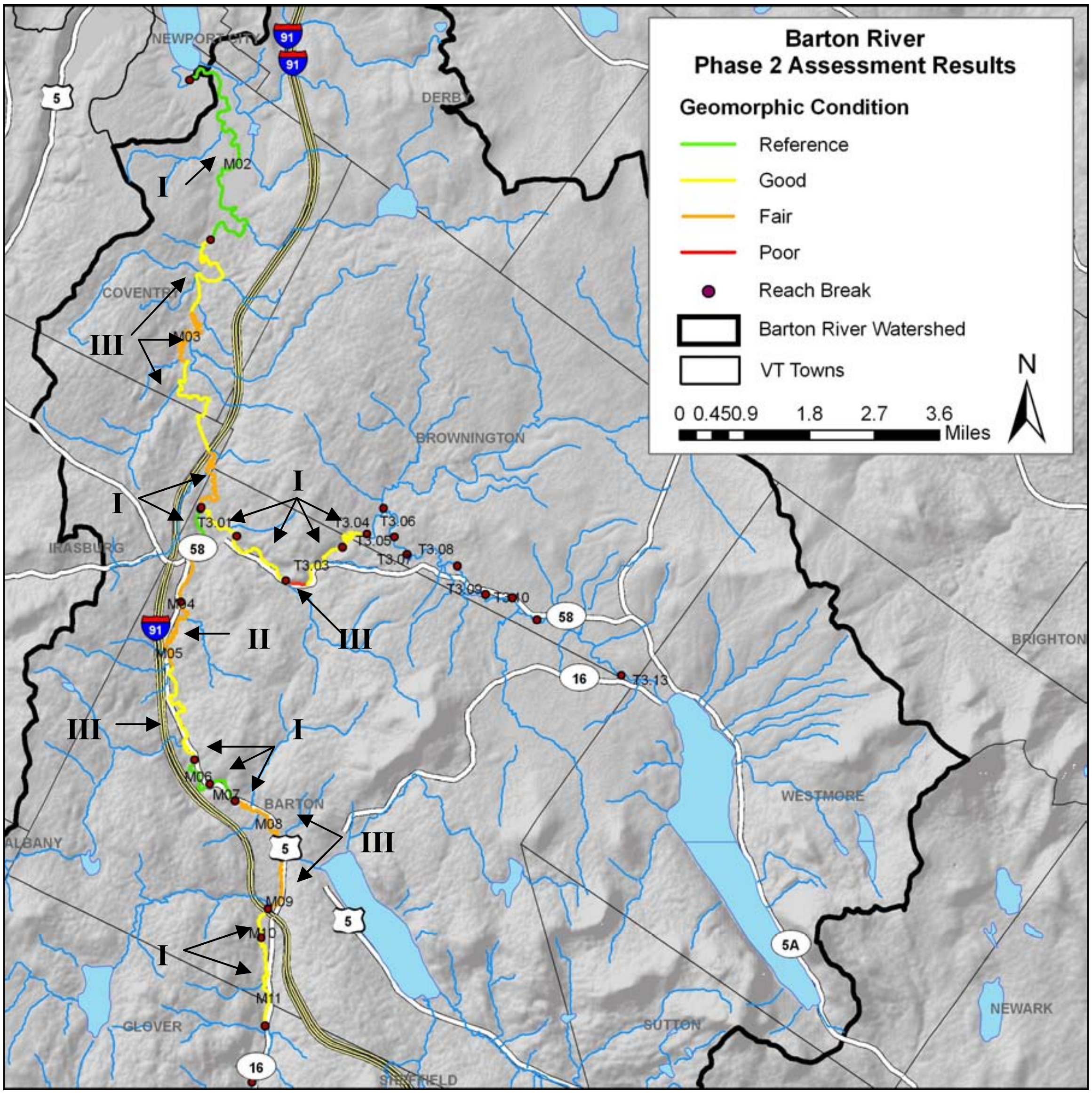


Figure 11. Map of geomorphic conditions in the Barton River Watershed. Channel evolution stages are in black.

Both watershed-scale and reach-scale stressors are summarized and quantified in Table 4. These are the stressors that have influenced the geomorphic condition for each Phase 2 reach. This includes reaches which may be affected by changes to the watershed's hydrologic regime, watershed-scale or upstream sediment inputs, stream power, and bank resistance changes:

Table 4: Summary of Watershed and In-stream Stressors

	Watershed-Scale Stressors		**Reach-Scale Stressors**	
River Segment (Existing Stream Type, CES, RGA score*)	**Hydrologic (urban, roads, stormwater, wetland loss, development)**	**Sediment (depositional features, erosion, cropland, migration, mass failure)**	**Stream Power (Increase: straightening, encroachments; Decrease: deposition, migration)**	**Boundary Resistance (Increase: bank armoring, grade controls; decrease: erosion, reduced vegetation)**
M02 **(E5, I, Reference)** **Not incised**	Not Significant	Increased load: • Moderate (8%) cropland in watershed • Moderate (14%) bank erosion • Small mass failure	Increased power: • High (66%) railroad encroachment	Not Significant
M03A **(E5, III, Good)** Incision Ratio: 1.4	Increased flows: • Moderate (5%) urban land cover in watershed	Increased load: • Moderate (7%) cropland in watershed • High (60%) bank erosion	Increased power: • Moderate (6%) straightening • High (24%)road/railroad encroachment	Decreased resistance: • Woody riparian vegetation uncommon • High (60%) bank erosion
M03B **(C5, III, Fair)** Incision Ratio: 1.2	Increased flows: • Moderate (5%) urban land cover in watershed	Increased load: • Moderate (7%) cropland in watershed; high (10%) cropland in corridor • High (100%) bank erosion • Multiple migration features	Increased power: • High (22%) railroad encroachment Decrease: • Multiple migration features	Decreased resistance: • High (100%) bank erosion • Woody riparian vegetation uncommon

*For Stream Type descriptions, see Appendix B. Stream type lettering is followed by the dominant bed material: 1 = bedrock, 2 = boulder, 3 = cobble, 4 = gravel, 5 = sand; CES = Channel Evolution Stage (Figure 10); RGA Score = Rapid Geomorphic Assessment Score

	Watershed-Scale Stressors		Reach-Scale Stressors	
M03C **(E5, III, Good)** Incision Ratio: 1.3	Increased flows: • Moderate (5%) urban land cover in watershed • Minor stormwater inputs	Increased load: • Multiple depositional features • High (82%) bank erosion • Moderate (7%) cropland in sub-watershed; high (10%) cropland in corridor	Increased power: • High (34%) road/railroad encroachment • High (30%) channel straightening Decrease: • Multiple depositional features	Increased resistance: • Low to moderate (18%) bank armoring Decreased resistance: • High (82%) bank erosion • Woody riparian vegetation uncommon
M03D **(C5, I, Fair)** Incision Ratio: 1.2	Increased flows: • Moderate (5%) urban land cover in watershed	Increased load: • Moderate (7%) cropland in sub-watershed; high (10%) cropland in corridor • Abundant sediment deposition • High (100%) bank erosion	Increased power: • High (30%) road/railroad encroachment Decrease: • Abundant sediment deposition • Multiple migration features	Decreased resistance: • High (100%) bank erosion • Woody riparian vegetation uncommon
M04A **(F2, I, Reference)** Incision Ratio: 1.0	Increased flows: • Moderate (5%) urban land cover in sub-watershed • Extreme (50%) urban land cover along corridor • Multiple stormwater inputs • High road density in sub-watershed	Increased load: • Moderate (7%) cropland in sub-watershed • High (16%) cropland along corridor	Not significant	Increased resistance: • High (36%) bank armoring or walls • Multiple bedrock ledges
M04B **(E5, IV, Fair)** Incision Ratio: 1.3	Increased flows: • Moderate (5%) urban land cover in watershed • Extreme (50%) urban land cover along corridor • Multiple stormwater inputs • High road density	Increased load: • Moderate (7%) cropland in sub-watershed • High (16%) cropland along corridor	Increased power: • High (42%) channel straightening • High (70%) road/railroad encroachments	Increased resistance: • Moderate (12%) bank armoring

	Watershed-Scale Stressors		Reach-Scale Stressors	
M05A (C5, III, Fair) Incision Ratio: 1.6	Increased flows: • High (15%) urban land cover along corridor	Increased load: • Moderate (7%) cropland in sub-watershed • High (18%) cropland along corridor • Abundant sediment deposition • High (76%) bank erosion • Multiple migration features	Increased power: • Moderate (10%) channel straightening • High (76%) road/railroad encroachments Decrease: • Abundant sediment deposition • Multiple migration features	Increased resistance: • Moderate (20%) bank armoring Decreased resistance: • Woody riparian vegetation uncommon • High (76%) bank erosion
M05B (C4, I, Good) Not Incised	Increased flows: • High (15%) urban land cover along corridor	Increased load: • Moderate (7%) cropland in sub-watershed • High (18%) cropland along corridor • Abundant sediment deposition • Moderate (18%) bank erosion • One mass failure	Increased power: • Moderate (19%) channel straightening • High (42%) road encroachments	Increased resistance: • Moderate (14%) bank armoring Decreased resistance: • Woody riparian vegetation uncommon • Multiple bedrock ledges • Moderate (18%) bank erosion
M06 (C4, I, Reference) Not Incised	Increased flows: • Moderate (9%) urban land cover along corridor	Increased load: • Moderate (6%) cropland in sub-watershed • High (10%) cropland along corridor • Some sediment deposition • Multiple mass failures • Few migration features	Not Significant	Not Significant
M07 (B1, I, Reference) Not Incised	Increased flows: • Extreme (31%) urban land cover along corridor	Increased load: • Moderate (6%) cropland in sub-watershed	Not Significant	Increased resistance: • Multiple bedrock ledges and waterfalls

	Watershed-Scale Stressors		**Reach-Scale Stressors**	
M08 (C5, III, Fair) Incision Ratio: 1.5	Increased flows: • High (10%) urban land cover along corridor • Minor stormwater inputs • High road density	Increased load: • Moderate (6%) cropland in sub-watershed • Extreme (22%) cropland along corridor • High (74%) bank erosion	Increased power: • Moderate (17%) channel straightening • High (48%) road encroachments	Increased resistance: • High (42%) bank armoring Decreased resistance: • Woody riparian vegetation very uncommon • High (74%) bank erosion
M09 (E4, III, Fair) Incision Ratio: 1.5	Increased flows: • Extreme (20%) urban land cover along corridor	Increased load: • Moderate (8%) cropland in sub-watershed • Extreme (23%) cropland along corridor • High (80%) bank erosion • Abundant sediment deposition • Few migration features	Increased power: • High (47%) historic channel straightening • High (82%) road encroachments Decrease: • Abundant sediment deposition • Multiple migration features	Increased resistance: • High (32%) bank armoring Decreased resistance: • Woody riparian vegetation uncommon • High (80%) bank erosion
M10 (C5, I, Good) Not Incised	Increased flows: • Moderate (9%) urban land cover along corridor	Increased load: • Moderate (7%) cropland in sub-watershed • High (13%) cropland along corridor • Moderate (24%) bank erosion • Abundant sediment deposition	Increased power: • Moderate (18%) channel straightening Decrease: • Abundant sediment deposition	Increased resistance: • Moderate (22%) bank armoring Decreased resistance: • Moderate (24%) bank erosion
M11 (E4, I, Good) Not Incised	Increased flows: • Moderate (10%) urban land cover along corridor	Increased load: • Moderate (7%) cropland in sub-watershed • High (14%) cropland along corridor • High (32%) bank erosion • Abundant sediment deposition	Increased power: • Moderate (9%) channel straightening • High (30%) road encroachments Decrease: • Abundant sediment deposition • Multiple migration features	Increased resistance: • High (26%) bank armoring Decreased resistance: • High (32%) bank erosion • Woody riparian vegetation uncommon

	Watershed-Scale Stressors		Reach-Scale Stressors	
T3.01A **(C5, I, Good)** Incision Ratio: 1.2	Increased flows: • Extreme (30%) urban land cover along corridor	Increased load: • Moderate (7%) cropland in sub-watershed • Extreme (20%) cropland along corridor • High (58%) bank erosion • Abundant sediment deposition • Migration	Increased power: • High (92%) road encroachments Decrease: • Abundant sediment deposition • Migration	Increased resistance: • Moderate (14%) bank armoring Decreased resistance: • High (58%) bank erosion • Woody riparian vegetation uncommon
T3.01B **(C5, I, Good)** Not Incised	Increased flows: • Extreme (30%) urban land cover along corridor	Increased load: • Moderate (7%) cropland in sub-watershed • Extreme (20%) cropland along corridor • High (28%) bank erosion • Abundant sediment deposition • Migration	Increased power: • Moderate (20%) road encroachments Decrease: • Abundant sediment deposition • Migration	Increased resistance: • Moderate (14%) bank armoring Decreased resistance: • High (28%) bank erosion • Woody riparian vegetation uncommon
T3.02 **(C4, I, Good)** Not Incised	Increased flows: • High (12%) urban land cover along corridor	Increased load: • Moderate (7%) cropland in sub-watershed • High (15%) cropland along corridor • Moderate (18%) bank erosion • Abundant sediment deposition • Migration features	Increased power: • High (64%) road encroachments Decrease: • Abundant sediment deposition • Migration features	Increased resistance: • Moderate (14%) bank armoring • Multiple bedrock ledges and waterfalls Decreased resistance: • Moderate (18%) bank erosion
T3.03A **(F3, III, Poor)** Incision Ratio: 2.2	Increased flows: • High (12%) urban land cover along corridor	Increased load: • Moderate (6%) cropland in sub-watershed • High (73%) bank erosion • Migration features	Increased power: • High (95%) road encroachments • Very incised Decrease: • Migration features	Decreased resistance: • High (73%) bank erosion

	Watershed-Scale Stressors		Reach-Scale Stressors	
T3.03B **(C3, I, Good)** Not Incised	Increased flows: • High (12%) urban land cover along corridor	Increased load: • Moderate (6%) cropland in sub-watershed • Moderate (18%) bank erosion • Migration features • Two mass failures • Abundant sediment deposition	Increased power: • High (22%) road encroachments Decrease: • Migration features • Abundant sediment deposition	Increased resistance: • Moderate (9%) bank armoring Decreased resistance: • Moderate (18%) bank erosion
T3.04 **(C3, I, Good)** Not Incised	Increased flows: • High (19%) urban land cover along corridor	Increased load: • Moderate (6%) cropland in sub-watershed • Migration features • Four large mass failures • Abundant sediment deposition	Increased power: • High (29%) road encroachments Decrease: • Migration features • Abundant sediment deposition	Increased resistance: • Moderate (9%) bank armoring

5.3 RESULTS AND RECOMMENDATIONS FROM PHASE 2 FIELD SURVEYS

The results of the Phase 2 field surveys are summarized in the following pages along with restoration and management recommendations. All stream types are listed, followed by the dominant streambed material, geomorphic condition, channel evolution stage, habitat condition, and stream sensitivity. In the accompanying figures, the field measurements and locations of other features are overlaid on 2003 aerial photographs (USDA 2003). The reach descriptions refer to left and right banks; these are determined when facing downstream (north). For stream type descriptions, see Appendix B.

<u>Barton River Reach M02</u> – South Bay to Coventry Station Road

Reference Stream Type: E dune-ripple, sand
Geomorphic Condition: Reference
Channel Evolution Stage: I (stable)
Habitat Condition: Reference
Stream Sensitivity: High

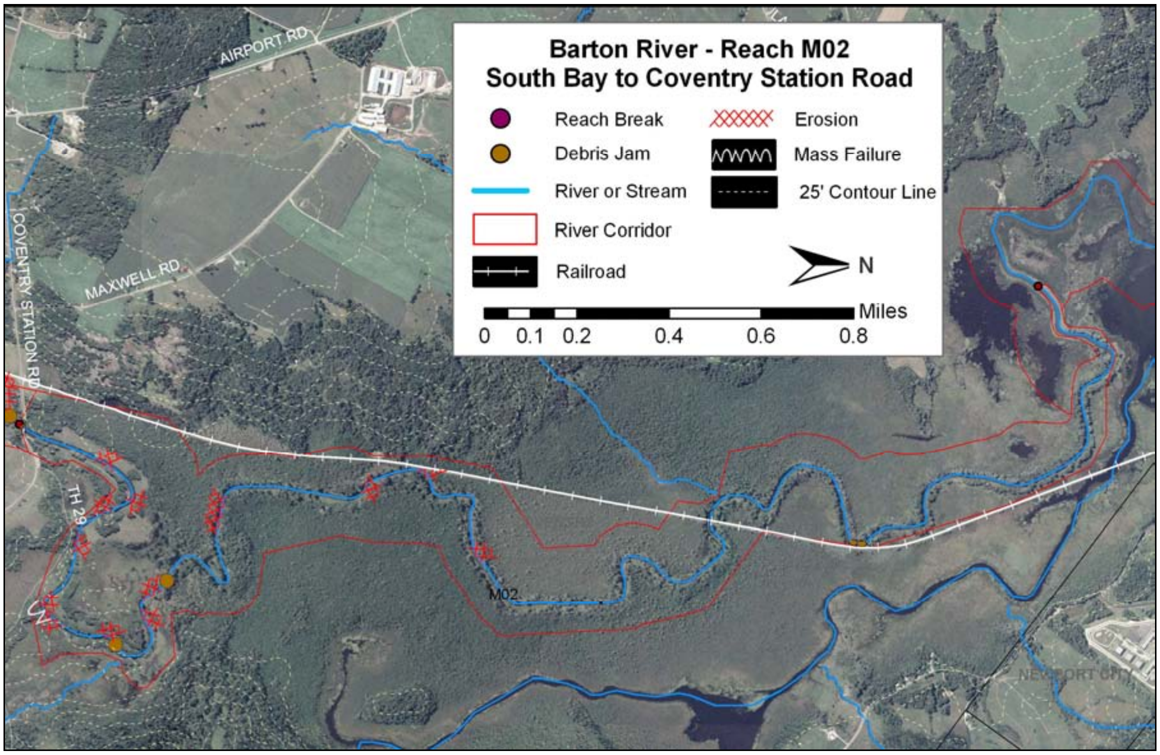


Figure 12: *Results for Barton River reach M02, which traveled through the South Bay Wildlife Management Area before entering Lake Memphremagog.*

Reach M02 is a long, slow, and sandy portion of the Barton River which flows entirely through the South Bay Wildlife Management Area. Riparian habitat here is notably intact and excellent. Aquatic plants, mussels, and schools of fish were observed throughout the reach. Most of the corridor is forested with native floodplain tree species; the only exception being the abandoned fields in the vicinity of Coventry Station Road.

The reach is stable due to minimal alterations to the floodplain and the river itself and relatively minimal sediment inputs from the upstream reach. Bank erosion manifests itself as slumping banks along the fallow fields near Coventry Station Road and occasional areas of falling and leaning trees downstream.

Although the fields are no longer managed, tree and willow plantings are recommended along the more exposed, slumping banks and adjacent areas to slow sediment inputs and hasten forest regeneration. If trees are planted, measures should also be taken to deter beaver activity, as they appear very active downstream of this area.

Barton River Reach M03A – Upstream of Coventry Station Road

Reference Stream Type: E dune-ripple, sand
Geomorphic Condition: Good
Channel Evolution Stage: III (widening)
Habitat Condition: Good
Stream Sensitivity: High

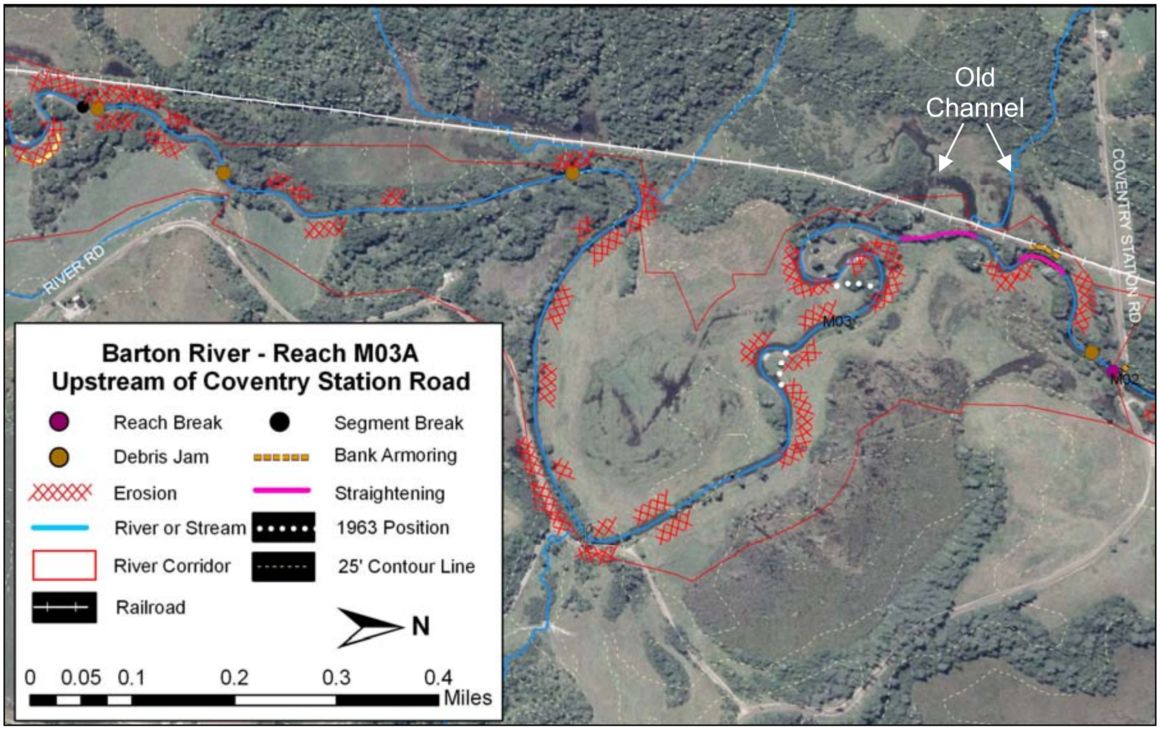


Figure 13: *Phase 2 results for Barton River reach M03A in Coventry.*

Reach M03A flows slowly through forests and fallow fields between River Road and the railroad in Coventry (Figure 13). Although two meanders were cut off since the construction of the railroad, most of the channel remains undisturbed. Some channel migration has occurred since the 1960s, but the channel is largely stable. The river is incised (incision ratio 1.5) and appears to be widening. Woody riparian vegetation is uncommon along the stream banks in the northern half of the segment. Bank erosion and leaning trees are found along 60% of this segment. Since the majority of the erosion appears older and less active than in upstream reaches, this segment is in “good” geomorphic condition.

Most of the riparian corridor is classified as wetland in the Vermont Significant Wetland Inventory; however the landscape is dominated by old fields. The northern half lies in the South Bay WMA. This segment is an excellent candidate for buffer plantings, particularly because seed sources along the large western bend are sparse and the re-establishment of woody vegetation may take a long time. Tree and willow plantings would greatly speed up natural re-vegetation as well as stabilizing some of the eroding banks and improving wildlife habitat.

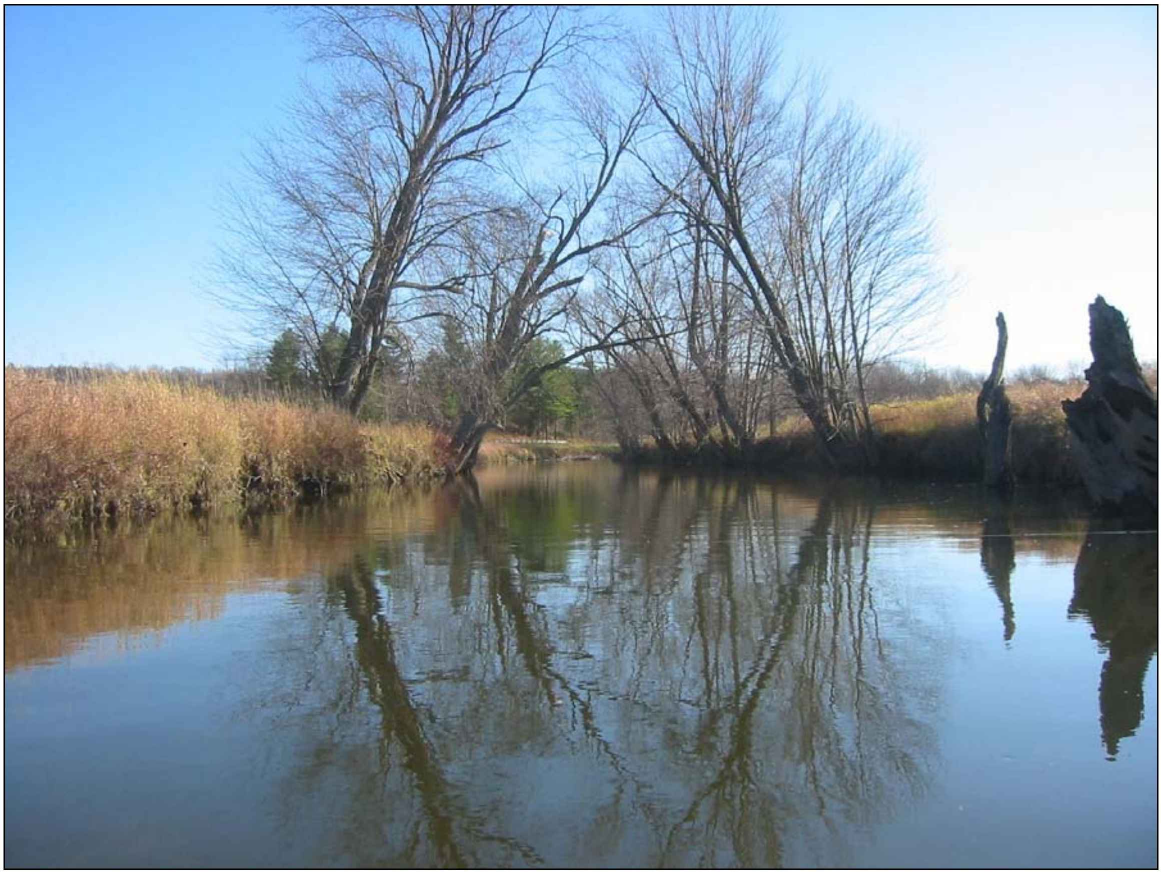


Figure 14: *Leaning trees on reach M03A. Riparian vegetation is uncommon along this section.*

Barton River Reach M03B – Paralleling River Road and the Railroad

Reference Stream Type: C dune-ripple, sand
Geomorphic Condition: Fair
Channel Evolution Stage: III (widening)
Habitat Condition: Good
Stream Sensitivity: Very High

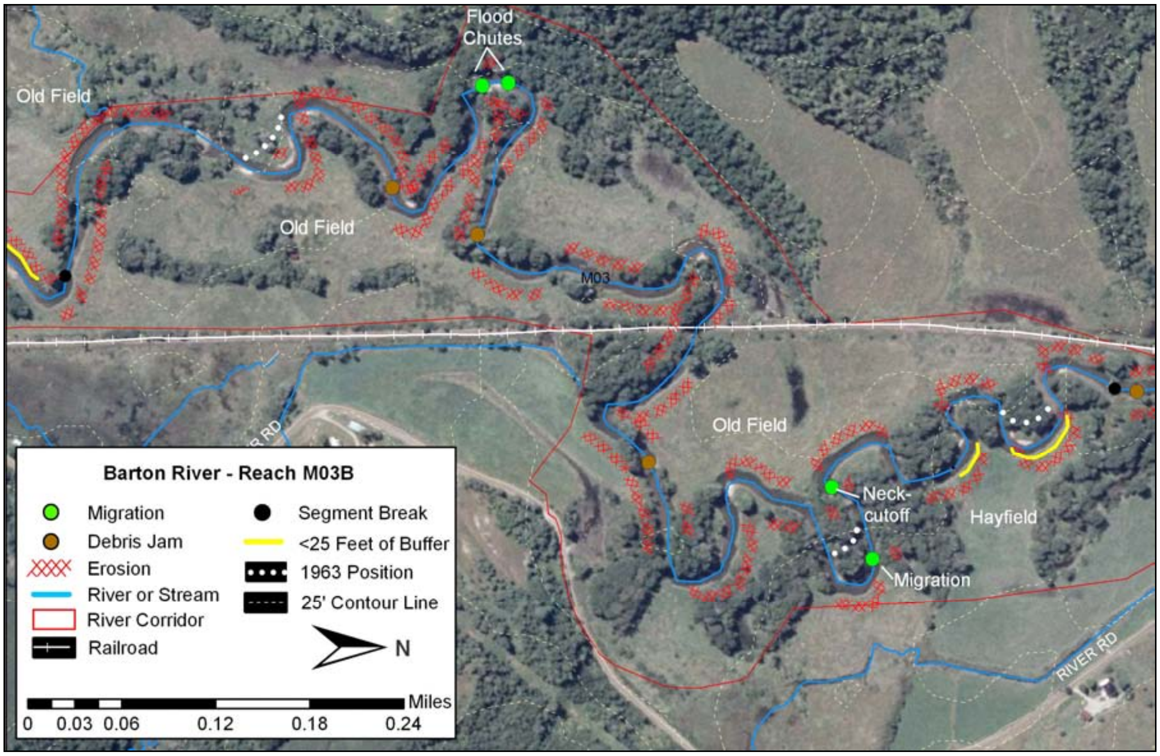


Figure 15. Results for Barton River Reach M03B

Most of the river corridor along reach M03B (Figure 15) consists of unmanaged fields with pockets of natural deciduous vegetation. This reach is slightly incised (incision ratio 1.3) and is migrating (note the river's 1963 position), as evidenced by the multiple migration and erosion features observed throughout the reach. Normally erosion occurs on the outside of meander bends, while sediment deposits on point bars on the inside of meander bends. On this reach there are several eroding point bars, particularly in the middle section. Excessive sediment inputs from upstream and in-reach combined with the lack of stabilizing woody vegetation (note that erosion is predominantly along stream banks that lacked trees) are likely causing the channel's migration.

The Vermont Significant Wetland Inventory classifies the entire corridor as class 2 wetland. The restoration and protection of the entire river corridor is recommended for channel stability and habitat values, because it is evident that the river will change from its current position and very little of the corridor is in active land use. Haying along the river should be discouraged and field areas planted with trees.

Barton River Reach M03C – Webster Road to I-91 Bridge

Reference Stream Type: E dune-ripple, sand
Geomorphic Condition: Good
Channel Evolution Stage: III (widening)
Habitat Condition: Fair
Stream Sensitivity: High

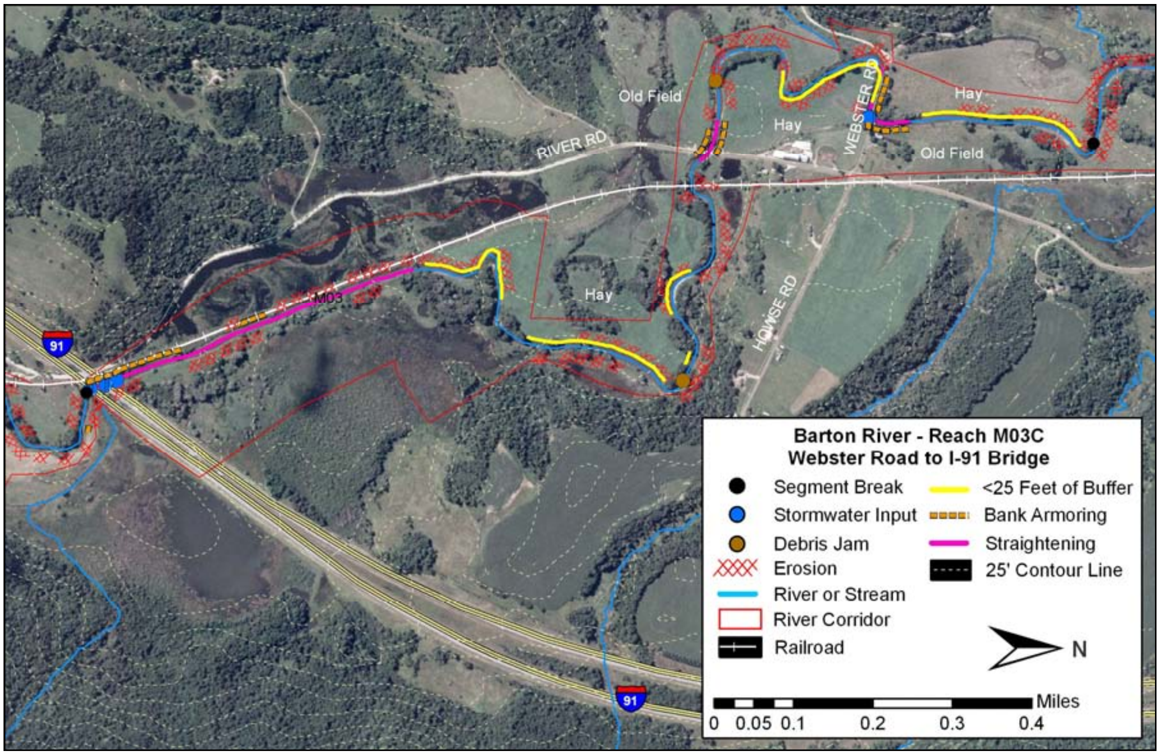


Figure 16. *Results for Barton River Reach M03C.*

Much of the river corridor along Reach M03C (Figure 16) is Class 2 wetland based upon the Vermont Significant Wetland Inventory. Much of this wetland has been altered, however, due to haying and filling of the floodplain to accommodate the railroad. Thirty percent of the reach has been straightened (note old river channel cut off by the railroad) and armored, though portions of the bank armoring along the railroad are failing. This reach is slightly incised (incision ratio 1.3) and erosion was observed along most outside bends, though less severe than in the adjacent upstream reach.

Approximately 32% of the left bank and 10% of the right bank lacks riparian buffers. Much of this land is mowed to the river's edge. There is abundant potential for river restoration projects along this reach. The river here appears stable enough to support buffer planting projects along both the managed and unmanaged fields.

Barton River Reach M03D – Willoughby Falls Wildlife Management Area

Reference Stream Type: E dune-ripple, sand
Geomorphic Condition: Fair
Channel Evolution Stage: I (stable)
Habitat Condition: Good
Stream Sensitivity: Very High

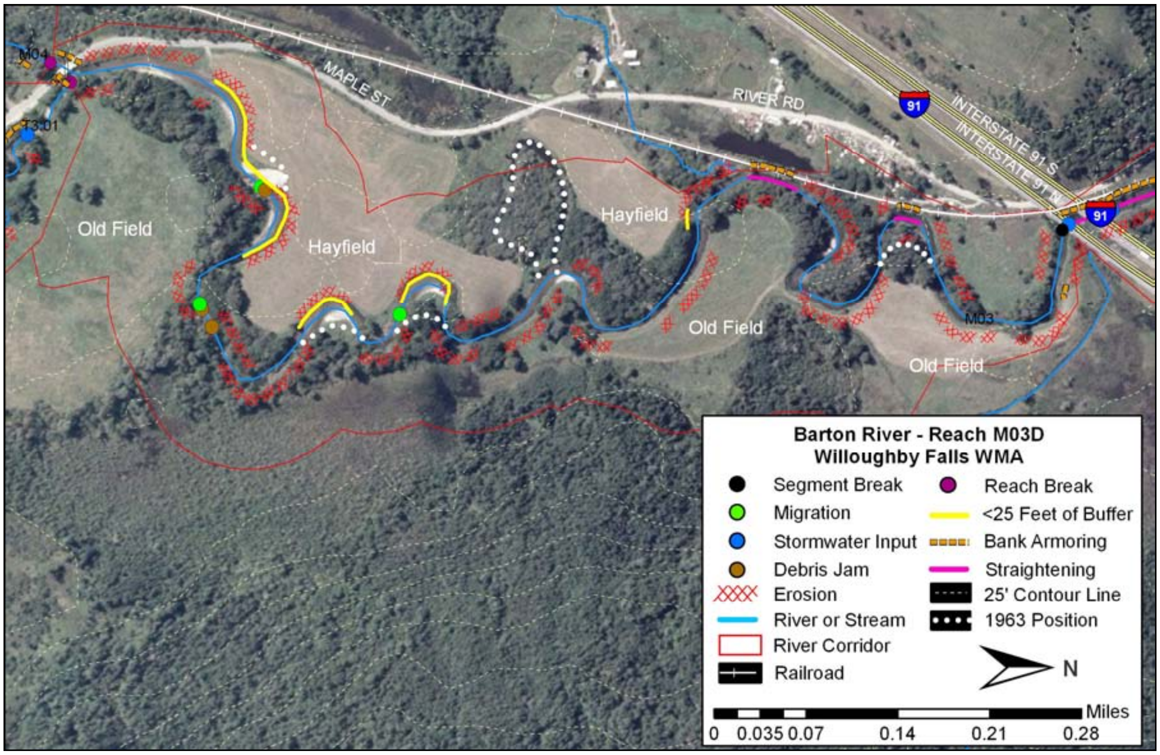


Figure 17. *Results for Barton River Reach M03D, which flows through the Willoughby Falls Wildlife Management Area.*

Reach M03D flows in its entirety through the Willoughby Falls Wildlife Management Area (WMA). It is naturally dynamic due to receiving flows and sediment from the Willoughby River, the Barton River's largest tributary. This reach is slightly incised (incision ratio 1.2) and abundant sediment deposition was noted on both the bars and the stream bed. While bank erosion and leaning trees are present throughout the reach on outside meander bends, erosion is more severe near the Willoughby River confluence.

The land along the left bank is mowed to the river's edge, leaving no vegetated buffer to keep 12' high banks from eroding into the channel (Figure 17). We anticipate this reach to be dynamic in the future, and recommend that the existing hayfield be reduced or retired within the river corridor to accommodate changes in the river planform. Additionally we recommend planting a wide buffer (>50') of native trees found in the area such as willow, silver maple, and ash to protect the riverbanks and improve wildlife habitat.

Figure 18. *Haying and eroding banks along the river's edge near the Barton /Willoughby River confluence.*

Barton River Reach M04 – Orleans Village

	Segment M04A:	Segment M04B:
Reference Stream Type:	F step-pool, boulder	E dune-ripple, sand
Geomorphic Condition:	Reference	Fair
Channel Evolution Stage:	I (stable)	II (downcutting)
Habitat Condition:	Reference	Fair
Stream Sensitivity:	Low	Very High

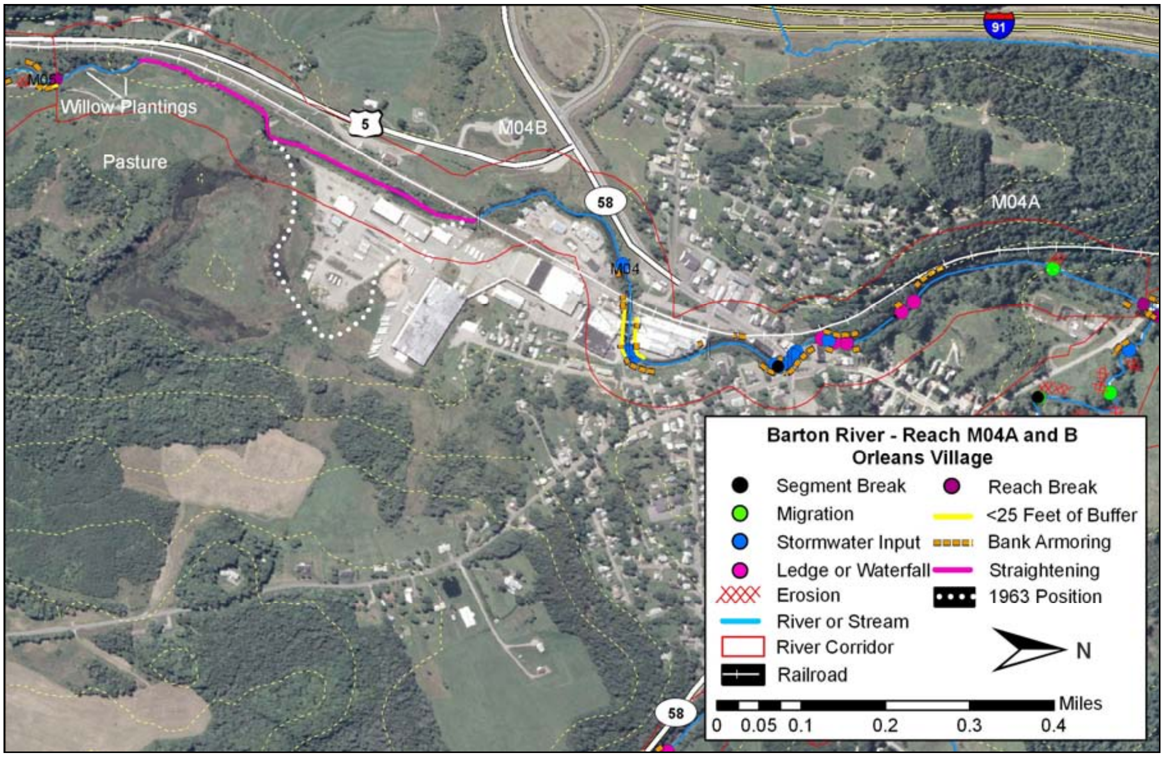


Figure 19: *Phase 2 results for Barton River Reach M04A and B, which flows through Orleans Village.*

M04A is a confined, bedrock-dominated segment with several bedrock ledges and waterfalls (Figures 19 and 20). Concerns with this reach are minimal due to the non-erosive bed and bank sediments. Steep slopes and the railroad along the left bank discouraged development and buffers >100' wide dominate that side; Willoughby Falls WMA lies along the right bank. M04B is a slow, deep, and highly-altered segment that flowed through the Ethan Allen furniture plant as it passes through Orleans Village. Much of the reach is straightened, and an entire meander has been cut off to make room for part of the Ethan Allen plant (note 1963 position). Additionally, much of the floodplain area has been cut-off due to railroad and road encroachments. One portion of this straightened section contains banks exceeding 15' in height, however this is not the case for the overwhelming majority of the reach, which is only slightly incised (incision ratio 1.3). Depositional features are rare in this segment; straightening, berms, and development activities have eliminated the reach's ability to meander and develop gravel bars. Instead, sediment generated within the reach and upstream of it is transported to the already dynamic Reach M03.

Because most of the river corridor is already developed, options to improve river morphology and habitat conditions are limited. Willow plantings and tree revetments were implemented on the upstream portion of this reach by Lake Region High School teacher Greg Hennemuth several years ago and have stabilized those banks well.

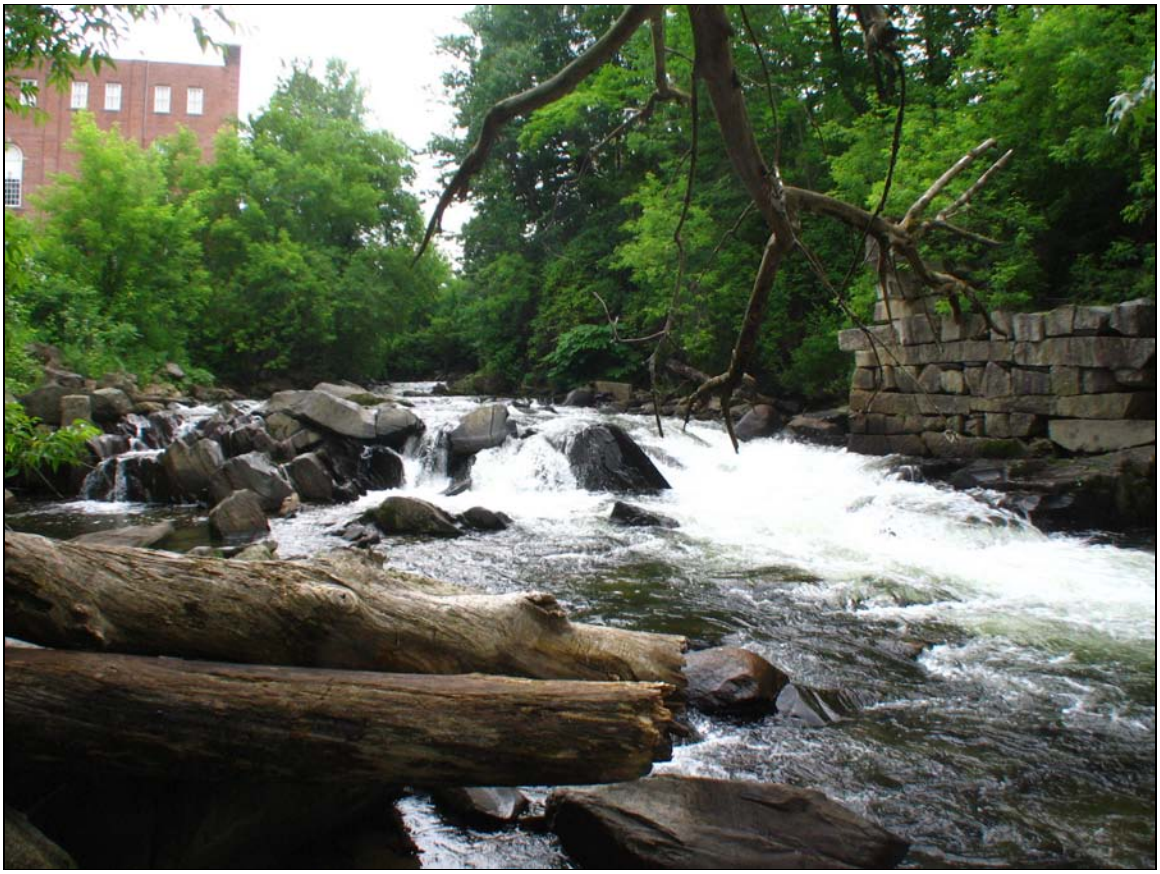


Figure 20: *Bedrock ledge and old mill foundation along Reach M04A.*

<u>Barton River Reach M05A</u> – Souliere Lane to May Farm Road

Reference Stream Type: C riffle-pool, sand
Geomorphic Condition: Fair
Channel Evolution Stage: III (widening)
Habitat Condition: Fair
Stream Sensitivity: Very High

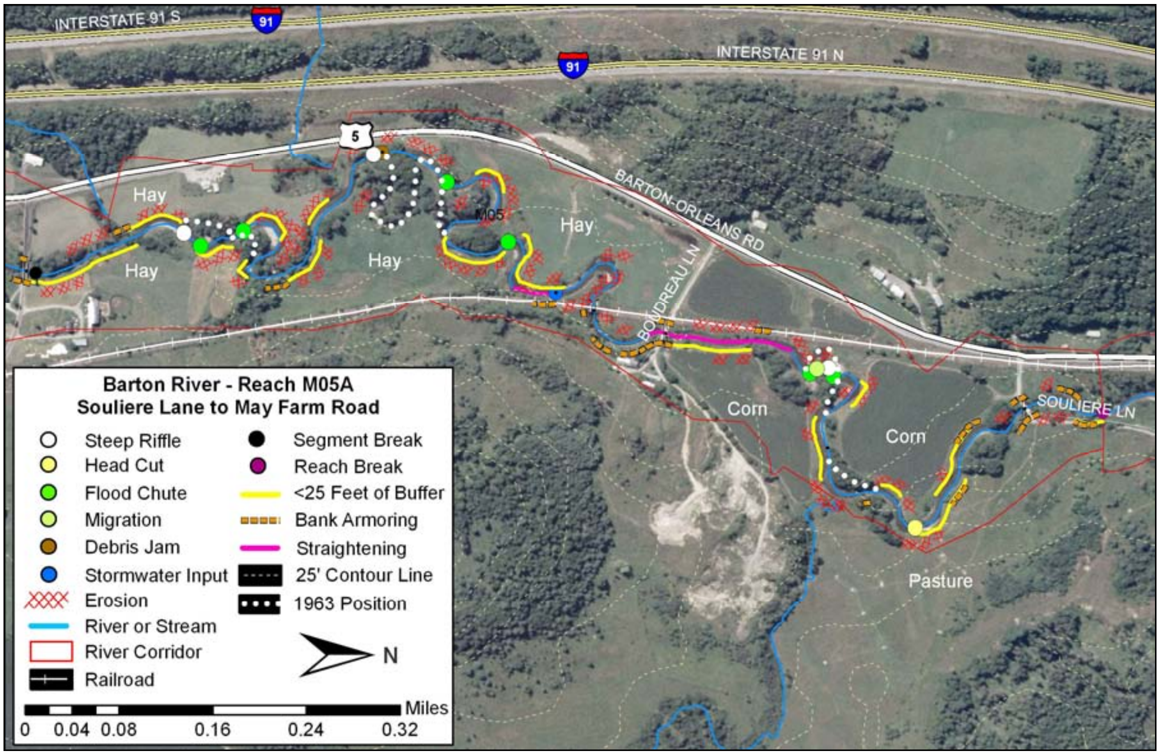


Figure 21: *Results for Barton River reach M05A. High levels of erosion were observed on most outer meander bends.*

The corridor is almost entirely in agricultural use and the river lacks a buffer in many areas (Figure 21). Erosion is occurring throughout the reach, with high slumping banks common. One 30’ high mass failure is present in the vicinity of Boudreau Lane. The streambed is very soft throughout most of the reach and large gravel bars are common. The channel is incised (incision ratio 1.6) and unstable. Several significant migrations have occurred during the past few decades, and the current condition of the segment indicates that this pattern will likely continue. Tree revetments were installed several years ago along the northern portion of the reach to stabilize the banks there. Most have succeeded but several sections have not.

Riparian buffers are lacking along 23% of the left banks and 30% of the right banks (Figure 22). Given the dynamic nature of this segment, a very wide buffer of willows with trees set back from the river is needed. In order to protect the Barton River and decrease sediment inputs from this reach, as much of the corridor as possible should be restored. The lack of bank-stabilizing vegetation means that large amounts of sediment are entering the river, building up gravel bars, and causing the river to migrate more to accommodate its sediment load. One meander bend just south of Boudreau Lane, immediately upstream of the railroad crossing, will likely be cut off within the next few years, changing the sediment/flow regime downstream.

Figure 22: *Erosion and deposition (left); Slumping banks and herbaceous buffer along Reach M05A (right).*

<u>Barton River Reach M05B</u> – May Farm Road to Route 5 Crossing

Reference Stream Type: C riffle-pool, gravel
Geomorphic Condition: Good
Channel Evolution Stage: I (stable)
Habitat Condition: Good
Stream Sensitivity: High

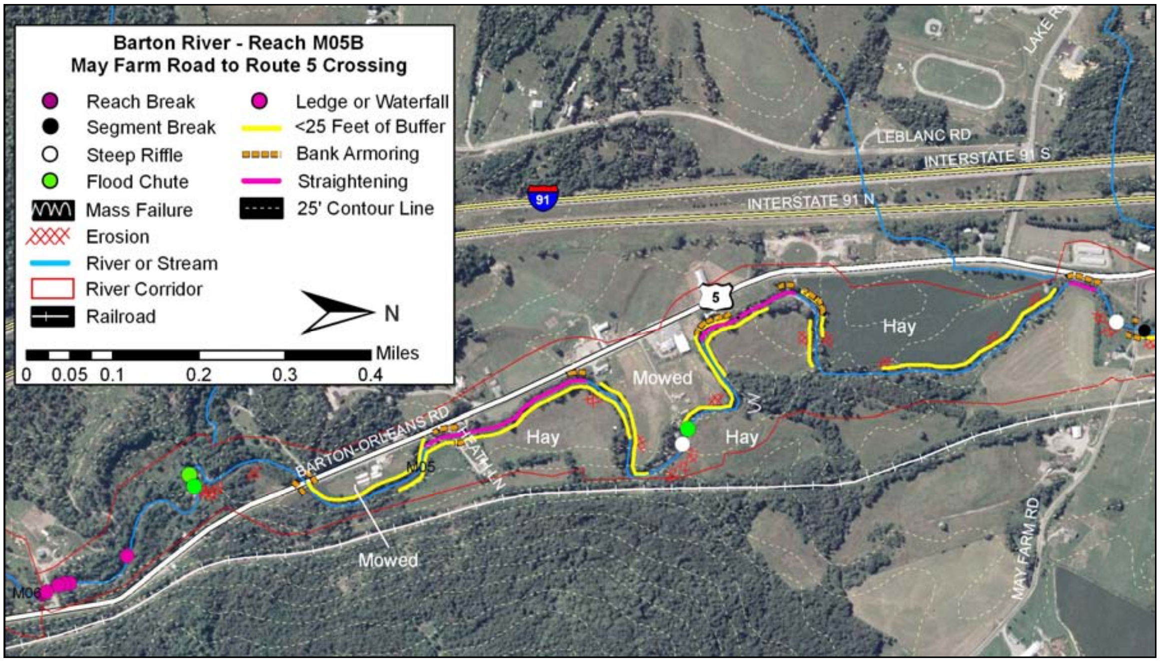


Figure 23: *Results for Barton River reach M05B. Although erosion is low, most of the banks are mowed to within 25' of the river.*

Like M05A, reach M05B’s corridor is almost entirely devoted to agricultural use and lacks a wide riparian buffer for most of its length (Figure 23). However, M05B appears much more stable and is not incised like many of the Barton River reaches. Bank erosion is much less frequent. Most banks are covered in woody vegetation which stabilizes the banks well (Figure 24), but riparian habitat is limited. Ideally, mowing should cease within 50’ of the river in order to improve habitat conditions.

Figure 24: *The mostly forested riverbanks along Reach M05B.*

Barton River Reaches M06 and M07 – Route 5 Crossing to Kinsey Road

	Reach M06:	Reach M07:
Reference Stream Type:	C riffle-pool, gravel	B bedrock, bedrock
Geomorphic Condition:	Reference	Reference
Channel Evolution Stage:	I (stable)	I (stable)
Habitat Condition:	Reference	Reference
Stream Sensitivity:	High	Very Low

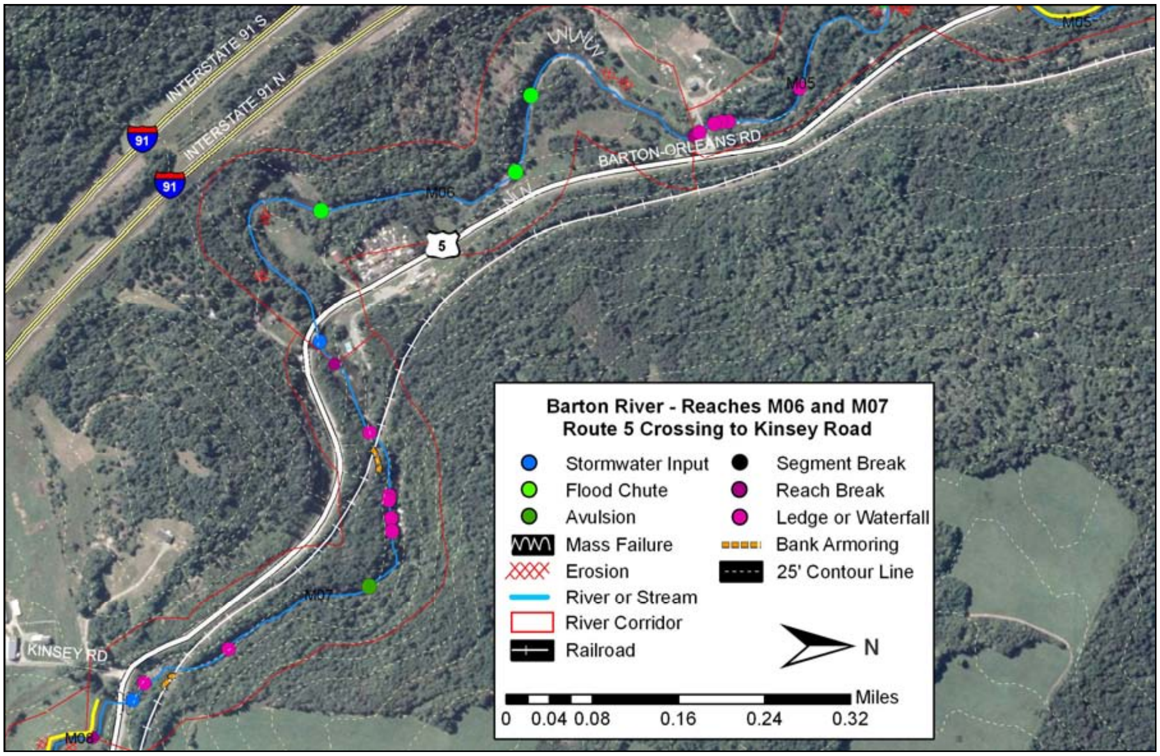


Figure 25: *Results for Barton River reaches M06 and M07. Steeper slopes have limited development along the corridors here.*

M06 and M07 (Figure 25) are excellent, reference-quality reaches located in a steep valley between Barton and Orleans. Both contain sections of quickwater and deep pools which provide excellent fish habitat. M06 contains cobbles and gravel as its bed sediments, while M07 is mostly bedrock with many ledges and waterfalls (Figure 26) scattered throughout the reach. Development along the corridors is limited by steep slopes and, in the case of M07, bedrock. The corridors should be protected against any future development in order to protect the uniquely intact habitats and aesthetics of the area.

Figure 26: *One of many bedrock ledges located in Reach M07.*

Barton River Reach M08 – Kinsey Road to Crystal Lake Outlet

Reference Stream Type: C dune-ripple, sand
Geomorphic Condition: Fair
Channel Evolution Stage: III (widening)
Habitat Condition: Fair
Stream Sensitivity: Very High

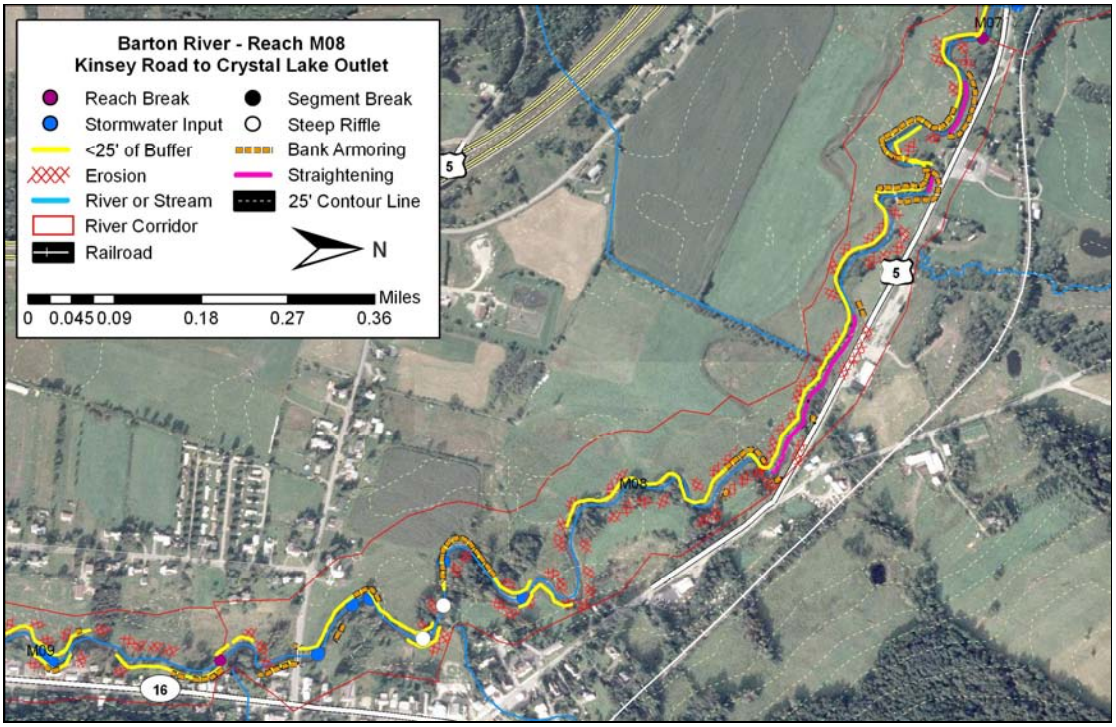


Figure 27: *Results for Barton River reach M08.*

Reach M08 flows through pasture for nearly its entire length. Forty-two percent of the reach has been rip-rapped, sometimes along both banks. The bank armoring is failing in many places. In areas where the rip-rap is intact, erosion is occurring along the opposite bank. Erosion is found along 77% of the reach, often along both sides. Bed sediments are very soft and the river appears very deep and slow-moving. The reach is incised (ratio 1.5) and appears to be aggrading and widening, except in places where it is fixed in place by rip-rap.

Fencing the entire corridor (which is also the entire floodplain) and establishing a forested buffer is recommended along this reach. This will greatly improve water quality, as most of the corridor is pasture and cattle are accessing the river. Portions of the reach are migrating (Figure 28), while others are fixed in place by rip-rap. An active restoration approach could include removal of the rip-rap to help the river establish an equilibrium state.

Figure 28: *Extensive erosion in this area of Reach M08 has caused several sections of a drainage pipe to collapse.*

Barton River Reach M09 – Crystal Lake Outlet to I-91

Reference Stream Type: E riffle-pool, gravel
Geomorphic Condition: Fair
Channel Evolution Stage: III (widening)
Habitat Condition: Fair
Stream Sensitivity: Very High

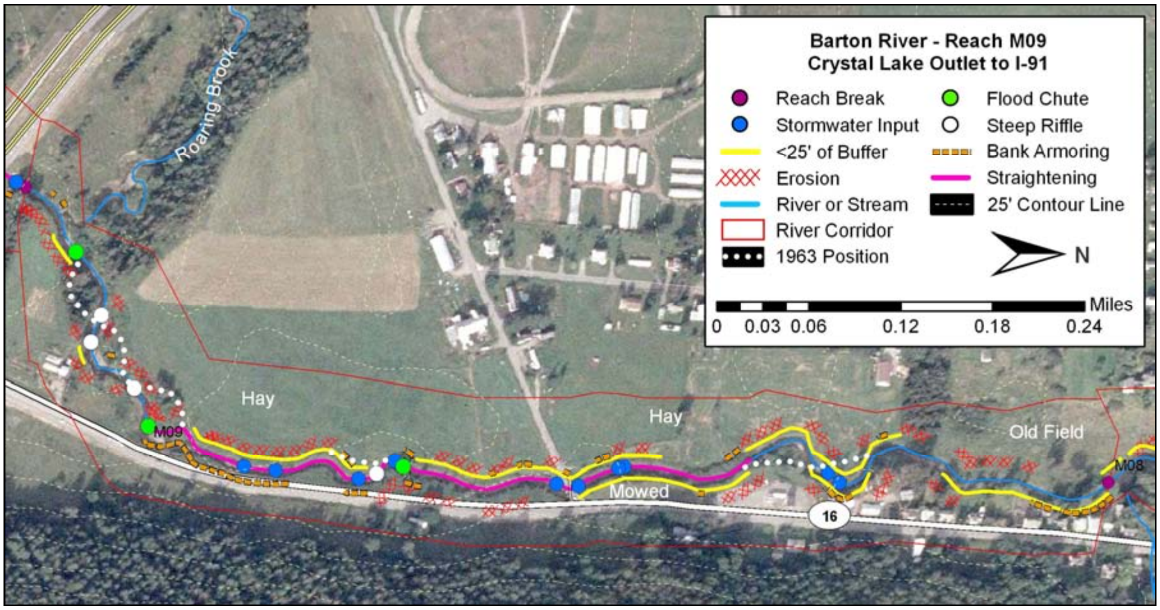


***Figure 29:** Results for Barton River reach M09.*

Most of the northern three-quarters of reach M09 (Figure 29) appears to have been straightened historically and remnants of rip-rap are found along the reach. Multiple stormwater inputs are also found along the reach. The river is incised (incision ratio 1.5) and appears to be widening and eroding to eventually develop a more meandering planform (Figure 30). The corridor is encroached upon by Route 16 and residential development on the right side. The left corridor is managed as hay field and is mowed to within 25' of the stream banks. The left banks are covered by herbaceous vegetation and woody vegetation is rare.

The southern quarter of this reach appears to be very dynamic, likely due to the influence of Roaring Brook and possibly due to the channel straightening that occurred to accommodate the I-91 bridge.1963 aerial photos show the river meanders to be in very different positions than they were at the time of this assessment. This pattern appears to be continuing, as fast waters are flowing directly against stream banks and several steep riffles are present in the area.

Establishment of a wide strip of natural woody vegetation along the left corridor will be necessary to improve habitat and water quality conditions along this reach. It should be kept in mind that the river will likely transition to a more meandering planform in future decades. The area in the vicinity of Roaring Brook will probably always be dynamic as it reacts to the sediment and flows originating from that tributary; development and agricultural practices should be kept as far from this area as possible.

Figure 30: *Eroding banks along reach M09*

Barton River Reach M10 – Upstream of I-91

Reference Stream Type: C riffle-pool, sand
Geomorphic Condition: Good
Channel Evolution Stage: I (stable)
Habitat Condition: Fair
Stream Sensitivity: High

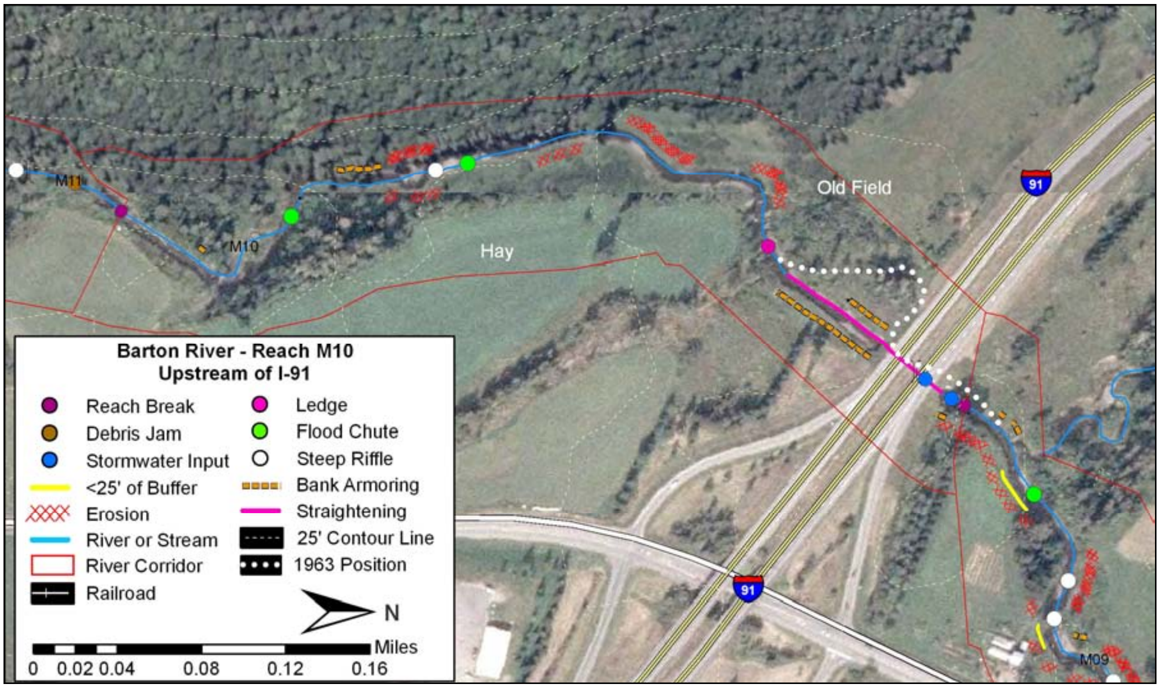


Figure 31: *Results for Barton River reach M10.*

Reach M10 flows through old fields and young forest. Overall, the reach is in good condition; it does not appear incised and erosion is infrequent. A portion is straightened to accommodate the I-91 bridge (Figure 31) but other human alterations of the river and its corridor are minimal. Given enough time, a forested buffer on the northern half of the reach will likely regenerate on its own. Protection of the corridor will be the key strategy to keep this portion of the river in good condition.

Barton River Reach M11 – Downstream of Route 16 Crossing in Glover

Reference Stream Type: E riffle pool, gravel
Geomorphic Condition: Good
Channel Evolution Stage: I (stable)
Habitat Condition: Fair
Stream Sensitivity: High

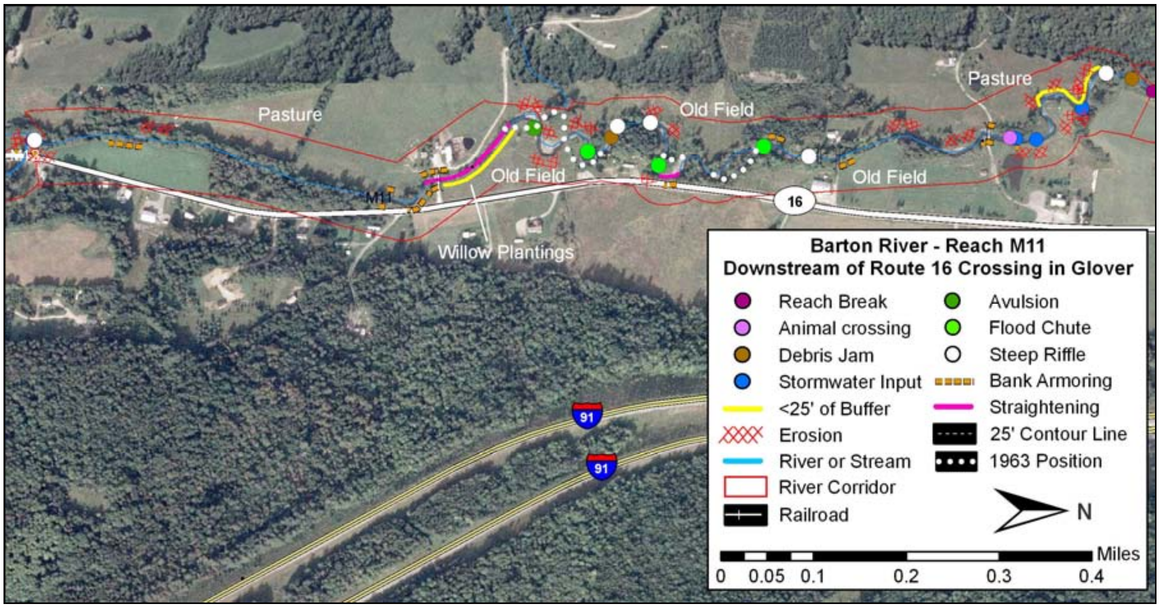


Figure 32. *Results for Barton River reach M11.*

Starting just below Glover Village as a fast flowing river over a cobble bed, Reach M11 (Figure 32) quickly transitions to become sinuous and dynamic. The reach has changed position in several locations since the 1963 aerial photographs were taken, and continued migration is evident, including numerous aggradational features (steep riffles, flood chutes, and an avulsion). Significant sequences of erosion and deposition were observed as well.

Old fields dominate the corridor, with some active pasture towards the beginning and end of the reach. A willow planting project was started along the southern portion of the reach in the spring of 2008 by Greg Hennemuth, NorthWoods Stewardship Center staff, and several volunteers. This project was intended to restore woody vegetation along the river bank and to serve as a nursery for future willow plantings. Further downstream, there is a need to fence off a buffer from cattle, as the land is currently grazed to the river's edge. Willow and tree plantings are necessary here to help stabilize some of the high eroding banks. Overall, the entire corridor needs to be restored and protected, as the river is likely to continue migrating in the future.

Figure 33: *Erosion and deposition along Reach M11.*

Willoughby River Reach T3.01A and T3.01B – Barton River Confluence to Willoughby Falls

Segment T3.01A:	Segment T3.01B:
Reference Stream Type: E dune-ripple, sand	C riffle-pool, sand
Geomorphic Condition: Good	Good
Channel Evolution Stage: I (stable)	I (stable)
Habitat Condition: Good	Good
Stream Sensitivity: High	High

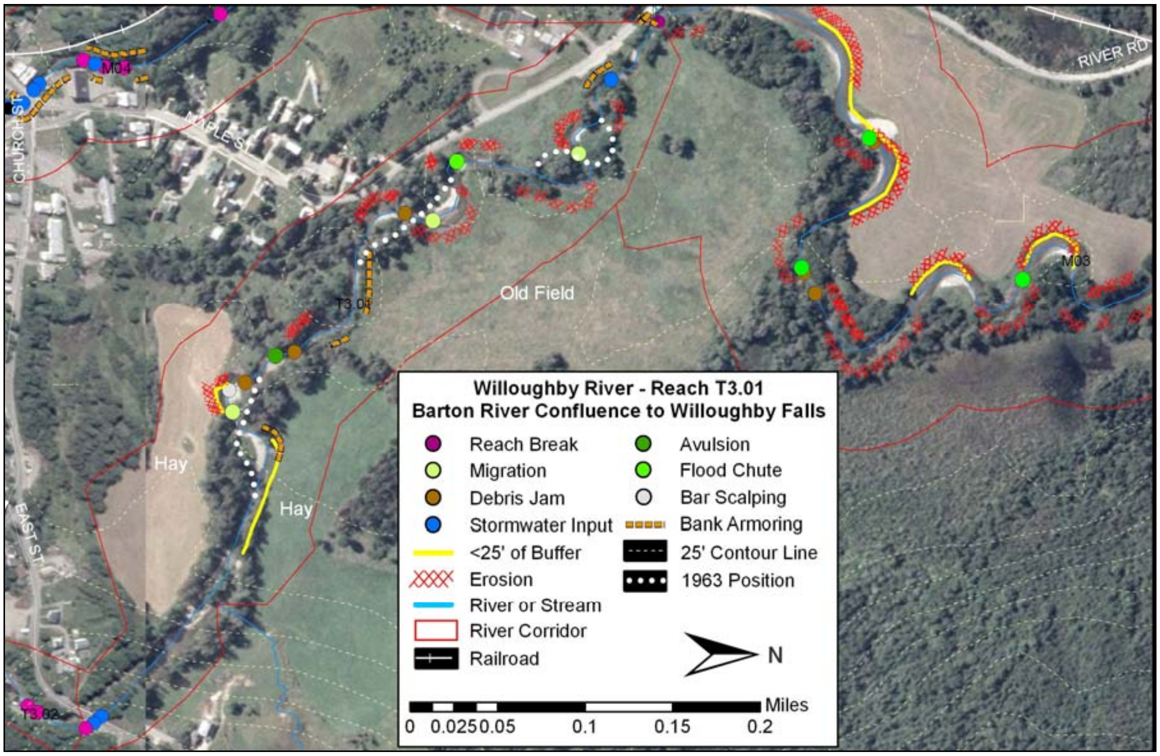


Figure 34. *Results for Willoughby River reach T3.01. Note the river's 1963 position (white dotted line).*

A popular fishing area, Reach T3.01 (Figures 34 and 35) is at the receiving end of several miles of fast-flowing river that has carried and deposited a significant amount of sediment originating from multiple large mass failures located several miles upstream. The river levels out at reach T3.01, and it is clear that large amounts of sediment are working through this section. This is particularly evident in segment A where sand and silt deposits are very deep. The river has migrated at several points since the 1963 aerial photos. This process seems to be ongoing, as large trees are leaning in a few areas and there are several sections with high, slumping banks. Some portions have been rip-rapped, but it appears that these efforts have only deflected the flows to erode the downstream banks.

The fields along the western portion of the river are in the Willoughby Falls WMA and are no longer managed. Tree and willow plantings have been done along the banks and seem to be well-established in some areas, although large eroding banks remain in other areas. Upstream there are two managed hay fields and both are mowed close to the river banks. Due to the dynamic nature of this reach, as much of the river corridor as possible should be restored to natural forest cover. A significant need for tree and willow planting exists here for habitat improvement and erosion control.

Figure 35: *Gravel bars along Willoughby River reach T3.01B.*

<u>Willoughby River Reach T3.02</u> – Willoughby Falls to Churchill Road

Reference Stream Type: C riffle-pool, gravel
Geomorphic Condition: Good
Channel Evolution Stage: I (stable)
Habitat Condition: Reference
Stream Sensitivity: High

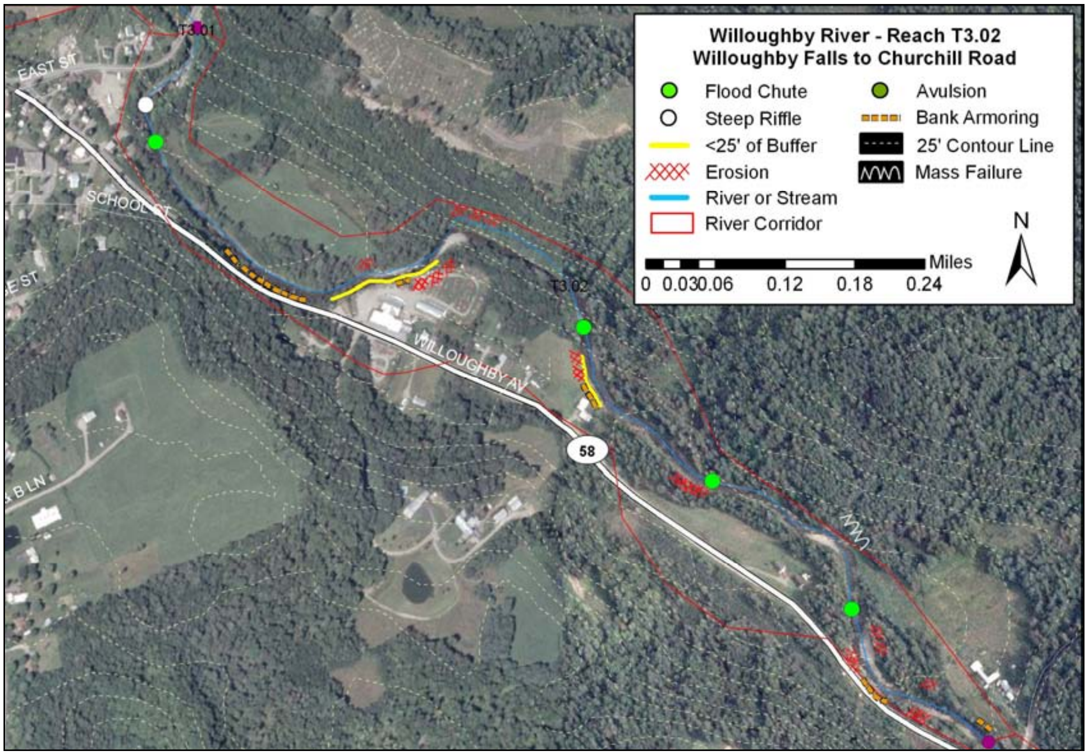


Figure 36: *Results for Willoughby River reach T3.02*

Reach T3.02, which includes Willoughby Falls, is in good condition overall (Figure 36). It contains many gravel bars and flood chutes due to the large amount of sediment introduced to the reach from sources upstream. Mowing has occurred up to the top of the left bank in places, but development is sparse, particularly along the steep right corridor. Typical of much of the Willoughby River, the majority of the corridor is forested and the water is swift and clear.

Willoughby River Reaches T3.03A and B; T3.04 – Churchill Road to Center Road

	Segment T3.03A:	Segment T3.03B:
Reference Stream Type:	C riffle-pool, cobble	C riffle-pool, cobble
New Stream Type:	F plane-bed, cobble	
Geomorphic Condition:	Poor	Good
Channel Evolution Stage:	III (widening)	I (stable)
Habitat Condition:	Good	Reference
Stream Sensitivity:	Extreme	Moderate

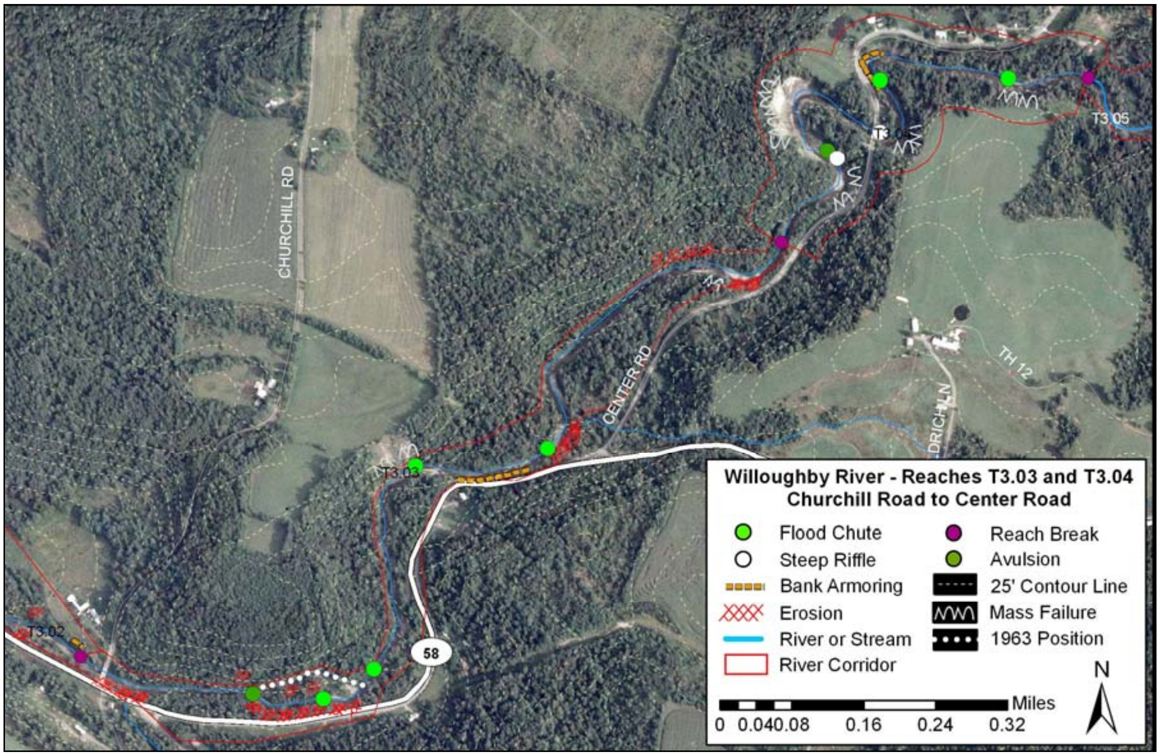


Figure 37: *Results for Willoughby River reaches T3.03 and T3.04.*

Reach T3.03 flows swiftly over boulders and cobbles in a mostly forested corridor (Figure 37). Reach T3.03A has avulsed; the river has abandoned its old channel (utilized in 1963) and has formed a new channel approximately 600ft in length. This section is very incised (incision ratio 2.2), with flooding only possible during very high flows. Development within this corridor is not advisable, as it is in poor geomorphic condition and further erosion and widening are anticipated. Reach T3.03B passes through two mass failure sites, which serve as large sediment sources for reaches downstream.

Another swift and boulder-dominated reach, Reach T3.04 passes through four large mass failure sites (Figure 38). Large sediment inputs manifest themselves as the multiple steep riffles and flood chutes seen along both this reach and the downstream reaches as it attempts to transport the sediment downstream. One of the steep riffles is located just upstream of the Center Road bridge and has directed the majority of the flow against the left bridge abutment.

Figure 38: *Typical section of the Willoughby River (Reach T3.03, above); One of several mass failure sites on the Willoughby River (Reach T3.04, below).*

PART II
JOHNS RIVER

6. BACKGROUND WATERSHED INFORMATION

6.1 GEOGRAPHIC SETTING

6.1.1 Johns River Watershed Description

The Johns River drains an area of approximately 10mi^2, extending from its headwaters east of I-91 to its mouth at Derby Bay in Lake Memphremagog. The mainstem originates amid rolling hills in the southeast portion of the watershed and is approximately 8.6 miles in length. The largest and only named tributary to the Johns River is Crystal Brook, which originates in the northeast portion of the watershed and joins the river shortly downstream of the I-91 crossing. There are no lakes in the watershed and only a handful of small, un-named ponds.

6.1.2 Political Jurisdictions

The Johns River Watershed lies in Orleans County in northeast Vermont, almost entirely within the Town of Derby. A small portion of the river flows through Stanstead, Quebec, then re-enters Derby 0.9 miles downstream. About 96% of the watershed lies in Vermont and 4% lies in Quebec.

6.2 GEOLOGIC SETTING

The Johns River Watershed lies entirely within the Northern Vermont Piedmont biophysical region. Elevations in the watershed range from 700 feet above sea level at Lake Memphremagog to 1732 feet at Nelson Hill. The region is dominated by rolling hills and calcium-rich soil which facilitated the establishment of many farms in the area and the clearing of approximately 80% of the original forest cover by 1900 (Thompson and Sorenson 2000). Much of the lower watershed was once occupied by proglacial Lake Memphremagog, whose shoreline was as much as 300 feet higher than the current lake level (Stewart and MacClintock 1969).

6.3 GEOMORPHIC SETTING

6.3.1 Description and Mapped Location of the Assessed Reaches

The Johns River and most of its tributaries were divided into 35 reaches and sub-watersheds using topographic maps and aerial photographs. Each reach represented a section of stream with physical attributes that distinguished it from reaches immediately upstream and downstream. These attributes include valley width, valley slope, channel width, and sinuosity. We focused these assessments in the Beebe Plains area of Derby to better explain high nutrient and sediment inputs found in the region, targeting the Johns

River and a portion of an unnamed tributary paralleling Darling Hill Road. Eight of these reaches received Phase 1 Assessments; six were chosen for the Phase 2 field assessments.

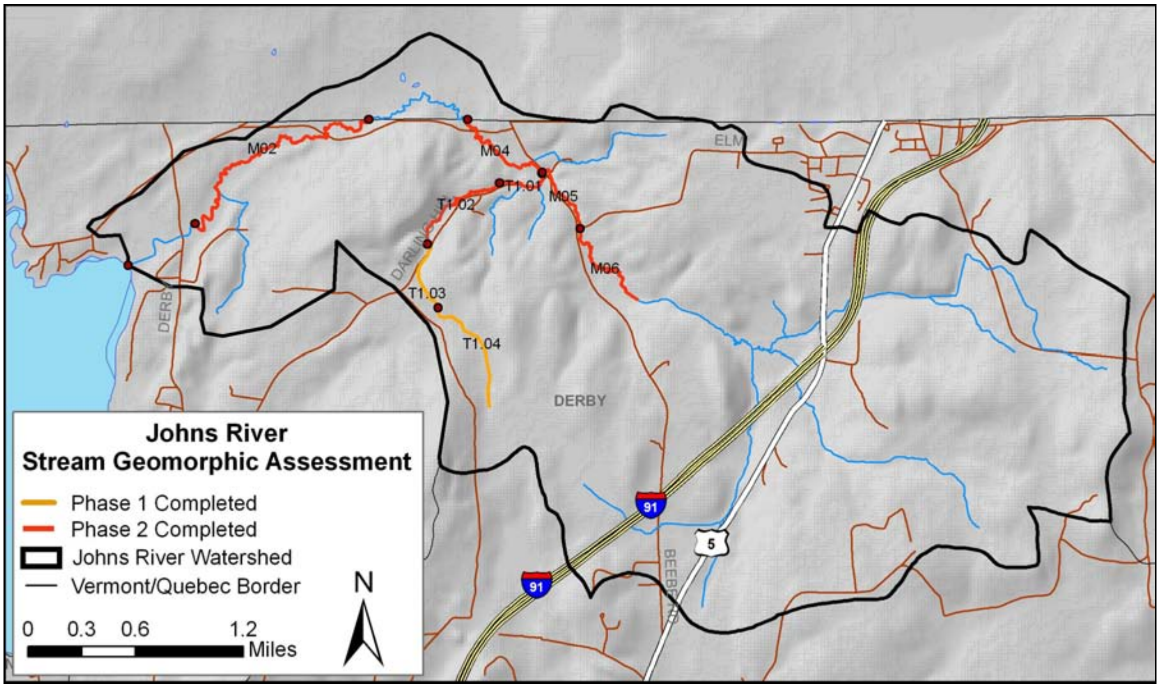


Figure 39: *Assessed and numbered reaches in the Johns River Watershed. Phase 1 Assessments were completed on 8 reaches (totaling 5.8 river miles); Phase 2 Assessments were completed on 6 reaches (totaling 4.6 river miles).*

6.3.2 Longitudinal Profile, Alluvial Fans, and Natural Grade Controls

The Johns River originates as a small stream amid agricultural fields in hilly terrain at approximately 1378 feet in elevation. The river then flows steeply through a forested area until the I-91 crossing (Reaches M11-M10), dropping 374 feet over 1.6 miles. Below the I-91 crossing, the Johns River receives inputs from two tributaries, Crystal Brook and an unnamed tributary, in a broad and flat wetland. The river meanders through the wetland for 0.8 miles before entering another steeper and confined valley.

The river then cascades through the steep, forested valley for 0.5 miles, dropping another 197 feet (Reach M07). It then quickly flattens out in a beaver wetland where the channel is split and flows through both active and breached beaver dams for approximately 0.7 miles (Reach M06). After passing Elm Street, the river flows over steeper terrain and one small bedrock ledge before leveling off near Darling Hill Road (Reach M05), dropping 40 feet in 0.4 miles. From Darling Hill Road to Lake Memphremagog (Reaches M04-M01), the Johns River slowly meanders through a pasture and extensive alder wetlands for the remaining 3.4 miles.

6.3.3 Valley and Reference Stream Data

Using topographic maps and windshield surveys, data were collected to describe the valley setting for each reach, determining the type of stream found there (Table 5). Stream types were assigned based on the Rosgen stream classification system (Appendix B). For example, C and E stream types were found in the wider valleys of the watershed, where the river deposits sediments on the adjacent floodplain. These stream types were found in river reach with 0-2% slope. Faster, cascading B stream types were found in confined valleys in a few locations in the watershed where channel slopes exceeded 2%. Here sediment transport is the dominant regime; these sediments are eventually deposited in the broad floodplains encountered along the way to the river's mouth at Lake Memphremagog.

Table 5. Valley and channel characteristics for the main stem of the Johns River (reaches M02-M06) and an unnamed tributary (reaches T3.01-T3.04)

Reach	Channel Width (ft)	Channel Slope (%)	Sinuosity	Valley Type	Reference Stream Type	Reference Stream Bedform
M02	19	0.09	1.31	Very Broad	E	Dune-Ripple
M04	33.1	0.47	1.3	Very Broad	E	Dune-Ripple
M05	29.9	1.7	1.11	Semi-Confined	C	Plane Bed
M06	29.7	1.06	1.26	Very Broad	E	Dune-Ripple
T1.01	7.5	1.13	1.13	Very Broad	E	Dune-Ripple
T1.02	11.1	2.19	1.18	Very Broad	E	Riffle-Pool
T1.03	10	5.27	1	Narrowly-Confined	B	Step-Pool
T1.04	8.4	2.05	1	Narrow	B	Not Evaluated

7. RESULTS AND DISCUSSION

7.1 IDENTIFICATION OF HYDROLOGIC AND SEDIMENT REGIME STRESSORS IN THE WATERSHED

7.1.1 Hydrologic Regime Stressors

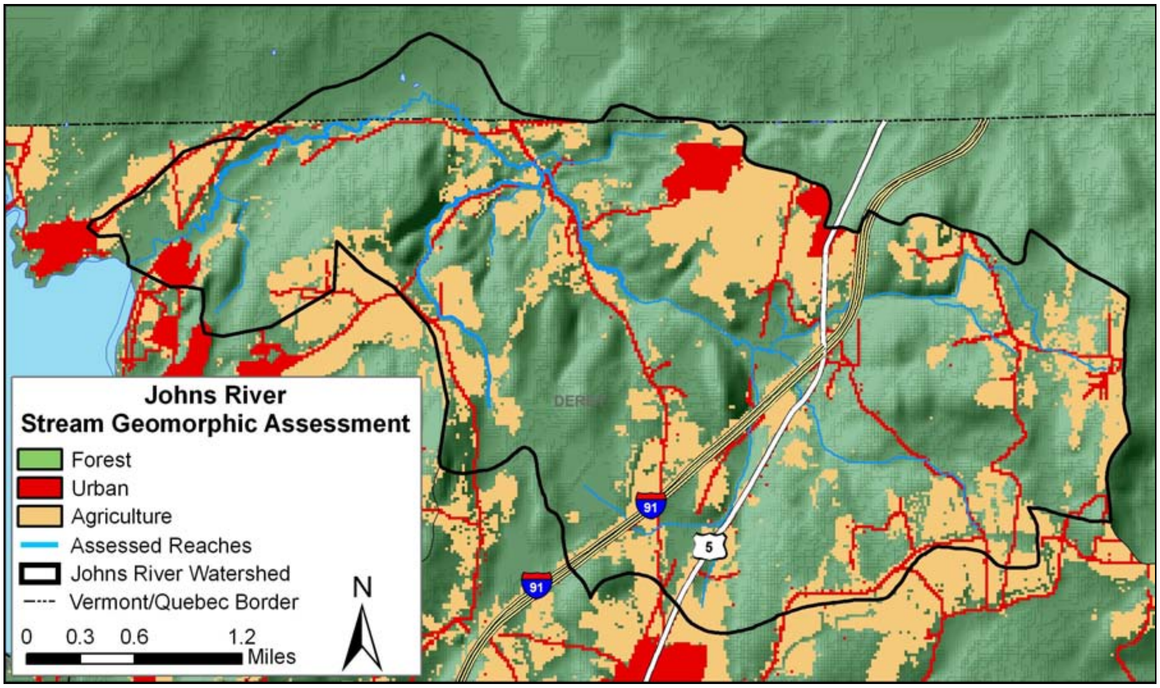


Figure 40: *Land Use in the Johns River Watershed, showing agricultural land (uses include hay, crops, and pasture) and urban land (includes residential, industrial, commercial, and transportation uses).*

Land Cover / Land Use

Natural land cover types, such as forests and 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 and snowmelt runoff by decreasing the amount of natural vegetation available to naturally filter water and sediment. Urban lands also contain large amounts of impervious surfaces where stormwater will quickly run off into adjacent drainages rather than slowly percolating through the soil, resulting in higher peak flood levels in addition to high nutrient and sediment inputs. Consistently high stormwater runoff can trigger a channel to enlarge and incise.

Figure 40 depicts current land uses in the Johns River Watershed, which are summarized by type in Table 6. Natural vegetation like forests and wetlands cover 62% of land in the Johns River watershed, compared with 70.8% and 68.9% of forest cover in the Barton and Clyde Watersheds, respectively. Agricultural land uses occur over 27.1% of the watershed, a value that is much higher than in the Barton (16.9%) and Clyde (18.1%) watersheds. Agricultural land occasionally occurs near the Johns River and its tributaries, particularly in the Beebe Plains area and tributary headwaters, but usually occurs in upland areas. Most urban lands are concentrated in Derby Line but also occurred sporadically in Beebe Plains. The urban land at river's mouth in Figure 41 is comprised of a residential neighborhood and the accompanying large lawn areas. Urban lands make up 8.5% of the Johns River Watershed, similar in extent to the Clyde River Watershed (8.6%), but significantly more than the Barton River Watershed (5.5%).

Table 6. Summary of Land Uses in the Johns River Watershed

Land Use	Percentage of Watershed	
Mixed coniferous-broadleaf forest	23.7%	Forested or brush: 57.3%
Broadleaf forest (generally deciduous)	15.2%	
Coniferous forest (generally evergreen)	18.4%	
Brush or transitional between open and forested	<0.1%	
Forested wetland	3.7%	Wetland: 4.7%
Non-forested wetland	1.0%	
Row crops (not including orchards and berries)	12.7%	Agriculture: 27.1%
Hay/rotation/permanent pasture	14.4%	
Other agricultural land	<0.1%	
Residential	2.0%	Urban: 8.5%
Commercial, services, and institutional	0.2%	
Industrial	<0.1%	
Transportation, communication, and utilities	6.3%	
Outdoor and other urban and built-up land	<0.1%	
Barren land	<0.1%	Other: 2.3%
Water	2.3%	

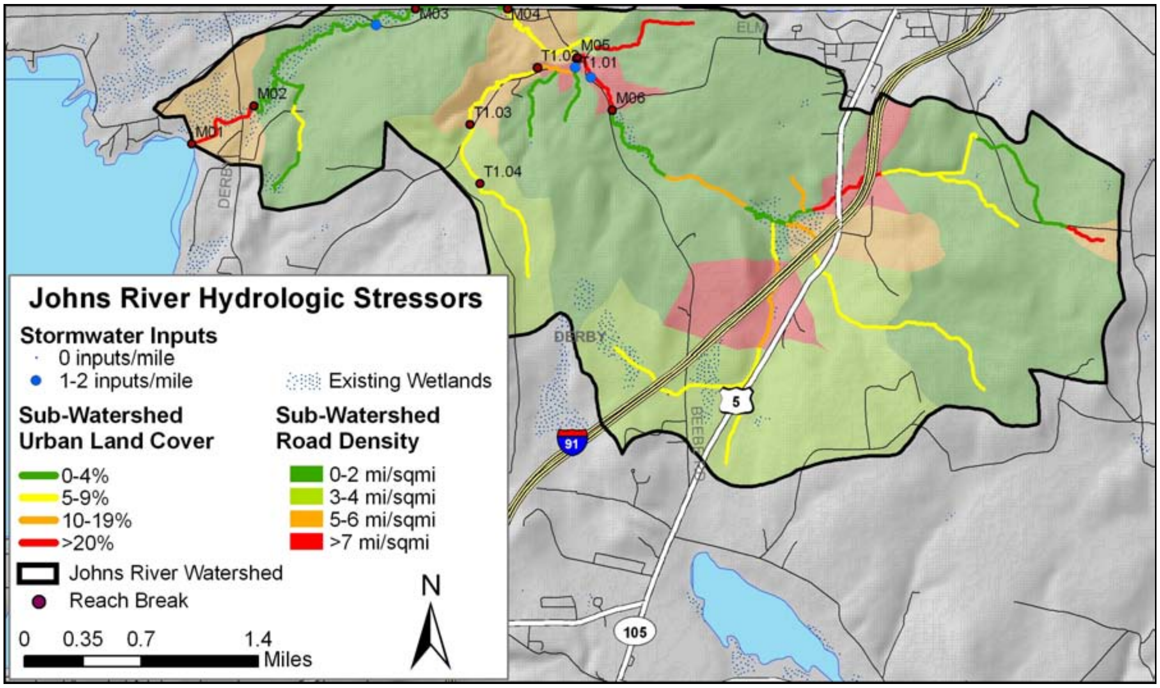


Figure 41: Hydrologic Stressors in the Johns River Watershed, including road density, stormwater inputs, and sub-watershed urban land cover.

Hydrologic Stressors: Stormwater Inputs, Road Densities, and Urban Land Cover

Figure 41 depicts hydrologic stressors within individual sub-watersheds in the Johns River Watershed. Collectively, these stressors could increase peak flow levels, leading to increased erosion levels and sediment inputs into the Johns River and its tributaries. Stormwater inputs were documented during the Phase 2 assessments to determine whether a reach may be responding to periodic high water flows during rain events. Examples of stormwater discharges include field and road ditches, tile drains, and urban stormwater inputs. These features function to whisk water quickly away from land surfaces and into nearby stream channels. Reaches receiving many stormwater inputs may erode and enlarge to accommodate those sudden high flows. Stormwater inputs were only occasionally encountered along the Johns River, and never exceeded densities greater than 1-2 inputs per mile.

Urban land cover includes residential, industrial, and commercial development as well as transportation infrastructure. These land uses create impervious surfaces that shed water quickly into nearby drainages, rather than allowing it to slowly percolate through the soil. In Figure 41, red lines highlight sub-watersheds with the highest urban land uses (over 20% of the sub-watershed area), which are found near the mouth of the Johns River, in the Beebe Plains area, and a portion of Crystal Brook near I-91.

Both gravel and paved roads affect the watershed like urban lands, containing impervious surfaces which shed water quickly. Ditching along these roads functions to whisk water quickly away into nearby tributaries. Road densities have been calculated based on the number of miles of road per square mile of land. Densities for Johns River sub-watersheds range from 0 miles/square mile to 11 miles/square mile. The highest densities exist in areas along the I-91 corridor and in the Beebe Plains area.

7.1.2 Sediment Regime Stressors

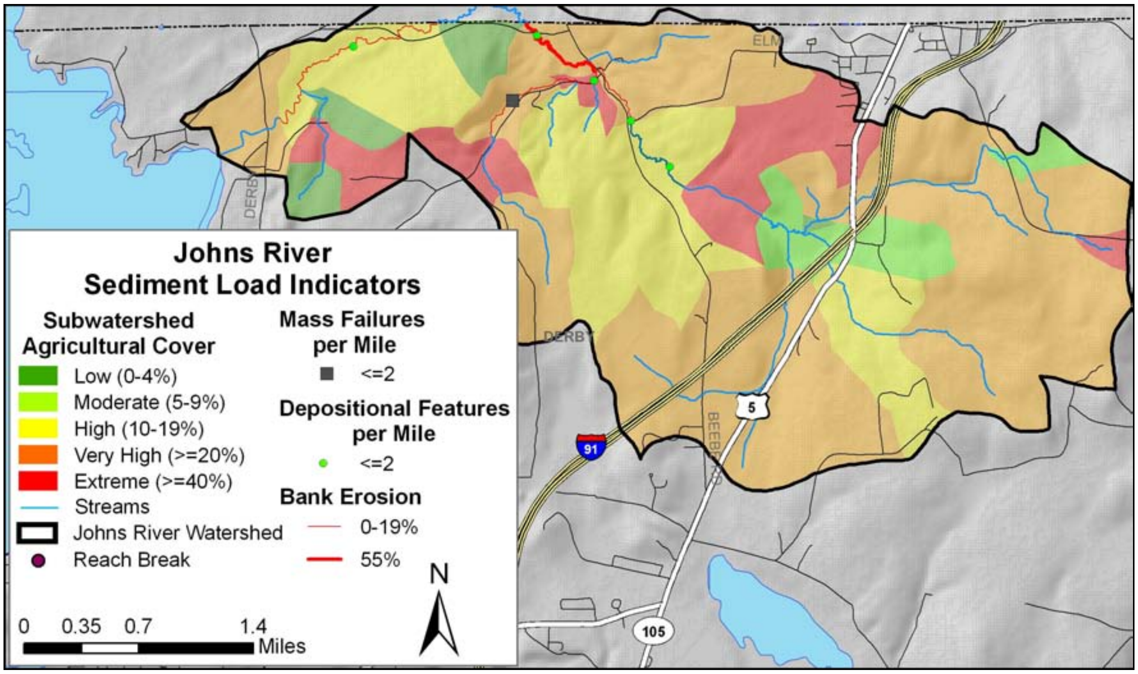


Figure 42: Sediment Load Indicators in the Johns River Watershed. Mass failures, depositional features, and bank erosion apply to Phase 2 reaches only.

Sediment Load Indicators: Agricultural Cover, Sediment Sources, Depositional Features

Streams naturally erode, move, and deposit sediment. Erosion occurs on the outer bank of meander bends, where the water flows fastest and contains the most energy. The sediment is then deposited on point bars along the inner bank, where the current is slowest. This process is a natural part of stream evolution as it responds to varying flow levels and sediment inputs over time, and results in the maintenance of relatively moderate stream power and resulting channel erosion.

In the absence of human influences average flow levels and sediment inputs vary little over time and the erosion process is quite slow, although some streams located on alluvial fans or at the base of very steep valleys are naturally more dynamic. Streams that exhibit excessive adjustments in the form of lateral and vertical migration (such as avulsions, neck cut-offs, channel widening and incision) and widespread erosion are likely to be responding to a variety of stream channel or watershed stressors disturbing the sediment regime.

Indicators and sources of the sediment load within the Johns River watershed are displayed in Figure 42. Erosion was infrequently encountered along assessed reaches, with the exception of continuous erosion in the Beebe Plains area. Erosion was occasionally found along the small tributary paralleling Darling Hill Road and one mass failure was found there as well. The most significant sediment stressor in the Johns River Watershed appears to be the amount of land devoted to agriculture, which is measured here as the percentage of land devoted to crop, hay, pasture, and other agricultural uses. Most sub-watersheds have over 20% of their land converted to agriculture, while several sub-watersheds contain more than 40% agricultural land. Depositional features and channel adjustments that indicate a high sediment load are also displayed in Figure 42. These features include steep riffles, mid-channel bars, flood chutes, and channel avulsions. Such features were infrequently encountered along the Johns River.

7.1.3 Channel Constrictions and Stream Crossings

Bridges and culverts that are narrower than the stream channel width may exacerbate channel stability by causing excessive deposition upstream of the structure and increasing stream velocity and erosive energy downstream of the structure. This often results in localized areas of sediment deposition, erosion, fish passage problems, and ice and debris jams. In some cases, the stream crossing may increase the risk of flooding and property damage by forcing the river to flow around or over the bridge during high flows.

Table 7 shows the widths of all bridges, culverts, and old abutments measured in the Phase 2 assessments. Of the 10 structures listed, all are constricting the stream channel. However, because of the slow flows typical of the Johns River, few stream crossings have actually affected the river. Three structures have affected the river to a significant extent, and of these one culvert should be reinstalled because it is at high risk for becoming plugged with debris and sediment (Figure 43).

Table 7. Channel constrictions and stream crossings.

Reach	Road Name	Type	Structure Span (ft)	Channel Width (ft)	% of Stream Width	Floodplain Constriction?	Length of River Affected (ft)	Comments/ Problem Associated With Bridge
M02	Private	Culvert	9	19	47	No	30	Some minor scour upstream of the culverts
M02	Private	Old Abutment	7	19	37	No	20	Some scour downstream but not significant
M02	N. Derby Road	Culvert	11	19	58	No	100	Scour pools upstream and downstream
M04	N. Derby Road	Culvert	8.5	16	53	Yes	0	None
M04	Private	Bridge	15	16	94	No	0	None
M05	N. Derby Road	Bridge	22.5	30	75	Yes	80	River is flowing against left abutment; gravel bar beneath bridge
M05	Elm Street	Culvert	9.5	30	32	Yes	70	Minor scour upstream and downstream
T1.01	Darling Hill Road	Culvert	5	8	63	Yes	0	None
T1.01	Darling Hill Road	Culvert	5	8	63	Yes	54	Abundant sediment deposition in and downstream of culvert. Culvert is over halfway plugged with sand. Needs attention.
T1.02	Private	Culvert	4	9	44	Yes	70	Culvert is perched with about 1’ drop to water surface. Cinder blocks placed downstream to hinder scouring.

Figure 43: *Sediment accumulation downstream of culvert on Reach T1.01; deposition beneath bridge on M05.*

7.2.1 Geomorphic Condition Ratings and Channel Evolution Stage

For explanations of channel evolution and geomorphic condition ratings, refer to section 5.2.1 in Part 1 of this report. All assessed reaches in the Johns River watershed are in stable (Stage I) condition; none have experienced the stressors required to cause incision or any of the subsequent steps of channel evolution. The majority (77%) of the Phase 2 reaches are in reference condition. The remaining two (23%) of the six Phase 2 reaches are in good condition (Figure 44).

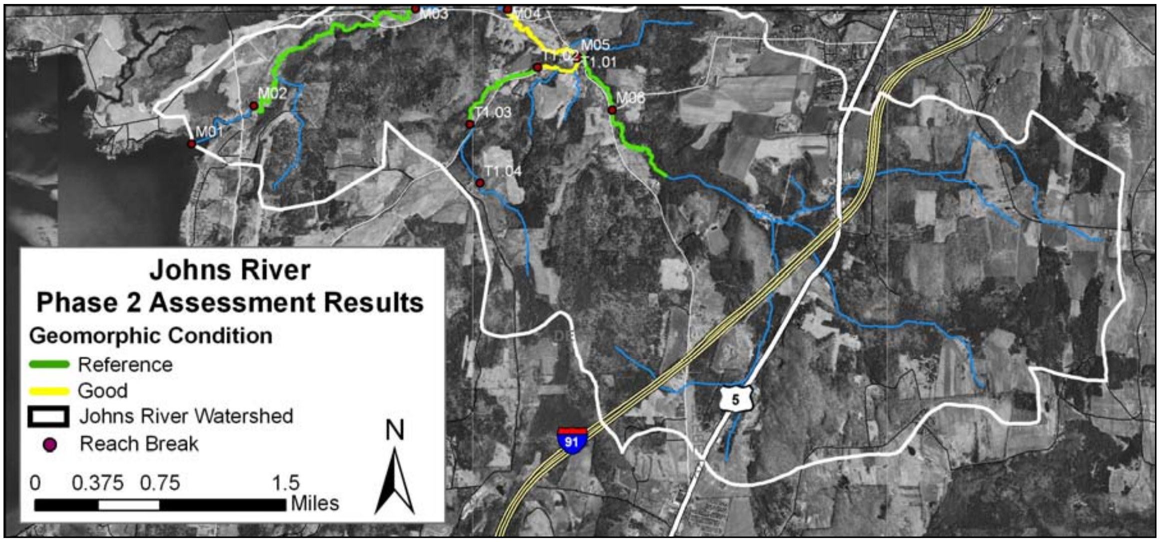


Figure 44: *Stream Geomorphic Assessment results for the Johns River.*

The watershed-scale and reach-scale stressors for each Phase 2 reach are summarized in Table 8. This table depicts reaches which may be affected by changes to the watershed's hydrologic regime, watershed-scale or upstream sediment inputs, and bank resistance changes. Most Johns River reaches may be affected by watershed-scale stressors (such as upstream land uses) rather than stressors within the stream corridor or the river itself.

Table 8: Summary of Watershed and In-stream Stressors along the Johns River

	Regime Stressors		**Reach Modification Stressors**	
River Segment (Existing Stream Type, CEM, RGA score*)	**Hydrologic (urban, roads, stormwater, wetland loss, development)**	**Sediment (depositional features, erosion, cropland, migration, mass failure)**	**Stream Power (Increase: straightening, encroachments; Decrease: deposition, migration)**	**Boundary Resistance (Increase: bank armoring, grade controls; decrease: erosion, reduced vegetation)**
M02 **(E5, I, Reference)** Not Incised	Increased flows: • Moderate (7%) urban land cover in watershed	Increased load: • High (12%) cropland in watershed	Not Significant	Not Significant
M04 **(E5, I, Good)** Not Incised	Increased flows: • Moderate (7%) urban land cover in watershed • Wetland loss • Moderate (7%) urban land cover in corridor	Increased load: • High (14%) cropland in watershed • Extreme (>60%) cropland in corridor • High (55%) bank erosion • Migration	Increased power: • High (22%) channel straightening • Moderate (13%) road encroachment Decreased power: • Migration	Decreased resistance: • Woody riparian vegetation uncommon • High (55%) bank erosion Increased resistance: • Low to moderate (10%) bank armoring
M05 **(C3, I, Reference)** Not Incised	Increased flows: • Moderate (7%) urban land cover in watershed • Extreme (30%) urban land cover in corridor	Increased load: • High (13%) cropland in watershed • Moderate (11%) bank erosion	Not Significant	Decreased resistance: • Moderate (11%) bank erosion Increased resistance: • High (20%) bank armoring • Two bedrock ledges
M06 **(E5, I, Reference)** Not Incised	Increased flows: • Moderate (6%) urban land cover in watershed	Increased load: • High (14%) cropland in watershed • Moderate (8%) cropland in corridor	Not Significant	Not Significant

T1.01 **(E5, I, Good)** Not Incised	Increased flows: • Extreme (24%) urban land in corridor	Increased load: • High (11%) cropland in watershed • High (11%) cropland in corridor • Moderate (9%) bank erosion	Increased power: • High (41%) channel straightening • High (99%) road encroachments Decreased power: • Sediment deposition	Decreased resistance: • Moderate (9%) bank erosion
T1.02 **(E4, I, Reference)** Not Incised	Increased flows: • Moderate (6%) urban land cover in watershed • High (11%) urban land cover in corridor	Increased load: • High (14%) cropland in watershed • Moderate (8%) cropland in corridor • Moderate (12%) bank erosion • Migration features	Increased power: • High (54%) road encroachments Decreased power: • Migration features • Sediment deposition	Decreased resistance: • Moderate (12%) bank erosion

*For Stream Type descriptions, see Appendix B. Stream type lettering is followed by the dominant bed material: 1 = bedrock, 2 = boulder, 3 = cobble, 4 = gravel, 5 = sand; CES = Channel Evolution Stage (Figure 10); RGA Score = Rapid Geomorphic Assessment Score

7.3 RESULTS AND RECOMMENDATIONS FROM PHASE 2 FIELD SURVEYS

The results of the Johns River Phase 2 field surveys are summarized in the following pages along with restoration and management recommendations. All stream types are listed, followed by the dominant streambed material. In the accompanying figures, the field measurements and locations of other features are overlaid on 1999 aerial photographs (USDA 1999). For stream type descriptions, see Appendix B.

<u>Johns River Reach M02</u> – Fishing Access to Quebec Border

Reference Stream Type: E dune-ripple, sand
Geomorphic Condition: Reference
Channel Evolution Stage: I (stable)
Habitat Condition: Reference
Stream Sensitivity: High

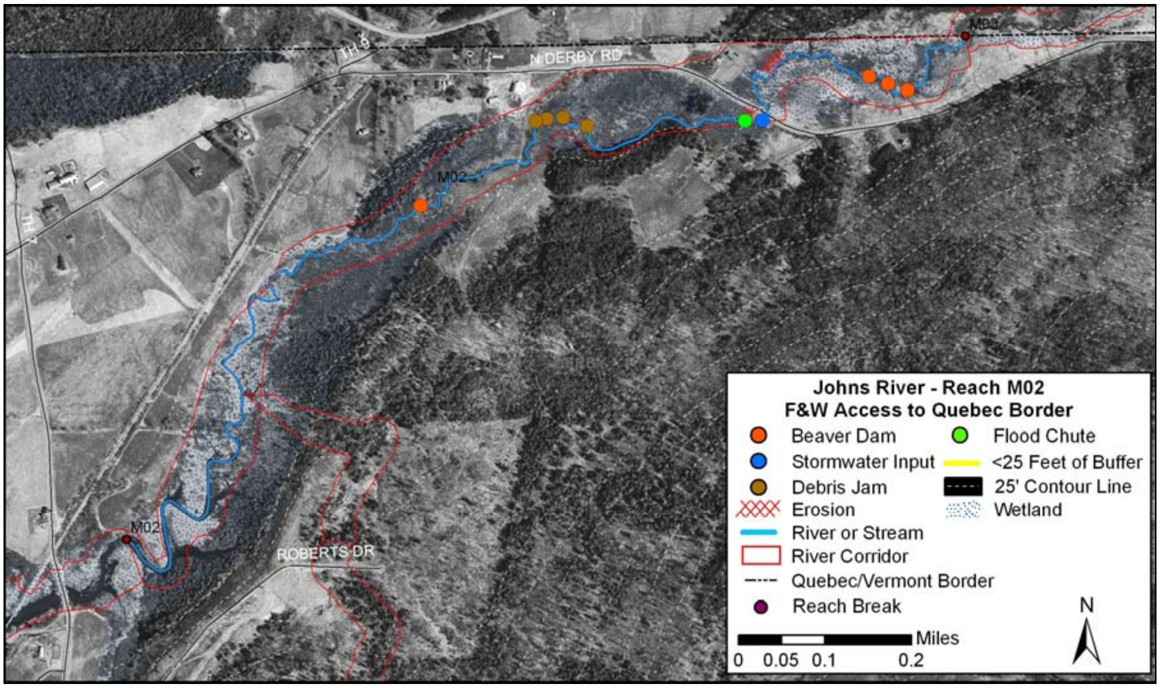


Figure 45: *Results for Johns River Reach M02.*

The overwhelming majority of Reach M02 is an alder wetland with minimal human impact within the channel's corridor. Most hay fields along the western portion of the reach begin at least 50 feet from the channel, due to very wet and swamp-like conditions caused by nearby Lake Memphremagog. Since the 1999 photograph shown in Figure 45, several land-use changes have occurred. A field south of North Derby Road has been abandoned and stream bank vegetation should re-establish itself well. A fenced horse pasture has been added just south of the Quebec/Vermont border but is located at least 50 feet from the river.

Reach M02 is in excellent geomorphic condition and contains excellent aquatic habitat. Restoration projects should not be necessary here, but protection of the wetlands along the stream corridor should be a priority to maintain stream health and habitat quality.

Johns River Reach M04 – Quebec Border to Lawson Road

Reference Stream Type: E dune-ripple, sand
Geomorphic Condition: Good
Channel Evolution Stage: I (stable)
Habitat Condition: Fair
Stream Sensitivity: High

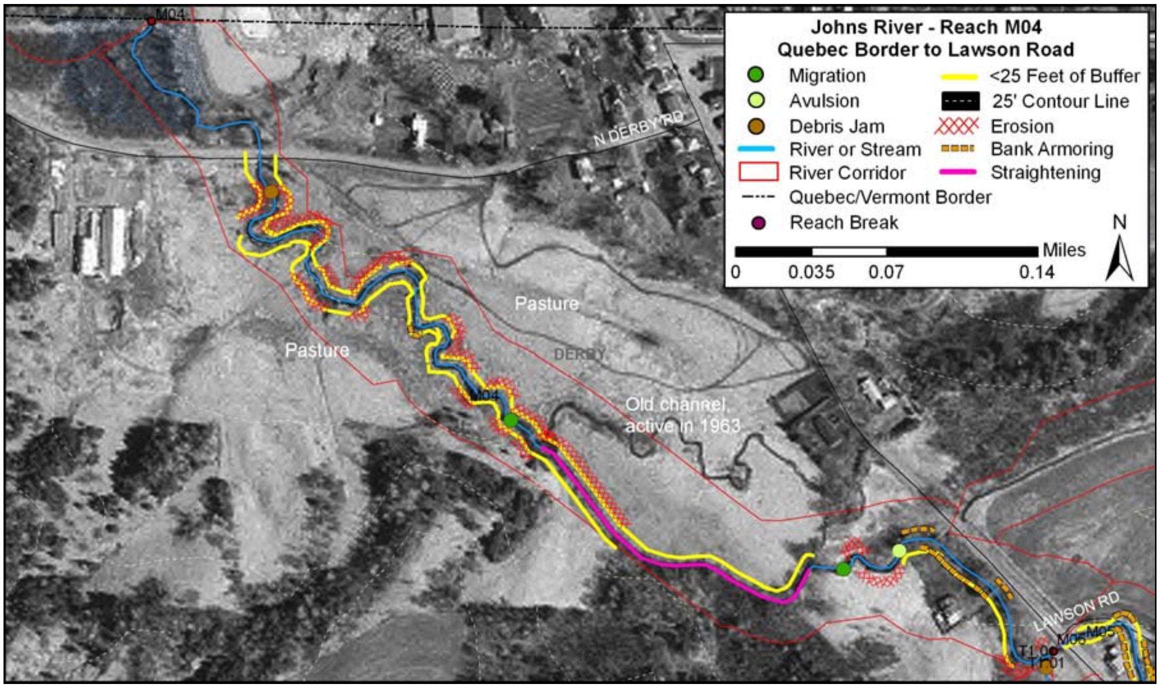


Figure 46: Results for Johns River Reach M04.

Reach M04 flows through an active pasture for nearly its entire length. An old channel (seen in Figure 46) meanders through the pasture while the river now occupies a straightened channel located against a hillside to the south of the pasture. Fencing is located along one bank in the straightened portion, set back about five feet from the river, but is absent along the remainder of the reach. Eroding banks are present throughout most of the reach, and grazing clearly occurs along most banks (Figure 47). It appears that cattle utilize the river both as a water source and to access the pasture located to the northeast of the river. Numerous drainage ditches exist in the pasture which appears to flood regularly, and was likely a wetland prior to being ditched and drained. Although these issues exist, the reach is still in good geomorphic condition because the channel is not incised and most stressors are local. Water quality would likely improve in this area if the entire northeast side of the pasture was restored. Fencing should be installed along the left corridor to allow woody vegetation to flourish and to prevent cattle from accessing the river.

Figure 47: *Evidence of cattle accessing the Johns River along Reach M04.*

Johns River Reach M05 – Lawson Road to Elm Street

Reference Stream Type: C plane bed, cobble
Geomorphic Condition: Reference
Channel Evolution Stage: I (stable)
Habitat Condition: Good
Stream Sensitivity: Moderate

Reach M05 parallels Beebe Road, beginning and ending in residential areas (Figure 48). Development in this area is hindered by steep topography along the right bank and the road along the left. A brief section in the middle of the reach flowed between bedrock and a steep forested hillside, cascading over two bedrock ledges. Overall the reach is in excellent condition, though lawns are mowed to the bank edges near the end of the reach (Figure 49).

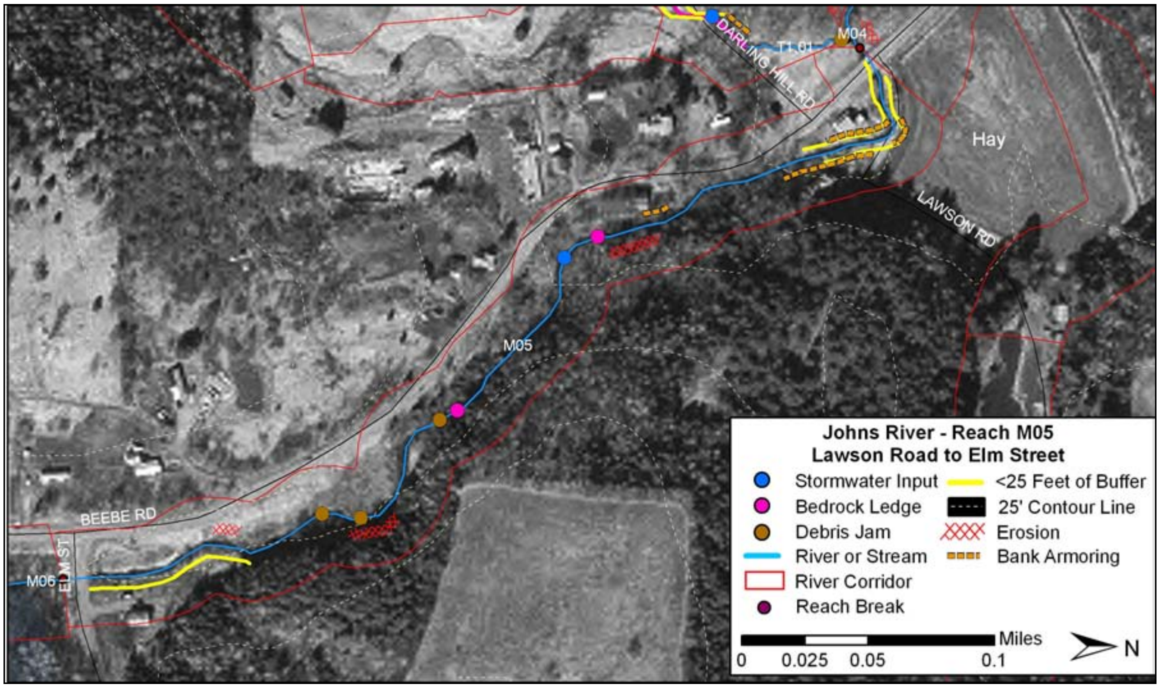


Figure 48: *Results for Johns River Reach M05.*

Figure 49: *Reach M05 near Darling Hill Road.*

Johns River Reach M06 – Upstream of Elm Street

Reference Stream Type: E dune-ripple, sand
Geomorphic Condition: Reference
Channel Evolution Stage: I (stable)
Habitat Condition: Good
Stream Sensitivity: High

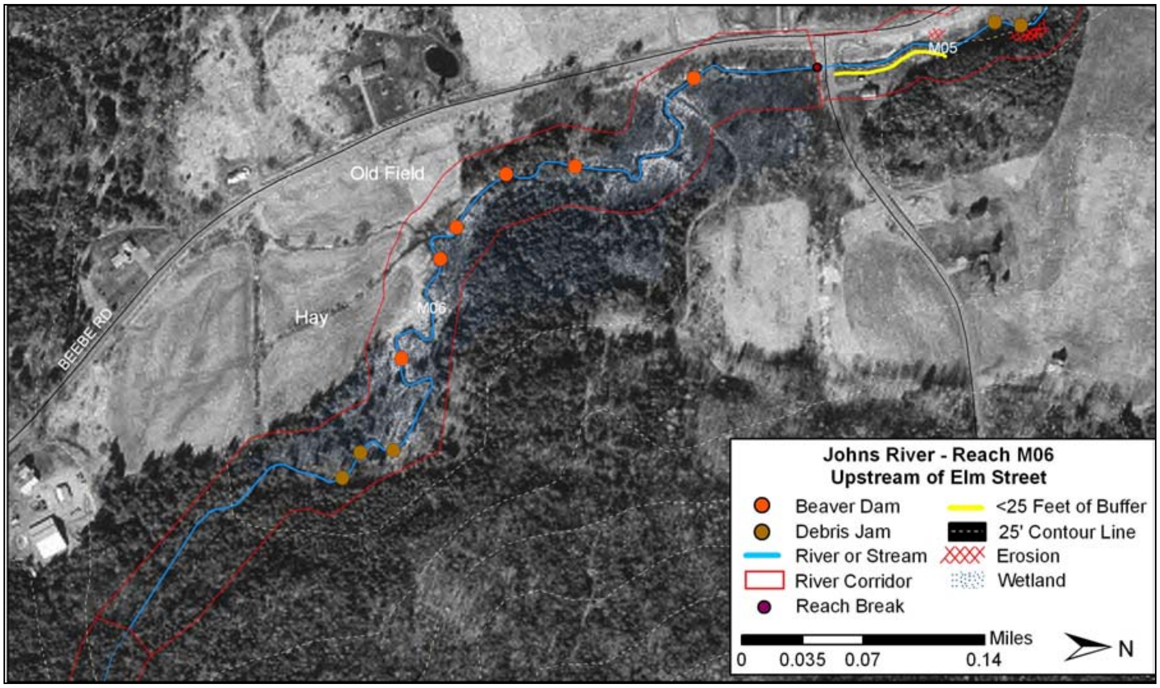


Figure 50: *Results for Johns River Reach M06.*

Beginning as crystal-clear water amidst a beautiful cedar forest, Reach M06 quickly becomes a multi-channeled beaver wetland. Fallen trees and debris are present throughout the reach. The entire section is affected by beaver activity and contains several dams (Figure 50) that have backed up silt for several hundred feet upstream, rendering the river un-walkable in those areas. Several of these dams have breached, resulting in silt being washed downstream. Breached beaver dams may help explain the high sediment levels observed in downstream portions of the Johns River; however this effect may be balanced by the remaining intact dams which allow sediment from upstream to settle out within the reach.

Alterations to the corridor are minimal due to the nearby wetlands. Most fields adjacent to the river are too wet to support regular mowing, and alders and willows are currently becoming established. Management objectives in this area should include protection of the river corridor to allow natural wetland habitats to re-develop.

Un-named Tributary to Johns River, Reach T1.01 and T1.02

Parallels Darling Hill Road

	Reach T1.01:	Reach T1.02:
Reference Stream Type:	E dune-ripple, sand	E riffle-pool, gravel
Geomorphic Condition:	Good	Reference
Channel Evolution Stage:	I (stable)	I (stable)
Habitat Condition:	Good	Reference
Stream Sensitivity:	High	Moderate

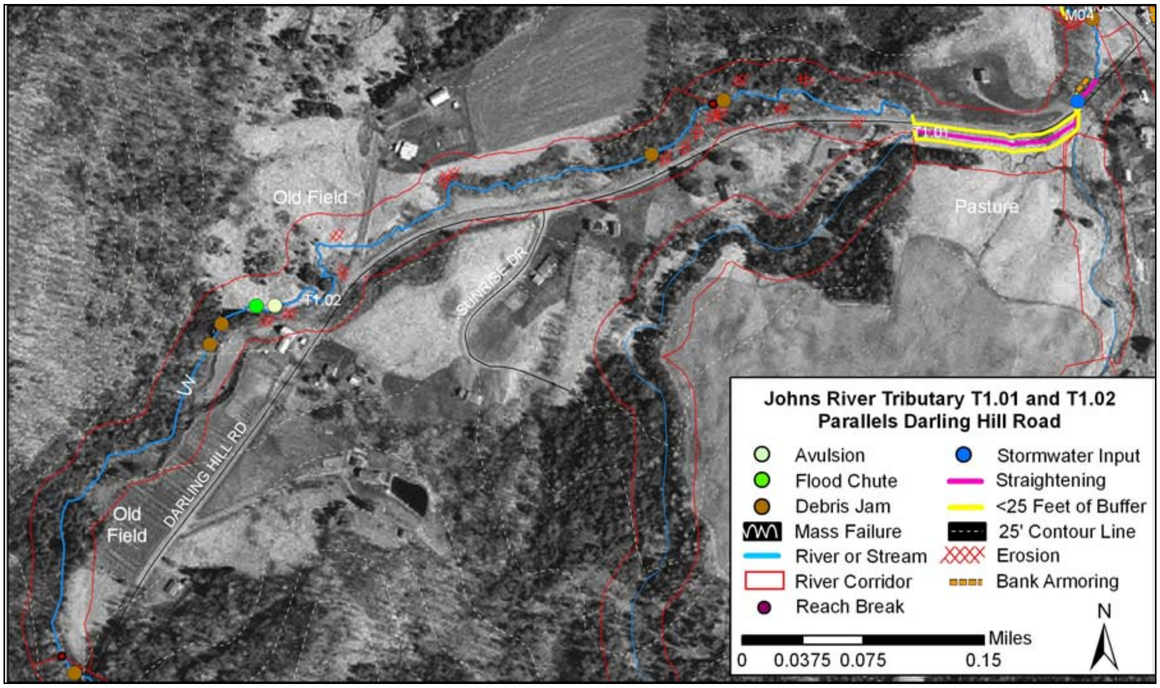


Figure 51: *Results for an un-named tributary to the Johns River, Reaches T1.01 and T1.02.*

Reaches T1.01 and T1.02 (Figure 51) are portions of a small tributary which parallels Darling Hill Road before joining the Johns River. Both flow through forests and old fields, and a small portion flows along and active pasture near North Derby Road. Though high nutrient levels afflict this tributary (Dyer and Gerhardt 2007), no clear sources were observed to explain these levels in the vicinity of the stream during this assessment. These inputs likely originate from farmland along an upstream reach and runoff from elsewhere in the watershed. One culvert, at the second North Derby Road crossing, needs to be replaced or realigned, as it is more than halfway plugged with sand.

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Glossary

Aggradation – Accumulation of sediment on the channel bed.

Alluvial – Refers to sediment materials deposited by a river or stream.

Avulsion – A change in a stream's course caused by the stream breaking through the banks and forming a new channel.

Basin – see Watershed

Degradation –Process of scouring of the channel bed due to changes in flow rates or sediment loads.

Entrenched – Having little space to flood. A stream's entrenchment is represented by its entrenchment ratio (the width of the floodprone area divided by the width of the channel).

Erosion – The loosening and transport of soil and other particles. Erosion is a natural process but can be accelerated by human activities, such as vegetation removal and stream channel alteration.

Flood chute – An area outside the main channel that a stream accesses during high flows. These areas may become the future location of the channel as the stream migrates.

Floodplain – The area adjacent to a stream that becomes inundated with water during high flows. This land is built of sediment originating from flooding of the stream. Floodplains have important roles in reducing sediment transport and stream power during floods.

Incision – The process by which a river erodes its channel bed to a lower level than existed previously.

Incision ratio – The lower floodplain height divided by the depth of the channel at bankfull. A stable stream in reference condition would have an incision ratio of 1, meaning that degradation of the channel bed has not occurred. A stream which has undergone degradation of the channel bed would have an incision ratio greater than 1. The higher the ratio, the less likely a stream can access its floodplain.

Neck Cutoff – The narrow strip of land that exists between two meanders migrating closer to one another; eventually, the channel may break through this strip of land and the old channel will form an oxbow.

Nonpoint source pollution – Pollution that does not originate from a single location or source (for example, a drainage pipe) but rather from many sources spread out across the landscape (for example, runoff from agricultural fields).

Planform – The shape and pattern that a stream forms on a landscape.

Riffle – A section of stream characterized by fast, shallow water flowing over coarser bed materials, such as cobbles and boulders

Riparian buffer – A strip of natural vegetation growing along a waterbody which serves to reduce erosion, filter sediment and pollutants, and enhance aquatic biodiversity.

Sensitivity – A measure of how likely a reach would react to human or natural stressors to the watershed or the reach itself. This takes into account the current geomorphic condition of the reach and the composition and erodibility of its bed and bank materials.

Sinuosity – A measure of how meandering a stream is. Sinuosity is displayed as a ratio of the length of the river divided by the length of its valley.

Stream corridor – The area of land adjacent to a stream that influences and is influenced by that stream. During the Phase 1 and Phase 2 assessments, this corridor is at least 100 feet on either side of the stream.

Tributary – A body of water, such as a stream, that flows into another body of water.

Watershed (or basin) – A region drained by all of the rivers and streams flowing into a lake, river, or ocean. The relative size of a watershed and the human alterations to that watershed greatly affect the quality of the water in the waterbody into which it drains.

Appendix A. Phase 1 Project Metadata.

Parameter	**Source**
Alluvial fan	1:24K topos
Bank armoring and revetments	Not Evaluated
Bank erosion - relative magnitude	Field observation
Dominant bed form and material	Field observation
Belt width	1:5K NHD, 1:5K orthos
Berms and roads	1:24K topos, 1:5K orthos
Bridges and culverts	1:24K topos, 1:5K NHD & orthos
Channel length	SGAT automated
Channel straightening	1:24K topos, 1:5K NHD & orthos
Confinement type	1:24K topos
Corridor land use - land cover data	Land use - land cover (1990s statewide)
Corridor soil data	NRCS soil survey maps – (updated 2005)
Debris and ice jam potential	Field obs. at access point along reach
Depositional features	1:5K orthos
Dredging and gravel mining history	Interviews - DEC, NRCS
Downstream and upstream elevations	1:24K topos
Flow regulations and water withdrawals	1:24K topos, 1:5K NHD & orthos
Grade controls	1:24K topos, field observation
Latitude and Longitude	SGAT automated
Meander centerline	1:24K topos, 1:5K NHD
Meander migration and channel avulsion	1:5K orthos (1990s & 1970s), other aerial photographs
Historic corridor land use - land cover	Not Evaluated
Historic watershed land use - land cover	Not Evaluated
Reach breaks	1:24K topos, 1:5K NHD
Riparian buffer width	1:5K orthos
River corridor development	1:24K topos, 1:5K orthos
Stream type	1:24K topos
Towns that reaches are in	1:24K topos
Valley length	SGAT automated
Valley side slopes	1:24K topos, soils slope data
Valley walls	1:24K topos
Valley width	SGAT automated
Groundwater and small tributary inputs	1:24K topos, 1:5K NHD, NWI maps
Wavelength	1:5K NHD, 1:5K orthos
Watershed delineations	1:24K topos, 1:5K NHD
Watershed land use - land cover data	Land use - land cover (1990s statewide)

Appendix B: Summary of Rosgen Stream Classifications and Descriptions of Channel Bed Forms

Rosgen Stream Classifications (Rosgen 1994)

Stream Type	Sinuosity	Slope (%)	Features
A	Low	>10	Steep, entrenched, high energy/debris transport stream. Contain vertical steps, deep scour pools, waterfalls
B	Low to moderate	4-10	Moderately entrenched, dominated by riffles, pools infrequent. Stable bed and banks
C	High	<2	Low gradient, meandering, alluvial channels with broad and well defined floodplains. Exhibit point bars and riffle-pool characteristics
D	Variable	<4	Braided, very wide channels with eroding banks, in broad valleys with abundant sediment supply
E	Very high	<2	Low gradient, highly sinuous channel with very broad and alluvial floodplain
F	High	<2	Entrenched stream in highly weathered, low gradient material. Laterally unstable, high bank erosion. Riffle-pool characteristics
G	Low to moderate	2-4	Entrenched stream in narrow valley or deeply incised in alluvial or colluvial materials. Unstable, high bank erosion rates

Descriptions of Channel Bed Forms (State of Vermont 2007b)

Bed Forms	Description
Cascade	Generally occur in very steep channels, narrowly confined by valley walls. Characterized by longitudinally and laterally disorganized bed materials, typically bedrock, boulders, and cobbles. Small, partial channel-spanning pools spaced < 1 channel width apart common.
Step-Pool	Often associated with steep channels, low width/depth ratios and confining valleys. Characterized by longitudinal steps formed by large particles (boulder/cobbles) organized into discrete channel-spanning accumulations that separate pools, which contain smaller sized materials.
Plane Bed	Occur in moderate to high gradient and relatively straight channels, have low width/depth ratios, and may be either unconfined or confined by valley walls. Composed of sand to small boulder-sized particles, but dominated by gravel and cobble substrates. Channel lacks discrete bed features (such as pools, riffles, and point bars) and may have long stretches of featureless bed.
Riffle-Pool	Occur in moderate to low gradient and moderately sinuous channels, generally in unconfined valleys, and has well-established floodplain. Channel has undulating bed that defines a sequence of bars, pools, and riffles. Pools spaced every 5 to 7 channel widths in a self-formed (alluvial) riffle-pool channel.
Dune-Ripple	Usually associated with low gradient and highly sinuous channels. Dominated by sand-sized substrates. Channel may exhibit point bars or other bedforms forced by channel geometry. Typically undulating bed does not establish distinct pools and riffles.
Bedrock	Lack a continuous alluvial bed. Some alluvial material may be temporarily stored in scour holes, or behind obstructions. Often confined by valley walls.
Braided	Multiple channel system found on steep depositional fans and deltas. Channel gradient is generally the same as the valley slope. Ongoing deposition leads to high bank erosion rates. Bed features result from the convergence/divergence process of local bed scour and sediment deposition. Unvegetated islands may shift position frequently during runoff events. High bankfull widths and very low meander (belt) widths.

NorthWoods
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fostering stewardship of human and natural communities

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