Phase 2 Stream Geomorphic Assessment
Rock River Watershed
Highgate and Franklin, Franklin County, Vermont
December 2006 (Revised January 2007)

Rock River main stem at Tarte Road crossing, Highgate, VT.

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This study was made possible through River Corridor Grant funding from the Vermont Department of Environmental Conservation (Governor Douglas's Clean & Clear program).

Field work was conducted with the cooperation of many riparian landowners in Highgate and Franklin who granted permission to cross their property to access the river. Historical accounts of past flood events and channel management activities were also generously offered by many local representatives.

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EXECUTIVE SUMMARY

Phase 2 stream geomorphic assessments were completed on 15 reaches (25.9 river miles) of the Rock River and select tributaries in the towns of Highgate and Franklin during June and early July of 2006. Six main stem reaches were assessed from the vicinity of Hannah Road in southwestern Franklin, downstream to the point where the Rock River crosses into Quebec in northeastern Highgate. Nine tributary reaches in Highgate were also assessed: two draining to the Rock River just downstream of the Cassidy Road crossing; four tributaries draining to the Rock River between the Gore Road and the Tarte Road crossings; and three reaches of the Saxe Brook along St. Armand Road.

Geomorphic data will be used by watershed stakeholders (including landowners, community members, watershed organizations, and state and federal resource agencies) to inform future management strategies along the assessed reaches. The geomorphic condition of a given reach or segment will help to define the short-term compatibility and long-term sustainability of various restoration or conservation projects and future land use or channel management activities.

Various watershed-scale and channel-level disturbances, noted through field investigation and historical data review, have impacted the Rock River main stem and tributaries. Significant disturbances to the assessed river reaches have included:

- Channelization / straightening / dredging of tributaries and the upper main stem;
- Berming of select tributaries and upper main stem reaches;
- Channel armoring (rip-rap), typically limited to culvert and bridge crossings;
- Floodplain encroachment by roads, and residential and commercial development;
- Undersized culverts and bridges, which constrict channel flows;
- Direct pasturing of livestock in select main stem and tributary reaches;
- Introduction of increased flows and sediments through tile drains and drainage ditches from adjacent agricultural fields;
- Stormwater runoff from roads, driveways and crossing structures;
- Active stream crossings (fords);
- Minimal or absent forested buffers along portions of the study reaches; and
- Flood events, including a reasonably large event in January of 1996, and the larger floods of 1938 and 1927.

The Rock River and tributary channels are responding to these past disturbances through adjustment of channel dimensions (cross section geometry), planform (position in the landscape), and profile (slope). Adjustments have occurred to varying degrees, as dependent on many factors, including the magnitude of past disturbances, the erosion resistance of sediments in the channel bed and banks, the type and density of vegetative cover along stream banks, and presence of grade controls.

In general, the assessed main stem reaches are showing minor degrees of channel adjustment. Downstream of the Highgate / Franklin town line, the Rock River is entrenched within a somewhat narrow, meandering valley with steep forested side slopes. This position in the landscape resulted from several thousand years of erosion following the last glacial period in Vermont. Given the topography in this section of the Rock River, there are relatively few examples of development or roads encroaching on the channel, except for a few bridge or culvert crossings. Direct channel disturbances, such as straightening, dredging, or gravel extraction are also rare. This minor degree of channel disturbance, together with the cohesive (erosion-resistant) nature of the clay and silt substrates in the channel bed and banks, have resulted in the relatively stable condition of these lower main stem reaches. Where riparian buffers have been removed (for example, near road crossings or along isolated pastured areas), stream bank erosion is more pronounced. However, these appear to be localized areas of instability and are not indicative of system-wide imbalances.

In contrast, the upper reaches of the Rock River main stem (within the town of Franklin) and the tributary reaches, generally, have been subjected to greater degrees of channel disturbance – notably, extensive channelization, dredging, berming, and removal of forested buffers - to facilitate cropping, pasture or residential uses and to allow for road maintenance. Such direct manipulations would ordinarily be expected to initiate system-wide channel instabilities. In fact, segments within two of the assessed reaches were found to be actively adjusting; both segments have undergone a stream type departure and lost access to the floodplain. Direct channel manipulations (straightening, dredging, berming) and increased stormwater inputs from drainage tiles have contributed to excessive vertical and lateral adjustments in these segments.

For the most part, however, the upper reaches of the Rock River main stem and tributary reaches were found to be in relatively minor to moderate states of adjustment, with reasonable floodplain access. Factors which may have moderated lateral and vertical adjustments in response to considerable channel disturbances include: the cohesive, erosion-resistant nature of the silt/clay channel bed and banks; presence of stabilizing exposures of bedrock in several of the assessed reaches; the small drainage areas and shallow gradient of many of the segments; and wetlands within the river network that may be providing flow attenuation.

In summary, the Rock River appears to be in fairly stable condition, not exhibiting the kinds of extreme lateral and vertical channel adjustments that characterize sand and gravel bed streams in disequilibrium (like the nearby Trout River in Montgomery). However, the fine-grained clay and silt which dominate channel boundaries in most of the Rock River and tributary reaches impart a different kind of vulnerability to the watershed, related to high suspended sediment loads and their association to nutrient loading.

Where channel scour is mobilizing silt and clay from the bed and banks, these sediments (and associated nutrients) tend to stay in suspension and travel for great lengths downstream (into Quebec and ultimately to Lake Champlain). Opportunities within the stream network (in Franklin County) to attenuate fine sediments and nutrients are limited. Many of the Rock River main stem and tributary segments are entrenched within narrow valleys – either over geologic time frames (thousands of years) as a result of base-level lowering and continental rebound following recession of the glaciers; or over recent human time scales (last several decades) as a result of channelization and other disturbances. Thus, floodplains along many of the reaches are narrow with limited space for flow and sediment attenuation. Where such opportunities do exist within the river network, very long residence times are required to permit the finest silt and clay particles to settle out. Bullis Pond in Franklin, for example, provides such a sediment attenuation function. Flow dynamics elsewhere in the river network most often do not provide sufficient residence time.

Significant mobilization of fine sediments and nutrients is occurring along the margins of the Rock River and tributary corridors, related to: (1) stormwater runoff from road networks; (2) tilling and cropping practices in close proximity to surface water swales and first-order tributaries; and (3) maintenance of tile networks and drainage ditches in agricultural fields.

Ultimately, best opportunities for controlling the transport and delivery of fine sediments and nutrients within the Rock River watershed are through: (1) improved management of nutrient inputs within the upstream extents of the river network; and (2) interruption of the transport processes of sediments and nutrients at their source.

Opportunities for channel restoration in specific segments of the assessed Rock River and tributary reaches have been identified. Recommended measures include active geomorphic approaches such as: arresting headcuts in actively incising segments; restoring floodplain access; removing berms; and restoring channel planform, dimensions, and profile in previously channelized segments.

Passive geomorphic approaches are also offered for segments in minor adjustment. These include: replacing crossing structures with less constricting bridges and culverts; improving boundary resistance along channel margins through restoration of forested buffers; excluding livestock from stream channels; preserving flow and sediment attenuation functions through voluntary conservation and rehabilitation of wetland areas in the river network; and preserving equilibrium functions of stream channels, by refraining from future channel manipulations through voluntary conservation of riparian corridors.

Restoration or preservation of geomorphic equilibrium in the Rock River and its tributaries will contribute to water quality improvements and reduced sediment loading in the long term.
To improve water quality in the short term, resources in this watershed are best directed toward preventing fine sediments and nutrients from entering the tributaries and main stem of the Rock River at their source. Substantial technical and financial resources are currently available to landowners and the towns of Highgate and Franklin from various regional, state and federal agencies to implement recommended changes.

This study and the identification of geomorphically-compatible river management opportunities has formed the basis for follow-on project development activities being carried out by the Towns of Highgate and Franklin through their consultant, Brian Jerose of WASTE NOT Resource Solutions (Fairfield, VT).

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1.0 INTRODUCTION

Phase 2 geomorphic and habitat assessments were completed from 1 June to 3 July 2006 on fifteen reaches (25.9 river miles) of the Rock River main stem and tributaries located in the towns of Highgate and Franklin, Vermont. Assessments were conducted following protocols published by the Vermont Agency of Natural Resources (VTANR, 2006). Objectives of the Phase 2 geomorphic assessments were to:

- determine the geomorphic condition of targeted reaches, and identify active vertical and lateral adjustment processes;
- identify current and historic channel and watershed disturbances that may lead to vertical and lateral adjustments; and
- evaluate 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).

Assessment results will be used by watershed stakeholders (e.g., landowners, towns of Highgate and Franklin, Friends of Mississquoi Bay, state and federal agencies) to:

- provide a watershed and river-network context for site-specific restoration and conservation projects (i.e., understand if the river is actively degrading, aggrading, widening, or shifting its planform in the areas upstream and downstream of a proposed project site);
- support site-specific channel restoration design and planning;
- understand water quality trends in the river;
- plan for future development which is compatible with adjusting river channels;
- support the evaluation of Vermont rivers for listing or de-listing of waters pursuant to Part G, State of Vermont List of Priority Surface Waters Outside the Scope of Clean Water Act, Section 303(d) of the Federal Clean Water Act (VTDEC WQD, 2004).

Assessment data were entered into the online Data Management System (DMS), a custom database of stream geomorphic data developed and maintained by the Vermont Agency of Natural Resources, Water Quality Division (VTANR WQD). This summary report has been prepared by Kristen Underwood of South Mountain Research & Consulting (SMRC) based in Bristol, Vermont under contract to the Town of Highgate. SMRC has been assisted on this project by subconsultants, Brian Jerose of WASTE NOT Resource Solutions (Fairfield, Vermont) and Brendan O'Shea of Carmi Consulting (Franklin, Vermont).

2.0 BACKGROUND

Phase 2 assessments were undertaken in the Rock River watershed to provide a geologic and geomorphic context for the streambank erosion and water quality issues documented in the river over the past several years.

Sampling conducted near the mouth of the Rock River in 1990 to 1992 as part of the Lake Champlain Diagnostic /Feasibility Study (VTDEC / NYSDEC, 1997) established the Rock River as a significant contributor of phosphorus from non-point sources to the Missisquoi Bay of Lake Champlain. Nonpoint sources account for essentially the total contribution of phosphorus in the watershed, as there are no significant point sources of phosphorus (e.g., wastewater treatment facility discharges) within the Rock River (VTDEC/NYSDEC, 2002; VTDEC/NYSDEC, 1997).

Subsequent land-use based modeling efforts identified that the Missisquoi, Rock, and Pike watersheds contributed higher loads of phosphorus (on a per-acre basis) than other watersheds in Vermont, New York, and Quebec, draining to Lake Champlain (Budd & Meals, 1994; Hegman *et al.*, 1999). The agricultural land areas in these watersheds appear to deliver greater per-unit-area phosphorus loads than agricultural lands in other watersheds of the Lake Champlain basin. Rock River watershed, in particular, contributes higher per-unit-area total phosphorus than either the Pike or Missisquoi watersheds (Hegman *et al.*, 1999).

The State of Vermont has listed several sections of the Rock River watershed as impaired and not meeting VT Water Quality Standards (VTDEC WQD, 2006; VTDEC WQD, 2004):

- 3.6 miles of the Rock River main stem from the mouth upstream to the Canadian border. Aesthetics impaired as a result of algal growth, agricultural runoff, and documented fish kills (1991).
- Approximately 13 river miles upstream from the Canadian border. Aquatic life support uses impaired as a result of agricultural runoff and nutrient enrichment.
- 1 mile of the Saxe Brook tributary upstream from its confluence with the Rock River in northwestern Highgate. Aquatic life support uses impaired as a result of agricultural runoff.

The 303(d) listing cites these segments of the Rock River as having moderate priority for development of a Total Maximum Daily Load (TMDL) determination, meaning that a TMDL plan is scheduled for completion within the next 4 to 8 years, unless remediation and other measures can be implemented prior to TMDL development to address the noted water quality impairments and result in the waters' compliance with VT Water Quality Standards.

The Missisquoi Bay portion of Lake Champlain, into which the Rock River drains, is also listed as impaired by phosphorus enrichment. During monitoring from 1990 through 2004, phosphorus concentrations in this part of the Lake consistently exceeded target levels outlined in the September 2002 Lake Champlain Phosphorous TMDL (Medalie & Smeltzer, 2004; Lake Champlain Basin Program, 2005).

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 (Addison County), 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 (DeWolfe *et al.*, 2004).

This study of the Rock River watershed was undertaken, in part, to understand where streambank erosion and other physical adjustments are occurring along the main stem and tributaries, as these may be contributing to phosphorus loading.

2.1 Geographic Setting

The Rock River drainage area is approximately 56.5 square miles. From the headwaters located in the southeast part of the town of Highgate, the Rock River flows to the northeast into the town of Franklin, then to the west back into the town of Highgate. The main stem then drains northward into Quebec and subsequently turns to the west and south to re-enter the United States before joining Lake Champlain at Missisquoi Bay (Figures 1 and 2).

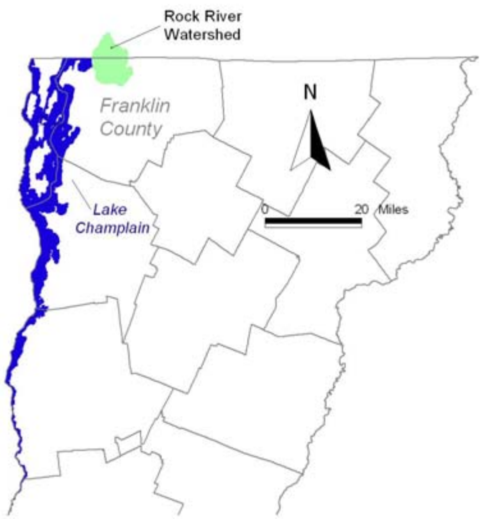
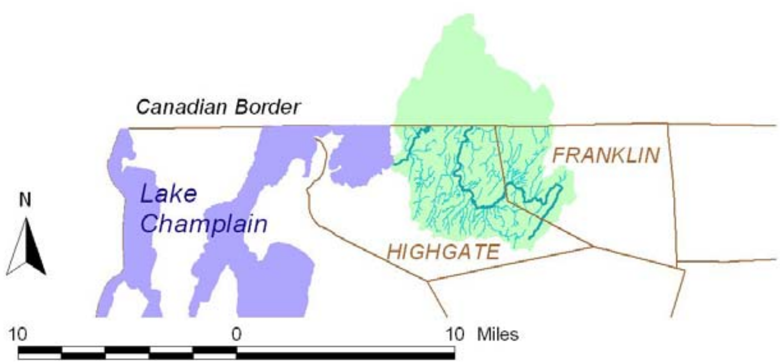


Figure 1. (left)
Location of Rock River watershed within Franklin County, Vermont.

Figure 2. (below) Location of Rock River watershed within towns of Highgate and Franklin, Vermont.



This study focused on the Vermont portion of the Rock River watershed which is approximately 35.4 square miles in area, or 63% of the total watershed (Figure 2). The upstream watershed draining north to the Canadian border is approximately 24.6 square miles (see Figure 3). In the western extent of the watershed, approximately 5.7 square miles of land area, including the Saxe Brook tributary watershed, drain to the lower four miles of Rock River downstream of the Canadian border. The remaining 5.1 square miles of land area are located along the Canadian border and drain to the north to the Quebec portion of the watershed.

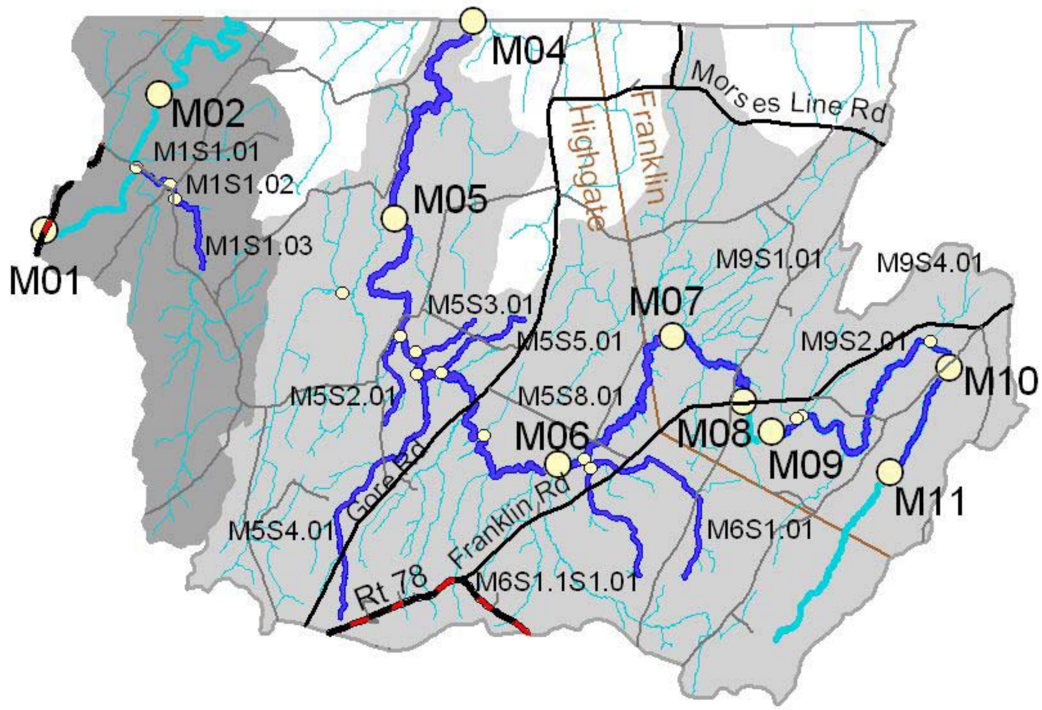


Figure 3. Location of major subwatersheds within Vermont portion of Rock River drainage area. (Rock River watershed upstream of Canadian border shaded light gray; Rock River watershed upstream of Lake Champlain and downstream of the Canadian border shaded darker gray; area draining to Quebec portion of watershed, unshaded).

This Phase 2 Stream Geomorphic Assessment focused on six river reaches along the Rock River main stem and nine tributary reaches (noted in bold blue in Figure 3, above).

2.2 Regional Geologic Setting

The Rock River watershed is located largely within the Champlain Valley physiographic province (Thompson & Sorenson, 2000; Dennis, 1964), the broad north-south trending valley which surrounds Lake Champlain and covers portions of Vermont, New York and Quebec. The Rock River watershed is located in the higher-elevation area of the Champlain Valley in the foothills near the boundary with the Green Mountain physiographic province to the east. Some publications have described the general location of the eastern margins of the Rock River watershed (near Rice Hill and Minster Hill) to be within the Green Mountain province (Stewart, 1974). There is some variance among publications as to the position of the boundary between these two provinces (Dennis, 1964).

In recent geologic time (from 20,000 to 13,200 years before present) this landscape was occupied by advancing and retreating glaciers, with ice up to a mile or more in thickness above the present land surface in the Champlain Valley (Stewart & MacClintock, 1969). Glacial tills now blanket much of the bedrock-controlled slopes and headwaters of the watershed (Doll, 1970).

As the global climate warmed and the glaciers receded, a large fresh-water lake inundated the Champlain Valley. At its highest stage, Lake Vermont's shoreline extended into the Rock River watershed and beyond (Stewart & MacClintock, 1969; Doll, 1970).

Lake Vermont waters receded in stages as natural dams in southern Vermont and New York gave way. From approximately 12,800 to 10,200 years before present, 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). The maximum elevation of these brackish waters is believed to have extended to the eastern margins of the present-day Rock River watershed in the vicinity of Rice Hill (Stewart & MacClintock, 1969; Wagner, 1972).

Champlain Sea waters had receded from the Champlain Valley by approximately 10,000 years before present, as the rate of land rise began to outpace the rate of sea-level rise. As the Champlain Sea levels receded from the Champlain Valley, river systems, including the Rock River and the Missisquoi River, continued their work eroding the landscape. The Rock River main stem in western and northern Highgate has incised below adjacent terraces over thousands of years (Dennis, 1964; Stewart & MacClintock, 1969). In the nearby Missisquoi River valley, Brakenridge, *et al.* (1988) estimate the greatest rates of post-glacial incision occurred between 10,000 and 8,000 years before present. Tributaries to the Rock River main stem downstream of the Franklin / Highgate town line, also incised through thicknesses of lacustrine silts and clays as the base level of the main stem dropped. Today, the upper extents of these tributaries are low-gradient meandering channels on relatively flat terraces, while the downstream extents near the confluence with the main stem are higher-gradient channels that cut down through 20 to 50 feet of layered sediments (Figure 4).

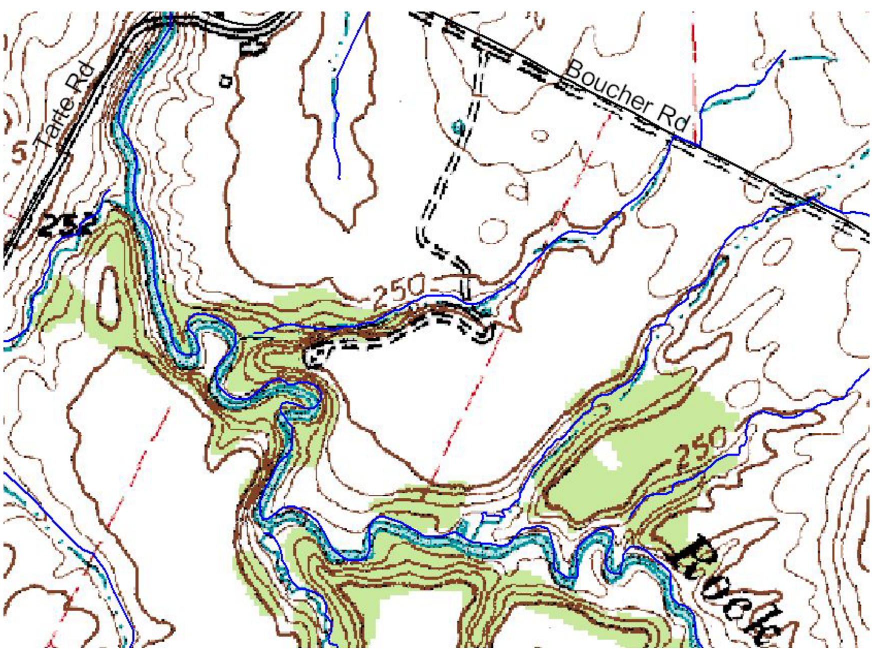


Figure 4.
Topographic relief of the Rock River and tributary channels upstream of the Tarte Road.
Flow in the Rock River is from southeast (lower right) to northwest (upper left).

Source: Highgate Center, VT, USGS 7.5-Minute topographic map, dated 1987.
10-foot contour intervals.

2.2.1 Bedrock Geology

In general, the bedrock geology of the Rock River watershed consists of fractured shales and slates, with lesser occurrences of dolomites, sandstones, and limestones (Stewart, 1974; Dennis, 1964; Mehrtens and Dorsey, 1987). The shales and slates originated as sedimentary mudstones deposited in an ancient sea (450 to 550 million years old). They were later compressed and altered under elevated temperature and pressure conditions during the Taconic mountain building event and subsequent regional deformations to form metamorphic slates. In the process of mountain-building, older Cambrian and Ordovician rocks were folded and thrust over younger Ordovician limestones and marbles. Later, regional stresses caused further folding and faulting of the bedrock.

The underlying bedrock geology of the watershed influences the Rock River in many ways. The topography of the watershed is, in part, a direct result of the characteristics of the underlying bedrock. Quartzite and dolomite members that are more resistant to weathering, and comprise thrust sheets, form the uplands along the eastern and western margins of the watershed. The eastern extent of the watershed is bounded by higher-relief, erosion-resistant quartzites and dolomites of the northeast-trending Hinesburg-Oak Hill Thrust at the foothills of the Green Mountain province. The western edge of the watershed is bounded by dolomites along the north-northeast-trending Champlain Thrust fault (Stewart, 1974).

Elevated terrain along the Champlain Thrust appears to have diverted much of the drainage from the watershed toward the north into Quebec. At approximately 8.4 miles upstream from the mouth (USACOE, 1978), the Rock River crosses the Canadian border and travels another 4.5 miles before turning to the west and south to re-enter Vermont in the northwestern corner of Highgate. At this point, approximately 3.6 miles from the confluence with Lake Champlain, the Rock River is flowing over lower-elevation limestones along the northwestern flanks of the Champlain Thrust fault. Saxe Brook, a tributary to the Rock River main stem, cuts across the Champlain Thrust near historic Saxe's Mills, exposing dolomite in a 35-foot high falls near the intersection of St. Armand and Ballard Roads.

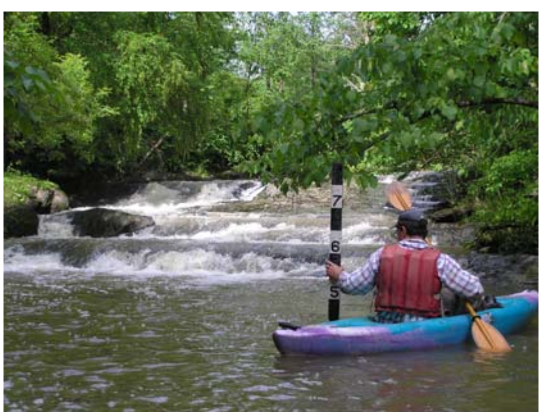


Figure 5. (M05) Bedrock falls at the site of a historic bridge crossing (now abandoned) southeast of Rollo Road in Highgate. This channel-spanning exposure of bedrock serves as a vertical grade control for the Rock River channel.

Frequent bedrock exposures influence the channel position and profile in the watershed. Bedrock along the valley walls controls the lateral position of the river channel. Occurrences of channel-spanning bedrock offer vertical grade control, preventing possible downward erosion of the channel in response to regional or local stressors (at least over the 10- to 100-year time spans on which this study is focused). Within the study area there are several exposures of bedrock along the main stem and tributary channels. Two prominent examples are a bedrock falls along the main stem southeast of Rollo Road (Figure 5) and the falls on Saxe Brook downstream of the Ballard Road crossing northeast of St Armand Road, which was the site of a historic grist mill (Walling, 1860). A third bedrock gorge downstream of Browns Corners in the town of Franklin was also the site of historic saw mill operations.

2.2.2 Surficial Geology

Glacial activity has influenced the surficial sediments and soil types which are present in the Rock River watershed today. Upland slopes of Rice Hill and Bridgeman Hill in the Rock River headwaters area (town of Franklin) are dominated by shallow- to moderate-thickness glacial till deposits overlying bedrock. Shore features from the Champlain Sea marine waters have been identified along the Missisquoi River valley in the vicinity of East Highgate (at the southern boundary of the Rock River watershed) and along the western flanks of Rice Hill in the upper Rock River watershed. Freshwater and marine lake clays and silts are mapped over the central portion of the watershed (Stewart & MacClintock, 1969; Doll, 1970; Stewart, 1974).

Soil survey mapping for the watershed (USDA, 2003: USDA, 1979) indicates soil type distributions consistent with mapped surficial geology. Figure 6 depicts the generalized soil types in the watershed, grouped by geologic parent material. Soil types in the upland portions of the watershed are dominated by soils derived from glacial till (for example, Farmington and Lordstown Rock Outcrop complexes in the western margins and Woodstown Rock Outcrop complexes in the eastern margins). The central portion of the watershed is dominated by silt loams with subhorizons of silty clay (for example, Munson, Scantic and Raynham silt loams on the higher plains and Buxton and Binghamville silt loams in the valleys of the Rock River main stem and tributaries). These silt loams have their origin in silty clay deposits of marine and freshwater lake environments.

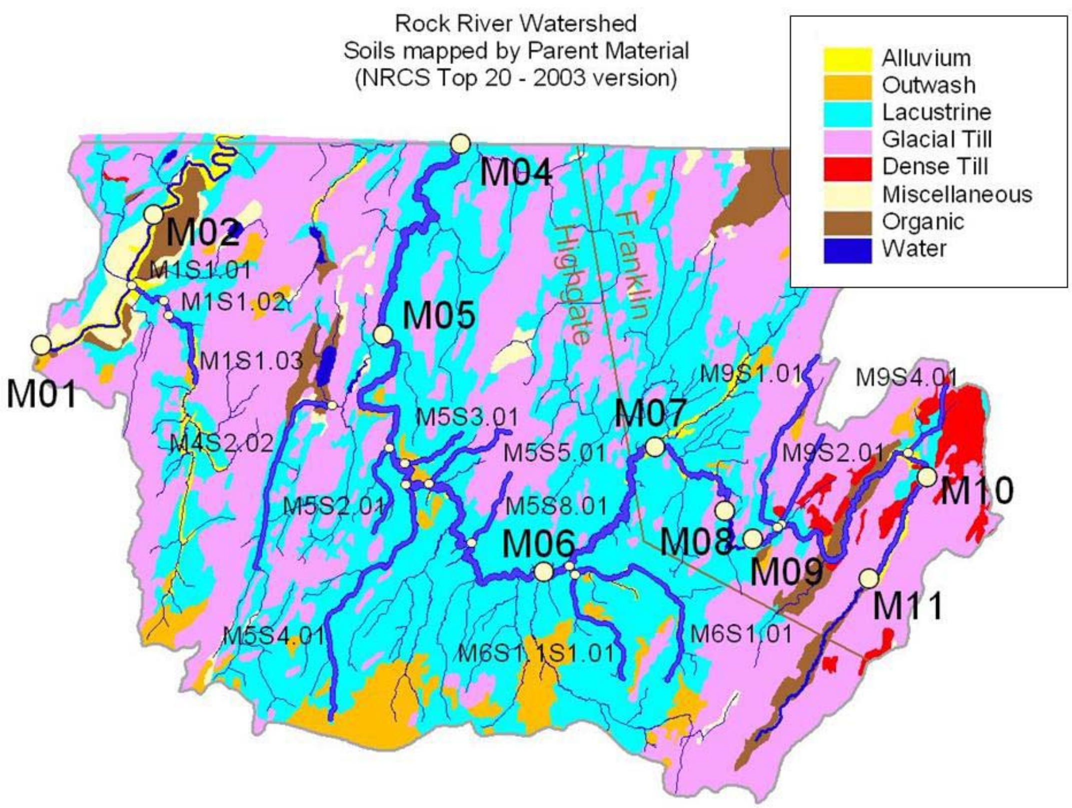


Figure 6. Generalized map of soil parent material in the Rock River watershed. NRCS parent material classification of "lacustrine" does not differentiate between lake silts/clays of glacial versus marine origin.

2.3 Geomorphic Setting

Figure 7 illustrates the Rock River main stem and select tributaries in longitudinal profile. Generally, valley and river channel slopes become shallower as one progresses downstream toward Lake Champlain. Relief in the watershed varies from highest elevations of 860 feet east of Rice Hill near the upper extent of the main stem, to a low elevation of approximately 94 feet at the mouth in Missisquoi Bay of Lake Champlain.

In the Phase 1 Stream Geomorphic Assessment of the lower Missisquoi River basin (NWRPC/SMRC, 2006), the Rock River watershed was delineated into geomorphic reaches using remote sensing methods supported by windshield surveys. Geomorphic reaches were defined based on variation in valley confinement, slope, and sinuosity. The reader is referred to the Phase 1 summary report for details of the Phase 1 assessment.

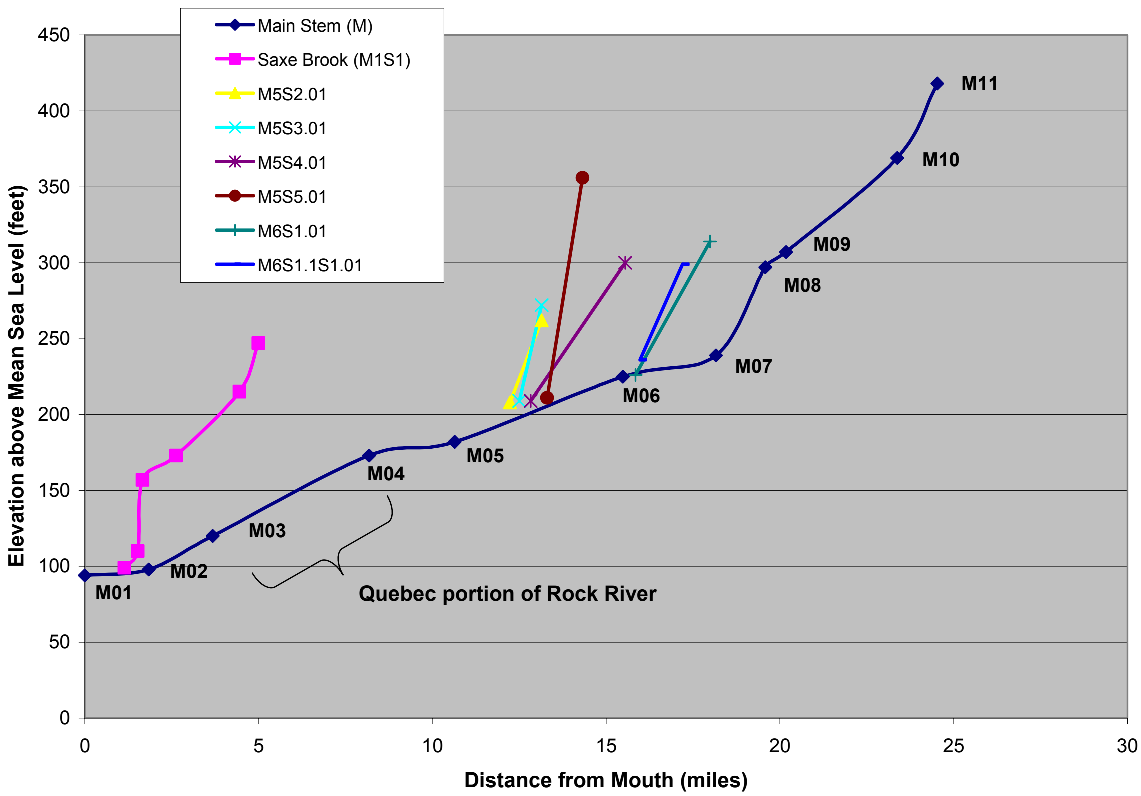
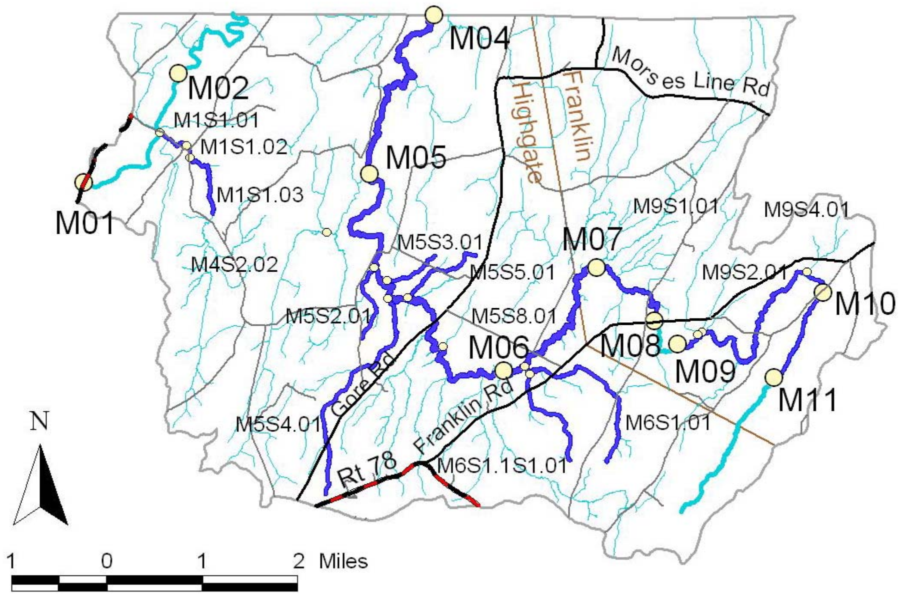


Figure 7. Longitudinal profile of Rock River main stem and assessed tributaries.

Based on the channel and watershed stressors identified through remote sensing, windshield surveys and limited historical research during the Phase 1 Geomorphic Assessment, fifteen reaches along the main stem and select tributaries in the towns of Highgate and Franklin were prioritized for Phase 2 Stream Geomorphic Assessments in 2006 (see Figure 8). Targeted reaches were those expected to demonstrate higher degrees of channel adjustment and sensitivity based on their topographic setting and provisional identification of past and current watershed and channel disturbances.



	Reach	Channel Length (ft)	Provisional Phase 1 Impact Score	Location
Main Stem	M04	12,999	1	Highgate
	M05	25,574	5	Highgate
	M06	14,116	9	Highgate; Franklin
	M07	7,528	13	Franklin
	M09	16,920	12	Franklin
	M10	6,078	9	Franklin
Tributaries	M1S1.01	2,004	11	Highgate: Saxe Brook: along St Armand Rd; first reach above confluence with Rock River.
	M1S1.02	741	4	Highgate: Saxe Brook: short, steep reach under Ballard Rd.
	M1S1.03	5,114	7	Highgate: Saxe Brook: from St Armand Rd downstream to Ballard Rd.
	M5S2.01	4,804	9	Highgate: unnamed trib to M05: along Tarte Rd near Parent Rd intersection.
	M5S3.01	3,409	5	Highgate: unnamed trib to M05: crosses Boucher Rd.
	M5S5.01	5,392	7	Highgate: unnamed trib to M05: crosses Boucher Rd.
	M6S1.01	11,339	9	Highgate: unnamed trib to M06; crosses Franklin and Durkee Rd.
	M6S1.1S1.01	6,470	NM	Highgate: unnamed trib to M6S1.01; crosses Franklin Rd.
	M5S4.01	14,347	8	Highgate: unnamed trib to M05; west of Gore Road

Notes:

NM = Not Measured; Reach was delineated in Phase 1 but not selected for completion of Steps 4 through 7 of Phase 1 which summarize impacts.

Figure 8. Location of reaches selected for Phase 2 Stream Geomorphic Assessments on Rock River main stem and tributaries.

2.4 Hydrology

The United States Geological Survey (USGS) does not currently operate flow gages in the Rock River watershed. To characterize the hydrology of the Rock River watershed, available records were reviewed for one historic gage on the Saxe Brook tributary, and one current gage in the nearby Pike River watershed.

Historically, a USGS gage was located near the Ballard Road crossing of the Saxe Brook tributary of Rock River (reach M1S1.02) near the intersection with St. Armand Road in northwestern Highgate. The upstream drainage area of the Saxe Brook at this point is approximately 2.79 square miles (USGS, 2006). This former gage was operational from 1963 to 1974, and later from 1999 – 2002.

From the relatively limited period of record existing for this 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 the historic Saxe Brook gage (Table 1).

Table 1. Estimated flood magnitudes for Saxe Brook tributary to Rock River.

	USGS Stn #	4294200
	USGS Description	Saxe Brook near Highgate Springs, VT
	USGS Period of Record	1963-74; 1999-2002
	Upstream Dr. Area (sq mi)	2.79
	Geomorphic Reach	M1S1.02
Magnitude	**Data Source**	**Discharge (cfs)**
$Q_{1.5}$	*(VTDEC, 2001)*	50
Q_2	*(Olson, 2002)*	66
Q_5		121
Q_{10}		164
Q_{25}		225
Q_{50}		273
Q_{100}		325
Q_{500}		456

In absence of available gaging data for a given watershed, it is possible to look to gaging data for adjacent watersheds in similar geologic and topographic settings. A nearby gage in the Pike River was utilized for this purpose (see Figure 9). Station #04294300 is located mid-way along the Pike River main stem, east of the intersection of Scott Road and Boston Post Road near the Franklin / Berkshire town line. This gage measures flow from an approximate drainage area of 34.5 square miles. This is a real-time monitoring station with flow records available on the internet (http://waterdata.usgs.gov/vt/nwis). It has been operational since August of 2001, and has four complete water years of discharge records available.

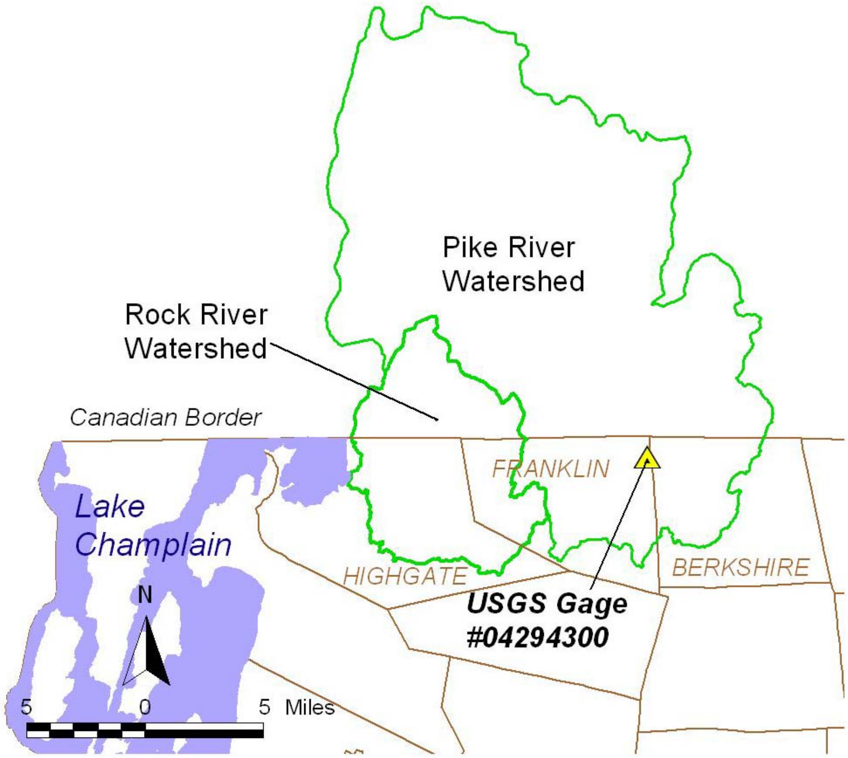


Figure 9. Location of USGS Gaging Station in nearby Pike River Watershed

Phase 2 Stream Geomorphic Assessments in the Rock River watershed were completed between 1 June 2006 and 3 July 2006. Figure 10 illustrates daily mean flows measured at the nearby Pike River gage during this time period. Daily mean flows ranged from a minimum of 56 cfs (June 25) to a maximum of 1,340 cfs (June 30), based on provisional data available from USGS (USGS, 2006).

Flows appear to have been affected by two principal rain storms (June 7-11, and July 1-2) and three lesser events (June 3-4, June 19-20, and June 26-28) (Weather Underground, 2006; precipitation records for Burlington, VT and Plattsburg, NY). During the June 7-11 and July 1-2 events, flows on the Pike River at the USGS gaging station exceeded the estimated bankfull discharge calculated using Vermont Regional Hydraulic Geometry Curve data (VTDEC WQD, 2001). Flows in the Summer of 2006 were higher than average, based on comparison to the median flow for the four years of available records for this station.

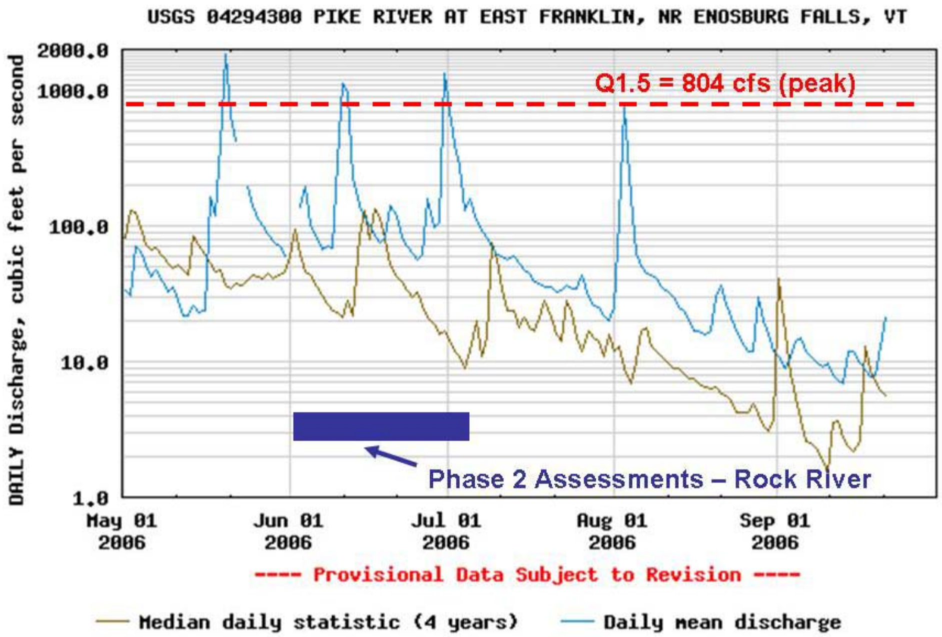


Figure 10. Provisional Daily Mean Discharges for Pike River Gage Station #04294300, during Phase 2 Stream Geomorphic Assessments, Summer of 2006.
(Base figure obtained from USGS on-line surface water data, <http://waterdata.usgs.gov/vt/nwis> *annotated with duration of Phase 2 assessments, and estimated bankfull discharge after VTDEC WQD, 2001).*

By reference to recorded flows on the Pike River, flows on the Rock River during the assessment period can be inferred to represent moderate flow conditions. It is probable that flows on the Rock River exceeded bankfull conditions during one or both of the rain events recorded for northwestern Vermont on June 7-11 and July 1-2. Field observations confirmed the occurrence of greater-than-bankfull flows (Figure 11).

Figure 11. Sediment "halo" on vegetation (see arrow) marks the high water elevation from the 6/10 – 6/12/06 storm event on the Rock River main stem downstream of the Cassidy Road crossing.

Sediment line observed was 0.5 to 1.0 foot higher than bankfull elevation measured at two cross sections within reach M06, and approximately 2.5 to 3.0 feet higher than flow stages on 6/12 and 6/13 during assessments.

There are limitations associated with using Pike River flow data to characterize flows in the Rock River, and caution should be exercised. The Pike River gage is located downstream of the confluence of the outlet channel from Lake Carmi. This channel drains an upstream area of 13.95 square miles, including the 2.1 square-mile surface area of Lake Carmi (NWRPC/SMRC, 2006; VT Dept of Forest, Parks, & Recreation, 2006). In other words, Lake Carmi and the watershed draining to it account for approximately 40% of the total Pike River watershed upstream of the USGS gaging station. Such a large waterbody can have the effect of reducing peak flows to the Pike River, as precipitation and runoff to the lake are attenuated, or stored, for a period of time before being released over the dam at the downstream end of the lake. Thus, the peak flows measured at the downstream gage are probably lower in magnitude and slower in occurrence than would be the case if Lake Carmi was not present. It is important to note that the Rock River watershed does not have a large water body like Lake Carmi. Thus, using peak flow information from Pike River to describe peak flow occurrences in the nearby Rock River, may underestimate the magnitude and timing of peak flows in the Rock River.

In addition, currently available data for the Pike River comprise only four full water years of data. Thus, the mean flow record indicated in Figure 10 (tan line), is drawn on the basis of averaging flow data from only four years of record. With increasing years of data, this median flow line may change considerably.

2.5 Flood History

Flood events can serve as a stressor to the Rock 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 Rock River watershed (Table 2). A limited historical review included annual reports for the towns of Highgate and Franklin, history books, state-wide flood publications, and interviews with local citizens. The 1927 flood is the highest flood on record in the State of Vermont.

Table 2. Notable flood events in Rock River watershed

Notable Flood Dates	Data Source
1913	USGS, 1990
1927	USGS, 1990
1936	USGS, 1990
1938	USGS, 1990; Doherty *et al.*., 1997
1940, May	US ACOE, 1978
1984, June	VTDEC WQD, 1999
1996, January	Town of Highgate & Franklin annual reports; VTDEC WQD, 1999
1997, July 5	VTDEC WQD, 1999

2.6 Land Use

The following land cover / land use data set available from the Vermont Center for Geographic Information (www.vcgi.org) was utilized to summarize land cover / land use in the Rock River watershed:

- Landcover / Landuse for Vermont and Lake Champlain Basin (LandLandcov_LCLU, edition 2003). Source dates of 1991 to 1993. Further details of this land cover / land use data set are available at: http://www.vcgi.org/metadata/LandLandcov_LCLU.htm.

Classification of land cover/ land use in the above data set follows methods of Anderson, *et al*, 1976. Land surface characteristics are classified into 17 different categories. These 17 categories were consolidated into 5 broader groups: commercial / industrial, residential, agricultural, forest / shrub, and water/wetlands.

Table 3. Land cover/ land use in Rock River watershed (Vermont portion)

Land Cover/ Land Use	Rock River upstream of Canadian border (M04); 24.6 sq. mi. drainage area
Commercial / Industrial	0.0%
Residential	5.8%
Agricultural	45.0%
Forest / Shrub	39.9%
Water / Wetland	9.3%

The above-referenced land cover / land use data set extends into Quebec, and a 1999 Lake Champlain Basin Technical Report (Hegman *et al*., 1999) summarized land cover / land use for the entire Rock River watershed as being 40% forested; 41.4% agricultural, and 5.4% urban.

Land uses have changed somewhat in the watershed since the source date for these land cover / land use classifications (1993). Anecdotal accounts indicate increased clearing of forest lands for agricultural use. There is also a reported trend of agricultural and forested lands being converted to residential and commercial uses, and the associated increase in impervious surfaces (MRBA, 2004).

3.0 ASSESSMENT METHODS

Stream geomorphic assessments conducted in the Rock River watershed utilized protocols published by the Vermont Agency of Natural Resources (VTANR, 2006), and available at: http://www.vtwaterquality.org/rivers/htm/rv_geoassesspro.htm. Reference is made to these protocols for a description of specific methods followed to complete Phase 2 Stream Geomorphic Assessments and Bridge and Culvert Assessments.

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 identify 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.

Main stem reaches from the vicinity of Browns Corners downstream to the Canadian border (reaches M07, M06, M05 and M04) were assessed by kayak. Other reaches were accessed on foot. During Phase 2 assessments, specific features and present channel positions were located using a Garmin™ eTrex Vista global positioning system (GPS) unit. Pictures were recorded with a digital camera.

Assessments were completed during the month of June 2006 and early July 2006; June was a wetter than average month. Field work was conducted within days of two principal rain storms (June 7-11, and July 1-2) and three lesser events (June 3-4, June 19-20, and June 26-28) (Weather Underground, 2006; precipitation records for Burlington, VT and Plattsburg, NY). During the June 7-11 and July 1-2 events, flows are estimated to have exceeded bankfull discharge (see Section 2.4). In particular, main stem reaches M07, M06, M05 and M04 were assessed during moderate to high flows on June 12 through 15, 2006. While the high-water conditions likely masked certain stream bank and stream bed features, this provided an excellent opportunity to observe runoff contributing areas and locations of active rill and gully erosion delivering sediment and nutrients to the Rock River main stem and its tributaries. Several small tributaries, field ditches and gullies were observed yielding small fans of sediment at their confluence with the main stem.

In accordance with protocols, specific features were digitized in ArcView© 3.x shape files, referenced to the Vermont Hydrography Dataset (VHD), using the Feature Indexing Tool, a component of the Stream Geomorphic Assessment Tool (SGAT). Phase 2 assessment data were entered into the online Data Management System (DMS) maintained by the VTDEC WQD. Phase 2 reach summary reports, standard output from the DMS, are compiled in Appendix A.

Assessments were performed under a programmatic Quality Assurance Project Plan (QAPP) generated by the Vermont Water Quality Division, River Management Section (VTDEC WQD, 2003). Quality assurance documentation is included in Appendix B.

3.2 Bridge and Culvert Assessments

Twenty-two (22) bridge and culvert crossing structures were assessed following Appendix G of the geomorphic assessment protocols (VTANR, 2006). The majority of these structures were located on reaches targeted for Phase 2 assessment; eight structures were located on alternate reaches. A listing of these 22 crossing structures is provided in Table 4; field map numbers in this table correspond to labels on the location map in Figure 12.

Table 4. Identification of Crossing Structures Assessed

Field Map No.	Reach	Road	Town	VTrans Structure Number
1	M1S1.01	St Armand Rd	Highgate	NA
2	M1S1.02	Ballard Rd	Highgate	NA
3	M1S1.04	St Armand Rd	Highgate	NA
4	M09	Hanna Rd	Franklin	NA
5	M09	Beaver Meadow Rd	Franklin	400607002106071
6	M08	Browns Corner Rd	Franklin	NA
7	M07	Barnum Rd	Franklin	400607001306071
8	M06	Cassidy Rd	Highgate	400609002206091
9	M05	Gore Rd	Highgate	400609000706091
10	M05	Tarte Rd	Highgate	100609002406091
11	M5S3.01	Boucher Rd	Highgate	NA
12	M5S5.01	Boucher Rd	Highgate	NA
13	M6S1.1S1.01	Franklin Rd	Highgate	NA
14	M6S1.01	Franklin Rd	Highgate	NA
15	M6S1.01	Durkee Rd	Highgate	NA
16	M5S8.01	Cassidy Rd	Highgate	NA
17	M9S1.01	Browns Corner Rd	Franklin	NA
18	M9S2.01	Browns Corner Rd	Franklin	NA
19	M9S4.01	Browns Corner Rd	Franklin	NA
20	M7S2.01	Browns Corner Rd	Franklin	NA
21	N/A	Hanna Rd	Franklin	NA
22	M5S4.01	Tarte Rd	Highgate	NA

Notes:
NA = Not Available

A few of the bridge and culvert structures had an assigned VTrans Structure number. Following protocols, a preliminary VTrans Structure number has been assigned to the remaining structures. Details of this process are presented in Appendix C.

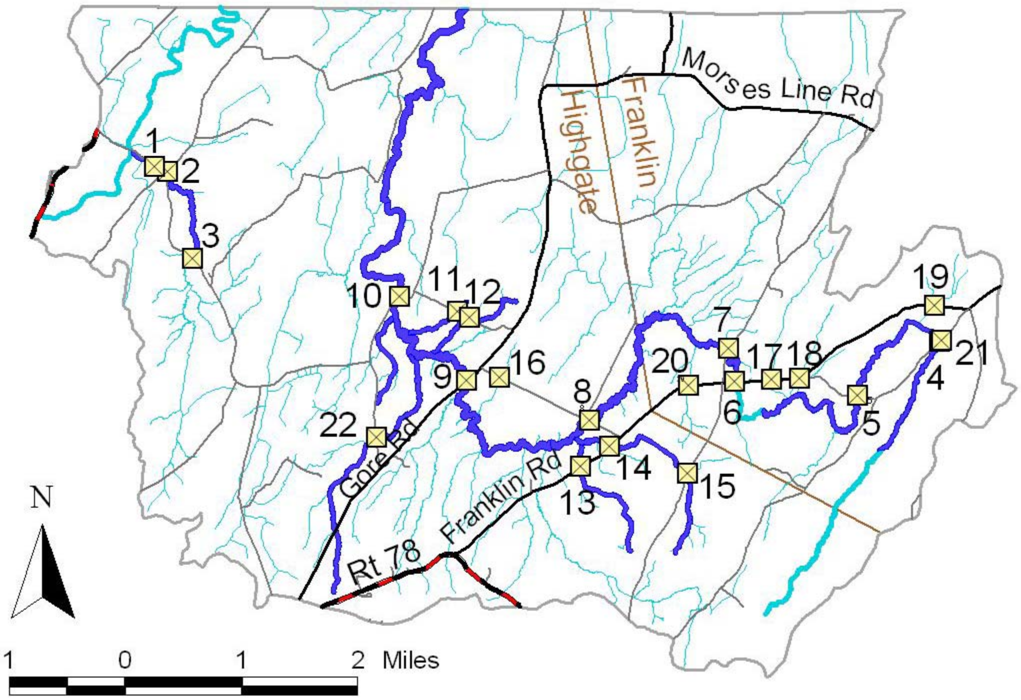


Figure 12. Location of bridge and culvert crossing structures assessed by Appendix G of VTANR protocols.

In addition to the above 22 structures, the spans of minor crossing structures, including culverts for farm roads or bridges for snowmobile trails, were also measured and recorded during Phase 2 assessments. The span of each minor and major crossing was compared to measured or predicted bankfull widths (VTDEC, 2006b), to determine if the structure was a constrictor of flows at the bankfull stage or the flood prone width elevation (10-year to 50-year flood).

3.3 Quality Assurance / Quality Control

Assessments were carried out in compliance with the VTANR Programmatic QAPP (VTANR, 2003). Select features were geo-located using the Feature Indexing Tool of SGAT (v.4.53). Data were entered into the VTANR web-based Data Management System https://anrnode.anr.state.vt.us/ssl/sga/index.cfm

Following completion of standard Phase 2 quality control checks (X.1 through X.4), Phase 2 data were submitted to the River Management Section for a quality assurance review. QA/QC documentation are contained in Appendix C.

The following considerations and limitations apply to the Phase 2 data for the Rock River watershed:

- Where applicable, reaches were segmented using the Segmentation Tool contained in SGAT (v. 4.53). Segmentation was necessary to:
  - Capture subreaches of a stream type (after Montgomery & Buffington, 1997; and Rosgen, 1994) 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;
  - Isolate in-stream wetlands;
  - Set apart sections of a reach that exhibited intermittent flow; and/or
  - Identify sections of a reach that had been tiled underground.

- 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 E, along with channel gradients calculated for each segment. Segment slopes were factored into the stream-type designation for each segment. The elevation data for the downstream and upstream ends of the overall reach were originally developed in the Phase 1 assessment of the lower Missisquoi River basin (NWRPC/SMRC, 2006). During this Phase 2, reach break elevations were often updated as a result of field-based observations, or to correct for apparent interpolation or data entry errors in Phase 1. Accordingly, channel and valley gradient calculations were updated. In no case did these updates result in a change in stream type (slope) for the overall reach.

- 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 Rock River basin (source date of 1995). However, in many cases surface waters depicted on the 1995 VHD were significantly offset from their actual position on 1995 orthophotos available for the study area. Additionally, in some cases, the actual channel position has moved from its 1995 position as a result of channel management activities (e.g., straightening) or natural channel migrations. These cases were revealed by comparison of the 1995 orthophotos with the 2003 aerial imagery (NAIP, 2003), or by review of 2006 channel positions recorded with a hand-held GPS. Thus, locations and lengths of features indexed to the VHD should be considered approximate. Waypoint logs and sketch maps contained on the Project CD provide more insight into the recorded locations of these features.

- Most of the assessed main stem and tributary reaches of the Rock River could be classified as suspended-load channels (Schumm, 1977) or washload-dominated channels (Knighton, 1998). These stream segments, flowing through cohesive silts and silty-clays of glacial and post-glacial lacustrine origins, were dominated by suspended loads of finer materials. Bedloads of coarser sands, gravels or cobbles were minor to absent in the assessed reaches. It is expected that channel form in these Rock River and tributary reaches is less connected to the erosion and deposition cycles of bedload, and more related to the flow resistance of the cohesive parent materials comprising the bed and banks. Cross sections performed in these silt/clay bed channels tended to be somewhat narrower and significantly deeper than predicted by the VTANR regional hydraulic geometry curves which have been developed for non-cohesive alluvial (gravel- and sand-bed) streams (VTDEC WQD, 2006b; VTDEC WWD, 2001). This finding is consistent with Schumm (1960), who reported a decrease in width/depth ratios with increasing percentage of silt and clay sediments in channel bed and banks.

- Most of the pebble counts performed at cross section sites in the assessed cohesive-bed reaches (outside of bedrock exposures) were over 85% silt and clay. Accordingly, stream bed substrates for these segments were classified as a "6" substrate under stream type following Rosgen (1994) (see Tables 5 and 6). However, a "6" stream type is not available at present in the DMS; stream type designations offered in the VTANR protocols for dominant particle size on the bed are classified from 1 to 5, bedrock through sand. Therefore, the silt-bed segments of the Rock River watershed were classified as "5" stream types in the DMS.

- High water conditions (6/12/06, 6/13/06) may have limited observation of streambank erosion, revetments, and bed substrates in main stem reaches M07, M06, and M05; as a consequence, quantification of these parameters may be under-represented. Turbidity of the surface water due to high suspended sediments limited observation of channel bed form and channel bed features to some degree in nearly all assessed reaches.

4.0 PHASE 2 ASSESSMENT RESULTS

Geomorphic and habitat assessments were completed on 15 reaches (25.9 river miles) in the Rock River watershed: six main stem reaches and nine tributary reaches (see Figure 8). Phase 2 assessment results are summarized below for the Rock River main stem (Section 4.1) and its tributaries (Sections 4.2, 4.3, and 4.4). Detailed Phase 2 assessment results are tabulated in Appendix A, the standard report output from the online DMS for Phase 1 & 2 Stream Geomorphic Assessment data.

Stream type designations are after Rosgen (1996) and Montgomery & Buffington (1997). Abbreviations used in the sections below include the following (see protocols):

- Left Bank, facing downstream (abbreviated, "LB")
- Right Bank (RB).
- Incision Ratio (IR) = Low Bank Height / Bankfull Max Depth
- Entrenchment Ratio (ER) = Flood Prone Width / Bankfull Width
- Large Woody Debris (LWD)
- Rapid Geomorphic Assessment (RGA)
- Rapid Habitat Assessment (RHA)

4.1 Rock River Main Stem (M)

Phase 2 assessments were completed on 15.8 miles of the Rock River main stem, including reaches M10 and M09 in the town of Franklin, skipping M08 (Bullis Pond at Browns Corners), and continuing downstream through the town of Highgate to the Canadian border. Results for the 6 reaches which comprise this section are summarized in Table 5 (and Appendix A), and findings are discussed by reach in the following text, proceeding from upstream to downstream.

Table 5. Results of Phase 2 Geomorphic Assessments, Rock River Main Stem

Reach	Seg-ment	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq mi)	Stream Type	RHA Condition	RGA Condition	Adjustment	Stream Type Departure?	Sensitivity
M10	--	6,078	0.8	1.8	C5c-R/P	0.65 Good	0.69 Good	None (minor)	No	High
M09	F	2,973	***1.2***		E4c-R/P	0.63 Fair	0.71 Good	None (minor)	No	High
	E	4,672	***0.1***		NM - Wetland (Beaver Meadow)					
	D	3,769	***0.1***		E6c-PB	0.50 Fair	0.80 Good	None	No	High
	C	913	***1.9***		C4c-R/P	0.82 Good	0.84 Good	None	Subreach	High
	B	2,445	***0.04***		NM - Wetland in upstream 1/2 and No Permission for majority of Segment					
	A	2,148	***0.05***	5.0	NM - Wetland					
M08	--	3,112	0.5	5.4	NM - Impoundment (mill pond above earthen dam/ culvert)					
M07	B	2,163	***2.0***		B3b-R/P	0.82 Good	0.90 Ref	None	Subreach	Moderate
	A	5,365	***0.2***	6.4	C6c-PB	0.69 Good	0.75 Good	None (minor)	No	High
M06	--	14,116	***0.1***	12.9	C6c-R/D	0.80 Good	0.88 Ref	None	No	High
M05	--	25,574	***0.2***	19.6	E6c-R/D	0.83 Good	0.84 Good	None	No	High
M04	B	10,180	***0.1***		C5c-R/D	0.82 Good	0.83 Good	None	No	High
	A	2,819	***0.1***	24.6	NM - limited access due to proximity to Canadian border					

Abbreviations:
S/P = Step/Pool; R/P = Riffle/Pool; R/D = Ripple/Dune; PB = Plane Bed; Casc = Cascade; Ref = Reference
RHA = Rapid Habitat Assessment; RGA = Rapid Geomorphic Assessment (VTDEC, 2006).
PF = Planform Adjustment; Aggrad = Aggradation; Wid = Widening; Deg = Degradation; NM = Not Measured.
Note: Channel slope values in italic bold have been updated since the Phase 1 SGA, due to field-truthing and/or segmentation.

M10

The Rock River originates in a wetland in a low-gradient bedrock-controlled valley near Rice Hill in the southeastern corner of the town of Highgate. Rock River flows to the northeast through this narrow valley, somewhat parallel with the Hanna Road, soon crossing into the town of Franklin. Reach M10 begins approximately 2/3 of a mile northeast of the Highgate / Franklin town line, and extends just over a mile in length (6,078 feet) downstream to the Hanna Road crossing. The valley is flanked on either side by steep slopes with shallow soil cover overlying bedrock. Given the small upstream drainage area (1.8 square miles), the channel is quite small at this point (10 to 15 feet wide). Average valley width for the channel ranges from 6 to 10 times the channel width (defined as a "Broad" valley under the geomorphic protocols).

A minor degree of development was evident along reach M10, including the Hanna Road near the downstream extent of the reach, and a residence along the left bank mid-reach. Agricultural activities have encroached on the channel to a greater degree.

Recent channelization was evident near the upstream end of the reach through hay fields. A previously meandering channel was ditched to flow first parallel with the left valley wall, then from west to east perpendicular to the valley, and finally parallel and tight to the right valley wall. This channelization appears to have been completed between 1995 and 2003 based on review of aerial photos from those years. A culvert crossing is present where the channel crosses the valley. The span of this culvert is less than the bankfull width of the channel in this location; this crossing structure is therefore considered a constrictor of bankfull and higher-magnitude flood flows.

Hay fields are present within the left corridor in the upstream half of the reach. Tree buffers are minimal to absent along left bank. The channel is "pinned" along the bedrock-controlled right bank; forested buffers extend for a width of several hundred feet from the right bank in this upper half of the reach. It is possible that the channel was historically moved to occupy the far right (eastern side) of this valley. The narrow valley through which M10 flows is created by the Hinesburg Oak Hills thrust fault; it is likely that much of the linear planform observed is also the result of lateral bedrock controls. Currently, the channel has established some sinuosity and a riffle-pool morphology (some grass channel), with occasional sediment storage in point and side bars. The channel has good floodplain access through this section. Streambank erosion is minimal.

Near the mid-point of the reach, the Rock River leaves the right valley wall and flows through hay fields, with no tree buffer on either bank. This section of the reach appears to have been historically straightened, given the nearly linear planform for a length greater than 20 channel widths. Berms are present along both left and right banks – likely sediments historically dredged from the channel. However, the channel has good floodplain access, has re-established some local sinuosity, and exhibits minimal streambank erosion.

Next, the Rock River flows through a short section (approximately 350 feet) of pasture where cows have direct access to the stream. Near-bank erosion is common through this section due to closely-cropped vegetation and hoof damage. A recently-constructed (post 2003) residence is located within the river corridor along left bank just downstream of the pasture.

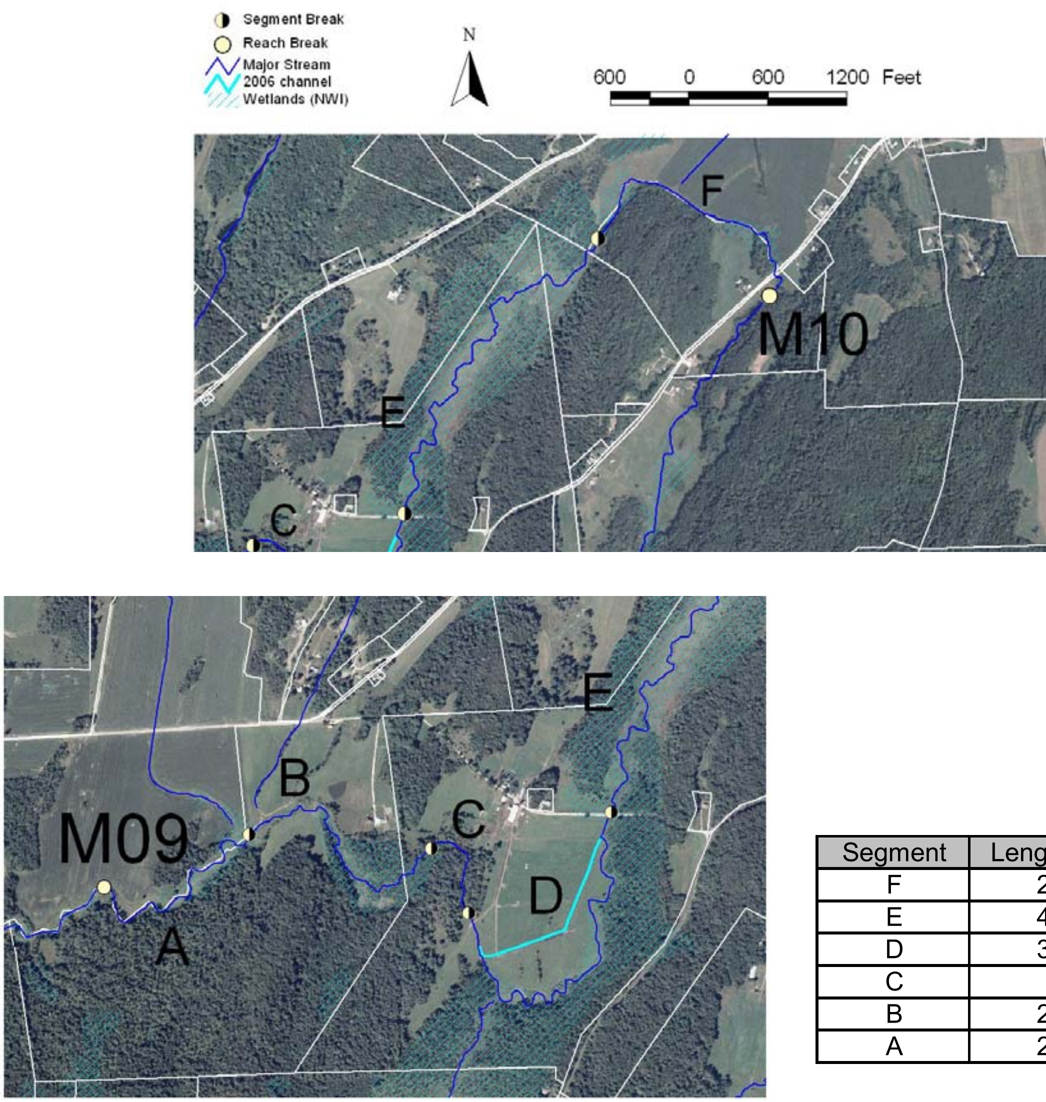
Downstream of this residence, the river is once again flowing along the right valley wall, where the occasional exposure of near-vertical bedrock walls is evident. In a couple of locations, bedrock was observed to be channel-spanning providing vertical grade control. Forested buffers are present along the right bank in this downstream section. A fallow pasture is present along the left valley wall, and a mixed herbaceous and deciduous tree buffer is revegetating along the left bank.

A cross section completed near the downstream end of the reach, indicated a C4-riffle/pool stream type, consistent with the reference stream type expected in this valley and topographic setting. Despite extensive historic channelization and limited recent straightening, the reach has good access to its floodplain and no indication of a stream type departure. It is likely that the cohesive nature of channel and valley soil types and exposures of channel-spanning bedrock have contributed to stability within the reach. Overall, the reach was rated in "Good" condition following the RGA protocol.

Habitat conditions were rated on the low end of "Good" (on the cusp with "Fair") following RHA protocols. A low diversity of channel bed forms was evident, due to historic channel management. Limited woody buffers (particularly along left bank) and streambank erosion through direct-pastured areas also contributed to less than optimal habitat conditions.

M09

Reach M09 of the Rock River main stem is approximately 3.2 miles long. It begins just upstream of the Hanna Road crossing, turns to the north and northwest around a forested bedrock knoll, flows through a broad valley between the Hanna Road to the southeast and Browns Corner Road to the northwest, crosses the Beaver Meadow Road and ends just upstream of Bullis Pond. The considerable diversity of channel types, slope, and land cover/land use within this reach, resulted in its segmentation into six distinct sections (see Figure 13). Within reach M09, the Rock River flows past corn fields along the left bedrock valley wall (Segment F), through a large beaver meadow (E), an organic farm (D), cedar forest over bedrock falls (C), a second wetland and nearby hay fields (B), and a third wetland (A).



Segment	Length (ft)
F	2,973
E	4,672
D	3,769
C	913
B	2,445
A	2,148

Figure 13. Segmentation of Reach M09, Rock River.

Overall, reach M09 has a shallow channel gradient (0.4%), an unconfined valley setting, and moderate to high sinuosity which are indicative of an E reference stream type.

Segment F

Segment F of Reach M09 extends from the Hanna Road culvert crossing downstream to the beaver meadow, flowing along the left valley wall which is bedrock-controlled. Overall, this segment has low gradient (1.2%) and channel dimensions over a majority of the reach suggested an E stream type, consistent with reference. Discrete sections of B3-step/pool and B2-cascade stream type were noted in a steeper-gradient bedrock-controlled channel in the upstream half of the segment. These occurrences of channel-spanning bedrock within the segment offer stability to the channel.

A portion of Segment F downstream of the bedrock grade controls appears to have been historically channelized. Corn is planted along the right bank where herbaceous buffers are limited to an average of 10 feet in width. A tributary (M9S4.01) joins M09-F, mid-segment. This tributary has also been channelized to create a drainage ditch through the corn field, which itself has very minimal buffer and substantial streambank erosion. A sediment delta was evident at the confluence of this tributary with the Rock River.

A cross section completed near the downstream end of M09-F indicated an E stream type (width/depth ratio of 7.4) with a fine gravel substrate. Good connection with the floodplain was indicated at the cross section location (IR = 1.0), while visual observations suggested a slight to moderate degree of channel incision further upstream in discrete sections of the segment which had undergone historic channelization.

A history of channel management in some sections of Segment F has contributed to a lack of morphologic and flow diversity, as well as limited epiphaunal substrates. Tree buffers are generally limited to the left corridor. Habitat conditions were rated in Fair condition, on the cusp with Good.

Segment E

Segment E of Reach M09 consists of a large beaver meadow. National Wetlands Inventory (NWI) wetlands and hydric soils (USDA, 2003; USDA, 1979) are mapped contiguous to the stream channel throughout the segment. The valley is very wide and slopes are gradual. The channel loses its single-thread form through this section and flow is dispersed through many braided channels winding around hummocks of soil with herbaceous and scrub/shrub (e.g., alder) vegetative cover. An RGA was not completed in Segment E, given the wetland conditions.

Segment E would be a good candidate for conservation, as it is serving an important flow attenuation function to offset the impacts of tributary ditching and tile drainage in upstream agricultural fields. Flow attenuation would reduce flood damages and associated scouring at higher flows. This segment may also be serving important sediment and nutrient attenuation functions.

Segment D

Segment D extends from the Beaver Meadow Road crossing through hay fields and pasture of an organic farm to a cedar forest. Nearly the entire length of Segment D has been modified. A 1600-foot long trench has been dredged to convey Rock River water through the hay fields and pasture of the farm. However, a portion of the flow continues to have access to the old meandering channel which flows along the left valley wall (see Figure 13). Individual paddocks on the farm are drained by several tile drains and ditches which flow from northwest to southeast and terminate at the dredged channel. The dredged channel then rejoins the original channel at the western periphery of the farm before the Rock River flows through a cedar forest (Segment C).

NWI wetlands are mapped along the left valley wall at the southern and eastern edges of the farm where the original channel flows. It is likely that prior to development of the farmstead in this location, Segment D would have been similar in appearance and stream type to Segment E. Extensive hydric soils (organic Carlisle Muck) are mapped through both segments (USDA, 2003; USDA, 1979).

A quick cross section conducted in the upper third of the ditched channel in Segment D indicated an E5-plane bed stream type. The dredged channel appeared to have good flood plain access throughout. Despite extensive channel dredging and straightening, Segment D is exhibiting very minor channel adjustments, and was rated in "Good" condition following RGA protocols. A representative for the landowner indicated that the dredged channel has not required maintenance since its original dredging in the late 1960s/ early 1970s (Gates, 2006). Several factors probably contribute to the overall channel stability in spite of significant past management. First, the original meandering channel which flows through wetlands along the left valley wall still accepts partial flow from the Rock River. Thus, bankfull and flood flows can be dissipated and attenuated in the adjacent wetlands. Secondly, the mucky, organic soils in the stream bed and banks are cohesive and largely resistant to erosion. The very gradual slope through this segment of the Rock River valley and the upstream beaver meadow also mean that flow velocities (and thus erosive forces) are quite low even during flood events. And finally, the upstream beaver meadow would tend to attenuate sediment contributions from farther up in the watershed, so that they would not be available to accumulate through Segment D and potentially lead to excessive aggradation or planform adjustment.

While Segment D is not exhibiting signs of channel adjustment or significant departure from reference condition, it remains sensitive to future changes, particularly in the event of channel or watershed modifications to upstream segments that might further alter the hydrologic or sediment regimes.

Habitat is significantly compromised within the segment; a "Fair" rating was assigned following RHA protocols. Substantial channelization has led to a plane bed channel with very limited morphologic diversity. Limited-width buffers lack mature trees which could otherwise offer shading to moderate stream temperatures, and provide LWD to serve as epiphaunal substrates. Also, close pasturing and nutrient applications and presence of limited herbaceous buffers often less than 5 feet in width along the right bank are likely contributing to nutrient impacts within the segment. Often paddock fencing was installed to the top of right bank within a couple of feet from the right edge of water.

Segment C

Segment C of Reach M09 is a brief section of channel situated between a prior-converted wetland upstream (Segment D) and a wetlands near residential and agricultural land uses downstream (Segments B, A). Segment C flows through a young growth forest of cedars and deciduous trees. Overall, the segment could be considered a gravel-bed C stream with riffle/pool to step/pool bedform in a narrow valley setting. A cross section performed near the upstream end of the reach indicated a C4-riffle/pool stream type. This cross section is characteristic of the upper and lower ends of the segment. Mid-segment, there are discrete sections of cobble and boulder step/pool channel and cascade-flow over bedrock where the channel gradient is considerably steeper and valley walls are more narrowly-confining.

Encroachments are limited in this segment. Forested buffers are greater than 100 feet in width along the left bank, and are typically greater than 100 feet along the right bank, except for a brief section of fallow pasture near the downstream end.

The segment shows good floodplain access, and was rated at the high end of "Good" following RGA protocols, meaning that it is in regime and exhibiting minor adjustments. Channel-spanning bedrock mid-segment, and ample tree cover along the near bank areas, are contributing to channel stability. Following protocol, a "High" sensitivity was assigned to the Segment due to the predominance of a C4 stream type. However, this sensitivity rating probably overstates the actual degree of sensitivity for the mid-segment bedrock controlled sections.

Habitat was rated on the high end of "Good", constrained only by the somewhat marginal buffer widths along the right bank at the downstream end of the segment, as well as some minor increases in sedimentation near this downstream end, as the channel gradient decreased heading into the downstream wetland.

Segment B

Segment M09-B was delineated to capture a wetland in the upstream half (which was not accessible or appropriate for assessment by RGA methods) and a section through hay fields in the downstream half for which access was not permitted by the landowner. Segment B was not assessed. As with Segment D (and with landowner willingness), the wetland portion of Segment B may be a good conservation location, for the potential flow, sediment and nutrient attenuation functions it could serve.

Segment A

Segment M09-A consists of a wetland, which was not appropriate for assessment by RGA methods. Again this wetland area, contiguous to downstream Bullis Pond, may serve important nutrient, sediment and flow attenuation functions, as well as contribute wildlife and instream habitat values.

M08

Reach M08 consists of the 11-acre former mill pond upstream of the Browns Corner Road crossing (alternate spellings of Bullice mill pond [Doherty *et al.*., 1997] or Bullis Pond [VTDEC WQD, 2003] have been noted). As this reach does not exhibit fluvial characteristics, it is not appropriate to assess the reach by VTANR Stream Geomorphic Assessment protocols. Reach M08 was therefore removed from the preliminary list of reaches for assessment during early Steering Committee meetings for this project (SMRC/WNRS, 2006). However, the history of channel management associated with this reach has relevance to the current condition of surrounding reaches.

The Browns Corner Road crosses an earthen dam which was originally constructed circa 1842 by Lorenzo Olds. Water power at this dam site served a sawmill operating along the eastern bank of the Rock River, and a box shop and blacksmith for manufacture of wagon wheels and boxes operating on the west bank of the river. The box shop was apparently operational from circa 1847 until the early 1880s; the sawmill was in operation from approximately 1843 through 1951. During this time span, historical records indicate that a shingle mill and a grist mill may have also operated at the sawmill site. The saw mill was washed out during flooding from the 1938 hurricane, but was later rebuilt (Doherty *et al.*, 1997; Walling, 1860).

Floods in January of 1996 reportedly exposed the original mill dam under the Browns Corner Road. The present culvert was installed in 1997 to replace a culvert blown out during flooding. The elevation of the culvert was reportedly lowered during this most recent replacement, leading to a reduced elevation of the water surface in Bullis Pond (Fiske, 2006; Kempton, 2006).

(a)

(b)

Figure 14. M08. (a) Bullis Pond upstream of Browns Corner Road. (b) Rock River flows through a squash-bottom culvert under Browns Corner Road; water free falls, dropping approximately 8 feet to a cobble-dominated riffle-pool channel.

M07

Reach M07 extends from Bullis Pond near Browns Corners downstream through agricultural and residential properties to the vicinity of the Franklin / Highgate town line. The upstream end of reach M07 flows over channel-spanning exposures of ledge and small bedrock waterfalls. This portion of the channel has a notably steeper slope (2.1%) than the remainder of the reach (0.2%). The upstream end of the channel is also somewhat more confined by the valley walls (one to three times the channel width) than the remainder of the reach which runs through a narrow valley typically five to six times the channel width. These geologic and geomorphic features suggest a different reference stream type for the upstream end of the reach. To capture this "subreach" as defined in VTANR assessment protocols, the reach was segmented just upstream of the Barnum Road crossing (upstream Segment B: 2,163 feet; downstream Segment A: 5,365 feet).

Segment B

Segment B extends from just below Bullis Pond and the Browns Corners Road crossing downstream nearly to the Barnum Road crossing. From the upstream end of this segment, a cobble- and gravel-dominated riffle/pool channel flows through a semi-confined valley, passing over several channel-spanning ledge exposures. The river then turns sharply to the southwest to flow through vertical walls of bedrock up to 16 feet above the channel. The channel is locally steeper through this mid-section (closer to 4%), exhibiting both a boulder-step/pool and bedrock-cascade channel form. This section of gorge was estimated at 280 feet in length. The Walling historic map indicates a mill pond and saw mill in this approximate location (Walling, 1860). The presence of a historic mill dam at this location was also indicated by the landowner, Adrian Rainville (Rainville, 2006). The channel then turns sharply to the northeast and north, evolving back to a gravel-dominated riffle/pool channel, through a semi-confined valley. In this lower third of the segment, the channel passes over more exposures of bedrock ledge east of the barns along Barnum Road, through pasture spanning both banks, to the Barnum Road crossing.

(a)

(b)

Figure 15. Boulder step/pool channel location at the mid-point of Segment M07-B. 29 June 2006. (a) view upstream to waterfall (b) view downstream.

Channel dimensions and stream types were highly variable throughout the subreach, due to significant planform and profile controls offered by bedrock. A cross section performed in the narrow bedrock gorge, indicated an A1-cascade stream type. In channel lengths immediately surrounding this cross section point, boulders obscured bedrock and valley walls were slightly less confining, suggesting a B2-step/pool stream type. Outside of the gorge, substrates were a mixture of gravel riffle/pool bedforms with frequent exposures of bedrock (not always channel-spanning) and bedrock step/pool bedforms. Visual observation of bankfull features and valley walls, indicated good channel connection to a semi-confined (2 to 4 times channel width) floodplain, consistent with a B stream type. To capture the average overall condition, Segment B of M07 was assigned a B3-riffle/pool stream type.

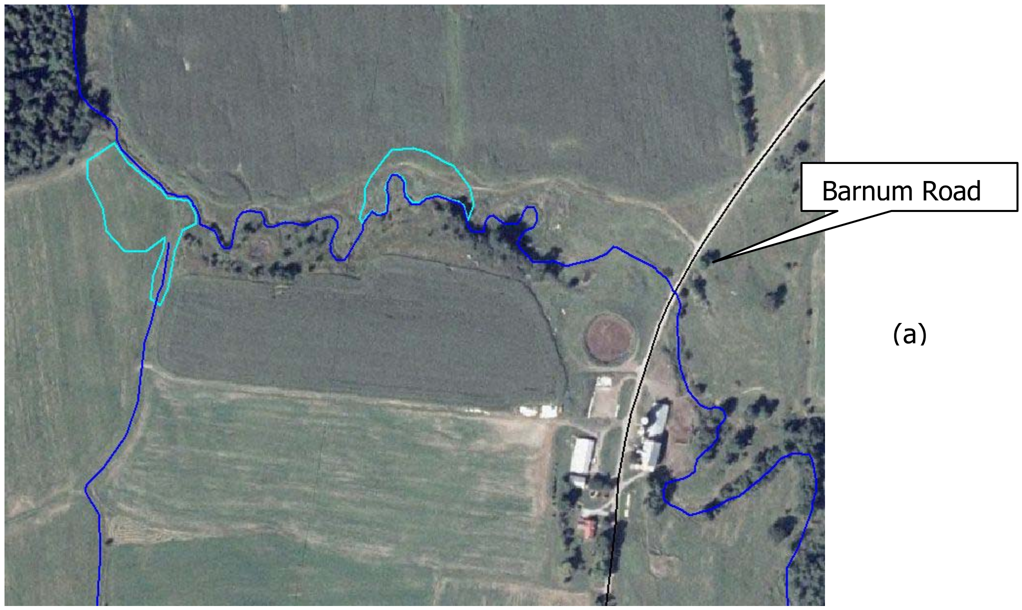
Frequent exposures of bedrock in the channel bed and banks offer stability to the segment. Minimal stressors were identified within the segment, save for direct pasturing at the downstream end. It is likely that sediments are trapped in upstream wetlands and Bullis Pond at the upstream end of the segment. However, since bedload is minor in the Rock River to begin with, and the stream is dominantly a suspended-load channel, the minor reduction in sediment loads is not expected to have had a significant impact on the channel downstream of this dam (for example, in the form of sediment-depleted waters initiating channel scour). No evidence of active channel incision was noted in Segment B. Minor channel aggradation and widening were noted immediately upstream of the bedrock gorge and local to LWD. Stream bank erosion in the segment was very minor and typical of natural channel processes. Channel planform was largely the same as viewed on 1995 and 2003 aerial photographs. The segment scored in Reference condition following the RGA protocol.

Overall, Segment B scored in Good habitat condition. The upper two-thirds of the segment is optimal, while the lower third would probably score in the Fair category due to direct-pasturing effects. The RB has more continuous and well-vegetated buffers than the LB, which is more closely encroached upon by agricultural activities. There is an abundance of fresh-water mussels within the channel upstream of the gorge; an abundance and good variety of macroinvertebrates were also observed in this section based on a brief visual survey. Turbidity was very low in this segment, which was assessed on 29 June within two days after a small storm event, but more than 17 days after the approximate bankfull event on 6/11 – 6/13/06. The upstream wetlands and Bullis Pond likely provide sufficient residence times for deposition of suspended sediments, as well as potential treatment of nutrients.

Segment A

Segment A of Reach M07 extends through a broad, low-gradient valley passing from low-intensity horse pasture near the Barnum Road crossing, through agricultural fields and forested wetlands to the confluence of a large right-bank tributary. Other than adjacent croplands, encroachments are minimal throughout the segment. A farm road follows along right bank for approximately 150 feet of the segment; and fill material for the Barnum Road culvert crossing fills the stream valley at the upstream end of the segment. This culvert crossing is undersized with respect to the bankfull width, and a large scour hole has developed downstream of the culvert outlet. Possible channel straightening is indicated by the linear planform of the channel within 500 feet of the crossing. Channelization is also suggested by linear planform between closely encroaching crop fields near the middle of the segment. Herbaceous buffer widths are limited in this 750-foot long section, ranging from 5 to 10 feet. These two separate sections of inferred historic straightening total approximately 1,270 feet in length, or approximately 24% of the total length of segment M07-A.

Observation of bankfull features, and a cross section completed near the upstream end of the reach, indicated good floodplain access throughout the segment. Assessments were conducted as flows from a recent rain storm were just beginning to recede (explained further in Section 2.4). This timing afforded the observation of saturation excess overland flow from the lower-elevation portions of adjacent croplands along the segment (see Figure 16).



(a)

(b) (c)

Figure 16. M07-A. Runoff contributing areas (saturation excess overflow) observed on 12 June 2006, as flood waters from a greater-than-bankfull flow were receding. (a) runoff contributing areas (RCAs) are outlined in light blue; Rock River flow is from picture right to picture left. Kayak access was possible in the downstream RCA which inundated recently emerged alfalfa (b); and in the downstream RCA which extended well into a recently planted corn field (c).

Buffer areas were inundated and water extended well into fields that had been recently tilled and planted. Rill erosion was also observed through the emergent crops, and small deltas of fine sands and silt extended out into the runoff contributing areas.

Despite some evidence of historic channelization, the Rock River appears to be maintaining good access to its floodplain through M07-A. At the cross section site conducted in the upstream half of the segment, an incision ratio of 1.27 was measured. A minor degree of planform adjustment and localized widening are occurring, as well as some minor aggradation due to limited streambank erosion within the reach and point sources of sediment runoff from fields. However, the segment appears to be in regime, and is not exhibiting a stream type departure. The measured C6-plane bed stream type is consistent with the reference stream type. A rating of "Good" was assigned to the segment following RGA protocols. Channel adjustments might be expected given the apparent channelization in discrete locations, as well as the lack of vertical grade control and absence of forested buffers. However, the cohesive nature of silt bed and banks, as well as the relatively shallow gradient of this reach may be moderating the potential for channel incision and widening.

An overall habitat rating of "Good" was assigned following RHA protocols. Good bank stability is afforded by cohesive soils, and excellent vegetative cover (although trees are not well represented in the upstream half of the segment). Buffer widths could be increased in the upstream half of the segment, although the landowner reported the current infrequent horse pasture is an improvement over previous more intensive pasturing (Rainville, 2006). Water quality impacts (sediment / nutrients) are likely due to the observed high-water inundation of corn and alfalfa fields, as well as rill erosion.

M06

Reach M06 flows from the vicinity of the Franklin / Highgate town line downstream to a point mid-way between the Cassidy Road crossing and the Gore Road crossing. This low-gradient highly sinuous reach is in a narrow valley, generally 4 to 6 times the channel width – a valley setting that would suggest a C reference stream type. The top of the valley wall along left and right bank varies from perhaps 5 to 25 feet in height along the reach. Hay and cropped fields, and the occasional pasture are developed along the tops of LB and RB valley walls. Within the reach, the Rock River is crossed once by a VAST trail bridge near the upstream end and a second time by the Cassidy Road box culvert. The VAST trail bridge decking had separated from its foundation and was observed floating and wedged between the stream banks approximately 320 feet downstream of the crossing location (see Figure 17). A third crossing was visible on 2003 aerial photography at a pasture area mid-reach; however, this crossing had apparently been removed or washed out in the subsequent three years. A large culvert was observed along right bank in the vicinity of this former crossing.

(a)

(b)

(c)

Figure 17. M06. VAST trail bridge crossing near the upper end of reach M06. The bridge decking and railing has separated from the bridge foundation and has moved approximately 320 feet downstream where it is now wedged between left and right banks.
(a) map view (2003 aerial photograph), flow in Rock River is from upper right to lower left.
(b) left bank bridge foundation on concrete; recent flows have scoured around the footer;
(c) decking and railing floating mid channel.

Other than the road approach material which fills essentially the entire bankfull channel at the Cassidy Road box culvert, encroachment by roads, berms, railroads or other development is negligible within the reach. Agricultural lands encroach somewhat closely along the channel margins. Buffers of alders and other shrubs, as well as occasional pockets of deciduous floodplain forest, are maintained at an average width of 50 to 100 feet along both banks. In certain areas, buffers are greater than 100 feet, and there are select locations where buffers are absent or very minor in extent. One prominent example is a 1,580-foot length of channel mid-way along the reach, through pasture where dairy cattle have direct access to the Rock River and probably cross the channel during lower flows.

At the downstream reach break of M06, the Project Team encountered a channel-spanning exposure of varved clays. This low-profile "ledge" of clays is exposed for an approximate channel length of 120 feet (Figure 18). At moderate to high flows encountered on the assessment date (6/13/2006) 24 to 36 hours following a storm event, a portion of the clays was exposed above water level along the inside of the meander bend adjacent to a vegetated point bar feature. Apparent desiccation cracks observed in the clay exposed at and just below the day's water level, had allowed for individual blocks of clay to separate from the "ledge" and these were being mobilized downstream as bed load.

(a) (b)

Figure 18. M06. A 120-foot channel-spanning exposure of varved clays serves as a local vertical grade control for the channel. (a) view downstream (b) closeup view of varved clays exposed above 6/13/2006 water level on the inside of the meander bend.

Two cross sections completed within the reach, near the upstream and downstream ends, indicate a C6-plane bed stream type. The upstream cross section had a width/depth ratio close to 12, suggesting the narrower and deeper channel cross section of an E stream type. Channel bed and banks were dominated by silt and clay with an occasional, very thin veneer of fine to medium gravel at the thalweg. The channel had good access to the floodplain throughout. A silt "halo" on the stream bank vegetation, left by the recent bankfull or higher flow event, supported more traditional indicators of bankfull elevation, such as sediment benches (see Section 2.4, Figure 11). It is anticipated that tile drainage and ditch drainage networks along adjacent fields have lead to an increase in magnitudes of peak flows within the Rock River main stem. Despite this upland channel management, the Rock River does not appear to be exhibiting signs of active channel incision (such as, tributary rejuvenation, disconnection with its floodplain, or head-cutting within the main channel). It is likely that the cohesive silt and clay bed and banks of the river have moderated the potential for channel incision. It is also possible that the degree of increased flows from tiling and ditching has not exceeded thresholds for erosion of the silt/clay bed and banks.

There are minor signs of channel widening or aggradation. Some evidence of planform adjustment was noted (e.g., flood chutes on the inside of meander bends, and a mild degree of meander migration apparent from comparison of 1995 to 2003 aerial photos). Other than a background level of low-level scour at and below the bankfull elevation and one mass failure, erosion along stream banks was minimal through the reach. Riverbank soils are cohesive and resistant to major erosion; a high density of alders and other shrubs along the near-bank channel margins, appears to be contributing to channel stability. Erosion on the outside of bends did appear somewhat excessive in the pastured area, stressing the importance of maintaining shrub and tree buffers along the channel margins.

The reach appears to be efficiently transporting its bedload (which is minor given the geologic parent material). Suspended sediment loads are very high, particularly downstream of tributary and ditch / tile confluences. Several small wetland areas adjacent to the channel were observed (i.e., former meander oxbows); the silt line from recent high water indicated that these wetland areas are inundated at bankfull and higher flow stages. Many of the tributary confluences demonstrated wide areas of inundation as well. These channel-contiguous wetlands may provide flow and nutrient attenuation functions for the Rock River and sufficient residence time to deposit some of the suspended sediment loads.

Several tile drains and ditches were observed leading from adjacent hay and corn fields to join the main channel from both LB and RB. Two of these channels had developed into small gullies with active head-cutting. In local areas of adjacent fields, saturated soils and tile infiltration rates appeared to be overwhelmed by the rains of June 12-13. Saturation excess overland flows were converging in surface swales and flowing through herbaceous buffers directly to the Rock River. The observed practices of tilling/cropping on moderate slopes and cropping directly through surface swales are contributing to the mobilization of fine sediments and nutrients. Fine sands and silts had accumulated in at least four of these channels, just upstream from their confluence with the Rock River. It is possible that recent high flows had eroded more delta sediments downstream. One prominent delta of recently deposited fine sands and silts was also observed at the confluence of tributary reach, M6S1.01 (see Section 4.2.1). Sediment bars were negligible through the reach M06; it is possible that small bars would be submerged below the day's moderate flow stage, obscured from view by the turbidity.

Habitat conditions in M06 were rated as "Good" following the RHA protocols. A moderate number of snags, submerged logs, and undercut, submerged benches of varved clays and till provided good epifaunal substrates. High sinuosity within the reach created frequent meander cross-overs and pools; however, pool depths in this cohesive, silt-bed system were only marginally deeper than the runs at meander crossover points. Near-bank areas are generally well covered by herbaceous plants and shrubs; however, spotty tree cover has resulted in less than optimal bank canopies. Direct-pasturing in one location mid-reach has resulted in closely-cropped vegetation along the channel margins, bare streambank soils due to hoof damage, absence of woody buffers to provide shading and sediment stability, and opportunities for animal waste to enter directly to the Rock River.

Other conditions were noted within the reach that are not well captured by the RHA in its current form, but nevertheless are expected to have a detrimental impact to instream habitats. These include: (1) the high suspended load (turbidity) observed in the channel, which is not necessarily limited to stormflow conditions; and (2) observed runoff of sediment and nutrients from adjacent hay and crop fields.

M05

Reach M05 of Rock River is a very long reach meandering nearly 5 miles through southern Highgate. The reach extends from a point mid-way between the Cassidy Road crossing and the Gore Road crossing to the vicinity of Rollo Road. Rock River crosses under Gore Road and Tarte Road along the length of reach M05.

Over geologic time frames (several thousand years before present) the Rock River within reach M05 has incised into lacustrine silts and clays of the Champlain Sea and Lake Vermont (see Section 2.2). The channel now flows through a narrow to semi-confined valley setting, ranging from 3 to 5 channel widths. While some variation in valley confinement and channel bed material was observed along the reach, features were not compelling enough to warrant segmentation or delineation of a subreach.

Figure 19. Reach M05 flows through a narrow to semi-confined valley.

Overall, Reach M05 was typed as an E6-ripple/dune channel with stream bed and banks dominated by cohesive silts and clays. For approximately one mile at the upstream extent of the reach, channel dimensions indicate a slightly greater width/depth ratio, slightly steeper gradient, and coarser bed materials (a C4-riffle/pool stream type). There are also two short sections of locally narrower valley setting: (1) near the downstream end of the reach just upstream of the Tarte Road crossing (a Bc5-ripple/dune setting); and (2) a brief section of Bc stream type downstream of the Tarte Road crossing, where bedrock exposed in the bed and banks has resulted in a narrowly-confined valley and linear planform.

Channel-spanning bedrock is exposed upstream and downstream of the Tarte Road bridge crossing, and a series of waterfalls are revealed mid-way between the Tarte Road crossing and the downstream reach break (Figure 20). These exposures are vertical grade controls offering stability to the reach.

Encroachment by roads and development is limited within reach M05 probably due to the topographic setting of the river in a valley with steep slopes. A majority of the reach has well-developed buffers of mixed deciduous and coniferous forest. There are a few locations of recent pasture use, such as downstream of the Gore Road crossing and upstream of the Tarte Road crossing. Livestock have recently been excluded from these areas and previously pastured areas are now fallow.

*Figure 20.
Bedrock falls encountered near the downstream end of reach M05.*

Several tributaries draining residential and agricultural sub-watersheds join the Rock River within reach M05 (see Section 4.2.2). Small deltas of fine sand were observed at four of these tributary confluences, and fine sediments were accumulating in these tributaries upstream of the confluence. It is possible that recent high flows had eroded more delta sediments downstream. High turbidity in the tributary and main stem channels indicated ample suspended clays and silts. Point, mid- and side bars were minor through the reach; although it is possible that small bars would be submerged below the day's moderate flow stage, obscured from view by the turbidity.

Two cross sections were completed within reach M05. The first near the upstream end indicated a C4-riffle/pool stream type, consistent with the valley setting and locally steeper gradient in this upper 1/5 of the reach. A second cross section, completed near the downstream end of the reach, was considered more characteristic of the reach overall. A width/depth ratio less than 12 and a pebble count dominated by silt, suggested an E6c-ripple/dune stream type. The channel had good access to the floodplain throughout.

It is anticipated that tile drainage and stormwater runoff have lead to an increase in magnitudes of peak flows within the Rock River main stem. Despite these flow alterations, the Rock River does not appear to be exhibiting signs of active channel incision. It is likely that the cohesive silt and clay bed and banks of the river have moderated the potential for channel incision. It is also possible that the degree of increased flows from tiling and ditching has not exceeded thresholds for erosion of the silt/clay bed and banks.

Signs of substantial channel widening or aggradation were not observed. Some evidence of planform adjustment was noted (one recorded flood chute on the inside of a meander bend, six mass failures indicating active meander extension). Other than these localized areas of mass failure, erosion along stream banks was reasonably limited through the reach.

Habitat conditions were rated as "Good" following RHA protocols. Moderate numbers of snags, debris jams, and submerged logs, were noted in the reach, providing epifaunal substrates. Moderate to high sinuosity within the reach created frequent meander cross-overs and pools. Near-bank areas were well covered by herbaceous plants and trees, except in localized areas of active and healed mass failures.

M04

Reach M04 flows from the vicinity of the southern loop in Rollo Road north to the Canadian border. Due to limited access, the Project Team pulled out of the Rock River approximately 3,000 feet upstream of the Canadian border during kayak assessments on 14 June 2006. This downstream portion of the reach was segmented (Segment A) to record that it was not assessed.

Natural valley widths in this reach range from 1.5 to 5 times the bankfull width. The upper third of the reach is narrowly-confined by steep bedrock-controlled valley walls, while the remainder of the reach is semi-confined to narrow.

The RB corridor is mostly forested, with occasional crop fields; buffer widths are greater than 100 feet. The LB corridor is occasionally forested, but predominantly active dairy pasture (Figure 21a). Buffer widths are often 5 to 25 feet in width, but sometimes absent. High streambank erosion is evident at these gaps in the woody buffer along LB. Several sections of pasture fencing were observed leaning into (or collapsed into) the river channel from the left top of bank.

(a) (b)

Figure 21. Reach M04. (a) View upstream (to south) from LB pasture accessed along Rollo Road. (b) equipment ford leading from LB pasture. 3 July 2006.

Other than pasture along the LB, encroachments along reach M04 are relatively minor. Old laid-up stone abutments are present near the upstream end of the reach, coincident with a historic road crossing indicated on the 1987 USGS 7.5-minute topographic map. Further downstream, there are two equipment fords which permit access to agricultural fields to the east of the river. One is located mid-pasture (Figure 21b); the second is located further downstream north of the adjacent Rollo Road farmstead. The relatively coarser sediments comprising the second equipment ford form a local nick point with a control height of approximately 2 feet. A large lateral and vertical scour pool has developed downstream of this ford. Based on comparison of 1995 photographs to 2006 GPS points, this ford appears to have been in the same location for at least the previous 10 years.

A cross section completed mid-reach suggests a C-stream type with bed and banks that are comprised dominantly of silt with a small percentage of coarse sands (Figure 22). Overall, there is a lack of pool-riffle diversity, and pool depths are not much deeper than runs. The upstream third of the reach would likely be classified as a Bc stream, given the more narrow confinement by the bedrock-controlled valley walls.

Overall, Reach M04 is in a minor state of adjustment, and rated in Good condition following the RGA protocol. Three small tributaries draining the pasture along LB were observed to have deltas of fine sediment at their confluence with the main stem. The farm roads leading to the equipment ford crossings are sources of stormwater and sediment runoff to the Rock River.

Figure 22. M04. Cross section measurement on 3 July 2006; flows are moderate to high following 30 June and 1 July greater-than-bankfull event; high suspended sediment loads result in very high turbidity.

Habitat conditions in reach M04 (Segment B) were rated in Good condition. Factors contributing to a less than optimal rating included streambank erosion, particularly along the LB. Typically, these areas of erosion are associated with close pasturing and localized absence of tree buffers. Sediment loading from pasture areas and equipment fords are also contributing to turbidity in the reach and likely nutrient impacts. On a positive note, ample recruitment of LWD (104 LWD and 4 debris jams in this 10,180-foot segment) is contributing to development of pools and is providing epiphaunal substrates.

4.2 Tributary Reaches

Several tributary reaches draining to the main stem of the Rock River were selected for study, as detailed in the *Initial Field Visit & Scoping Report* (SMRC/WNRS, Jan 2006). Most of the tributaries are short in length and unnamed on the USGS topographic coverage for the basin, with the exception of Saxe Brook.

Phase 2 results for the tributaries are summarized in Table 6. Findings are discussed by reach (segment) in the sections below, proceeding generally from upstream along the main stem (town of Franklin) to downstream (town of Highgate). Data are also provided in Appendix A.

Table 6. Results of Phase 2 Geomorphic Assessments, Rock River Tributary Reaches

Reach	Seg-ment	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq mi)	Stream Type	RHA Condition	RGA Condition	Adjustment	Stream Type Departure?	Sensitivity
M6S1.01	D	1,566	***0.6***		NM - tiled underground					
	C	3,312	***0.9***		NM - Wetland					
	B	2,082	***1***		E6c-PB	0.46 Fair	0.64 Fair	Deg (moderate)	No	Very High
	A	4,380	***0.7***	1.5	E6c-PB	0.61 Fair	0.75 Good	No (minor)	No	High
M6S1.1S1.01	B	1,949	***1.2***		NM - intermittent					
	A	4,521	***0.9***	0.4	E6c-PB	0.45 Fair	0.78 Good	No (minor)	No	High
M5S5.01	D	1,904	***2.7***		NM - intermittent					
	C	1,029	***4.4***		NM - intermittent					
	B	870	***2.1***		NM - Wetland					
	A	1,589	***1.9***	0.2	B6c-PB	0.64 Fair	0.55 Fair	Deg (moderate)	No	High
M5S4.01	G	2,395	***1.4***		NM - intermittent					
	F	1,645	***0.9***		NM - Wetland					
	E	2,012	***0.4***		G6c-PB	0.38 Fair	0.53 Fair	Deg	E to G	Extreme
	D	3,136	***0.5***		B6c-PB	0.40 Fair	0.55 Fair	No (minor)	E to Bc	Extreme
	C	2,442	***0.9***		E6c-PB	0.56 Fair	0.83 Good	None	No	High
	B	2,238	***0.4***		E6c-R/D	0.76 Good	0.85 Ref	None	No	High
	A	480	***0.2***	1.0	C4c-R/P	0.81 Good	0.79 Good	Minor Aggrad, PF	Subreach	High
M5S3.01	D	895	***1.3***		NM - tiled underground					
	C	738	***1.8***		F6c-PB	0.42 Fair	0.59 Fair	None (historic deg)	E to F	Extreme
	B	607	***1.6***		NM - Wetland					
	A	1,169	***2.4***	0.15	G6b-PB	0.45 Fair	0.53 Fair	Deg, Wid	E to G	Extreme
M5S2.01	C	1,814	***2.6***		NM - tiled underground					
	B	2,585	***1.0***		F6c-PB	0.41 Fair	0.59 Fair	None (historic deg)	C to F	Extreme
	A	405	***1.0***	0.35	E6c-PB	0.80 Good	0.75 Good	None (minor)	No	High
M1S1.03	B	1,614	***0.4***		E4c-R/P	0.83 Good	0.84 Good	None (minor)	No	High
	A	3,499	***0.1***	2.6	E6c-PB	0.41 Fair	0.59 Fair	Deg	No	Very High
M1S1.02	B	511	***2.3***		C4b-R/P	0.82 Good	0.81 Good	None (minor)	No	High
	A	230	***15.2***	2.6	A1a-casc	0.83 Good	NM	None	Subreach	Low
M1S1.01	B	156	***1.9***		D4-braided	0.65 Good	0.53 Good **	PF, Aggrad, Wid	Subreach	Extreme**
	A	1,848	***0.4***	2.9	C6c-PB	0.45 Fair	0.69 Good	None (minor)	No	High

Abbreviations:
S/P = Step/Pool; R/P = Riffle/Pool; R/D = Ripple/Dune; PB = Plane Bed; Casc = Cascade; Ref = Reference
RHA = Rapid Habitat Assessment; RGA = Rapid Geomorphic Assessment (VTDEC, 2006).
PF = Planform Adjustment; Aggrad = Aggradation; Wid = Widening; Deg = Degradation; NM = Not Measured.
** Adjustment processes are natural in alluvial fan setting; over-rode condition to Good due to absence of human stressors. Assigned "Extreme" sensitivity.
Note: Channel slope values in italic bold have been updated since the Phase 1 SGA, due to field-truthing and/or segmentation.

4.2.1 Unnamed Tributaries to M06

Windshield surveys during 2004 Phase 1 assessments revealed closely-cropped pasturing, direct stream access by cattle, and substantial rill erosion along tributary M6S1.01. Therefore, this reach, and a tributary to the tributary, were selected for field-based assessment in Phase 2. Supporting the need for assessment, this tributary confluence of M6S1.01 was the site of a large sediment delta observed during assessment of the Rock River main stem (reach M06). M6S1.01 and M6S1.1S1.01 have drainage areas of 1.5 square miles and 0.4 square mile, respectively.

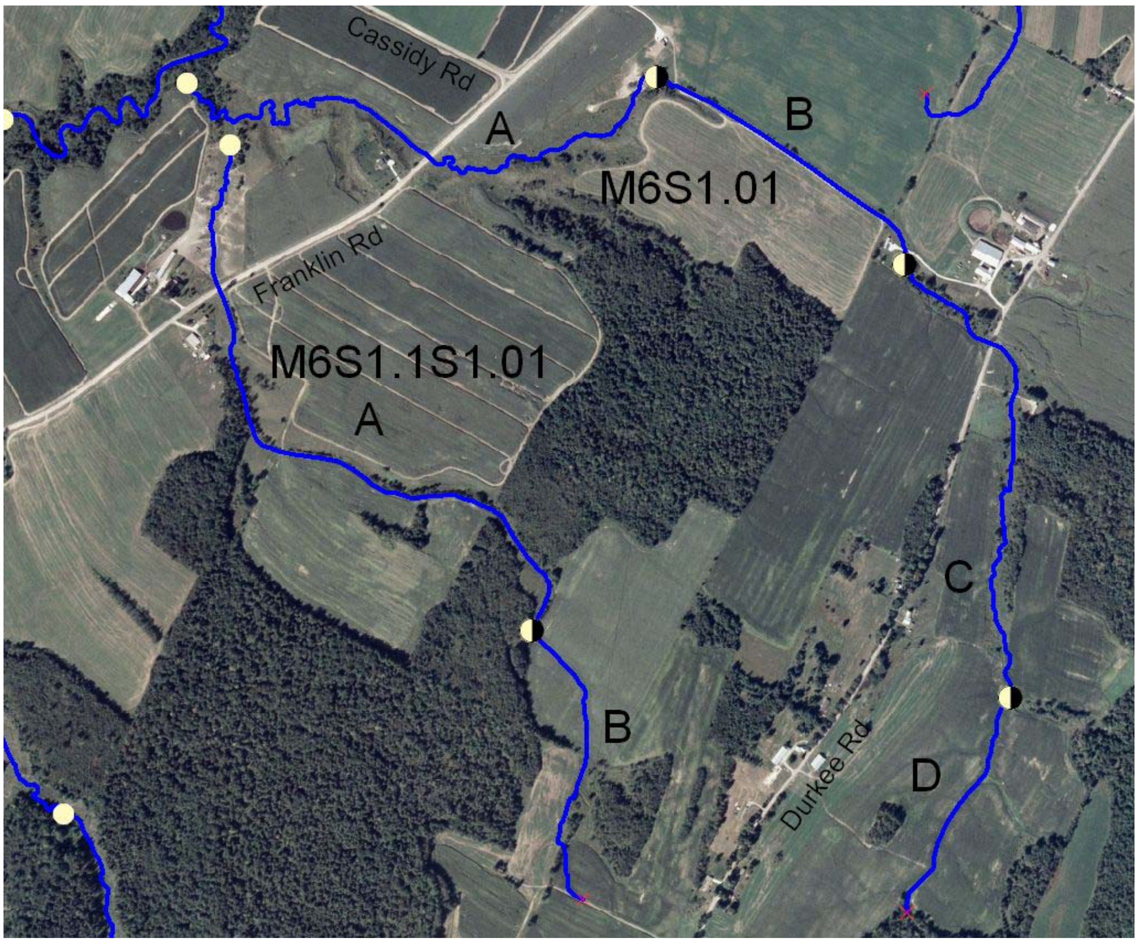


Figure 23. Location of assessed tributaries to M06, Rock River, Highgate, Vermont.

M6S1.01

Reach M6S1.01 is a two-mile reach originating in agricultural fields southeast of Durkee Road, then flowing through residential and agricultural lands under Durkee and Franklin Roads before joining the Rock River main stem downstream of the Cassidy Road crossing. The channel is located in an unconfined setting of valley widths which are typically greater than 6 times the channel width. Reach M6S1.01 was segmented: Segment D (tiled underground), Segment C (predominantly, a marshy wetland channel), Segment B (historically channelized), and Segment A (showing a greater degree of floodplain connection and more sinuous planform) (Figure 23).

Segment D

Segment M6S1.01-D is approximately 1,566 feet in length and has been tiled underground to facilitate cropping. As such, this segment was not assessed.

Segment C

Segment M6S1.01-C is approximately 3,312 feet in length and flows through marshy vegetation over hydric soils. NWI wetlands are mapped contiguous to the channel. One farm road culvert crossing and one residential driveway culvert crossing span Segment C before it crosses under Durkee Road to flow through a brief section of gravel-dominated, riffle-pool channel. Given the wetland characteristics of the majority of this segment, a Rapid Geomorphic Assessment was not completed. Segment C may be serving an important nutrient and sediment attenuation function downstream of cropped fields.

Segment B

Segment B begins at the next downstream culvert crossing for a residential driveway and extends approximately 2,082 feet downstream to another driveway culvert crossing. This segment of M6S1.01 has been historically straightened to facilitate cropping. Recent dredging appears to have been conducted to maintain this channel as an agricultural ditch (Figure 24). As a result, the channel bed has been lowered in elevation relative to the surrounding floodplain. Spoils from dredging have been placed along the left bank of the channel, further limiting floodplain access. A farm road also encroaches along the left bank of the channel for a few hundred feet. Several points of surface runoff and tile drainage from adjacent fields were noted along the segment.

A cross section completed mid-segment indicates an Ec-plane bed stream type with a silt/clay bed and a minor degree of incision (IR = 1.2). At discrete locations along the length of the segment, incision ratios appeared greater in degree, but not to the extent of causing a stream type departure. A possible head cut or nick point in the cohesive silt bed of the channel was noted near the upstream end of the segment. It is likely that the cohesive silts and clays of the stream bed and banks are moderating channel incision and widening processes. Also, an occurrence of channel-spanning bedrock near the culvert crossing at the upstream end of the segment would likely serve to isolate incision processes within the segment from migrating upstream in the tributary.

Figure 24. M6S1.01-B.
Recent dredging was evident in this channelized segment which flows through dense silts and silty-clays.
View upstream, 29 June 2006.

Overall, the segment was rated in Fair geomorphic condition. Following VTANR protocols, the segment was assigned a D-stage Channel Evolution Model (CEM), and appears to be in Stage IIb. In contrast to the description of typical D-stage channels provided in the VTANR protocols (Appendix C), it is theorized that future widening, aggradation and planform adjustments will not be substantial in this segment, for the following reasons:

- high degree of erosion resistance of the silt and silt-clay bed and banks;
- relatively low stream power of the channel which drains less than 1.5 square miles at this point;
- observation of the condition of similar sized channels in similar topographic and geologic setting (e.g., M5S2.01-B; M5S3.01-C; M5S4.01-D); and
- the very fine-grained nature of source materials in the bed and banks of this segment which largely precludes the production of bed load. In a coarser-grained, less cohesive system, more stream bank erosion and widening would be expected, leading to aggradation, further widening, and shifts in channel planform.

However, the above statements are based on the assumption that added hydrologic pressures on the channel are not realized, including increased flows from stormwater runoff, tile drainage for agricultural or residential purposes, or an increasing magnitude and intensity of precipitation events.

Habitat conditions in M6S1.01-B were rated as Fair, characterized by a lack of epiphaunal substrates and morphological diversity resulting from recent and recurring channelization and dredging. Buffer widths along cropped and hay fields are generally less than 15 feet, and buffers are absent of trees. Canopy shading along the channel margins is therefore absent, and opportunities for detritus and LWD recruitment are very limited.

Segment A

Segment M6S1.01-A appears to have a slightly more natural (meandering) planform, with the exception of a channelized section immediately downstream of the Franklin Road crossing. Residential uses (driveway, lawn, recreational pond) encroach along the right bank of the channel in Segment A. In pasture areas downstream of Franklin Road, livestock have historically been permitted direct access to the channel, at apparently low frequency. Erosion from trampling is minor and herbaceous vegetation is not closely cropped. The channelized section is regaining sinuosity, and previously pastured areas are revegetating.

Despite some evidence of increased flows to the tributary (from road drainage and tile drains), and limited channel straightening, the segment appears to have good floodplain access particularly in the downstream half. The segment is in Good geomorphic condition overall, with minor aggradation and planform adjustments (flood chute).

Riparian habitats are compromised by the lack of epiphaunal substrates and morphological diversity due in part to the history of channelization and direct pasturing. Buffer widths are improving. Habitat was rated in Fair condition.

M6S1.1S1.01

Reach M6S1.1S1.01 is a 1.2-mile tributary to M6S1.01. It originates in cropped fields west of Durkee Road, flows to the northwest through crop fields and under Franklin Road to join

M6S1.01 just upstream of its confluence with the Rock River. Reach M6S1.1S1.01 was segmented to separate the upstream third of the channel, exhibiting intermittent flows (Segment B), from the remainder of the channel (Segment A) (see Figure 23).

Segment B

Segment B is approximately 1,949 feet in length, and is characterized by intermittent flow in a shallow valley of moderate slope (1.2%). Historically, crops have been tilled and planted across the stream valley (Fig. 25). Since this portion of the tributary does not have year-round flow, a Rapid Geomorphic Assessment was not completed. However, select features, including culvert crossings, were documented for the reach on the Field Notes form and in GIS using FIT.

*Figure 25. M6S1.1S1.01-B.
Flow is intermittent in this upstream segment of the reach.
Crops are planted through the channel and stream valley.
View upstream, 3 July 2006.*

Segment A

Segment A is approximately 4,521 feet in length. It flows between through a shallow valley of moderate slope (0.9%) surrounded by hilly terrain which is mostly developed in crops and pasture (see Figure 23). Channelization mid-segment is indicated by the linear planform. A cross section completed here indicated a C stream type with a width/depth ratio on the cusp with an E stream type. A minor degree of incision (IR = 1.2) was measured. It is likely that the silt and silty-clay stream channel substrates have limited the potential for incision and widening in this channelized portion of the reach. Overall, Segment A was rated in Good geomorphic condition, exhibiting minor widening, aggradation and planform adjustments. The channel appears to have maintained reasonable connection to its floodplain. However, adjacent land uses are contributing to very high suspended sediment loads in segment M6S1.1S1.01-A.

Several points of surface water runoff (rill erosion) were noted along the segment, particularly upstream of Franklin Road (Figure 26). Stormwater runoff was also noted at the downstream side of a farm road culvert crossing, mid-segment.

*Figure 26. M6S1.1S1.01-A.
Stormwater runoff eroded deep rills in the mostly bare soils of newly planted corn fields along the left bank and right bank corridors.
View upstream, 3 July 2006.*

Downstream of Franklin Road, direct pasturing of livestock has resulted in trampling of stream bank soils and localized channel widening (Figure 27). Waters of this tributary are frequently turbid, even during baseflow conditions between rain events (Figure 28). A Fair score was assigned to this segment following the RHA. Conditions are compromised by the lack of morphological diversity and substrates for epiphaunal colonization. Woody buffers are minimal to absent through the segment.

Figure 27. M6S1.1S1.01-A
Direct pasturing of livestock occurs downstream of Franklin Road.
29 July 2006.

Figure 28. M6S1.1S1.01-A; 29 July 2006.
As a result of direct pasturing, waters of this tributary are frequently turbid, even during baseflow conditions between rain events.
(a) view upstream from confluence with M6S1.01.
(b) view downstream in M6S1.01 from confluence with M6S1.1S1.01

(a)

(b)

4.2.2 Unnamed Tributaries to M05

Several small tributaries drain directly to reach M05 of the main stem between the Cassidy Road crossing and the Tarte Road crossing in the town of Highgate. Four of these unnamed tributaries were assessed. Each of them originates in cultivated fields or pasture up on the broad plains and eventually cut through several tens of feet of sediments to meet the Rock River down in its forested valley (see Section 2.2, Figure 4). The four tributaries have drainage areas ranging from 0.2 to 1.0 square mile.

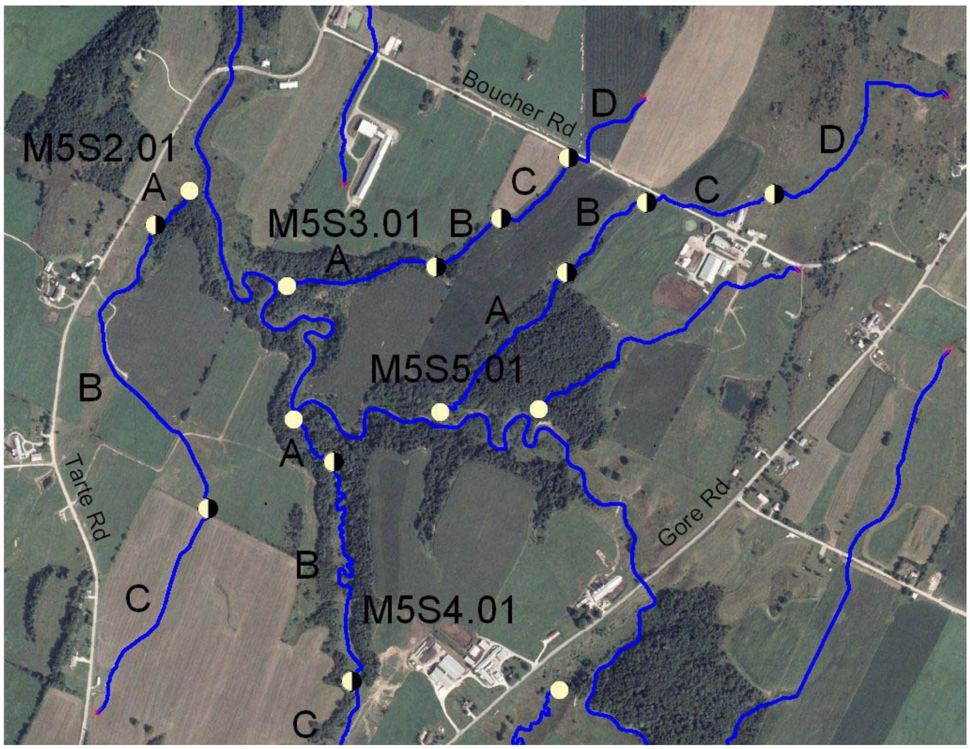


Figure 29. Location of assessed tributaries to M05, Rock River, Highgate, Vermont.

M5S5.01

M5S5.01 is a mile-long tributary which originates west of Gore Road and flows to the southwest across the Boucher Road to join the Rock River. This reach was segmented to distinguish intermittent flow sections and a short wetland section from the remainder of the channel.

Segment D

Segment D is approximately 1,904 feet in length with a moderately-steep gradient (2.7%). This upstream end of the tributary exhibits intermittent flow connecting two instream ponds through a low-intensity pasture. NWI wetlands are mapped in isolated locations along the segment. Given the ephemeral nature of Segment M5S5.01-D, a Rapid Geomorphic Assessment was not completed.

Segment C

Segment C is approximately 1,029 feet in length, passing through a dairy barn yard and along Boucher Road before crossing under the road through an instream culvert. The gradient of this segment is steep (4.4%). Two locations of channel-spanning bedrock were recorded in the segment, providing vertical grade control. The planform of Segment C was recently re-directed to pass along the eastern and southern sides of the barn to flow for a greater length along the north side of Boucher Road. Several occurrences of stormwater (road) runoff and one occurrence of field runoff were recorded for Segment C. Given the intermittent flow of this segment, a Rapid Geomorphic Assessment was not completed.

Segment B

Segment M5S5.01-B is a short section (870 feet) of moderately-sloped (2.1%) marshy channel flowing through a shallow valley immediately downstream of the Boucher Road crossing. Hydric soils are mapped in the immediate vicinity along the right bank. Given the wetland nature of the channel in this location, a Rapid Geomorphic Assessment was not completed. Segment B may serve important flow, sediment and nutrient attenuation functions in the reach.

Segment A

Segment A of reach M5S5.01 is approximately 1,589 feet in length and has a moderate gradient (1.9%). This segment flows through a broad to narrow valley (4 to 10 times channel width) with steep forested side slopes – a C reference stream type. Within Segment A, this tributary cuts down through nearly 30 feet of lacustrine clays and silts to join the Rock River. Floodplain access was generally good, although a few isolated occurrences of channel scour suggested localized incision. A cross section completed mid-segment in one of these localized areas of channel incision, indicated a Bc-plane bed stream type in silt/clay-dominated substrates, with occasional cobbles and coarse to fine gravel.

Overall, the segment was assigned a Rapid Geomorphic Assessment rating of Fair, with minor to moderate incision and evidence of planform adjustments (neck cutoff, meander extension). It is possible that increased flows from stormwater runoff in upstream segments may have contributed to channel incision in Segment A. Channel widening is minor, and may be moderated by cohesive nature of the stream bed and bank materials. Most eroded sediments appear to be mobilized as suspended sediments; little evidence of channel bars was observed.

Following VTANR protocols, the segment was assigned a D-stage Channel Evolution Model (CEM), and appears to be in Stage IIb of that CEM. In contrast to the description of a typical D-stage channel provided in the VTANR protocols (Appendix C), it is theorized that future widening, aggradation and planform adjustments will tend to be moderated, for the following reasons:

- high degree of erosion resistance of the silt and silt-clay bed and banks;
- relatively low stream power of the channel which drains approximately 0.2 square miles; and
- the very fine-grained nature of a majority of the bed and banks sediments in this segment. In a coarser-grained, less cohesive system, more stream bank erosion and widening would be expected, leading to aggradation, further widening, and shifts in channel planform.

However, the above statements are based on the assumption that added hydrologic pressures on the channel are not realized, including increased flows from stormwater runoff, tile drainage for agricultural or residential purposes, or an increasing magnitude and intensity of precipitation events. For an example of a similar tributary being impacted by added hydrologic stresses, one can look 1/3 mile to the northwest to tributary segment M5S3.01-A. This adjacent tributary is similarly sized (0.15 square mile), located in a similar forested valley setting, drains upper slopes of crop and hay, and is only slightly steeper in gradient (approximately 2.4%, as compared to 1.9%). However, its downstream segment is exhibiting a significantly greater degree of active incision and widening, likely due to increased flows from agricultural tile drains (see text in later section, titled "M5S3.01").

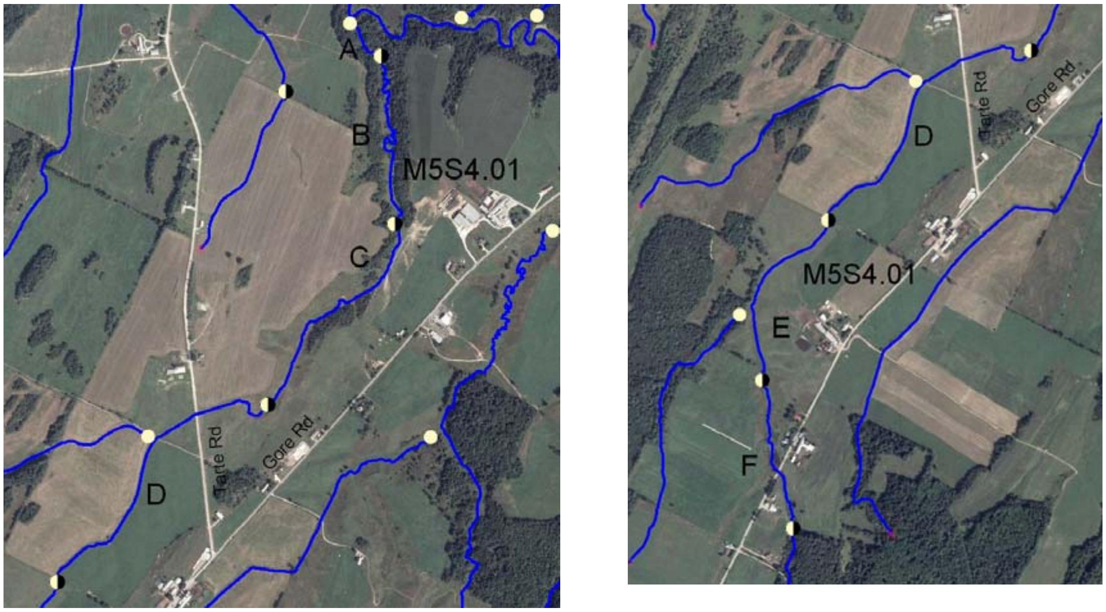
The RHA for M5S5.01-A revealed a rating of Fair, on the cusp with Good. Habitat conditions were compromised by the overall lack of morphological diversity and few epiphaunal substrates. On the positive side, deciduous forested buffers were ample and appear to be providing detritus and organic material for riparian habitats. Six debris jams (and 13 LWD) were recorded in the 1/3-mile segment.

M5S4.01

This 2.7-mile reach flows to the north from the vicinity of Highgate Springs, along Gore Road and Tarte Road to join the Rock River approximately 4,100 feet upstream of the Tarte Road crossing. This tributary drains residential and agricultural lands in a 1.0-square mile watershed. Reach M5S4.01 was segmented to distinguish a section of intermittent flow (G), a section of wetlands (F), two sections exhibiting stream type departure (E and D), and a subreach of alternate stream type (A), from two sections of Ec reference stream type (C, B) with differing land uses. Segment delineations are illustrated in Figures 30a (downstream) and 30b (upstream).

Segment G

Segment M5S4.01-G is a section of intermittent flow at the upstream, forested extent of the reach - approximately 2,395 feet in length (not pictured in Figure 30b). A Rapid Geomorphic Assessment was not completed in this segment, given its ephemeral nature.



(a) (b)

Figure 30. Segment delineation in tributary reach M5S4.01, Rock River, Highgate, Vermont.

Segment F

Segment M5S4.01-F is approximately 1,645 feet in length. The segment spans Gore Road, flowing through hydric soils in a shallow, marshy, valley of low to moderate slope (0.9%) with wetland vegetation. NWI wetlands are mapped contiguous to this section of the tributary channel. Given the wetland nature of the channel in this location, a Rapid Geomorphic Assessment was not completed.

Segment E

Segment M5S4.01-E is approximately 2,012 feet in length, flowing through fields of corn and hay. The entire length of the segment appears channelized, given the linear planform. The upstream half of the segment has been recently dredged, with spoils placed along alternating right and left banks (Figure 31).

Several tile drains were observed along both the left and right banks of this segment which flows through hydric soils. Minimal grass buffers were present along both banks, with localized areas of bare soils. A left-bank tributary joining the segment mid-way along its length was observed to have been very recently dredged, with near-bank areas of bare soil.

A cross section completed in the upstream half of the segment indicated a stream type departure from reference Ec to a disturbed Gc. An incision ratio of 3.6 was measured. Dredging has lowered the channel bed, resulting in a loss of floodplain connection. Excavated soils placed along the channel banks are serving as a berm to further confine the channel and limit the channel's floodplain access.

Figure 31. M5S4.01-E.
Recent dredging was evident in this channelized segment which flows through dense silts and silty-clays. Corn fields were present on the right bank; hay fields on the left bank. Dredging spoil piles were bermed along left bank. Several tile drains were noted along left and right banks terminating at the channel. View upstream, 8 June 2006.

Headcuts in the silt bed of the channel were noted at the boundary with the upstream wetland (Segment F), just upstream of the property line (fence line). This location appears to be coincident with the upstream extent of dredging. It does not appear that headcuts have migrated significantly upstream into Segment F. The channel becomes multi-threaded at this transition from Segment E upstream into the wetlands. It is likely that the cohesive nature of silts and clays in the channel bed and banks have served to limit the migration of headcuts. Also, as the channel splits into a multi-thread planform at this point, flow velocities would be reduced in any one channel thread, possibly below the erosion threshold for the channel substrates. Further monitoring would be required to understand the potential for headcut migration at this location. Signs of active widening were minor, and much of the near bank area is covered with grassy vegetation. The dimensions (width, depth) of the current channel appear to be a function more of the profile of the excavator bucket used to accomplish dredging, and the subsequent placement of spoils serving to berm the channel, than to any active lateral or vertical adjustments ongoing in the channel in response to past channelization and dredging. This is a channel expected to be of limited stream power, as a result of its small drainage area (perhaps 0.5 square mile at this location) and shallow gradient (estimated 0.4%).

Segment E was rated in Fair condition due to moderate incision. Conservatively, the segment was classified as having undergone a stream type departure (Ec to Gc), given the uncertainty with respect to the migration potential for head cuts observed at the upstream end. Thus, a sensitivity rating of "Extreme" was assigned, as per protocols. Following VTANR protocols, an F-stage CEM was assigned and the segment was estimated to be in stage III, characterized by widening in a channel which has lost floodplain connection. Given the fine-grained, cohesive nature of channel bed and bank materials in this segment, the description of a typical F-stage channel evolution provided in the VTANR protocols (Appendix C), may not directly apply to segment M5S4.01-E. It is theorized that much of the eroded sediments have been transported downstream in suspension contributing to turbidity, but not aggrading to any substantial degree as sediment bars that might cause a sudden shift in channel planform.
Habitat in segment M5S4.01-E was rated on the low end of Fair, given the lack of epiphaunal substrates, minimal diversity of flow patterns, and limited herbaceous buffers.

Segment D

Segment M5S4.01-D is approximately 3,136 feet in length. This low-gradient segment (0.5%) flows through a shallow valley, between hilly slopes of corn and hay, then into livestock pastures, through the Tarte Road culvert crossing, ending just downstream of three closely-spaced exposures of channel-spanning bedrock. The current planform of the segment is linear. In the absence of bedrock orientations or other geologic factors that may explain this, and given the very close proximity of crops along a majority of the length, historic channelization and ditching are inferred.

Based on visual observations and a cross section completed mid-segment, the channel has lost connection with its historic floodplain (IR = 2.4). Since the indicators of active incision noted under Step 7 were absent from this cohesive bed segment, degradation was determined to be historic in nature. The floodplain is inferred to have been abandoned by virtue of bed-lowering accomplished during channelization / ditching, and perhaps by build up of the surrounding floodplain elevation through incorporation of dredged spoils into adjacent plow zones.

Cross section measurements indicate a stream type of Bc in a setting that would suggest an E reference stream type, constituting a stream type departure. Reasonable floodplain access was available within this narrow valley, approximately 2 times wider than the measured channel width. Within this linear ditched valley, the stream channel itself appears to have a low degree of secondary sinuosity. Overbank deposits of very fine sand and silt were evident along the channel margins. Occasionally, flows were bifurcated around grass islands. A relatively high width/depth ratio was measured (37). Width/depth dimensions of the channel may be influenced by the dimensions of the original ditch excavated by heavy equipment in this cohesive-bed system. The tributary could almost be considered "underfit" with respect to the channel created for it through excavation. Near bank areas and the channel bed are well vegetated with grasses. No signs of eroded or collapsing stream banks, or other signs of active widening, were noted in the segment.

Geomorphic conditions were rated as Fair following the RGA. Current channel adjustments are minor; instead, the Fair condition results largely from the "incision" ratio caused by historic channelization / ditching. The sides of the excavation effectively became the new valley walls of a Bc channel at a lower elevation than the pre-disturbance state. Detailed studies would be required to characterize the erosion resistance of the silt and silty-clay substrates in the channel margins, in the face of variable shear stresses. However, it is conceivable that this channel is of sufficiently small size (less than 1 square mile drainage area) where flow velocities (and imparted shear stresses) are insufficient to erode the cohesive streambed and streambank soils to a degree that would lead to system-wide lateral and vertical channel adjustments – thus, preventing the channel from evolving back to the natural reference stream type (in this case "E").

In the upstream half of Segment D, minimal herbaceous buffers are present, with close encroachment of corn and hay fields. Livestock have direct access to the stream in the pastured lower half. Large woody debris is absent from the segment. The channel has a nearly uniform bed of silt and silty clays. Locally, the silt and clay-rich bed is mucky where fines have accumulated and/or where groundwater discharge is active. Habitat conditions were rated at the low end of Fair.

Figure 32. M5S4.01-D.
Dredging appears less recent in this channelized segment, which has achieved a greater degree of floodplain access and a minor secondary sinuosity within a narrow linear valley than upstream Segment E.
View downstream, 8 June 2006.

Segment C

Segment C of reach M5S4.01 flows through a broad valley setting, approximately 6 to 10 times wider than the measured channel width. The steep valley walls along the left corridor are pastured, and along the right corridor are a mix of pasture and young deciduous forest. The channel has a somewhat linear planform, suggestive of historic channelization, but appears to be regaining some sinuosity. The channel gradient is shallow (0.2%), and flow velocities are low. The channel meanders through low-intensity pasture, where cattle have created "post-holes" in the silt and clay soils. Flows are often divergent around hummocks of grass, and wetlands are abundant along the channel margins. Soils in the floodplain surrounding the main channel were highly saturated. Trail patterns indicate that livestock most often traverse the valley walls rather than the valley floor.

Figure 33. M5S4.01-C.
This segment flows through a broad valley of low-intensity pasture.
View downstream, 8 June 2006.

At the downstream end of Segment M5S4.01-C, there is a short section of high-intensity pasture along the right bank (Figure 34). Valley wall slopes are mostly bare, dissected by erosional rills. Minimal vegetation - closely-cropped grass - exists on floodplain terraces. A large scour pool beneath a tile drain terminating mid-slope (upper right in Figure 34) has delivered very fine sandy soils creating a delta into the tributary channel. The main channel of M5S4.01-C appears to have recently avulsed through a fence line and into the adjacent pasture.

*Figure 34. M5S4.01-C. View downstream, 8 June 2006.
Debris is caught in a wire fence where a recent avulsion toward right bank has occurred into a high-intensity pasture. Note: Youth Conservation Corps has assisted the landowner in revegetating these slopes as of September 2006.*

Segment C was delineated to account for a difference in land uses between this and the next downstream segment (Segment B). The segment has channel dimensions and valley characteristics of an E stream type, similar to Segment B - a low width/depth channel in an unconfined, broad valley setting. Stream type designation in Segment C relied on cross section data for Segment B. Substrates were dominated by silt and clay. Overall, Segment C was rated in the Good quadrant of the Rapid Geomorphic Assessment. Adjustments were minor (except for the localized avulsion and associated fine sediment aggradation near the downstream end).

Habitat conditions were rated as fair. Direct pasture access and historic channelization have significantly limited the availability of epiphaunal substrates, and the diversity of channel morphology. Direct livestock access has likely contributed nutrients and fine sediments.

Segment B

Segment B of M5S4.01 is 2,238-foot, highly-sinuous section of channel flowing through a wetland meadow. (Note that the VHD surface water coverage for this location indicates a linear planform, when in fact the channel is highly sinuous as depicted on 2003 aerial imagery [NAIP, 2003]). NWI wetlands are mapped contiguous to the channel throughout this segment. The valley is broad overall, approximately 6 to 10 times wider than measured channel widths. Buffers of herbaceous wetland vegetation fill the valley up to valley side slopes of mixed coniferous and deciduous forest. Land uses at the top of the valley wall side slopes include pasture, hay and crop fields. Tile drains and surface water swales direct drainage from these agricultural areas to the tops of the valley walls surrounding tributary M5S4.01. In many cases, gullies have developed at the terminus of these tiles and swales, and erosion within the gullies is contributing sediments (and likely, nutrients) to the tributary valley. In some cases, there is evidence that sediments and surface runoff are directly discharging to the tributary channel (Figure 35).

Figure 35. M5S4.01-B. The bold white line at the center of the plan view (left) marks the approximate path of a sediment flow (fine sand and silt) originating in a gully at the margins of the barnyard pasture area (picture right) and leading down the forested valley wall and out into the valley directly to the tributary channel. (Observed on 8 June 2006). Flow in the tributary (blue line) is from south (picture bottom) to north (picture top).

Segment M5S4.01-B is flowing through an unconfined valley setting and has ample access to its floodplain. A cross section measured mid-segment indicates an E stream type of low width/depth ratio and dune/ripple bedform. There is no evidence of channel incision or widening. Planform adjustments within the segment include moderate meander extension and one historic neck cutoff, not uncharacteristic of an E channel in regime. Some minor evidence of aggradation was noted. Given the fine-grained nature of sediments in the channel boundaries, and those delivered as point sources from adjacent gullies, it appears that sediments delivered to the channel are being transported as suspended load downstream to the Rock River.

Segment A

Segment A of reach M5S4.01 is a short subreach (480 feet) of reference C stream type in contrast to the reference E stream type of the remainder of the reach. Given the short length of the segment (3% of the reach length), a formal cross section was not completed. However, visual observations suggested a width/depth ratio greater than 12, and a riffle/pool bedform dominated by gravels, with the occasional cobble and boulder. The segment has a shallow gradient (0.2%) and meanders through a semi-confined to narrow valley setting, through a deciduous forest, to meet the Rock River main stem.

Segment M5S4.01-A was rated in Good geomorphic condition with minor evidence of aggradation. Mature forested buffers and cohesive stream bank soils have contributed to overall stability in the segment. Habitat conditions were also classified as Good. Forested buffers and a closed canopy provide shading to the channel. Multiple debris jams and LWD were noted, providing epiphaunal substrates and contributing to a diversity of flow patterns.

M5S3.01

Reach M5S3.01 is a 3,409-foot tributary which originates in crop fields north of Boucher Road, crosses through and instream culvert under Boucher Road, and continues southwest to meet the Rock River (see Figure 29). This reach was segmented to separately delineate a section of tiled flow (D); a section of straightened channel (C); and a short section of wetland from the downstream extent of the reach.

Segment D

Segment D of reach M5S3.01 appears to have been tiled underground to facilitate cropping. Therefore, this upper extent of the reach upstream of the Boucher Road crossing was not assessed.

Segment C

Segment M5S3.01-C is a 738-foot section of the tributary leading from the instream culvert under Boucher Road to a small wetland. The unconfined valley setting in cohesive soils with low to moderate gradient (<2%) suggests an E reference stream type. The channel is closely encroached upon by hay fields along the right bank and crop fields (currently alfalfa) along the left bank. A very limited herbaceous buffer is present. Several tile drains were observed leading from left and right bank fields and terminating within the tributary channel. Saturation excess overland runoff was also observed following afternoon thundershowers. Surface swales drained stormwater and manure residues directly to the channel on the observation date (20 June 2006).

Segment C has been historically channelized and dredged as indicated by the linear planform and presence of tile drains. However, the channel has a slightly sinuous planform and appears to have connection to an incipient floodplain at a lower elevation. The modified "valley" setting of the ditch excavated into cohesive sediments is approximately two times wider than the measured bankfull width. Dense herbaceous vegetation and cohesive silt bed and banks are contributing to overall stability of the channel.

Based on visual observations and a cross section completed mid-segment, the channel has lost connection with its historic floodplain (IR = 2.9). Since the indicators of active incision noted under Step 7 were largely absent from this cohesive bed segment, degradation was determined to be historic in nature. The floodplain is inferred to have been abandoned by virtue of bed-lowering accomplished during channelization / ditching, and perhaps by build up of the surrounding floodplain elevation through incorporation of dredged spoils into adjacent plow zones.

Cross section measurements indicate a stream type of F in a setting that would suggest an E reference stream type, constituting a stream type departure. It should be noted that, channel dimensions measured at the cross section in Segment M5S3.01-C could also suggest a Bc stream type, rather than an F stream type, considering the (+/-) 0.2 value permissible under evaluation of entrenchment. The segment is likely on the cusp between an F and Bc channel. It is theorized that the channel is slowly evolving to a Bc, as fine sediments from several small surface water and tile channels fill the trenched valley to broaden the incipient floodplain, raise the channel bed slightly, and in the process increase the width/depth ratio and decrease the entrenchment ratio. Future monitoring of this segment would be required to better understand the channel evolution.

Geomorphic conditions were rated as Fair following the RGA. Current channel adjustments are minor; instead, the Fair condition results largely from the "incision" ratio caused by historic channelization / ditching. Given the apparent stream type departure (from E to F), an Extreme sensitivity classification was assigned per Table 7.2 of the protocols (page 79). Detailed studies would be required to characterize the erosion resistance of the silt and silty-clay substrates in the channel margins, in the face of variable shear stresses. However, it is conceivable that this channel is of sufficiently small size (less than 0.15 square mile drainage area) where flow velocities (and imparted shear stresses) are insufficient to erode the cohesive streambed and streambank soils to a degree that would lead to system-wide lateral and vertical channel adjustments – thus, preventing the channel from evolving back to the natural reference stream type (in this case "E").

Habitat conditions were rated as Fair, compromised by the extensive channel management, and resulting lack of morphologic and flow diversity. Very limited buffer widths and absence of trees or shrubs along this segment also contribute to the less than optimal habitat conditions.

Segment B

Segment M5S3.01-B is a short section (607 feet) of moderately-sloped (1.6%) marshy channel flowing through a semi-confined valley immediately downstream of Segment C. Hydric soils are mapped in the area (in the fields in the left and right corridors), although not in the immediate location of the Segment B channel (USDA, 2003; USDA, 1979). At the downstream end of the segment is a farm road culvert crossing which has filled the stream valley entirely to an approximate height of 15 feet above the channel. A road crossing has been present in this location since at least 1987 (the publication date of a USGS topographic map showing the farm road). At present, tributary flows are conveyed under the farm road by a 2-foot culvert at the base of the fill. The valley fill material has had the effect of impounding water in Segment B, and a large scour hole is evident on the downstream side of the culvert. The impounded wetland area of Segment B may be serving an important attenuation function for flows and fine sediments; it may also be serving as a nutrient sink. Given the wetland nature of the channel in this location, a Rapid Geomorphic Assessment was not completed.

Segment A

Segment M5S3.01-A begins immediately downstream of the farm road culvert crossing and extends 1,169 feet downstream to the confluence with Rock River. The majority of Segment A is actively incising and widening into cohesive silts and clays (Figure 36). Several nick points in the cohesive bed materials were noted, and the relief of the current bed elevation compared to the recently abandoned floodplain suggests an incision ratio over 4. This segment is located in a forested, narrow valley approximately ¼ mile upstream from the Rock River main stem.

There is no apparent evidence of direct channel management (e.g., dredging, channelization) within Segment M5S3.01-A. However, indirect sources of hydrologic stressors were noted. First, the undersized instream culvert crossing at the upstream end of the segment is a significant constrictor of flows, and has contributed to channel scouring. Second, gullies were noted along the left and right valley walls of the segment near the top of the forested valley side slopes. Agricultural tiles drain the adjacent fields and terminate at the tops of the side slopes. Installation of drainage tiles in adjacent fields has improved field drainage, but as a consequence, delivers groundwater and surface water runoff to the tributary valley in greater volumes over shorter time periods. These effects have likely increased the peak and magnitude of flows in the tributary during storm events. Flows velocities may now exceed thresholds for erosion of the channel bed and bank materials with greater frequency, contributing to channel incision and widening. No energy dissipation mechanisms are in place at tile outlets. In at least three cases, gullies have developed at the tile outlets, resulting in sediment erosion down the side slopes into the tributary valley below (Figure 37). These gully locations are local points of lower elevation, and saturation excess overland flow (surface runoff) was observed draining to these gully locations on the date of assessment (20 June 2006).

(a) (b)

Figure 36. M5S3.01-A. Segment is actively incising, and widening to expose bare clay and silt soils in the channel bed and near bank areas.
(a) channel is wider and deeper than regime; foam builds at a small plunge pool below one of several nick points in the cohesive silt/clay bed; view downstream 20 June 2006.
(b) incision ratio of 4.2 is measured where channel has incised to abandon the recent floodplain.

Figure 37. M5S3.01-A. 20 June 2006. Example of scour hole at a tile outlet along the edge of a hay field at the top of the right valley wall. Flows were high immediately following an afternoon thunderstorm. The scour hole leads to a gully which is approximately 15 feet wide and more than 8 feet deep, conveying stormwater and fine sediments down-slope to the tributary channel.

Overall Segment M5S3.01-A was rated in Fair geomorphic condition. A stream type departure was evident (Cb to G), due to active incision and consequent loss of floodplain connection. Following VTANR protocols, an F-stage CEM was assigned and the segment was estimated to be in stage III, characterized by a transition from incision-dominated to incision accompanied by widening. Given the fine-grained, cohesive nature of channel bed and bank materials in this segment, the description of a typical F-stage channel evolution provided in the VTANR protocols (Appendix C), may not directly apply to segment M5S3.01-A. It is theorized that much of the eroded sediments have been transported to the Rock River in suspension contributing to turbidity, but not accumulating to any substantial degree as bedload. Thus, aggradation and planform adjustments within this tributary channel would not be expected to become excessive adjustment processes in future. If the added hydrologic pressures on the channel are not remedied, channel incision may be re-initiated.

Habitat conditions in M5S3.01-A were rated as Fair by the RHA. Active incision and widening has lead to a lack of epiphaunal substrates, and minimal diversity of bed forms. Near bank areas are often bare of vegetation. On the other hand, the corridor surrounding the channel is reasonably well forested and there are signs of active LWD recruitment in the downstream portion (LWD = 16; Debris Jams = 3).

M5S2.01

This 4,804-foot reach flows from south to north largely parallel to and on the east side of Tarte Road (see Figure 29). The upper third of this reach has been tiled underground and was treated as a distinct segment (Segment C) to account for its present condition. For the remainder of the reach, all but the downstream 400 feet, has been straightened and ditched to facilitate agricultural uses including crop land and pasture. Therefore, the reach was further segmented to capture the differences between the downstream 400 feet (Segment A) which has a more natural meandering planform and much less intensive management history and the middle portion of the reach (Segment B) which has undergone substantial planform changes as a result of human activities.

Segment C

Segment C is approximately 1,814 feet in length and has been converted to an underground channel conveyed through drainage tiles. Based on review of historic aerial photographs, the upper third of this tributary was tiled underground stream sometime between 1995 and 2003. The field is now cropped, where previously it had been in hay. This field is moderately sloped, and some erosional rills were observed forming in bare soils of this recently tilled field. When overland flow in storm events is significant enough, it is likely that this field serves as a point source of fine sediments to the reach. Segment C could not be assessed following RGA protocols, as it no longer exhibits open-channel fluvial form.

Segment B

The middle portion of reach M5S2.01, some 2,585 feet in length, has been substantially modified to accommodate close cropping and pasture uses. The natural valley is somewhat narrow, set between rolling hills to left and right banks. The upper portion of Segment B passes through fallow pasture; the middle portion of the segment passes between a corn field on the right and hay fields and pasture on the left. The downstream 1,000 feet of the segment flows through pasture with closely-cropped vegetation where cattle have recently had direct access to the stream. Anecdotal evidence suggests that as of June or July of 2006, this pasture is now fallow.

Essentially the entire length of Segment B has been channelized and ditched, with the natural meanders removed. The ditch itself is approximately 8 to 14 feet wide, and is confined between tall banks on both LB and RB. The relief between the top of the banks (at the edges of the hay and corn fields) and the thalweg of the channel measured 3.8 feet at a cross section performed near the upstream extent of the corn field. The degree of channel entrenchment appeared to decrease gradually with distance downstream. It is likely that the channel entrenchment was enhanced over recent years through periodic dredging, berming (of dredging spoils), and subsequent plowing to within 3 to 6 feet of the channel margins.

In the upper half, the stream channel is observed to have established a low-amplitude, secondary meandering pattern around vegetated benches through the straightened ditch. Intermittently along the length of the ditch, there are point source contributions of sediment and surface water runoff being delivered to the channel from the adjacent recently-plowed corn field along right bank. These small gully-like channels cut through narrow herbaceous buffers at the field margins, and serve as the collection point for a branched network of erosional rills through the field (Figure 38). Six separate point sources of surface water / sediment runoff were located along a 1,020-foot length of channel on the assessment date (20 June 2006). This section of the channel also receives some surface water runoff and tile drainage from the hay field along left bank.

In the downstream portion of the segment flowing directly through pasture, trampling action of cattle hooves appears to have disrupted the channel structure. While a straight channel appears to have been dredged through the pasture, the original meandering channel can still be seen positioned near the right valley wall at the eastern edge of the pasture. The channelization appears to have occurred prior to 1995 based on review of 2003 and 1995 photos.

(a)

(b)

Figure 38. M5S2.01-B. (a) View downstream: channel located in ditch between recently-plowed corn field on RB and hay field on LB. (b) Rill erosion through corn field – flow is concentrated to small channels which cut through the narrow herbaceous buffer and deliver sediment and surface water directly to the tributary channel.

Approximately 115 feet of channel length was lost through this more recent straightening action, which would be expected to locally steepen the channel gradient. A subtle berm was visible along the right bank of the straightened channel, where it is likely that dredging spoils would have been placed (Figure 39). The prominence of this berm has probably been reduced over recent years by direct trampling action of pastured cattle.

Figure 39. M5S2.01-B. View downstream. Straightened channel dredged along left valley wall through cow pasture to the tree line at picture background. Original channel visible meandering along right valley wall (beyond picture right). Straightening removed approximately 115 feet of length along a 590-foot channel, increasing local gradient.

Cross section measurements indicate a stream type of F in a setting that would suggest an E reference stream type, constituting a stream type departure. The width of the ditch excavated to convey the channel (15 to 20 feet) is two to three times the expected width (8 feet) of the channel for this drainage area (perhaps 0.3 square mile). Originally, the stream probably had a more meandering profile with floodplain access in a narrow valley (reference E stream type). The effect of dredging, berming and encroachment of cultivated fields has been to deepen the channel, and increase the degree of entrenchment, to the point where the channel has lost access to its former floodplain. The channel also receives drainage from the adjacent fields, at an increased magnitude and velocity, from tile drainage and from direct runoff. Such channel disturbances would be expected to lead to channel incision, and widening in a mobile-bed alluvial channel. However, the potential for channel incision and widening in this case appears to have been moderated by: (1) the cohesive silts in the bed and banks of the channel, (2) the thick herbaceous vegetation offering channel roughness, and possibly (3) the seasonally intermittent flows of this small drainage area. Also, the frequent, episodic (runoff-related) delivery of fine sediments into the channel from the adjacent corn field appears to have filled the channel margins in the ditch and helped to offset the tendency for channel incision and widening. The current channel is fairly stable with limited evidence of streambank erosion. A few discrete nick points were noted along the channel but appeared to be related to the exposure of relatively more cohesive silt layers in the bed, rather than indicating an active wave of incision migrating headward.

It should be noted that, channel dimensions measured at the cross section in Segment M5S2.01-B could also suggest a Bc stream type, rather than an F stream type, considering the (+/-) 0.2 value permissible under evaluation of entrenchment. The segment is likely on the cusp between an F and Bc channel. It is theorized that the channel is slowly evolving to a Bc, as fine sediments from several small surface water and tile channels fill the trenched valley to broaden the incipient floodplain, raise the channel bed slightly, and in the process increase the width/depth ratio and decrease the entrenchment ratio. Future monitoring of this segment would be required to better understand the channel evolution.

Geomorphic conditions in M5S2.01-B were rated as Fair following the RGA. Current channel adjustments are minor; instead, the Fair condition results largely from the "incision" ratio caused by historic channelization / ditching. Given the apparent stream type departure (from E to F), an Extreme sensitivity classification was assigned per Table 7.2 of the protocols (page 79). Detailed studies would be required to characterize the erosion resistance of the silt and silty-clay substrates in the channel margins, in the face of variable shear stresses. However, it is conceivable that this channel is of sufficiently small size (less than 0.35 square mile drainage area) where flow velocities (and imparted shear stresses) are insufficient to erode the cohesive streambed and streambank soils to a degree that would lead to system-wide lateral and vertical channel adjustments – thus, preventing the channel from evolving back to the natural reference stream type (in this case "E").

Habitat conditions were rated on the low side of Fair. Channel straightening over 100% of the segment length and absence of woody buffers has stripped the channel of natural sources for bed feature diversity and epiphaunal substrates. Direct access by cattle in the lower half of the segment has further disturbed the natural bed forms and provides a direct source of nutrients and increased suspended sediment loading to the stream. Herbaceous buffers of minimal width appear inadequate to filter runoff of sediment and nutrients to the stream.

Segment A

In the downstream 400 feet, reach M5S2.01 flows through a narrow to semi-confined valley along the eastern edge of fallow pasture (site of recent tree plantings by MRBA). A mixed tree forest exists along the right valley wall, and ample buffers (>100 feet) are present along both banks. The channel has a natural meandering planform through this segment - a higher sinuosity than the remainder of the reach. Backwater effects are evident at the confluence with the Rock River main stem.

A cross section performed within the reach identified an E-plane bed stream type in a silt/clay bed. Some degree of channel incision was suggested by a measured incision ratio of 1.2. The peak, magnitude and frequency of flows to this point in reach M5S2.01 have probably all been increased as a result of the tile drainage, straightening and ditching in upstream segments. Despite these stressors, Segment A does not indicate substantial evidence of channel incision. It is likely that the cohesive silt bed and banks, as well as dense vegetative cover in this segment, have provided resistant boundary conditions to moderate the tendencies for channel incision. (Note that bankfull indicators in this segment were scarce, and it is possible that the bankfull elevation was underestimated. If so, the Incision Ratio would be closer to 1.0 and an optimal degree of floodplain connection would be present. Even if the bankfull elevation were higher, the channel would still have a width/depth ratio less than 12, characteristic of an E channel).

The silt-bed channel appears transport-dominated with little evidence of aggradation, save for locally at debris jams. Direct pasturing, channelization, rill erosion from the recently plowed corn fields, and recent increases in tile drainage network ordinarily might be expected to substantially increase sediment loading to Segment A. However, given that the geologic source materials available along the bed and banks are dominantly silts and clays, bed load in the channel is negligible, except downstream of and local to a farm road crossing with associated sediment runoff. Suspended sediment loads, on the other hand, are very high. Tile drainage and direct cattle access to the stream have contributed to turbidity that was evident in the stream even before a thunder shower that occurred during assessment. Turbidity increased substantially as a result of the brief but heavy shower, and a suspended sediment plume of markedly higher turbidity was observed mixing with the Rock River main stem at the confluence (Figure 40).

Overall, Segment A is exhibiting minor adjustments, despite considerable upstream stressors and historic in-segment stressors. The segment was rated in Good condition following RGA protocols. Its sensitivity to future stressors is still High, given its setting downstream of an intensively managed channel. Continued buffer protections and restoration of woody vegetation along the LB will help to off-set these impacts.

Figure 40. M5S2.01-A. View of confluence with Rock River main stem. Following a brief but heavy thunder shower on 20 June 2006, a suspended sediment plume from tributary M5S2.01 (picture right) was observed flowing into and mixing with the Rock River main stem waters of lesser turbidity (picture left).

Habitat conditions were rated as Good, following RHA protocols. The RHA (as presently constructed) does not appear to account for the potential influence of high suspended loads and nutrient contributions on habitat, which would be considerable in this segment. Historic pasturing along the LB means that trees are not well-represented at this time. However, this condition will continue to improve as seedlings mature, and shading will increase along the LB stream margins. Some LWD recruitment is occurring along RB, and providing some important diversity of epiphaunal substrates to the channel.

4.2.3 Saxe Brook (M1S1.03, M1S1.02, M1S1.01)

The Saxe Brook tributary drains a 2.9-square mile area in the northwest portion of the watershed. This tributary joins the Rock River main stem (reach M01) immediately downstream of the St. Armand Road crossing of the Rock River near the Wildlife Management Area access (Figure 41). Three reaches comprising the downstream 1.5 miles of this tributary were assessed in 2006.

Phase 2 assessments revealed greater variation in channel profile along this lower portion of the Saxe Brook than was apparent at the remote-sensing scale of Phase 1 assessments. The lower two reaches were each segmented to capture the change in gradient (and reference stream type) along the profile of this tributary. The uppermost assessed reach (M1S1.03) was also segmented to capture changes in channel management and land use.

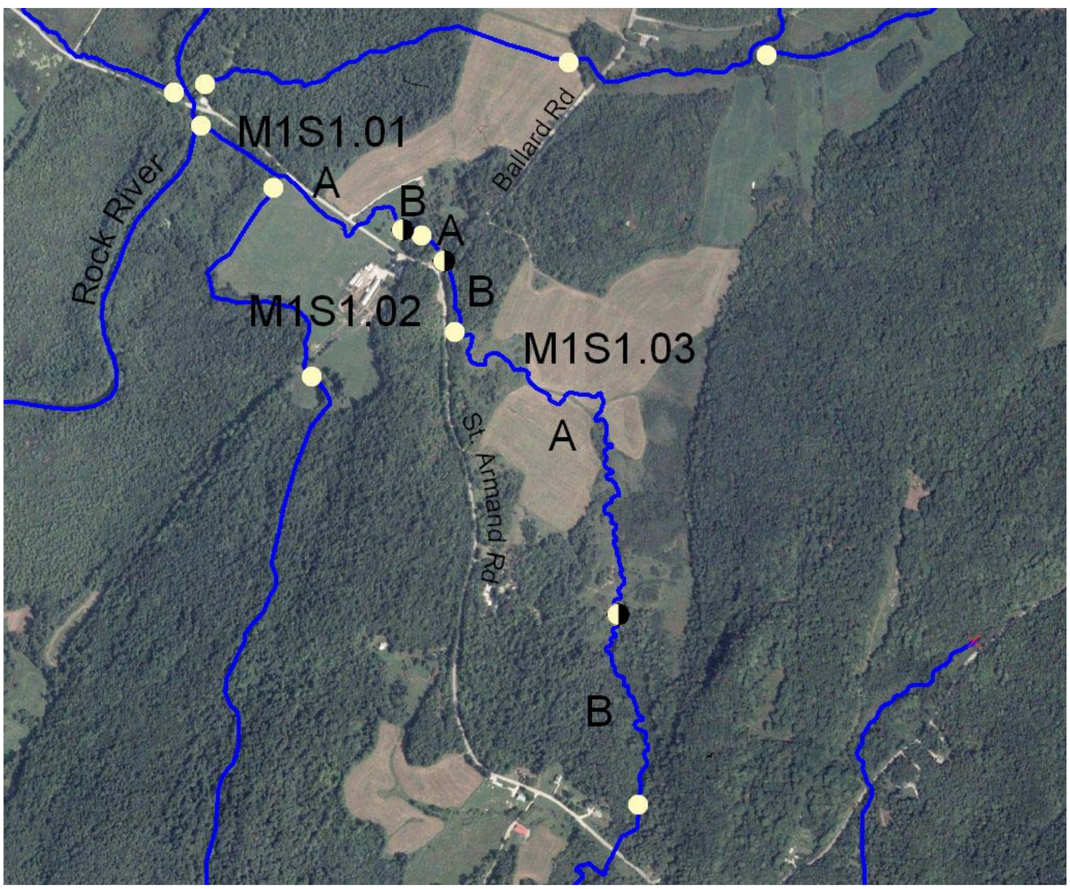


Figure 41. Location of Saxe Brook reaches / segments assessed in 2006, Rock River, Highgate, Vermont..

M1S1.03

Reach M1S1.03 begins just downstream of the St. Armand Road crossing and extends for nearly a mile downstream through wetlands, a residential property and crop fields.

Segment B

Segment B is approximately 1,614 feet in length, flowing through a largely, undisturbed alder swamp, then entering the southern portion of a residential property which has been historically cleared, and more recently developed with a recreational pond and access roads. Segment B flows through a very broad valley underlain by hydric soils. NWI wetlands are within the valley, contiguous to the channel. The majority of the segment has ample shrub buffers. Steep valley walls along left and right corridors are forested with a mix of deciduous and coniferous trees. The channel is highly sinuous, and the valley setting suggests an E reference stream type.

A cross section completed mid-segment indicated a channel of low width/depth ratio with ample floodplain access. Channel substrates at the cross section were dominated by fine gravels. Substrate materials however, became increasingly more fine grained with distance downstream, and at the segment's lower end, channel substrates were dominated by silt and clay. The E4-riffle/pool stream type measured at the cross section location was consistent with the expected reference stream type.

Segment B was determined to be in Good geomorphic condition, on the cusp with a Reference ranking. Minor planform adjustments were noted (neck cutoff, meander extension, and flood chutes). Shrub and herbaceous buffers, as well as cohesive streambank soils are offering channel stability.

Habitat conditions were rated as Good following RHA protocols. Ample buffers are providing detritus and organic material, and offering shading to the channel. Occasional LWD was observed, probably originating from the upstream extent of the reach, where mature forest surrounds the stream channel. Reasonable diversity of channel bed forms and flow patterns is present, along with epiphaunal substrates.

Segment A

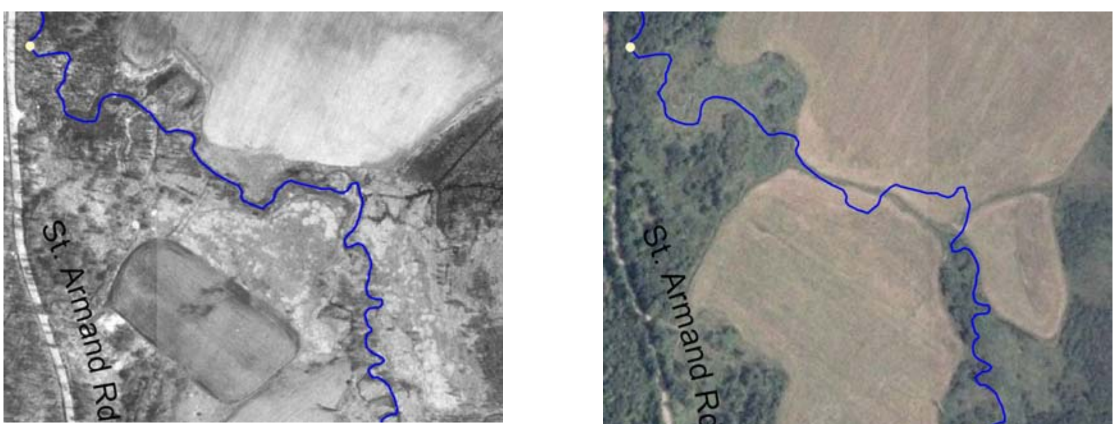
Segment A of reach M1S1.03 is approximately 3,500 feet in length, and extends through the middle and northern portions of a residential property which has been historically cleared, and more recently developed with access roads. Saxe Brook then continues downstream through agricultural fields and ends in a small wetland area with beaver dams east of St Armand Road.

Like the upstream end of the reach, Segment A flows through a broad valley underlain by hydric soils. NWI wetlands are mapped within the valley, contiguous to the channel. The valley setting and sinuosity in undisturbed sections suggest an E reference stream type.

Residential lands surrounding the upstream end of the segment have been recently cleared of shrubs and small trees. Historic channelization is suggested by a mostly linear planform. Small tributaries to the Saxe Brook along the right bank have been recently dredged and channelized. The resulting channel widths and depths are significantly greater than regime, and intermittent flows were observed to pass over bare silt and silty-clay soils (Figure 42). Small instream culverts have been installed in the Saxe Brook and its small tributaries as part of a network of improved gravel paths.

Figure 42. Tributary to M1S1.03-A.
Recently, lands surrounding M1S1.03-A have been partially cleared of vegetation, and tributaries have been dredged and channelized.

In the downstream half of the segment, channelization of the Saxe Brook appears more recent. Based on a comparison of historic air photos, the Saxe Brook was channelized between 1995 and 2003 to facilitate cropping on either side of the channel. More than 800 feet of sinuous planform has been reduced to approximately 600 feet of straightened channel. Shrub and tree buffers are nearly absent. Near bank areas are covered by grasses of moderate height, where recent dredging activities have not stripped the vegetation. A freshly tilled crop field was noted along the left bank, while fields along the right bank were in hay on the observation date (6 June 2006). At least five drainage tiles lead from the LB corn field and terminate in the Saxe Brook; one tile was observed leading from the hay field along the RB.



(a) (b)

Figure 43. Saxe Brook segment M1S1.03-A. Channelization of Saxe Brook has occurred between 1995 and 2003 based on review of aerial photographs. (a) 1995 digital orthophotographs – Vermont Mapping Program (b) 2003 aerial imagery [NAIP, 2003]).

A cross section completed in the upstream end of the segment in the historically channelized section on residential lands indicated a channel of low width/depth ratio with reasonable floodplain access (IR = 1.2). Channel dimensions indicated an E-plane bed stream type; substrates at the cross section were silt and silty-clay.

In contrast, a cross section measured in the recently straightened and dredged downstream half of the segment, indicated a channel which has lost connection to its floodplain. The loss of floodplain connection is localized in nature and appears to have occurred through a combination of: (1) dredging which has lowered the bed elevation relative to the surrounding floodplain, and (2) berming of dredging spoils and partial incorporation of bermed materials into a plowed horizon, which together have raised the floodplain elevation relative to the channel bed. This recently channelized section represents a localized area of stream type departure from a reference E stream to an F stream.

It is expected that cohesive, erosion-resistant silts and clays in the bed and banks of the Saxe Brook in this segment, along with the low gradient (0.1%), have moderated the tendency for channel degradation and widening in response to recent and historic channelization. A steep nick point was observed approximately 500 feet upstream of this recently channelized section. The nick point appears to be related to the exposure of a relatively more cohesive silt layer in the bed, rather than indicating an active wave of incision migrating headward.

Overall, Segment A was determined to be in Fair geomorphic condition, with minor evidence of widening, aggradation or planform adjustments. As a whole, the segment has not undergone a stream type departure. Of the two CEMs currently available under VTANR protocols and within the DMS, a D-stage CEM better describes the condition of the segment overall. A stage IIb within this CEM is suggested by the low to moderate degree of channel incision, generally, through the reach. As noted above, there are discrete locations within the channelized section near the downstream end of the segment that appear to have lost floodplain connection.

Habitat conditions were rated in the Fair quadrant of the RHA, on the cusp with Poor. Extensive channel management has resulted in a plane bed morphology with little diversity of flow patterns. Near bank areas are often bare, stripped of vegetation. Lack of trees and shrubs along the channel banks has limited the availability of LWD, detritus, and epiphaunal substrates.

M1S1.02

Reach M1S1.02 is a short section of the Saxe Brook located at a local pinch-point in the valley spanning the Ballard Road crossing. At the resolution of the 1987 USGS 7.5-Minute topographic maps, this reach was identified as being approximately 741 feet long with a steep slope (5.67%) in a semi-confined valley setting. Once in the field, it was determined that this reach was comprised of two segments of distinctly different stream type and slope. Segment B is a 511-foot section of 2.3%-gradient, riffle-pool channel upstream of and including the Ballard Road crossing (C4b stream type). Segment A is a 230-foot section of bedrock gorge beginning just downstream of the Ballard Road crossing (A1-cascade stream type).

Segment B

Segment B is located in a wooded semi-confined, bedrock-controlled valley. The upstream end of the segment is marked by a distinct transition in channel bed material and form, from the silt bed of the reference E-stream type of upstream reach M1S1.03, to a mixed boulder, cobble, gravel and silt bed of riffle-pool bedform.

The St. Armand Road parallels Segment B on the left bank, but at an elevation above the flood-prone (Q10 to Q50) stage. No other encroachments are currently apparent within the segment, except for road fill associated with the box culvert crossing structure for Ballard Road at the downstream extent of the segment.

A cross-section measured mid-segment indicates a C4b riffle-pool stream type, largely consistent with the reference stream type for the overall reach (C4a-riffle-pool). Minimal evidence of active channel adjustments was noted.

A relatively mature deciduous forest is present along both left and right corridors, providing shading to the closed canopy channel, and sources of detritus and LWD. Habitat is somewhat compromised by the encroachment of St. Armand Road along the far left corridor, and by minimal epiphaunal substrates and pool diversity for in-stream habitats.

Segment A

Segment A of reach M1S1.01 consists of a bedrock-controlled channel extending downstream from the Ballard Road crossing. The Saxe Brook cascades over ledge and waterfalls through a narrowly-confined valley flanked by bedrock. GIS measurements, supplemented by field observations, indicate that the brook drops some 35 feet over a distance of approximately 230 feet, for an approximate gradient of 15.2%. Isolated small trees and shrubs are growing amidst herbaceous cover along both left- and right-bank corridors. Farther from the channel, the vegetation becomes more dense and includes taller, more mature deciduous trees. A grist mill was built at the bedrock falls on Saxe Brook near the current intersection of Ballard Road and St. Armand Road circa 1787 (Doherty *et al*., 1997; Walling, 1860).

As per VTANR protocols (2006, p. 72) the Rapid Geomorphic Assessment (Steps 7.1 through 7.6) was skipped for this bedrock gorge, and the segment was assigned a "Low" sensitivity, as the bedrock will offer stability to the channel and provide extensive vertical and lateral grade controls.

Minimal epiphaunal substrates, shallow flows cascading over bedrock, and sparse tree cover in near-bank areas are factors contributing to a less than optimal habitat (as rated by the RHA). However, Segment A scored in "Good" condition on the cusp with the "Reference" category.

Figure 44. M1S1.02-A. Bedrock falls in the Saxe Brook downstream of the Ballard Road box culvert. Site of historic Saxe's Mills.
View upstream, 6 June 2006.

M1S1.01

The downstream reach of Saxe Brook extends from the base of the bedrock falls downstream through fallow pasture, under the St. Armand Road, through active dairy pasture, and through wetlands to join the Rock River. Reach M1S1.01 was segmented to capture the brief subreach of alluvial fan constituting a different stream type than the remainder of the reach.

Segment B

Segment B, at the upstream extent of reach M1S1.01, is 156 feet of multi-thread channel located at the base of the bedrock falls. Within Segment B, the Saxe Brook is transitioning from the 15.2% gradient of the bedrock falls to the much shallower gradient (0.4%) of the remainder of the reach flowing across the very broad Rock River main stem valley. As the gradient of the Saxe Brook sharply decreases, the flow velocities (and stream power) also decrease, and the stream is less able to transport coarser-grained sediments such as cobbles and gravels. These coarser materials drop out in the channel at this alluvial fan, and the channel widens as flows diverge around the sediment bars. A D4-braided stream type is evident in Segment B.

Segment B scored in the Fair quadrant of the RGA, suggesting a moderate degree of stream type departure. However, the active lateral adjustments, channel braiding, widening and aggradation noted within the segment are natural in this alluvial fan setting, and are consistent with the reference stream type. As per VTANR protocols (2006, p. 72) this condition rating was overridden to "Good" in the DMS, as the adjustment processes are not the result of human disturbances. However, a sensitivity rating of "Extreme" was retained, to acknowledge this actively adjusting channel which would pose risks to potential floodplain developments.

Segment A

Segment A of reach M1S1.01 extends from the alluvial fan approximately 1,848 feet downstream to the confluence with the Rock River. Upstream of the St. Armand Road box culvert, the channel meanders through herbaceous cover. Downstream of St. Armand Road, the linear planform of the channel and its position parallel to St. Armand Road at the margins of a dairy pasture, suggest historic channelization. Livestock have direct access to the channel within the pastured area. A scour hole is also evident on the downstream side of the box culvert crossing. At the northwestern corner of the dairy pasture, nearly 675 feet upstream from the Rock River, Saxe Brook enters the Rock River Wildlife Management Area - wetland and floodplain forest lands owned by the State of Vermont and managed by the Vermont Department of Fish & Wildlife.

A cross section completed upstream of St. Armand Road suggests a C-plane bed stream type in silt and clay substrates. The channel has good floodplain connection throughout the segment. Cohesive stream bed and banks, as well as a shallow gradient (0.4%) have likely moderated the potential for channel incision or widening in response to channelization and direct pasturing. Segment A was rated in Good geomorphic condition.

Lack of forested buffers upstream of St Armand Road and in the downstream pasture, as well as historic channelization are factors which contributed to a Fair rating for the segment following the Rapid Habitat Assessment. Direct access by livestock is also contributing to nutrient and fine sediment loading.

5.0 Bridge and Culvert Assessment Results

A database summary report for each of the 22 bridge and culvert crossings assessed following Appendix G of the VTANR protocols is contained in Attachment D to this report. The constriction status of assessed crossing structures, including the additional 23 minor structures encountered, is depicted graphically in Figure 45. All but two of the 45 structures encountered had spans which were undersized with respect to the width of the bankfull stage (and therefore were also constricting of the flood prone width). Only the Tarte Road bridge crossing of the main stem, which is elevated well above the bedrock channel, was found not to be constricting to the channel. Span data for each of the structures assessed (41 culverts and 4 bridges) can be reviewed in the Data Management System (Phase 2 Step 4.8).

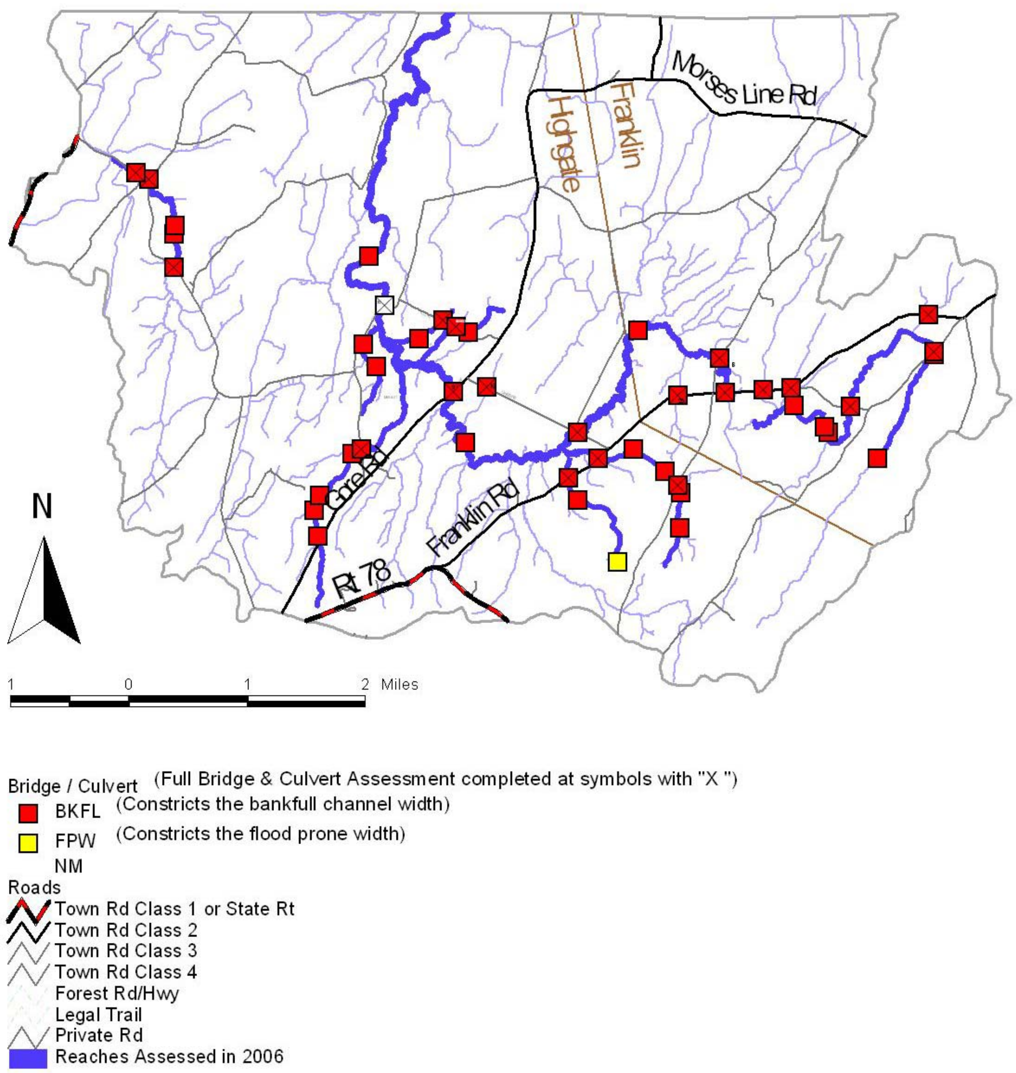


Figure 45. Constriction Status of Bridge and Culvert Crossings Encountered during Phase 2 Stream Geomorphic Assessments, Rock River watershed, 2006.

6.0 Phase 1 Updates

For the 15 reaches assessed in Phase 2, Phase 1 assessment data were reviewed and verified during field work as per VTANR protocols. Necessary corrections or updates were documented on Phase 1 summary sheets for each reach (see Project CD). As appropriate, GIS shape files were corrected or updated (using the Feature Indexing Tool), as well as the Phase 1 data in the DMS. As a result of field-based observations and measurements, changes were made to data for each of the 15 reaches.

Phase 1 parameters that were most commonly updated, included:

- presence of alluvial fans (Phase 1 Step 3.1);
- presence and location of bedrock or other grade controls (Phase 1 Step 3.2)
- steepness of valley side slopes (Phase 1 Step 3.4);
- width of riparian buffers (Phase 1 Step 4.3);
- groundwater inputs (Phase 1 Step 4.4);
- revetment lengths and locations (Phase 1 Step 5.3);
- channel straightening (Phase 1 Step 5.4);
- location and lengths of berms and roads (Phase 1 Step 6.1);
- location and lengths of development (Phase 1 Step 6.2);
- occurrence of depositional bars and bedforms (Phase 1 Step 6.3);
- occurrence of channel avulsions, neck cut-offs, flood chutes (Phase 1 Step 6.4);
- erosion lengths and heights (Phase 1 Step 7.2);
- occurrence of, or potential for, ice/debris jams (Phase 1 Step 7.3)

The above features can be more comprehensively inventoried for the study reaches during field assessments, than they are able to be during a Phase 1 which is accomplished through remote sensing and limited windshield surveys.

Occasionally, the reference stream type was updated as a result of field observation of valley confinement, or channel gradient and dimensions. Usually, this was a change from C stream type to E stream type.

Often, elevation data for the downstream and upstream reach breaks were updated as a result of field-based observations, or to correct for apparent interpolation or data entry errors in Phase 1. Accordingly, channel and valley gradient calculations were updated. In no case did these updates result in a change in stream type (slope) for the affected reaches.

As detailed in the protocols (VTANR, 2006), watershed and channel stressors defined in Steps 4 through 7 of Phase 1 are factored into impact ratings that are assigned to each reach. It was these impact ratings, in part, that helped the Project Steering Committee to prioritize reaches for field-based assessments (SMRC/WNRS, 2006). Many of these Step 4 through Step 7 parameters were updated as a result of field-based observations. Consequently, Phase 1 impact ratings changed.

Figure 46 summarizes how the total impact rating for each of the Phase 2 assessed reaches changed; in each case, the total impacts increased. Note that tributary reach M6S1.1S1.01 was not selected for complete evaluation in Phase 1 (including Steps 4 through 7 which enable calculation of the impact score); therefore, an original Phase 1 impact score for this reach is not available for comparison to the post-Phase-2 impact score.

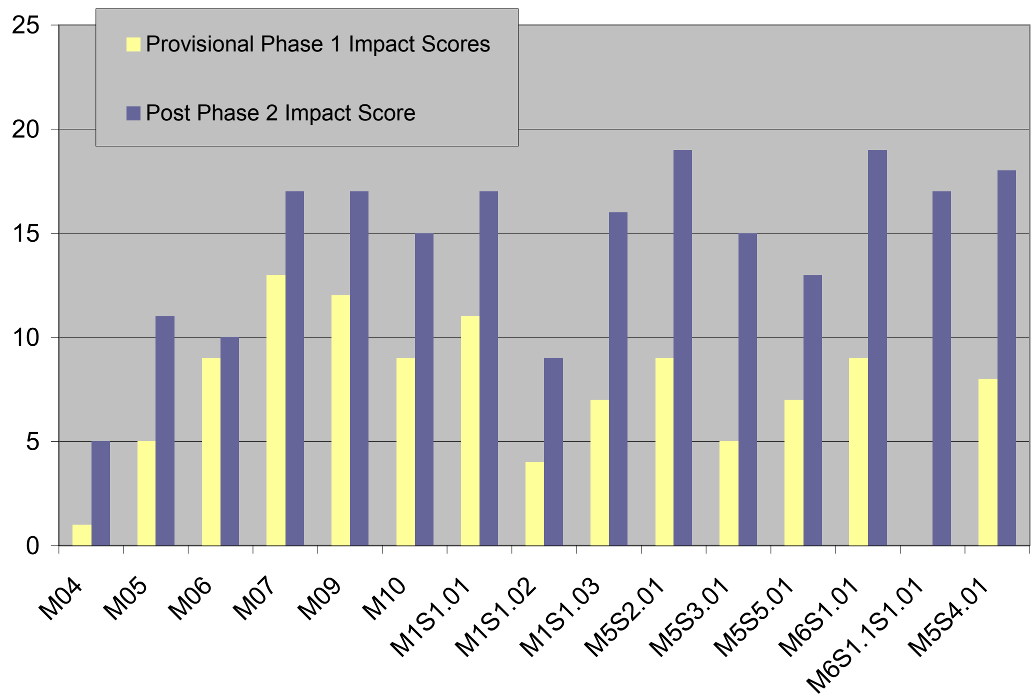


Figure 46. Comparison of Phase 1 Impact Scores before and after updating with field-based Phase 2 Data.

7.0 Summary and Discussion

Phase 2 and updated Phase 1 assessment results have begun to characterize the watershed and channel stressors to the Rock River watershed over time, and the spatial and temporal variability in adjustment processes, which together have resulted in the present day geomorphic conditions. These interpretations can be used by watershed stakeholders to identify possible consequences of land use and watershed management decisions on future geomorphic condition of the river to minimize erosion and flooding hazards and to optimize water quality and aquatic habitats.

7.1 Watershed and Channel Stressors

Various watershed-scale and channel-level disturbances have served as stressors to the Rock River main stem and tributaries (Table 7). These stressors have been identified through direct observation, limited historical research, anecdotal accounts from landowners and local citizens, as well as remote sensing. This listing is not comprehensive, but it begins to characterize the degree of natural and anthropogenic disturbance to the watershed, that has caused variable and overlapping adjustment responses in the channel.

7.2 Dominant Adjustment Processes and Reach Sensitivity

The Rock River and tributary channels are responding to stressors through adjustment of their dimension, planform, and profile. Adjustments have occurred to varying degrees, as dependent on multiple factors (including channel sediment types, vegetative cover type and density, presence of grade controls, etc.). The relative magnitude of these channel adjustment processes, together with the topographic, geologic, and vegetative settings define the sensitivity of each reach / segment to continuing and future stresses.

Generally speaking, channels with steeper gradients in confined valleys carrying coarser sediment loads (boulders, cobbles) and showing good vertical grade controls (e.g., channel-spanning bedrock) are considered to be most stable and less sensitive to vertical and lateral adjustments that may present conflicts with human investments in the corridor. In contrast, the more sensitive reaches (High, Very High, or Extreme), susceptible to future adjustments in response to channel and watershed stressors, include the low- to moderate-gradient (less than 2%) channels dominated by gravels or sands, and absent of grade controls.

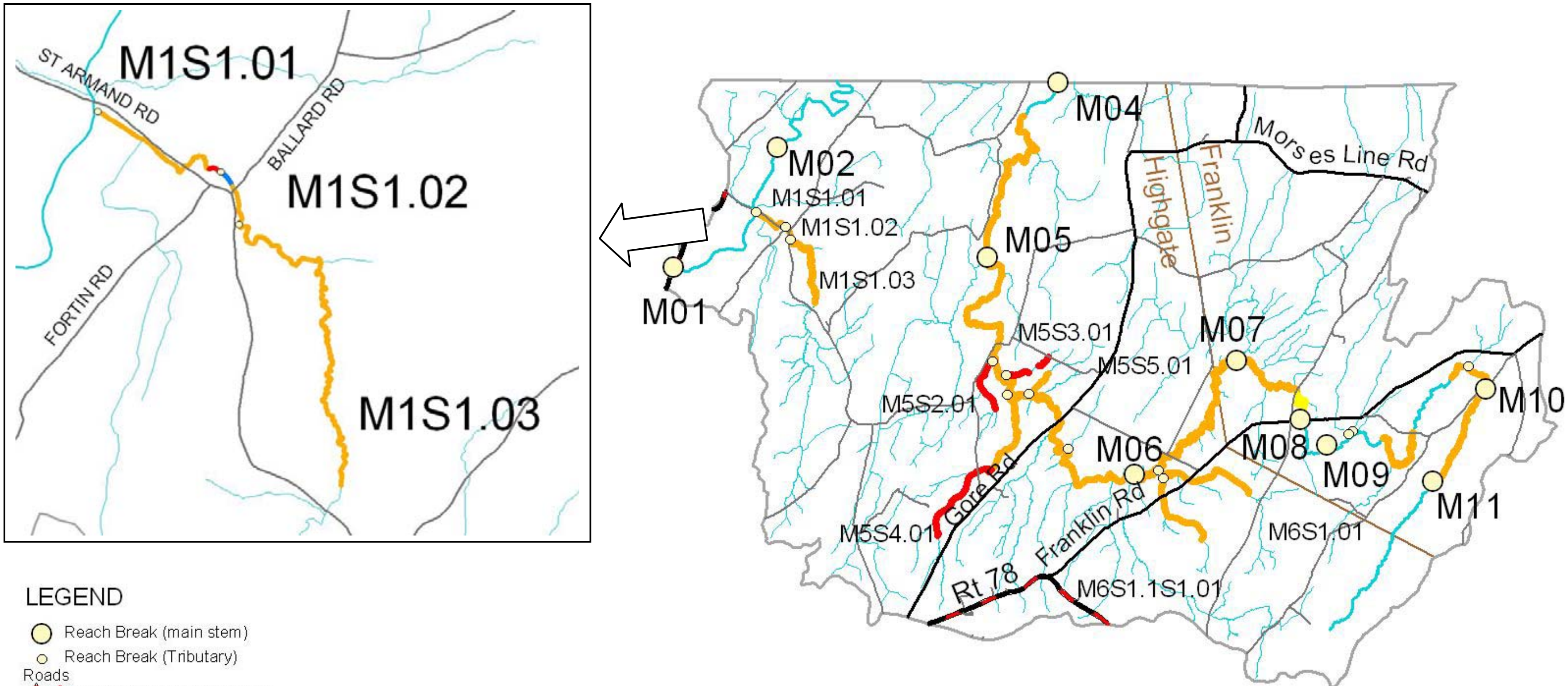
Sensitivities of the study area reaches/segments as defined in VTANR protocols (2006) are presented in Figure 47. For the most part, this Phase 2 purposely targeted lower-gradient, (reference C or E-stream-type) reaches that would be expected to exhibit higher sensitivity, and which have current constraints within the river corridor (and elevated impact ratings in the Phase 1; NWRPC/SMRC, 2006). Therefore, it is not unexpected that most of the study area reaches were defined as having sensitivities at the high end of the scale. Exceptions to this generalization were:

- M1S1.02-A, the bedrock gorge segment of Saxe Brook immediately downstream of the Ballard Road crossing in Highgate (Low sensitivity);
- M07-B, containing a bedrock gorge downstream of Bullis Pond and upstream of Barnum Road in Franklin (Moderate sensitivity, due to inclusion of some riffle/pool alluvial sections).

These segments are afforded greater stability by the underlying bedrock, and are less susceptible to lateral and vertical adjustments.

Table 7. Summary of Watershed and Channel Stressors in Study Area Reaches / Segments.

Reach / Segments	Deforestation in 1800s	Road Networks (1700s, 1800s)	Flood events	Channelization / Straightening	Dredging	Berming	Bank Armoring	Floodplain Encroachment	Loss of Forested Buffers	Impoundment (dam)	Gravel extraction	Undersized Bridge / Culvert	Constricting Old Abutments	Direct Pasturing by Livestock	Ford
	Watershed			**Channel - Reach Scale**							**Channel - Site Scale**				
Main Stem															
M04-B								√	√				√		√
M05							√	√	√			√			√
M06							√	√	√			√		√	√
M07-A				√				√	√			√			
M07-B						√	√	√	√					√	√
M09-C															√
M09-D				√	√		√		√			√			
M09-F				√			√	√	√			√			
M10				√	√	√		√	√			√		√	√
Tributaries															
M1S1.01-A				√			√	√	√			√		√	√
M1S1.01-B															
M1S1.02-A															
M1S1.02-B							√	√	√			√			
M1S1.03-A				√	√	√	√		√			√			
M1S1.03-B												√			
M5S2.01-A															
M5S2.01-B				√	√	√	√		√			√		√	
M5S3.01-A										√ (US)					
M5S3.01-C				√	√				√	√ (DS)					
M5S4.01-A															
M5S4.01-B															
M5S4.01-C				√					√					√	√
M5S4.01-D				√	√				√			√		√	
M5S4.01-E				√	√	√			√			√			
M5S5.01-A															
M6S1.01-A				√				√	√			√		√	√
M6S1.01-B				√	√	√		√	√			√			√
M6S1.1S1.01-A	▼	▼	▼	√	√			√	√			√		√	√



Reach / Segment		Sensitivity
M04	B	High
M05	--	High
M06	--	High
M07	A	High
	B	Moderate
M09	C	High
	D	High
	F	High
M10	--	High

Reach / Segment		Sensitivity
M1S1.01	A	High
	B	Extreme
M1S1.02	A	Low
	B	High
M1S1.03	A	Very High
	B	High
M5S2.01	A	High
	B	Extreme
M5S3.01	A	Extreme
	C	Extreme

Reach / Segment		Sensitivity
M5S4.01	A	High
	B	High
	C	High
	D	Extreme
	E	Extreme
M5S5.01	A	High
M6S1.1S1.01	A	High
M6S1.01	A	High
	B	Very High

Figure 47. Reach / Segment Sensitivity, Rock River Watershed, 2006 Stream Geomorphic Assessments.

In contrast, segments in Poor condition or exhibiting a pervasive stream type departure were assigned an Extreme sensitivity. For example:

- Segment M5S3.01-A, due to the very active channel adjustments (incision and widening), recent loss of floodplain connection, and stream type departure observed for this segment.
- Segment M5S4.01-E, due to the stream type departure and loss of floodplain connection rendered by very recent dredging and berming.

Three segments (M5S2.01-B, M5S3.01-C, and M5S4.01-D) were classified as having Extreme sensitivity, although conditions resulting in their Stream Type Departure were inferred to be historic in nature, and not the result of active incision. Protocols (Section 7.7) specify that a segment which has undergone a Stream Type Departure should be ranked with an Extreme sensitivity. These three segments are moderately or fully entrenched, having lost access to their floodplains as a result of historic channelization and dredging; as a result they have been historically altered from a reference E channel to either an F or Bc stream type. However, subsequent channel incision and widening appear to have been moderated by the cohesive silt bed and banks, as well as the limited stream power of these channels which have very small drainage areas (ranging from less than 0.15 square mile to less than 1.0 square mile).

A sixth segment, located on Saxe Brook downstream of the Ballard Road crossing and upstream of the St. Armand Road crossing, was conservatively assigned an Extreme sensitivity, although assessments did not reveal either a Poor condition or Stream Type Departure (see Figure 47). M1S1.01-B is a short, alluvial fan segment, exhibiting lateral adjustments, aggradation and widening. These processes in this setting of substantial slope reduction are natural, and not the result of any apparent human stressor(s). Thus the condition rating was noted as Good, with no apparent departure from reference condition. However, sensitivity of this segment to future adjustments is considered Extreme given the alluvial fan setting.

Those segment/ reaches exhibiting moderate adjustments and classified in Fair condition were assigned a Very High sensitivity (e.g., M1S1.03-A along Saxe Brook and M6S1.01-B downstream of the Durkee Road crossing).

The remaining study area reaches, in Good or Reference condition, were assigned a High sensitivity as prescribed in VTANR protocols, due to their shallow to moderate gradient (< 2%) and dominance of fine sediment sizes in the channel bed.

Most of the assessed reaches in Rock River watershed can be classified as suspended-load channels (Schumm, 1977) or cohesive channels (Knighton, 1998). The silts and silty-clay materials which constitute the channel boundaries in these reaches are relatively resistant to erosion, somewhere on the erosion continuum closer to bedrock than to non-cohesive sands and gravels. This has caused some to classify such channels as "non-alluvial" (e.g., MacBroom, 1998). These reaches have negligible bed loads and are instead dominated by suspended loads of finer materials. The cohesive sediments of glacial and post-glacial lacustrine origins in the Rock River watershed appear to have relatively high thresholds for erosion, and arguably lower sensitivity to vertical and lateral adjustments than a sand or gravel-bed stream flowing through less cohesive materials. Thus, sensitivity for those reaches undergoing minor to negligible channel adjustments may be overstated.

7.3 River Corridor Management Strategies

Preliminary identification of corridor management strategies was conducted following guidance contained in two documents recently published by the VTDEC River Corridor Management Section:

- *Alternatives for River Corridor Management* (VTDEC, 2003)
- *Using geomorphic assessment data to guide the development of River Corridor Management Plans to achieve: Fluvial Erosion Hazard (FEH) Mitigation, Sediment and Nutrient Load Reduction, and Ecological-based River Corridor Conservation* (VTDEC, draft Oct 2005)

Landowners, community members, and resource agencies, can use geomorphic data to inform future management strategies for the river corridor. 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. VTDEC River Management Section has developed guidelines for classifying reaches / segments into potential management approaches based on geomorphic characteristics.

- Equilibrium – Stable Reference (Conservation Reach)
- Equilibrium – Minor Adjustment (Eroding Banks, High Recovery Reach)
- Unstable – Moderate Departure (Moderately Unstable Reach)
- Unstable – Downcutting (Incising Reach)
- Unstable – Severe Departure (Highly Unstable Reach)

The study area reaches / segments have been classified into these general categories in Sections 7.3.1 through 7.3.5, below. Based on these categorizations, various opportunities for geomorphically-compatible river corridor management strategies have been outlined in Section 8.0 and Appendix F. These opportunities for corridor management can be broadly categorized into active versus passive approaches, with respect to the geomorphic condition.

Active vs. Passive Management Strategies

Active geomorphic approaches are typically appropriate for unstable reaches exhibiting active bed degradation and/or a severe departure from reference condition. Certain moderately unstable reaches can also be candidates for active geomorphic solutions, particularly where infrastructure may be at risk or where such active approaches are strategic in the protection of upstream stable or reference reaches. Active approaches are also relevant when there is a desire among stakeholders to accelerate the river's return to a more balanced condition. Cost of active approaches and their risk of failure are typically much higher than other alternatives.

A passive geomorphic approach involves long-term management and preservation of a defined river corridor. Under this approach, the river channel is allowed to freely meander within the area defined as the belt-width-derived river corridor. 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 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.

Generally speaking, the river can achieve a sustainable and balanced planform, profile and channel geometry more successfully and much more cheaply than humans engaged in a series of active channel restoration projects. Floodplain access for the river can be maintained and enhanced by protecting the corridors from development and floodplain filling, and refraining from channel management activities that tend to cause the channel to become disconnected with its floodplain (e.g., channelization, dredging, berming).

Generally, passive approaches to channel and floodplain restoration and conservation are most appropriate for reaches / segments in the following stream condition categories:

- Equilibrium – Stable Reference - where conservation of the corridor can serve to protect stream equilibrium conditions and ecological processes within the riparian corridor.
- Equilibrium – Eroding Banks – High Recovery Reach where restoring channel boundary conditions (vegetation, to increase roughness elements
- Unstable – Moderate Departure.

7.3.1 Equilibrium – Stable Reference

Tributary	Reach / Segment		Sensitivity
Saxe Brook	M1S1.02	A	Low
Unnamed trib	M5S4.01	B	High

Two examples of a stream channel in approximate dynamic equilibrium were noted during 2006 field assessments in the Rock River. The bedrock streambed and high banks at the falls on Saxe Brook below the Ballard Road crossing offer stability to the channel (Segment M1S1.02-A); negligible erosion or channel adjustments were noted in this segment. Segment M5S4.01-B is an E-stream-type channel meandering through a wetland. Very minor adjustments were noted in this channel.

Management strategies recommended for reaches in reference condition include conservation strategies to preserve the equilibrium function. Conservation measures should also address potential changes to sediment or water loading within these regime channels, as significant changes in either the sediment or hydrologic balance could destabilize the channel. For example, several gullies and point sources of fine sediments were noted within and upstream of segment M5S4.01-B; at the moment the degree of sediment inputs does not appear to have impaired the sediment transport capacity of the channel, however, continued increases in sediment inputs could cause thresholds to be exceeded.

7.3.2 Equilibrium – Minor Adjustment

A majority of the main stem reaches and segments assessed on the Rock River in 2006 were in regime, exhibiting only minor adjustments.

Tributary	Reach / Segment		Sensitivity
Rock main stem	M04	B	High
Rock main stem	M05	--	High
Rock main stem	M06	--	High
Rock main stem	M07	A	High
Rock main stem	M07	B	Moderate
Rock main stem	M09	C	High
Rock main stem	M09	D	High
Rock main stem	M09	F	High
Rock main stem	M10	--	High

In addition, several of the tributary segments can also be categorized as Equilibrium-Minor Adjustment segments.

Tributary	Reach / Segment		Sensitivity
Saxe Brook	M1S1.01	A	High
Saxe Brook	M1S1.02	B	High
Saxe Brook	M1S1.03	B	High
Unnamed trib	M5S2.01	A	High
Unnamed trib	M5S4.01	A	High
Unnamed trib	M5S4.01	C	High
Unnamed trib	M6S1.01	A	High
Unnamed trib	M6S1.1S1.01	A	High

Overall, the above main stem and tributary segments appear to be in an approximate state of dynamic equilibrium, with only localized areas of imbalance. Main stem reaches M06, M05, and M04 have experienced relatively limited human encroachments or disturbances, due to their topographic position in the geologically-incised, narrow-valley setting. Other reaches/ segments tended to have more occurrences of channel encroachments including straightening, dredging, berming, undersized bridges and culverts. However, cohesive silt and silty-clay soils in the channel bed and banks seem to have moderated the tendency for lateral and vertical adjustments in most cases.

Equilibrium-Minor Adjustment reaches have high recovery potential. As with Equilibrium-Reference reaches, conservation strategies are suggested to preserve equilibrium functions, and land uses that might result in significant changes in the sediment and hydrologic regimes should be avoided.

Preservation of flow and sediment attenuation areas along the river network is an important element in the passive geomorphic approach. Many of the assessed reaches were wash-load dominated, and there was little evidence of impaired transport capacity for coarser sediments in the assessed reaches. Thus, sediment attenuation is not suggested as a means of improving the bedload sediment regime. However, there are many benefits to attenuation of fine sediments, as arguably they may have more affinity for nutrients than coarser bed sediments. The main stem of the Rock River, downstream of the Franklin / Highgate town line is confined to a narrow valley between steep slopes. Given these topographic characteristics of the river and tributaries, there are fewer opportunities for sediment attenuation, as compared to the broader valley settings with contiguous wetlands in the upper part of the watershed. For example, the beaver meadow upstream of Beaver Meadow Road (M09-E) and wetlands upstream of Bullis Pond (M09-A, -B) have potential to serve sediment and nutrient attenuation functions. Many of the tributary reaches also have in-stream wetland segments which can offer effective flow (and fine sediment and nutrient) attenuation. With the willingness of landowners, these sites may be good candidates for conservation.

Continued maintenance and enhancement of naturally vegetated riparian buffers will enhance stream stability. Secondary benefits of such buffer developments will be organic matter and LWD recruitment for aquatic insects and fish, as well as increased shading to reduce river temperatures.

Active geomorphic restoration solutions can be appropriate in Equilibrium-Minor Adjustment reaches, to accelerate a return to equilibrium or to accomplish associated water quality or habitat improvements. For example, in segment M5S2.01-B east of the Tarte Road near the intersection with Parent Road, an opportunity for channel restoration has been identified (Table F2, Project A-5). The downstream half of the segment flows through a formerly pastured area and was recently channelized and bermed. The land use has recently changed and this area is no longer used as dairy pasture. There is an opportunity to restore the channel to its meandering planform along the eastern margins of the valley, thereby restoring floodplain access and reducing nutrient and fine sediment inputs to the Rock River.

7.3.3 Unstable (Dis-equilibrium) – Moderate Departure

Rock River tributary segments in unstable condition exhibiting moderate degrees of departure include the following:

Tributary	Reach / Segment		Sensitivity
Saxe Brook	M1S1.01	B	Extreme
Saxe Brook	M1S1.03	A	Very High
Unnamed trib	M5S5.01	A	High
Unnamed trib	M6S1.01	B	Very High

It should be noted that M1S1.01-B was assigned an "Extreme" sensitivity classification due to the active lateral adjustments, widening and aggradation that are ongoing in this brief segment. However, these processes are natural in this alluvial fan setting at a sudden reduction in slope at the base of a bedrock falls.

The other three segments are exhibiting moderate departures from reference. In segments M1S1.03-A and M6S1.01-B, moderate degrees of incision appear related to widespread channelization, dredging, and berming along agricultural fields, and in the vicinity of undersized crossing structures. Channel management in M1S1.03-A is more recent in nature than in M6S1.01-B. Channel adjustments to these disturbances are systemic. However, the loss of floodplain connection is not yet severe enough to result in a stream type departure. Incision and widening have likely been moderated by the cohesive nature of erosion-resistant silts and silty-clays in the channel bed and banks. While these segments have the appearance of stability over recent years, they are more likely than other reaches to experience catastrophic stream bank erosion in sudden avulsion episodes during the next large-magnitude flood. The partially incised status of these segments, and limited access to their floodplains, means that the power of flood flows will be trapped within the banks. They lack the active floodplains which are critical for energy dissipation during low to high magnitude flows. These reaches remain particularly sensitive to future increases in flow from upstream or up-watershed management practices. For this reason, the sensitivity of these segments is considered Very High.

Segment M5S5.01-A is located in the forested narrow valley downstream from agricultural fields along Boucher Road. Moderate, localized incision in this channel appears to be the result of indirect causes rather than direct channel management. Increased flows from stormwater inputs and agricultural tiles may have increased flows in this tributary channel to a degree that exceeds thresholds for erosion in discrete locations. The segment still maintains connection with its floodplain along much of the length. Sensitivity of this channel to future disturbances is High.

Generally, passive geomorphic approaches are advised for reaches / segments in the Unstable-Moderate Departure category. Strategies should include actions to control sources of increased runoff to the channels. It is important to maintain floodplain access in these reaches to allow for flow and sediment attenuation. Greater floodplain access can be accomplished by protecting the corridors from development and floodplain filling, and refraining from channel management activities that tend to cause the channel to become disconnected with its floodplain (e.g., channelization, dredging, berming). Preservation and enhancement of woody riparian buffers is also advised for maintaining erosion-resistance in the channel margins.

7.3.4 Unstable (Dis-equilibrium) – Incising Reach

Tributary	Reach / Segment		Sensitivity
Unnamed trib	M5S3.01	A	Extreme

Segment M5S3.01-A is actively incising and widening into cohesive silts and silty-clays. Several nick points in the cohesive bed materials were noted, and the relief of the current bed elevation compared to the recently abandoned floodplain suggests an incision ratio over 4. While, there is no apparent evidence of direct channel management within the segment (e.g., dredging, channelization), hydrologic stressors were noted that could have indirectly resulted in incision. Increased flows from tile drainage and gully development along the top of the valley walls, likely has caused flows in the segment at one or more times to exceed thresholds for erosion of the cohesive silts and clays in the bed. An undersized, instream culvert may also be contributing to scouring.

There are opportunities for active geomorphic measures within incising reaches. Headcuts in the channel can be stabilized, and the floodplain restored either through raising the bed and providing grade controls, or by creating a wider floodplain at the lower elevation. In addition to these measures, however, it would be necessary to control for future hydrologic impacts and reduce sediment inputs to the channel (for example, by providing energy dissipation at tile outlets and stabilizing gullies). Recommendations specific to M5S3.01-A are provided in Table F-2, Project A-4.

7.3.5 Unstable (Dis-equilibrium) – Severe Departure

Tributary	Reach / Segment		Sensitivity
Unnamed trib	M5S2.01	B	Extreme
Unnamed trib	M5S3.01	C	Extreme
Unnamed trib	M5S4.01	D	Extreme
Unnamed trib	M5S4.01	E	Extreme

Current dimensions of Segment M5S4.01-E suggest a severe stream type departure (from reference E channel to a G channel). This departure from reference appears to be related to recent channelization, dredging, and berming (see Section 4.2.2). Possible headcuts are located at the upstream extent of dredging at the boundary with an upstream wetland segment. The channel has lost connection to its floodplain, in all but the largest magnitude floods, as a combined effect of channel excavation and placement of berms within the floodplain.

Stream Type Departures in the other three segments of tributary reaches (M5S2.01-B, M5S3.01-C, and M5S4.01-D) appear more historic in nature. Following extensive, historic channel straightening, dredging and berming, these channels lost connection to their floodplains. In more recent years, these channels appear to have re-established a subtle meandering planform within a narrow to semi-confined floodplain at a lower elevation; terrace walls of the recently abandoned floodplain now serve as valley walls to the incipient floodplain. Cohesive silt and silty-clay soils in the channel bed and banks appear to have limited the potential for incision and widening, and these channels are currently exhibiting only minor adjustments.

Detailed studies would be required to characterize the erosion resistance of stream bed and bank materials in the face of variable shear stresses. However, it is conceivable that these channels are of sufficiently small size (less than 1 square mile drainage area) where flow velocities (and imparted shear stresses) are insufficient to erode the cohesive streambed and streambank soils to a degree that would lead to system-wide lateral and vertical channel adjustments that would permit these channels to evolve back to the reference E stream type.

Active geomorphic measures which can be considered for segments in severe departure (G-stage or F-stage) include arresting / stabilizing head cuts, restoring floodplain access through berm removal, restoring the reference (meandering) planform, and replacing undersized culverts. Such active measures have associated costs and can have relatively high risks of failures. In the process, substantial volumes of fine sediments and nutrients may be released downstream to impact receiving waters.

Passive geomorphic measures appropriate to these segments would include attenuating flows from tile drainage (made possible by alternate cropping), restoring woody riparian buffers to increase roughness along channel margins, and refraining from continued dredging and channelization.

Recommendations specific to these segments are provided in Tables F-1 and F-2 of Appendix F.

8.0 RIVER CORRIDOR MANAGEMENT OPPORTUNITIES

Based on Phase 2 assessment results, the Project Team has identified potential opportunities for geomorphically-compatible river corridor management. Steps taken to manage for the equilibrium channel will reduce instream production of sediment and nutrients and enhance sediment and nutrient attenuation.

Specific project opportunities are listed by reach/segment in Appendix F. Table F-1 lists passive geomorphic approaches; Table F-2 identifies active geomorphic measures. Through limited project scoping and landowner outreach, the logistical constraints, budgetary realities and technical feasibility of alternatives have been provisionally identified in these tables.

This list of geomorphically-compatible river management opportunities has formed the basis for follow-on project development activities being carried out by the Towns of Highgate and Franklin through their consultant, Brian Jerose of WASTE NOT Resource Solutions (Fairfield, VT).

Watershed stakeholders which can look to this data for guidance include (but are not necessarily limited to):

- landowners,
- towns of Highgate and Franklin,
- Friends of Mississquoi Bay,
- Missisquoi River Basin Association,
- VT Department of Environmental Conservation, Water Quality Division – River Management Section and Wetlands Section,
- Vermont Agency of Agriculture,
- Vermont Department of Transportation,
- Vermont Land Trust,
- Vermont River Conservancy,
- Northern Vermont Resource Conservation and Development Council (Better Back Roads),
- US Fish and Wildlife, and
- US Department of Agriculture, Natural Resources Conservation Service.

9.0 CONCLUSIONS

Phase 2 stream geomorphic assessments were completed on 15 reaches (25.9 river miles) of the Rock River and select tributaries in the towns of Highgate and Franklin during June and early July of 2006. Six main stem reaches were assessed from the vicinity of Hannah Road in southwestern Franklin, downstream to the point where Rock River crosses into Quebec in northeastern Highgate. Nine tributary reaches in Highgate were also assessed: two draining to the Rock River just downstream of the Cassidy Road crossing; four tributaries draining to the Rock River between the Gore Road and the Tarte Road crossings; and three reaches of the Saxe Brook along St. Armand Road.

Geomorphic data will be used by watershed stakeholders (including landowners, community members, watershed organizations, and state and federal resource agencies) to inform future management strategies along the assessed reaches. The geomorphic condition of a given reach or segment will help to define the short-term compatibility and long-term sustainability of various restoration or conservation projects and future land use or channel management activities.

Various watershed-scale and channel-level disturbances, noted through field investigation and historical data review, have impacted the Rock River main stem and tributaries. Significant disturbances to the assessed river reaches have included:

- Channelization / straightening / dredging of tributaries and the upper main stem;
- Berming of select tributaries and upper main stem reaches;
- Channel armoring (rip-rap), typically limited to culvert and bridge crossings;
- Floodplain encroachment by roads, and residential and commercial development;
- Undersized culverts and bridges, which constrict channel flows;
- Direct pasturing of livestock in select main stem and tributary reaches;
- Introduction of increased flows and sediments through tile drains and drainage ditches from adjacent agricultural fields;
- Stormwater runoff from roads, driveways and crossing structures;
- Active stream crossings (fords);
- Minimal or absent forested buffers along portions of the study reaches; and
- Flood events, including a reasonably large event in January of 1996, and the larger floods of 1938 and 1927.

The Rock River and tributary channels are responding to these past disturbances through adjustment of channel dimensions (cross section geometry), planform (position in the landscape), and profile (slope). Adjustments have occurred to varying degrees, as dependent on many factors, including the magnitude 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.

In general, the assessed main stem reaches are showing minor degrees of channel adjustment. Downstream of the Highgate / Franklin town line, the Rock River is entrenched within a somewhat narrow, meandering valley with steep forested side slopes. This position in the landscape resulted from several thousand years of erosion following the last glacial period in Vermont. Given the topography in this section of the Rock River, there are relatively few examples of development or roads encroaching on the channel, except for a few bridge or culvert crossings. Direct channel disturbances, such as straightening, dredging, or gravel extraction are also rare. This minor degree of channel disturbance, together with the cohesive (erosion-resistant) nature of the clay and silt substrates in the channel bed and banks, have resulted in the relatively stable condition of these lower main stem reaches. Where riparian buffers have been removed (for example, near road crossings or along isolated pastured areas), stream bank erosion is more pronounced. However, these appear to be localized areas of instability and are not indicative of system-wide imbalances.

In contrast, the upper reaches of the Rock River main stem (within the town of Franklin) and the tributary reaches, generally, have been subjected to greater degrees of channel disturbance – notably, extensive channelization, dredging, berming, and removal of forested buffers - to facilitate cropping, pasture or residential uses and to allow for road maintenance. Such direct channel manipulations would be expected to initiate system-wide imbalances. Channel incision (or downward scour) would typically result, with consequent loss of floodplain connection, followed by widening, excessive sediment buildup downstream of eroding locations (aggradation) and accelerated shifts in planform.

Segments within two of the assessed reaches were actively adjusting, indicating system-wide imbalance. Both have undergone a stream type departure and lost access to their floodplain. Flow velocities have exceeded thresholds for erosion of the channel bed and bank materials in these two assessed segments, contributing to channel incision and widening. Direct channel manipulations (straightening, dredging, berming) have contributed to incision in one of the segments. The other segment does not appear to have been subjected to direct channel disturbances. Instead, active incision and widening are suspected to have been caused by increased flows from drainage structures (drainage tiles, stormwater) and gullies developed along the valley margins of this segment.

- Agricultural tiles drain adjacent fields and terminate at the tops of the side slopes along many of the main stem reaches and tributaries. Presence of drainage tiles in adjacent fields may have improved field drainage, but as a consequence, groundwater and surface water runoff are discharged to the Rock River main stem and tributaries in greater volumes over shorter periods of time. While impacts of any one tile may be considered minor, the cumulative effect may be significant, resulting in increased flow peaks and magnitudes in the Rock River and tributaries during storm events.

For the most part, however, the upper reaches of the Rock River main stem and tributary reaches were found to be in relatively minor to moderate states of adjustment. Most have reasonable floodplain access. Factors which may have moderated lateral and vertical adjustments in response to considerable channel disturbances include the:

- Cohesive nature of the clays and silts of lacustrine origin in channel bed and banks which appear to have high erosion resistance;

- Presence of channel-spanning bedrock serving as vertical and lateral grade controls to many of the assessed reaches; including the following more notable cases,

- the bedrock gorge segment of Saxe Brook immediately downstream of the Ballard Road crossing in northwestern Highgate (M1S1.02-A); and
- the bedrock gorge downstream of Bullis Pond and upstream of Barnum Road in Franklin (M07-B).

- Small drainage areas (0.2 to 2.6 square miles) of these upper main stem and tributary reaches (thus, relatively low flow velocity and stream power to erode channel bed and banks);
- Shallow-gradient settings of many of these upper main stem and tributary reaches with instream ponds (e.g., Bullis Pond) and channel-contiguous wetlands (e.g., beaver meadow of M09) providing for flow and sediment attenuation; and
- Suspended-load dominance of many of the tributary reaches. The fine-grained sediments of the cohesive channel margins are relatively resistant to erosion. When particles do erode, they tend to stay in suspension and travel for great lengths downstream, rather than accumulate within the channel and potentially lead to widening or initiate channel avulsions. Where opportunities for flow and sediment attenuation are present within the river network, very long residence times are required to permit these fine silt and clay particles to settle out.

A few tributary segments subjected to extensive channelization and dredging appear to have evolved to a new quasi-equilibrium condition, with a much narrower available floodplain at a lower elevation. This condition could be viewed as a model for restoration of other reaches in less stable condition. The trade-off however, may be that such a modified stream type is a very efficient conveyor of fine sediments (and nutrients), and has limited floodplain area for attenuation of those fine sediments and nutrients.

In summary, the Rock River would appear to be in fairly stable condition, not exhibiting the kinds of extreme lateral and vertical channel adjustments that characterize sand and gravel bed streams in disequilibrium (like the nearby Trout River in Montgomery). However, the fine-grained clay and silt which dominate channel boundaries in most of the Rock River and tributary reaches impart a different kind of vulnerability to the watershed, related to high suspended sediment loads and their association to nutrient loading.

In localized areas of instability, where channel scour is mobilizing fine sediments, these sediments (and associated nutrients) tend to stay in suspension and travel for great lengths downstream (into Quebec and ultimately to Lake Champlain). Opportunities within the stream network (in Franklin County) to attenuate fine sediments and nutrients are limited. Many of the Rock River main stem and tributary segments are entrenched within narrow valleys – either over geologic time frames (thousands of years) as a result of base-level lowering and continental rebound following recession of the glaciers; or over recent human time scales (last several decades) as a result of channelization and other disturbances. Thus, floodplains along many of the reaches are narrow with limited space for flow and sediment attenuation. Where such opportunities do exist within the river network, very long residence times are required to permit the finest silt and clay particles to settle out. Bullis Pond in Franklin, for example, provides such a sediment attenuation function. Flow dynamics elsewhere in the river network most often do not provide sufficient residence time.

Ultimately, best opportunities for controlling the transport and delivery of fine sediments and nutrients within the Rock River watershed are through: (1) improved management of nutrient inputs within the upstream extents of the river network; and (2) interruption of the transport processes of sediments and nutrients at their source. Significant mobilization of fine sediments and nutrients is occurring along the margins of the Rock River and tributary corridors. For example:

- In fields adjacent to the channel, silt- and clay-rich soils become quickly saturated during rain events. In tiled fields, tile infiltration rates appear to be overwhelmed by intense rains. Saturation excess overland flow converges in surface swales, and over tile locations to flow through herbaceous and woody buffers directly to the Rock River. Often installation of the tiles themselves leads to soil compaction and development of surface swales that concentrate surface runoff and provide a pathway for direct drainage to the river and tributaries.

- Observed practices of tilling/cropping on moderate slopes and cropping directly through surface swales that ultimately drain to the Rock River are contributing to the mobilization of fine sediments and nutrients. In many cases, fields traditionally in hay have been recently converted to crop (usually, corn), made possible by installation of tiles and drainage ditch networks. While these measures may have improved overall drainage in the fields, they result in more rapid delivery of flows to the Rock River and tributaries. Tillage practices in corn fields, and nutrient requirements of those crops, result in higher erosion and nutrient mobilization than in hay fields.

- No energy dissipation mechanisms were observed at tile outlets and surface water swales terminating at the periphery of agricultural fields along the tops of the valley walls surrounding the Rock River and tributaries. In many cases, large scour holes have developed at the tile outlets, resulting in sediment erosion down the side slopes into the floodplain below. Some of these scour holes have created large gullies dissecting the valley side slopes of tributary channels.

- Saturation excess overland flow was observed to collect within the floodplain valley along the base of moderately-sloped cropped fields. The saturated runoff-contributing areas (RCAs) were hydrologically connected to the Rock River. Buffer areas were inundated and water extended well into fields that had been recently tilled and planted. Rill erosion was also observed through the emergent crops, delivering small deltas of fine sands and silt out into the RCAs.

10.0 RECOMMENDATIONS

10.1 Restoration

Restoring channel equilibrium will reduce instream production of sediment and nutrients and enhance sediment and nutrient attenuation over the long term. Opportunities for channel restoration in specific segments of the assessed Rock River and tributary reaches are provided in Appendix F.

Active geomorphic measures are specified for segments in moderate to major adjustment, including those which have undergone stream type departures. Recommended active measures include:

- arresting headcuts in incising segments;
- restoring floodplain access, either by raising the bed and providing grade controls, or by forming a new floodplain at a lower elevation;
- removing berms; and
- restoring channel planform, dimensions, and profile in previously channelized segments.

Passive geomorphic measures offered for restoration of segments in minor adjustment include:

- improving boundary resistance along channel margins through restoration of forested buffers. Tree buffers will provide the additional benefits of organic matter, detritus, and LWD to aquatic and riparian habitats. Connectivity of buffer areas from reach to reach along the river network is also supportive of mammalian terrestrial habitats by providing wildlife corridors;
- excluding cattle to reduce channel trampling and allow buffers to revegetate;
- improving crossing structures, with less constricting bridges and culverts;
- preserving flow and sediment attenuation functions through voluntary conservation and rehabilitation of instream or channel-contiguous wetlands; and
- preserving equilibrium functions of stream channels, by refraining from future channel manipulations, through voluntary conservation of riparian corridors.

Two impoundments were noted in or immediately upstream of assessed reaches: (1) the earthen dam and culvert under the Franklin Road at Browns Corners which impounds Bullis Pond (reach M08); and (2) the earthen dam and small culvert under a farm road which crosses a tributary to the Rock River southwest of Boucher Road (Segment M5S3.01-B). If future plans involve rehabilitation or removal of these dams, or if a future flood event leads to damage of the structures, any changes in the control heights and sediment attenuation functions of these impoundments should be reevaluated in light of the resultant changes to flow and sediment regime in the Rock River, upstream and downstream of these locations.

10.2 Water Quality

Restoration or preservation of geomorphic equilibrium in the Rock River and its tributaries will contribute to water quality improvements and reduced sediment loading in the long term. To most effectively improve water quality in the short term, resources in this watershed are best directed toward preventing fine sediments and nutrients from entering the tributaries and main stem of the Rock River at their source. This can be accomplished on multiple fronts:

1. Address increased flows to the Rock River from agricultural drainage tiles, erosional gullies, drainage ditches and stormwater runoff.

    a. In the residential, commercial and municipal arenas, stormwater flows can be managed through compliance with state regulations. The towns of Highgate and Franklin can consider local ordinances to provide more stringent controls on stormwater runoff and which could apply to smaller developments and road / driveway installations that may not be subject to state stormwater regulations.

    b. Road maintenance practices to mitigate for stormwater and sediment runoff to the Rock River and tributaries 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; and protection of culvert headers. 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.

    c. In agricultural settings, increased flows from drainage tiles, ditches and erosional gullies can be addressed through design and retrofitting of tile networks to provide for energy dissipation at tile outlets; gully stabilization; and consideration of crop rotation or alternative farming practices that reduce the need for drainage tiles. Considerable technical and financial resources are available to farmers to implement these practices (see below).

2. Identify saturated runoff-contributing areas (RCAs) along the channel margins (for example, see Section 4.2, reach M07, segment A). Where these RCAs overlap with land uses that involve fertilizers or manure, manage nutrient applications to prevent mobilization of nutrients and sediments during snowmelt and precipitation events. Meals, *et al*. (2006) found nutrient management, particularly in RCAs, to be the overriding factor in achieving greatest reductions of phosphorus export in a study of the Little Otter Creek in Addison County. RCAs are defined by the topography, soil characteristics, and groundwater / river interactions. They vary in aerial extent with the magnitude and intensity of rainfall events (Dunne & Black, 1997). In select locations, RCAs may extend to distances from the channel margins that exceed default set backs or buffer widths specified in regulations (e.g., AAPs) or existing management agreements (e.g., CREP).

3. Exclude livestock from direct access to stream channels. Livestock exclusion (fencing) can be accompanied by provisions for alternative water sources and installation of stabilized livestock crossings. Opportunities for livestock exclusion in the Rock River watershed were noted on the following reaches / segments: M06, M07-B, M10, M1S1.01-A, M5S2.01-B, M5S4.01-C, M5S4.01-D, M6S1.01-A, and M6S1.1S1.01-A. Technical and financial resources are available to farmers to implement these practices (see below).

4. Implement changes in cropping practices to reduce direct runoff of fine sediments and nutrients to drainage ditches, surface swales, and the Rock River channel and tributaries. Possible measures include crop rotation, filter strips, grass buffers, cover cropping, interseeding, and no-till options in the fall of the year. At a minimum, improved compliance with current agricultural regulations, including Accepted Agricultural Practices (AAPs), Large Farm Operation (LFO) rules, and Medium Farm Operations (MFO) rules, will begin to address reduction in fine sediment and nutrient mobilization.

Substantial technical and financial resources are currently available to farmers from various regional, state and federal agencies to implement the above changes in farming practices. Resource agencies and programs include, but are not necessarily limited to:

- Vermont Agency of Agriculture
    - Conservation Reserve Enhancement Program
    - Best Management Practices cost-share program
    - Integrated Crop Management cost-share program
    - Nutrient Management Plan incentive grants

- Vermont Natural Resources Conservation Districts
    - Agricultural Resource Specialists

- USDA Natural Resources Conservation Service
    - Agricultural Management Assistance
    - Conservation Reserve Program
    - Environmental Quality Incentives Program

10.3 Community Planning

The present degree of residential / commercial development along the Rock River is currently low in many of the reaches, presenting landowners and the communities of Franklin and Highgate with a strategic opportunity. Planning processes can be undertaken to support the river's equilibrium condition, and limit the sources of increased flows and sediments that will contribute to destabilization of the channel and mobilization of fine sediments and nutrients. Agricultural and forested lands are under pressure of residential and commercial development. Installation of new road and driveway networks would be required to service this new development. Such development will increase impervious surfaces in the watershed. Proper planning and oversight will ensure that stormwater runoff from these impervious surfaces is appropriately managed and does not drain to the Rock River or its tributaries without measures taken to reduce the magnitude and peak of flows and treat for sediment and contaminant impacts.

Planning strategies can ensure that new development does not encroach on the river corridor, reduce the sediment and flow attenuation functions of the floodplain area, and place the infrastructure at risk of fluvial erosion losses. Geomorphic data can be used to define a corridor overlay district for town planning purposes. Currently, funding and technical resources are available to the towns of Highgate and Franklin for such planning processes through the Governor's Clean and Clear Action program.

With regard to bridge and culvert structures and other infrastructure, the geomorphic context should be considered when designing new and rehabilitated structures.

- New or replacement bridges should ideally have openings which pass the bankfull width to flood-prone-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 and tributaries should be considered when installing new or replacement crossing structures, and when constructing new roads, driveways, and buildings.
- 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.
- Divert road ditch runoff 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.

10.4 Further Technical Studies

This study focused on a limited portion of the Rock River watershed. Phase 2 assessments of additional tributaries would provide similar base line information for future corridor management strategies, and would provide a greater watershed context for results of this study. Specifically, tributaries to reach M07, draining the northeastern portion of the watershed would be important to assess, as well as tributaries to reach M04. In addition, deltas of fine sediment were observed at the confluence of M5S7.01 and M5S1.01, tributaries draining to reach M05. These tributary watersheds (each less than 0.5 square mile) are developed by agricultural crop lands, residential properties and road/driveway networks. Phase 2 assessment would better characterize potential channel adjustments within these tributaries that may be contributing significant sediments to the Rock River.

11.0 REFERENCES

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer, 1976, *A Land Use and Land Cover Classification System for Use With Remote Sensor Data*. US Geological Survey Professional Paper 964. Washington D.C., Department of the Interior.

Beers, Frederick, 1871. *Atlas of Franklin and Grand Isle Counties, Vermont*. New York, NY: F. W. Beers & Co.

Brakenridge, G. Robert, Peter A. Thomas, Laura E. Conkey, and Jane C. Schiferle, 1988. Fluvial Sedimentation in Response to Postglacial Uplift and Environmental Change, Missisquoi River, Vermont. *Quaternary Research*. 30: 190-203.

Budd, Lenore F. and Donald W. Meals, 1994 (February), *Lake Champlain Nonpoint Source Pollution Assessment*. Lake Champlain Basin Program Technical Report No. 6A.

Cronin, C. M., 1977, *Late-Wisconsin Marine Environments of the Champlain Valley (New York, Quebec).* Quaternary Research 7: 238-253.

Dennis, John G., 1964. The Geology of the Enosburg Area, Vermont. Vermont Geological Survey Bulletin No. 23, Vermont Development Department, Montpelier, VT.

DeWolfe, Matthew N., W. Cully Hession, Mary C. Watzin, 2004. *Sediment and Phosphorus Loads from Streambank Erosion in Vermont, USA*. In Critical Transitions in Water and Environmental Resources Management.

Doherty, Prudence, Robert Florentin, Kathleen Kenny, and Robert Sloma, 1997 (March), Phase 2 Site Evaluation for Highgate-Franklin RS 0301(1) SA, Highgate and Franklin, Franklin County, Vermont. Prepared by the Consulting Archaeology Program, UVM. Submitted to the Vermont Agency of Transportation.

Doll, Charles G., Ed., 1970. *Surficial Geologic Map of Vermont*. Waterbury, VT: Vermont Geological Survey.

Dunne, T. and R.D. Black. 1970. Partial area contributions to storm runoff in a small New England watershed. Water Resources Research 6(5): 1296-1311.

Fiske, Wayne, 2006, personal communication. Franklin Selectboard member, dairy farmer, and former road commissioner.

Gates, Ben, 2006, personal communication.

Hegman, William, Deane Wang, and Catherine Borer, 1999 (September). *Estimation of Lake Champlain Basinwide Nonpoint Source Phosphorus Export*. Lake Champlain Basin Program Technical Report No. 31.

Kalma, D. and R. Ulmer. 2003. Estimating desorbed phosphorous and sediment loading by streambank erosion, Boquet River (Essex County, NY). Boquet River Association, Elizabethtown, NY., 76p.

Kempton, Larry, 2006, personal communication. Town Manager, Highgate, Vermont.

Knighton, David, 1998. Fluvial Forms and Processes. New York, NY: Oxford University Press Inc.

Lake Champlain Basin Program, 2005, *State of the Lake: Lake Champlain in 2005--A Snapshot for Citizens*. Available at: http://www.lcbp.org/PDFs/sol_web.pdf

Meals, Donald W., E. Alan Cassell, David Hughell, Lynnette Wood, Robert Parsons, William E. Jokela, 2006 (March 27). Interactive Spatially Dynamic Framework for Sustainable Watershed Phosphorus Management (Draft Final Report).

MacBroom, James Grant, 1998. The River Book: The Nature and Management of Streams in Glaciated Terranes. Connecticut: Hartford. DEP Natural Resources Center Technical Publications Program. DEP Bulletin 28.

Medalie, Laura and Eric Smeltzer, 2004. *Status and Trends of Phosphorus in Lake Champlain and its Tributaries, 1990-2000.* Chapter in Lake Champlain: Partnership and Research in the New Millennium. Edited by T. Manley *et al.*, Kluwer Academic/ Plenum Publishers, 2004.

Mehrtens, C.M., and R.J. Dorsey, 1987, *Stratigraphy and Bedrock Geology of the Northwestern Portion of the St. Albans Quadrangle and the Adjacent Highgate Center Quadrangle, Vermont*. Vermont Geological Survey Special Bulletin No. 9. Charles A. Ratte and Robert Cushman, ed.

Missisquoi River Basin Association, 2004 (March 4), personal communications from members in attendance at meeting in Highgate, Vermont.

Montgomery, D. R. and J. M. Buffington, 1997, Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin, v.109, no. 5, p. 596-611.

National Agricultural Imagery Program (NAIP), 2003, TIFF ortho images obtained from Vermont Center for Geographic Information. http://www.vcgi.org/dataware/products/metadata/naip2003.htm#Technical%20Doc

Nelson, E. J. and D. B. Booth, 2002. *Sediment budget of a mixed-land use, urbanizing watershed*. J. Hydrology, v. 64, p. 51-68.

Northwest Regional Planning Commission and South Mountain Research & Consulting, June 2006. *Phase 1 Stream Geomorphic Assessment: Missisquoi River Watershed, Franklin County, VT*.

Olson, Scott A., 2002, Flow-Frequency Characteristics of Vermont Streams. USGS Water-Resources Investigations Report 02-4238.

Rainville, Adrian, 2006, personal communication.

Rosgen, D., 1996, Applied Fluvial Morphology. Wildland Hydrology Books, Pagosa Springs, Co.

Rosgen, D.L., 1994, A Classification of Natural Rivers. *Catena*: 22. 169-199.

Schumm, S., 1977. The Fluvial System. Caldwell, NJ: The Blackburn Press.

Schumm, S.A., 1960. The effect of sediment type on the shape and stratification of some modern fluvial deposits. *Am. J. Sci.,* 258: 177-184.

South Mountain Research & Consulting and WASTE NOT Resource Solutions, 2006 (Jan), *Initial Field Visit and Scoping Report: Rock River Watershed, Franklin County, VT*. Prepared for the Town of Highgate, VT.

Stewart, David P., 1974, Geology for Environmental Planning in the Milton-St. Albans Region, Vermont. Vermont Geological Survey Environmental Geology No. 5. Montpelier, VT: Water Resources Department.

Stewart, David P. and Paul MacClintock, 1969, *The Surficial Geology and Pleistocene History of Vermont*. Vermont Geological Survey Bulletin No. 31.

Thompson, Elizabeth H. and Eric R. Sorenson, 2000. Wetland, Woodland, Wildland: A Guide to the Natural Communities of Vermont. Hanover, NH: University Press of New England.

US Army Corps of Engineers, Sept 1978, *Flood Plain Information: Missisquoi and Rock Rivers, Swanton and Highgate, Vermont*. New York, NY.

US Department of Agriculture, Soil Conservation Service, 1979. Soil Survey of Franklin County, Vermont.

US Department of Agriculture, 2003. Supplemental to the Soil Survey of Franklin County, VT.

USGS, 2006, on-line surface water data, <http://waterdata.usgs.gov/vt/nwis>.

USGS, 1990, National Water Summary 1988-89 – Floods and Droughts: State Summaries: Vermont.

Vermont Center for Geographic Information, www.vcgi.org
LandLandcov_LCLU – Landcover/Landuse for VT and Lake Champlain Basin

VT Agency of Natural Resources, 2006, Stream Geomorphic Assessment Protocol Handbooks, Remote Sensing and Field Surveys Techniques for Conducting Watershed and Reach Level Assessments. Available at http://www.vtwaterquality.org/rivers/htm/rv_geoassesspro.htm

VT Agency of Natural Resources, 2001, The Streamside Sentinel, published by the Vermont Agency of Natural Resources, Division of Water Quality, Waterbury, VT.

VT DEC River Management Section, 2005 (26 October draft), *Using geomorphic assessment data to guide the development of River Corridor Management Plans to achieve: Fluvial Erosion Hazard (FEH) Mitigation, Sediment and Nutrient Load Reduction, and Ecological-based River Corridor Conservation.*

VT DEC River Management Program, 2003 (18 April), Alternatives for River Corridor Management: Vermont DEC River Management Program Position Paper.

VT DEC Water Quality Division, 2005, Lake Champlain Long-term Monitoring – Tributary Station Summary Statistics available at:
http://www.anr.state.vt.us/dec/waterq/cfm/champlain/tribstats_results.cfm

VT DEC Water Quality Division, 2006a (February), draft for public comment, *State of Vermont 2006 303(d) List of Waters*: *Part A – Impaired Surface Waters in Need of TMDL*.

VT DEC Water Quality Division, 2006b, *Vermont Regional Hydraulic Geometry Curves*.

VT DEC Water Quality Division, 2004, *State of Vermont 2004 303(d) List of Waters*: *Part A – Impaired Surface Waters in Need of TMDL*.

VT DEC Water Quality Division, 2003 (December), Basin 5 Surface Water Quality Assessment Report. (Available online at: http://www.anr.state.vt.us/dec/waterq/planning/docs/pl_basin5assessmntrpt.pdf)

VT DEC Water Quality Division, 2003 (30 July, v. 1.0), Programmatic Quality Assurance Plan for Stream Geomorphic Assessment Protocols. http://www.vtwaterquality.org/rivers/docs/assessmenthandbooks/rv_sgaquappsigned.pdf

VT DEC Water Quality Division, 2001, *Vermont Regional Hydraulic Geometry Curves: 2001 Provisional*.

VT DEC Water Quality Division, 1999 (February), Options for State Flood Control Policies and a Flood Control Program, prepared for the Vermont General Assembly pursuant to Act 137 Section 2 (1998).

VT DEC and NYS DEC, 2002 (September 25). Lake Champlain Phosphorus TMDL.

VT DEC and NYS DEC, 1997 (January). A Phosphorus Budget, Model, and Load Reduction Strategy for Lake Champlain: Lake Champlain Diagnostic-Feasibility Study, Final Report

VT Department of Forests, Parks & Recreation, 2006, "Lake Carmi State Park" web site viewed online at Http://www.vtstateparks.com/htm/carmi.cfm.

Walling, H.F., 1860. Map of Franklin County, VT. New York, NY: W.E. Baker & Co.

Wagner, W. Philip, 1972, Ice Margins and Water Levels in Northwestern Vermont. New England Intercollegiate Geological Conference, 64th Annual Meeting Guidebook for Field Trips in Vermont, pp. 319-342.

Weather Underground website, accessed 23 September 2006, daily precipitation history for Burlington Airport weather station, www.wunderground.com/history/airport/KBTV/...