Lewis Creek Watershed:
River Corridor Conservation & Management Plan

Addison & Chittenden Counties, Vermont
Starksboro, Monkton, Hinesburg, Charlotte, Ferrisburgh

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Lewis Creek at confluence with Lake Champlain, Ferrisburgh, VT

Prepared under contract to

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This plan also leverages previous work completed by SMRC, LCA and Milone & MacBroom, with technical and financial assistance of Addison County Regional Planning Commission, Lake Champlain Basin Program, and the Federal Emergency Management Agency, in addition to the Clean & Clear grant funding.

Field work was conducted with the cooperation of Starksboro, Monkton, Hinesburg, Charlotte, and Ferrisburgh landowners who granted permission to cross their property to access the river.

EXECUTIVE SUMMARY

Phase 2 geomorphic assessments were completed between 2001 and 2009 on 36 reaches (42.6 river miles) of the Lewis Creek and major tributaries following protocols published by the Vermont Agency of Natural Resources. Field investigations and limited historical reviews have identified various watershed and channel disturbances that have impacted these reaches of the Lewis Creek network, including:

Watershed-scale Modifiers:

- Historic deforestation and subsequent reforestation from the mid-1800s through the early 1900s;
- Significant flood events in 1927, 1936, 1938, and 1973;
- Historic conversion of wetlands for agricultural and residential land uses;
- Road runoff; and
- Upstream erosion and tributary sources of sediment.

Reach-scale Modifiers:

- Historic channelization especially associated with agricultural uses and road crossing sites;
- Berming along stream banks often in vicinity of bridge crossings and along road segments;
- Streambank armoring (rip-rap);
- Floodplain encroachment by roads and residential and commercial development;
- Undersized public and private bridges and in-stream culverts, serving as flow constrictors at bankfull flow or higher-magnitude flood events;
- Stormwater runoff from roads and driveways;
- Current impoundments on the Lewis Creek main stem in Charlotte (Scott Pond Dam); Hollow Brook in Hinesburg (two driveway / dams); and High Knob Brook in Starksboro (irrigation pond / driveway earthen dam); and
- Historic impoundments associated with industrial and manufacturing interests in Starksboro, Charlotte and North Ferrisburgh.

The Lewis Creek and tributary channels are adjusting in response to these past and present watershed and channel disturbances. Adjustments have occurred to varying degrees, depending on many factors, including the magnitude and timing of past disturbances, the erosion resistance of sediment types in the channel bed and banks, the type and density of vegetative cover along stream banks, and presence of grade controls such as exposed bedrock. Broadly speaking, the assessed reaches can be grouped into three categories:

- Some of the assessed river segments were in regime, showing an expected (natural) level of change or adjustment, and maintaining average channel dimensions, planform, and profile, over time. This category includes:
    - bedrock-controlled segments – such as States Prison Hollow gorge north of Starksboro village, the short bedrock falls upstream of Seguin covered bridge on Roscoe Road in Charlotte, a short gorge on the High Knob tributary off Freedom Acres Rd in Starksboro, a gorge on Hollow Brook south of Lincoln Hill Road in Hinesburg, and a bedrock channel section in Cedar Brook tributary just above the confluence with Lewis Creek. These segments are afforded greater stability by the underlying bedrock, and are less

susceptible to lateral and vertical adjustments, even where significant watershed and channel disturbances have occurred.

- <u>bedrock-influenced segments confined closely by valley walls</u> – such as, segments of the Lewis Creek (a) upstream of Tatro Rd crossing in Starksboro, (b) along Lewis Creek Road in Hinesburg, (c) downstream of Seguin covered bridge in Charlotte, (d) upstream of Old Hollow Road crossing in North Ferrisburgh; a segment of the High Knob tributary upstream of the gorge off Freedom Acres Rd; and a segment of the Hollow Brook tributary downstream of the gorge south of Lincoln Hill Road in Hinesburg. The erosion resistance offered by the occasional exposures of bedrock in the channel boundaries, as well as mature forested buffers (in many cases), have offered stability to these segments, even where they have been subjected to significant watershed and channel disturbances.

- <u>Lower-gradient segments, not significantly confined by valley walls, with good connection to the surrounding floodplain</u> – such as, select Lewis Creek reaches (a) downstream of States Prison Hollow gorge in Starksboro, (b) about ½ mile upstream of Turkey Lane crossing in Hinesburg, (c) downstream of the Quinlan covered bridge in Charlotte, and (d) between Route 7 and Greenbush Road in Ferrisburgh; upper reaches of High Knob tributary along Big Hollow Road in Starksboro; the downstream 4000 feet of Hollow Brook near the confluence with Lewis Creek; and portions of the Pond Brook tributary spanning Silver Street in Monkton, and downstream of the Monkton / Hinesburg town line. Generally, these segments are connected to their surrounding floodplain and appear to be maintaining average channel dimensions, planform, and profile, over time. These are identified as key attenuation assets in the watershed, providing for attenuation of sediment and flows.

- In contrast, some of the assessed main stem and tributary reaches have become disconnected from their surrounding floodplain, following extensive historic channel manipulations to protect adjacent development, roads, or impoundments. Often channel entrenchment has been exacerbated by floodplain encroachments such as berms, road bed materials, or building foundations.

  Through historic channel manipulations, these channel segments have been converted from unconfined, meandering channels with opportunities for overbank and point bar sediment deposition to entrenched, linear more transport-dominated channels. The modified channel would be expected to have enhanced sediment transport capacity as a result of the increased slope and increased stream power. At present, enhanced erosive energies of these segments appear to be balanced by the resisting forces of the channel margins (e.g., forested buffers, armored beds, streambank revetments). Dominant adjustment processes observed in these reaches were planform adjustment, aggradation and widening; none of the segments exhibited signs of system-wide active incision. Nevertheless, these channel segments remain highly susceptible to catastrophic channel adjustments and associated fluvial erosion losses in future flood events, given their entrenched status. Also, they tend to translate erosive energies and sediment loads to downstream reaches.

  This category includes segments of the Lewis Creek (a) along Ireland Road in Starksboro at the transition from steeper slopes along the flanks of the Green Mountain out into the broad alluvial valley, (b) downstream of Tatro Road crossing in Starksboro, (c) along Lewis Creek Road in Charlotte downstream of Scott Pond dam; a segment of High Knob Brook downstream of Brown Hill W Rd; and a segment of Hollow Brook through Lazy Brook mobile home park in Starksboro.

- Between these extremes, a third broad category of the assessed reaches was apparent - segments where historic incision or disturbance has led to a minor to moderate degree of channel entrenchment, but the channel has some degree of floodplain connection, particularly in larger flood events. Dominant adjustment processes observed in these reaches were minor to moderate planform adjustment, aggradation and widening; none of the segments exhibited signs of system-wide active incision. In some cases, the coarseness and erosion resistance of materials in the stream bed and banks (including exposed or shallow bedrock, cohesive silts and silty-clays, and intact forested buffers) has moderated the potential for channel adjustments.

  This category includes many of the remaining assessed segments of the Lewis Creek and major tributaries, such as the Lewis Creek channel upstream of the Starksboro ballfields, portions of the Hollow Brook spanning Route 116 in Starksboro; and a channelized section of Pond Brook just upstream of the Monkton / Hinesburg town line.

Opportunities for river restoration and conservation have been identified based on the Phase 2 geomorphic assessment results. A preliminary project listing forms the basis for follow-on project development and planning activities which can be carried out by watershed stakeholders. A subset of the identified projects has progressed through development phases, and are ready for implementation.

1.0 INTRODUCTION

This plan compiles the results of Phase 2 stream geomorphic assessments completed from 2001 through 2009 for 42.6 river miles of the Lewis Creek main stem and major tributaries. Based on this geomorphic data, short-term and long-term actions, projects and strategies have been identified and ranked for implementation at the site-level, reach-level and community scale. The current status of project development is summarized. Overall objectives of this ongoing planning process are to:

a) Improve water quality, restore habitats, and reduce erosion hazards by managing toward the equilibrium channel;

b) Plan for future development which is compatible with adjusting river channels;

c) Identify sustainable river corridor management strategies through continued outreach to individual landowners and through public meetings;

d) Analyze previous geomorphic assessment work, identify the causes of channel instability, and evaluate options for restoring long-term stability in the river network; and

e) Evaluate potential channel management choices for their effectiveness and potential consequences to downstream and upstream properties and infrastructure.

Managing toward dynamic equilibrium of river channels can reduce erosion hazards and improve channel stability in the long term, thereby reducing sedimentation and nutrient loading to our rivers. Decreased sediments and nutrients, in turn, will improve in-stream and Lake Champlain habitats and water quality.

Through evaluation of existing geomorphic assessment data and outreach to individual landowners along the corridor, various watershed-, reach- and site-level river corridor management strategies have been identified. This plan is intended to facilitate action, and contains a prioritization of various planning, restoration and conservation projects. Resources are listed so that community members and willing landowners can follow through on recommended implementation strategies, and secure necessary funding and technical support. This community-based river corridor and watershed planning process recognizes the public value of riparian areas and the need for public resources to support and facilitate stewardship of these lands in private and public ownership. This plan is intended to support an adaptive management approach to the river corridor, as conditions change and the community's understanding of river dynamics evolves.

This plan has been approved by the River Management Section of the VT Department of Water Quality Division, and is offered for public review and comment. It is anticipated that the final, publicly-approved plan would be incorporated by reference in the next updates to the town plans of Starksboro, Bristol, Hinesburg, Monkton, Charlotte and Ferrisburgh and to the Natural Resources sections of the Addison County and Chittenden County Regional Plans. This corridor plan should also be considered in the context of future updates to the Addison County and Chittenden County Region-wide All Hazards Mitigation Plans and relevant town sections.

This river corridor planning process has been funded in part by a Category 2 - Project Development grant through the VTDEC Water Quality Division, River Management Section. Project tasks have been carried out by the Lewis Creek Association (LCA) and South Mountain Research & Consulting (SMRC) of Bristol, VT, under direction of the VTDEC River Management Section. This plan also leverages previous work completed by SMRC, LCA and Milone & MacBroom, with technical and financial assistance of Addison County Regional Planning Commission, Lake Champlain Basin Program, and the Federal Emergency Management Agency, in addition to the Clean & Clear grant funding.

2.0 BACKGROUND

Phase 2 geomorphic assessments in the Lewis Creek watershed were undertaken to provide a geologic and geomorphic context for the erosion and water quality issues documented in this river network over the past several years.

2.1 Geographic Setting

The Lewis Creek watershed is an 81-square-mile basin located in Addison County (77% by area) and Chittenden County (23%), Vermont. The Lewis Creek drains portions of seven towns (Figures 1, 2):

- Addison County: Bristol, Ferrisburgh, Monkton, Starksboro
- Chittenden County: Charlotte, Hinesburg, Huntington

Figure 1. Location of Lewis Creek Watershed in the state of Vermont.

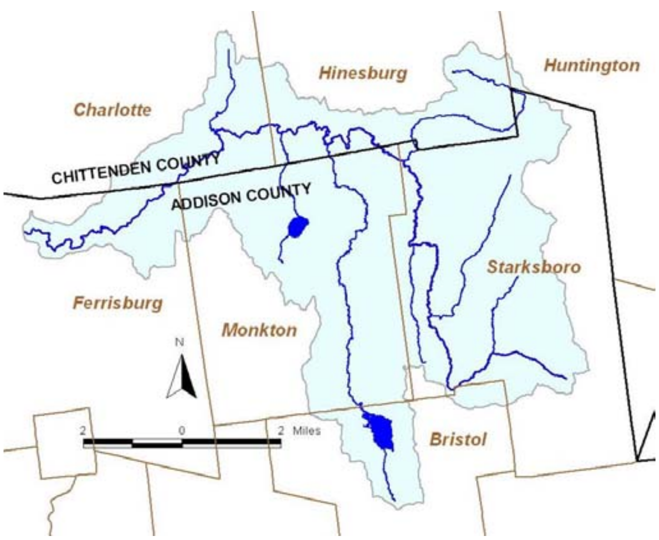


Figure 2. Location of Lewis Creek Watershed within Addison and Chittenden County towns.

The Lewis Creek drains directly into Lake Champlain at Hawkins Bay near Long Point and Gardner Island. This location is within the Otter Creek lake segment defined within the Vermont Water Quality Standards (Vermont Natural Resources Board, 2008) and by the Lake Champlain Phosphorus Management Task Force (1993). Under the VTDEC basin planning process, the Lewis Creek watershed is considered a part of the Otter Creek Basin, although these river systems drain separately to Lake Champlain; the mouth of the Otter Creek is located 2.7 miles to the southwest of the mouth of Lewis Creek.

This plan focuses on portions of the Lewis Creek main stem and three major tributaries (Figure 3):

- 29 continuous miles (23 reaches/ 38 segments) of the **Lewis Creek main stem**, from Starksboro, downstream through Monkton, Hinesburg, and Charlotte, to the mouth in Ferrisburgh;
- 4.6 miles (3 reaches / 9 segments) of the **Hollow Brook** tributary, including a section along Lincoln Hill Road (in Hinesburg / Starksboro) and a section along Hinesburg Hollow Road, under Route 116, to the confluence with the Lewis Creek main stem;
- 1.5 mile (2 segments) of an unnamed tributary to Hollow Brook, which flows north along Big Hollow Road in Starksboro to join Hollow Brook near the intersection of Big Hollow Road and the Hinesburg Hollow Road.
- 1.8 miles (1 reach / 3 segments) comprising the downstream-most section of the **Pond Brook** tributary extending from above the Silver Street culvert crossing to the confluence with Lewis Creek; and
- 0.6 mile (1 reach) at the downstream end of the **Cedar Brook** tributary just above the confluence with Lewis Creek.

A separate study (Milone & Macbroom, 2008) details geomorphic assessment results for the **High Knob** tributary to Lewis Creek, including 5.7 miles (7 reaches / 13 segments) draining along the Big Hollow Road in Starksboro, and joining the Lewis Creek just downstream of the Tatro Road crossing.

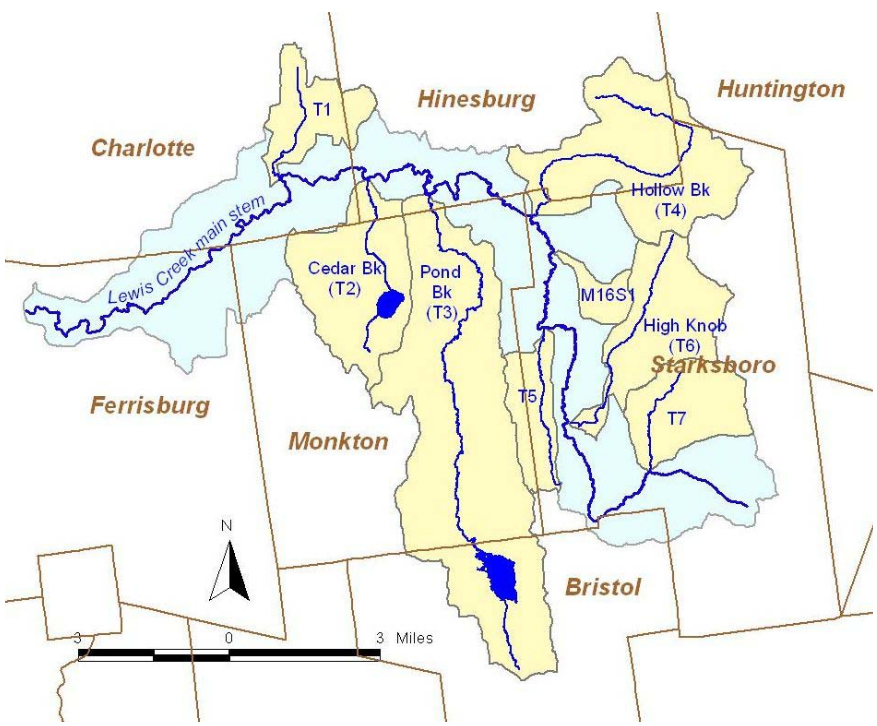


Figure 3. Location of tributary subwatersheds in the Lewis Creek watershed.

2.2 Regional Geologic Setting

The 81-sqaure-mile Lewis Creek watershed spans two major geologic provinces. Approximately 30% of the watershed occupies the till-blanketed bedrock slopes of the Northern Green Mountain province at the steep headwaters of Lewis Creek main stem, High Knob tributary and Hollow Brook in eastern Starksboro and Hinesburg. The remaining 70% of the Lewis Creek watershed is positioned in the broad Champlain Valley province (Stewart, 1973; Capen, 1998).

The Green Mountain province is comprised of high-elevation rocks which have been folded and faulted in a series of ancient mountain-building events. The rock types present in the mountain province are metamorphic in nature, having been formed under extreme temperature and pressure conditions during repeated deformations. The Champlain Valley is underlain by less-intensely-deformed rocks, which have undergone low-angle thrusting and folding, to create locally elevated slabs of crystalline rock. Near the eastern extent of the Champlain Valley at the base of the Green Mountains, the Hogback Anticline (an arch in regionally-folded bedrock) has formed the north-south trending Hogback Mountain (Stewart, 1973). Farther to the west, the north-south trending Monkton Ridge is comprised of locally more erosion-resistant quartzite associated with the Monkton Thrust fault. In the western portion of the Lewis Creek watershed, a major thrust fault zone called the Champlain Thrust has resulted in the erosional remnants of Mount Philo, Mount Fuller, and Shellhouse Mountain. Over geologic time, the Lewis Creek has found ways to navigate around and through these higher-relief features. In part, the pattern of this drainage network has been influenced by the underlying bedrock.

In recent geologic time (from 24,000+ to 13,500 years before present; Ridge, 2003) this landscape was occupied by advancing and retreating glaciers, with ice up to a mile or more in thickness above the present land surface. Glacial tills now blanket much of the upper bedrock-controlled slopes in the headwaters of the Lewis Creek watershed. As glaciers melted and receded, deposits of water-washed boulders, cobbles, gravel and sand (kame moraines, kame terraces) built up along the ice margins at the contact between the Champlain Valley and the Northern Green Mountains (Stewart, 1973; Stewart & MacClintock, 1969).

As the global climate warmed and the glaciers receded, a large fresh-water lake inundated the Hudson Valley Lowland (Lake Albany) and later extended northward into the Champlain Valley (Lake Vermont) (Connally & Sirkin, 1969; Chapman, 1937; Stewart & MacClintock, 1969; DeSimone & LaFleur, 1985). Since flow was blocked to the north by the retreating Laurentide ice lobe, freshwater entering Lake Albany / Lake Vermont from tributaries including the Lewis Creek drained to the south via the Hudson River valley to Long Island, NY. At its highest stage, the Lake Vermont shoreline extended to the foot of the Green Mountains near the present location of Starksboro Village and South Hinesburg. The isolated bedrock knobs and ridges such as Mt. Philo, Monkton Ridge and Hogback Mountain, were islands emerging above the lake surface.

Lake Albany / Lake Vermont waters receded in stages as natural dams in southern Vermont and New York gave way. For a short time (c. 13,500 years before present), glacial meltwaters of the Ontario basin drained to the south via the Champlain / Hudson lowlands as retreating ice revealed a passage at Covey Hill, Quebec (Pair and Rodrigues, 1993). Previously, drainage from this basin had entered the Hudson lowland via the Mohawk valley (Chapman, 1937; Connally & Sirkin, 1969). The Laurentide ice lobe retreated further to the north and east, until the St. Lawrence valley was no longer blocked by ice. From approximately 13,100 to 12,700 years before present (Ridge, 2003), marine waters filled the valley from the St. Lawrence Seaway as the rate of rise in ocean water levels far exceeded the rate of rise, or isostatic rebound, of the land surface now relieved of its glacial burden (Stewart and MacClintock, 1969; Cronin, 1977; Wagner, 1972; Connally and Calkin, 1972). The maximum elevation of these brackish waters is believed to have extended into the present-day Lewis Creek watershed, perhaps not much farther east than the North Ferrisburgh village (Wagner, 1972). Champlain Sea waters had receded from the greater Champlain Valley by approximately 10,000 years before present, as the rate of land rise began to outpace the rate of sea-level rise. Fresh water then filled the Champlain Lowland (analogous to present-day Lake Champlain). Surface waters from the Lake Champlain basin now drain to the north, while the Hudson River basin continues to drain to the south.

The landscape of Vermont was dissected by river systems following glacial retreat, driven in part by dropping base levels in the Hudson River valley and Lake Champlain. Significant channel incision may also have been driven by isostatic rebound of the land surface in the late Pleistocene and early Holocene (Brakenridge *et al*, 1988). The Lewis Creek river network eroded downward through glacial-fluvial kame terrace deposits and Lake Vermont silt and clay lake deposits. Downward incision was apparently arrested at exposures of channel-spanning bedrock along the channel, including the falls at North Ferrisburgh, and the short bedrock gorge along States Prison Hollow Road in Starksboro. Today, these bedrock exposures serve as fixed base levels for upstream reaches of the Lewis Creek and its tributaries. Absence of vegetation on the recently-deglaciated hillslopes probably contributed to floodplain aggradation in the late Pleistocene. Sedimentation rates would have declined as the landscape became revegetated and forests matured, and floodplain incision may have begun to dominate. Rates of sedimentation on alluvial fan surfaces and in ponds were relatively high during the early Holocene based on research from Northwestern Vermont (Bierman *et al*, 1997). Bierman *et al* (1997) theorize that "early Holocene hillslope erosion may have been driven by episodic large storms in a drier [but stormier] climate than today. Late Holocene erosion and aggradation were also event driven, but greater ambient levels of soil saturation [in a cooler, moister climate] may have allowed smaller storms to trigger similar landscape responses." In colonial times, hillslope erosion and floodplain aggradation increased substantially as a result of wide-spread deforestation by the early- to mid-1800s (Brakenridge *et al*, 1988; Severson, 1991; Thomas, 1985). These trends may have again reversed themselves when most hillslopes became reforested in the late 1880s and early 1900s.

2.2.1 Bedrock Geology

In general, bedrock geology of the Lewis Creek watershed can be grouped into three main categories:

- the Cambrian crystalline and metamorphosed rocks (e.g., schistose greywacke, phyllites, schist, gneiss) of the north-south trending Green Mountains at the eastern portion of the watershed (DePietro, 1983; Stewart, 1973);
- the Cambrian quartzites forming the ridges within the Champlain Valley province such as Hogback Mountain, Monkton Ridge, and Mount Philo (Stewart, 1973; Doll, 1961); and
- the Cambrian and Ordovician limestones, dolostones and marbles of the Champlain Valley lowland (Stewart, 1973; Doll, 1961).

The underlying bedrock geology of the watershed influences the Lewis Creek river network in many ways. The phyllites, schists, gneiss of the Green Mountains and quartzites forming the ridges in the Champlain Lowland are relatively resistant to chemical and physical weathering, while the limestones and other calcitic rocks of the Champlain Lowland are less resistant to erosion. In this way, the bedrock geology of the basin has controlled the regional topographic setting. The resistant crystalline rocks form the steeper slopes of the Green Mountains and the less-resistant limestones and dolostones form the broad Champlain Valley Lowland, punctuated by the emergence of moderately resistant quartzites that form the mid-valley ridgelines of Hogback Mountain, Monkton Ridge, Shellhouse Mountain, Mount Fuller, and Mount Philo.

The Lewis Creek headwaters drain the steep, western slopes of the Green Mountains in eastern Starksboro and Hinesburg. In central Starksboro, the upper main stem of Lewis Creek flows in the dolomite valley between the Green Mountains to the east and Hogback Ridge to the west. Similarly, Pond Brook tributary (flowing north from Bristol to join the main stem in Hinesburg) drains a narrow dolomite valley between Hogback Ridge to the east and Monkton Ridge to the west. At the common border of Starksboro, Monkton and Hinesburg, the Lewis Creek main stem curves around the northern extent of these prominent mid-valley quartzite ridges, and flows to the west, cutting across the regional thrust faults and north-south trending bands of moderately-resistant quartzite to make its way eventually to Lake Champlain.

Frequent bedrock exposures influence the channel position and profile of the Lewis Creek main stem and its tributaries. In the upper elevations of the watershed, channel gradients and valley confinement are largely controlled by the underlying bedrock topography and structure (joints, faults, strike and dip of bedding planes and schistosity) (Dipietro, 1983; Stewart, 1973). Occasional bedrock exposures along the valley walls control the lateral position of the Lewis Creek and tributary channels. Locations of channel-spanning bedrock offer vertical grade control, preventing possible downward erosion of the channel in response to regional or local stressors (at least for the 10- to 100-year time spans of this study).

2.2.2 Surficial Geology

The nature of the surficial sediments and soils present in the Lewis Creek watershed today reflects the glacial and post-glacial lake history of the region. Upland slopes are dominated by shallow- to moderate-thickness glacial till deposits overlying bedrock, with alluvial sands, gravels and cobbles found locally in stream corridors. These till deposits are typically a dense mixture of sediment sizes from silts to cobbles and boulders; the till sediments are typically cohesive and of low permeability (Stewart, 1973; Stewart & MacClintock, 1969).

At the foot of the Green Mountains are kame terrace deposits of sands, gravels and cobbles which formerly developed at the marginal contact between the glaciers and the mountains. Some of these deposits were subsequently re-worked as beach gravels by wave action during the time of Lake Vermont. For example, these deposits form the terraces we recognize along the east side of Route 116 from Starksboro Village to east of Hinesburg. Geologists theorize that glaciers retreating northward at one time blocked the Winooski River near Burlington, and the river detoured to Lake Vermont through the Hollow Brook of present-day Lewis Creek watershed (Wagner, 1972). Resulting delta deposits are found overlying kame terrace deposits at the Hinesburg Sand & Gravel quarry in south Hinesburg.

Out in the broader Champlain Valley, near South Hinesburg, north of Monkton Ridge and south of Prindles Corner, the landscape is dominated by clay and silt deposits generated during former occupation by Lake Vermont. These locations would have been in deeper sections of the lake, far from the eastern shorelines which were actively receiving runoff from the Green Mountains. Layer upon layer of fine-grained silts and clays were deposited in the quiet lake waters in alternating sequences resulting from annual cycles of spring and summer storm activity followed by winter quiet. Exposures of these varved clays, or rhythmites, are noted today in the Lewis Creek west of Route 116 and north of States Prison Hollow Road, and near the confluence of Hollow Brook. The clay and silt deposits of the Champlain Valley contain frequent large boulders. It is hypothesized that these boulders were contained within or on "rafts" of ice which broke off in large blocks from the edge of the receding ice sheet and floated out into Lake Vermont. As the ice blocks melted, their cargo was released, dropping out to settle in the clay and silt deposits at the bottom of the lake. The higher elevations such as Hogback Mountain and Monkton Ridge which remained isolated above lake-level, today are veneered with relatively thin to negligible deposits of glacial till (Stewart & MacClintock, 1969).

Methods and rates of erosion in the Lewis Creek channel are influenced by the types of sediments blanketing the land surface of the watershed. The kame terrace and beach deposits of eastern Hinesburg and Starksboro represent a transition zone for the Lewis Creek and the Hollow Brook as they pass from steeper bedrock slopes of the headwaters to the broader Champlain Valley. These sand and gravel sediments are loose (non-cohesive) and highly erodible. All but the largest boulders are able to be mobilized by at least the highest annual flows in the Lewis Creek. Over several thousands of years, sands and gravels have been transported downstream by the Lewis Creek, and now form a blanket of alluvial material along the river corridor, up to several hundreds of feet downstream of the kame terrace deposits. Where channel downcutting is induced by natural or human stressors, sands and gravels in the channel bed are quite susceptible to erosion. These coarser-grained materials in the channel banks are also very susceptible to widening (if unchecked by stabilizing vegetation). Shear by flowing water at the toe of channel banks can create oversteepened slopes which then collapse under forces of gravity.

Once the Lewis Creek passes north of States Prison Hollow Road in Starksboro, surficial soils are dominated by the lacustrine boulder clay and silt deposits of former Lake Vermont. Clays and silts are more dense and more cohesive than the sand and gravel kame terrace deposits; they are therefore more resistant to downward erosion by the Lewis Creek. However, these cohesive soils are susceptible to lateral erosion in the form of meander migration through progressive stream bank collapse, particularly in reaches absent of woody and mixed vegetative buffers.

At the transition from steeper, bedrock slopes to broad alluvial floodplains, some sections of the Lewis Creek and tributaries run dry in the late Summer or early Fall of most years. Glacial kame terrace deposits and/or alluvial fan deposits are mapped at these transitional zones. Given the high permeability of these underlying sediments, stream flow in these "losing reaches" has a component of downward-directed vertical flow. During the driest months of the year, when the groundwater table drops in elevation, the downward component of flow can become significant enough that all channel flow is lost to the subsurface. These "losing reach" conditions have been observed in the Lewis Creek main stem spanning the Hillsboro Road crossing (Starksboro); in a tributary to the High Knob Brook in vicinity of Brown Hill West Rd (Starksboro) (MMI, 2008, p19); and in the Hollow Brook below the Lazy Brook mobile home park (Starksboro) and in the vicinity of the Hinesburg sand and gravel quarry along Hollow Road (Hinesburg).

Soil survey mapping for the watershed (USDA, 2006: USDA, 2007) indicates soil type distributions consistent with mapped surficial geology. Figure 4 depicts the generalized soil types in the watershed, grouped by geologic parent material. Soil types in the upland, eastern extents of the watershed are dominated by soils derived from glacial till. The central and western portions of the watershed are dominated by silt loams. These silt loams have their origin in silty-clay deposits of marine and freshwater lake environments.

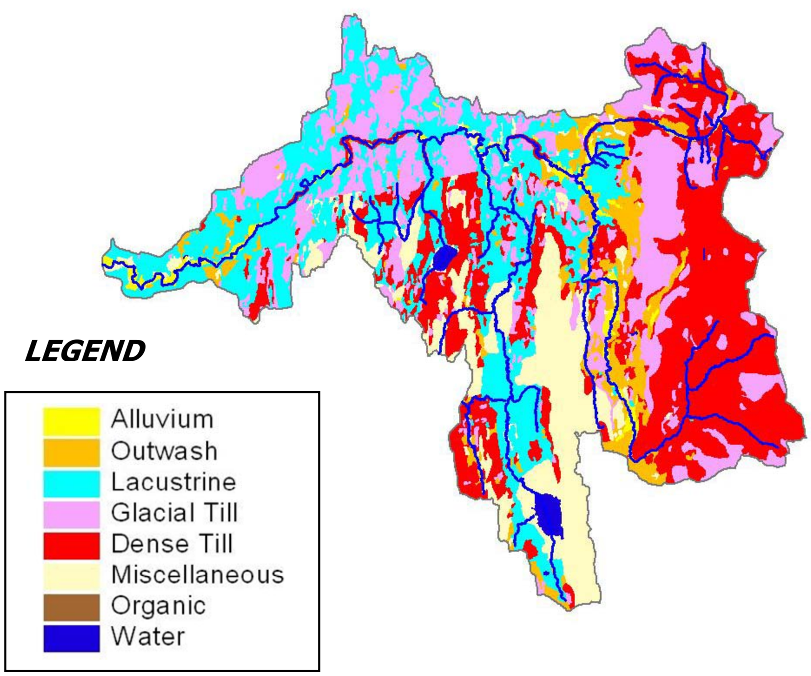


Figure 4. Generalized map of soil parent material in the Lewis Creek watershed. NRCS parent material classification of "lacustrine" does not differentiate between lake silts/clays of glacial versus marine origin.

2.3 Geomorphic Setting

Surface waters of the Lewis Creek watershed were delineated into a total of 103 reaches in a previously-completed Phase 1 Stream Geomorphic Assessment (VTDEC WQD, 2001a – updated in 2005/2006; see Appendix B). Geomorphic reaches were defined based on variation in valley confinement, gradient, and sinuosity, as well as tributary influence (see protocols for further background).

Seven (7) Major Tributaries of the Lewis Creek were identified (see Figure 5, Table 1). Each reach was assigned a unique alphanumeric identification. Reaches along the main stem of the Lewis Creek were prefixed with a capital "M". Major tributary reaches were denoted with a capital "T"; minor tributaries with a capital "S". Further details of the reach-labeling procedure are outlined in VTANR protocols.

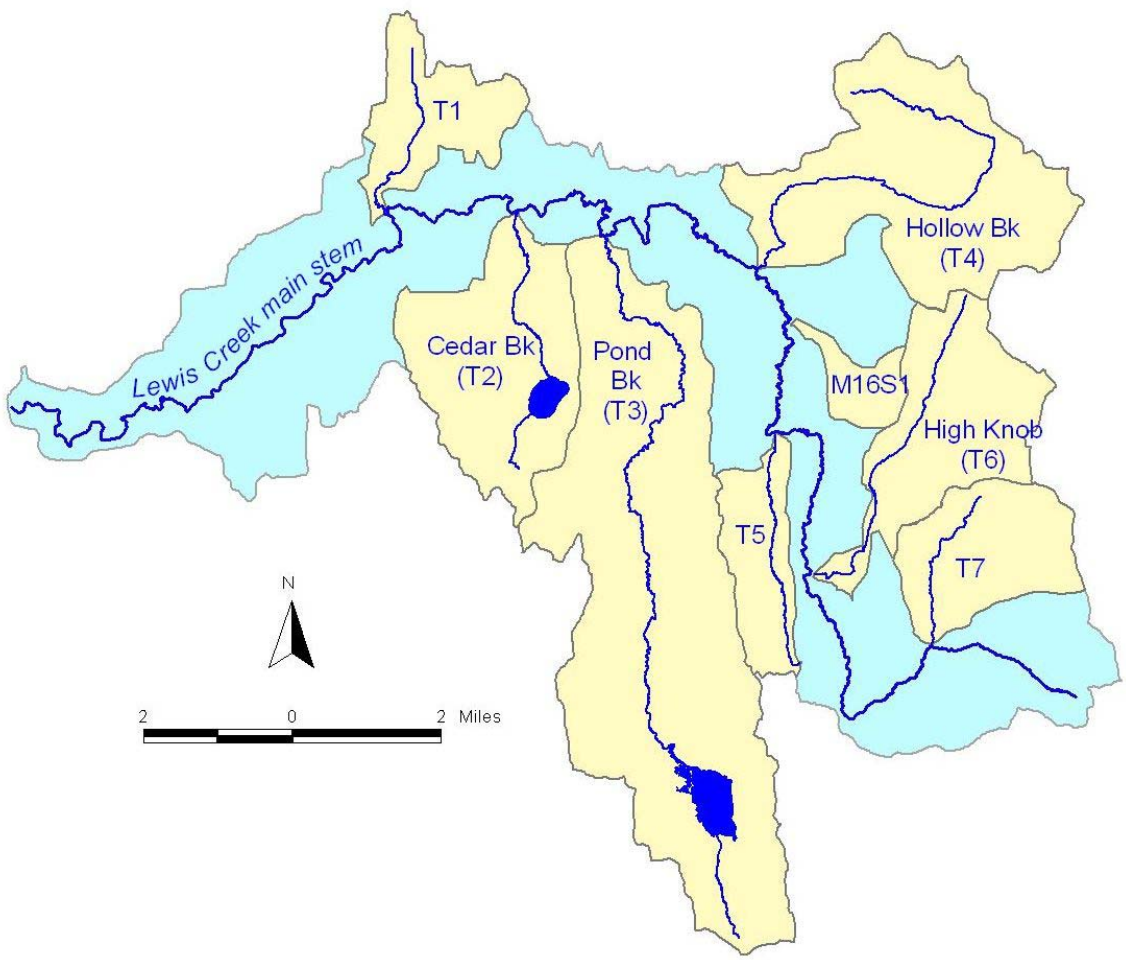


Figure 5. Major Sub-watersheds Delineated in the Lewis Creek Watershed

Table 1. Phase 1 Tributary Delineation in the Lewis Creek Watershed.

Tributary Identification	Name	Drainage Area (sq mi)	Channel Length (mi)	Number Reaches
M	Lewis Creek main stem	81.1	32.4	26
Tributaries				
T1	Prindle (aka Pease) Brook	2.9	3.1	4
T2	Cedar Brook	6.3	4.4	6
T3	Pond Brook	18.3	14.0	7
T4	Hollow Brook	9.2	8.3	7
T5	Hogback Brook	2.4	3.8	5
M16S1	Unnamed tributary	1.0	2.3	4
T6	High Knob Brook	5.2	5.4	6
T7	Headwater Tributary	3.7	2.6	2

Based on the channel and watershed stressors identified through remote sensing, windshield surveys and limited historical research during the Phase 1 Geomorphic Assessment, several reaches along the main stem and major tributaries were prioritized for Phase 2 Stream Geomorphic Assessments carried out between 2001 and 2009 (see Figure 6, Table 2, next pages).

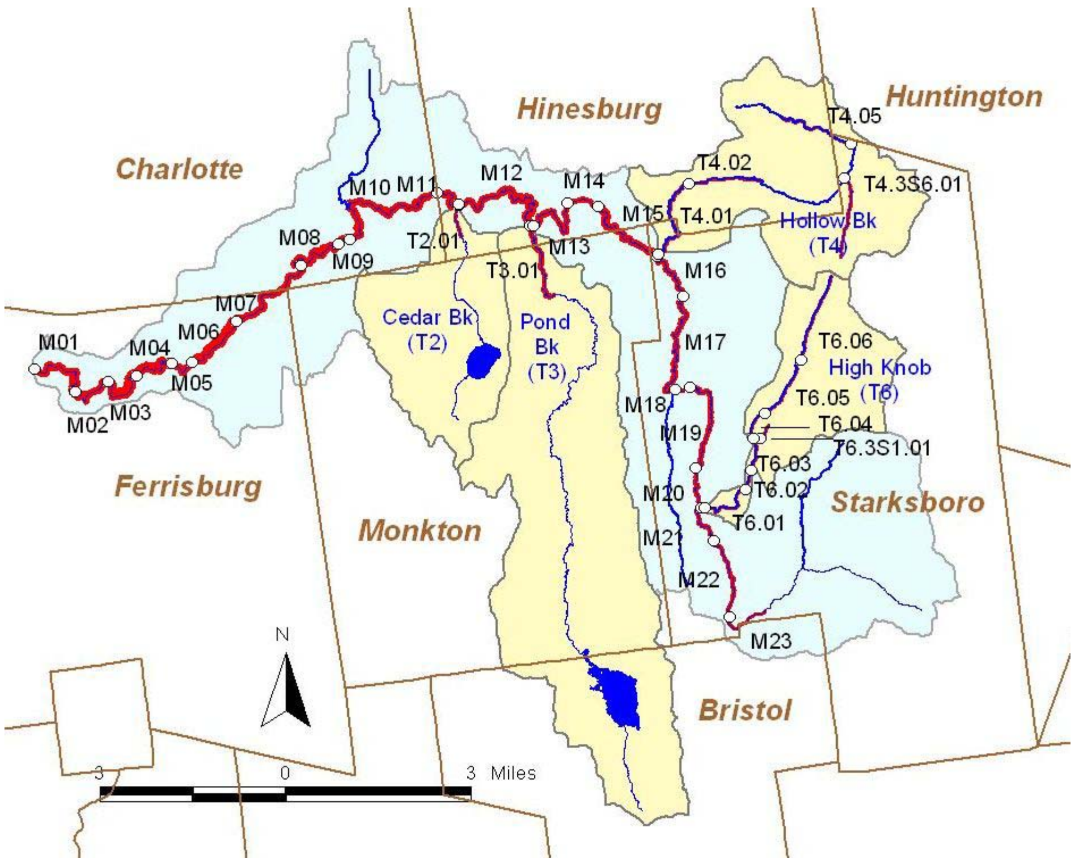


Figure 6. Location of reaches assessed in 2001– 2009.

Table 2. Reaches selected for Phase 2 Stream Geomorphic Assessments on Lewis Creek main stem and tributaries, 2001 - 2009.

Tributary	Towns	Reach Number	Reach Length (ft)	Reach Length (miles)
Lewis Creek	Bristol, Starksboro	**M23**	4,505	0.9
Main Stem	Starksboro	**M22**	7,944	1.5
	Starksboro	**M21**	4,398	0.8
	Starksboro	**M20**	4,032	0.8
	Starksboro	**M19**	10,885	2.1
	Starksboro	**M18**	1,446	0.3
	Starksboro	**M17**	14,003	2.7
	Starksboro	**M16**	6,559	1.2
	Hinesburg, Monkton, Starksboro	**M15**	10,151	1.9
	Hinesburg	**M14**	3,003	0.6
	Hinesburg	**M13**	7,844	1.5
	Hinesburg	**M12**	14,294	2.7
	Hinesburg	**M11**	3,341	0.6
	Charlotte	**M10**	13,833	2.6
	Charlotte	**M09**	1,305	0.2
	Charlotte	**M08**	6,484	1.2
	Charlotte, Ferrisburg	**M07**	9,124	1.7
	Ferrisburg	**M06**	5,831	1.1
	Ferrisburg	**M05**	2,394	0.5
	Ferrisburg	**M04**	5,344	1.0
	Ferrisburg	**M03**	5,471	1.0
	Ferrisburg	**M02**	4,092	0.8
	Ferrisburg	**M01**	6,693	1.3
High Knob Brook	Starksboro	**T6.06**	8,482	1.6
	Starksboro	**T6.05**	6,236	1.2
	Starksboro	**T6.04**	2,907	0.6
	Starksboro	**T6.03**	3,438	0.7
	Starksboro	**T6.02**	1,854	0.4
	Starksboro	**T6.01**	5,649	1.1
(Unnamed Trib)	Starksboro	**T6.3S1.01**	1,586	0.3
Hollow Brook	Hinesburg, Starksboro	**T4.05**	7,879	1.5
	Hinesburg	**T4.02**	7,019	1.3
	Hinesburg, Starksboro	**T4.01**	9,650	1.8
(Unnamed Trib)	Hinesburg, Starksboro	**T4.3S6.01**	7,746	1.5
Pond Brook	Hinesburg, Monkton	**T3.01**	9,402	1.8
Cedar Lake	Hinesburg	**T2.01**	3,202	0.6
			Total:	**43.2**

Several occurrences of channel-spanning bedrock were noted on the assessed reaches of the Lewis Creek main stem and major tributaries (Figure 7, Figure 8). These are locations of vertical grade control, including some more prominent falls such as the States Prison Hollow gorge, the falls above the Seguin Covered Bridge (M10) and North Ferrisburgh village (M06), and the falls at the former Route 7 crossing in Ferrisburgh. The Scott Pond Dam in reach M09 is founded on channel-spanning bedrock. These grade controls – particularly where closely spaced in reaches M05 through M09 - constrain the ability of the Lewis Creek to adjust its profile, and may instead enhance lateral adjustment of the channel boundaries.

Figure 8 (next page) illustrates the Lewis Creek main stem in longitudinal profile; bedrock outcrops are indicated in orange. Generally, valley and river channel slopes become shallower with distance downstream toward Lake Champlain. Relief in the watershed varies from highest elevations of nearly 2,250 feet above mean sea level (ft amsl) in the headwaters on the western flanks of Hillsboro Mountain in eastern Starksboro, to approximately 95 ft amsl at the mouth in Lake Champlain.

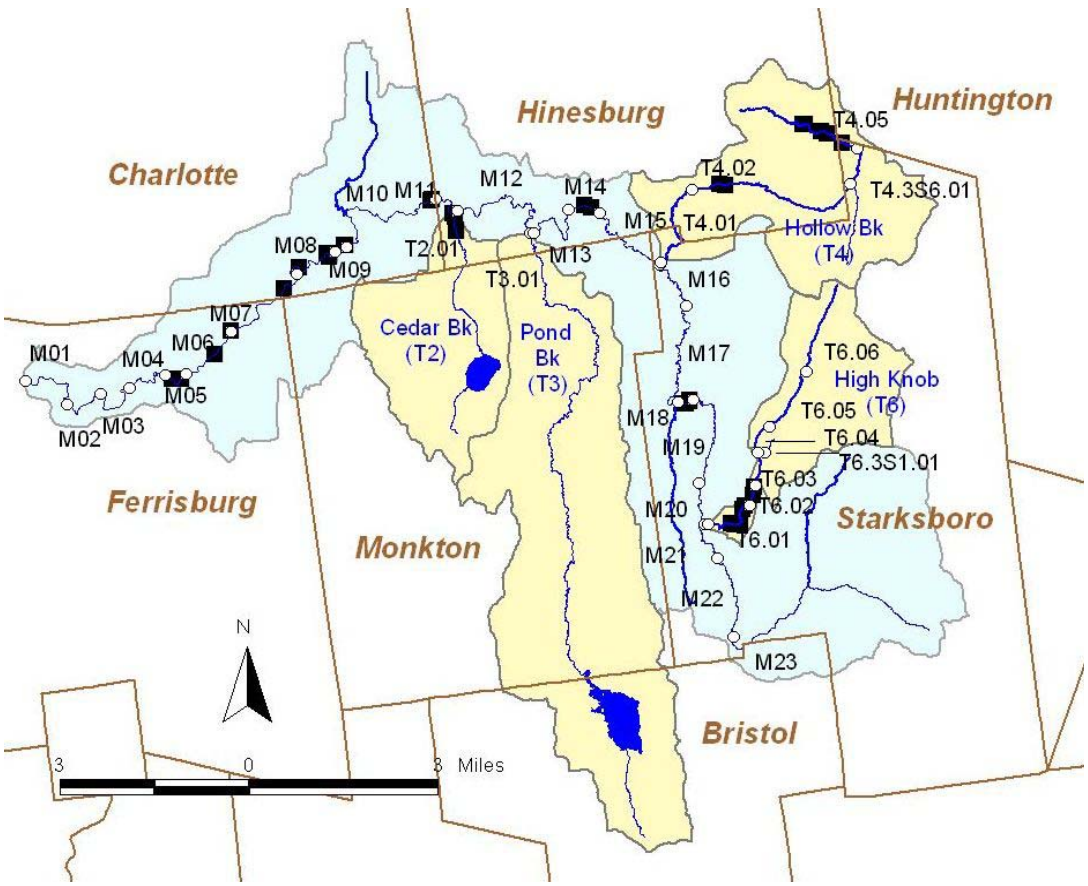


Figure 7. Occurrence of channel-spanning bedrock on assessed reaches of the Lewis Creek watershed (black squares).

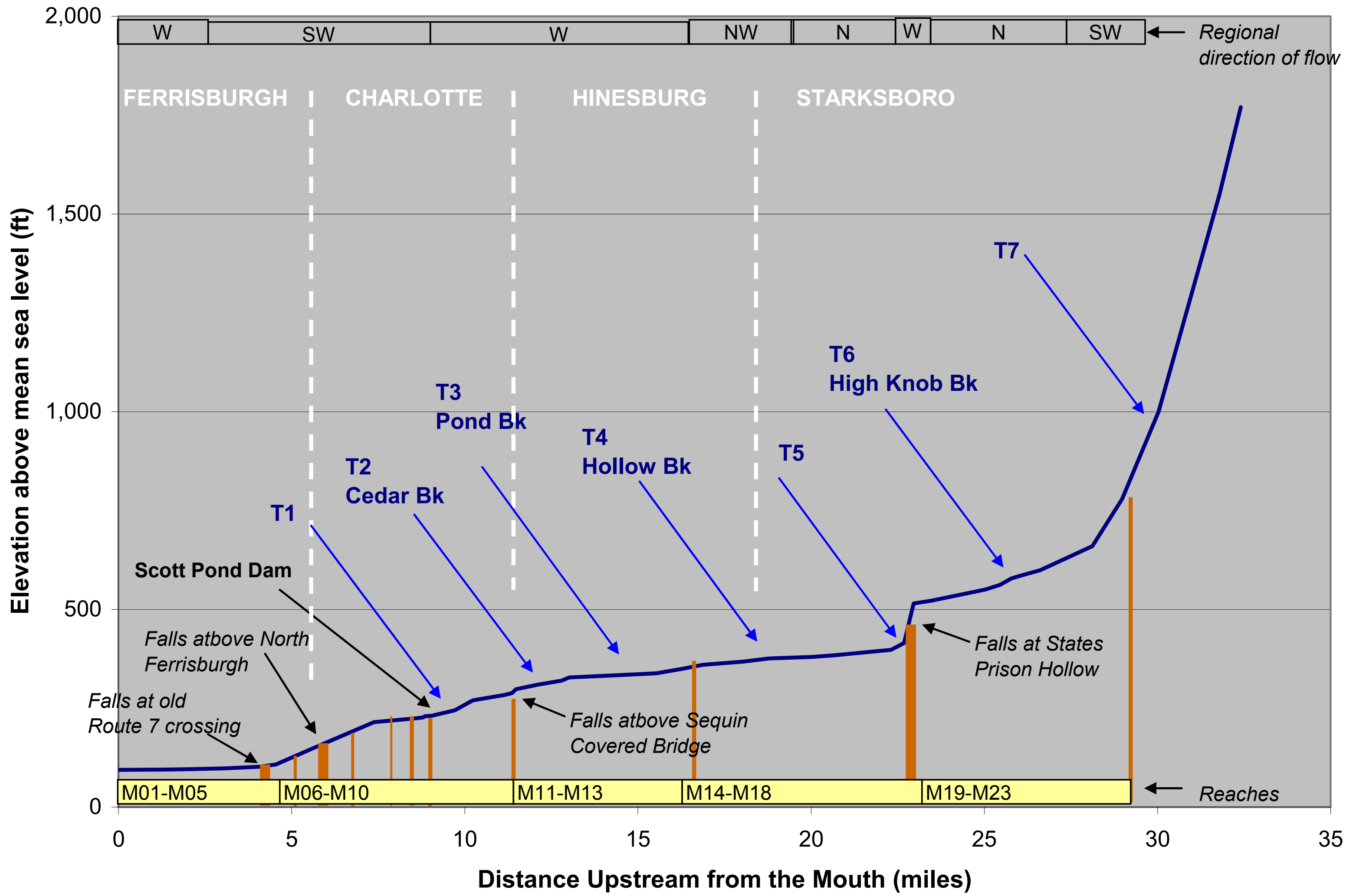


Figure 8. Longitudinal Profile of Lewis Creek main stem
(Orange vertical bars indicate approximate location of channel-spanning bedrock outcrops).

2.4 Hydrology

Given the high relief in the eastern portion of the Lewis Creek watershed, as well as the predominance of low-permeability glacial till and bedrock (Figure 4), flows in this mountainous portion of the watershed can be flashy. Snowmelt events in the late winter and early spring months can contribute to relatively high discharges. In the western portion of the watershed, where slopes are less pronounced and frequent wetland areas and lakes/ponds provide for attenuation of flows, peak flows tend to be more moderate. Prindle (aka Pease) Brook (T1), Cedar Brook (T2), and Pond Brook (T3) have significant instream wetlands and ponds that would tend to store and attenuate storm flows to result in a less flashy hydrograph down in the lower watershed. Periodic ice jams may locally enhance flood stages and lead to catastrophic erosion in break-out events. Ice jams have been recorded near the Quinlan Covered Bridge in Charlotte on the Lewis Creek main stem and on the High Knob (T6) tributary (CRREL Ice Jam database, 2009; Illick, 2009). Occasional blow outs of beaver dams along the main stem and tributaries can also increase flood stages locally.

The lower reaches of Lewis Creek in Ferrisburgh are influenced by backwater effects from Lake Champlain. Historically, water levels in Lake Champlain have ranged from a low of 92.6 to 101.9 feet (USGS, 2009). The average annual water level is 95.5 feet (LCBP, 2006). The top-of-bank elevations of downstream reach breaks for reaches on the lower Lewis Creek range from an estimated 94 feet in M01 to 96 feet at M03 and 102 feet at M05. Thus, from the upstream end of reach M02 at the railroad crossing downstream to Lake Champlain, the Lewis Creek is influenced by backwater effects from the Lake. During wetter periods, these lake effects may extend upstream into reach M03 to the vicinity of Greenbush Road.

The United States Geological Survey (USGS) maintains records for three flow gages on the Lewis Creek (see Figure 9). Only one of the three (Station #04282780) is currently active, with real-time data available on the Internet (http://waterdata.usgs.gov/vt/nwis/).

- Station #04282780 is located near the Route 7 crossing (Reach M05), and measures flow from an approximate drainage area of 77.2 square miles (or 95% of the watershed). This station has daily flow records dating back to 1990, or approximately 19 years. The maximum peak flow recorded during this period was 4,030 cubic feet per second (cfs) on 20 May 2006; the corresponding daily mean flow for this date was 2,710 cfs.

- Station #04282750 was located on a small unnamed tributary (M16S1) near its confluence with the Lewis Creek main stem at the upstream end of reach M16. The upstream drainage area of this gage was 1.07 square miles. This former gage was in operation for a period of 13.5 years from 1964 through 1977. The maximum recorded peak flow during this time period was 95 cfs on 21 December 1973.

- Station #04282700 was located at the Route 116 crossing of an unnamed tributary to the Lewis Creek (T6, referred to as High Knob Brook) which joins the main stem near the upstream end of reach M20. The upstream drainage area of this gage was 5.3 square miles. Daily mean and peak flows were recorded at this gage for approximately 11.5 years from 1963 through 1974. Following a 25-year lapse, peak flows have been calculated for this station beginning in 1999 through the present. Like Station #04282750, the maximum recorded peak flow at Station #04282700 during the indicated time periods was on 21 December 1973 (1,350 cfs); the corresponding daily mean flow for this date was 310 cfs.

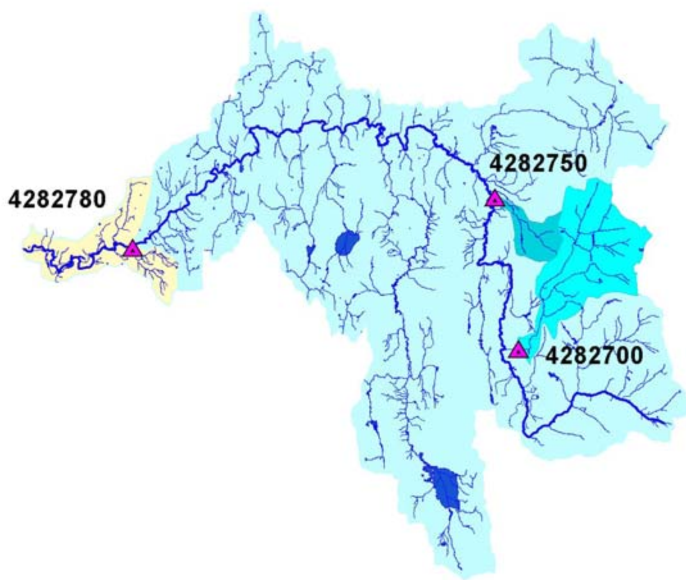


Figure 9. Location of USGS Gaging Stations in Lewis Creek Watershed.

From a relatively limited period of record existing for each gaging station, and relying on relationships established for other regional gaging stations with longer periods of record, the USGS (Olson, 2002) has estimated the approximate magnitude of peak flows for each gaging station (Table 3, next page). From the actual records for these three gages, it is evident that the Lewis Creek has not experienced a substantial flood event in the previous 19 years (see Figure 10, next page). The maximum peak flow recorded at the Route 7 gage during this period was 4,030 cfs on 20 May 2006; which corresponds to an approximate 50-year flood magnitude, or Q50 (Olson, 2002; see Table 3). Historic records (mid-1960s to mid-1970s) for the smaller tributary gages (draining the western Green Mountains) indicate a significant flood event on 21 December 1973 (a Q50 to Q500 magnitude event).

2.5 Flood History

Flood events, particularly higher magnitude flows, can serve as a stressor to the river network leading to localized or systemic channel adjustments. Available historic data and USGS flow data were reviewed to identify flood events of significance over the last century in the Lewis Creek watershed (Table 4). Limited historical review included review of State-wide flood publications. The 1927 flood was the highest flood on record in the State of Vermont.

Table 4. Notable flood events in Lewis Creek watershed

Notable Flood Dates	Data Source
1913	USGS, 1990
1927	USGS, 1990
1936	USGS, 1990
1938	USGS, 1990
1973, Dec 21 *	USGS, 2009

** Note that the USGS gaging records for the two mountainous Lewis Creek tributaries indicate a Q50 to Q500 flood event peaking on 21 December 1973; this date is different from the 30 June – 1 July 1973 flood event which affected a majority of the State (VTDEC WQD, 1999).*

Table 3. Estimated flood magnitudes for Lewis Creek watershed

	USGS Stn #	4282780	4282750	4282700
	USGS Description	Lewis Creek at North Ferrisburg	Lewis Creek Tributary No. 2 Near Rockville	Lewis Creek Tributary at Starksboro (High Knob Trib)
	USGS Period of Record	1990 - present	1964 - 1978	1963-74, 1999-2000
	Upstream Dr. Area, (USGS, 2009) (sq mi)	77.2	1.07	5.31
	Upstream Dr. Area, (Olson, 2002) (sq mi)	77.4	1.23	5.34
	Geomorphic Reach	M05	M16S1.01	T6.01
Storm Magnitude	**Data Source**	**Discharge (cfs)**		
$Q_{1.5}$	(VTDEC WQD, 2001b)	1,851	19	106
Q_2	(Olson, 2002)	2,280	46	118
Q_5		2,990	63	207
Q_{10}		3,420	75	266
Q_{50}		4,270	103	543
Q_{100}		4,590	115	704
Q_{500}		5,290	144	1,210

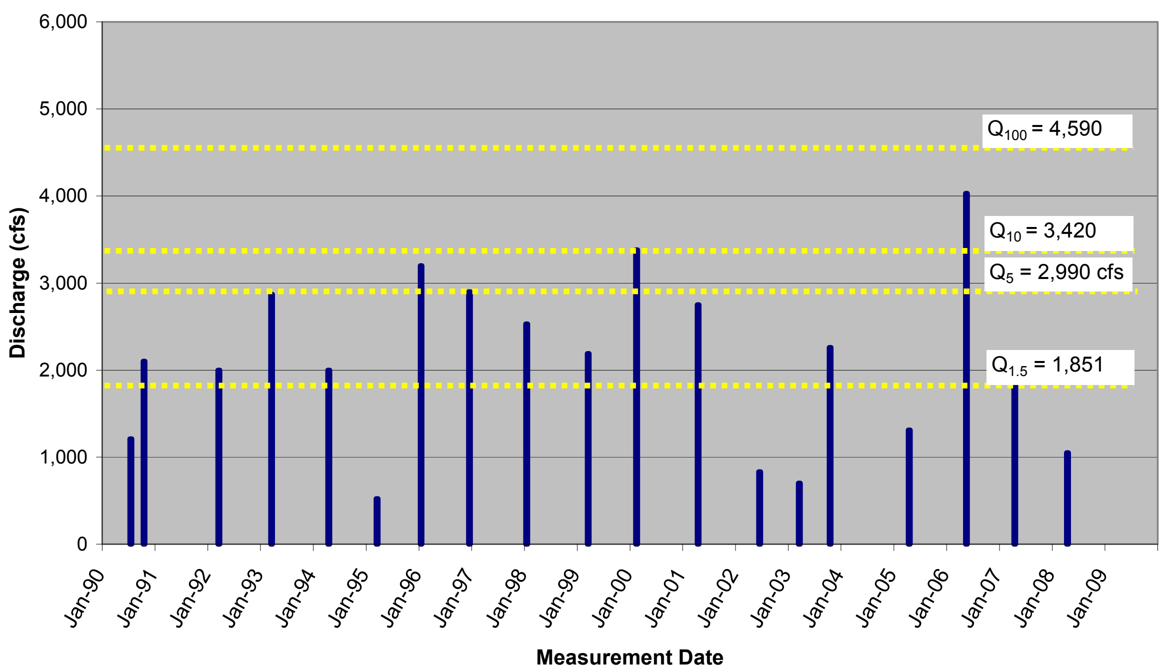


Figure 10. Recorded Peak Flows for Lewis Creek at North Ferrisburgh, VT gage, USGS Stn #04282780 77.2 square miles, reach M05 (compared to estimated flood peaks after Olson, 2002)

2.6 Land Use

Current (1993) land use / land cover is summarized for the overall Lewis Creek watershed, as well as seven of the major tributaries in Table 5. Land use within the Lewis Creek watershed is estimated as 61% forested, 26% agricultural fields, and 5% urbanized (developed, transportation, utilities), with the remaining 8% comprised of lakes, ponds, and wetlands (VCGI, 2003; Millette, 1997 – source imagery dated 1991 to 1993).

Table 5. Land cover/ land use in Lewis Creek watershed and select Major Tributaries.

Watershed	Drainage Area (sq mi)	Commercial / Industrial	Residential	Agricultural	Forest / Shrub	Water / Wetland
Lewis Creek (full watershed)	81.1	0%	5%	26%	61%	8%
Lewis Creek (upstream of M06)	77.4	0%	5%	25%	62%	8%
Lewis Creek (upstream of M11)	65.6	0%	4%	21%	66%	8%
Lewis Creek (upstream of M14)	38.2	0%	4%	14%	76%	5%
Lewis Creek (upstream of M19)	18.4	0%	4%	11%	81%	5%
T1 (Prindle Brook)	2.9	0%	5%	46%	39%	10%
T2 (Cedar Brook)	6.3	0%	7%	31%	49%	12%
T3 (Pond Brook)	18.3	0%	4%	28%	57%	11%
T4 (Hollow Brook)	9.2	2%	4%	12%	77%	6%
T5 (Hogback Brook)	2.4	0%	0%	7%	87%	5%
T6 (High Knob Bk)	5.2	0%	5%	6%	85%	4%
T7 (Unnamed Bk)	3.7	0%	2%	1%	92%	5%

Forest cover is particularly abundant in the eastern portion of the watershed (including Hollow Brook and High Knob Brook) located in the Northern Green Mountain Province, and generally decreases in the watershed with distance downstream along the main stem. Conversely, agricultural uses increase in percentage with distance downstream, tending to be concentrated in the Champlain Valley lowlands of the watershed. Higher densities of agricultural activities tend to be coincident with the silt and clay-rich soils of glaciolacustrine origin found in the western half of the watershed, including Prindle Brook, Cedar Brook, and Pond Brook subwatersheds.

Residential and commercial development in the Lewis Creek watershed is relatively sparse. The 2% commercial development in Hollow Brook subwatershed is the Hinesburg sand & gravel quarry. Village centers in vicinity of the assessed reaches include Starksboro and North Ferrisburgh, as well as the commercial / residential properties built up along Rt. 7 north of Ferrisburgh village.

Historically, some industrial and manufacturing activities were located along the Lewis Creek main stem (Beers, 1869; Beers, 1871; Walling, 1857; Smith, 1886). Dams were present on the Lewis Creek channel to provide power to these manufacturing interests. Most of these dams are no longer present, having been breached or destroyed in past floods. One dam persists on the main stem: Scott Pond dam. This structure is further discussed in Section 5.1.1 and in Appendix G.

Widespread deforestation of Vermont's landscape occurred by the early- to mid-1880s to support subsistence and sheep farming and lumber industries. Forest cover in the highlands began to regenerate in the late 1800s and early 1900s, during the industrial age when upland farms and sawmills were commonly abandoned (Thompson & Sorensen, 2000).

2.7 Water Quality

Long term water quality monitoring near the mouth of the Lewis Creek has identified elevated phosphorus levels and turbidity (VTDEC WQD and NYSDEC, 2009). Phosphorus loading targets have been established for tributaries draining to Lake Champlain as part of the strategy to achieve in-lake target concentrations of phosphorus for various segments of Lake Champlain. Phosphorus loading from the Lewis Creek to Lake Champlain for monitoring years 1990 to 2006 has exceeded target levels (Medalie & Smeltzer, 2004; LCBP, 2008). A slight increasing trend of phosphorus loading for Lewis Creek is apparent (LCBP, 2008), influenced by a few high (flow-adjusted) phosphorus concentrations recorded in years 2003 and 2004 (Medalie, 2005). Lewis Creek drains to the Otter Creek segment of Lake Champlain, which has an established target concentration of 14 micrograms per litre (VTANR & NYSDEC, 2002). Concentrations of phosphorus in the Otter Creek segment of Lake Champlain are sometimes higher than this target, and sometimes lower; overall, there is no statistically significant trend in phosphorus levels in this lake segment (LCBP, 2008).

Within the Lewis Creek watershed, historic water quality sampling during summer-season, low- to moderate-flow conditions at nineteen (19) sample stations (8 regular and 11 occasional) along the main stem and major tributaries has identified phosphorus and *E. coli* impacts in Lewis Creek, as well as sedimentation from unstable stream reaches and road / culvert maintenance practices (ACRWC, 2009).

At present, seven stations are regularly monitored by the Addison County River Watch Collaborative for turbidity, phosphorus, and nitrates (Table 6) – *E.coli* is also monitored at five of these stations (excluding LCR9.9 and LCT3D.5). These ACRWC stations complement the Long-term Monitoring station maintained by VTDEC Water Quality Division near the Route 7 bridge (vicinity of traditional ACRWC Site LCR3.7 – Reach M05).

Table 6. Water Quality stations regularly monitored by the Addison County River Watch Collaborative (ACRWC) on Lewis Creek.

Stream	Reach	ACRWC Site No.	Site Name
Lewis Creek	M08	LCR7.25	Lower Covered Bridge (Quinlan)
	M10-F	LCR9.9	Upper Covered Bridge (Seguin)
	M15-B	LCR14	Tyler Bridge
	M19-A	LCR17.2	Starksboro Ball Fields
	M19-B	LCR18.6	Lewis Creek Farm footbridge
	M20-A	LCR19.5	Parsonage Road bridge
Pond Brook	T3.01-C	LCT3D.5	Silver Street bridge

E.coli is frequently above the State water quality standard (77 organisms per 100 mL) at regularly monitored sampling stations located from river mile 3.7 to river mile 19.5 (monitored from 1992-2008).

More recent (2004-2008) monitoring initiated at the mouth of Pond Brook tributary has also noted *E.coli* concentrations well above the standard (ACRWC, 2009).

Turbidity levels (suspended sediments) are generally low in Lewis Creek and Pond Brook, below the state standard of 10 Nephelometric Turbidity Units (NTUs) for this Class B cold-water stream (Vermont Natural Resources Board, 2008). Occasionally, summer turbidity levels increase above the standard -usually associated with a summer storm and moderate (below bankfull) flow event (ACRWC, 2009).

Total Phosphorus concentrations have consistently been above levels which would suggest nutrient enrichment at sampling sites from river mile 3.7 to 19.5 on the main stem (1997-2008) and at the mouth of Pond Brook (2004-2008). Historic phosphorus concentrations at these stations have been above the recently proposed instream nutrient criteria of 0.044 mg/L for Class B "warm-water medium-gradient" wadeable streams (VTDEC WQD, 2009).

There are no significant ***point*** sources of phosphorus (such as wastewater treatment plants) within the Lewis Creek watershed (VTANR and NYSDEC, 2002); nonpoint sources account for essentially the total contribution of phosphorus in the watershed. Eroding streambanks have been identified as a contributing ***nonpoint*** source of phosphorus in rivers and streams of Vermont (VTANR, 2001; DeWolfe *et al*., 2004) and elsewhere in the nation (Kalma & Ulmer, 2003; Nelson & Booth, 2002). Recent investigations (2002-2003) of three streambank erosion sites along the Lewis Creek, coupled with land-use based computer modeling, indicated that streambank erosion was the second highest contributor of total phosphorus loading to Lewis Creek, behind agricultural runoff. The proportion of total phosphorus loads from streambank erosion ranged from 22 to 35% at the three sites which were located upstream of the Route 7 crossing in Ferrisburgh, downstream of the Route 7 crossing, and west of Route 116 in vicinity of the Clifford farm, Starksboro (DeWolfe *et al*., 2004).

Based on VTDEC and Lewis Creek Association water quality monitoring results, the State of Vermont has listed the following Lewis Creek sections as impaired for contact recreation use due to *E. coli* impacts likely resulting from agricultural runoff (VTDEC WQD, 2008a):

- Lewis Creek main stem, 12.3 miles from Lower Covered Bridge upstream to footbridge (Reaches M08 through M20)
- Pond Brook from confluence with Lewis Creek upstream approximately 1.5 miles (Reach T3.01)

In addition, the following river section is listed on Part C (List of Priority Surface Waters in need of Further Assessment) for nutrient impacts (to aquatic life support and contact recreation uses) from bank instability, erosion, and loss of riparian buffer (VTDEC WQD, 2008b):

- Lewis Creek river mile 7.5 to 16.6 (Reach M08 through M14)

3.0 ASSESSMENT METHODOLOGY

Phase 2 Stream Geomorphic Assessments conducted on the Lewis Creek main stem and tributary reaches utilized protocols published by the Vermont Agency of Natural Resources and available at: http://www.vtwaterquality.org/rivers/htm/rv_geoassesspro.htm.
Reference is made to these protocols for a description of specific methods (VTANR, 2007a).

3.1 Phase 2 Stream Geomorphic Assessment

Phase 2 Stream Geomorphic Assessment protocols are field procedures for geomorphic and habitat assessment. Reach-specific and cross-section data gathered during Phase 2 characterize the present geomorphic condition of the river reach and the dominant process(es) of adjustment (i.e., degradation, widening, aggradation and/or planform adjustment). Phase 2 results, along with Phase 1 assessment results, define the natural and human disturbances to the watershed and channel over time and the composite response or adjustment of the channel to these stressors. The Phase 2 assessment evaluates the sensitivity of reaches to future channel and watershed stressors given their current geomorphic condition and inherent vulnerability (e.g., valley setting, slope, streambed and streambank sediments, vegetative buffer conditions).

The Lewis Creek and tributary reaches were assessed between 2001 and 2009 (VTDEC WQD, 2001a, 2003a; LCA, 2006, 2008; SMRC, 2004, 2007; MMI, 2008, 2009). Many changes to the Phase 2 protocols have occurred over that time span. Appendix B provides a detailed summary of these changes and the updates that were undertaken to bring assessments generally up the standard of the 2007 protocols, within the constraints of available funding.

Specific features and channel positions were located using either a Garmin™ eTrex VISTA model or a Garmin™ 76CSx model global positioning system (GPS) unit. Pictures were recorded with a digital camera. Select features were digitized in ArcView© 3.x and referenced to the Vermont Hydrography Dataset (VHD), using the Feature Indexing Tool, a component of the Stream Geomorphic Assessment Tool (SGAT, v. 4.56). Certain parameters documented during the original Phase 1 Stream Geomorphic Assessment were updated based on field observations in Phase 2 (see Section 3.2). Phase 2 assessment data were entered into the online Data Management System (DMS, v.4.56) maintained by the VTANR. Phase 2 reach summary reports are compiled in Appendix C.

Valley wall shape files were generated for a majority of the main stem reaches. Shape files are contained on the Project CD. With the exception of reach M15 and the High Knob tributary reaches, these delineations were completed by VT Agency of Natural Resources staff. A summary of valley wall status is provided in Appendix D. Further discussion of valley walls is found in the Quality Assurance documentation (Appendix E).

Phase 2 assessments incorporate the updated sensitivity assignments presented in the November 2008 draft River Corridor Protection Guide issued by VT Agency of Natural Resources (VTANR, 2008a).

For the majority of the reaches, the habitat assessment (Step 6 of the Phase 2 protocols) was conducted to 2007 standards. For nine Lewis Creek main stem reaches and eleven High Knob tributary reaches, a habitat assessment was completed to a newer version of the protocols (2008) and was separately reported by Milone & Macbroom (2009) (see Appendix B for more details).

3.2 Phase 1 Updates

Phase 1 assessment data for the main stem and tributary reaches were reviewed and verified during Phase 2 field work as per VTANR protocols. Necessary corrections or updates were documented on Phase 1 summary sheets for each reach. As appropriate, GIS shape files were corrected or updated (using the Feature Indexing Tool). Phase 1 data in the DMS were updated, and the metadata for each Phase 1 step in the database were reviewed and updated (where necessary) to reflect that data were supported by field observations. Updated Phase 1 reach summary reports are presented in Appendix C.

3.3 Quality Assurance / Quality Control

Phase 2 data were reviewed against standard DMS Phase 2 quality control checks (X.1 through X.4), and then submitted to the River Management Section for a quality assurance review. Quality assurance documentation is contained in Appendix E.

The following considerations and limitations apply to the Phase 2 data for the Lewis Creek main stem and tributary reaches:

- Where applicable, reaches were segmented using the Segmentation Tool contained in SGAT (v. 4.56). Segmentation was necessary to:
    - Capture subreaches of a stream type (after Montgomery & Buffington, 1997; and Rosgen, 1996) that was different than the reference stream type of the overall reach;
    - Identify sections of a reach that were of distinctly different geomorphic condition;
    - Identify sections of a reach undergoing a different channel management or land use;
    - Delineate wetland-dominated or beaver-impounded reach sections; and
    - Define bedrock channel sections, defined as "gorges" by protocols.

- The Segmentation Tool within SGAT automates the calculation of segment lengths. Elevation data for the downstream and upstream segment breaks were interpolated from USGS 7.5-Minute topographic maps. Segment lengths and elevations are presented in Appendix F, along with channel gradients calculated for each segment. Segment slopes were factored into the stream-type designation for each segment. Occasionally, a subreach of alternate stream type was identified based on the calculation of segment slopes.

- Select Phase 2 features (including, grade control locations, stormwater inputs, streambank erosion, revetment locations, and more) were geo-located using the Feature Indexing Tool (FIT) in SGAT. Using FIT, these features are indexed to the available Vermont Hydrography Dataset (VHD) for the Lewis Creek. In some cases, surface waters depicted on the VHD were significantly offset from their actual position on 1995 / 1999 orthophotos available for the study area. In some cases, the actual channel position has moved from its 1995 or 1999 position as a result of natural channel migrations. These cases were revealed by comparison of the 1995 / 1999 orthophotos with the 2003 aerial imagery (NAIP, 2003), or by review of channel positions recorded with a hand-held GPS receiver during assessment. Thus, locations and lengths of features indexed to the VHD should be considered approximate.

4.0 PHASE 2 ASSESSMENT RESULTS

Geomorphic and habitat assessments were completed on 36 reaches (42.6 river miles) of the Lewis Creek and major tributaries. Phase 2 assessment results are discussed below for the Upper and Lower main stem reaches (Sections 4.1 and 4.2, respectively) and the High Knob Brook and Hollow Brook reaches (Sections 4.3 and 4.4, respectively). Results for two additional tributary reaches are discussed in Section 4.2 in conjunction with the Lower main stem: the downstream-most reaches of Cedar Brook and Pond Brook. Reach and segment reports are provided in Appendix C. Detailed reach summaries are provided in Appendix G. A separate report provides details of the assessment of 7 reaches [5.7 river miles] in the High Knob tributary in Starksboro (Milone & MacBroom, 2008).

A reference stream type (Phase 1) and an existing stream type (Phase 2) have been classified for each reach. Stream type designations are based on Rosgen (1996) and Montgomery & Buffington (1997). A sensitivity classification was also assigned to each reach based on the Phase 2 stream geomorphic assessment data. The sensitivity classification is intended to identify "the degree or likelihood that vertical and lateral adjustments (erosion) will occur, as driven by natural and/or human-induced fluvial processes" (VTANR, 2007b). Inherent in the stream sensitivity rating are:

- the natural sensitivity of the reach given the topographic setting (confinement, gradient) and geologic boundary conditions (sediment sizes) – as reflected in the reference stream type classification; and

- the enhanced sensitivity of the reach given by the degree of departure from reference (or dynamic equilibrium) condition – as reflected in the existing stream type classification and the condition (Reference, Good, Fair to Poor) rating of the Rapid Geomorphic Assessment).

Abbreviations used in the sections below include the following (see protocols for further description):

- Left Bank, facing downstream (abbreviated, "LB")
- Right Bank, facing downstream (RB).
- Incision Ratio (IR) = Low Bank Height / Bankfull Max Depth
    - IR_{RAF} = Recently Abandoned Floodplain Incision Ratio
    - IR_{HEF} = Human-Elevated Floodplain Incision Ratio
- Entrenchment Ratio (ER) = Flood Prone Width / Bankfull Width
- Width / Depth Ratio (W/D) = Bankfull Width / Mean Depth
- Flood Prone Width (FPW) – estimated as the 10- to 50-year flood event
- Stream Type Departure (STD)
- Large Woody Debris (LWD)
- Debris Jams (DJs)
- Rapid Geomorphic Assessment (RGA)
- Rapid Habitat Assessment (RHA)
- Vermont Hydrography Dataset (VHD)
- National Wetlands Inventory (NWI)
- Vermont Significant Wetlands Inventory (VSWI)

4.1 Lewis Creek – Upper Main Stem - Starksboro, Monkton, Hinesburg

The upper main stem of Lewis Creek is comprised of reaches M23 (in vicinity of Ireland Road, Starksboro) through M14 (near the intersection of Lewis Creek Road and Turkey Lane in Hinesburg) (Figure 11). These ten reaches have upstream drainage areas ranging from 8.9 to 38.2 square miles. Assessment results are summarized below in Table 7. Detailed reach narratives are presented in Appendix G. Two major tributaries join the Lewis Creek in this upper section; High Knob tributary and Hollow Brook tributary. Results for those tributary reaches are presented separately in sections 4.3 and 4.4.

Generally, the upper main stem of Lewis Creek has a relatively low gradient (<1%) with an unconfined setting (Narrow to Very Broad valley confinement). Exceptions to this generalization include: reach M23 which is of steeper gradient (2.6%), since it is transitional between the upper, semi-confined, steep reaches of the headwaters and the broad alluvial valley along Route 116 in southern Starksboro; and the bedrock falls (6.9%) at States Prison Hollow (M18). Also, there are occasional valley pinch points along the channel where bedrock-controlled valley side slopes confine the channel, such as a short segment (A) of reach M21 near the Tatro Rd crossing at Camp Common Ground; and the semi-confined reach M14 along Lewis Creek Rd in Hinesburg which contains exposures of channel-spanning bedrock.

Above the States Prison Hollow bedrock gorge, the Lewis Creek generally flows through sediments of alluvial and glaciofluvial origin. Below the gorge, valley soils are dominated by sediments of alluvial and glaciolacustrine origin; and streambanks are often cohesive in nature. The hydric nature of corridor soils becomes more prevalent downstream of the gorge. Channel-contiguous wetlands are present in reaches M17 and M15.

Residential and commercial encroachments along the upper main stem reaches are generally minor. There a few residential structures located within the floodplain in reaches M22, M21, and M17-C (Starksboro) and along M15-A and M14 (Hinesburg). A community ball field is constructed in the floodplain in segment M19-A in Starksboro. A commercial tree nursery is located in the floodplain in M15-B. Otherwise, homes and buildings are situated along the valley margins. Similarly, road encroachments are limited along the upper main stem; Ireland Road follows reach M23; a short stretch of VT Route 116 encroaches on reach M22 near the mid-point of the reach; States Prison Hollow Road follows the Lewis Creek at the bedrock gorge (typically elevated well above the floodplain, but is a source of stormwater inputs to the channel); States Prison Hollow Road Extension encroaches within the floodplain along M17-C; and Lewis Creek Road parallels the channel along reach M14 (typically elevated well above the floodplain, but contributing road sediment to the channel). Berms have been constructed along Ireland Road (M23) to protect the road and nearby homes. Berms and armoring have been installed at the upper end of reach M22 where the channel is transitioning out of upstream steeper-gradient settings into the broad alluvial valley – to protect agricultural fields and residential homes. At a similar reduction in gradient at the base of States Prison Hollow gorge, the channel was historically dredged, windrowed and bermed along both sides following the 1938 flood – when flood waters caused damage to homes along the north side of the channel.

Channelization is known or suspected along sections of reaches M22, M21, M20, and M19, the upper half of M17 and the upper end of M15. Occasionally, channelization is associated with road encroachments and bridge crossing sites: Hillsboro Rd (M22), Route 116 (M22), Meadowlark Lane (M22), Parsonage Rd (M20), farm bridge (M19), States Prison Hollow Rd Ext (M17-C), Tyler Bridge Rd (M15-B). Otherwise, straightening is associated with agricultural land uses.

Agricultural uses – including pasture, hay and crop fields - are concentrated along select reaches of the upper Lewis Creek main stem, including M22, M21-B, M20-A, M19-B, M17-B, M17-A, M16, and M15-B. Livestock has direct access to the channel in reaches M17-A, and via fenced crossing sites in M19-B and M16.

Upstream of the States Prison Hollow gorge, each of the upper main stem segments from M23 downstream to M19-B in Starksboro has incurred some degree of historic incision. Two of the segments (M23 and M20-B) have undergone a vertical stream type departure (from a Cb-to-Fb and C-to-F stream type, respectively), losing connection to the surrounding floodplain as a result of historic incision and downstream channel management. (In these cases, there is uncertainty whether incision occurred (in part or in whole) as a result of disturbances to the channel / watershed occurring over the last 300 years, or whether some degree of incision occurred over the past thousands of years). The channel begins to regain reasonable access to the floodplain in segment M19-A immediately upstream of the valley pinch point and grade control of the bedrock gorge. Downstream of the gorge, the channel has generally good access to the floodplain (IR<1.3) with a couple of exceptions. The upstream segment of M17 at the base of the gorge is somewhat disconnected from the floodplain (IR=1.4) probably as a result of downstream channelization and/or the extensive channel management following the 1938 flood. Also, segment M15-B is moderately entrenched (IR=1.6) perhaps as a result of channelization local to the Tyler Bridge Road bridge and/or as a result of increased hydrologic loading from upstream reaches and the Hollow Brook tributary (see Section 4.4).

Sensitivities of the upper main stem reaches/ segments range from High to Extreme, indicating the likelihood for adjustment in the case of future channel modifications or a change in watershed inputs of flow and/or sediment. Two exceptions are the Very Low sensitivity bedrock gorge (M18) and Moderate sensitivity of the confined, bedrock-controlled reach M14. The upper main stem reaches/segments are presently dominated by minor to moderate lateral adjustments (widening, planform adjustment) and minor (often localized) aggradation. Unconfined segments upstream of the States Prison Hollow gorge generally persist in late stage II [F] where boundary resistance is offered by confining valley walls (M21-A), forested buffers (M23, M21-A, M20-B), and/or streambank armoring (portions of M19-B and upper extent of M22). Otherwise, reaches with little boundary resistence due to erodible channel margins and lack of forested buffers (majority of M22, M21-B, M16, M15-A) are in stage III[F] or early stage IV[F] of evolution. A lateral stream type departure (from E to C) is inferred in reach M16. Beaver activity is contributing to localized aggradation and widening in several segments (M22, M21-A, M19-B, M19-A, M17-B, M17-A, M16, M15-B, and M15-A).

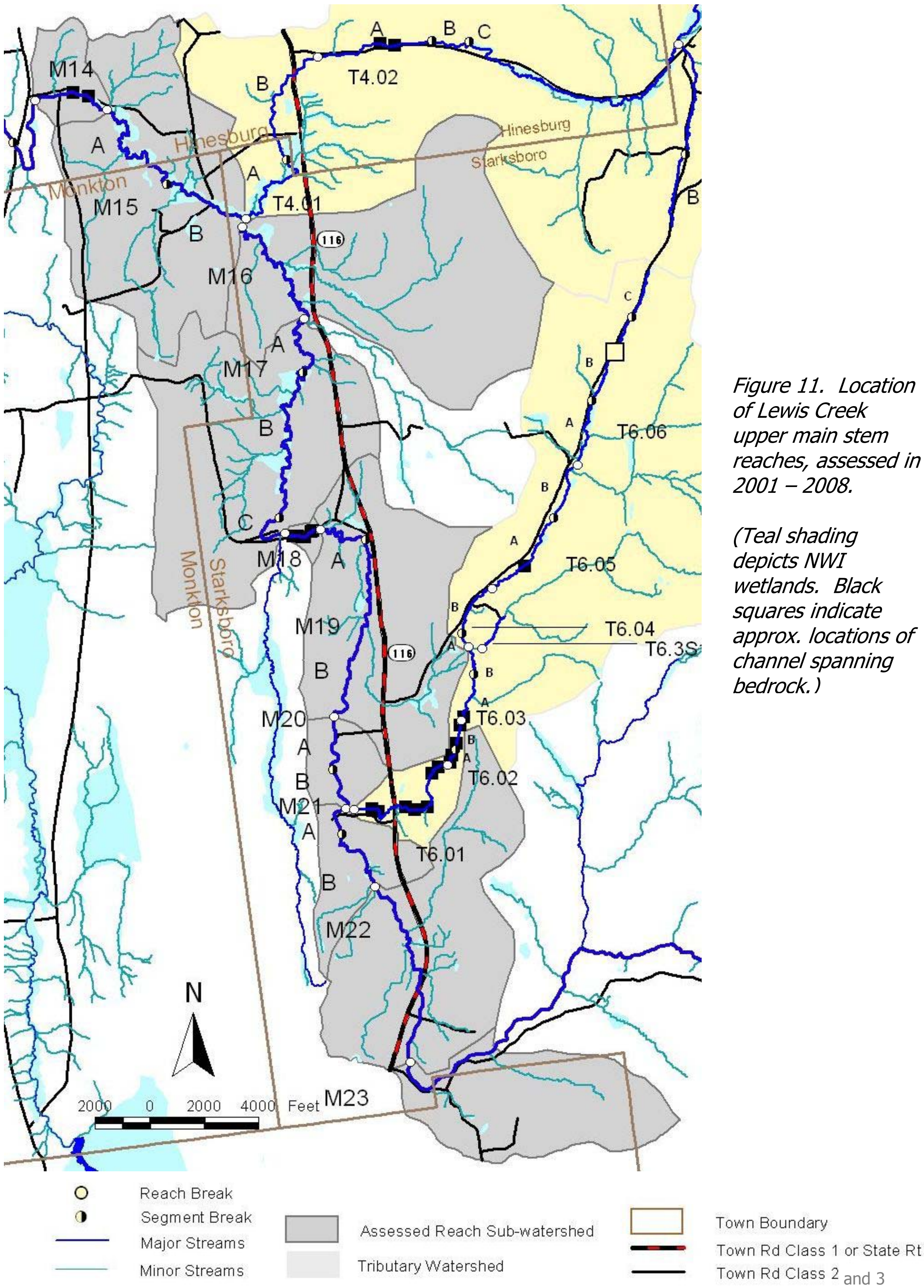


Figure 11. Location of Lewis Creek upper main stem reaches, assessed in 2001 – 2008.

(Teal shading depicts NWI wetlands. Black squares indicate approx. locations of channel spanning bedrock.)

Table 7. Results of Phase 2 Geomorphic Assessments, in 2001-2008.
Lewis Creek – upper main stem – Starksboro, Monkton, Hinesburg

Reach	Seg-ment	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq mi)	Stream Type	Incision Ratio	Width Depth Ratio	RGA Condition	Active Adjustment Process	Channel Evolution Stage	Stream Type Departure?	Sensitivity
M23	--	4,505	2.6	8.9	F4b-PB	3.95	28.4	0.49 Fair	Mod aggr; local Wid	II [F]	Cb to Fb	Extreme
M22	--	7,944	***0.8***	10.7	C4-R/P	1.6	22.96	0.51 Fair	Mod PF, local Aggr/Wid	III [F]	No	Very High
M21	B	3,118	***0.4***		C4-R/P	1.49	14.7	0.48 Fair	Substantial PF, Mod Aggr	IV [F]	No	Very High
	A *	1,280	***0.5***	11.1	B3c-PB	1.4	12.2	0.58 Fair	Min wid	III [F]	No	High
M20	B	1,738	***0.9***		F3-R/P	2.6	33.3	0.48 Fair	Mod wid, local aggr	II [F]	C to F	Extreme
	A	2,294	***0.5***	16.6	C4-R/P	1.89	21.9	0.50 Fair	Mod PF, Min aggr	IV [F]	No	Very High
M19	B	8,077	***0.3***		C4-R/P	1.26 [RAF]	15.2	0.63 Fair	Mod PF, Aggr	III [F]	No	Very High
	A *	2,808	***0.2***	18.4	E4-R/P	1.17 [RAF]	8.01	0.75 Good	Min to mod PF	I [D]	No	High
M18	--	1,446	6.9	18.4	B2a-S/P	1.0 [RAF]	12.8	0.78 Good	None (minor)	I [D]	No	Very Low
M17	C *	2,005	***0.8***		C4-R/P	1.4 [RAF]	11.6	0.61 Fair	Min Wid, PF	III [F]	No	Very High
	B	8,552	***0.2***		E4-R/P	1.0 [RAF]	6.8	0.65 Good	Mod PF, Min aggr	IV [F]	No	High
	A	3,446	***0.1***	23.1	E4-R/P	1.25 [RAF]	3.35	0.68 Good	Minor PF (migration)	I [F]	No	High
M16	--	6,559	0.06	26.6	C4-R/P	1.16 [RAF]	20.2	0.55 Fair	Mod PF & Wid	III [F]	E to C	Very High
M15	B	3,989	***0.2***		C4-R/P	1.6 [RAF]	36.3	0.54 Fair	Signif PF, Mod aggr	IV [F]	No	Very High
	A *	6,162	***0.1***	37.9	E4-R/P	1.0 [RAF]	10.65	0.61 Fair	Mod PF, aggr	IV [F]	No	Extreme
M14	--	3,003	0.33	38.2	B3c-R/P	1.0 [RAF]	21.02	0.83 Good	None (minor)	I [D]	No	Moderate

Notes / Abbreviations:

Channel Slope: Values in italic bold have been updated since the Phase 1 SGA, due to field-truthing and/or segmentation.

Stream Type: S/P = Step/Pool; R/P = Riffle/Pool; R/D = Ripple/Dune; PB = Plane Bed; Br = Braided; Casc = Cascade; Ref = Reference

Incision Ratio: RAF = Recently Abandoned Floodplain; HEF = Human-elevated Floodplain (following protocols, VTANR, 2007).

Condition: RHA = Rapid Habitat Assessment; RGA = Rapid Geomorphic Assessment (VTANR, 2007).

Adjustment: PF = Planform Adjustment; Aggr = Aggradation; Wid = Widening; Deg = Degradation; NM = Not Measured.

Channel Evolution Stage: F = F-stage model; D = D-stage model (see Appendix C of protocols, VTANR, May 2007).

Sensitivity - assigned as per updates communicated by VTANR in Nov 2008 DRAFT River Corridor Protection Guide.

* Subreach of alternate reference stream type.

4.2 Lewis Creek - lower main stem – Monkton, Hinesburg, Charlotte, Ferrisburgh

The lower main stem of Lewis Creek is comprised of reaches M13 (in vicinity of Silver Street, Hinesburg) through M01 (at the mouth of the river – its confluence with Lake Champlain in Hawkins Bay). The locations of these reaches are depicted on Figures 12-a (east) and 12-b (west). These thirteen reaches have upstream drainage areas ranging from 38.9 to 81 square miles. Assessment results for two tributary reaches at the confluence with the main stem in this section are also presented: the downstream-most reach of Pond Brook (T3.01) which has an upstream drainage area of 18.3 square miles; and the downstream-most reach of Cedar Brook (T2.01) which has an upstream drainage area of 6.3 square miles. Results are summarized below in Tables 8 and 9, respectively. Detailed reach narratives are presented in Appendix G.

Generally, the lower main stem of Lewis Creek has a relatively low gradient (<1%) with an unconfined setting (Narrow to Very Broad valley confinement). Exceptions to this generalization include locations of bedrock-controlled channel in confined settings, including the bedrock falls upstream of the Seguin covered bridge (M10-F); a half-mile segment between the Seguin covered bridge and Scott Pond (M10-C); and the 1.7-mile reach upstream of North Ferrisburgh village (M07). Additional exposures of channel-spanning bedrock, offering grade control to the channel, were observed in segments M11, M09-B, M08, M06, and M05. The Scott Pond Dam on Segment M09-B also serves as a vertical grade control (Figures 12-a, 12-b).

The Semi-confined, bedrock-controlled, moderately steep (2.3%) reach of Cedar Brook joins the Lewis Creek channel at the upstream end of reach M11. The unconfined, lower-gradient reach of Pond Brook (T3.01) joins the Lewis Creek channel at the upstream end of reach M12.

Along the lower main stem, the Lewis Creek generally flows through sediments of alluvial and glaciolacustrine origin. A degree of cohesiveness in streambank soils was noted, due to moderate silt content and occasional varved clays. Occasionally, the channel impinges on a terrace of glacial till sediments. (Exceptions to this generalization include reach M06 downstream of North Ferrisburgh village, where channel and floodplain sediments are of alluvial and glaciofluvial origin). Floodplain soils are frequently hydric in nature. Channel-contiguous wetlands (NWI, VSWI) are mapped along several reaches; wetland conditions and associated beaver impoundments precluded assessment on segments M13-A, M12-C, and M12-A. Downstream reaches M01 and M02 were not able to be assessed due to backwater effects from Lake Champlain.

Impoundment effects of the Scott Pond Dam precluded assessment on short segments M09-B and M10-A. This concrete dam is founded on bedrock, and operates as a run-of-river structure with a minimal upstream impoundment. At present, the dam is maintained as a barrier to the upstream migration of sea lamprey (USFW et al, 2001) (see Section 5.1.1 and Appendix G).

Residential and commercial encroachments along the lower main stem reaches (and tributary reaches, T3.01 and T2.01) are generally minor. A few homes are present along the valley margins; and some development is concentrated in the North Ferrisburgh village at the reach break between reaches M07 and M06. Similarly, road encroachments are minimal along the lower main stem; notable exceptions include a short stretch of the Roscoe Road along segment M10-E in Charlotte; Lewis Creek Road in Charlotte along segments M09-B and M09-A; and Spear Street along the upper end of M08. Berms have been constructed along Roscoe Road (M10-E) and Spear Street (M08) to protect these road segments. Streambank armoring and revetments have also been installed.

Channelization is possible along these segments, given the presence of berms and a linear planform of the channel. Elsewhere along the lower main stem, channelization is inferred from linear planform and a degree of historic entrenchment in vicinity major road crossings: Silver Street (M13-A), Baldwin Rd (M12-

B, -A), Seguin Covered Bridge (M10-E), Quinlan Covered Bridge (M08), North Ferrisburgh (M07/ M06), Route 7 (M05), and Greenbush Road (M04/ M03). Channelization is also inferred along the middle segment (B) of Pond Brook reach T3.01 in active pasture lands, based on comparison of 1974 to 1999 aerial photographs (see Appendix G).

Historic impoundments at North Ferrisburgh (M07), Scott Pond (M09-A) and the falls above Seguin Covered Bridge (M10-E) may have contributed to historic incision in their vicinity as a result of "hungry water" effects downstream of the dam sites while these structures were intact and subsequent to breaching effects upstream of the dam sites (see Section 5.1.1 and Appendix G).

Agricultural uses – including pasture, hay and crop fields - are concentrated along select reaches of this lower Lewis Creek main stem, including M13-B, M13-A, M12-A, M11, M10-E, M10-B, M08, M04, M03, M02, and T3.01-B. Livestock has direct access to the channel in reaches M02, M01, and T3.01 (Segment B). Some reaches receive flow from tributary channels that drain intensively farmed acreage. Occasionally, tributaries through areas of hydric soils (and prior wetlands) have been channelized, ditched and tiled to improve drainage. Notable in this regard are reaches M02, M05, M06, M10-B (receiving Prindle [aka Pease] Brook drainage), M11 (receiving Cedar Brook drainage from the south and tiled field drainage from the north), and M12 (receiving Pond Brook drainage).

With the exception of wetland segment M12-C, each of the lower main stem segments from M13 downstream to M08 in Hinesburg and Charlotte has incurred some degree of historic incision. (In some cases, there is uncertainty whether incision occurred (in part or in whole) as a result of disturbances to the channel / watershed occurring over the last 300 years, or whether some degree of incision occurred over the past thousands of years). Two of the segments (M12-B and M09-A) have undergone a vertical stream type departure (from a C-to-Bc and Bc-to-F stream type), losing connection to the surrounding floodplain as a result of historic incision, channel management, and (in the case of M09-A) road encroachment and upstream impoundments. Sensitivities range from High to Extreme, indicating the strong propensity for adjustment in the case of future channel modifications or a change in watershed inputs of flow and/or sediment. These reaches/segments persist in a partially to fully entrenched condition, and are presently dominated by minor (often localized) aggradation, widening and/or planform adjustment. Middle segments of M10 (D and C) are in later stages of channel adjustment and pockets of incipient floodplain are apparent at a lower elevation. In M13-A, M12-A and M11, beaver activity may be contributing to recovery of these reaches where transient beaver dams induce upstream aggradation.

Reaches M08 and M07 are reasonably stable with good floodplain access, except for the very upstream end of reach M08 in vicinity of the Quinlan covered bridge (see Appendix G). Reach M06 is actively widening and adjusting its planform in response to a high degree of historic incision. Historic impoundments at North Ferrisburgh village may have contributed to incision, as well as channelization within the reach. The surrounding corridor – once in agricultural use – is now fallow and buffers are slowly regenerating. To the extent that this corridor is protected, this reach will continue to recover. Reach M05 persists in a state of moderate historic incision, and is dominated by minor aggradation and planform adjustments. Stability is offered by the channel-spanning bedrock exposures in this reach. From M04 downstream to the lake, the Lewis Creek channel has good access to the floodplain (IR<1.1) and is in reasonable shape. M04 is impacted by aggradation from upstream reaches / tributaries which are inducing lateral adjustments.

The Pond Brook reach T3.01 has reasonable access to the floodplain in upper segment C and lower segment A. The previously-channelized segment B has lost some connection to the floodplain (IR=1.4) and is presently dominated by lateral adjustments – undergoing a lateral stream type departure from E to C stream type. The Cedar Brook reach T2.01 is in stable condition due to the extensive exposures of bedrock. This reach operates as a transport reach and may be conveying sediments from the upstream watershed where agricultural land uses and residential development have resulted in ditching and channelization of contributing tributaries. A build up of sediments at the Cedar Brook confluence with Lewis Creek has been noted in past assessments.

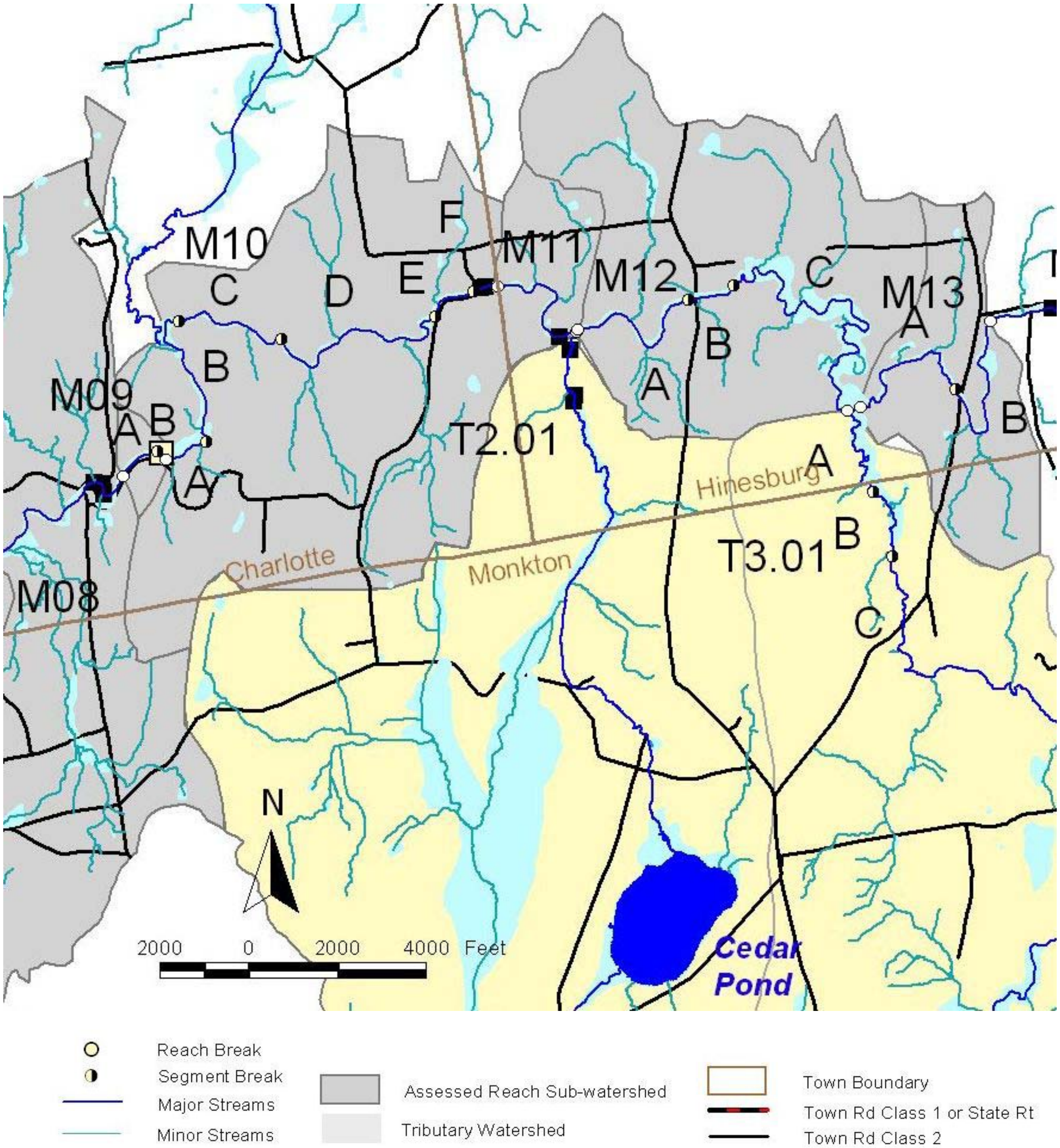


Figure 12-a. Location map of assessed reaches, Lewis Creek lower main stem – east. (Teal shading depicts NWI wetlands. Black squares indicate location of channel-spanning bedrock.)

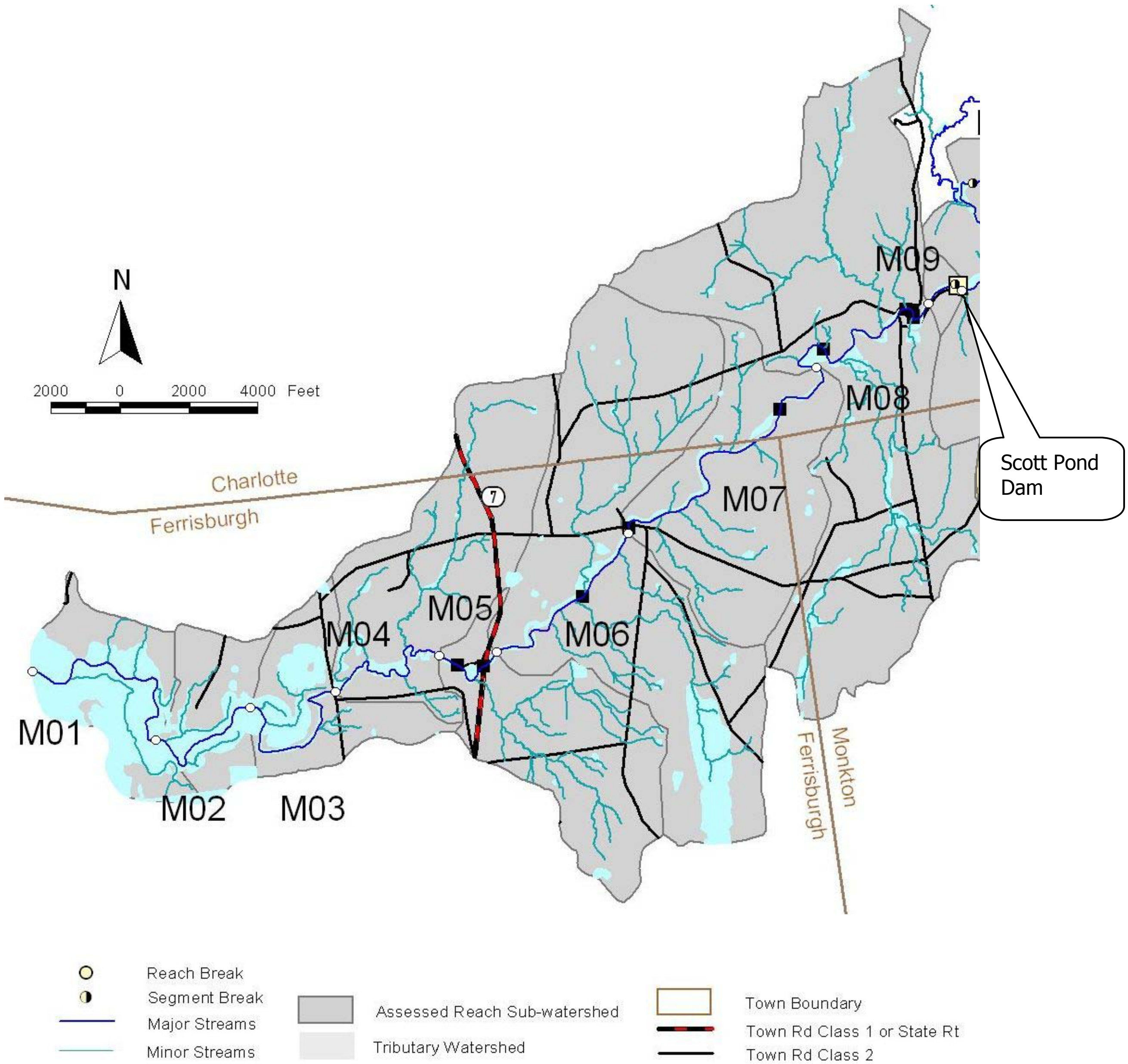


Figure 12-b. Location map of assessed reaches, Lewis Creek lower main stem – west. (Teal shading depicts NWI wetlands. Black squares indicate location of channel-spanning bedrock.)

Table 8. Results of Phase 2 Geomorphic Assessments, 2001-2008. Lewis Creek lower main stem – Hinesburg, Charlotte, Ferrisburgh

Reach	Seg-ment	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq mi)	Stream Type	Incision Ratio	Width Depth Ratio	RGA Condition	Active Adjustment Process	Channel Evolution Stage	Stream Type Departure?	Sensitivity
M13	B	4,041	***0.3***		C4-R/P	1.86 [RAF]	29.95	0.59 Fair	Min, localized aggr	II [F]	No	Very High
	A	3,802	***0.1***	38.9	Not Assessed - Beaver-impounded.							
M12	C	9,501	***0.1***		Not Assessed - Wetland-dominated; beaver-impounded.							
	B *	1,161	***0.7***		B4c-PB	1.7 [RAF]	17.8	0.69 Good	Historic incision	II [F]	C4 to B4c	Very High
	A	3,632	***0.3***	59.0	Not Assessed - Beaver-impounded.							
M11	--	3,341	0.36	65.6	C4-R/P	1.57 [RAF]	19.25	0.58 Fair	Mod wid, aggr, hist incis	III [F]	E to C	Very High
M10	F *	564	***1.8***		B1c-S/P	Not Assessed - Bedrock channel						
	E	1,149	***0.3***		C3-R/P	1.45 [RAF]	21.2	0.60 Fair	Min/ mod aggr, wid, PF	II [F]	No	High
	D	4,868	***0.3***		C4-R/P	1.59 [RAF]	57	0.54 Fair	Min/ mod aggr, PF	IV [F]	No	Very High
	C *	2,701	***0.9***		B4c-R/P	1.54 [RAF]	28.8	0.64 Fair	Min aggr	IV [F]	No	Very High
	B	3,535	***0.4***		C4-R/P	1.59 [RAF]	32.9	0.46 Fair	Mod PF, min/mod aggr	III [F]	No	Very High
	A	1,016	***0.1***	70.9	Not Assessed - Scott Pond dam impoundment							
M09	B	301	***1.0***		Not Assessed - Scott Pond dam and impoundment							
	A	1,004	***0.2***	71.0	F4-PB	2.7 [RAF]	31.7	0.46 Fair	Min Aggr/ Hist incis, Wid	II [F]	Bc to F	Extreme
M08	--	6,484	0.15	74.0	C4-R/P	1.0 [RAF]	20.9	0.76 Good	Min aggr, PF. Local wid	I [D]	No	High
M07	--	9,124	0.71	75.2	B4c-R/P	1.0 [RAF]	22.1	0.89 Ref	None	I [D]	No	High
M06	--	5,831	0.72	77.4	C3-R/P	1.96 [RAF]	24.5	0.45 Fair	Mod PF. Local aggrad	III [F]	No	High
M05	--	2,394	0.25	78.4	C3-R/P	1.5 [RAF]	33	0.60 Fair	Min aggr, PF	III [F]	No	High
M04	--	5,344	0.07	79.6	E5-D/R	1.0 [RAF]	10.7	0.59 Fair	Mod PF, min wid	IIc [D]	No	Extreme
M03	--	5,471	0.04	80.1	C5-D/R	1.03 [RAF]	14.7	0.75 Good	Min aggr, PF	I [F]	No	High
M02	--	4,092	0.02	80.5	Not Assessed - Influenced by Backwater Effects from Lake Champlain							
M01	--	6,693	0.01	81.1	Not Assessed - Influenced by Backwater Effects from Lake Champlain							

<u>Notes / Abbreviations:</u>

Channel Slope: Values in italic bold have been updated since the Phase 1 SGA, due to field-truthing and/or segmentation.
Stream Type: S/P = Step/Pool; R/P = Riffle/Pool; R/D = Ripple/Dune; PB = Plane Bed; Br = Braided; Casc = Cascade; Ref = Reference
Incision Ratio: RAF = Recently Abandoned Floodplain; HEF = Human-elevated Floodplain (following protocols, VTANR, 2007).
Condition: RHA = Rapid Habitat Assessment; RGA = Rapid Geomorphic Assessment (VTANR, 2007).
Adjustment: PF = Planform Adjustment; Aggr = Aggradation; Wid = Widening; Deg = Degradation; NM = Not Measured.
Channel Evolution Stage: F = F-stage model; D = D-stage model (see Appendix C of protocols, VTANR, May 2007).
Sensitivity - assigned as per updates communicated by VTANR in Nov 2008 DRAFT River Corridor Protection Guide.
* Subreach of alternate reference stream type.

Table 9. Results of Phase 2 Geomorphic Assessments, 2001-2008. Pond Brook and Cedar Brook tributaries draining to Lewis Creek lower main stem – Monkton, Hinesburg

Pond Brook (T3) - Monkton, Hinesburg

Reach	Seg-ment	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq mi)	Stream Type	Incision Ratio	Width Depth Ratio	RGA Condition	Active Adjustment Process	Channel Evolution Stage	Stream Type Departure?	Sensitivity
T3.01	C	4,363	***1.4***		C4-R/P	1.0 [RAF]	29.3	0.60 Fair	Mod PF; Local wid, aggr	I [F]	No	Very High
	B *	1,840	***0.1***		C4-R/P	1.4 [RAF]	16.4	0.51 Fair	Mod PF; Min aggr; hist wid	III [F]	E to C	Very High
	A *	3,199	***0.06***	18.3	E5-D/R	1.0 [RAF]	10.4	0.68 Good	Mod PF; Local aggr	I [F]	No	High

Cedar Brook (T2) - Monkton, Hinesburg

Reach	Seg-ment	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq mi)	Stream Type	Incision Ratio	Width Depth Ratio	RGA Condition	Active Adjustment Process	Channel Evolution Stage	Stream Type Departure?	Sensitivity
T2.01	--	3,202	2.3	6.3	B3-S/P	1.0 [RAF]	11.6	0.88 Ref	None	I [D]	No	Moderate

<u>Notes / Abbreviations:</u>

Channel Slope: Values in italic bold have been updated since the Phase 1 SGA, due to field-truthing and/or segmentation.

Stream Type: S/P = Step/Pool; R/P = Riffle/Pool; R/D = Ripple/Dune; PB = Plane Bed; Br = Braided; Casc = Cascade; Ref = Reference

Incision Ratio: RAF = Recently Abandoned Floodplain; HEF = Human-elevated Floodplain (following protocols, VTANR, 2007).

Condition: RHA = Rapid Habitat Assessment; RGA = Rapid Geomorphic Assessment (VTANR, 2007).

Adjustment: PF = Planform Adjustment; Aggr = Aggradation; Wid = Widening; Deg = Degradation; NM = Not Measured.

Channel Evolution Stage: F = F-stage model; D = D-stage model (see Appendix C of protocols, VTANR, May 2007).

Sensitivity - assigned as per updates communicated by VTANR in Nov 2008 DRAFT River Corridor Protection Guide.

* Subreach of alternate reference stream type.

4.3 High Knob tributary (T6) – Starksboro

High Knob Brook drains a 5.2-square-mile area in the eastern-central region of the Lewis Creek watershed in the town of Starksboro. This tributary joins the Lewis Creek just downstream of the Tatro Road crossing, at the upstream end of reach M20. A total of 7 reaches (5.7 miles) of the High Knob Brook were assessed in 2008 by Milone & MacBroom (Figure 13). Results are summarized below in Table 10. Detailed reach narratives are presented in Appendix G.

Generally speaking, the gradient of this channel decreases along the length of study. In the upper three miles (reaches T6.06, T6.05, T6.04-B), the channel is unconfined and relatively small in size, meandering through a narrow valley of moderate gradient between steep, bedrock-controlled valley walls along Big Hollow Road. Hydric soils and channel-contiguous wetlands are common in the upper two miles of assessed channel. Below the Brown Hill West Rd crossing, the channel then turns sharply to the south (T6.04-A), receives drainage from the tributary T6.3S1.01, and continues in an unconfined, low-gradient setting for approximately 4,000 feet above a valley pinch point. The channel then becomes steeper pitching through a steep bedrock gorge (T6.02-A). From this point downstream to the Lewis Creek, the High Knob Brook is transitional between the Green Mountains to the east and the Champlain Valley to the west. Several channel-spanning exposures of bedrock are present in the lower mile of the tributary below the gorge. E and C reference stream types dominate the upper 5 miles of assessed channel, above the bedrock gorge. B and Ba stream types are evident through the valley pinch point and gorge. Cb stream types are present in the mile of channel below the gorge.

Big Hollow Road encroaches within the High Knob Brook floodplain in the upper 3.5 miles. A 300+ foot section of the High Knob tributary (T6.06-A) in vicinity of the Dugway Lane intersection was channelized to flow along the west side of this road prior to 1962 – crossing under the road and back through two undersized culverts, and eliminating the Dugway Lane crossing of the tributary. Elsewhere channelization was evident particularly in segments T6.05-B, T6.04-B, T6.04-A and T6.3S1.01. A length of berm has enhanced the degree of channel entrenchment in reach T6.3S1.01. Some of the floodplain (in the lower-gradient, unconfined channel sections – reaches T6.06, T6.04-A, T6.03-B) has been converted to agricultural uses including pasture and hay fields. In Segment T6.06-B, the channel has been impounded above an earthen embankment that supports a driveway; this pond is apparently utilized for livestock irrigation. Some residential development has encroached within the floodplain of the High Knob Brook. Driveway and road crossings of the channel to access these residences are commonly undersized with respect to the bankfull width.

Generally, the upper and lower extremes of the assessed portion of High Knob tributary are in reasonably stable condition with access to the floodplain (IR < 1.3). In the upper reaches, despite a degree of historic channelization, potential widening and incision appear to have been moderated by the low gradient and cohesive sediments. In the downstream reaches (T6.02 and T6.01) the frequent exposures of bedrock in the channel banks and bed, and forested buffers, have afforded channel stability. Two of the middle segments spanning the Brown Hill West Rd crossing (T6.05-A and T6.04-B) have undergone an apparent vertical stream type departure (from C to Bc stream type). Sensitivities generally range from High to Extreme (MMI, 2008), indicating the likelihood of adjustment in the case of future channel modifications or a change in watershed inputs of flow and/or sediment.

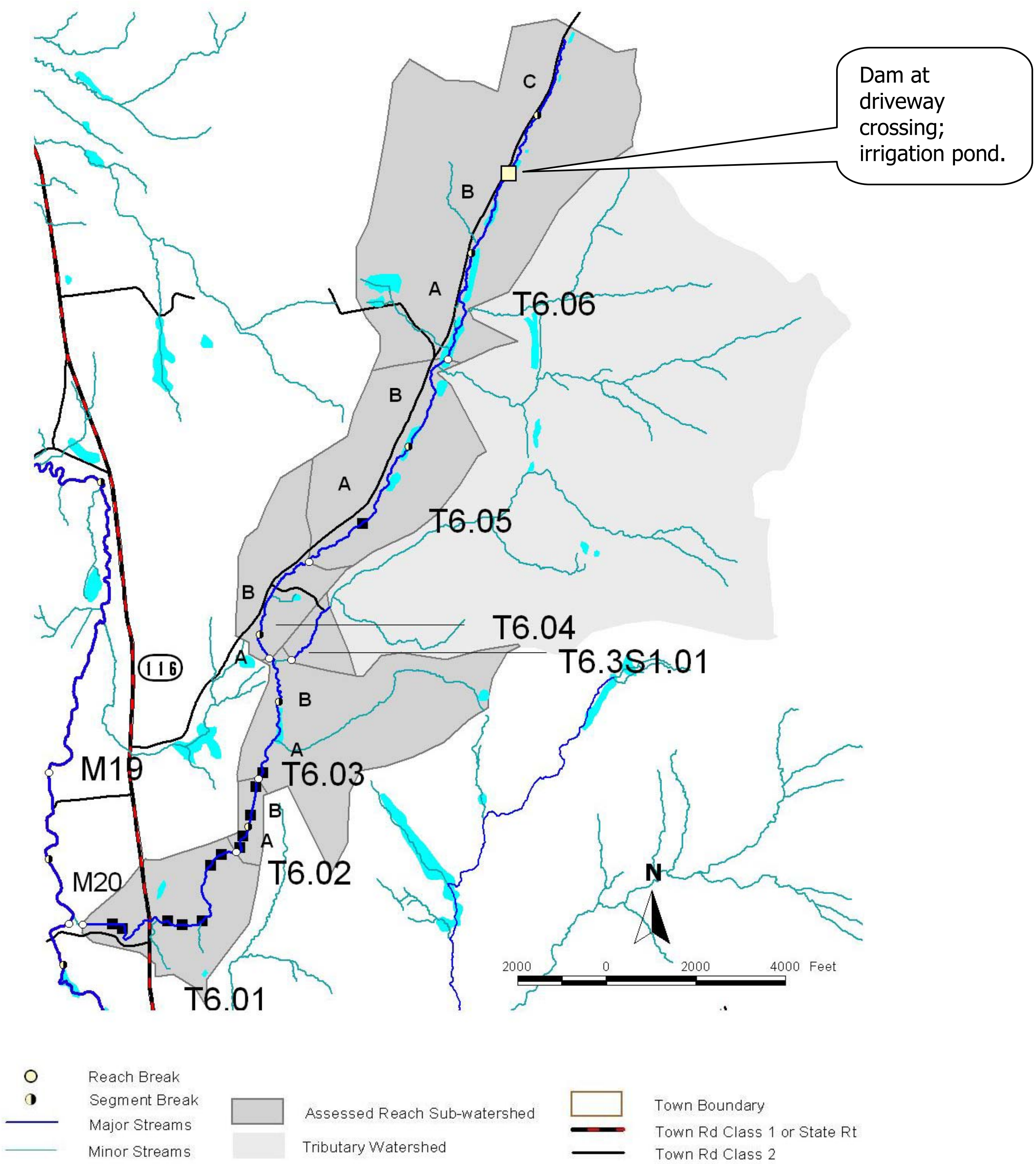


Figure 13. Location map of assessed reaches, High Knob tributary. (Teal shading depicts NWI wetlands. Black squares indicate location of channel-spanning bedrock – approximate locations only.)

Table 10. Results of Phase 2 Geomorphic Assessments, High Knob reaches assessed in 2008.

Reach	Seg-ment	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq mi)	Stream Type	Incision Ratio	Width Depth Ratio	RGA Condition	Active Adjustment Process	Channel Evolution Stage	Stream Type Departure?	Sensitivity
T6.06	C	1,918			Not Assessed - Wetland-dominated							
	B	3,677			E4-R/P	1.2	12.6	0.56 Fair	Aggr	III [F]	No	Very High
	A	2,887		1.6	E4-R/P	1.0	12.1	0.8 Good	None	I [F]	No	High
T6.05	B	2,378			C4-R/P	1.1	29	0.66 Good	Wid (local)	I [F]	No	High
	A	3,858		3.0	B4c-R/P	1.2	22.9	0.26 Poor	Widening, Aggr	III [F]	C to Bc	Very High
T6.04	B	2,263			B4c-R/P	1.8	14.8	0.64 Fair	None (hist Deg)	II [F]	C to Bc	Very High
	A *	644		3.2	E4-R/P	1.0	10.8	0.75 Good	Aggrading	I [F]	No	High
T6.03	B *	1,370			E4-R/P	1.3	10.9	0.68 Good	None	I [F]	No	High
	A	2,068		4.9	C4-R/P	1.3	14.5	0.71 Fair	Localized, min aggr	III [F]	No	Very High
T6.02	B	1,094			B4-S/P	1.06	15.3	0.91 Ref	None	I [D]	No	Moderate
	A	760		4.9		Not Assessed - Bedrock channel						
T6.01	--	5,649		5.2	C4b-R/P	1.06	20.4	0.88 Ref	None	I [D]	No	High
T6.3S1.01	--	1,568		1.2	C4b-R/P	1.8 [HEF]	12.5	0.49 Fair	None (hist Deg)	III [F]	No	Very High

Notes / Abbreviations: ***Data obtained from Milone & MacBroom, Inc, 2008***

Channel Slope: Values in italic bold have been updated since the Phase 1 SGA, due to field-truthing and/or segmentation.

Stream Type: S/P = Step/Pool; R/P = Riffle/Pool; R/D = Ripple/Dune; PB = Plane Bed; Br = Braided; Casc = Cascade; Ref = Reference

Incision Ratio: RAF = Recently Abandoned Floodplain; HEF = Human-elevated Floodplain (following protocols, VTANR, 2007).

Condition: RHA = Rapid Habitat Assessment; RGA = Rapid Geomorphic Assessment (VTANR, 2007).

Adjustment: PF = Planform Adjustment; Aggr = Aggradation; Wid = Widening; Deg = Degradation; NM = Not Measured.

Channel Evolution Stage: F = F-stage model; D = D-stage model (see Appendix C of protocols, VTANR, May 2007).

Sensitivity - assigned as per updates communicated by VTANR in Nov 2008 DRAFT River Corridor Protection Guide.

* Subreach of alternate reference stream type.

4.4 Hollow Brook (T4) – Hinesburg, Starksboro

The Hollow Brook tributary of the Lewis Creek drains a 9.2-square-mile area in the north-eastern region of the watershed. This tributary joins the Lewis Creek at the upstream end of reach M15 in the northwest corner of Starksboro. A total of four reaches (6.1 miles) of the Hollow Brook were assessed in 2002 – 2008 (Figure 14). Results are summarized below in Table 11. Detailed reach narratives are presented in Appendix G.

The assessed portions of Hollow Brook included:

- an upper reach (4 segments) along Lincoln Hill Road crossing from Hinesburg into Starksboro and ending at the Lazy Brook Mobile Home Park (T4.05);
- the downstream-most two reaches of the tributary (5 segments) from the vicinity of a driveway crossing at 1237 Hollow Road in Hinesburg and ending at the confluence with Lewis Creek (T4.02, T4.01); and
- and an unnamed tributary to Hollow Brook at the upstream end of reach T4.03 near the intersection of Big Hollow Road and the Hinesburg Hollow Road in Hinesburg (T4.3S6.01).

Generally speaking, the gradient of the Hollow Brook channel decreases along the length of study, in two steps. The upper reaches of the Hollow Brook flow to the southeast (parallel to Lincoln Hill Road) over till-veneered shallow bedrock, pitching through a steep (10.7%) bedrock gorge then down a steep (8%) semi-confined valley to the Lazy Brook Mobile Home Park. The channel then turns sharply to the south and southwest out into a wide, flat (0.6 to 0.3%) valley along Hinesburg Hollow Road. Here the channel meanders for approximately 2.8 miles through wetland complexes developed in hydric, alluvial sediment and muck & peat. (These intermediate reaches [T4.04 and T4.03] were not assessed, since they were dominated by wetland conditions, including large ponded areas and multi-thread channels. The unnamed tributary to Hollow Brook [T4.3S6.01] drains to the north along Big Hollow Road in Starksboro to join Hollow Brook in the middle of this section at the upstream end of reach T4.03.) In the vicinity of a driveway crossing at 1237 Hollow Road, the Hollow Brook channel turns to the northwest, the valley narrows, and the gradient once again increases (2%). For a little over one mile, the channel flows to the west through this relatively narrow valley underlain by glacial till and glaciofluvial sediments, where bedrock is exposed occasionally in the channel bed and banks, past the Hinesburg sand & gravel quarries to Route 116. Here, the gradient again decreases and the valley opens considerably; Hollow Brook turns to flow to the southwest. The lower mile of the Hollow Brook is a lower-gradient (0.5%) channel that meanders across hydric sediments of glaciolacustrine and alluvial origin (and through wetlands) to join the Lewis Creek at the upstream end of reach M15.

Residential and commercial encroachments along the assessed portions of Hollow Brook are variable. In some segments, structures are absent (T4.05-C, T4.05-B, T4.01-B). In other segments, a few homes are present generally along the valley margins (T4.05-D). However, in segment T4.05-A several residential homes (i.e., Lazy Brook mobile home park) are concentrated at the marked transition in slope between the upper semi-confined, steep reaches and the lower-gradient, downstream wetland reaches. This segment is a location of reduced sediment transport capacity and has an Extreme sensitivity due to its entrenched status and the propensity for lateral channel adjustments and avulsions. At present the channel appears relatively stable in its incised and entrenched linear planform. However, this segment is at high risk for catastrophic erosion in a future large flood. Two other segments with concentrated residential development are T4.02-B and T4.02-A, where residential homes are built alongside the channel on relatively high terraces of erodible sediments. These homes are highly susceptible to fluvial erosion hazards, given the incised / entrenched channel and erodible streambank materials. Streambank armoring (as well as other household items such as tires, appliances, and general household rubbish) were observed along the streambanks adjacent to some of these properties, indicating that erosion has been an issue in the past. In segment T4.01-A, one residential home is located in the RB floodplain within 50 ft of the channel, where the streambank has been reinforced by rip-rap. Recent (2002) dredging of the channel was attempted by the landowner to redirect flows farther from this residence.

The formerly dredged channel was observed to be largely abandoned in 2008, with flows restored to the original channel.

The status of road encroachments on the assessed reaches of the Hollow Brook subwatershed are variable in nature. Some segments are relatively remote and do not have road encroachments (T4.05-C, T4.05-B, T4.01-A). Others may have short sections of driveways that are not significantly constricting to the channel (T4.05-D, T4.05-A, T4.02-B, T4.01-B). However, road encroachments are significant along segment T4.02-A (Hinesburg Hollow Rd, Hinesburg) and T4.3S6.01 (Big Hollow Rd, Starksboro). Berms have been constructed along the channel in segment T4.05-A to protect the Lazy Brook mobile home park and along portions of segments T4.01-B and T4.01-A to protect private driveways, residences and nearby agricultural fields.

Channelization is known or suspected along portions of each of the assessed Hollow Brook reaches. Channelization is prevalent along T4.02-A and T4.3S6.01 given the road encroachments. The Hollow Brook channel was actually moved at some time between 1962 and 1974 to the north side of this the Hinesburg Hollow Road (segment T4.02-A), cutting off a significant area of floodplain (see Appendix G). Elsewhere in the assessed reaches, channelization is limited generally to the vicinity of major road and driveway crossings. Channelization is notable in segment T4.05-A through the Lazy Brook mobile home park.

Present impoundments by driveway crossings along the upper segment of Hollow Brook (T4.05-D) may have contributed locally to historic incision in their vicinity as a result of "hungry water" effects downstream of the dam sites (see Section 5.1.1 and Appendix G). It is possible that upstream sedimentation has also resulted. The history of operations and construction specifics of these dams are not known at present. Further information would be required to understand the impacts of these dams on the Hollow Brook channel.

Agricultural uses – including hay and crop fields - are concentrated along the lower reach of Hollow Brook downstream of Route 116 and in the vicinity of the Tyler Bridge Rd crossing. A network of several tributaries joins segment T4.01-B near the upstream end. These tributaries drain hydric soils of glaciolacustrine origin to the east of Route 116 and pass through crop, hay and pasture areas. Some tributary segments appear ditched.

With the exception of the bedrock gorge in reach T4.05 and the intermediate wetland reaches (T4.04 and T4.03) nearly each of the assessed Hollow Brook segments has incurred some degree of historic incision. (In some cases, there is uncertainty whether incision occurred (in part or in whole) as a result of disturbances to the channel / watershed occurring over the last 300 years, or whether some degree of incision occurred over the past thousands of years). Three of the segments have undergone a vertical stream type departure: T4.05-B (Ba-to-Fa); T4.05-A (Ca-to-Fa); and T4.02-A (C-to-B). These segments have lost connection to the surrounding floodplain as a result of historic incision, historic channel management, and (in the case of T4.02-A) road encroachment and channel relocation. Sensitivities range from High to Extreme, indicating the likelihood for adjustment in the case of future channel modifications or a change in watershed inputs of flow and/or sediment. Most of these reaches/segments persist in a partially to fully entrenched condition, and are presently dominated by minor to moderate aggradation, widening and/or planform adjustment. The lower two segments (T4.01-B and T4.01-A) are in later stages of channel adjustment and pockets of incipient floodplain are apparent at a lower elevation. Segment T4.01-A has undergone a lateral stream type departure (from E to C) due to widening and aggradation. In these lower segments, beaver activity may be contributing to recovery of these reaches where transient beaver dams induce upstream aggradation.

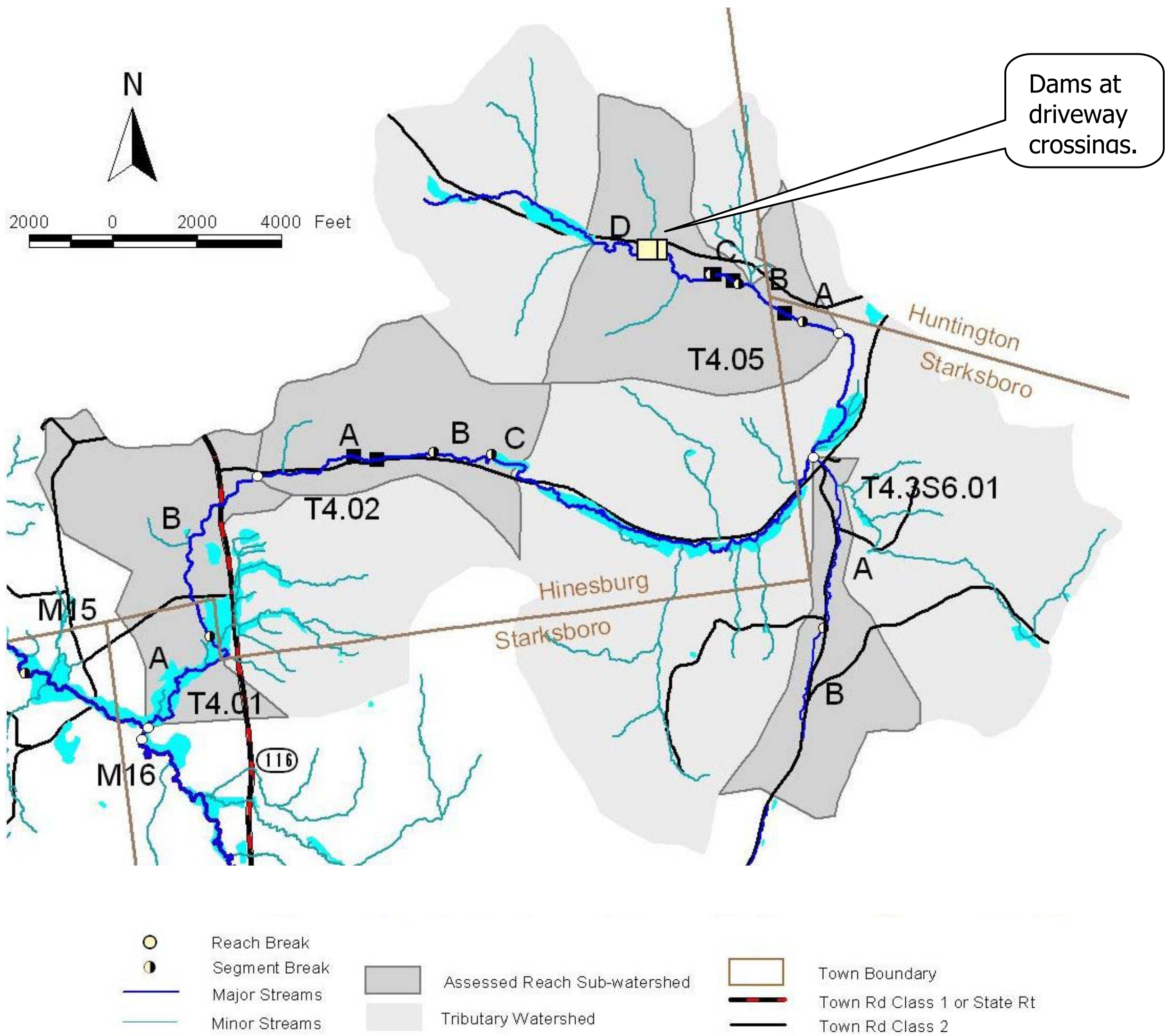


Figure 14. Location of Hollow Brook tributary reaches assessed in 2002 – 2008. (Teal shading depicts NWI wetlands. Black squares indicate location of channel-spanning bedrock)

Table 11. Results of Phase 2 Geomorphic Assessments, Hollow Brook reaches assessed in 2002 - 2008.

Hollow Brook (T4) - Hinesburg, Starksboro

Reach	Seg-ment	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq mi)	Stream Type	Incision Ratio	Width Depth Ratio	RGA Condition	Active Adjustment Process	Channel Evolution Stage	Stream Type Departure?	Sensitivity
T4.05	D *	4,373	***3.2***		C4b-PB	1.56 [RAF]	21	0.55 Fair	Mod aggr, Min/mod PF	III [F]	No	Very High
	C *	750	***10.7***		B1a-casc	Not Assessed - Bedrock channel						
	B	1,851	***8.1***		F3a-S/P	2.59 [RAF]	24.4	0.54 Fair	Mod aggr, Min PF	II [F]	Ba to Fa	Extreme
	A	905	***4.4***	2.3	F4a-PB	2.4 [RAF]	16	0.55 Fair	None; historic incis	II [F]	Ca to Fa	Extreme
T4.04	--	3,862	0.6	2.7	Not Assessed - Wetland-dominated							
T4.03	--	10,730	0.3	6.8	Not Assessed - Wetland-dominated							
T4.02	C	764	***0.9***		Not Assessed - Wetland-dominated; beaver impounded.							
	B *	1,746	***1.9***		B3c-R/P	1.4 [RAF]	22.0	0.61 Fair	Mod PF, Min aggr	II [F]	No	Very High
	A	4,509	***2.1***	7.5	B3-PB	2.3 [RAF]	14.4	0.56 Fair	Min aggr, PF, wid	II [F]	C to B	High
T4.01	B	5,235	***1.2***		C4-PB	1.47 [RAF]	38.2	0.43 Fair	Mod PF, aggr	IV [F]	No	Very High
	A *	4,415	***0.5***	9.2	C4-D/R	1.0 [RAF]	25.1	0.53 Fair	Mod PF, wid, aggr	IIc [D]	E to C	Very High
T4.3S6.01	B	2,905	***4.5***		Not Assessed - Access Denied (2001)							
	A	4,840	***6.0***	1.8	A3-S/P	1.0 [RAF]	14.6	0.63 Fair	Moderate aggrad	I [F]	No	Very High

Notes / Abbreviations:

Channel Slope: Values in italic bold have been updated since the Phase 1 SGA, due to field-truthing and/or segmentation.

Stream Type: S/P = Step/Pool; R/P = Riffle/Pool; R/D = Ripple/Dune; PB = Plane Bed; Br = Braided; Casc = Cascade; Ref = Reference

Incision Ratio: RAF = Recently Abandoned Floodplain; HEF = Human-elevated Floodplain (following protocols, VTANR, 2007).

Condition: RHA = Rapid Habitat Assessment; RGA = Rapid Geomorphic Assessment (VTANR, 2007).

Adjustment: PF = Planform Adjustment; Aggr = Aggradation; Wid = Widening; Deg = Degradation; NM = Not Measured.

Channel Evolution Stage: F = F-stage model; D = D-stage model (see Appendix C of protocols, VTANR, May 2007).

Sensitivity - assigned as per updates communicated by VTANR in Nov 2008 DRAFT River Corridor Protection Guide.

* Subreach of alternate reference stream type.

5.0 DEPARTURE ANALYSIS, STRESSOR IDENTIFICATION & SENSITIVITY

Phase 1 and Phase 2 stream geomorphic assessments of the Lewis Creek main stem and tributary reaches provide for a better understanding of how human-caused disturbances at the watershed and reach level may have altered or constrained the river's ability to convey the water and sediment inputs to the watershed. Consideration of the current state of channel evolution and reach sensitivity will help to ensure that identified river management strategies and restoration or conservation projects will be successful over the long term.

Channel and watershed disturbances that exceed thresholds for change can upset the dynamic equilibrium of stream systems. Imbalance in the channel affects the sediment transport capacity of the stream system, and has significant consequences for erosion hazards, water quality and riparian habitats. Equilibrium can be disturbed locally and result in channel adjustments that are limited in magnitude and extent (for example, scour at an undersized culvert crossing). Alternately, the disturbance (or an overlapping combination of disturbances) can be of sufficient size, duration, or frequency to cause substantial channel adjustments that result in a system-wide imbalance extending far upstream and downstream through the river network.

Such imbalances, whether localized or systemic, can interfere with the river's ability to efficiently convey its water and sediment loads. These interruptions may be expressed as a sediment transport deficiency where sediment accumulates in the channel (which itself may lead to further imbalances - e.g., flow widens and splits to erode streambanks on either side, or flow may avulse or jump its banks in a flood event). Alternately, the imbalance can be expressed as an increase in sediment transport capacity. For example, a channel that has been straightened, dredged, armored and bermed has a local increase in channel slope and channel entrenchment, which creates higher flow velocities, and an increased power to erode the streambed. If the channel bed is scoured, this condition often leads to further channel adjustments including streambank collapse and widening.

Sediment transport capacity of the channel can be inferred from the geomorphic features observed during field work and from the identified reach-scale and watershed-scale stressors. Even a qualitative understanding of features and fluvial processes can help to identify and prioritize appropriate management strategies for the river that will facilitate a return toward a more balanced (dynamic equilibrium) condition.

As stated in VTANR (2007b) guidance: "Within a reach, the principles of stream equilibrium dictate that stream power and sediment will tend to distribute evenly over time (Leopold, 1994). Changes or modifications to watershed inputs and hydraulic geometry create disequilibrium and lead to an uneven distribution of power and sediment. Large channel adjustments observed as dramatic erosion and deposition may be the result of this uneven distribution and may continue until [quasi-]equilibrium is achieved."

The departure analysis and sensitivity analysis presented below characterize the current condition of the Lewis Creek and tributary reaches, and their degree of departure from reference, or a pre-disturbed state.

5.1 Departure Analysis

The departure analysis reviews watershed-level and reach-level disturbances to the channel and characterizes the potential nature and extent of these disturbances as stressors to the overall equilibrium of the river network. Changes to the hydrology and/or sediment load are important as they may significantly affect the hydraulic geometry and fluvial processes of the river and lead to an imbalance of the river network. A channel in dis-equilibrium may undergo substantial lateral and vertical adjustments that may be "at odds" with human infrastructure or land uses in the river corridor. Watershed-scale hydrologic and sediment regime stressors are addressed in Section 5.1.1. Changes in sediment loading characteristics that influence sediment regime at both the watershed level and reach level are addressed in Section 5.1.2. Direct disturbances of the channel and/or surrounding floodplain are addressed as possible modifiers of the channel slope, channel depth, and channel and riparian boundary conditions (Sections 5.1.3 and 5.1.4). While these factors are addressed in separate sections below, in reality they are inextricably linked in the overall cause and effect cycles and fluvial processes which together govern the form and function of the river network.

As defined in VTANR guidance (VTANR, 2007b), the hydrologic regime of the river system refers to the "input and manipulation of water at the watershed scale" that may modify the timing, volume, duration and periodicity of flows in the river network. In turn, these changes to the hydrologic regime may have the potential to cause adjustments in the channel dimensions, slope, or planform – and influence the sediment transport regime. The sediment regime is defined in VTANR guidance as "the quantity, size, transport, sorting, and distribution of sediments".

5.1.1 Watershed Scale Hydrologic and Sediment Regime Stressors

Data are not sufficient to know with certainty whether (and to what extent and in what locations) a given change in the water or sediment inputs to a river corridor will cause the channel to incise or aggrade, widen or shift its planform. However, potential influences on the hydrology of the Lewis Creek watershed (or its tributary sub-watersheds) can be identified in a qualitative sense as a possible contributor(s) to channel dis-equilibrium. Watershed-level hydrologic and sediment regime stressors are identified through a review of existing Phase 1 and Phase 2 stream geomorphic data and include deforestation, stormwater inputs, dams, flow regulations, land use (degree of urbanization), ditching, and wetland loss. Watershed stressors are summarized in Table 12 and described further in the sections below.

Deforestation

Widespread deforestation of Vermont's landscape occurred by the early- to mid-1880s (Thompson & Sorensen, 2000) to support subsistence and sheep farming and the lumber industries. Deforestation is inferred to have caused increased water and sediment loads to be mobilized from the Lewis Creek watershed. Rainfall, which would previously have been intercepted by tree leaves and branches, and which would have been taken up by tree roots and evapo-transpired, instead ran off the land surface. Infiltrative capacities of the soils would have been reduced by compaction of the soils during harvesting. Increased volumes of stormwater runoff would have had increased capacity for gullying and entrainment of soils and sediments from the land surface, delivering increased sediment loads to the river network. Sediment supplies to Lewis Creek and tributary reaches would have been increased especially during flood events, leading to aggradation and planform adjustments (with the increased sediment loading), and possibly localized incision and widening (where increased hydrologic loading occurred).

Forest cover in the Vermont highlands began to regenerate in the late 1800s and early 1900s, during the industrial age and abandonment of upland farms and sawmills. During reforestation, the water and sediment balance would have again shifted (independent of global climate cycles) back to lesser volumes of runoff and reduced sediment loading. This change in the hydrologic and sediment regimes may have led to net incisional processes in portions of the Lewis Creek channel network.

Table 10. River Stressor Identification Table (Watershed Level)

	Watershed Input Stressors	
Stressor Type	**Hydrologic Regime**	**Sediment Regime**
Floods	Events (such as the floods of 1973, 1938, 1936, and 1927) imparted event-based **increase** in hydrologic loading to the watershed (see Section 2.5).	**Increased** sediment loading from active channel adjustments in upstream reaches, would be expected as a result of major flood events, such as the 1973, 1938, 1936, and 1927 (see Section 2.5).
Deforestation	**Increased** hydrologic loading due to deforestation in mid- to late-1800s; subsequent **decreased** hydrologic loading as slopes partially reforested through the 1900s.	**Increased** sediment loading due to deforestation in mid- to late-1800s; subsequent **decreased** sediment loading as slopes partially reforested through the 1900s.
Urbanization	**Minor** increased hydrologic loading inferred due to development and increased road densities of reach subwatersheds and upstream drainage areas in recent decades. Upstream watershed development percentages are at or below the threshold of concern (5%) noted in VTANR guidance (11 July 2007) - with the exception of Cedar Brook (T2.01) estimated at 7%.	**Minor** increased sediment loading inferred due to development and increased road densities of reach subwatersheds and upstream drainage areas in recent decades. Upstream watershed development percentages are at or below the threshold of concern (5%) noted in VTANR guidance (11 July 2007) - with the exception of Cedar Brook (T2.01) estimated at 7%..
Stormwater Inputs	**Minor to moderate increased** hydrologic loading inferred due to road ditch, field ditch, and engineered stormwater inputs. Drainage area of most assessed reaches equals or exceeds the drainage area (0 - 15 sq mi) likely to be influenced by stormwater inputs (as noted in VTANR guidance, 11 July 2007). Potentially significant concentrations of stormwater inputs were indexed in select reaches of the upper main stem, High Knob Bk, and Hollow Bk, which have upstream drainage areas less than 15 sq mi.	**Minor to moderate increased** sediment loading inferred due to road ditch, field ditch, and engineered stormwater inputs. Drainage area of most assessed reaches equals or exceeds the drainage area (0 - 15 sq mi) likely to be influenced by stormwater inputs (as noted in VTANR guidance, 11 July 2007). Potentially significant concentrations of stormwater inputs were indexed in select reaches of the upper main stem, High Knob Bk, and Hollow Bk, which have upstream drainage areas less than 15 sq mi.
Dams / Impoundments	Four dams are currently located on the assessed reaches of Lewis Creek watershed (Scott Pond Dam, M09; two on Hollow Bk, T4.05-D; one on High Knob, T6.06-B) and may have contributed to historic downstream incision due to "hungry water" effects, and may have contributed to upstream historic incision resulting from episodes of dam breaching. Historic dams possibly contributed to historic incision in vicinity of North Ferrisburgh (M06), Seguin Bridge (M10).	Four dams are currently located on the assessed reaches of Lewis Creek watershed (Scott Pond Dam, M09; two on Hollow Bk, T4.05-D; one on High Knob, T6.06-B) and operate as a run-of-river structures. Historically at these sites, and at other historic dam sites, sediments may have been trapped in impoundments and may have been released to downstream reaches upon dam breaching.
Diversions / Water Withdrawals	**Negligible** hydologic impacts. No significant water withdrawal or diversion sites encountered on assessed reaches.	**Negligible** sediment regime impacts. No significant water withdrawal or diversion sites encountered on assessed reaches.
Loss of Wetlands	Increase in hydrologic loading to the assessed reaches as a result of conversion of wetlands (hydric soils) to agricultural uses through tributary channelization and ditching: **Moderate** for most of the assessed subwatersheds.	Increase in sediment loading to the assessed reaches as a result of conversion of wetlands (hydric soils) to agricultural uses through tributary channelization and ditching: **Minor** to **Moderate** for most of the assessed subwatersheds.
Crop Lands	Possibly significant **increase** in hydrologic loading to the assessed reaches as a result of crop land use (implying possible ditching, tile networks) in all assessed portions of the Lewis Creek watershed, except High Knob tributary, especially Cedar Bk and Pond Bk. Potential significance tempered by the size of the upstream watershed for main stem reaches downstream of M20.	Potentially significant increase in sediment loading to the assessed reaches as a result of crop land use (implying possible ditching, tile networks) in all assessed portions of the Lewis Creek watershed, except High Knob tributary, especially Cedar Bk and Pond Bk. Potential significance tempered by the size of the upstream watershed for main stem reaches downstream of M20.

Floods

Floods are natural events which influence the sediment and hydrologic regimes of river networks. Increased flows can lead to channel widening and incision, where the increased scour energy exceeds thresholds for erosion in the streambank and bed materials. In turn, flood-event erosion mobilizes sediments that can lead to downstream aggradation and lateral adjustments. Large-magnitude flood events occurring decades in the past may still be influencing the morphology and active adjustment processes of river channels today.

Average annual precipitation in the Northeastern United States has increased approximately 3.3 inches over the 100-year period from 1900 to 2000 (UNH Climate Change Research Center, 2005). The frequency and number of intense precipitation events (defined as more than two inches of rain in a 48-hour period) has also increased, particularly in the last quarter of the 19th century (UNH Climate Change Research Center, 2005). Available historic resources indicate that the Lewis Creek watershed has been affected by the large flood events of 1913, 1927, 1936, and 1938 and, to a lesser extent, the 1973 flood (see Section 2.5). These flood events would have episodically increased flows and sediment loading in the channels of the Lewis Creek watershed.

Anecdotal accounts and pictures in a Starksboro history book indicate that a significant avulsion occurred in corridor reaches M18 and M17 during the 1938 flood (Jennings, 2002; Hanson, 1998). The Lewis Creek channel jumped its banks at the downstream end of reach M18 and cut across the broad meander comprising segment M17-C (Figure 15). The front porch of the upstream-most house on the right bank was washed away, and several other homes in this area were inundated (Jennings, 2002; Paskiewicsz, 2007). Reportedly, two historic bridges over Lewis Creek were washed out (Jennings, 2002). At the time, the States Prison Hollow Road followed the alignment of what is now named States Prison Hollow Extension. Straightening with windrowing is inferred associated with this post-flood response, based on a picture recorded in *Bertha's book: a view of Starksboro's history* (Hanson, 1998). Boulder/cobble berms are present along both banks near the transition between reach M18 and M17 (see Appendix G).

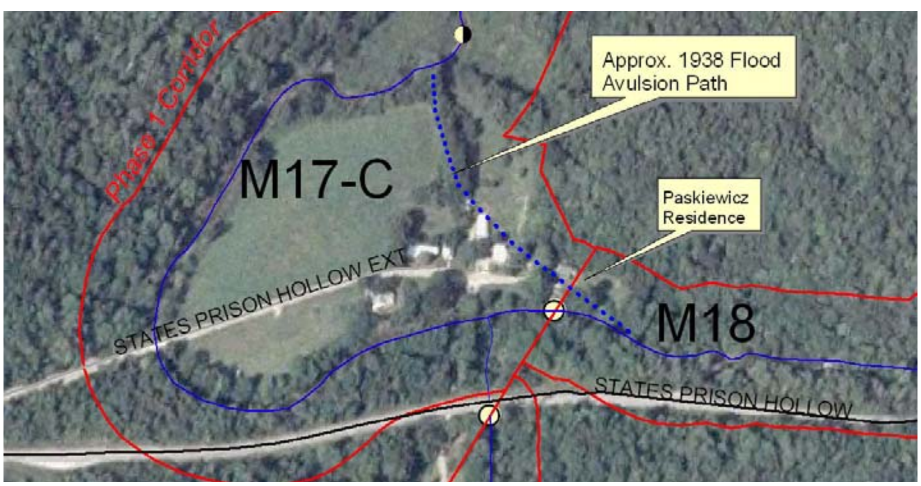


Figure 15. Avulsion site on reaches M18 and M17 (Segment C) in 1938 flood.

Urbanization

Urbanized land uses in the watershed draining to the river can be a source of increased runoff that may serve as a stressor to the channel. Regionally, the balance of water and sediment loads conveyed within a watershed is altered by the density of settlements on the landscape and its effect on the percent of land area impervious to rainfall. Impermeable (or partially impermeable) surface types associated with development can include roof-tops, pavement, roads, and dense gravel-pack roads or driveways. Percent imperviousness refers to the proportion of the land surface converted to impermeable or reduced-permeability surfaces. In general, development results in a reduction in total land area remaining pervious to rainfall. Rainfall and snowmelt waters quickly run off the land surface to the nearest swale or stream; they are not able to infiltrate through the surface soil layers and flow diffusely through the subsurface to the river network. Instead, stormwaters are delivered in higher magnitudes to stream networks and over shorter durations, leading to a prevalence of "flashy" runoff conditions. Stormwaters diverted overland in this way have high velocities and therefore an increased capability to erode sediment and debris from the land surface.

Upland development can also bring more localized stressors to the river channel including: (1) additional bridge and culvert crossings which are often undersized with respect to the bankfull widths and (2) floodplain encroachment by roads, driveways, and crossing structures which reduce the floodplain area available to the river during flood stage. Such floodplain access is a critical need of the river channel in order to dissipate energies associated with flood-stage flows – serving as a kind of pressure release valve for the river.

VTANR guidance (2007b) suggests evaluating the Land Cover / Land Use data developed in the Phase 1 Stream Geomorphic Assessment (Step 4.1) to identify the potential for changes to the hydrologic regime from urbanization. Caution should be applied in using these data, due to: (1) the fact that percent development does not necessarily equate to percent imperviousness (particularly in rural watersheds); (2) the fact that developed (impervious) surfaces are hydrologically connected to the river to varying degrees; and (3) scale, minimum mapping units, age, and accuracy of the land cover / land use data sets utilized (*Landcover / Landuse for Vermont and Lake Champlain Basin [LandLandcov_LCLU, edition 2003]. Source dates of 1991 to 1993. Available at: http://www.vcgi.org/metadata/LandLandcov_LCLU.htm).*

The upstream watersheds draining to each of the assessed reaches have urbanized land percentages ranging from approximately 2.3 to 7.3%, with the maximum being the upstream drainage area of Cedar Brook reach T2.01. With the exception of Cedar Brook reaches, the range of values (for the assessed reaches) is at or below the percentage (5%) suggested as a threshold of concern in VTANR guidance (2007b). Thus, watershed-scale urbanization is expected to represent a relatively minor stressor to the Lewis Creek and its tributaries, overall.

Table 13. Urbanized Land Cover in Upstream Watershed of Lewis Creek main stem and major tributaries

Stream	Subwatershed	Subwatershed Area (sq mi)	Urbanized land cover (Residential, Commercial, Industrial) (%)
Lewis Creek	Upstream of M01	81.0	5.1
Lewis Creek	Upstream of M14	38.2	4.4
Cedar Brook (T2)	Upstream of confluence w/ Lewis Creek	6.3	7.3
Pond Brook (T3)	Upstream of confluence w/ Lewis Creek	18.3	3.9
Hollow Brook (T4)	Upstream of confluence w/ Lewis Creek	9.2	5.7 *
High Knob (T6)	Upstream of confluence w/ Lewis Creek	5.2	4.5

** The Urbanized percentage for the Hollow Brook subwatershed includes the Hinesburg sand & gravel quarry which is classified as "Industrial", and which is relatively pervious to rainfall. If this industrial use in Hollow Brook subwatershed is not counted, the urbanized land use is estimated as 4.1% - below the threshold of concern expressed in VTANR guidance (2007b).*

Present zoning in the watershed towns may permit development densities that result in future percent urbanized cover to rise above thresholds for concern (SMRC, 2005). To the extent that stormwater runoff is not controlled or managed through treatments prescribed by State or local regulations, future development may increase to densities that present a significant impact to the Lewis Creek and its tributaries. Recent Vermont-based studies linking percent imperviousness to geomorphic and biologic condition of streams suggests that low-order streams (headwaters tributaries) may experience impacts at thresholds lower than 5% impervious cover (Fitzgerald, 2007).

Road Networks / Ditches

In rural watersheds, particularly on upland slopes (such as those draining the Northern Green Mountain province in eastern Starksboro and Hinesburg), road and driveway ditches can be a significant contributor of stormwater and sediment to receiving tributaries and rivers. A study of imperviousness in the Lewis Creek watershed determined that roads and driveways accounted for the vast majority of impervious surface percent in these rural areas (SMRC, 2005). Often road ditch networks terminate at stream crossings without provision for sediment and stormwater retention, detention or treatment.

While a full inventory of these tributary road crossings was beyond the scope of Phase 2 assessments to date, the potential impact of road ditch networks on the watersheds draining to the assessed reaches can be qualitatively evaluated by summing the total length of roads in each sub-watershed and calculating road density. Table 14 summarizes road density in the upstream watershed draining to four of the major Lewis Creek tributaries and sections of the Lewis Creek main stem. When calculated at this large subwatershed scale, there are relatively minor differences in road density for these portions of the Lewis Creek watershed. However, it is notable that road density appears to increase marginally with distance downstream in the watershed. Road densities in the Cedar Brook and High Knob tributaries are somewhat higher than in the Pond Brook and Hollow Brook tributaries, although this difference may be in part controlled by the smaller watershed sizes of Cedar Brook and High Knob.

Table 14. Road Density in Upstream Watershed of Study Area Subwatersheds

Stream	Subwatershed	Subwatershed Area (sq mi)	Road Density (linear feet roads per square mile of upstream watershed)
Lewis Creek	Upstream of M01	81.0	10,066
Lewis Creek	Upstream of M14	38.2	8,446
Cedar Brook (T2)	Upstream of confluence w/ Lewis Creek	6.3	12,655
Pond Brook (T3)	Upstream of confluence w/ Lewis Creek	18.3	9,125
Hollow Brook (T4)	Upstream of confluence w/ Lewis Creek	9.2	9,401
High Knob (T6)	Upstream of confluence w/ Lewis Creek	5.2	11,863

Road densities were calculated at a finer resolution for the individual subwatersheds draining to each of the reaches assessed in this study. Road densities ranged from 0 (in High Knob reach T6.02) to 33,700 feet/square mile; the average reach-based subwatershed road density for the 36 assessed reaches was 12,634 feet / square mile. Road density values were arbitrarily grouped into ranges for qualitative comparison: High road density at more than 25,000 feet / square mile; Medium road density for values between 10,000 and 25,000 feet / square mile; and Low road density for values up to and including 10,000 feet /square mile. These relative road densities are illustrated in Figure 16. Two reach-based subwatersheds were classified with High road density: T6.01 on the High Knob Bk in Starksboro and M18 draining to the States Prison Hollow gorge in Starksboro. The High road density in these two subwatersheds is (at least in part) a function of the small watershed size compared to other reaches. The overall medium to low road density values are consistent with the relatively sparsely populated nature of the Lewis Creek watershed. A VTANR literature search is underway to characterize the degree of road density which will be considered a stressor to river channels under Vermont guidance (VTANR, 2007b).

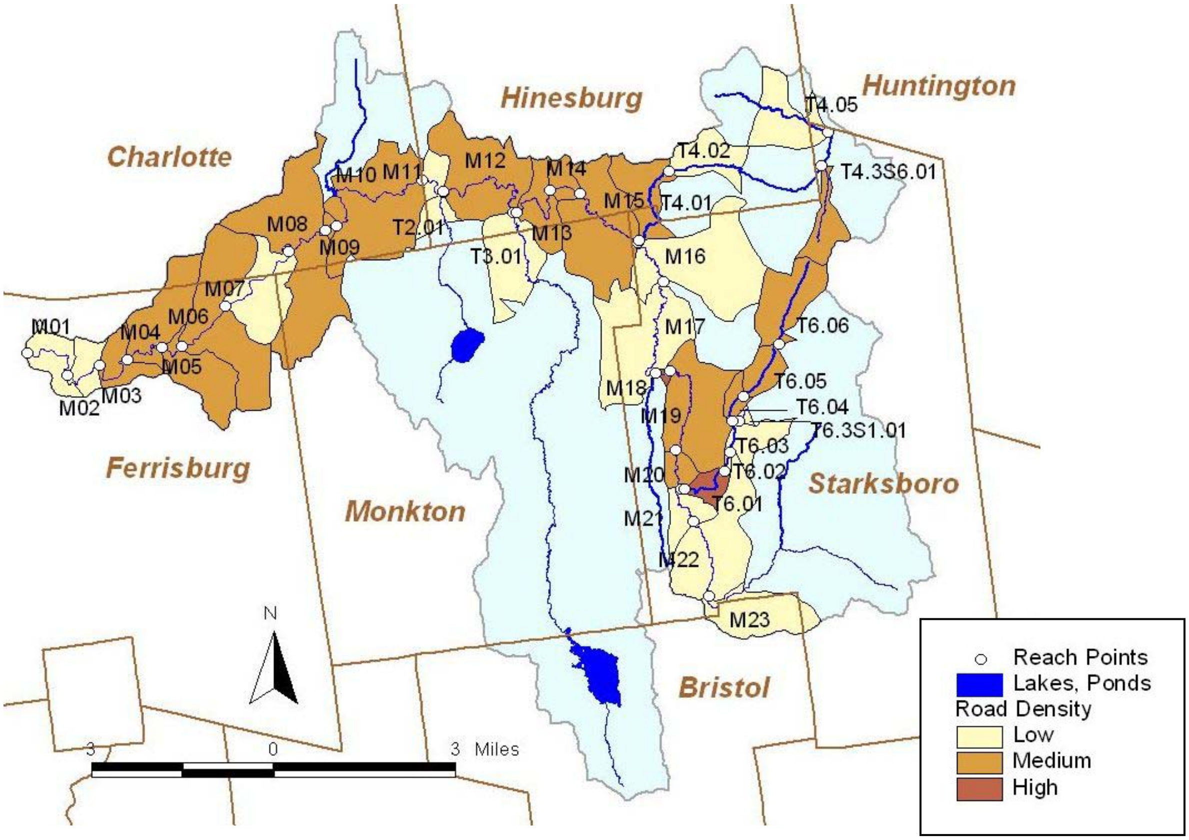


Figure 16. Relative road density in reach-based subwatersheds for the 36 reaches of the Lewis Creek watershed assessed in 2001 – 2009.

Stormwater inputs

The previous sections indirectly addressed the potential for stormwater runoff, through review of urbanized land cover and road density at the watershed scale. This section more directly evaluates stormwater inputs to the channel, including such features as road ditch outlets, road culvert outlets (connected to road ditches), agricultural ditch or tile outlets, engineered stormwater system outlets, and other outlets such as building foundation drains. While the flow of an individual stormwater outlet may be quite small, the cumulative impact of multiple, upstream stormwater inputs can have a measurable effect on a receiving channel, depending on the magnitude of the cumulative stormwater input compared to the flow of the receiving water. The concentration of flows from stormwater runoff can also lead to increased power to erode sediments in the stormwater channel, leading to increased gullying, sediment mobilization to the river and a potential impact on the sediment regime of the river.

VTANR guidance (2007b) suggests that stormwater inputs are potentially significant only in reaches with upstream drainage areas less than 15 square miles due to the assimilative capacity of larger channels. Most of the assessed reaches of the Lewis Creek and tributaries have upstream drainage areas greater than 15 square miles, and the potential influence of stormwater inputs on the hydrologic and sediment regimes of the channel in these reaches is considered minor to negligible. Of the 36 assessed reaches, three of the main stem reaches (M21 – M23), the Cedar Brook reach (T2.01), the Hollow Brook reaches (T4.01, T4.02, T4.05 and T4.3S6.01), and the High Knob reaches (T6.01-T6.06, T6.3S1.01) have upstream drainage areas less than 15 square miles; conditions on these reaches were more closely evaluated for potential stormwater-related stressors.

In the upper main stem in the town of Starksboro, there are two notable concentrations of stormwater inputs to the Lewis Creek channel that may have significance as contributors of additional storm flows (and sediments):

- Two stormwater channels in vicinity of driveway and private drive runoff near the Tatro Road bridge crossing in the 1,280-foot downstream segment of M21-A; and

- Seven stormwater inputs from the gravel Ireland Road along reach M23 – culverts and turnouts from ditches along this road direct stormwater and road sediment directly to the channel.

In the High Knob Brook (town of Starksboro), Milone & MacBroom (2008) indexed 3 stormwater inputs within the 2378-foot segment (B) of reach T6.05 along Big Hollow Road. These inputs are associated with road ditches / culverts where the Hollow Brook channel was diverted from its original planform to cross to the far side of Big Hollow Road.

In the Hollow Brook subwatershed (Starksboro and Hinesburg), there are three notable occurrences of concentrated stormwater runoff:

- In the downstream 900 feet of reach T4.05 (located in the Lazy Brook Mobile Home Park, Starksboro), there is a LB ephemeral tributary which appears to receive stormwater runoff from ditches along Lincoln Hill Road (in Hinesburg) approximately 300 feet to the north and 140 feet upslope. In recent years this channel has been dredged near its confluence with Hollow Brook;

- Culverts and turnouts from ditches along the Big Hollow Road direct runoff to the LB of the channel in at least five places along a 4,840-foot segment (A) of reach T4.3S6.01, an unnamed tributary to Hollow Brook located near the Starksboro / Hinesburg border;

- Two culverts direct stormwater runoff under the Hinesburg Hollow Road along the short (1,746-foot), middle segment (B) of reach T4.02 in Hinesburg (bedrock controls in this segment likely offer boundary resistance to potential increased stormwater runoff, but enhanced erosional energies would be translated to downstream reaches).

One additional stormwater / gully site of significance was observed along the assessed reaches. It is located on the Lewis Creek main stem just upstream of the Tyler Bridge Road crossing in Monkton (Segment M15-B). While the upstream watershed of the Lewis Creek at this point is greater than 15 square miles (approximately 36 square miles), this stormwater channel has developed into a gully that is a significant source of sediment to the Lewis Creek (see Appendix G).

Dams

Dams disrupt the flow dynamics (and sediment transport continuity) of rivers to varying degrees and extents, depending on their size, height, topographic setting, and operational status, and depending on the hydrologic, geomorphic and geologic characteristics of the river being impounded (Williams and Wolman, 1984; Kondolf, 1997). Depending on the size of the impoundment and operational status of the dam, sediments can be trapped in the impoundment upstream of a dam; bed load and a portion of the suspended sediment load settle out in the still water environment of the reservoir. The sediment (bed) load of water leaving the impoundment may be significantly reduced, and the water may possess enhanced energy to erode the stream bed and banks. Depending on the nature of sediments in the channel margins and underlying surficial deposits, and vegetative boundary conditions, this increased erosional potential can lead to channel incision and/or widening downstream of the dam as the river seeks to restore its sediment load – a condition often termed "hungry water" (Kondolf, 1997). If scour is significant, the channel can incise below the surrounding floodplain. On the other hand, if flows are regulated so as to significantly reduce flood peaks and magnitudes, channel aggradation and/or narrowing may result downstream of the dam. Sediments may accumulate in the downstream channel, where they are mobilized from tributaries, if flushing effects of bankfull flows and low-magnitude flood events have been eliminated or reduced as a result of flow regulation (Kondolf, 1997; Magilligan, *et al*, 2003).

The bankfull discharge is considered the dominant discharge of rivers that reworks the channel margins to create the width, depth, slope and planform for optimal conveyance of water and sediments (Wolman & Miller, 1960). Reduced magnitude and frequency of bankfull discharge downstream of impoundments can lead to changes in the cross sectional area of channels, as well as channel slope and planform, and often results in progressive buildup of sediments in the downstream channel (Williams and Wolman, 1984). Degraded aquatic systems may result from flow regulation by dams, due to reduced frequency and magnitude of overbank flooding which is a requirement for many riparian and floodplain ecosystems (Magilligan, *et al*, 2003).

At present, there are four dams on the assessed reaches of the Lewis Creek watershed (see Appendix G and Table 15 for more details).

- <u>3052 Big Hollow Road, Starksboro, T6.06-B (High Knob Brook)</u>
  A 400-foot long and 100-foot wide earthen impoundment extends upstream from a driveway crossing near the mid-point of reach T6.06 (Segment B) on the High Knob Brook (Figure 17). No formal dam structure was apparent (and no such feature was identified on the Vermont Dam Inventory [VCGI, 2005]). The approximate drainage area to this location is small – an estimated 0.4 square mile. A small in-stream pond is created by the earthen dam. This impoundment is present on the 1974, 1995 and 2003 aerial photography, but absent on the 1962 and 1942 aerial photos of the region, suggesting that it was formed between 1962 and 1974. This impoundment is located in a livestock pasture and is likely utilized for irrigation.

Figure 17. Driveway / impoundment at 3052 Big Hollow Road, Starksboro, T6.06-B.

View downstream, 5 August 2008. Photo Credit: Milone & MacBroom, Inc.

Table 15. Summary of Available Data, Historic and Existing Dams On the Assessed Reaches

Status	Reach/ Segment	Dam	Date Constructed	Date Breached	Associated Use / Industry	Data Source
Lewis Creek main stem						
H	M23	Dam?	Unknown	Unknown	Mill pond	Beers Atlas, 1871
H	M18	Dam? At falls at States Prison Hollow gorge	Unknown	Unknown	Saw mill, Grist mill	Beers Atlas, 1871
H	M10-F	Dam? At falls upstream of Seguin Covered Bridge	Unknown	Unknown	Grist mill, Saw mill	Beers, 1869; Walling, 1857.
E	M09-B	Scott Pond Dam	c. 1850s?	1927 ? 1973 ? Rehabilitated in 1992	E: Lamprey control H: water power for saw & grist mills, & buttertub factory	Beers, 1869; 1905 USGS map; Rann, 1886; Walling, 1857
H	M07	Dam(s) at North Ferrisburgh	Unknown	Unknown	Grist mill, Saw mill, Woolen mill	VT Landscape Change Program; Beers, 1871.
High Knob Brook						
E	T6.06-B	Dam / driveway at 3052 Big Hollow Rd	Unknown	Intact	Residential pond	Visual assessment, 2008 (MMI, 2008)
Hollow Brook						
E	T4.05-D	Dam / driveway bridge at 2538 Lincoln Hill Rd	Unknown	Intact	Residential pond	Visual assessment, 2005
E	T4.05-D	Dam / driveway bridge at 2572 Lincoln Hill Rd	Unknown	Intact	Unknown	Visual assessment, 2005

- 2538 Lincoln Hill Rd, Hinesburg, T4.05-D (Hollow Brook)
  A small dam with apparent flashboards impounds a relatively wide, but shallow, pond at a residential property. The dam supports a bridge crossing for a driveway to another residence.

(a)

(b)

Figure 18. Bridge / dam on Hollow Brook in segment T4.05-D. (a) view downstream to the inlet. (b) view upstream to the outlet (concrete apron). 8 September 2005.

- 2572 Lincoln Hill Road, Hinesburg, T4.05-D (Hollow Brook)
  An instream culvert is embedded in a stone and concrete structure, with a steel trap door on the upstream side (culvert inlet). Low stage flows appear to pass through the main culvert. Moderate to high stage flows would appear to be impounded behind the stone and concrete structure when flow through the main culvert is not sufficient to pass the full discharge (such near-bankfull-stage conditions were observed on 25 July 2008). As impoundment levels rise, some flow would presumably be diverted to an overflow culvert (visible at picture right in Figure 19 below). At very high stages of impoundment, it appears that flows would pass over the top of the stone/ concrete dam and under the concrete driveway bridge that crosses over the top of the dam. The upstream impoundment area is overgrown and does not appear to have a current use.

Figure 19. Culvert / dam on Hollow Brook segment T4.05-D.

View upstream to culvert outlet; 25 July 2008. Overflow culvert at picture right. Steel trap door at culvert inlet in raised (open) position. Moderate impoundment of channel flows observed in thickly vegetated wetlands area immediately upstream of dam.

- Lewis Creek Road, Charlotte, M09-B (Lewis Creek main stem)
  This concrete dam is founded on bedrock, and operates as a run-of-river structure with a minimal upstream impoundment. At present, the dam is maintained as a barrier to the upstream migration of sea lamprey (USFW et al, 2001). The current construction "is a concrete gravity structure approximately 130 feet long and 13 feet high at the end sections. The spillway is a 100' long concrete broad crested weir with 3.5' flat crest with a minimum crest elevation approximately 8 feet below the end sections. The dam appears to be founded on [bedrock] ledge for most of its length. It is provided with an overhanging steel lamprey interdiction plate and a stoplog spillway." (VT Dam Safety Section, 1994).

Figure 20. Scott Pond Dam on Lewis Creek segment M09-B.

View upstream, 3 November 2009.

These impoundments probably contributed to minor aggradation local to the impoundment effects, and may have resulted in some degree of historic incision downstream of the structures. In the case of Scott Pond Dam, a dam(s) has been present in this location since at least the 1850s (Walling, 1857). It is possible that episodes of breaching have contributed to upstream incision and/or downstream aggradation over the years (see more details in Appendix G).

Based on review of historic maps and other limited resources a few additional dams were likely present in past centuries on the Lewis Creek main stem associated with saw mills and grist mills in the vicinity of Ireland Road and States Prison Hollow in Starksboro, Seguin Covered Bridge in Charlotte, and the North Ferrisburgh village (Table 15). While these past structures no longer impound the channels, knowledge of their historic presence aids in characterizing the overall sensitivity of the river reaches and their degree of departure from reference condition, where applicable. In some cases, the present morphology and sediment regime of the river channel can still be influenced by the historic disruption of fluvial and sediment transport processes imparted by a dam(s).

Just as the presence of a dam influences the natural river balance, the subsequent removal of a dam can have an impact on future adjustment of the river channel. As the river readjusts to the lowered base level, incision and widening might be expected to migrate upstream from the former dam site. Sediments mobilized from the incising areas might contribute to aggradation, widening or planform adjustments downstream of the former dam site.

As further outlined in Appendix H and Appendix I, the historic dams along the main stem reaches may have contributed to historic incision in these reaches as a result of "hungry water" effects downstream of the dam sites while these structures were intact and subsequent to breaching effects upstream of the dam sites. While operating, these historic dams may have impounded sediments to varying degrees, depending on impoundment size and height. Upon breaching of the dams (especially during the flood of 1927 or the floods of the 1930s), sediments would have been released to downstream reaches.

Diversions, Water Withdrawals (flow regulation)

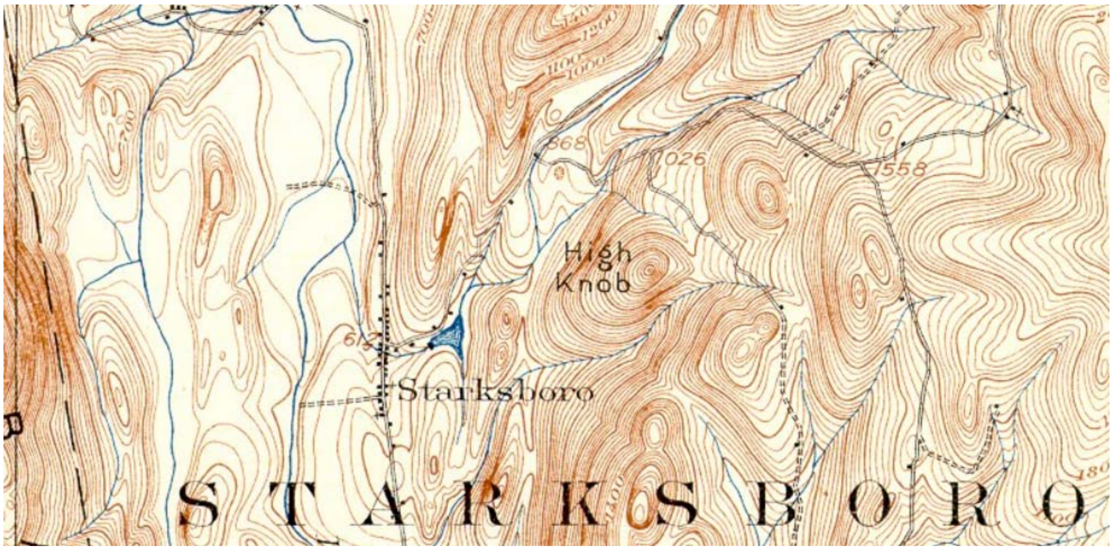
Changes in the flow characteristics of a river imparted by diversion structures or substantial water withdrawal sites can influence the magnitude of flows and interrupt the sediment transport functions of rivers, potentially resulting in areas of exacerbated erosion or system-wide instability in the river.

No significant diversion or withdrawal sites were located in the assessed reaches. A couple of small pipe or hose withdrawals for small-scale irrigation were observed (e.g., left bank of M15-B for tree nursery; left bank of M14 to adjacent field; apparent irrigation withdrawals in M03, M19). However, these withdrawals are very small compared to the total flow in Lewis Creek, and were therefore deemed "Not Significant".

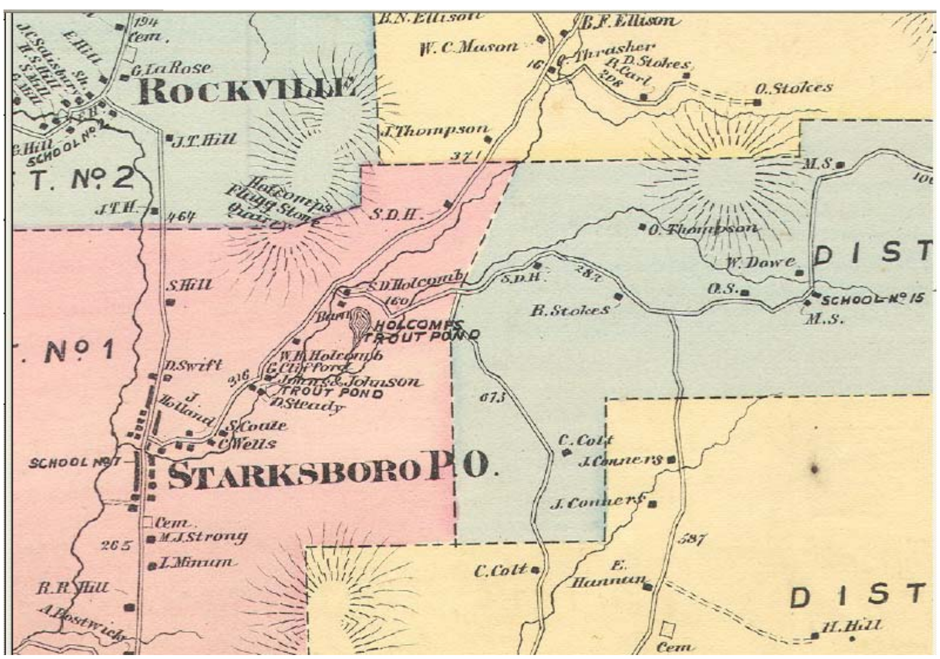
One curious finding in the High Knob tributary was noted during review of historic maps. According to the 1905 USGS Middlebury, VT 15-Mintue topographic map and the 1871 Beers Atlas for Addison County (Starksboro), the High Knob tributary previously continued along the Big Hollow Road, drained via the Baldwin Pond, through Starksboro village and joined the Lewis Creek main stem in reach M19 (see Figure 21). These early map publications may have been in error. This is a small tributary flowing through somewhat remote territory that would have been difficult to field survey at the time these maps were produced. Or perhaps the High Knob tributary did actually flow in this other planform at one time. If so, it is not known whether the current planform resulted from a sudden avulsion (perhaps the 1913, 1927 or 1938 flood), or as a result of channel manipulation in the early to mid-1900s. The available resources consulted in this Phase 2 assessment did not indicate either a historic avulsion or diversion of the channel in this location. In absence of specific data, neither an avulsion nor diversion was indexed.

Figure 21.
Potential historic diversion or avulsion of High Knob channel from a path through Starksboro village to the current planform which joins the Lewis Creek near the Tatro Rd crossing.

Such a diversion would have increased hydrologic stresses to M20 and upper reaches of M19, as the drainage area would have suddenly been increased – from approximately 11 to 16 square miles – or an increase of nearly 50%. Theoretically, such an increase could have contributed (at least in part) to observed historic incision in reach M20 and M19-B, as well as observed minor to moderate incision in middle segments of the High Knob tributary (current planform).



(a)



(b)

Figure 22. Historic maps depict different planform of the High Knob Brook in the late 1800s and early 1900s. (a) Middlebury, VT USGS 15-Minute Topographic Quadrangle map 1905 (surveyed 1903, reprinted 1943); (b) Beers Atlas of Addison County, 1871.

Loss of Wetlands / Agricultural Ditching

Channel-contiguous wetlands offer important flood attenuation functions in the river corridor, slowing the velocity of flows and thereby reducing erosion of the stream bed and banks. Over the last 200 or more years, wetland or hydric soils along the floodplains of Vermont rivers have commonly been converted to agricultural fields. Often, field drainage is improved by channelization of small tributaries or through installation of a network of constructed ditches or underground tiles. Conversion of channel-contiguous wetlands to agricultural uses and associated ditching can increase runoff volumes and velocities in the receiving river channel. In turn, those increased flows can exceed erosion thresholds in the channel bed and banks. This factor, along with periodic ditch maintenance, can result in increased sediment mobilization to the river.

The degree of wetland loss or conversion in a watershed is difficult to estimate with accuracy. However, a qualitative evaluation can be performed by comparing the percentage (by area) of hydric soils across a watershed, to the percentage of mapped wetlands. When this review was performed for select major tributaries and portions of the Lewis Creek watershed relevant to this Phase 2 study area, significant areas of possible wetland loss were apparent in the upper main stem watershed, and in the Pond Brook and Hollow Brook subwatersheds (Table 16 and Figure 23).

Table 16. Percent by Area of Hydric Soils (USDA) versus mapped wetlands in the Upstream Drainage Area of Select Major Tributaries and Portions of the Lewis Creek watershed.

Stream	Subwatershed	Subwatershed Area (sq mi)	Hydric Soils (% by Area)	VSWI Wetlands (% by Area)	NWI Wetlands (% by Area)
Lewis Creek	Upstream of M01	81.0	19.0	6.7	7.9
Lewis Creek	Upstream of M14	38.2	10.6	2.4	2.6
Cedar Brook (T2)	Upstream of confluence w/ Lewis Creek	6.3	22.2	10.2	13.7
Pond Brook (T3)	Upstream of confluence w/ Lewis Creek	18.3	33.4	13.7	16.9
Hollow Brook (T4)	Upstream of confluence w/ Lewis Creek	9.2	9.3	3.1	2.8
High Knob (T6)	Upstream of confluence w/ Lewis Creek	5.2	3.4	1.0	1.2

NWI = National Wetland Inventory; VSWI = VT Significant Wetlands Inventory

This comparison does not directly or accurately reveal the area of wetlands drained or otherwise converted to agricultural or urbanized use, since NWI or VSWI coverage does not include smaller Class III wetlands which may be present in the watershed. As with any spatial data sets, there are also issues of mapping methods, mapping resolution, scale, accuracy, and currency that would render the two data sets not directly comparable. Nevertheless, this comparison serves as a coarse measure of potential wetland loss in the portions of the Lewis Creek watershed draining to the study reaches.

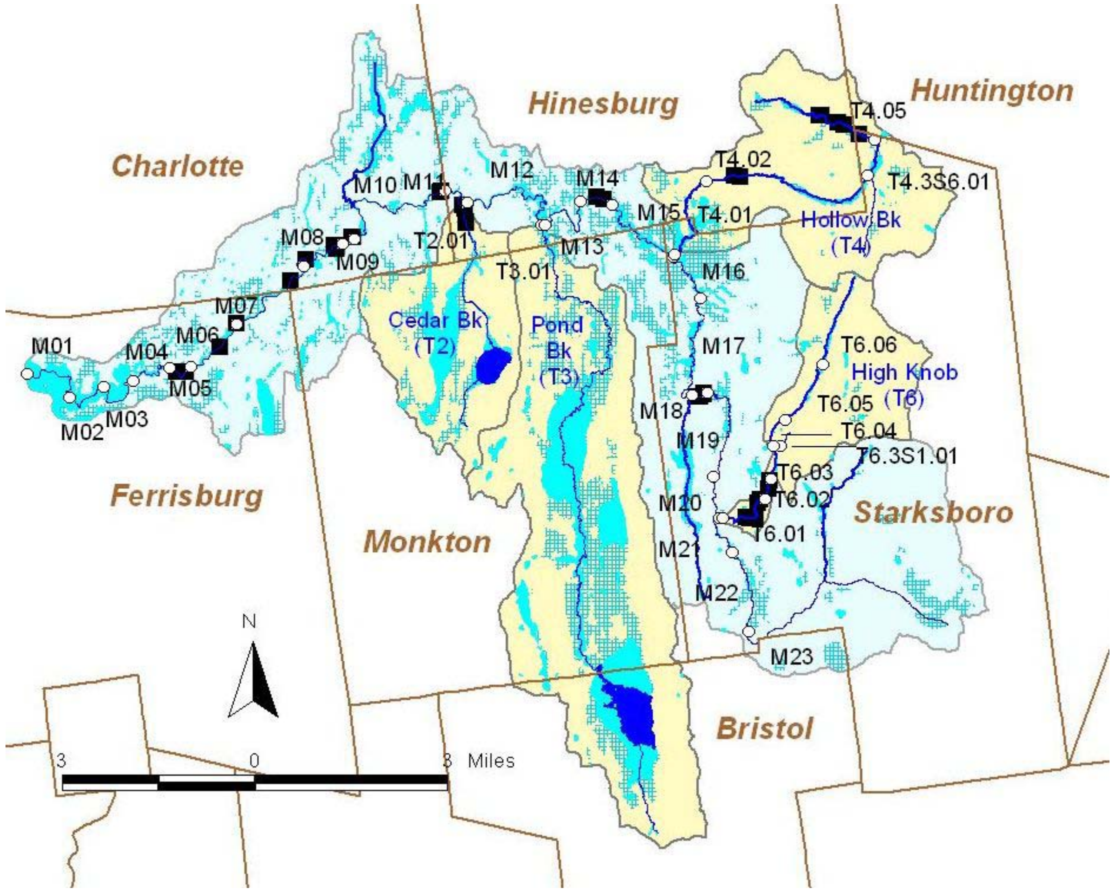


Figure 23. Hydric Soils (USDA; in hatched dark teal) versus mapped wetlands (VSWI; in solid, teal) in the Lewis Creek watershed. Black square indicate locations of channel-spanning bedrock on assessed reaches.

Crop Lands – Exposed Soils

VTANR guidance (2007b) states that the area of cultivated lands draining to each reach can suggest the potential for land surface erosion and sediment mobilization to assessed reaches. Caution should be applied, as such an evaluation does not take into account the degree of hydrologic connection of the noted crop lands to the receiving waters. Nor does it adjust for potential erosion prevention measures or practices in place on the indicated crop lands. Further limitations of this methodology are related to the scale, accuracy, and currency of the land cover / land use data sets utilized to summarize the data: (*Landcover / Landuse for Vermont and Lake Champlain Basin (LandLandcov_LCLU, edition 2003). Source dates of 1991 to 1993. Available at: http://www.vcgi.org/metadata/LandLandcov_LCLU.htm.)*

Phase 1 stream geomorphic data indicate that crop land use in the upstream watersheds draining to assessed reaches of the Lewis Creek and major tributaries is greater than the threshold (5%) considered to be of significance in VTANR guidance (2007b) – except for the High Knob tributary (see Table 17).

Table 17. Percent by Area of Crop Land Use in the Upstream Drainage Area of Select Major Tributaries and Portions of the Lewis Creek watershed.

Stream	Subwatershed	Subwatershed Area (sq mi)	Crop Land Use (% by Area)	Agricultural Land Use * (% by Area)
Lewis Creek	Upstream of M01	81.0	10.7	26
Lewis Creek	Upstream of M14	38.2	6.3	14
Cedar Brook (T2)	Upstream of confluence w/ Lewis Creek	6.3	10.7	31
Pond Brook (T3)	Upstream of confluence w/ Lewis Creek	18.3	12.5	28
Hollow Brook (T4)	Upstream of confluence w/ Lewis Creek	9.2	6.0	12
High Knob (T6)	Upstream of confluence w/ Lewis Creek	5.2	3.7	6

**Agricultural land use includes land cover / land use categories 22 (Orchard/ Tree Farm), 24 (Other Agricultural Land), 211 (Row Crops), and 212 (Hay/ Pasture). Crop Land Use refers to category 211 only.*

5.1.2 Sediment Regime Stressors (Watershed and Reach Scale)

Sediment regime stressors for the assessed reaches are summarized in Table 12 (Watershed Level Stressors) and in Appendix H (Reach Level Stressors); they are discussed briefly in the following sections. The purpose of this section is to evaluate the "cumulative impact of erosion and subsequent deposition at the watershed scale" through review of reach-based features (VTANR 2007b). Features were compiled from a review of Phase 1 and Phase 2 Stream Geomorphic Assessment data and included: (1) depositional bars / planform migration features; (2) bank erosion; (3) mass wasting sites; and (4) gully sites or rejuvenating tributaries.

Depositional bars and planform migration features

Select depositional and migration features are identified in VTANR guidance as indications of potentially enhanced sediment loading or a decreased sediment transport capacity of the river channel, or both. Features include steep riffles, mid-channel bars, delta bars, flood chutes, avulsions and channel braiding. Sediment contained in the depositional bars theoretically has its source from upstream, as well as in-reach, erosion. As sediment accumulates in the channel it can cause flow in the channel to diverge and create flood chutes or avulse into a different path altogether. Thus, multiple bars and lateral adjustments in a reach may indicate a reduction in sediment transport capacity and reflect the cumulative effects of erosion at the watershed scale.

Along the Lewis Creek upper main stem, five segments show a relatively high density of depositional bars and planform migration features. Generally, these features are associated with an absence of forested buffers and presence of erodible sediments in the channel boundaries:

- Reaches M23 and M22 in Starksboro where the channel transitions from upstream semi-confined sections of steeper gradient out into the lower-gradient, broader valley setting along Route 116. Sediment deposition in reach M22 is locally enhanced by beaver activity.
- Segment M17-B in Starksboro, downstream of the States Prison Hollow gorge contains multiple mid-channel bars, a couple flood chutes and one small avulsion, which are suggestive of sediment loading (perhaps from agricultural and road ditch runoff from smaller tributaries), and which also appear associated with beaver dam activity.

- Segments M15-B and M15-A contain multiple flood chutes and depositional bars which are suggestive of sediment loading from upstream, instream and tributary (Hollow Brook) sources. Beaver dam activity is likely to be a contributing factor. Deposition and lateral adjustments in M15-A may also be induced by the constraints of a downstream valley pinch point (reach M14).

Figure 24. Location of active planform adjustment, aggradation and widening upstream of Tyler Bridge Road crossing. View downstream. Segment M15-B, 29 November 2006.

Along the Lewis Creek lower main stem, one reach is particularly notable for the very high frequency of depositional and planform migration features:

- Reach M06 contains multiple steep riffles, mid-channel bars, and flood chutes. A couple of tributary confluence bars, one pre-2003 post-1995 avulsion, and two locations of channel braiding were also indexed. This mile-long reach is positioned between the somewhat steeper and bedrock-controlled upstream reach, M07, and the semi-confined and bedrock-controlled channel of downstream reach, M05. The active planform adjustment observed in this reach is, in part, a response of the channel to these natural variations in valley confinement and channel gradient. Conditions may also have been exacerbated by sediment loading from tributaries, historic removal of forested buffers, presence of erodible sediments in the channel margins, and inferred historic channelization and incision.

Figure 25. Location of active planform adjustment, aggradation and widening downstream of North Ferrisburgh village. View downstream. Reach M06. 2 October 2004.

Along the High Knob tributary, two segments are notable for the high density of depositional and planform migration features:

- Segment T6.05-A: "High levels of embeddedness, fining, and riffle stability index were observed along with general evidence of sediment mobility and lack of sorting" (MMI, 2008). "The increase in sediment deposition and LWD may be due to a decrease in channel slope" (MMI, 2008). This segment may also be receiving (and storing) sediment from upstream tributaries and road runoff.

- Reach T6.01 contains multiple steep riffles and mid-channel bars which are suggestive of sediment loading from upstream and instream sources, and which may also result from a localized reduction in sediment transport capacity upstream of undersized crossing structures and upstream of channel-spanning bedrock outcroppings (MMI, 2008).

Along the Hollow Brook, Segments T4.01-B and T4.01-A contain a relatively high density of depositional and planform migration features. These segments comprise the downstream-most 1.8 miles of the Hollow Brook tributary, extending from the Hinesburg Hollow Road, under Route 116 and Tyler Bridge Rd, to the confluence with Lewis Creek. A reduction in sediment transport capacity is governed by a decrease in valley gradient and confinement. Deposition and lateral adjustments have been enhanced in this reach by channel modifications / dredging, and by localized removal of tree buffers and beaver dam activity (T4.01-A). A reduction in sediment transport capacity may also have resulted, in part, from losing conditions in the upper section of T4.01-B (and T4.02-A) – where a reduction in discharge has occurred as a portion of streamflows are lost to the underlying shallow groundwater. These channel sections are typically observed to dry up in the late Summer months.

Within the one assessed reach of the Pond Brook, Segment T3.01-C shows a relatively high density of steep riffles, mid-channel bars, flood chutes, and channel braiding sites. To some degree (near the upper end of the segment), beaver dam activity is contributing to depositional features and planform adjustment. Tributary networks joining the upstream end of the segment as well as upstream reaches drain agricultural fields containing minimal buffers and contributing ditches; these upstream land uses may be contributing sediment to Segment T3.01-C.

Bank Erosion

Erosion was of some significance along segments where planform adjustment and/or widening are the dominant adjustment processes; for example:

- Upper main stem segments: M22, M21-B, M20-A, M19-B, M19-A, M17-C, M17-A, M16, M15-B, and M15-A

- Lower main stem segments: M13-A, M12-A, M11, M10-E, M10-D, M10-B, M06, M04, M03

- High Knob segments: T6.06-B, T6.05-A, T6.03-A, and T6.3S1.01

- Hollow Brook segments: T4.05-D, T4.01-B, T4.01-A

- Pond Brook segment: T3.01-B

These segments are likely to be contributing increased sediment loads to downstream segments.
In other reaches, erosion resistance in the channel boundaries has been offered by cohesive bank sediments, occasional lateral bedrock grade controls, and forested buffers.

Mass wasting and gully sites or rejuvenating tributaries

Eleven mass wasting sites were identified on ten of the assessed segments of the Lewis Creek main stem, where the channel impinged upon the valley wall or a nearby high terrace. Most often, sediments of a glaciolacustrine or till origin were mapped coincident with the mass wasting sites; generally, such sediments tend to be more cohesive in nature and would not be expected to generate large volumes of sediment over time. Two exceptions were a short, medium-height terrace of alluvium and/or fill materials in M22 downstream of the Rt 116 crossing and a short section of alluvial sediments mid-way along reach M06 downstream of North Ferrisburgh village, where mass wasting appears to have contributed to localized channel aggradation / braiding. Generally, sediments generated at the point of mass failures represent a low percentage of the overall bedload in these larger channels, and are not considered to be significant reach-scale or watershed-scale sediment stressors.

Similarly, eight mass wasting sites were indexed along three assessed reaches of the Hollow Brook. Mass failure sites on upper reaches were coincident with mapped till sediments and are not expected to represent significant sources of sediment. On the other hand, three mass failure sites in downstream segments T4.02-A and T4.01-B were exposing unconsolidated sands and gravels of likely glaciofluvial origin and may be contributing to bed load in the channel along this tributary.

One significant gully site was identified on the assessed reaches of the Lewis Creek watershed in segment M15-B. A LB channel directs overland flow from a commercial tree nursery to the Lewis Creek channel and has developed into a moderately-sized gully with an associated "delta" of fine to coarse gravel sediments (see Figure 26). This gully represents a source of stormwater flows and sediment to the Lewis Creek. Potential significance of this gully site as a source of sediments may be moderated somewhat by the size of the upstream watershed of the Lewis Creek at the confluence of this stormwater channel (approximately 36 square miles).

Figure 26. LB stormwater channel from commercial tree nursery in Segment M15-B just upstream of the Tyler Bridge Rd. With the addition of drainage diverted from an upstream residential property, this channel has developed into an erosional gully that has deposited gravels and sands in the Lewis Creek channel.
29 November 2006.

5.1.3 Reach Scale Modifiers

Valley, floodplain and channel modifications to accommodate human infrastructure and land uses can alter the channel cross section, profile and position in the landscape. Natural features of the river network, such as bedrock grade controls or tributary confluences, also influence the hydraulic geometry of the river. These modifications and features can be categorized broadly into:

- changes in channel slope and channel depth, which influence the energy gradient (stream power) of the river and the capacity to transport sediment, and
- changes in the boundary conditions (channel bed, banks, and riparian vegetation) which influence the resistance to erosion.

The impacts of reach-scale modifiers on the hydraulic geometry of the channel are complex. The influence of multiple stressors may overlap within a reach. The following sections describe reach-scale modifications in more detail. Appendix H presents a summary of the reach-scale modifiers catalogued for each of the assessed Lewis Creek main stem and tributary reaches / segments, together with the flow and sediment load modifications previously described.

Stream Power Modifiers

<u>Channel Slope</u>
Channel slope modifiers include stressors that lead to an ***increase*** in stream power, such as:

- channelization (straightening),
- floodplain encroachments (roads, berms, railroads),
- localized reduction of sediment supply below grade controls (bedrock, dams) or channel constrictions;

as well as stressors that can be expected to lead to a ***decrease*** in stream power, such as:

- a downstream grade control (dams, weirs),
- a downstream constriction (undersized bridge or culvert, bedrock constriction, armoring).

<u>Channel Depth</u>
Channel depth modifiers include stressors that lead to an ***increase*** in stream power, such as:

- dredging and berming,
- localized flow increases below stormwater and other outfalls;
- localized flow increases below constrictions (undersized bridge or culvert; armoring);

as well as stressors that can be expected to lead to a ***decrease*** in stream power, such as:

- gravel mining, bar scalping, where such activities result in overwidened conditions;
- localized increases of sediment supply occurring at tributary confluences and backwater areas, and impoundments behind beaver dams.

(VTANR guidance, 2007b)

A stressor imparting an increase in stream power may or may not lead to channel incising or widening. Effects are dependent on the magnitude of the stream power increase, the resistance to erosion offered by the unique set of boundary conditions, and whether there are other stressors acting on the reach that may decrease stream power, or lead to channel aggradation.

A stressor imparting a decrease in power may or may not lead to channel aggradation or planform adjustment. Effects are dependent on the magnitude of the stream power decrease, the degree of valley or infrastructure confinement of the channel, and whether there are other stressors acting on the reach that may increase stream power, or lead to channel incision.

Erosion Resistance Modifiers (Boundary Conditions / Riparian Vegetation)

The nature of sediments in the channel banks (e.g., grain sizes, cohesiveness) and the vegetative cover (e.g., type and density) or other "treatments" (e.g., rip-rap, gabion baskets, revetments, large woody debris) along the stream banks control the strength of the banks and their resistance to erosion. These boundary conditions in turn influence the degree and rate of channel widening or other lateral movement, thus influencing the ability of the river to adjust its cross-sectional dimensions to most effectively convey the water and sediment inputs to the channel. Boundary conditions also influence the nature and amounts of sediment available to be transported to downstream reaches.

Channel Bed

Channel bed modifications that lead to a ***decrease*** in erosion resistance include:

- snagging (removal of large woody debris),
- dredging, and
- windrowing.

Channel bed modifications that lead to an ***increase*** in erosion resistance include:

- grade controls (dams, weirs, channel-spanning bedrock), and
- bed armoring.

Streambank and Near-bank Riparian Area

Bank and riparian modifications that lead to a ***decrease*** in erosion resistance include:

- removal of vegetation.

Bank and riparian modifications that lead to an ***increase*** in erosion resistance include:

- bank armoring (rip-rap, gabion baskets, revetments, large woody debris).

(VTANR guidance, 2007b)

It is important to note that enhanced erosion resistance offered by the boundary conditions in one location along a river network may translate into increased stream power at a downstream site. For example, it is very common to observe streambank erosion beginning at the downstream end of a length of channel armoring, or bed scour downstream from a bedrock grade control or dam site.

5.1.4 Sediment Regime Departure, Constraints to Sediment Transport & Attenuation

Within a given reach, the watershed-level and reach-level flow and sediment load modifications, together with the reach-scale modifiers of stream power and boundary resistance, govern adjustments in the channel dimensions, profile and planform over time. These lateral and vertical adjustments, in turn, influence how the river channel transports its sediment and water inputs.

The **Departure Analysis Table** (Appendix I) summarizes the apparent status of each of the assessed reaches/segments as either transport- or attenuation-dominated. These tables also indicate the significant natural constraints (e.g., bedrock) and human constraints (e.g., roads, development) to channel adjustment that are, in part, influencing the current transport or attenuation status.

Bedrock-controlled reaches are natural transport-dominated reaches, due to the erosion resistance offered by the bedrock. It is likely that the sediment entering these channel segments is balanced by the sediment carried out of the reach (steady-state, dynamic equilibrium conditions). Bedrock-controlled segments on the assessed reaches included: the States Prison Hollow gorge in Starksboro (M18), the bedrock falls upstream of the Seguin covered bridge (M10-F), a gorge on the High Knob tributary off Freedom Acres Rd in Starksboro (T6.02-A), a gorge south of the Lincoln Hill Rd in Hinesburg on the

Hollow Brook (T4.05-C), and a gorge on the downstream-most reach of Cedar Brook (T2.01). Generally, bedrock gorges were not assessed, but are recognized for their role as bedrock grade controls and points of fixed elevation in the overall Lewis Creek network.

Seven other assessed reaches/segments were identified as natural transport-dominated reaches/segments, although bedrock exposures in the bed and banks were not prevalent in every case, and gradients were often less than 2%. These included sections of channel where close positioning of bedrock-controlled, steep valley walls result in a natural Semi-confined status of the channel:

- on the Lewis Creek main stem:
  - A short segment spanning the Tatro Road bridge near Camp Common Ground (M21-A);
  - A short reach along Lewis Creek Road in Hinesburg spanning the Turkey Lane crossing (M14);
  - A half-mile segment between the Seguin covered bridge and Scott Pond (M10-C);
  - A 1.7-mile reach upstream of North Ferrisburgh village (M07).

- on the High Knob tributary - 1000-foot segment in Starksboro above the gorge off Freedom Acres Rd (T6.02-B).

- in the Hollow Brook subwatershed:
  - A quarter-mile segment downstream of the gorge south of Lincoln Hill Rd (T4.05-B); and
  - A nearly mile-long segment of the unnamed tributary to Hollow Brook (T4.3S6.01).

Nearly all the remaining assessed reaches/ segments are located in unconfined, low- to moderate-gradient valley settings (0.04 to 0.9%: main stem; 0.06 to 1.4%: Pond Brook; 0.5 to 2.1%: Hollow Brook; < 2%: High Knob trib), and contain few or no channel-spanning exposures of bedrock. Under dynamic equilibrium conditions these (reference C or E stream type) reaches might be expected to deposit fine sediments in their floodplains through periodic bankfull and flood-stage flows, and balance the transport of coarser sediments (bed load), such that the bedload volumes entering the reach would be similar to bedload volumes leaving the reach averaged over a one- to two-year period.

Exceptions to this generalization are four unconfined segments which have moderate to steep slopes (2.6% to 4.4%) and are transitional between upstream bedrock-controlled, confined channels and downstream, lower-gradient, unconfined settings. All four segments have a reference Cb or Ca stream type.

- Reach M23 (2.6%) on the Lewis Creek main stem is located at a point of slope reduction below Semi-confined upstream channels and the broad alluvial valley along Route 116 in Starksboro;

- Segment T6.01 (3%) on the High Knob tributary is transitional between upstream bedrock gorge (5.6%) and the downstream segment M20-B of the Lewis Creek main stem (0.9%);

- Reach T6.3S6.01 (2.6%) on a tributary to the High Knob Brook is transitional between steep, confined upstream sections and the lower-gradient, meandering channel of the High Knob in reach T6.03;

- Segment T4.05-A (4.4%) on the Hollow Brook is located at a point of markedly reduced slope and valley confinement in vicinity of the Lazy Brook mobile home park below a Semi-confined bedrock channel (T4.05-B) and bedrock gorge (T4.05-C).

Due to the notable transition in confinement as well as gradient, these four segments are expected to represent locations of decreased sediment transport capacity and to be natural attenuation-dominated segments. These segments (as well as some additional lower-gradient segments) are identified as "alluvial fans" to highlight their expected function as natural depositional zones prone to enhanced lateral channel adjustments (although surficial geologic mapping to confirm this classification is beyond the scope of a Phase 2 geomorphic assessment). Sediment deposition in these locations was probably much more active in earlier post-glacial environments (1,000s of years before present), under more intense hydrologic and sediment regimes, just after glaciation and prior to vegetation of the landscape. These locations may also have seen renewed sedimentation and lateral adjustments during colonial times, during widespread deforestation of upland slopes in the 1800s.

Several of the unconfined segments have been converted from depositional or equilibrium conditions to transport-dominated conditions by virtue of various channel and watershed disturbances (Appendix H). Equilibrium transport of coarse sediment fractions that might be expected in these unconfined valley settings has been compromised substantially, and these segments have been converted to a transport-dominated condition as a result of:

- channelization, removal of meanders;
- dredging, windrowing (localized, following the 1927, 1936/38 floods);
- historic incision and the resultant decrease in degree of floodplain connection;
- floodplain encroachments (berming, roads);
- conversion or loss of channel-contiguous wetlands (especially in the Pond Brook and Cedar Brook tributaries); and
- historic flood impacts.

A few reaches/segments have experienced increased sediment attenuation in recent years, related to the upstream and in-reach production of sediments. In some locations, valley fill supporting culvert or bridge crossings is contributing to (or supporting) localized upstream attenuation (for example, in reach T6.01 of the High Knob Brook just upstream of the culvert crossing of Freedom Acres Rd and Route 116, and on T4.01-B on the Hollow Brook tributary upstream of Tyler Bridge Rd crossing). Transient, but persistent beaver activity is also contributing to aggradation in some reaches (M22, M17-B, M15-B, M15-A, T4.01-A, T3.01-C). Often, reaches/segments demonstrating enhanced sediment deposition are local to natural (bedrock-controlled) constrictions of the floodplain, just upstream of valley pinch points. Sediment loading has been enhanced to a degree by erosion from the incised and entrenched upstream segments. These segments have reasonable access to the floodplain (usually, IR < 1.2) and (where presently unconstrained by human-constructed features) may represent key attenuation assets in the Lewis Creek network:

- M21-B on the Lewis Creek main stem above the Tatro Rd crossing;
- M19-B, M19-A on the Lewis Creek above the States Prison Hollow Rd gorge;
- M17-B, M17-A, and M16 on the Lewis Creek above Hollow Brook confluence;
- M15-A above the natural valley pinch point along Lewis Creek Rd in Hinesburg;
- M12-C and M12-A (Wetlands) upstream and downstream of the Baldwin Rd crossing in Hinesburg;
- M08 below the Quinlan covered bridge in Charlotte;
- M06 below the North Ferrisburgh village in Ferrisburgh;
- M04 and M03 above and below the Greenbush Rd crossing in Ferrisburgh;
- T6.05-B. T6.04-A and T6.03-B on the High Knob tributary;
- T4.01-B and T4.01-A on the Hollow Brook downstream of the Route 116 crossing;

- T3.01-C on the Pond Brook spanning the Silver Street crossing; and
- T3.01-A above the Pond Brook confluence with Lewis Creek.

The current geomorphic condition of these reaches/segments, as modified by human factors, is summarized in the following Sediment Regime Departure Maps in Figures 27 through 31.

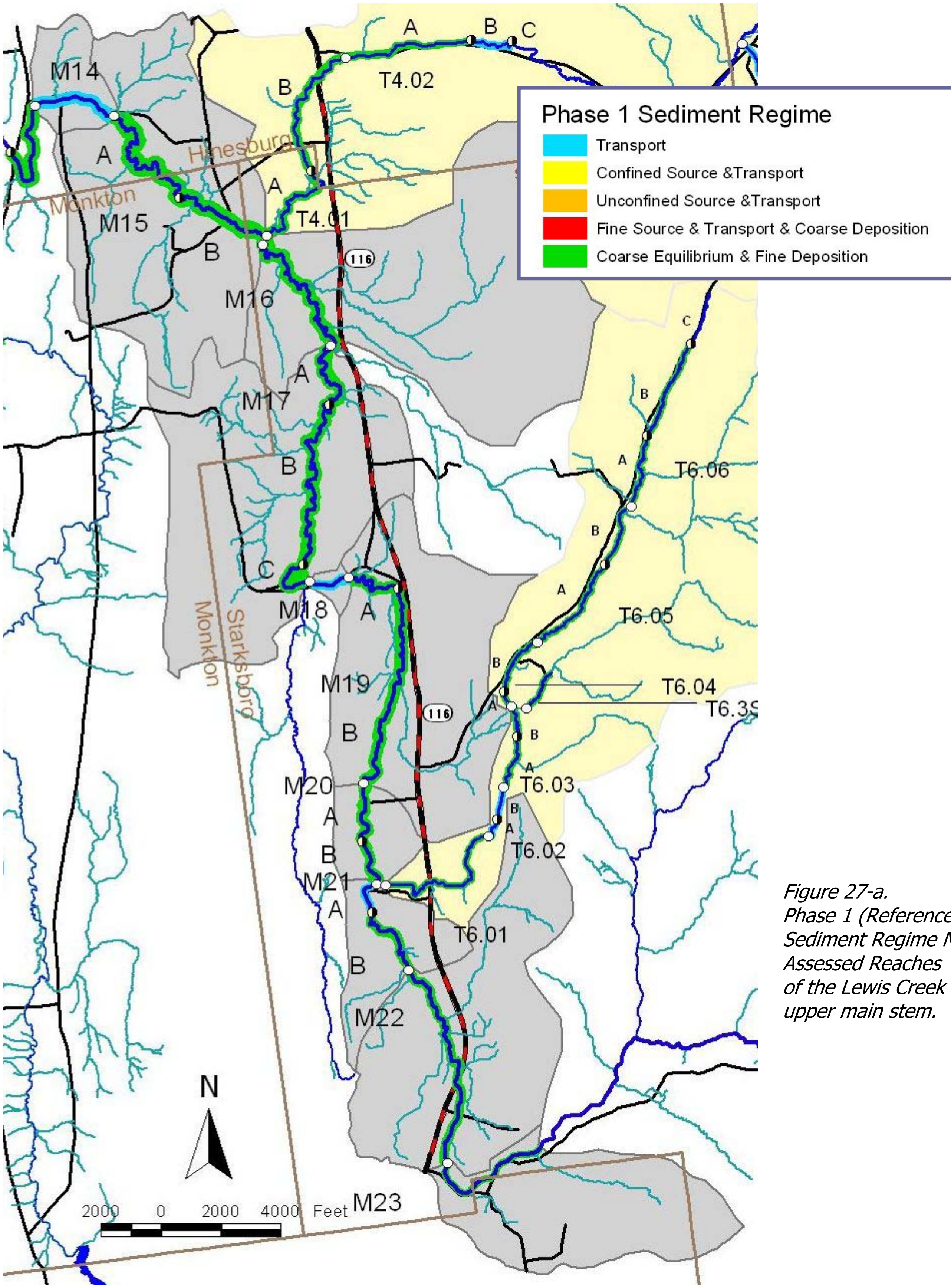


Figure 27-a.
Phase 1 (Reference) Sediment Regime Map, Assessed Reaches of the Lewis Creek upper main stem.

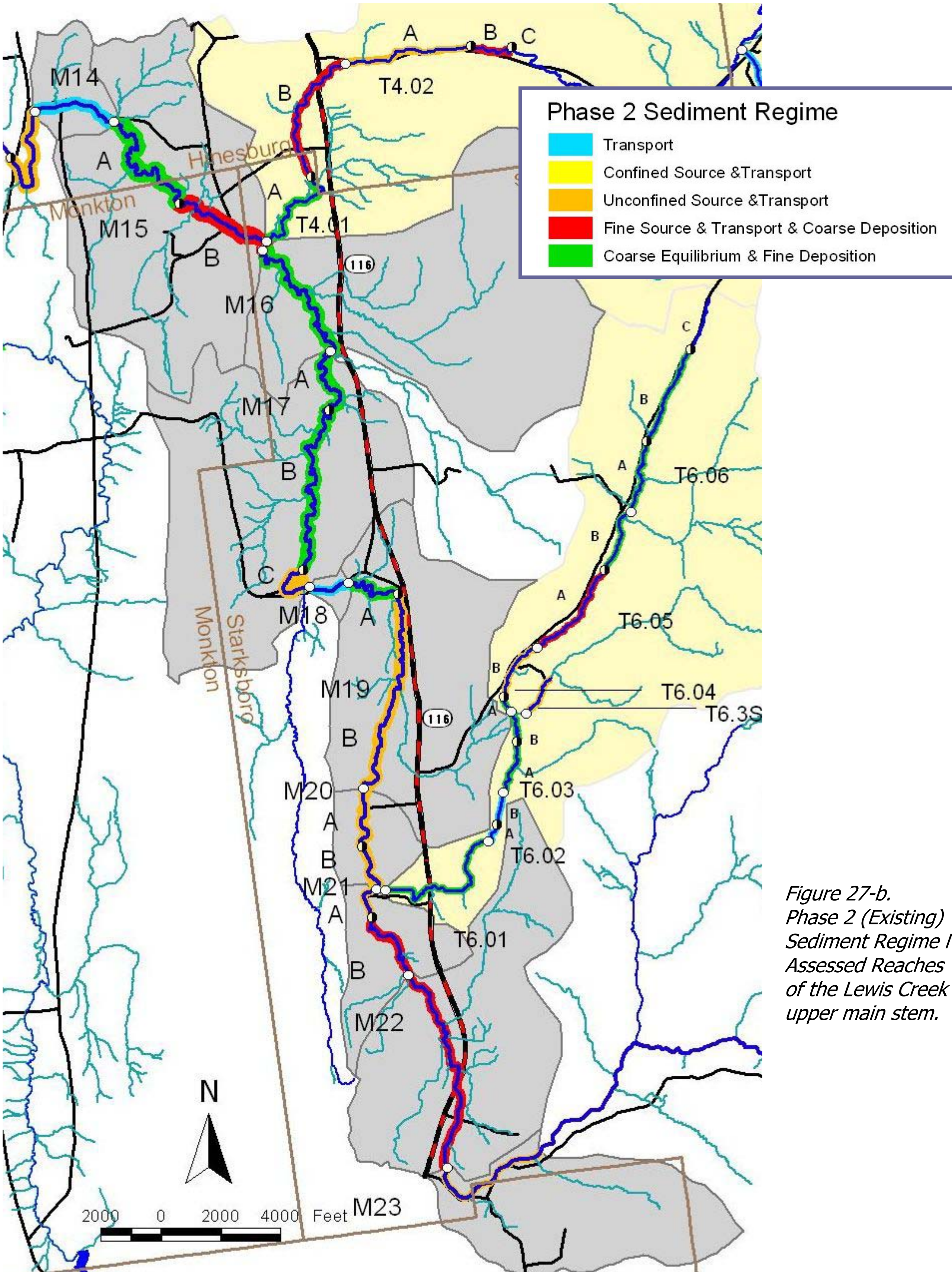


Figure 27-b. Phase 2 (Existing) Sediment Regime Map, Assessed Reaches of the Lewis Creek upper main stem.

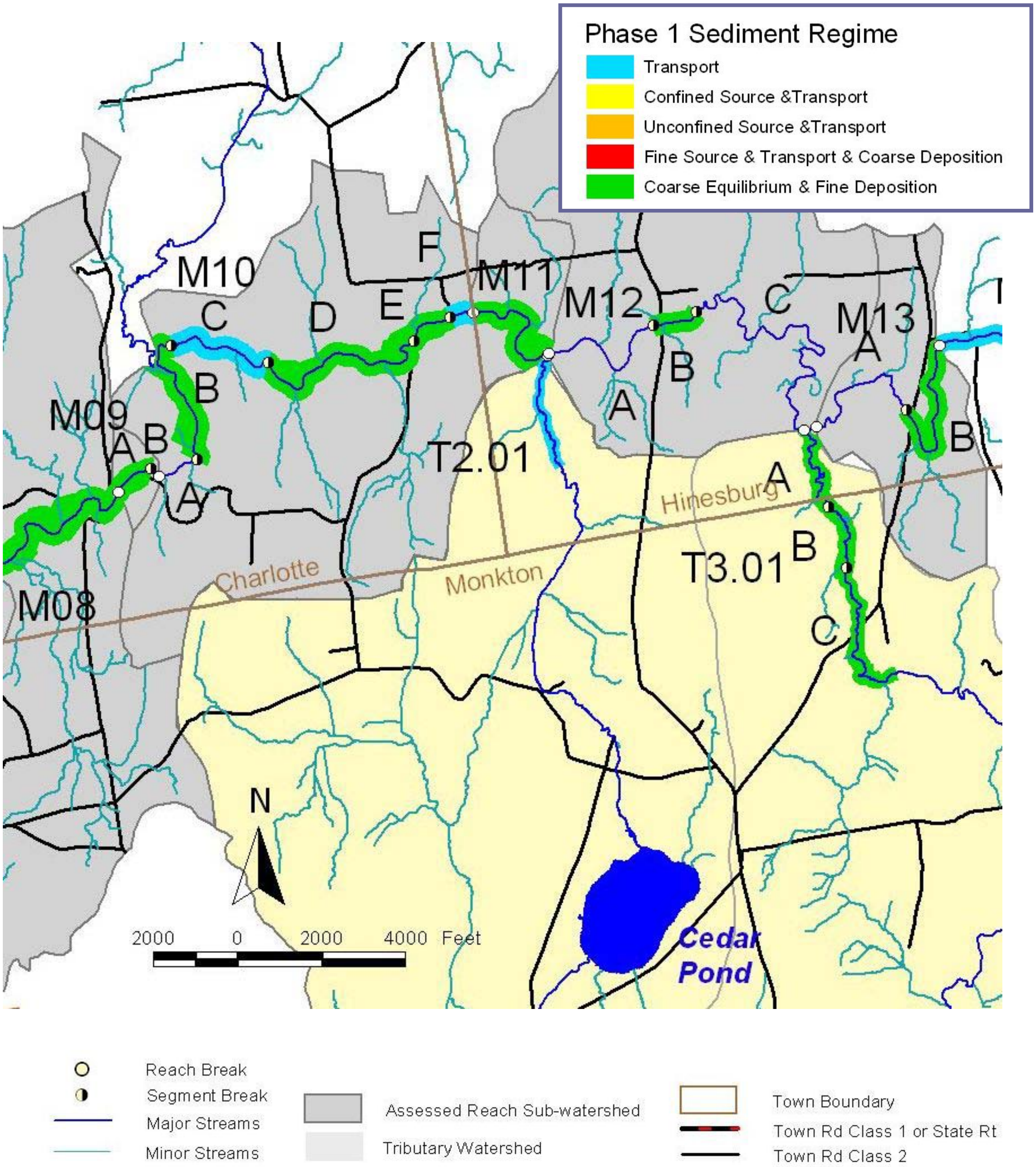


Figure 28-a. Phase 1 (Reference) Sediment Regime Map
Assessed Reaches of the Lewis Creek lower main stem - east.

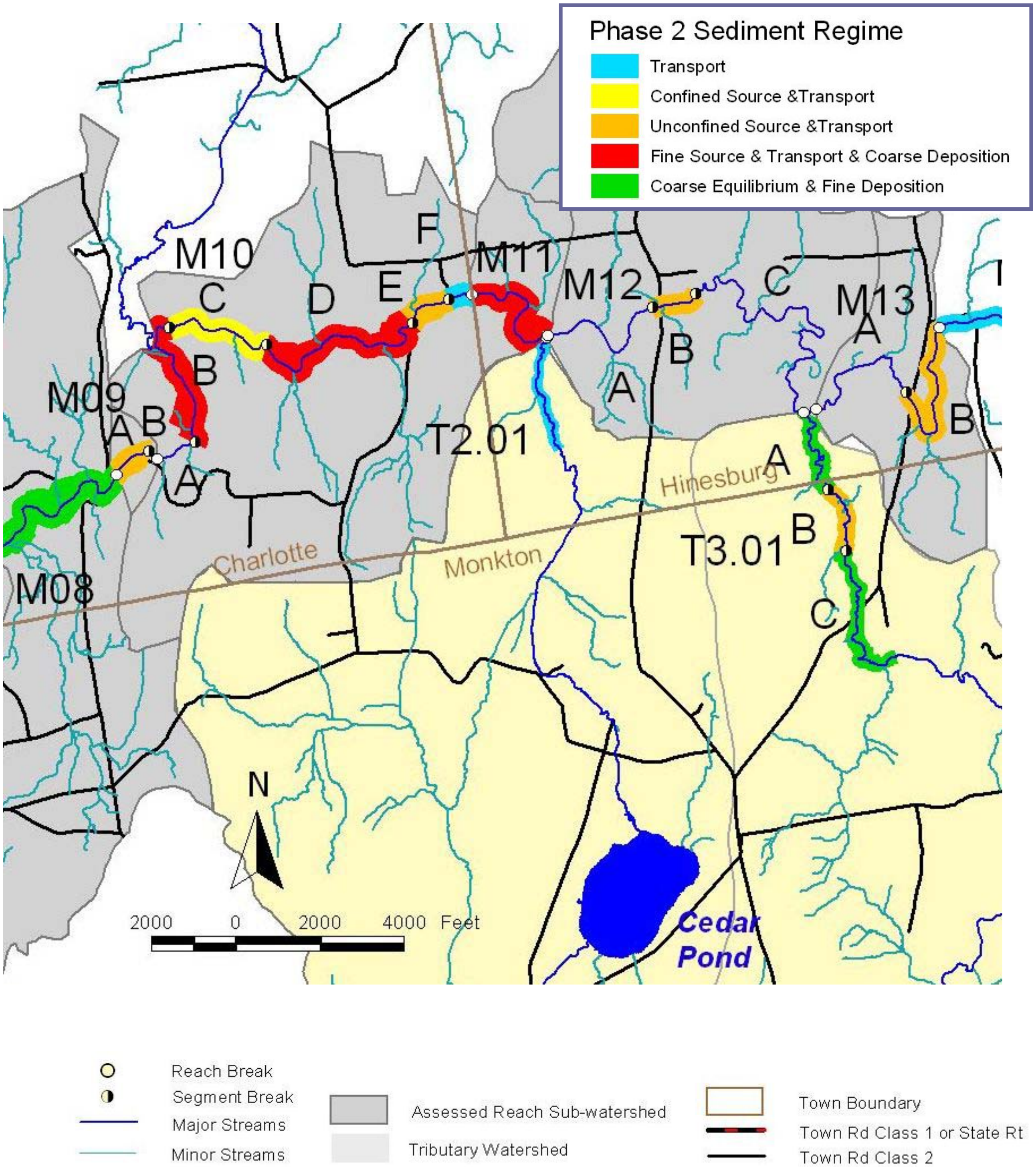


Figure 28-b. Phase 2 (Existing) Sediment Regime Map
Assessed Reaches of the Lewis Creek lower main stem - east.

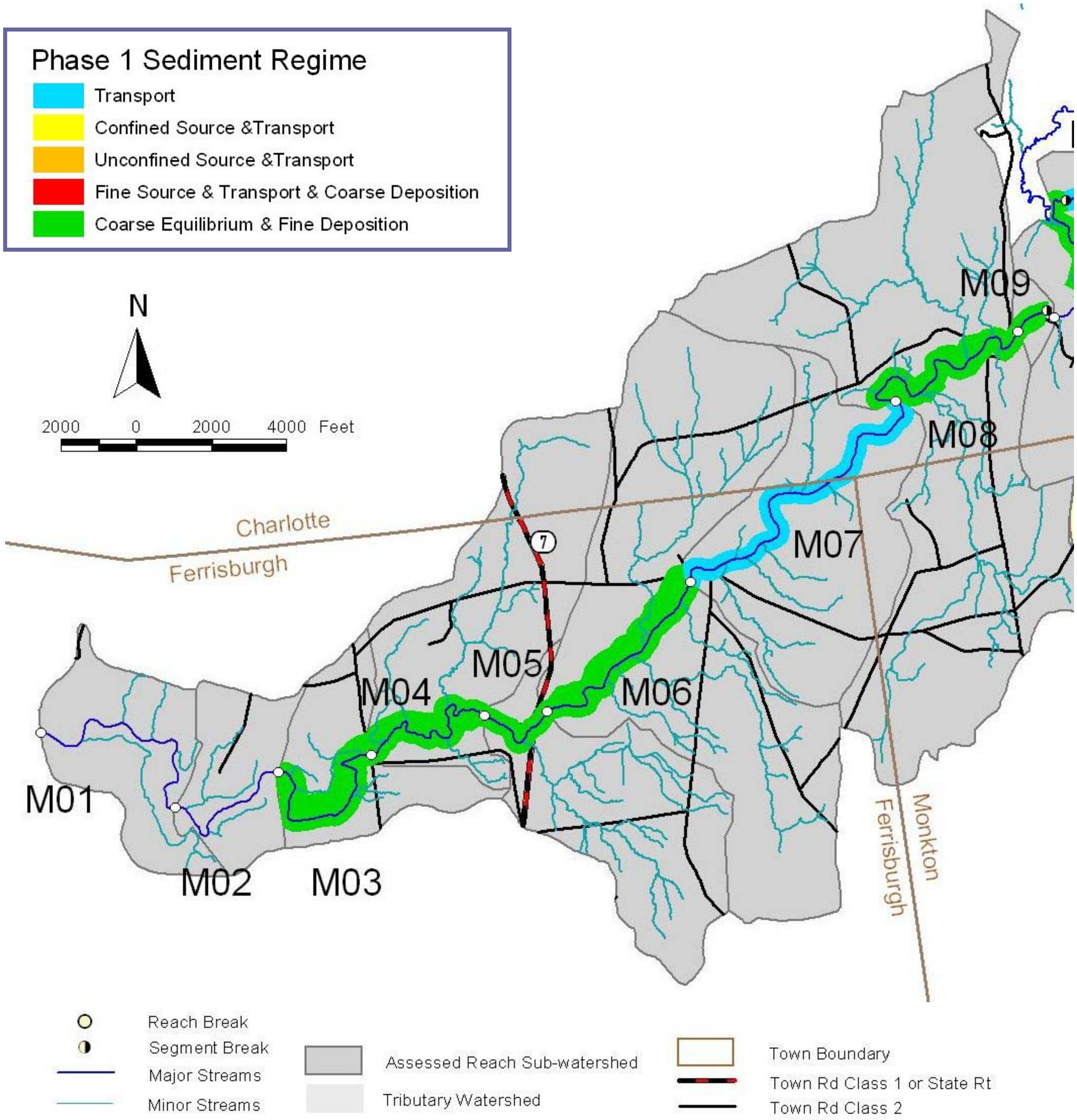


Figure 29-a. Phase 1 (Reference) Sediment Regime Map
Assessed Reaches of the Lewis Creek lower main stem - west

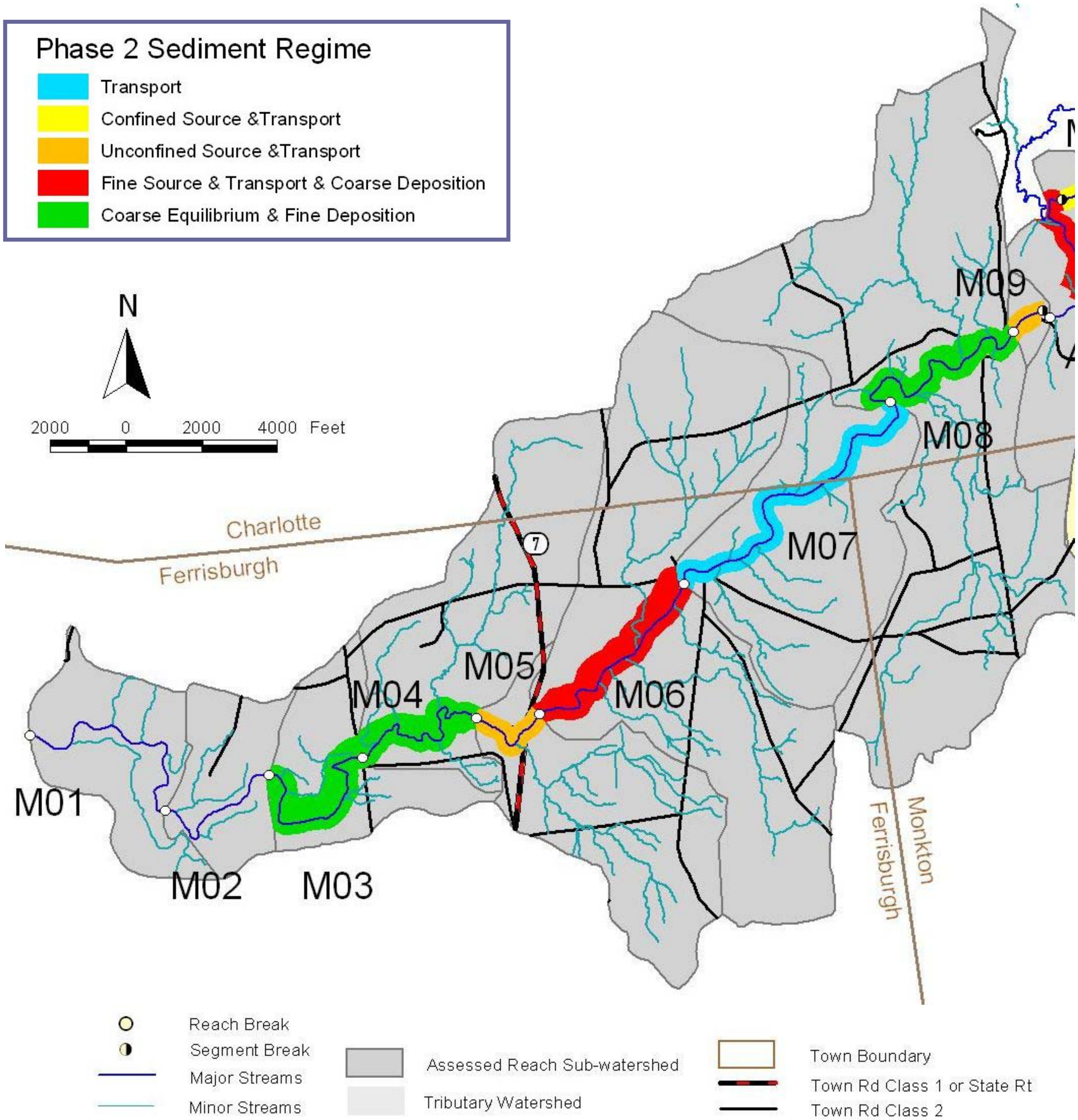


Figure 29-b. Phase 2 (Existing) Sediment Regime Map
Assessed Reaches of the Lewis Creek lower main stem – west.

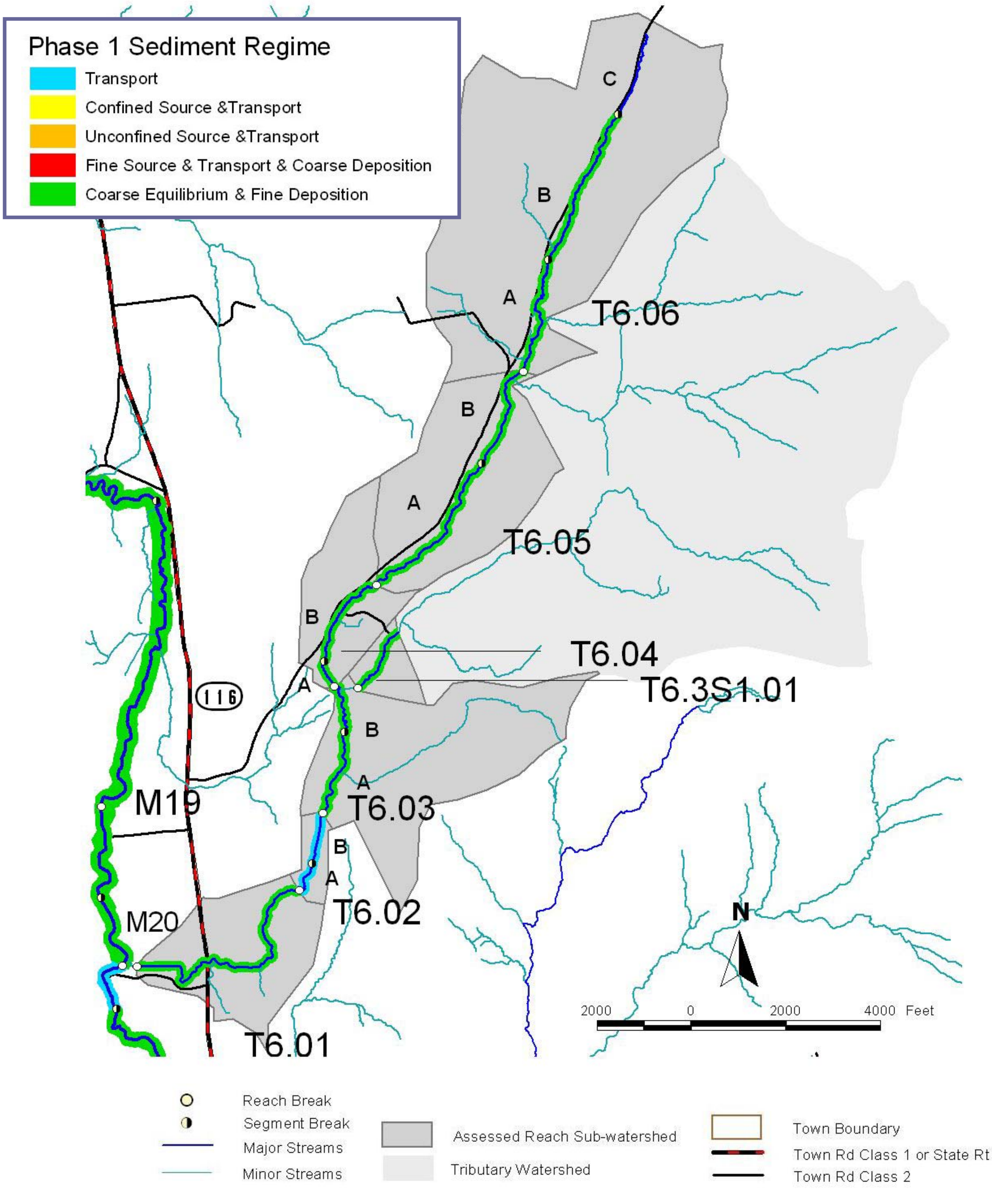


Figure 30-a. Phase 1 (Reference) Sediment Regime Map
Assessed Reaches of the High Knob tributary.

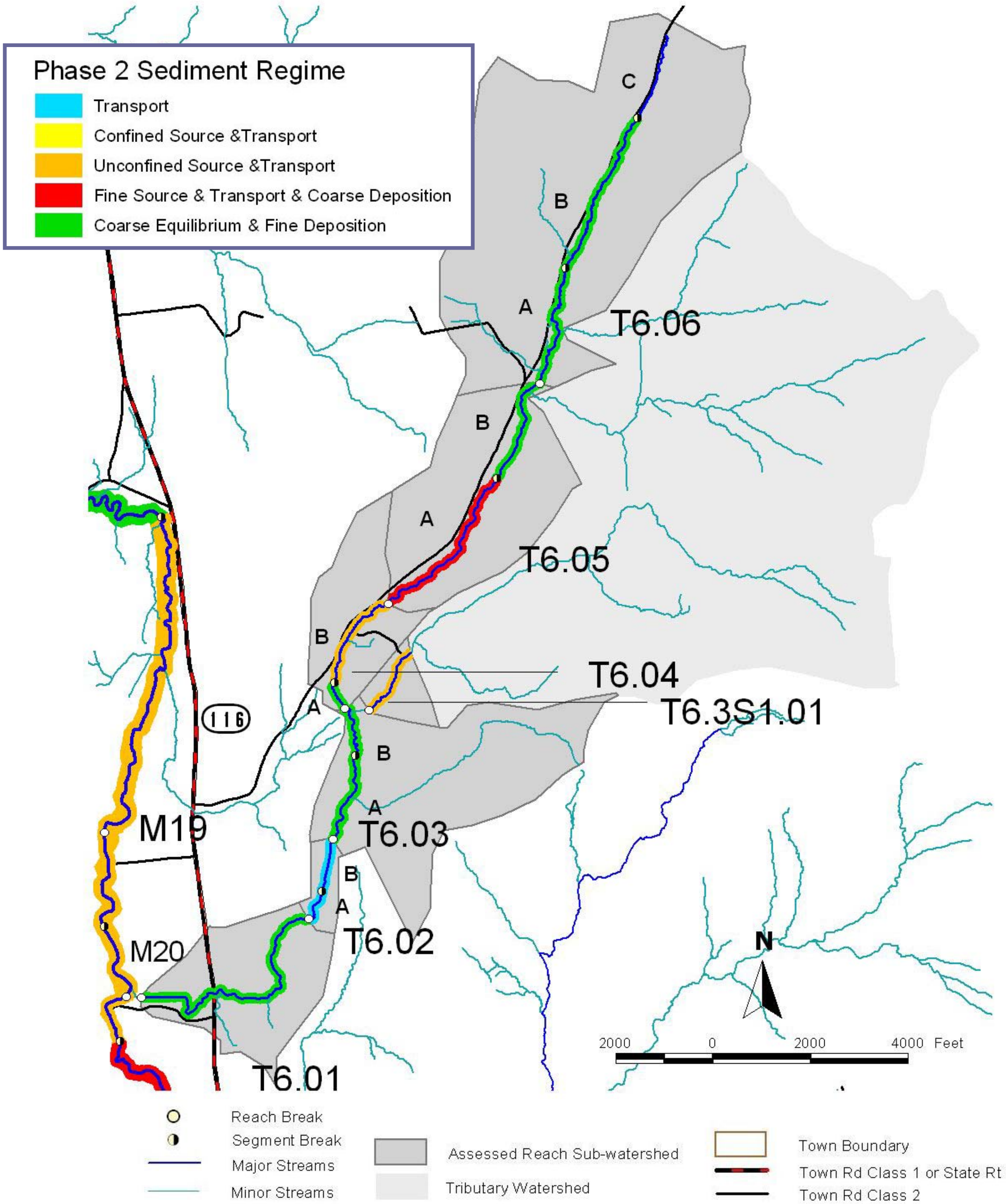


Figure 30-b. Phase 2 (Existing) Sediment Regime Map
Assessed Reaches of the High Knob tributary.

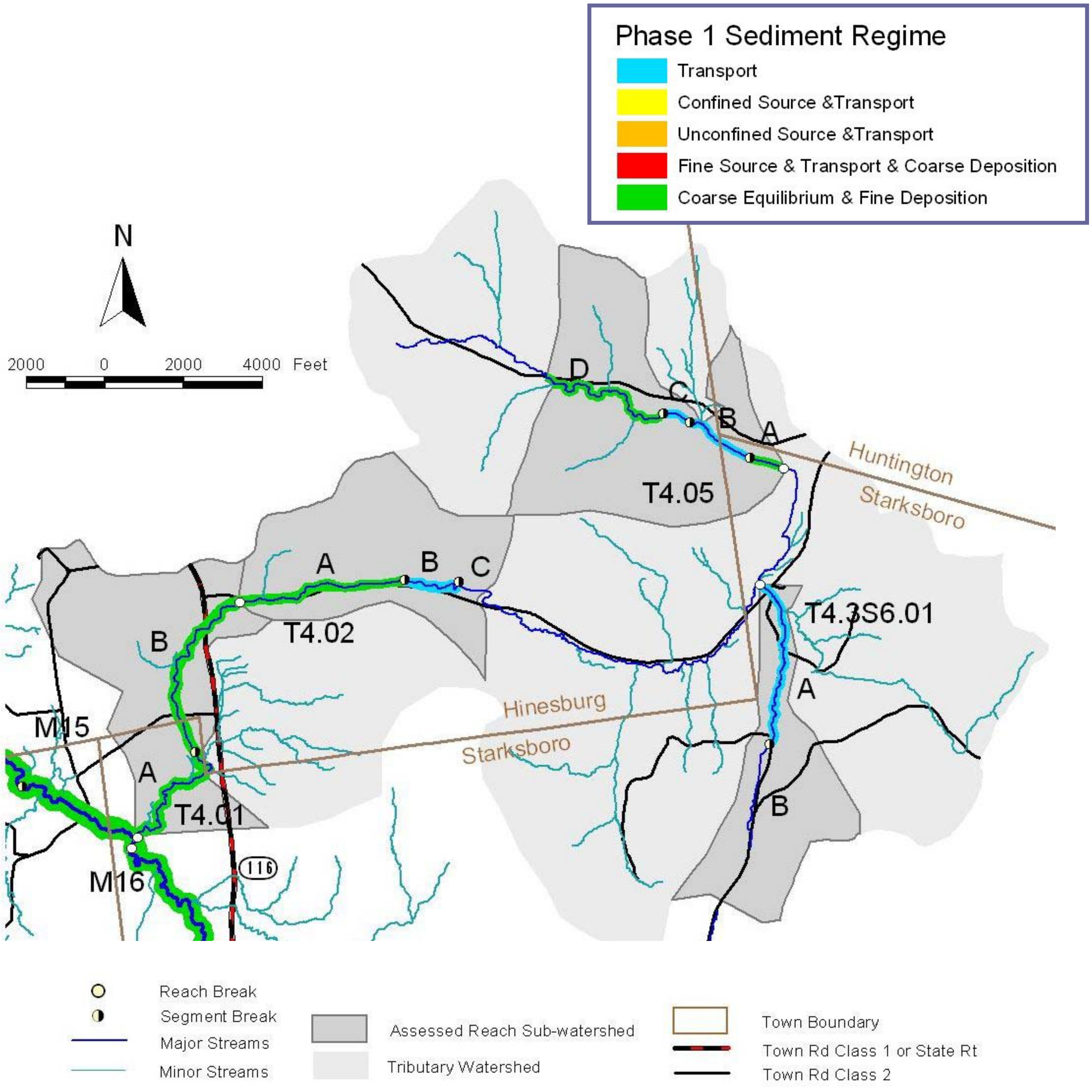


Figure 31-a. Phase 1 (Reference) Sediment Regime Map
Assessed Reaches of the Hollow Brook tributary

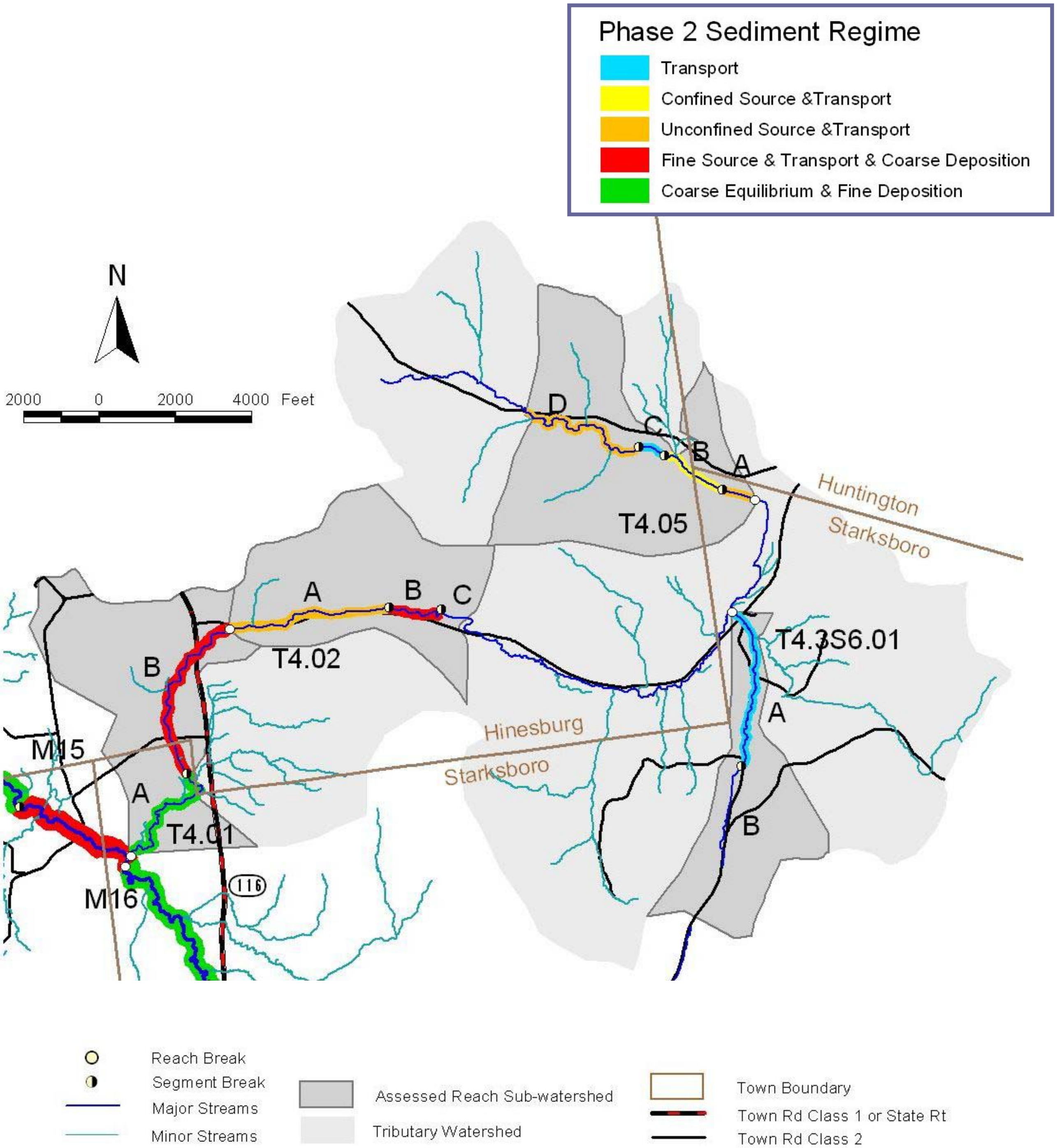


Figure 31-b. Phase 2 (Existing) Sediment Regime Map
Assessed Reaches of the Hollow Brook tributary.

Phase 1 (Reference) Sediment Regime

Figures 27-a, 28-a, 29-a, 30-a, and 31-a display the ***reference*** sediment regimes that are theorized to be characteristic of the assessed reaches prior to widespread human disturbance of the watershed (say, 300 years before present).

Transport (coded blue in figures)
Bedrock-controlled segments have been assigned a *Transport* classification for the reference (Phase 1) sediment regime, including:

Tributary	Reach/Segment	Phase 1 Reference Stream Type	Channel Gradient (%)
Lewis Creek main stem	M18	B2a-S/P	6.9%
	M10-F	B1c-S/P	1.8%
High Knob tributary	T6.02-A	B1a-S/P	5.6 %
Hollow Brook tributary	T4.05-C	B1a-casc	10.7%
Cedar Brook tributary	T2.01	B3-S/P	2.3%

Seven additional segments, while not characterized by fully-exposed bedrock in the channel bed and banks, are confined by steep, bedrock-controlled valley walls and may have some occurrences of channel-spanning bedrock. Generally, in these segments, close valley confinement creates a linear planform with limited available floodplain and no meanders for storage of sediment. In the case of T4.05-B and T4.3S6.01, the steepness of the slope (8.1% and 6.0%, respectively) also precludes significant storage of sediment. The erosion resistance offered by the occasional exposures of bedrock in the channel boundaries, as well as mature forested buffers, means that these channels are not a significant source of coarse and fine sediments. Therefore, these segments were also classified with a *Transport* reference sediment regime.

Tributary	Reach/Segment	Phase 1 Reference Stream Type	Channel Gradient (%)
Lewis Creek main stem	M21-A	B3c-PB	0.5%
	M14	B3c-R/P	0.3%
	M10-C	B4c-R/P	0.9%
	M07	B4c-R/P	0.7%
High Knob tributary	T6.02-B	B4-S/P	2.3%
Hollow Brook tributary	T4.05-B	F3a-S/P	8.1%
	T4.3S6.01	A3-S/P	6.0%

Coarse Equilibrium & Fine Deposition (coded green in figures)
Between these bedrock and transport reaches, it is theorized that the Lewis Creek and tributary channels would have had a more meandering planform (constrained locally by exposures of bedrock and variable sediment types in the stream bed and banks). If dynamic equilibrium existed (prior to widespread human modifications to the channel and watershed), each unconfined channel would have had access to the surrounding floodplain. Fine sediments would be deposited in the floodplains through periodic bankfull and flood-stage flows, and the transport of coarser sediments (bed load) would be balanced, such that the bedload volumes entering the reach would be similar to bedload volumes leaving the reach averaged over a one- to two-year period. Deposition and erosion cycles would have been balanced, such that there would be no net change in overall channel dimensions, gradient and planform. The channel would have moved within its floodplain in its reference (pre-disturbed) condition, but there would be no net change in average, reach-wide geometry such as slope and average meander width and amplitude.

Phase 2 (Existing) Sediment Regime

Figures 27-b, 28-b, 29-b, 30-b, and 31-b display the ***existing*** sediment regimes that are hypothesized based on Phase 2 assessment results and the departure analysis previously described. The contrast in coding of the reaches between the Phase 1 (Reference) Sediment Regime figures and these Phase 2 (Existing) Sediment Regime figures illustrates the degree of departure from reference that is inferred.

Transport (coded blue in figures)

A majority of semi-confined and bedrock-channel reaches/segments of the Lewis Creek and tributaries have not undergone significant lateral or vertical adjustments in response to channel and watershed disturbances, given the stability offered by the underlying bedrock and resistant boundary conditions. Thus, a *Transport* classification has been assigned for the Phase 2 (Existing) sediment regime of these segments.

Tributary	Reach/Segment	Phase 1 Reference Stream Type	Phase 2 Reference Stream Type
Lewis Creek main stem	M18	B2a-S/P	B2a-S/P
	M14	B3c-R/P	B3c-R/P
	M10-F	B1c-S/P	B1c-S/P
	M07	B4c-R/P	B4c-R/P
High Knob tributary	T6.02-B	B4-S/P	B4-S/P
	T6.02-A	B1a-S/P	B1a-S/P
Hollow Brook tributary	T4.05-C	B1a-casc	B1a-casc
	T4.3S6.01	A3-S/P	A3-S/P
Cedar Brook tributary	T2.01	B3-S/P	B3-S/P

Coarse Equilibrium & Fine Deposition (coded green in figures)

Based on Phase 2 assessments, a subset of the reaches/ segments appear not to have undergone a significant sediment regime departure (listed below). A minimal degree of net lateral and vertical adjustment in response to channel and watershed disturbances is apparent in these reaches/ segments. These reaches/segments have not undergone a vertical stream type departure and have maintained good floodplain access (IR < 1.2). Therefore, a *Coarse Equilibrium & Fine Deposition* classification has been assigned for the Phase 2 (Existing) sediment regime.

Tributary	Reach/Segment	Phase 1 Reference Stream Type	Phase 2 Reference Stream Type
Lewis Creek main stem	M19-A	E4-R/P	E4-R/P
	M17-B	E4-R/P	E4-R/P
	M17-A	E4-R/P	E4-R/P
	M16	E4-R/P	C4-R/P
	M15-A	E4-R/P	E4-R/P
	M08	C4-R/P	C4-R/P
	M04	E5-D/R	E5-D/R
	M03	C5-D/R	C5-D/R
High Knob tributary	T6.06-B	E4-R/P	E4-R/P
	T6.06-A	E4-R/P	E4-R/P
	T6.05-B	C4-R/P	C4-R/P
	T6.04-A	E4-R/P	E4-R/P
	T6.03-B	E4-R/P	E4-R/P
	T6.03-A	C4-R/P	C4-R/P
	T6.01	C4b-R/P	C4b-R/P

Tributary	Reach/Segment	Phase 1 Reference Stream Type	Phase 2 Reference Stream Type
Hollow Brook tributary	T4.01-A	E4-R/P	C4-R/P
Pond Brook tributary	T3.01-C	C4-R/P	C4-R/P
	T3.01-A	E5-D/R	E5-D/R

Note: blue highlighting indicates a lateral stream type departure.

In some cases, this inferred dynamic-equilibrium condition is associated with a relative lack of channel or watershed stressors. In other cases, the equilibrium condition exists despite the presence of channel and watershed disturbances, suggesting that boundary conditions offer sufficient resistance to stressors and/or stressors are low in magnitude or extent. A couple of segments (T4.01-A and M16) appear to have undergone a lateral stream type departure (from C to E) due to channel widening.

A minor (or localized) increase in sediment attenuation is sometimes evident in these segments, as a result of downstream grade controls or valley pinch points (and associated decrease in valley gradient), or as a result of downstream human-made constrictions such as bridge or culvert crossings. Most of the above-listed segments were identified as sediment attenuation assets (see pages 63-64 and Appendix I). The presence of occasional mid-channel or diagonal bars suggests that limited storage of coarser sediment fractions is occurring within the bankfull channel (though often at the expense of pool depths and riffle/pool diversity). However, such attenuation is not substantial enough to have resulted in dis-equilibrium conditions or a sediment regime departure.

On the other hand, a degree of sediment regime departure is theorized for the remaining assessed segments of Lewis Creek and major tributaries:

Confined Source & Transport (coded yellow in figures)
The transport function of two assessed segments has been enhanced by varying degrees of historic incision. In both cases, incision is inferred to have resulted – not from direct disturbance or encroachments along the channel – but either from watershed changes in hydrology (i.e, floods, historic deforestation, loss of wetlands [M10-C only]) and/or downstream channel manipulations that may have caused headward migration of incision. In the case of Lewis Creek main stem segment M10-C (approximately one mile upstream of the Scott Pond Dam site), incision is moderate in degree. In the case of Hollow Brook segment T4.05-B (upstream of channelized segment A in vicinity of the Lazy Brook mobile home park), historic incision was substantial enough to result in a vertical stream type departure. (There is uncertainty whether incision occurred (in part or in whole) as a result of disturbances to the channel / watershed occurring over the last 300 years, or whether some degree of incision occurred over the past thousands of years). As a result of historic incision, erosional energies of bankfull and flood events have been increased, and these segments have become more of a source of coarse and fine sediments by virtue of the increased channel entrenchment. To some degree, sediment erosion (and channel widening) have been moderated by the presence of moderately cohesive soils (glacial till origin) and forested banks and corridors.

Tributary	Reach/Segment	Phase 1 Reference Stream Type	Phase 2 Reference Stream Type
Lewis Creek main stem	M10-C	B4c-R/P	B4c-R/P
Hollow Brook tributary	T4.05-B	B3a-S/P	F3a-S/P

Note: yellow highlighting indicates a vertical stream type departure.

Unconfined Source & Transport (coded orange in figures)

Seventeen (17) of the assessed reaches/segments are classified in this category (listed below). Due to the vertical stream type departure (C-to-F, C-to-Bc or C-to-B) of seven segments and loss of floodplain connection (IR_{RAF} values ranging from 1.3 to 3.95), these segments have been converted to a more transport-dominated condition. They are inferred to have persisted in channel evolution stage II [F] or early III [F] following historic degradation often associated with channelization, dredging, berming, armoring, and/or road encroachments. Historic presence of dams within or in the vicinity of three segments (M09-A, M10-E, T4.05-D) may have contributed to historic degradation – either through "hungry water" effects downstream of the dam sites or as a result of dam-breaching effects upstream of the dam sites, or both. Historic flood events and loss of wetlands have also likely contributed to hydrologic loading at the watershed scale. (In some cases, there is uncertainty whether incision occurred (in part or in whole) as a result of disturbances to the channel / watershed occurring over the last 300 years, or whether some degree of incision occurred over the past thousands of years).

Plane-bed and weak riffle/pool morphologies tend to dominate these segments. Both fine and coarse sediment fractions are exported through the segments due to the minimal available floodplain and enhanced velocities of the incised and entrenched cross section. In various cases, extensive bank armoring, maintenance of tree buffers, cohesive sediments in the channel boundaries, and lateral exposures of bedrock provide erosion resistance which has moderated the degree of lateral and vertical adjustments. Width/depth ratios are generally low (12 to 33). The existing sediment regime for these segments has been classified as *Unconfined Source & Transport.*

Tributary	Reach/Segment	Phase 1 Reference Stream Type	Phase 2 Reference Stream Type
Lewis Creek main stem	M23	C4b-S/P	F4b-PB
	M21-A	B3c-R/P	B3c-PB
	M20-B	C3-R/P	F3-R/P
	M20-A	C4-R/P	C4-R/P
	M19-B	C4-R/P	C4-R/P
	M17-C	C4-R/P	C4-R/P
	M13-B	C4-R/P	C4-R/P
	M12-B	C4-R/P	B4c-PB
	M10-E	C3-R/P	C3-R/P
	M09-A	B4c-R/P	F4-PB
	M05	C3-R/P	C3-R/P
High Knob tributary	T6.04-B	C4-R/P	B4c-R/P
	T6.3S1.01	C4b-R/P	C4b-R/P
Hollow Brook tributary	T4.05-D	C4b-R/P	C4b-PB
	T4.05-A	C4a-R/P	F4a-PB
	T4.02-A	C3-R/P	B3-PB
Pond Brook tributary	T3.01-B	E4-R/P	C4-R/P

Note: yellow highlighting indicates a vertical stream type departure; blue indicates a lateral stream type departure.

Fine Source & Transport / Coarse Deposition (coded red in figures)

Ten of the assessed reaches/segments of Lewis Creek and major tributaries were classified in this category. These segments are moderately to substantially incised (IR_{RAF} values ranging from 1.2 to 1.96). One of these ten segments has undergone a vertical stream type departure (C-to-Bc). This sediment regime category includes segments classified in stage III [F] or IV [F] of channel evolution (and one segment in late stage II [F]. Like the other incised and entrenched segments, these segments have experienced increased velocities of bankfull and flood-stage flows, with enhanced scour energies, and have been converted to a more transport-dominated condition by virtue of the reduced frequency of overbank flooding. However, these segments are generally more prone to lateral adjustments, given: (1) the relative lack of armoring, extensive berms or encroachments, (2) the relative lack of forested buffers (along one or both banks), and/or (3) the presence of more erodible sediments in the channel boundaries. Historic and active widening and planform adjustments (flood chutes, bifurcations, meander extension and translation) have begun to create narrow, discontinuous pockets of floodplain at an elevation below the recently abandoned floodplain in some segments. Tree buffers are sometimes present along either or both banks of these segments and provide some measure of erosion resistance. On the other hand, historic recruitment of trees and debris jams probably contributed to the formation of flood chutes, bifurcations, and localized meander development. A low to moderate degree of coarse sediment deposition is occurring, leading to a shallow and overwidened bankfull cross section with little pool definition. A weak riffle/pool bedform has developed, characterized by diagonal riffles. Generally, width/depth ratios of these segments are slightly greater than their *Unconfined Source & Transport* counterparts (ranging from 15 to 57). Locally, channel widening may have contributed to a reduction in sediment transport capacity that has begun to drive deposition (for example, segment M15-B below the Tyler Bridge Rd crossing and reach M06 below North Ferrisburgh village). In-segment and upstream erosion is contributing to coarse sediment deposition within these segments, particularly at sharp bends or upstream of constrictions (bridge and culvert crossings, undersized [armored] cross sections). Thus, these segments have been converted from a *Coarse Equilibrium* condition to *Coarse Deposition*.

Tributary	Reach/Segment	Phase 1 Reference Stream Type	Phase 2 Reference Stream Type
Lewis Creek main stem	M22	C4-R/P	C4-R/P
	M21-B	C4-R/P	C4-R/P
	M15-B	C4-R/P	C4-R/P
	M11	E4-R/P	C4-R/P
	M10-D	C4-R/P	C4-R/P
	M10-B	C4-R/P	C4-R/P
	M06	C3-R/P	C3-R/P
High Knob tributary	T6.05-A	C4-R/P	B4c-R/P
Hollow Brook tributary	T4.02-B	B3c-R/P	B3c-R/P
	T4.01-B	C4-R/P	C4-PB

Note: yellow highlighting indicates a vertical stream type departure; blue indicates a lateral stream type departure..

5.2 Sensitivity Analysis

The **Stream Sensitivity Maps** (Figures 32, 33, 34, 35, and 36) identify the sensitivity classification for each of the assessed reaches / segments. Inherent in the stream sensitivity rating are:

- the natural sensitivity of the reach given the topographic setting (confinement, gradient) and geologic boundary conditions (sediment sizes) – as reflected in the reference stream type classification (after Rosgen, 1996 and Montgomery & Buffington, 1997); and

- the enhanced sensitivity of the reach given by the degree of departure from reference (or dynamic equilibrium) condition – as reflected in the existing stream type classification and the condition (Reference, Good, Fair to Poor ratings in the Rapid Geomorphic Assessment).

The sensitivity classification is intended to identify "the degree or likelihood that vertical and lateral adjustments (erosion) will occur, as driven by natural and/or human-induced fluvial processes" (VTANR 2007b).

These stream sensitivity data were utilized during subsequent planning steps to inform the identification and prioritization of restoration and protection projects and practices (Section 6).

This study utilized the updated sensitivity assignments presented in the November 2008 draft *River Corridor Protection Guide* issued by VT Agency of Natural Resources (VTANR, 2008a).

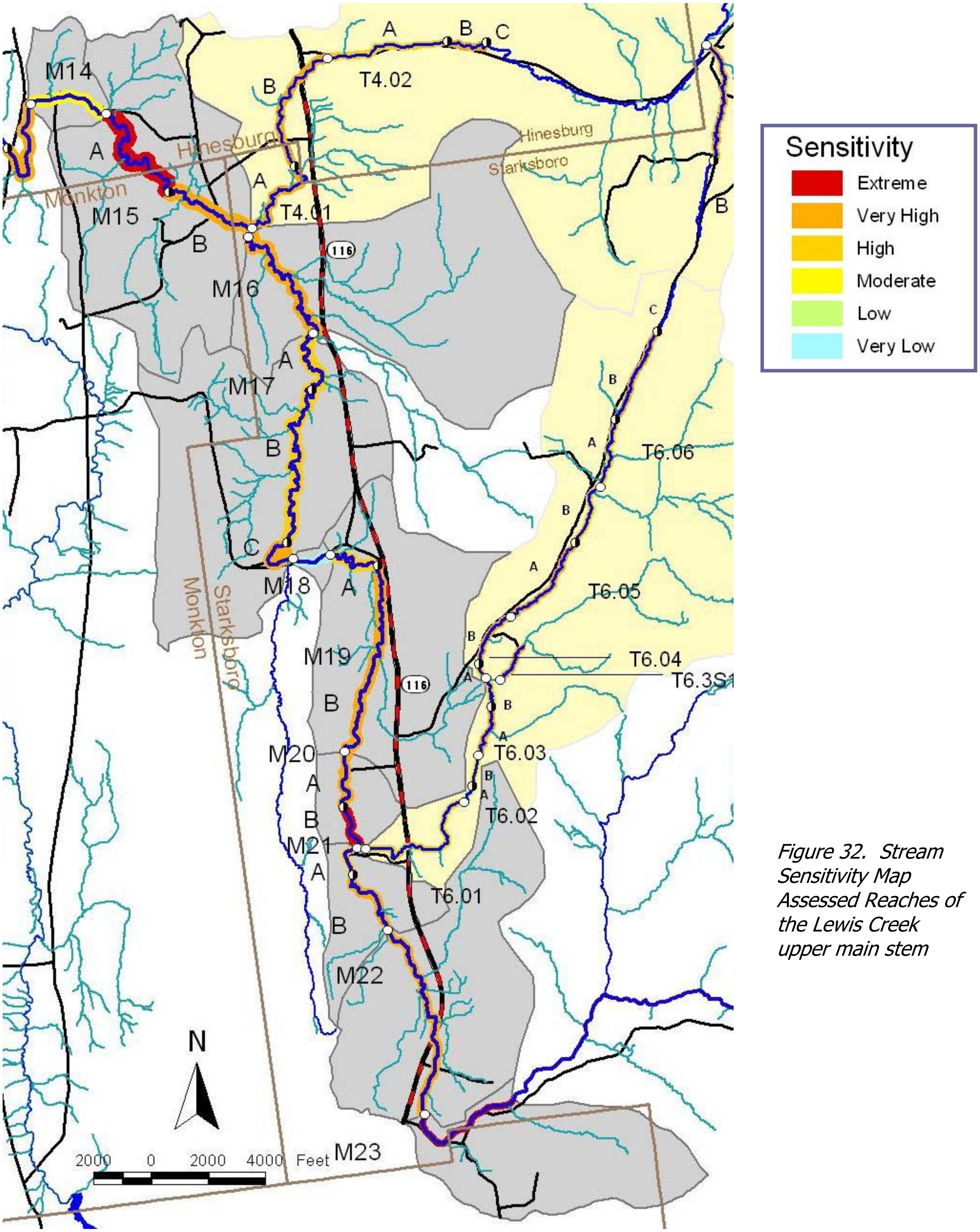


Figure 32. Stream Sensitivity Map Assessed Reaches of the Lewis Creek upper main stem

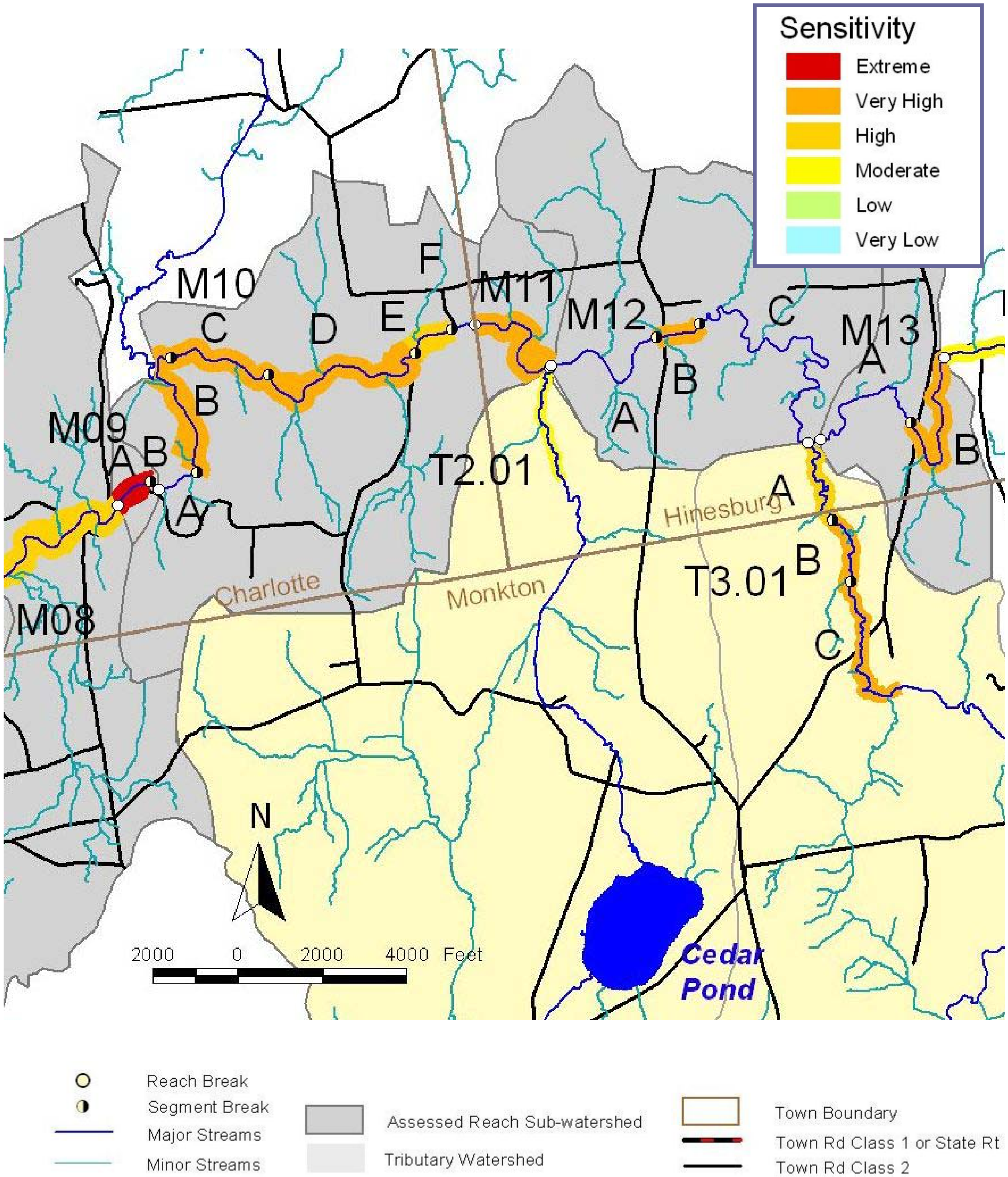


Figure 33. Stream Sensitivity Map
Assessed Reaches of the Lewis Creek lower main stem - east.

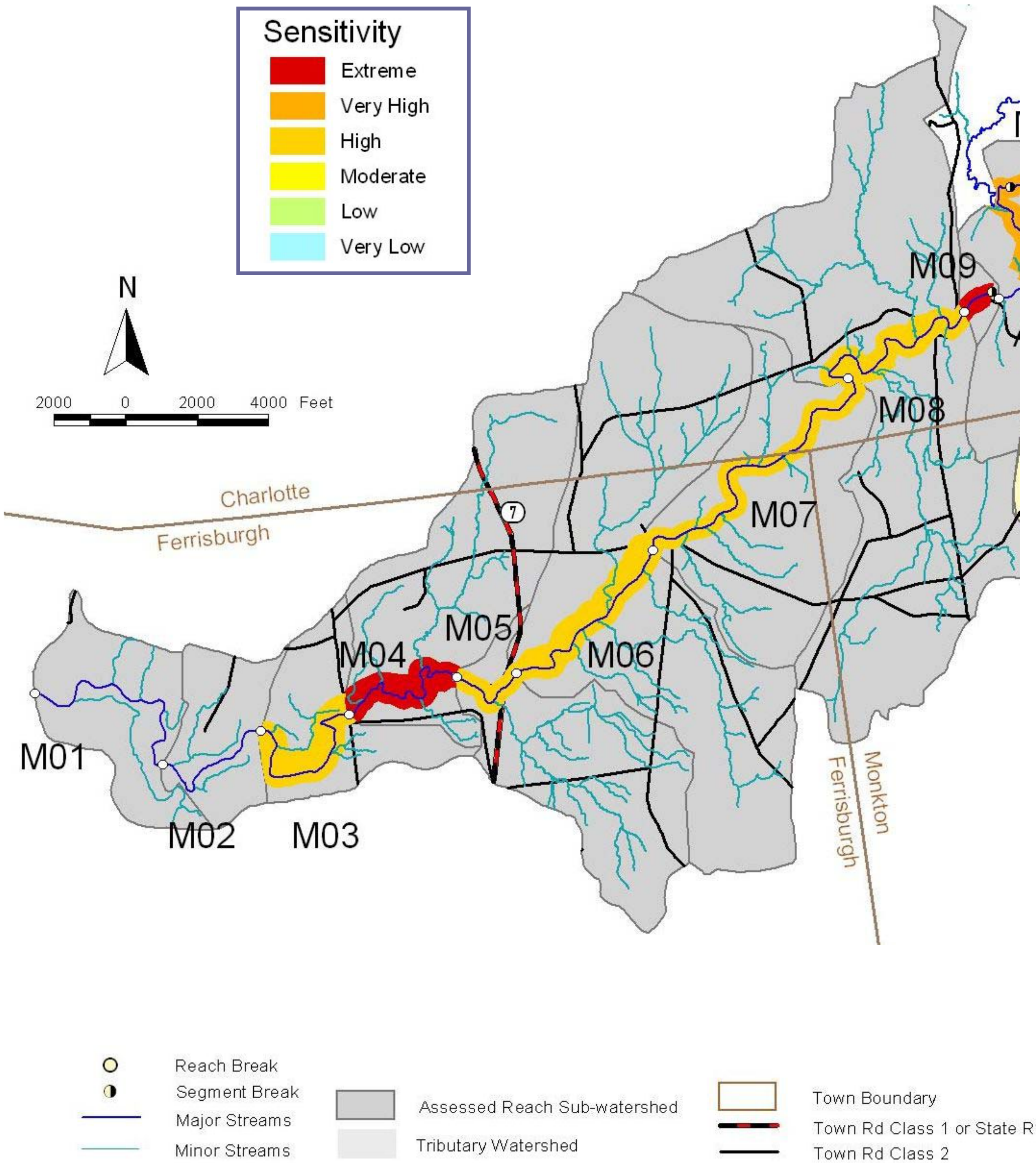


Figure 34. Stream Sensitivity Map
Assessed Reaches of the Lewis Creek lower main stem - west.

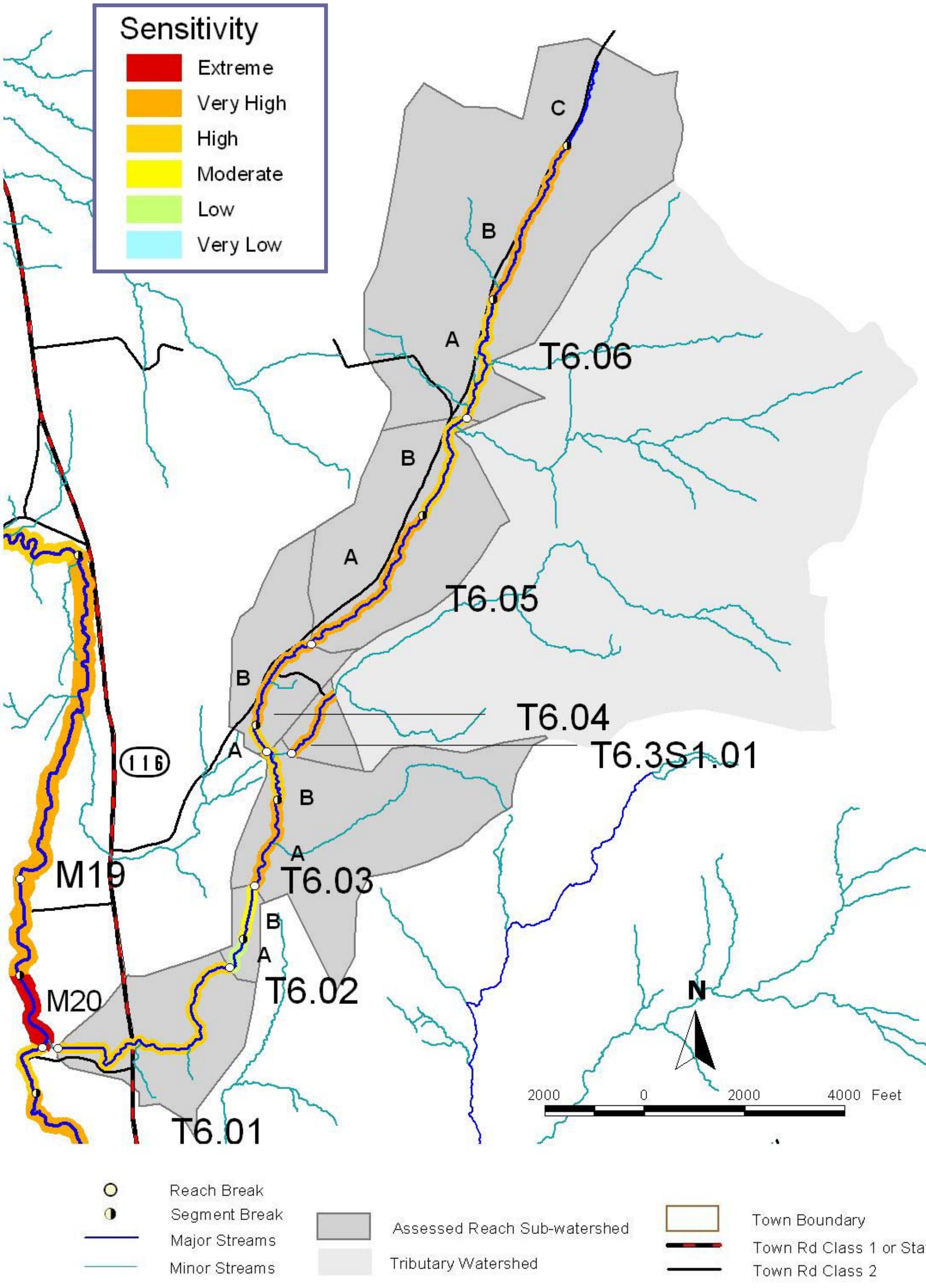


Figure 35. Stream Sensitivity Map
Assessed Reaches of the High Knob tributary.

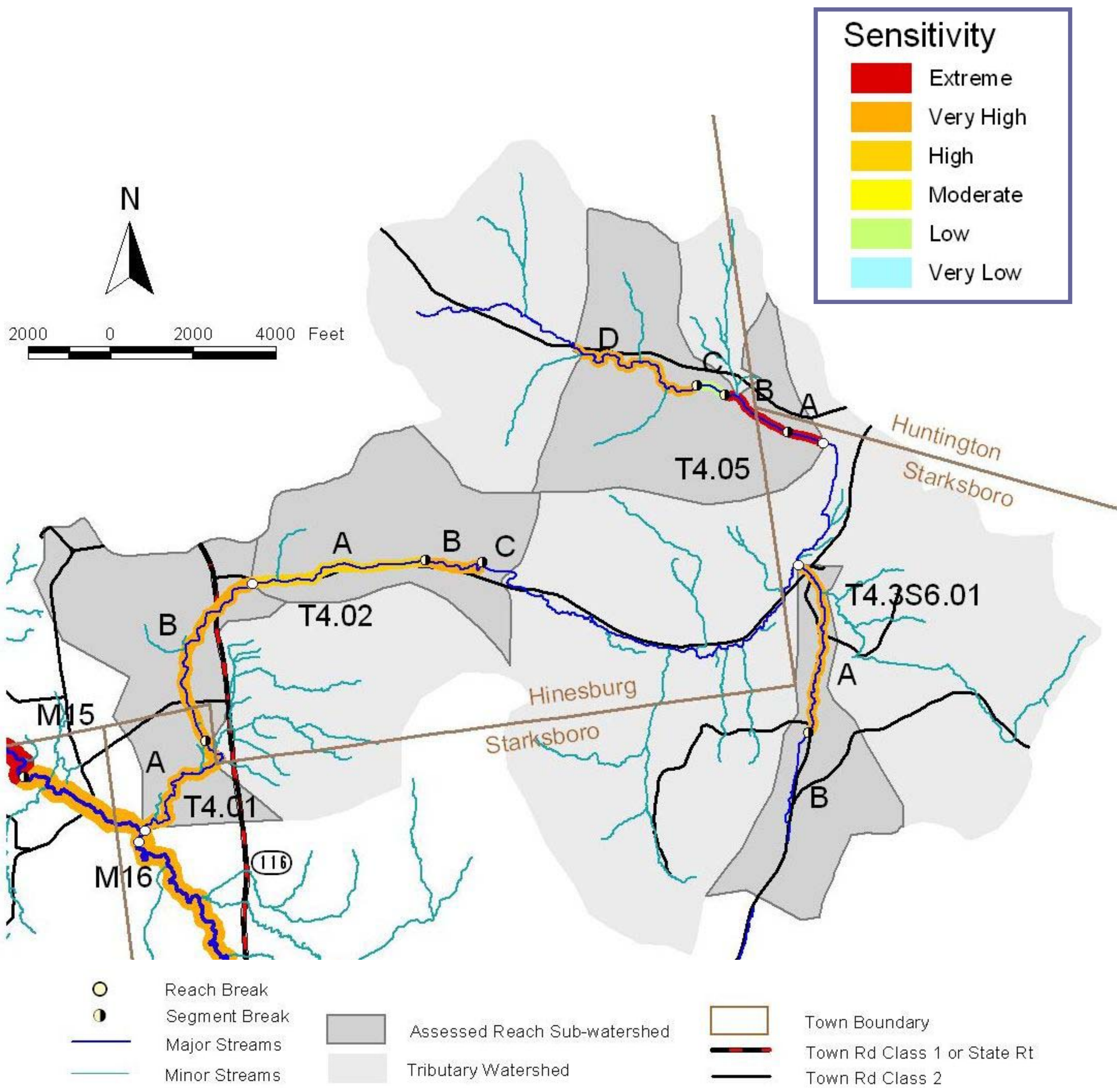


Figure 36. Stream Sensitivity Map
Assessed Reaches of the Hollow Brook tributary

6.0 PRELIMINARY PROJECT IDENTIFICATION (Reach & Corridor Scale)

Landowners, community members, and resource agencies, including Lewis Creek Association, Addison and Chittenden County Regional Planning Commissions, the Natural Resources Conservation Service, and Vermont Agency of Natural Resources, can use geomorphic data to inform future management strategies for the assessed reaches of the Lewis Creek and major tributaries. For a given reach or segment, the active adjustment processes, degree of departure from reference, and sensitivity ranking will define the short-term compatibility and long-term sustainability of various restoration or conservation options and future land use or channel management activities.

The preliminary identification and prioritization of corridor restoration and protection projects outlined below has been informed by:

- stream sensitivity data;
- qualitative observations of sediment transport and attenuation characteristics; and
- preliminary departure analysis contained in Section 5.

This provisional listing follows the outline of management actions identified in the *Step-Wise Procedure for Identifying Technically Feasible River Corridor Restoration and Protection Projects* included in VTANR guidance (2007b). The listed approaches can be classified under three broad management approaches:

> Active Geomorphic: Restore or manage rivers to a geomorphic state of dynamic equilibrium through an **active** approach that may include the removal or reduction of human-placed constraints or the construction of meanders, floodplains, and bank stabilization techniques. Active riparian buffer revegetation and long-term protection of a river corridor is essential to this alternative.
>
> Passive Geomorphic: Allow rivers to return to a state of dynamic equilibrium through a **passive** approach that involves the removal of constraints from a river corridor thereby allowing the river, utilizing its own energy and watershed inputs to re-establish its meanders, floodplains, and self maintaining equilibrium condition over an extended time period. Active riparian buffer revegetation and long-term protection of a river corridor is essential to this alternative.
>
> Active-Passive Combination: Use a sequenced combination of active and passive approaches to accommodate the varying constraints that typically occur along a project reach.
> *(VTANR, 2007b)*

Each category of restoration and conservation strategies identified in VTANR guidance (2007b) is discussed in Sections 6.1 through 6.8. An additional category (mitigating point sources of stormwater and sediment loading) is presented in Section 6.9. Section 6.10 identifies segments which are candidates for wetland restoration.

A few of these projects (e.g., buffer plantings) can be considered for immediate implementation, independent of other watershed projects, and will require only minimal feasibility analysis and project development activities. Other identified projects may require further evaluation and efforts to perform alternatives analyses, conduct landowner outreach and negotiations, and identify potential stakeholders and funding sources. The work scope for this Phase 2 assessment has included some public outreach and limited project development to determine the technical, financial and social feasibility of these listed project opportunities. Status of project development and outreach is summarized in Appendices J and K.

6.1 Protecting River Corridors

Protection of river corridors is an essential element to all passive and active geomorphic restoration and conservation projects. River corridor protection can support multiple objectives:

- Dynamic Equilibrium - Preserve (or support a return to) reference sinuosity, slope, and channel dimensions through active or passive geomorphic approaches.
- Floodplain Access – Preserve or restore a channel's access to its surrounding floodplain in bankfull and higher flow events through active or passive geomorphic approaches.
- Sediment Attenuation – Preserve, restore, or enhance the storage of sediments (from in-reach or upstream sources) within the channel margins, floodplain, and channel-contiguous wetlands.
- Flow Attenuation – Preserve, restore, or enhance the storage and detainment of flood flows through overbank flooding, increased channel length (sinuosity), increased channel roughness (e.g., buffers), and inundation of channel-contiguous wetlands.
- Avoidance – Refrain from developments and infrastructure in the corridor to minimize future fluvial erosion losses. This can be accomplished through conservation strategies or local planning and zoning strategies, such as fluvial erosion hazard overlay districts.

Under a passive geomorphic approach, the river channel is allowed to freely meander within the area defined as the belt-width-derived river corridor. Further channelization, dredging, berming and armoring are avoided. For a reach that is already close to reference condition or exhibiting only minor adjustments, preserving a river corridor will ensure the river's ability to continue to meander through the valley unconstrained by human infrastructure. In turn, human investments in the landscape will be protected from future channel adjustments. For a reach that has seen significant channel management in the past, and has lost some degree of floodplain connection and some measure of its sinuosity and balanced planform and profile, the channel is allowed to adjust unimpeded to a more sinuous, meandering planform closer to regime conditions. During ongoing adjustments, the river will re-establish greater floodplain access (where access has been lost) and adjust channel dimensions for optimum conveyance of its water and sediment loads. Restoring channel equilibrium will reduce instream production of sediment and nutrients and enhance sediment and nutrient attenuation over the long term.

Under an active geomorphic approach, protection of the river corridor will prevent future channel management that might unravel constructed features of a recently restored reach.

Lower priority reaches for river corridor protection include "wooded corridors experiencing very little threat from encroachment and less sensitive reaches not playing a significant flow or sediment load attenuation role in the watershed" (VTANR, 2007b). Of the assessed reaches, this category would include:

- The bedrock-controlled segments and gorges that are afforded stability by the surrounding bedrock (M18, M10-F, T6.02-A, T4.05-C, and T2.01); and
- The semi-confined, transport-dominated reaches with intact forested buffers which are showing minor adjustment (M21-A, M14, M12-B, M07, M05, T6.02-B, T4.05-B)

Highest priority reaches for river corridor protection include "highly sensitive reaches critical for flow and sediment attenuation from upstream sources or sensitive reaches where there is a major departure from equilibrium conditions and threats from encroachment (VTANR, 2007b)". Limited-term or permanent corridor easements are possible mechanisms for corridor protection, with the willingness of landowners. Protection of the river corridor in these reaches can serve the functions listed above. As summarized in Table 18, there are additional strategic factors that may raise the priority of corridor protection for a given reach, including:

- Locations Upstream of Constrained / Altered Reaches
  Reaches / segments which are constrained by the topographic setting (e.g., bedrock outcroppings) or by human infrastructure (e.g., berms, roads, development) are less able to adjust their dimensions, planform, and profile in response to excess sediment and water loads delivered from upstream. Corridor protection measures implemented upstream of these constrained / altered reaches will enhance sediment and flow attenuation, maintain or improve floodplain access and reduce streambank erosion over the long term. Sediment production and delivery and hydrologic stresses to the constrained / altered reach will be decreased given the flow and sediment attenuation achieved in the upstream protected corridor.

- Locations Downstream of Constrained / Altered Reaches
  Protection of segments downstream of constrained / altered reaches will help to offset the impacts of human encroachments in the disturbed reach which may have constrained the channel, reduced floodplain access, and converted a naturally deposition-dominated segment into a transport-dominated segment.

- Sediment attenuation areas
  Where increased attenuation functions are observed, and lateral adjustments can be tolerated given the adjacent land uses, such areas can be capitalized on as attenuation assets to offset the reduced floodplain access and sediment storage in upstream or downstream reaches that have been converted to a transport-dominated status. These sites are high-priority candidates for outreach and eventual conservation or protection with the willingness of landowners.

- Reaches with channel-contiguous wetlands
  Where wetlands and backwater areas are hydrologically connected to the channel, flow attenuation and suspended sediment (and nutrient) attenuation functions can be maximized.

- Reaches at alluvial fans or points of marked valley slope reduction that contribute to increased sediment aggradation and planform adjustment. Carefully manage land use changes in the upstream watershed to reduce the potential for increases in sediment or flows that may induce channel adjustments in the subject reach/segment.

- Reaches downstream of major sediment sources or tributary confluence bars that contribute to increased sediment aggradation and planform adjustment.

- Reaches where there is a major departure from equilibrium conditions – these are reaches where protection against fluvial erosion hazards (through local planning and zoning mechanisms) is especially critical as the channel is susceptible to sudden streambank erosion or avulsion in high flow events.

- Reaches Identified for Passive or Active Restoration – To support a channel where there is a moderate to major departure from equilibrium as it evolves to regain floodplain and natural meander patterns.

Table 18. River Corridor Protection opportunities
Lewis Creek main stem and tributary reaches

Reach / Segment	Town	Corridor Protection Priority	Protection Upstream of Constrained or Altered Reaches	Protection Downstream of Constrained or Altered Reaches	Key Sediment Attenuation Area	Channel-contiguous wetlands	Alluvial Fan or Point of Marked Valley Slope Reduction	Downstream from Major Tributary or Other Large Sediment Source	Moderate or Major Departure from Equilibrium	Accompany Passive or Active Restoration, Incised/Aggraded
Lewis Creek – upper main stem										
M23	Starksboro	Very High	√				√		√	
M22	Starksboro	**Exceptional**	√		√		√		√	√
M21-B	Starksboro	Very High		√	√	√			√	√
M21-A	Starksboro	Moderate							√	
M20-B	Starksboro	High	√					√	√	
M20-A	Starksboro	High	√					√	√	
M19-B	Starksboro	Very High			√	√			√	
M19-A	Starksboro	Very High		√	√	√				
M18	Starksboro	Low	Bedrock Channel							
M17-C	Starksboro	Very High		√			√		√	√
M17-B	Starksboro	Very High	√	√	√	√				
M17-A	Starksboro	High	√	√	√					
M16	Starksboro	Very High	√	√	√	√			√	√
M15-B	Monkton	Very High	√		√	√		√	√	
M15-A	Hinesburg	**Exceptional**	√	√	√	√		√	√	
M14	Hinesburg	Moderate								
Lewis Creek – lower main stem										
M13-B	Hinesburg	Moderate		√					√	
M13-A	Hinesburg	High		√		√			√	
M12-C	Hinesburg	Very High	√		√	√		√		
M12-B	Hinesburg	Moderate							√	
M12-A	Hinesburg	Very High	√	√	√	√				
M11	Hinesburg	Very High	√	√		√		√	√	
M10-F	Charlotte	Low	Bedrock Channel							
M10-E	Charlotte	Moderate							√	√
M10-D	Charlotte	High	√	√		√			√	
M10-C	Charlotte	Moderate							√	
M10-B	Charlotte	High	√	√		√		√	√	
M10-A	Charlotte	Moderate	Scott Pond Dam impoundment							
M09-B	Charlotte	Low	Scott Pond Dam impoundment							
M09-A	Charlotte	Low							√	
M08	Charlotte	**Exceptional**	√	√	√	√				√
M07	Ferrisburgh	Moderate								
M06	Ferrisburgh	**Exceptional**	√	√	√	√			√	√
M05	Ferrisburgh	Low							√	
M04	Ferrisburgh	Very High		√	√	√				
M03	Ferrisburgh	High			√	√				

Reach / Segment	Town	Corridor Protection Priority	Protection Upstream of Constrained or Altered Reaches	Protection Downstream of Constrained or Altered Reaches	Key Sediment Attenuation Area	Channel-contiguous wetlands	Alluvial Fan or Point of Marked Valley Slope Reduction	Downstream from Major Tributary or Other Large Sediment Source	Moderate or Major Departure from Equilibrium	Accompany Passive or Active Restoration, Incised/Aggraded
High Knob tributary										
T6.06-C	Starksboro	Moderate				√				
T6.06-B	Starksboro	High				√			√	
T6.06-A	Starksboro	Very High	√			√				
T6.05-B	Starksboro	Very High			√	√				
T6.05-A	Starksboro	High							√	
T6.04-B	Starksboro	High							√	
T6.04-A	Starksboro	Very High	√		√					
T6.03-B	Starksboro	Very High	√		√					
T6.03-A	Starksboro	High	√						√	
T6.02-B	Starksboro	High	√							
T6.02-A	Starksboro	Low	Bedrock Channel							
T6.01	Starksboro	Very High					√			
T6.3S1.01	Starksboro	Very High					√		√	
Hollow Brook tributary										
T4.05-D	Hinesburg	High	√				√		√	
T4.05-C	Hinesburg	Low	Bedrock Channel							
T4.05-B	Starksboro	Low							√	
T4.05-A	Starksboro	Very High					√		√	
T4.02-C	Hinesburg	Moderate	√			√				
T4.02-B	Hinesburg	Low							√	
T4.02-A	Hinesburg	Low							√	
T4.01-B	Hinesburg	Very High		√	√		√		√	
T4.01-A	Starksboro	Very High		√	√	√				√
T4.3S6.01	Starksboro	Low		√						
Pond Brook tributary										
T3.01-C	Monkton	High	√		√	√				
T3.01-B	Monkton	Very High					√		√	√
T3.01-A	Hinesburg	Very High		√	√	√		√		
Cedar Brook tributary										
T2.01	Hinesburg	Low				√				

6.2 Planting Stream Buffers

Forested riparian buffers improve water quality and contribute to greater flow and sediment attenuation in the floodplain. They will also help to restore and maintain dynamic equilibrium of the channel by increasing boundary resistance to shear stresses along the channel margins. Tree buffers will provide the additional benefits of organic matter, detritus, and LWD recruitment for aquatic and riparian habitats, as well as increased shading to reduce river temperatures. Connectivity of buffer areas from reach to reach along a river network also supports mammalian terrestrial habitats by providing wildlife corridors.

Tree buffers are intact along both banks of some of the assessed reaches. It is a very important to maintain buffers in these reaches, not only for streambank stability, but also for the shading and organic matter that the tree canopy provides to aquatic organisms. In other reaches through the village areas, buffers are largely absent, but buildings, roads and parking lots have encroached upon the channel, reducing the feasibility (and therefore the priority) of buffer treatments.

Low-priority segments for planting buffers are those segments which have departed from equilibrium to a moderate to severe degree, since ongoing adjustments will likely undermine the newly-planted trees / shrubs. This condition applies to a majority of the study reaches (such as at points of reduced valley slope [M17-C] or in segments that are located downstream of major sediment sources [M15-B]). In these cases, larger trees could be planted at the corridor limits to mark the outside area of the protected corridor.

High-priority opportunities to increase buffer widths and continuity are located along the following reaches which are closer to equilibrium condition and have good or reasonable floodplain access:

- upper main stem (M21-A; M19-B and –A; M17-B, -A; M15-A);
- lower main stem (M08, M04, and M03);
- High Knob Brook (T6.06-B and –A, T6.03-A);
- Hollow Brook (sections of T4.01-B and T4.01-A; T4.3S6.01); and
- Pond Brook (segment T3.01-B).

It will take some time for trees to establish, and sediment loading from eroding banks will continue in the short term until the vegetation matures and takes hold. However, as long as floodplain connection is maintained, suspended sediments can be attenuated in the corridor floodplain. Corridor protection efforts (Section 6.1) will ensure that no infrastructure continues to be at risk from the laterally adjusting channel. In the short term, coarse sediment from these stabilizing banks may serve a useful purpose in the re-establishment of the incipient floodplains in downstream segments that are more disconnected from their floodplain.

Associated with buffer restoration in select watershed reaches is the exclusion of livestock to reduce channel trampling (and nutrient / *E.coli* inputs) and allow trees and other native species to re-vegetate the channel margins. Opportunities for livestock exclusion in the Lewis Creek watershed include the following assessed reaches / segments (all high priority):

Table 19. Livestock Exclusion Opportunities on assessed reaches of the Lewis Creek main stem and tributaries.

Reach / Segment	Town
M22 (downstream of Meadowlark Lane)	Starksboro
M17-A	Starksboro
M16 *	Starksboro
M02	Ferrisburgh
M01	Ferrisburgh
T6.06-B	Starksboro
T4.3S6.01	Starksboro
T3.01-B	Monkton

** Note: cattle excluded in 2007.*

6.3 Stabilizing Stream Banks

Streambank stabilization can be considered in "laterally-unstable, [but vertically stable] reaches where human-placed structures are at high risk and not taking action may result in increased risk of erosion, to not only the structure, but lands that would provide the opportunity to establish a buffer" (VTANR, 2007b). Any bank stabilization project should be considered in the broader context (both in time and space) for the channel adjustment processes such management will set in motion and for the consequences to upstream and downstream reaches. Generally speaking, the Lewis Creek assessed reaches are located in rural settings with limited encroachments, where it is important to allow lateral adjustments to proceed unconstrained in order to support passive channel restoration and a return toward dynamic equilibrium.

Only two potential stabilization projects have been prioritized along the assessed reaches at this time, based on the *Step-Wise Procedure for Identifying Technically Feasible River Corridor Restoration and Protection Projects* (VTANR, 2007b). At both sites, the landowner has already undertaken streambank stabilization; therefore, these are considered low priority projects.

Table 20. Potential Streambank Stabilization Sites on assessed reaches of the Lewis Creek main stem and tributaries

Reach/ Seg	**M15-A**
Location	Right bank near downstream end of segment, Monkton parcel 12-01-38.000 (see Appendix B for location and further description).
Rationale	Protect residential buildings within 50 feet of the laterally adjusting channel.
Description	Install toe armoring, and bioengineering over the top of bank.
Priority	**Low**. The landowner initiated streambank stabilization in 2006 separate from this corridor planning project. Additional efforts could include re-establishment of woody buffer – with landowner willingness.
Other Considerations	Accompanied by corridor protection (see Section 6.1); accompanied by reduction of sediment loading in the upstream watershed (Section 6.9). See also Appendix K.

Reach/ Seg	**T4.01-A**
Location	Right bank near mid-point of segment, Starksboro parcel B254S (157 Tyler Bridge Rd).
Rationale	Protect residential buildings within 50 feet of the laterally adjusting channel.
Description	Install toe armoring, and bioengineering over the top of bank.
Priority	**Low**. The landowner initiated streambank stabilization prior to 2002 separate from this corridor planning project. Additional efforts could include re-establishment of woody buffer – with landowner willingness.
Other Considerations	Accompanied by corridor protection (see Section 6.1); accompanied by reduction of sediment loading in the upstream watershed (Section 6.9)

Additional structures are located within close proximity of the channel along other assessed reaches of the Lewis Creek watershed and may or may not be at risk of erosion hazards depending on their setting relative to the channel, the adjustment conditions of the channel, and the presence of mitigating factors (such as, protective exposures of bedrock).

It is important to note that river corridor restoration and protection projects have been identified in the context of supporting the natural adjustment processes of the river toward long-term equilibrium (or quasi-equilibrium) conditions following the *Step-Wise Procedure for Identifying Technically Feasible River*

Corridor Restoration and Protection Projects (VTANR, 2007b). Projects have been identified and prioritized to assist in the allocation of limited funding and technical resources (e.g. Clean & Clear program) to long-term, sustainable restoration of the Lewis Creek river network. This study has not been carried out explicitly to identify protection measures for structures at risk of fluvial erosion losses.

6.4 Arresting Head Cuts and Nick Points

No head cut sites or sections of actively incising channel were noted in the reaches of the Lewis Creek watershed assessed in years 2001 through 2009.

6.5 Removing Berms / Other Constraints to Flood & Sediment Load Attenuation

Removing berms or other constraints to the full meander expression and floodplain connection of a river channel may accelerate a return to dynamic equilibrium in the channel, and reduce impacts to downstream segments, by creating more opportunities for sediment and flow attenuation along the corridor. Further study is necessary to evaluate the feasibility of various active geomorphic and engineering techniques to remove constraints. The benefits of such projects need to be evaluated in light of the costs and potential short-term consequences in terms of sediment and nutrient mobilization, and risk to infrastructure and public safety.

While berms were noted along portions of one or both banks of several study reaches, berm removal was considered a low priority in most cases (following VTANR guidance) due to the fact that:

- the channel was already incised below the floodplain (IR_{RAF} 1.5 to 2.0) such that berm removal alone would not result in greater floodplain access – (e.g., M23, T4.01-B downstream of Rt 116 crossing);
- the noted berm(s) was coincident with a high bank or terrace, and removal of the berm would not appreciably increase the meander belt width area available to the channel (e.g., berm segments in M22 downstream of Rt 116 crossing);
- residential, commercial, or municipal infrastructure was present close to the channel and would be placed at greater risk of flooding if the berm were removed (e.g., T4.05-A at Lazy Brook mobile home park; M18 and M17-C at the base of the States Prison Hollow gorge);
- the noted berm(s) was very short in length (e.g., T4.01-B upstream of Rt 116 crossing) and/or was associated with nearby valley fill for a bridge crossing that was likely to be maintained (e.g., T4.01-B downstream of Tyler Bridge Rd crossing; LB berm section upstream of Meadowlark Lane crossing in M22); and/or
- the noted berm(s) had well-established mature tree or shrub buffers which – if removed – would degrade habitats or result in significant disruption of the corridor lands (e.g. T4.01-B upstream of Rt 116 crossing).

Four potential berm removal sites were identified and ranked from Very High to Low (Table 21). Two of the sites (M08, M22) are the subject of further project development activities documented in Appendix K.

Table 21. Potential Berm Removal / Floodplain Reconnection Sites on assessed reaches of the Lewis Creek main stem and tributaries

Reach/ Seg	**M08**
Location	Right bank along Spear Street at upstream end of reach on approach to Quinlan Covered Bridge, town of Charlotte.
Rationale	Restore floodplain access and remove constraints to full meander expression for increased flow and sediment load attenuation. Reconnect channel to riparian wetlands. Reduce frequency of and impacts from repeated ice jam flooding that threaten the integrity of the bridge abutments, and subject adjacent properties to inundation flooding and fluvial erosion hazards.
Description	Conduct a hydrologic/ hydraulic study & alternatives analysis that considers berm removal along with additional alternatives including road lowering, reconnection to upstream wetlands in a historically incised segment, and re-orientation of bridge abutments.
Priority	**Very High**. (Human structures [house, Quinlan Covered bridge, road segments] would be at reduced risk of inundation flooding and erosion hazards if the berm segments are removed. A large area of historic floodplain to the northeast of Spear Street could become accessible to the river if the berm was removed (and the road lowered).
Other Considerations	Accompanied by corridor protection (see Section 6.1); accompanied by reduction of sediment loading in the upstream watershed (Section 6.9). Consider attendant restoration of incised reach condition (Section 6.7). Impacts to road condition, public safety, and costs must also be weighed.

Reach/ Seg	**M22**
Location	Berm segments primarily along LB upstream and downstream of Hillsboro Road crossing that are protecting corn / alfalfa fields.
Rationale	Restore floodplain access and remove constraints to full meander expression for increased flow and sediment load attenuation at this regional transition point of reduced gradient and reduced valley confinement (decreased sediment transport capacity, or "alluvial fan" setting).
Description	Evaluate the feasibility of active geomorphic measures (e.g., lowering elevation of near-bank areas) where berms/armoring presently constrain the channel and limit floodplain access.
Priority	**Moderate to Low**. The channel is partly incised below the floodplain beyond the berm. The channel is already breaking out in sections eroding into the adjacent fields. Corridor protection could support this natural process rather than expending resources to actively lower the floodplain. On the other hand, removal of the berm would reduce the volume of sediment liberated to downstream segments by the naturally adjusting channel.
Other Considerations	Accompanied by corridor protection (see Section 6.1); accompanied by reduction of sediment loading in the upstream watershed (Section 6.9).

Reach/ Seg	**M17-C**	**M10-E**
Location	Right bank, downstream of States Prison Hollow Road Extension; Starksboro parcel C131W	Left bank, downstream of Seguin Bridge, along Roscoe Road, associated with revetments and Jersey barriers.
Rationale	Restore floodplain access and remove constraints to full meander expression for increased flow and sediment load attenuation	
Description	Evaluate the feasibility of active geomorphic measures (e.g., lowering elevation of near-bank areas) where berms/armoring presently constrain the channel and limit floodplain access.	
Priority	**Low.** Berm-removal segments are short. Thus, cost/benefit ratio of active floodplain restoration would be relatively high. Greater opportunities for floodplain access and sediment/flow attenuation are present nearby – especially downstream in segment M17-B.	
Other	Accompanied by restoration of incised condition (see Section 5.7); accompanied by	

Considerations	corridor protection (see Section 5.1). Feasibility partly a function of whether adjacent agricultural uses could be set back (both segments). Feasibility of M10-E bermed section potentially limited by presence of Roscoe Rd (unless road could be moved or designed to overtop occasionally).

6.6 Removing / Replacing Structures

Human-placed structures which span and "constrain the vertical and lateral movement of the channel and/or result in a significant constriction of the floodplain" can be considered for removal or replacement to support dynamic equilibrium of the channel (VTANR, 2007b)". In the study reaches, constraining structures included bridges and culverts (Section 6.6.1), old abutments (Section 6.6.2), and dams (Section 6.6.3).

6.6.1 Bridge and Culvert Crossings

A total of 51 bridge and culvert crossings were encountered on the assessed reaches: 32 bridges and 19 instream culverts. All the culverts were located on tributary reaches. Forty-one structures (including 17 culverts) supported road or driveway crossings. Nine structures (including 2 culverts) supported farm road or trail (e.g., snowmobile) crossings. One bridge supported a railroad crossing.

The status of each bridge and culvert as either a bankfull or flood-prone-width constrictor is summarized in Step 4.8 of the Phase 2 reach reports (Appendix C) and in Tables 22-a and 22-b (next pages). Thirty-four of the 51 crossings were bankfull-constricting structures. Ten out of the 24 structures on the Lewis Creek main stem (42%) were bankfull constrictors, while 24 out of 27 structures on the assessed tributary reaches (89%) were bankfull constrictors. These structures are displayed in map view on Figure 37.

Table 22 presents a replacement / retrofit priority for each of the bridges and culverts. Priority is suggested without regard to technical feasibility, social feasibility, or cost; rather the priority is based generally on the geomorphic and habitat condition of the given reach or segment, and its relationship to (and potential impact on) the crossing structure. These structures are listed as priorities for replacement: (1) since the span of these structures is less than 50% of the reference (or measured) bankfull channel width; and/or (2) due to conditions that suggest localized channel instability that has the potential to impact the stability of the crossing structure itself (e.g., sharp approach angle, scour undermining the abutments, sediment obstructing the inlet, scour pool developing at the outlet); and/or (3) due to conditions (e.g., perched culvert) impacting fish passage and continuity of aquatic habitats.

Only one of the main stem bridges is identified as a Very High priority for replacement: a wooden bridge in disrepair on Segment M17-B in Starksboro. Further details of this project are summarized in Appendix K. A majority of the tributary crossing structures are considered a High or Very High priority for replacement or retrofit given their bankfull constricting status. Some of these (e.g., T4.05-D driveway bridge and driveway culvert) are discussed in the context of dam evaluations (Section 6.3.3; see notes in Table 22-b). One instream culvert (Segment T3.01-B) is addressed in the context of a potential channel/ floodplain / wetland restoration project (Sections 6.7, 6.10). For six of the Very High priority structures, additional details (including location maps and photographs) are provided in Appendix L.

Table 22-a. Priority of Bridge & Culvert Structure Replacements, Assessed Lewis Creek main stem reaches

Stream	Reach/ Segment	Town	Road	Structure Type	Constriction Status *	Other Issues	Priority
Lewis Creek main stem	M23	Starksboro	driveway	Bridge	89%		Low
	M22	Starksboro	Hillsboro Rd	Bridge	103%		Low
	M22	Starksboro	VT Route 116	Bridge	84%	Sharp approach/exit angles.	Moderate
	M22	Starksboro	Meadowlark Lane	Bridge	72%	Scour upstream / downstream. Site of past debris jams.	Moderate
	M21-A	Starksboro	Tatro Rd	Bridge	96%	Direct road sediment inputs	Moderate
	M20-A	Starksboro	Parsonage Rd	Bridge	82%		Moderate
	M19-B	Starksboro	farm road	Bridge	148%		Low
	M19-B	Starksboro	farm road	Bridge	117%	Low clearance; site of debris jams.	Moderate
	M18	Starksboro	States Prison Hollow Rd	Bridge	150%		Low
	M18	Starksboro	footbridge	Bridge	120%		Low
	M17-C	Starksboro	States Prison Hollow Rd Ext	Bridge	148%		Low
	M17-B	Starksboro	farm road	Bridge	53%	Bridge in disrepair; low clearance; abutments undermined and outflanked.	Very High (See App. K)
	M17-A	Starksboro	farm road	Bridge	70%		High
	M15-B	Monkton	Tyler Bridge Rd	Bridge	108%		Low
	M14	Hinesburg	Turkey Lane	Bridge	79%	Direct road sediment inputs	Moderate
	M13-B	Hinesburg	Silver Street	Bridge	149%		Low
	M12-B	Hinesburg	Baldwin Rd	Bridge	110%	Streambank erosion downstream	Moderate
	M10-F	Charlotte	Roscoe Rd	Bridge	110%	Seguin covered bridge	Low
	M08	Charlotte	Monkton Rd	Bridge	92%	Quinlan covered bridge; history of ice jam flooding.	High
	M07	Ferrisburg	Old Hollow Rd	Bridge	97%		Low
	M05	Ferrisburg	VT Route 7	Bridge	FPW		Very Low
	M03	Ferrisburg	Greenbush Rd	Bridge	142%		Low
	M03	Ferrisburg	Railroad	Bridge	107%		Low
	M02	Ferrisburg	farm road	Bridge	68%	Relatively low scour velocities in this reach which is affected by backwater from Lake Champlain.	Moderate

** Constriction status is calculated as structure span divided by bankfull width, expressed as a percent.*

Table 22-b. Priority of Bridge & Culvert Structure Replacements, Assessed Lewis Creek tributary reaches

Stream	Reach/ Segment	Town	Road	Structure Type	Constriction Status *	Other Issues	Priority	App. L page
High Knob Brook	T6.06-C	Starksboro	driveway	Culvert	17%		Very High	**L-1**
	T6.06-B	Starksboro	path	Culvert	39%		Very High	**L-2**
	T6.06-A	Starksboro	Big Hollow Rd	Culvert	45%	Consider restoring channel planform to east of Big Hollow Road (MMI, 2008).	High	
	T6.06-A	Starksboro	Big Hollow Rd	Culvert	50%		High	
	T6.05-B	Starksboro	Stokes Hill Rd	Culvert	50%		High	
	T6.04-B	Starksboro	driveway	Bridge	63%		High	
	T6.04-B	Starksboro	Brown Hill Rd	Culvert	51%		High	
	T6.01	Starksboro	Freedom Acres Rd	Culvert	44%	Substantial upstream aggradation. Multiple culverts side-by-side.	Very High	**L-3**
	T6.01	Starksboro	VT Route 116	Culvert	24%	No Aquatic Organism Passage; mostly incompatible geomorphically (MMI, 2008)	Very High	**L-4**
	T6.3S1.01	Starksboro	driveway	Bridge	160%		Low	
Hollow Brook	T4.05-D	Hinesburg	Lincoln Hill Rd	Culvert	21%	Repeated washouts; sediment inputs to stream.	Very High	**L-5**
	T4.05-D	Hinesburg	driveway	Culvert	26%	Sharp approach/exit angles.	Very High	**L-6**
	T4.05-D	Hinesburg	driveway	Bridge	41%	Coincident with dam / pond. **See Figure 18, p. 49 & Section 6.3.3**	Very High	
	T4.05-D	Hinesburg	driveway	Culvert	10%	Coincident with dam. **See Figure 19, p. 49 & Section 6.3.3**	Very High	
	T4.02-B	Hinesburg	driveway	Culvert	52%	Multiple culverts side-by-side; repeated washouts; sediment inputs to stream.	High	**L-7**
	T4.02-A	Hinesburg	Hollow Rd	Bridge	139%	Sharp approach/exit angles.	Moderate	
	T4.01-B	Hinesburg	VT Route 116	Bridge	145%		Low	
	T4.01-B	Hinesburg	Tyler Bridge Rd	Bridge	76%	Stepped footers; upstream aggradation.	High	
	T4.01-B	Starksboro	driveway	Bridge	40%		Very High	
	T4.3S6.01-A	Starksboro	Big Hollow Rd	Culvert	16%	Direct road sediment inputs	Very High	
	T4.3S6.01-A	Starksboro	driveway	Culvert	BFL		Very High	
	T4.3S6.01-A	Starksboro	driveway	Culvert	BFL		Very High	
	T4.3S6.01-A	Starksboro	Ruby Brace Rd	Culvert	21%		Very High	
	T4.3S6.01-A	Starksboro	Hollow Rd	Culvert	32%		Very High	
Pond Brook	T3.01-C	Monkton	VAST trail	Bridge	56%	Bridge in disrepair; low clearance	High	
	T3.01-C	Monkton	Silver St	Culvert	38%	Sharp approach/exit angles.	Very High	**L-8**
	T3.01-B	Monkton	farm road	Culvert	16%	Scour upstream / downstream. In connection w/ possible channel/floodplain/wetland restoration (**see Sections 6.7 & 6.10**)	Very High	

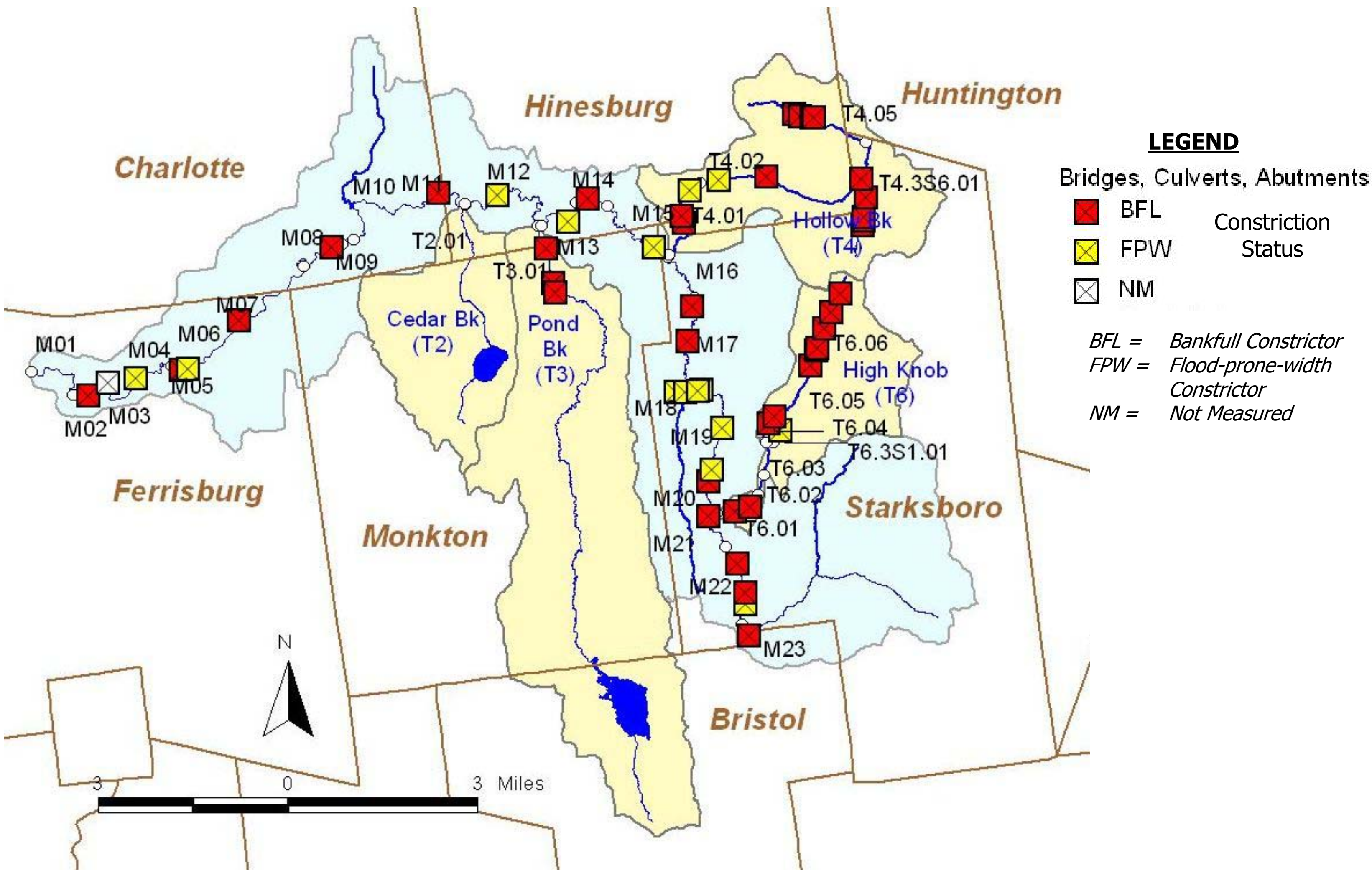


Figure 37. Constriction status of crossing structures located on assessed reaches of the Lewis Creek main stem and tributaries.

6.6.2 Old Abutments

Table 23 provides a listing of the old bridge abutments encountered on the study reaches and summarizes their priority for removal. One of the abutment sites (segment M17-C) is ranked as a high priority due to its regional setting at a point of marked reduction in gradient and valley confinement – where this structure would tend to be in conflict with a laterally adjusting channel. Due to the sensitivity of this setting, abutment removal is recommended as a high priority despite a span which does not constrict the bankfull flow, only larger flows. The second abutment site (M05) is a Low priority despite a bankfull-constricting span, given that bedrock is exposed in the channel at the abutment site and offers channel stability.

Table 23. Old abutment candidates for removal in the assessed reaches of Lewis Creek and major tributaries

Stream	Reach / Segment	Location	Constriction Status *	Issues / Considerations	Priority
Lewis Creek main stem	M17-C	Old bridge abutments for former States Prison Hollow Rd alignment; Upstream end of segment. Starksboro	134%	This abutment is positioned in the transition zone from steep bedrock gorge (upstream) to broad alluvial valley (downstream) – in area prone to sediment deposition & lateral adjustments.	High (due to setting). Moderate (due to Constriction status – FPW only).
	M05	Old bridge abutments for former Route 7 alignment. Ferrisburgh	74%	Channel-spanning bedrock upstream and downstream of this former crossing – offers stability to the channel.	Low

**Note: Constriction status is calculated as structure span divided by bankfull width, expressed as a percent.*

6.6.3 Dams

Table 24 provides a listing of the four dam sites encountered on the study reaches and summarizes their priority for removal. Further details of these dams are provided in a previous section (5.1.1, pp 46-51).

Table 24 Dam Site candidates for removal on assessed reaches of the Lewis Creek and major tributaries

Stream	Reach / Segment	Description /Location	Issues / Considerations	Priority
Lewis Creek main stem	M09-B	Scott Pond Dam, off Lewis Creek Road, Charlotte	Maintained for lamprey control. Operates as run-of-river structure. Engineered by VT Facilities Engineering Division and regularly inspected.	Very Low
High Knob Brook	T6.06-B	3052 Big Hollow Rd, Starksboro Earthen dam with outflow pipe and upstream irrigation pond.	Maintained as irrigation for livestock. Unknown engineering design.	Moderate
Hollow Brook	T4.05-D	2538 Lincoln Hill Rd, Hinesburg Concrete dam/bridge, small upstream impoundment next to residence.	Driveway access to other residences passes over dam. Concrete apron is perched above downstream channel (aquatic organism passage issue). Unknown engineering design and inspection frequency.	High *(pending landowner outreach and structure evaluation)*
Hollow Bk	T4.05-D	2572 Lincoln Hill Rd, Hinesburg Concrete bridge / dam founded on bedrock with embedded instream culvert; steel trap door on culvert inlet.	Driveway access to one residence passes over the dam. Culvert is severely constricting. Potential dam failure hazard. Aquatic organism passage issue. Sediment continuity issue. Unknown engineering design and inspection frequency.	High *(pending landowner outreach and structure evaluation)*

6.7 Restoring Incised Reaches

Further study can evaluate the feasibility of various active geomorphic and engineering techniques to restore historically-incised reaches, accelerate a return to dynamic equilibrium of the channel, and reduce impacts to downstream segments, by creating more opportunities for sediment and flow attenuation along the corridor.

A majority of the study reaches are historically incised and many have undergone a vertical stream type departure, losing access to the surrounding floodplain. Generally, historic incision is inferred to have been caused (in part) by a history of channelization/ berming/ armoring, as well as historical operation of dams and deforestation / reforestation cycles. Historic flood events likely also contributed to incision in select locations. In a few locations, development and encroachments (roads) have contributed to the incised and entrenched status of river reaches (e.g., Route 116 realignment at M22, Roscoe Rd in M10, Lewis Creek Rd in M09, Spear Street along M08, and North Ferrisburgh village (M07/M06), and Hollow Road along T4.02). None of the study reaches/segments was noted as having undergone active or recently-occurring incision.

Generally, ***active*** restoration of incised reaches in the study area is considered a very low priority for the following reasons:

- Intractable constraints of infrastructure (roads, dams or bridge / culvert crossings) (e.g., portions of M22, M10-E, M09-A, T4.02-A) that limits the full expression of meanders and floodplain access and would reduce the technical feasibility or effectiveness of active restoration;

- High density of residential, commercial, municipal, development and related encroachments that will likely require ongoing management of the entrenched and transport-dominated condition of the channel through developed areas (e.g., T4.05-A at Lazy Brook mobile home park, Huntington; M07 / M06 at North Ferrisburgh village; T4.02-B along Hinesburg Hollow Rd);

- Detrimental impacts to in-stream and riparian habitats, since lowering of the river-bank elevation adjacent to the channel to increase the degree of floodplain connection and flow and sediment attenuation would involve removal of mature or regenerating vegetated buffers (e.g., M21-A, M20-B, M20-A, M15-B, M13-B, M12-B, M10-E, M10-D, M10-C, M05, T6.04-B, T6.3S1.01, T4.05-D, T4.05-B, T4.02-B, T4.02-A, T4.01-B upstream of Tyler Bridge Rd); and

- Limited area of floodplain access gained by reconnecting the channel to the floodplain (e.g., M20-B, M20-A, M15-B, M13-B, M12-B, M11, M10-E, M10-D, M10-C, M09-A, M05, T4.02-B, T4.02-A).

Instead, ***passive*** restoration through corridor protection is recommended as a High, Very High or Exceptional priority for incised reaches in relatively undeveloped sections of the study area (see Section 6.1, Table 18) to support meander redevelopment and floodplain building. Naturally-enhanced attenuation at transition points of reduced valley gradient and/or confinement (in some locations, enhanced by natural LWD recruitment and/or beaver activity) will accomplish channel restoration within reasonable timeframes at much lower cost and higher success rates, if the corridor is protected and society refrains from further channel management (e.g., M23, M22, M17-C, M06, T6.01, T6.3S1.01, T4.05-A, T4.01-B). A Very High to Exceptional priority is also assigned to reaches located downstream or immediately upstream of constrained / channelized reaches.

A few possibilities for active restoration do exist along appropriate sections of the Lewis Creek and tributaries (listed below along with their recommended priority and rationale). At present, development is relatively minor along these segments. It would be technically feasible to lower the elevation of one or both banks along these sections in order to reconnect the incised channel with the floodplain and provide for increased flow and sediment (and nutrient) attenuation. Tree buffers along the bank(s) are largely absent. Therefore, impacts to instream habitat (through reduced shading, organic inputs) would be relatively negligible, and habitats could be improved through the establishment of native buffer plantings. Habitats may be further improved through increased meander development (and pool/riffle diversity) that would be expected to follow from improved floodplain connection. Improved flow and sediment attenuation in these segments would be particularly strategic both downstream and upstream of established encroachments where the channel is much more constrained.

Table 25. Potential Candidates for Active Restoration of Historically Incised Reaches of the Lewis Creek and tributary reaches.

Stream	Reach / Segment	Location	Description	Issues / Considerations	Priority
Lewis Creek main stem	M22	Upstream of Rt 116	Channel has lost FP connection through historic channelization, berming, and armoring through agricultural fields.	Coincident with berm removal (Section 6.5)	Low
	M21-B	Upstream of Tatro Road bridge	Channel has lost FP connection through limited historic channelization along RB agricultural fields.	Channel is building floodplain which can be supported more cost effectively through passive measures.	Low
	M19-B	Upstream of Starksboro Ballfields	Channel has lost some FP connection through historic channelization (former ag use)	Channel is building floodplain, which could be accelerated through introduction of LWD. *9/2009 application to Clean & Clear (with USFW matching funds) was not funded.*	**Moderate** *(pending hydraulic analysis)*
	M17-C	Right bank, downstream of States Prison Hollow Road Extension;	Relatively small area of floodplain would be gained but at a critical location at a point of notable reduced gradient and valley confinement near the base of the States Prison Hollow gorge.	Coincident with berm removal (Section 6.5). Presence of homes limits feasibility of restored floodplain upstream, closer to the base of the gorge.	Low
	M08	Upstream end in vicinity of Quinlan Covered Bridge	Limited gain of floodplain along LB upstream of bedrock outcroppings; but substantial possible gain of floodplain along RB just above Quinlan Bridge if combined with berm removal and/or road lowering.	Pair with berm removal (Section 6.5). Potential to help mitigate significant and frequent ice jam flooding that threatens the integrity of the bridge abutments, and subjects adjacent properties and Spear Street to inundation flooding and fluvial erosion hazards.	**Moderate** *(pending hydraulic analysis)*
	M06	Downstream of North Ferrisburgh village	Channel has lost FP connection through limited historic channelization, upstream impoundment effects; previously farmed fields are now fallow.	Channel is building floodplain which can be supported more cost effectively through passive measures.	Low
Hollow Brook	T4.01-A	Downstream of Tyler Bridge Rd	Could restore FP access immediately upstream of functioning channel-contiguous wetlands. Driveway crossing limits feasibility.	Pair with berm removal (Section 6.5) and wetland restoration.	Low
Pond Brook	T3.01-B	Channelized pasture lands	Restore meandering profile.	Combine with wetland restoration. Address tile drains. Setbacks for current pasture use required.	**Moderate** *(pending further analysis)*

Further study (including hydrologic and hydraulic analyses) would be warranted to evaluate the feasibility and potential benefits and impacts of these potential active restoration approaches. At a minimum, corridor protection in these segments should be pursued to limit the likelihood for further development along the channel that would then be at risk of fluvial erosion hazards.

6.8 Restoring Aggraded Reaches

Further study is sometimes warranted to evaluate the feasibility of various active geomorphic and engineering techniques to restore aggraded reaches which could accelerate a return to dynamic equilibrium of the channel, by restoring equilibrium of sediment transport processes. Aggrading reaches can also be restored through passive measures including corridor protection.

At least seven of the study segments were identified with locally aggrading conditions, possibly warranting restoration.

- Upper main stem: M22, M21-B, M15-B
- Lower main stem: M06
- High Knob Brook: T6.05-A
- Hollow Brook: T4.01-B
- Pond Brook: T3.01-C

In a few cases, aggradation is due to constriction by an undersized crossing structure or pair of abutments, and these are addressed in Section 6.6. Outside of these constrictions, the moderately-aggraded condition might feasibly be addressed with active restoration techniques (e.g., placement of structures to restore equilibrium width/depth ratio and support further development of the incipient floodplain). However, such an approach is not recommended at this time (for reasons discussed below).

- Most of these segments are moderately- to fully-incised below their floodplains (except T6.05-A, T3.01-C). Aggradation and associated planform adjustments are serving to build sections of incipient floodplain (at a lower elevation) or restore access to the original floodplain through build up of the channel bed. The channel in each of these segments is relatively unconstrained by encroachments, and is reasonably free to adjust its planform, dimensions and profile in response to changes in sediment and water loading. With a few exceptions, (e.g., Rt 116 along M22; driveway / home off Tyler Bridge Road in T4.01-B), lateral adjustments are presently not in conflict with adjacent human land uses and can be tolerated. Aggradation can be more cost-effectively supported through passive restoration techniques of river corridor protection (see Section 6.1).

- In two of the segments (e.g., M22, T4.01-B), aggrading conditions are reflective of a natural reduction in sediment transport capacity at a transition point of reduced gradient and/or reduced valley confinement (i.e., "alluvial fan"). These segments are particularly prone to lateral adjustments (which would reduce the longterm feasibility of active restoration methods). Instead, river corridor protection would be advised to avoid future conflicts in these (naturally) highly-depositional areas.

- Upstream (watershed-scale) hydrologic loading (associated with channelization, encroachment, and historic incision) is thought to be a contributing stressor governing adjustment processes in these reaches (particularly, T3.01-C with loss of conversion of wetlands in the upstream drainage area).

6.9 Mitigating Point Sources of Increased Stormwater and Sediment Loading

There are opportunities to improve management of stormwater runoff and reduce erosion along road ditches and at culvert outlets. Road maintenance practices to mitigate for stormwater and sediment runoff may include: stabilization of road surfaces (different gravel materials), improvement of roadside ditches (excavation, stone lining and/or seeding and mulching), alternative grading practices (turnouts, check-basins); re-orientation of culvert crossings; protection of culvert headers; and gully stabilization. Technical and financial resources are available to the towns through the Better Back Roads program (Northern Vermont Resource Conservation and Development Council) as well as the VT Department of Transportation.

Gullying along perennial or ephemeral tributaries draining to the Lewis Creek and major tributaries can be a significant source of fine and coarse sediment (and nutrients). Pending landowner permission, site reconnaissance and evaluation is required to establish the governing factors in gully development. Further study would characterize the feasibility of various active geomorphic and engineering techniques to control the driving forces and stabilize the gully.

Table 26 Potential Gully Restoration Sites
on assessed reaches of the Lewis Creek and major tributaries.

Reach/ Seg	**M15-B**
Location	Left bank, just upstream of Tyler Bridge Road bridge; draining from residential lands across a driveway and across lands of the Cobble Creek tree nursery at Monkton Padua parcel.
Rationale	Reduce point sources of sediment runoff to the Lewis Creek
Description	Evaluate the driving factors behind formation of the gully, including blockage of undersized culvert under a nearby residential driveway, and increased stormwater runoff.
Priority	**High.** Left untreated, headcutting in the channel could progress headward and destabilize driveway and agricultural soils with an expected nutrient legacy. If stabilized sooner than later, the cost/benefit ratio of restoration measures will be relatively low.
Other Considerations	Accompanied by corridor protection (see Section 5.1). Project development activities have occurred for this site in 2009-2010 (see Appendix K for a summary).

Table 27. Evaluate causal factors for sediment production in ephemeral tributaries
to assessed reaches of the Lewis Creek and major tributaries.

Reach/ Seg	**T4.05-A**
Location	Left bank, ephemeral tributary at the western extent of the Lazy Brook mobile home park
Rationale	Reduce point sources of sediment runoff to the Hollow Brook and Lewis Creek.
Description	Evaluate the driving factors behind sediment production in this ephemeral tributary that has caused a small bridge to be washed out and has lead to channelization, dredging, and berming of the tributary immediately above the confluence with Hollow Brook.
Priority	**High.** Collapsing trees along upper reaches of this tributary suggest that incision and widening are active, and excessive sediment will continue to be delivered to the Hollow Brook channel.
Other Considerations	Accompanied by corridor protection (see Section 5.1). Clean & Clear grant funding was sought in FY09 and not awarded.

6.10 Restoration of Channel-Contiguous Wetlands

Restoration of channel-contiguous wetlands can increase the flow and sediment attenuation role of the riparian areas surrounding the Lewis Creek reaches. Further study and project development would be required to evaluate the feasibility of active and/or passive measures to restore riparian wetland functions – and to identify landowner willingness.

At least two potential wetland restoration sites were identified on the assessed reaches of the Lewis Creek main stem and tributaries:

- M17-B Left bank, downstream of States Prison Hollow Road Extension; Starksboro parcel C131W – Hansen Farm (Moderate priority).
- T3.01-B (Both Banks) in an area of mapped hydric soils and NWI wetlands, where the stream has been channelized and tile drainage has been installed to facilitate livestock pasturing and adjacent hay fields (Figure 38) (High priority).

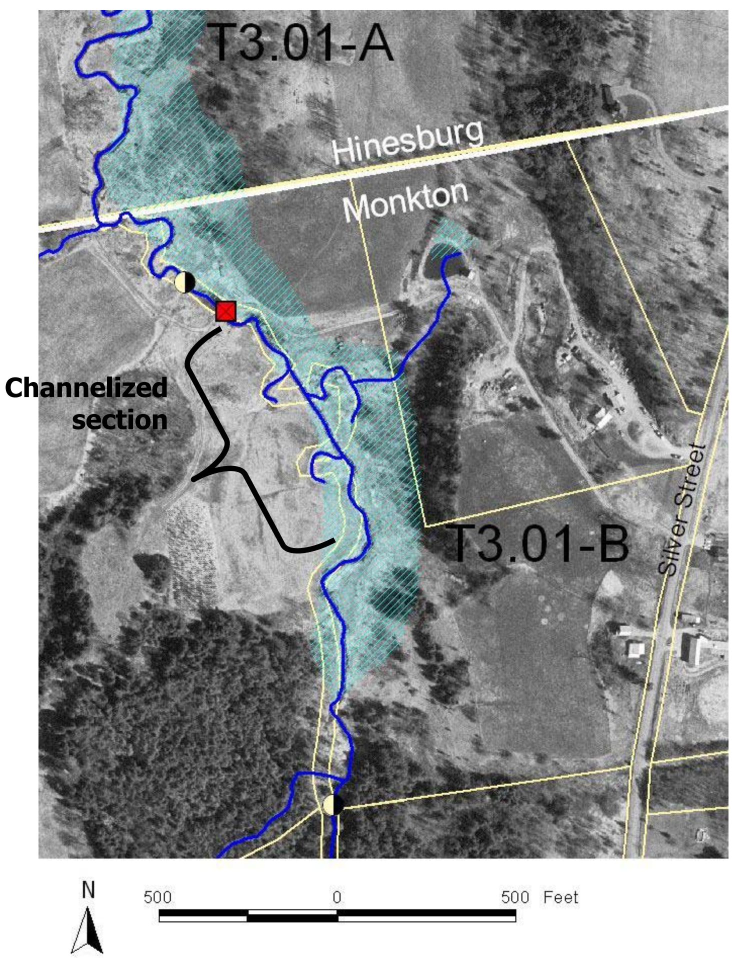


Figure 38. Potential wetland / floodplain restoration site on Pond Brook (T3.01-B) in Monkton, downstream of the Silver Street crossing near the Hinesburg town line.

Accompanied by restored floodplain connection (Section 6.7) and corridor protection (Section 6.1).

Teal hatched areas = NWI wetlands. Red square indicates bankfull-constricting instream culvert (see Table 22-b). White lines are approximate property boundaries (Monkton only).

In addition, *passive* restoration and conservation measures are recommended for several sites of channel-contiguous wetlands listed in Table 18 (Section 6.1).

7.0 WATERSHED-LEVEL MANAGEMENT STRATEGIES

The following sections identify watershed-level management strategies that should be undertaken to reduce potential for future fluvial erosion hazards, achieve nutrient / sediment reductions, and restore and conserve riparian habitats. Watershed-level management strategies are a combination of regulatory and nonregulatory approaches. Since the study reaches cross town boundaries, and many issues of river corridor management are shared by the watershed towns, efficiency can be gained by inter-town cooperation for certain education and outreach tasks. To facilitate the watershed-level strategies discussed below, as well as the relevant site-specific projects recommended in Section 6, towns should include the appropriate enabling language in next updates to the their respective Town Plans.

7.1 Town Planning incorporating river corridors

A river in dynamic equilibrium, connected to its floodplain, with a naturally-vegetated corridor can serve many important services for a community, namely:

- Flow attenuation to reduce the peak and intensity of downstream floods;
- Sediment storage, in river meanders, the floodplain, and in riparian wetlands and flood chutes;
- Attenuation, transformation, and uptake of nutrients such as phosphorus and nitrates in riparian wetlands and the floodplain;
- Diversity of channel bedforms and riparian landforms (pools, riffles, eddies, connected wetlands) which help to regulate water temperatures and provide habitat and refuge areas for riparian and aquatic species;
- Improved filtering and treatment of particulates and contaminants contained in storm flows; and
- Increased recharge to groundwater (which in turn supports the community with drinking and process water, and which increases base flows of the river during drought conditions).

When the river and floodplain are supported through corridor protection and management, the community can achieve the goals of: (1) reduced fluvial erosion hazards; (2) improved water quality; and (3) improved aquatic and riparian habitats.

A river corridor management area (or Overlay District) that acknowledges the dynamic nature of rivers and which is based on the geomorphic condition of the channel has advantages over a simple, no-build setback from the river. River channels vary in width along their length, depending on the size and nature of the upstream watershed draining to a given location, and the valley setting of the channel. Rivers are also continuously adjusting their position in the landscape, both vertically and laterally, in an attempt to optimize their slope and channel dimensions to efficiently carry the water and sediment loads supplied from the upstream watershed. A default setback is often inadequate and can be difficult to administer where a river is adjusting laterally at a rate of several feet per year.

A river corridor overlay district is a footprint in the landscape, which encompasses the dynamically-adjusting river channel. The corridor varies in width along its length, accounting for the actual width of the river channel at various locations, the size and nature of the watershed draining to that particular reach, the sensitivity of the reach (Section 5.2), knowledge of historic migration patterns of the river, and the position of the valley walls adjacent to the channel.

VT Agency of Natural Resources has developed protocols to define a Fluvial Erosion Hazard (FEH) zone that can be adopted by communities as a river corridor overlay district with the objective of supporting dynamic equilibrium in Vermont's channels. Methods for FEH zone development are provided in various guidance documents from VTANR (for example, see VTANR, 2008a; VTANR, 2008b; VTANR, 2009).

Definitions

Setback – a specified distance perpendicular to a channel or waterbody, in which specific standards are established concerning structures, land use activities, and/or vegetative conditions. For example, setbacks could be established to prevent new structures adjacent to waterways. While new structures would not be allowed, the area of land within the setback could be considered to count toward density requirements under zoning.

Buffer – zone of undisturbed natural vegetation alongside a channel or waterbody, in which no new structures are permitted, and disturbance of the natural land surface is minimized. The vegetated buffer represents a transition zone which functions to protect the waterway from disturbances and adjacent land uses. Buffers can be established at a default distance perpendicular to the channel or waterbody. Ideally, for rivers and streams, buffer distances should be informed by geomorphic assessments, and will be wider for adjusting reaches, narrower for stable reaches (e.g., following VTANR Riparian Buffer Guidance).

Overlay District – an area of variable size and width surrounding a channel or waterbody, in which specific standards are established concerning structures, land use activities, and/or vegetative conditions. A Fluvial Erosion Hazard zone overlay district is informed by geomorphic assessments and developed to meet specific functions, such as reducing streambank erosion losses and reducing sediment and nutrient loading to receiving waters by managing toward the equilibrium channel.

The FEH zone is designed as a minimum set-aside area within which the river can freely meander and adjust both laterally and vertically to maintain and/or re-establish connection with its floodplain and maintain and/or move toward a condition of dynamic equilibrium – with the expectation that setting aside this area will ***reduce*** fluvial erosion hazards (and also improve water quality and improve riparian and instream habitats) over the long term.

If a community(ies) adopts a regulatory approach to corridor protection, this FEH zone can serve as:

- a minimum set-aside area within which the community has decided it will no longer invest public resources to manage the channel (for example, through stream bank armoring, channelization, dredging, etc.) except where existing public (and possibly private) development warrants protection; and consequently:
- a minimum set-aside area within which the community will discourage new development so as to avoid future conflicts with an adjusting river, avoid future personal and property losses, and reduce future costs to the town associated with repeated, unsustainable channel management that would undoubtedly be required to protect new development if it were to be allowed in this set-aside area.

Lewis Creek watershed communities may opt to develop Fluvial Erosion Hazard (FEH) zones following VTANR guidance (2008a, 2008b), and based in part on the geomorphic data summarized in this report. A draft FEH zone has been developed by VTDEC River Management Section for portions of the main stem of the Lewis Creek channel through Starksboro, Monkton, Hinesburg, Charlotte and Ferrisburgh. The following specific recommendations are offered with regard to fluvial erosion hazard corridor development based on the Phase 2 assessment results for the Lewis Creek main stem and tributary reaches. (This is not necessarily a complete listing, and does not constitute a comprehensive review of fluvial erosion hazards in the study area).

1) In the following locations it would be prudent to expand the FEH zone to encompass locations of recent channel adjustment that extend outside the meander-belt-width area:

    a. M22 – at least two active meander extension sites and one historic meander site extend outside the FEH corridor along the left bank. Manual adjustment of the FEH corridor may be warranted.

    b. M19-A - This 70+year channel migration zone extends outside of the FEH corridor. It is therefore reasonable to expect that over the next 70 years, the channel may once again migrate to these extents.

    c. M18 / M17-C - An avulsion of the Lewis Creek channel in the 1938 flood followed a path that is outside of the FEH corridor – and resulted in fluvial erosion hazard losses to residential properties in the area.

    d. M16 – a large recently abandoned RB meander downstream of the Clifford Farm extends outside of the FEH corridor.

    e. M15-B – a large recently abandoned RB meander downstream of Tyler Bridge Rd. extends outside of the FEH corridor.

    f. T4.02-A – A portion of the Hollow Brook channel in this segment was channelized to fall along the north side of the Hinesburg Hollow Road sometime between 1962 and 1974. The former channel position of Hollow Brook is south of the meander belt width corridor.

2) In the following locations of marked reduction in gradient and valley confinement (i.e., "alluvial fans"), - where the propensity for lateral adjustments is very high due to the decreased sediment transport capacity - it may be prudent to manually adjust (widen) the FEH zone beyond the meander-belt-width area and restrict new development to avoid fluvial erosion hazard losses:

    a. M23 – downstream end of the reach, along Ireland Road.

    b. M22 – spanning the Hillsboro Road, upstream of the Route 116 crossing.

    c. M17-C (and the very downstream end of M18) – at the base of States Prison Hollow gorge.

    d. T4.05-A (and the very upstream end of T4.04).

    e. T4.01-B – upstream of the Route 116 crossing.

    Many of these alluvial fans are the site of developments, including M22 (residential homes along the LB), M17-C (residential homes along the RB at the base of the gorge), and T4.05-A (Lazy Brook mobile home park / commercial development). These buildings are at high risk of fluvial erosion hazards. Many of these homes have been constructed since the last major flood to impact the Lewis Creek watershed (i.e., 1938).

3) A potential avulsion / stream capture hazard exists in Segment T4.02-A of the Hollow Brook which flows along the northern perimeter of the Hinesburg sand & gravel quarry (Figure 39). Based on recent LiDAR data, the elevation of the bottom of the pit is on the order of 10 feet below the elevation of the Hollow Brook channel, which is separated from the quarry by a relatively narrow berm of gravels and sands that varies in height above the river along the length of segment T4.02-A. Materials comprising this berm are highly erodible and a sudden breach of

the berm during high flows in the Hollow Brook could result in avulsion of the channel into the Hinesburg sand and gravel quarry. A location of particular concern is the vicinity of a northern access road to the quarry located just east of the Hollow Road bridge crossing of Hollow Brook – where the berm separating the river and the sand and gravel quarry is at a low point and the access road provides a potential pathway for flood waters to enter the quarry. The bridge is undersized with respect to the flood-prone width of the channel, and is oriented at a sharp angle to the channel. A potential debris jam at this constricting structure could increase the likelihood of channel avulsion into the quarry. This potential avulsion hazard is noted for its possible destabilizing effects upstream and downstream on the Hollow Brook, and for the impacts to quarry operations and public safety.

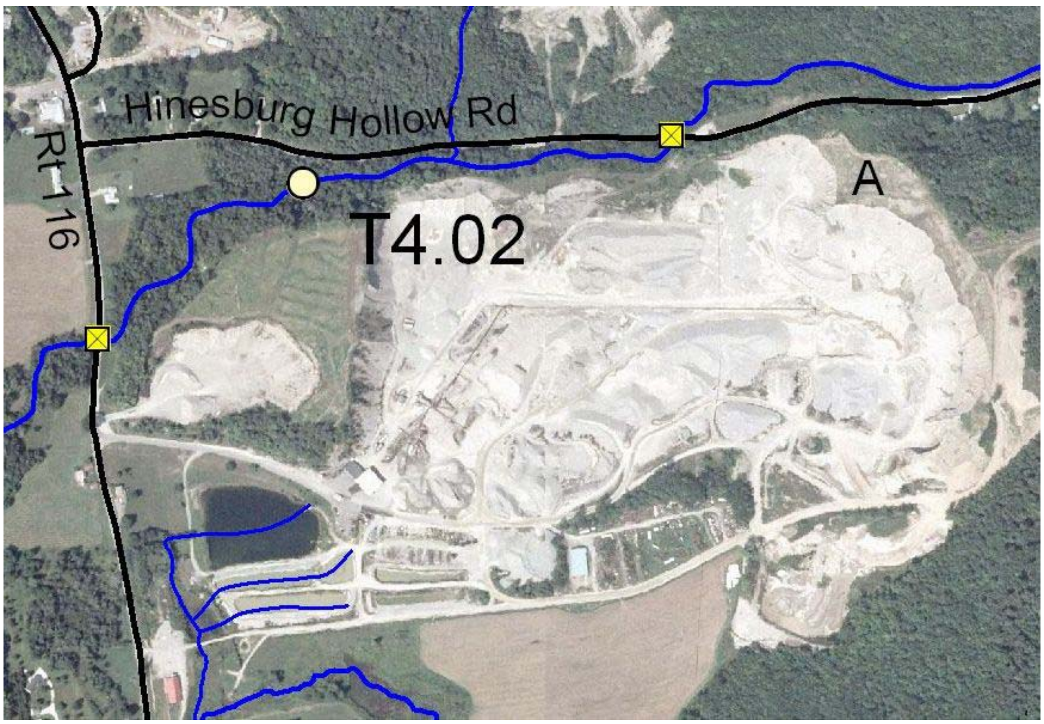


Figure 39. Potential site of Hollow Brook stream capture by Hinesburg sand & gravel quarry. (Base image: 2003. Yellow squares indicate bridge crossings with a span that is constricting to the flood-prone width of the channel.).

4) Valley walls suitable for the purpose of delimiting the meander belt width corridor to create a "Fluvial Erosion Hazard" area after VTANR guidance are referred to as "FEH valley walls" or "modified valley walls". FEH valley walls have been identified by VT River Management Section for the main stem reaches assessed during this study. Appendix D details the source of these valley wall delineations and associated limitations. "FEH valley walls" have yet to be defined for the major tributaries of Lewis Creek – including Hollow Brook, Cedar Brook and Pond Brook – this is recommended as a future task.

   Along several of the main stem reaches, the valley width defined by the FEH valley walls is narrower than the meander belt width prescribed under VTANR protocols for all or a portion of the reach. Thus, the "FEH corridor" is delimited by the FEH valley walls in these reaches: M21-B, M21-A, M20-B, M20-A, M19-B, M17-B, M17-A, M14 downstream to M07 and M05 downstream to M03. It is important to note that valley wall delineations rely on remote sensing resources (USGS topographic maps, published soils data, published surficial geologic data) and limited visual observations. No detailed assessments (such as subsurface geologic investigations, geotechnical evaluations, licensed land surveys, hydrologic or hydraulic assessments) are conducted to: (1) estimate the degree that either natural valley/terrace side slopes or human encroachments will laterally constrain the channel or (2) estimate the degree that human encroachments will change hydraulics of channel and floodplain flow during a flood event (of unspecified magnitude and duration).

Where "FEH valley walls" or "modified valley walls" are utilized to truncate the meander belt width corridor along "major" or "significant" roads or infrastructure (following VTANR guidance), this does not mean that erosion hazards will not exist beyond the road / infrastructure.

5) Where the channel impinges on valley walls that are comprised of erodible materials FEH delineation should be augmented with a Slope Stability Allowance, as per latest draft guidance from VTANR (October 9, 2009 *Technical Guidance for Determining Floodway Limits Pursuant to Act 250 Criterion 1[D]*).

Ideally, the protected area along the Lewis Creek main stem and major tributaries should include an additional channel width of buffer (undisturbed natural vegetation) beyond the FEH area on either side of the channel "to support the woody vegetation necessary to achieve bank stability, stream shading, and some aquatic and riparian habitat functions" beyond minimum area set aside for the river to achieve equilibrium function (FEH area) (VTANR, 2008a; VTANR, 2009).

7.2 Buffers for waterways not covered by Phase 2 Assessments

Beyond the 42.6 miles of channel assessed as part of this study, several additional miles of tributaries exist in the watershed towns. Often, these tributaries are small enough in size that geomorphic assessment is either not practical or affordable in the near term. Yet, protection of these smaller tributaries from encroachment, channelization, dredging, berming and other impacts is critical to the overall watershed goals of mitigating for increased flows and sediment loading. While impacts to any one small tributary may be small in degree, impacts to several small-order tributaries can accumulate in the watershed to result in significant impacts to the Lewis Creek and major tributaries.

For maximum protection of surface waters, towns can implement a combined approach of corridor protection and FEH corridors for larger waterways, and a default buffer for smaller channels. A minimal 50-foot setback maintained with natural vegetation (i.e., a buffer) is recommended by the VT Agency of Natural Resources for channels with upstream drainage areas equal to or less than 2 square miles (VTANR, 2008a).

7.3 Additional Strategies to Mitigate Stormwater / Sediment Impacts

Towns can consider a variety of additional planning and zoning strategies to reduce stormwater and sediment runoff to the Lewis Creek and its tributaries, such as:

- Implement Low Impact Development techniques:
  - Establish or Increase Minimum Lot Sizes
  - Establish or Reduce Maximum Lot Coverages / Minimize Percent Impervious
  - Minimize land disturbance / compaction during construction
  - Prevent stormwater outfalls from crossing vegetated buffers and entering rivers and streams without treatment or energy dissipation.

- Specify maximum road and driveway widths.
- Review parking space ratios for minimum impacts.

- Incorporate practices for area-based zoning, transfer-of-development rights and clustering into zoning and subdivision regulations to encourage protection of river corridors.

- Add relevant language to zoning and subdivision regulations for protection against fluvial erosion hazards – Special Flood Hazard Area regulations established for floodways defined on FEMA-FIRM maps are designed to protect against inundation (rising water) flooding. These practices do not necessarily adequately protect against erosion hazards (or sudden streambank erosion, avulsion) during flooding events.

- Consider forested (vegetative) buffers and erosion control along tributaries and unnamed streams that are not covered by corridor plans and/or Fluvial Erosion Hazard overlay districts.

- Consider local-level stormwater ordinances for development projects that fall under the thresholds for triggering Act 250 review or the States Stormwater Management rule.

- Consider local road & driveway and bridge & culvert ordinances or review standards.

- Continue improved road maintenance practices to mitigate for stormwater and sediment runoff, including: stabilization of road surfaces (different gravel materials), improvement of roadside ditches (excavation, stone lining and/or seeding and mulching), alternative grading practices (turnouts, check-basins); re-orientation of culvert crossings; and culvert header protection.

- Coordinate educational programs to increase awareness of permit requirements for stream alteration, stream crossings, and gravel extraction.

7.4 Maintenance and Replacement of Crossing Structures

Undersized bridge crossing structures were identified as contributors to localized channel instabilities in the assessed reaches (Section 6.6.1). Similar conditions likely exist at crossings sites dispersed throughout the watershed on smaller tributaries that ultimately drain to these reaches.

Additional watershed-wide and town-scale strategies for installation and maintenance of bridge and culvert structures should be considered. The watershed towns could establish ordinances or identify zoning requirements which would ensure adherence to proper siting and design practices for bridge and culvert crossings. The geomorphic context should be considered when designing new and rehabilitated structures within the watershed:

- New or replacement bridges and culverts should ideally have openings which pass the bankfull width without constriction.

- Bridges and culverts should be designed to cross the river without creating channel approaches at an angle to structures. Such sharp angles can lead to undermining of fill materials and structural components.

- The historic channel migration pattern of the river should be considered when installing new or replacement crossing structures (and when constructing new roads, driveways, and buildings). Corridor protection strategies that prevent or limit placement of infrastructure within the corridor will protect structures from future erosion and flood losses.

- Planned build-out for watershed communities and resultant channel enlargement (from increased percent imperviousness) should be considered when designing new or replacement bridges and crossing structures.

- Road ditch runoff should be diverted to side-slopes where energy can be dissipated, stormwaters can infiltrate, and sediment / detritus loads can be deposited on the land and not directly to streams.

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