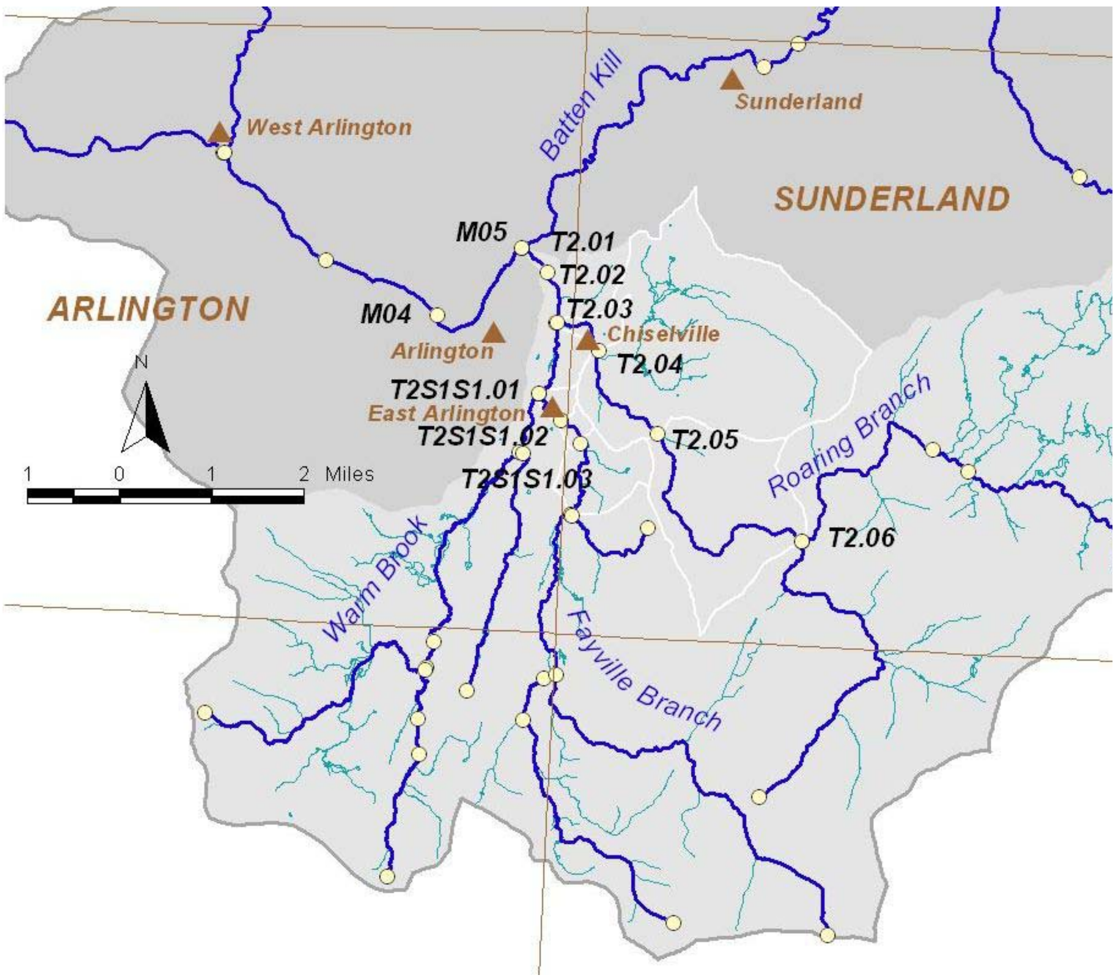
Phase 2 Stream Geomorphic Assessment
Batten Kill Watershed: Roaring & Fayville Branches
Towns of Sunderland & Arlington,
Bennington County, Vermont

January 2009



Prepared by | *Prepared under contract to*

South Mountain Research & Consulting
2852 South 116 Road, Bristol, VT 05443
802-453-3076

Bennington County Regional Commission
111 South Street, Suite 203
Bennington, VT 05201

TABLE OF CONTENTS

APPENDICES

A. Phase 2 Stream Geomorphic Assessment Reach Summary Reports
B. Bridge and Culvert Assessment Reports
C. Quality Assurance Documentation
D. Reach Segmentation

ACKNOWLEDGEMENTS

This study was made possible through funding received from the State of Vermont Emergency Management, coordinated through the Lamoille County Planning Commission, and administered by the Bennington County Regional Commission. Technical assistance was provided by the VT Department of Environmental Conservation, River Management Program.

Field work was conducted with the cooperation of Arlington and Sunderland landowners who granted permission to cross their property to access the river.

EXECUTIVE SUMMARY

Phase 2 geomorphic assessments were completed in 2008 on 6 reaches (7 river miles) of the Fayville and Roaring Branches of the Batten Kill following protocols published by the Vermont Agency of Natural Resources. Field investigations and limited historical data reviews have identified various watershed and channel disturbances that have impacted these reaches of the Fayville and Roaring Branch tributaries, including:

Watershed-scale Modifiers:

- Historic deforestation and subsequent reforestation from the mid-1800s through the early 1900s;
- Significant flood events in 1927, 1936, 1938, and 1973;
- Historic impoundments flow diversions associated with industrial and manufacturing interests in Chiselville and East Arlington village in the 1800s; and
- Upstream erosion and tributary sources of sediment (often enhanced by beaver activity).

Reach-scale Modifiers:

- Channelization (straightening) especially associated with bridge crossings and historic impoundments;
- Reported gravel extraction, dredging and windrowing of the channel in response to the flood events of 1936 / 1938 and 1973, particularly along the Fayville Branch through East Arlington village;
- Berming along stream banks (along Kelley Stand Rd, Roaring Branch; in vicinity of bridge crossings on both tributaries; and through the East Arlington village, Fayville Branch);
- Streambank armoring (rip-rap) and retaining walls;
- Floodplain encroachment by roads and residential and commercial development;
- Undersized public bridges and in-stream culverts, serving as flow constrictors at bankfull flow or higher-magnitude flood events (particularly, Prouty Hill Road culvert on the Fayville Branch);
- Stormwater runoff from roads (along Kelley Stand Rd, Roaring Branch; at Prouty Hill Road crossing and through East Arlington village, Fayville Branch); and
- An impoundment (Hale Company dam) on the Warm Brook 650 feet downstream of the Fayville Branch confluence which appears to have impounding effects that extend upstream into the Fayville Branch.

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

- Some of the assessed river segments were in regime, showing an expected (natural) level of change or adjustment, and maintaining average channel dimensions, planform, and profile, over time. This category includes a bedrock-controlled segment of the Fayville Branch above the Ice

Pond Road crossing, as well as the bedrock gorge beneath the Chiselville covered bridge on the Roaring Branch. These segments are afforded greater stability by the underlying bedrock, and are less susceptible to lateral and vertical adjustments, even where significant channel disturbances have occurred. This category would also include:

- the downstream end of Fayville Branch (below the East Arlington Road bridge);
- a mile-long section of Fayville Branch spanning the Route 313 culvert crossing;
- and the middle segment of a naturally-braided reach downstream of the Route 7 crossing on the Roaring Branch.

Generally, these segments are connected to their surrounding floodplain and appear to be maintaining average channel dimensions, planform, and profile, over time. These are identified as key attenuation assets in the watershed, providing for attenuation of sediment and flows.

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

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

- Between these extremes, a third broad category of the assessed reaches was apparent - segments where historic incision has led to a minor to moderate degree of channel entrenchment, but the channel has some degree of floodplain connection, particularly in larger flood events. Dominant adjustment processes observed in these reaches were minor to moderate planform adjustment, aggradation and widening; none of the segments exhibited signs of system-wide active incision. Often, the coarseness and erosion resistance of materials in the stream bed and banks (including exposed or shallow bedrock and intact forested buffers) has moderated the potential for channel adjustments. Also, channel disturbances or encroachments have been minimal. This category includes segments of the Roaring Branch: (a) along Kelley Stand Road, and (b) downstream of Chiselville on approach to the Warm Brook confluence.

Opportunities for river restoration and conservation have been identified based on the Phase 2 geomorphic assessment results. A preliminary project listing forms the basis for follow-on project development and planning activities which can be carried out by watershed stakeholders.

1.0 INTRODUCTION

Phase 2 geomorphic assessments were completed in 2008 on 6 reaches (7 river miles) of the Fayville and Roaring Branches of the Batten Kill following protocols published by the Vermont Agency of Natural Resources (VTANR, 2007a). Objectives of the Phase 2 assessments were to:

- determine the geomorphic condition of targeted reaches, and identify active vertical and lateral adjustment processes;
- identify current and historic disturbances to the channel at the reach and watershed levels; 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).

Three reaches of the Roaring Branch were assessed from the Kelley Stand Road downstream to the Warm Brook confluence below Chiselville. Three reaches of the Fayville Branch draining to East Arlington were assessed.

Assessment data were entered into the online Data Management System (DMS), a custom database of geomorphic data developed and maintained by the Vermont Agency of Natural Resources. Assessment results will be used by landowners and other watershed stakeholders to:

- identify restoration and conservation projects intended to improve water quality and enhance a return to a more balanced condition of the channel;
- plan for future development which is compatible with adjusting river channels; and
- support the development of a Fluvial Erosion Hazard corridor for the Roaring and Fayville Branches.

This summary report has been prepared by South Mountain Research & Consulting (SMRC) of Bristol, Vermont under contract to the Bennington County Regional Commission (BCRC).

2.0 BACKGROUND

Phase 2 assessments in the Fayville and Roaring Branches of the Batten Kill were undertaken to provide a geologic and geomorphic context for the erosion and water quality issues documented in these tributaries over the past several years. Phase 2 results for these tributaries build on assessments that were previously completed on the Batten Kill main stem and other major tributaries, including the downstream two reaches of the Roaring Branch, as reported in the following studies:

Field, John, 2007 February, River Corridor Planning on the Batten Kill, Vermont. Submitted to River Management Program, Dept of Environmental Conservation, VT Agency of Natural Resources. Available at: http://www.anr.state.vt.us/dec/waterq/rivers/docs/FinalReports/23_CPA.pdf

Field, John, 2005 December, Phase 2 Geomorphic Assessment of the Batten Kill, Vermont. Submitted to River Management Program, Dept of Environmental Conservation, VT Agency of Natural Resources. Available at: http://www.anr.state.vt.us/dec/waterq/rivers/docs/FinalReports/23_P2A.pdf

Field, John, no date, Changes on the Batten Kill, Vermont Since 1860 as Documented by Historic Ground Photographs. Available at: http://www.battenkillalliance.org/PDFs/BK_Paired_Photos.pdf

Jaquith, S., M. Kline, J. Field, & J. Henderson, 2004 February, Phase 1 Geomorphic Assessment of the Batten Kill Main-Stem and Major Tributaries, Vermont. Available at: http://www.anr.state.vt.us/dec/waterq/rivers/docs/FinalReports/23_P1A.pdf

2.1 Geographic Setting

The Batten Kill drains an area of land approximately 450 square miles located in Bennington County of Vermont and Washington County, New York (Figure 1). The Batten Kill watershed is part of the Hudson-Hoosic subbasin of the Upper Hudson River basin. The Batten Kill joins the Hudson River at Clarks Mills, south of Glens Falls, New York.

This study focused on portions of two tributaries of the Batten Kill located in Vermont:

- Roaring Branch, which joins the Batten Kill 1 mile upstream of Arlington village, and
- Fayville Branch, which flows through East Arlington village and joins the Warm Brook, which itself joins the Roaring Branch near Chiselville, approximately 1 mile upstream of its confluence with the Batten Kill.

Six river reaches along these tributaries in the towns of Sunderland and Arlington were assessed in July and August of 2008 (Figure 2).

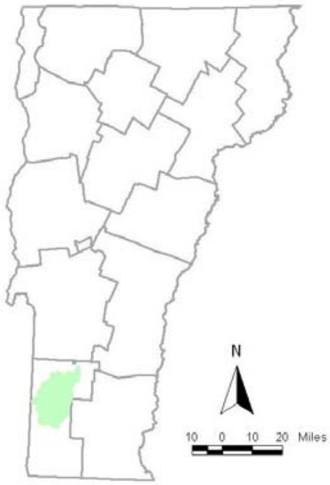
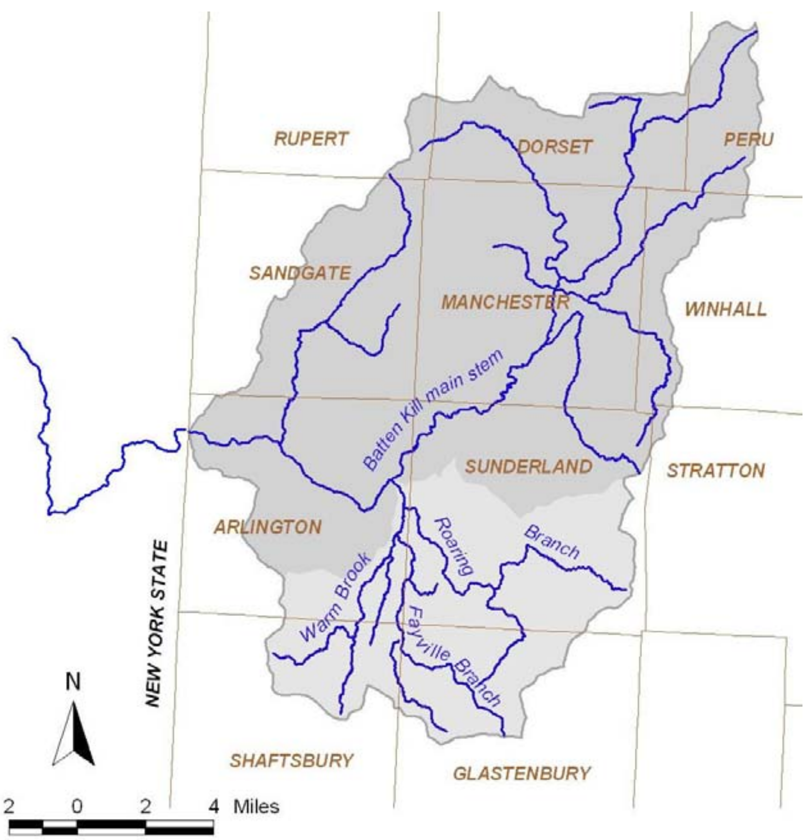


Figure 1a. (left) Location of Batten Kill Watershed in Vermont (portion draining to the Batten Kill main stem at the New York State border – excluding Rupert subwatershed which drains to Batten Kill in New York via the Black Creek).

Figure 1b. (below) Location of Batten Kill Watershed within northern Bennington County towns (portion draining to the Batten Kill main stem at the New York State border – excluding Rupert subwatershed). Roaring Branch subwatershed, which contains the Fayville Branch subwatershed, is highlighted in lighter gray.

.



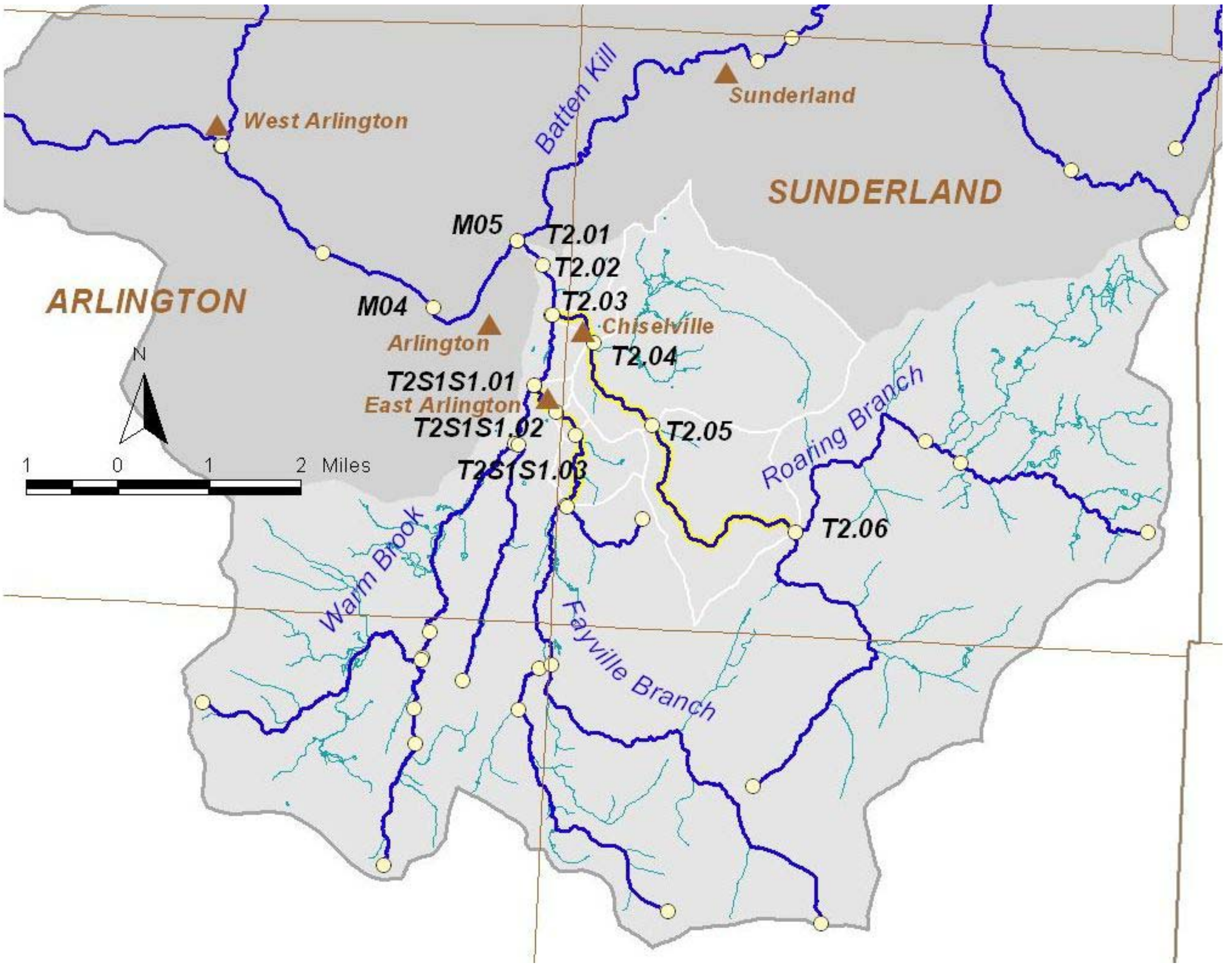


Figure 2. Location of Phase 2 reaches on Roaring Branch (T2.03, T2.04, T2.05) and Fayville Branch (T2S1S1.01, T2S1S1.02, T2S1S1.03) assessed in 2008 (highlighted in yellow).

2.2 Regional Geologic Setting

The upper Batten Kill watershed in Vermont spans the Green Mountain physiographic province to the east and the Taconic Mountains to the west. These provinces are separated by the northeast-southwest trending Vermont Valley which is coincident with the broad valley of the Batten Kill main stem northeast of Arlington.

In recent geologic time (from 24,000+ to 13,500 years before present; Ridge, 2003) this landscape was occupied by advancing and retreating glaciers, with ice up to a mile or more in thickness above the present land surface. Glacial tills now blanket much of the upper bedrock-controlled slopes and headwaters of the watershed. As glaciers melted and receded, deposits of water-washed boulders, cobbles, gravel and sand (kame moraines, kame terraces) built up along the ice margins in the Batten Kill valley (Doll, 1970; Behling, 1966; DeSimone, 2000). Associated with the latest advance of ice lobes down the Batten Kill valley, an ice-cored moraine deposit near Arlington impounded glacial meltwaters and created a temporary high-elevation lake (Lake Batten) between the present-day villages of Arlington and Manchester (DeSimone & LaFleur, 1985; Behling, 1966; Stewart & MacClintock, 1969). This short-lived lake drained when the ice core eventually melted and this moraine dam was breached by the Batten Kill. Lake Batten shore deposits were mapped at an approximate elevation of 720 feet (Stewart & MacClintock, 1969) in the vicinity of the Roaring Branch confluence.

As the global climate warmed and the glaciers receded, a large fresh-water lake inundated the Hudson Valley Lowland (Lake Albany) and later extended northward into the Champlain Valley (Lake Vermont) (Connally & Sirkin, 1969; Chapman, 1937; Stewart & MacClintock, 1969; DeSimone & LaFleur, 1985). Since flow was blocked to the north by the retreating Laurentide ice lobe, freshwater entering Lake Albany / Lake Vermont from tributaries including the Batten Kill drained to the south via the Hudson River valley to Long Island, NY (DeSimone & LaFleur, 1985). DeSimone & LaFleur (1986) note that the large delta deposited at the mouth of the Batten Kill extended out into the Lake Quaker Springs stage of this freshwater lake (near the present-day confluence with the Hudson River).

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

The landscape of Vermont was dissected by river systems following glacial retreat, driven in part by dropping base levels in the Hudson River valley. Significant channel incision may also have been driven by isostatic rebound of the land surface in the late Pleistocene and early Holocene (Brakenridge *et al*, 1988). Absence of vegetation on the recently-deglaciated hillslopes probably contributed to floodplain aggradation in the late Pleistocene. Sedimentation rates would have declined as the landscape became revegetated and forests matured, and floodplain incision may have begun to dominate. Rates of sedimentation on alluvial fan surfaces and in ponds were relatively high during the early Holocene based on research from Northwestern Vermont (Bierman *et al*, 1997). Bierman *et al* (1997) theorize that "early Holocene hillslope erosion may have been driven by episodic large storms in a drier [but stormier] climate than today. Late Holocene erosion and aggradation were also event driven, but greater ambient levels of soil saturation [in a cooler, moister climate] may have allowed smaller storms to trigger similar landscape responses." In colonial times, hillslope erosion and floodplain aggradation increased substantially as a result of wide-spread deforestation by the early- to mid-1800s (Brakenridge *et al*, 1988; Severson, 1991; Thomas, 1985). These trends may have again reversed themselves when most hillslopes became reforested in the late 1880s and early 1900s.

2.2.1 Bedrock Geology

The upper reaches of the Roaring Branch and Fayville Branch drain the western slopes of the Green Mountains which are generally comprised of folded and faulted gneiss, schist and phyllites of lower Cambrian and pre-Cambrian age. The gneiss, phyllites and schists of the Green Mountains are more resistant to erosion and are responsible for the high relief of the Roaring Branch subwatershed. The middle reaches of the Fayville and Roaring Branches then leave the Green Mountains and flow across a high valley underlain by less erosion-resistant Dunham Formation dolomites. This valley is bounded on the northwest by a northeast-trending ridge of more weather-resistant Monkton quartzite. Both tributary channels cross-cut this ridge: Fayville Branch at East Arlington village and Roaring Branch at Chiselville under the Chiselville covered bridge. Fayville Branch joins the Warm Brook at East Arlington, which then flows to the northeast along the contact between the Monkton quartzite and Winooski Formation dolomites. Roaring Branch receives the Warm Branch below Chiselville and then proceeds to cross cut dolomites of the Winooski Formation and Danby-Clarendon Springs Formation to join the Batten Kill which flows through a valley underlain by more weathered marble and dolomites of the Shelburne Formation (Hewitt & LaBrake, 1961).

Frequent bedrock exposures influence the channel position and profile in the Fayville and Roaring Branch subwatersheds. Fractures in the bedrock control the overall sinuosity of the Roaring Branch from Kelley Stand downstream to the Kansas Rd bridge crossing. In many sections of the other assessed Roaring Branch reaches, bedrock exposures along the valley walls constrain the lateral position of the river channel. Occasional exposures of channel-spanning bedrock offer vertical grade controls, 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 reaches, two discrete segments of bedrock channel were noted. One consists of a 900-ft length of bedrock channel along Old Mill Road in East Arlington, including the Grist Mill falls (Figure 3). A second bedrock gorge is located beneath the Chiselville covered bridge.

Figure 3. (T2S1S1.02) Bedrock falls at the grist mill, East Arlington village.

This channel-spanning exposure of bedrock serves as a vertical grade control for the Fayville Branch.

2.2.2 Surficial Geology

Glacial activity has influenced the surficial sediments and soil types which are present in the Roaring Branch watershed today (see Figure 4). Upland slopes are dominated by shallow- to moderate-thickness glacial till deposits overlying bedrock. The broad valley of the Batten Kill main stem in the study area is dominated by glacio-fluvial deposits and more recent alluvium. Assessed reaches of the Fayville Branch down to the confluence with Warm Brook are underlain by a mixture of glacio-fluvial sediments, till and recent alluvium. The Roaring Branch emerges from the western slopes of the Green Mountains to flow across an alluvial fan feature which likely formed during the late Pleistocene and early Holocene following retreat of the glaciers. Remaining reaches of the Roaring Branch down to the confluence with Warm Brook (and beyond to the Batten Kill main stem) flow through a mixture of glacio-fluvial sediments, till, and recent alluvium.

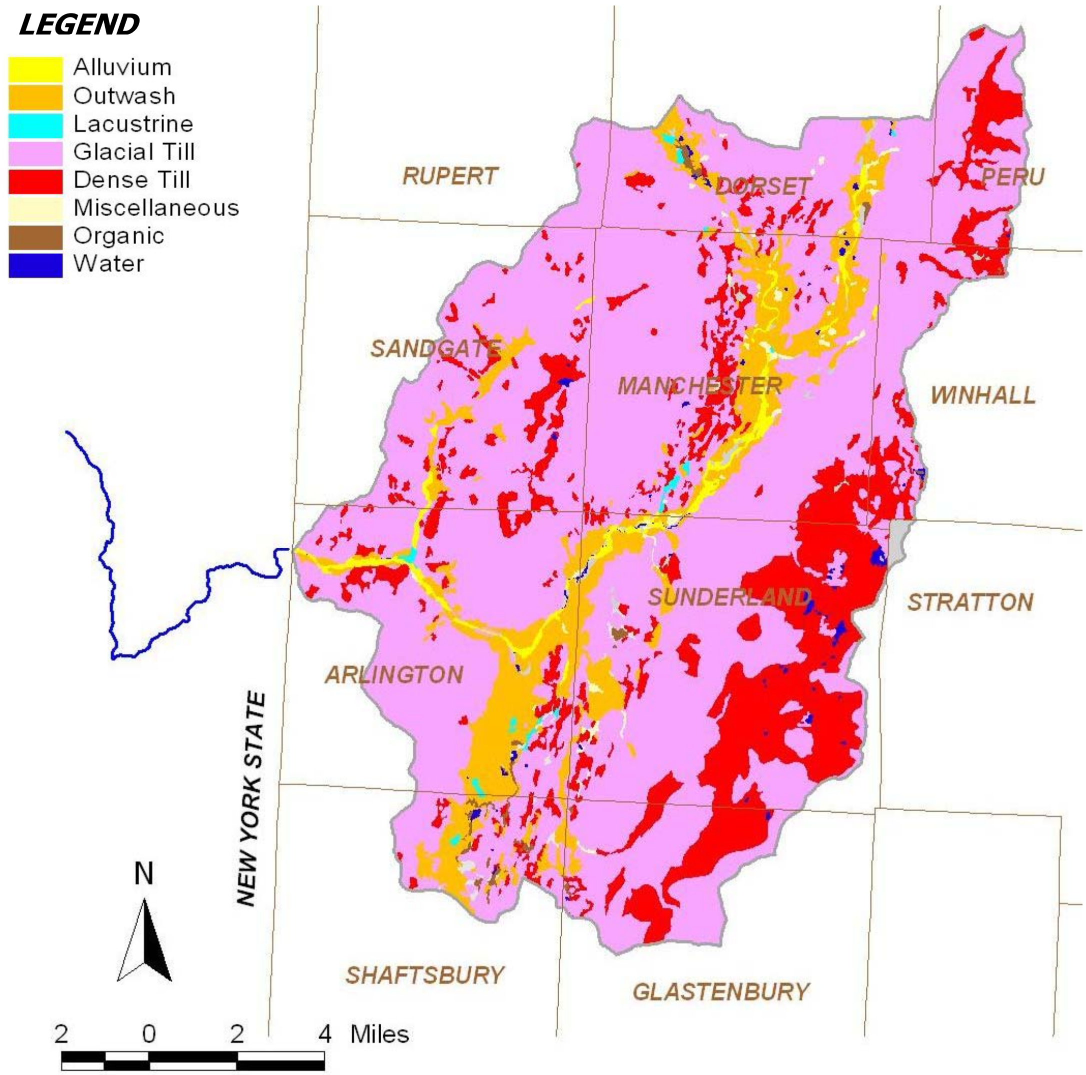


Figure 4. Soils types in the Vermont portion of the Batten Kill watershed (excluding Rupert subwatershed), classified by parent material (USDA, 2005; USDA, 1998; USDA, 1995).

Soils of the Roaring Branch watershed (including Fayville Branch) are dominated by soils of low to very low infiltration rate. Nearly 67% of the soil types are classified as C and D (or A/D and C/D) Hydrologic Soil Groups. Soils of greater permeability (Hydrologic Soil Groups A and B) tend to be associated with surficial deposits of glaciofluvial and alluvial origin and are concentrated in the valleys of the Batten Kill main stem and major tributaries.

2.3 Geomorphic Setting

The Vermont portion of the Batten Kill watershed (excluding Rupert subwatershed that drains to the Batten Kill in New York state via the Black Creek) was evaluated in a Phase 1 Stream Geomorphic Assessment prepared by the VTANR, Field Geological Services, and BCRC (Jaquith *et al*, 2004). The Batten Kill main stem and major tributaries were each 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 assessment.

Based on the channel and watershed stressors identified through remote sensing, windshield surveys and limited historical research during the Phase 1 Geomorphic Assessment, several reaches along the main stem and major tributaries were prioritized for Phase 2 Stream Geomorphic Assessments in 2005. The reader is referred to the *Phase 2 Geomorphic Assessment of the Batten Kill*, Vermont (Field, 2005).

The two downstream reaches of Roaring Branch (T2.01 and T2.02) and the downstream reach of Warm Brook (T2S1.01) were assessed in 2005 by Field Geology Services. This current study expanded investigation of these tributaries to include three additional reaches on the Roaring Branch, and three reaches on the Fayville Branch which joins Warm Brook at East Arlington village (Table 1).

Table 1. Reaches selected for Phase 2 Stream Geomorphic Assessments on Batten Kill tributaries, Summer 2008.

Tributary	Towns	Reach Number	Upstream Watershed Area (sq mi)	Reach Length (ft)	Reach Length (miles)
Roaring Branch	Arlington, Sunderland	**T2.03**	25.9	3,638	0.7
	Sunderland	**T2.04**	25.7	7,204	1.4
	Sunderland	**T2.05**	20.6	15,500	2.9
Fayville Branch	Arlington	**T2S1S1.01**	13.9	2,296	0.4
	Arlington, Sunderland	**T2S1S1.02**	13.8	1,930	0.4
	Sunderland	**T2S1S1.03**	13.7	5,224	1.0
			Total:	**35,792**	**6.8**

Relief in the Roaring Branch subwatershed (which includes the Fayville Branch) varies from highest elevations of 3,200 feet in the headwaters of Fayville Branch on the western flanks of Glastenbury Mountain, and 2,850 feet at the headwaters of Roaring Branch, to 620 feet at the confluence of Roaring Branch with the Batten Kill just north of Arlington village. Figure 5 illustrates the lower portions of Roaring Branch, Fayville Branch and Warm Brook tributaries in longitudinal profile. Generally, valley and river channel slopes become shallower with distance downstream toward the Batten Kill main stem.

The upper reaches of the Roaring Branch (reach T2.05 and above) flow across the western flanks of the Southern Green Mountains. Reach T2.05 flows through a narrow, "V" to "U"-shaped valley flanked on either side by steep, forested slopes. Velocities are high, and the channel has sufficient power to carry boulders, cobbles, and gravels. As the channel transitions out into the Vermont Valley near the Kansas Road bridge crossing, the reduced valley confinement permits a divergence of flows, and a braided channel is visible on the alluvial fan surface. Valley gradient begins to decline with distance downstream across the lower alluvial fan surface. The lower reaches of the Roaring Branch and the assessed reaches of Fayville Branch that flow through the Vermont Valley physiographic province generally have a lesser gradient and meandering profile (where they are not constrained by bedrock or where they have not been modified through past human actions).

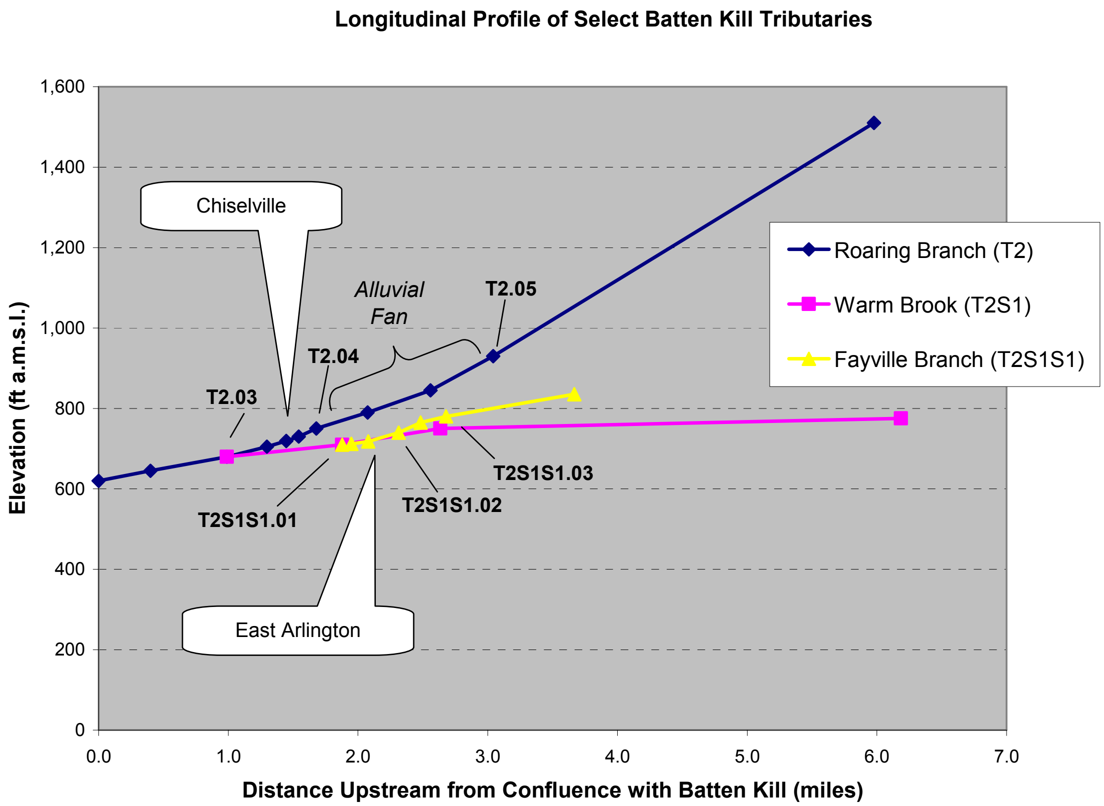


Figure 5. Longitudinal profile of lower portions of select Batten Kill tributaries.

Field (2007) noted that, in general, tributaries draining the Green Mountain physiographic province along the southeastern margins of the upper Batten Kill generated more post-glacial sediment than the tributaries draining the Taconic Highlands along the northwestern margins of the Batten Kill valley. Field (2005) noted that bed materials in the Batten Kill main stem increased considerably in median diameter at the confluence of these Green Mountain tributaries, including the Roaring Branch.

2.4 Hydrology

Given the high relief of the Roaring Branch watershed (including Fayville Branch), as well as the predominance of low-permeability glacial till and bedrock, flows in this mountainous basin watershed can be quite flashy. Snowmelt events in the late winter and early spring months can contribute to relatively high discharges. Periodic ice jams may locally enhance flood stages and lead to catastrophic erosion in break-out events. Occasional blow outs of beaver dams in the highland areas along the Roaring Branch (e.g., Kelley Stand) can also increase flood stages.

Reference was made to the nearest downstream flow gages (USGS, 2008) operated by the United States Geological Survey on the Batten Kill.

- Batten Kill at Arlington, VT - Station #01329000 is located on the Batten Kill main stem approximately 0.85 mile downstream of the Roaring Branch confluence. This station measures flow from an approximate drainage area of 152 square miles. While this station is not operational at present, historic data are available for the period from 1928 to 1984.

- Batten Kill Below Mill at Battenville, NY - Station #01329490 is located on the Batten Kill main stem in Washington County, New York State approximately 26 miles downstream of the Roaring Branch confluence. The upstream drainage area of this gage is 396 square miles. Prior to October 2003, this station operated approximately 0.75 mile further downstream of the present location, and was referred to as "Batten Kill at Battenville, NY" with a station #01329500 and an upstream drainage area of 397 square miles. A gage at one of these Battenville locations has been in operation since 1923, with an apparent gap in recording of daily flows between October 1968 and April 1998.

From a relatively limited period of record existing for each gaging station, and relying on relationships established for other regional gaging stations with longer periods of record, the USGS (Olson, 2002) has estimated the approximate magnitude of peak flows for each gaging station (Table 2). These values are compared to the estimated bankfull discharge (Q1.5) calculated from VT Regional Hydraulic Geometry Curve data (VTDEC, 2001). Recently published regionalized equations for bankfull discharge of New York streams in hydrologic region 1 indicate that the *Batten Kill at Battenville* station has a bankfull discharge of 6,320 cfs with a recurrence interval of 2.3 years (Mulvihill, *et al*, 2007). This value is less than the bankfull discharge estimated at a recurrence interval of 1.5 years from VT Regional Hydraulic Geometry Curves (VTDEC, 2001).

From the historic records for the *Batten Kill at Arlington* station, it can be seen that the Batten Kill has experienced a few moderate floods in recent decades (see Figure 6). Notably absent from the period of record represented in Figure 6 are the 1927 flood (largest recorded flood in Vermont) and the moderate floods in 1987 and 2000 that impacted the region.

Phase 2 Stream Geomorphic Assessments of the Roaring and Fayville Branches were completed between 16 July 2008 and 22 August 2008. Daily mean flows measured at the *Batten Kill below Mill at Battenville* gage during this time period ranged from a minimum of 185 cfs (7/19/2008) to a maximum of 2,570 cfs (7/27/2008) based on available provisional data (USGS, 2008). A few moderate rain storms occurred during this time period. Overall, however, flows on the Fayville and Roaring Branches on the 2008 assessment dates represented base flow to moderate flow conditions.

Table 2. Estimated flood magnitudes for Batten Kill watershed

	USGS Stn #	01329000	01329490 *
	USGS Description	Batten Kill at Arlington, VT	Batten Kill Below Mill at Battenville, NY
	USGS Period of Record	1929 - 1984	1923 - 2007 (discontinuous)
	Upstream Dr. Area (sq mi)	152	396
	Geomorphic Reach	M04	*N/A*
Magnitude	**Data Source**	**Discharge (cfs)**	
$Q_{1.5}$	*(VTDEC, 2001)*	3,800	10,600
Q_{2}	*(Olson, 2002)*	3,220	5,930
Q_{5}		4,520	8,770
Q_{10}		5,500	11,000
Q_{25}		6,870	14,200
Q_{50}		8,000	16,900
Q_{100}		9,230	20,000
Q_{500}		12,500	28,400

*Notes: * - Prior to Oct 2003, this gage published as "Batten Kill at Battenville" (01329500), and gage station was located 0.75 mile downstream of present location.*

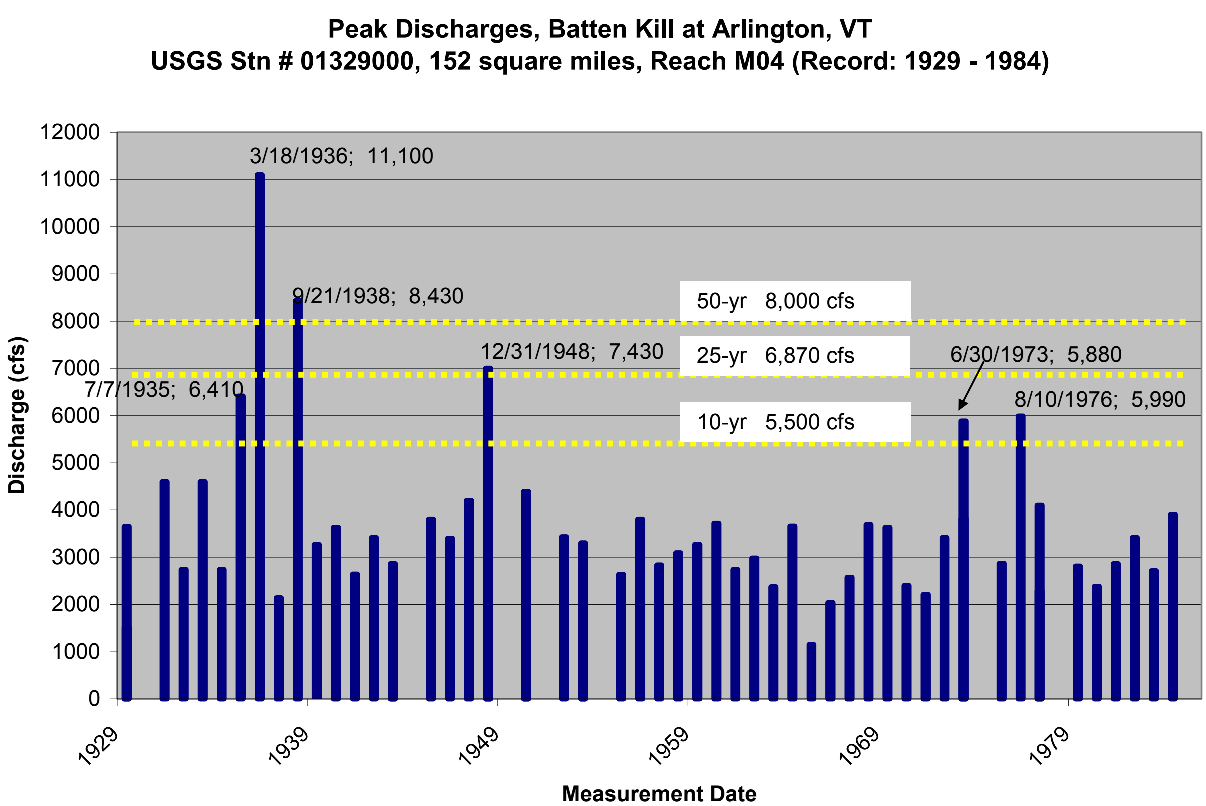


Figure 6. Recorded Peak Flows for Batten Kill at Arlington USGS Gage Station #01329000 (compared to estimated flood peaks after Olson, 2002)

2.5 Flood History

Available historic data and USGS flow data were reviewed to identify flood events of significance over the last century in the Batten Kill watershed (Table 3). Limited historical review included review of USGS gaging records, annual town reports for Arlington and Sunderland, a history book of Arlington, State-wide flood publications, and interviews with local citizens. The 1927 flood was the highest flood on record in the State of Vermont.

Table 3. Notable flood events in Batten Kill watershed

Notable Flood Dates	Data Source
1913, March	USGS, 1990
1927, Nov 3	USGS, 1990; Henry, 1993; Arlington town reports, 1928, 1929
1936, March	USGS, 1990; Henry, 1993; Arlington town reports, 1936, 1937; USGS, 2008
1938, Sept 21	USGS, 1990; Arlington town reports, 1938, 1939; USGS, 2008
1949, Jan 1	USGS, 1990; USGS, 2008
1973, Jun 28-Jul 1	USGS, 1990; VTDEC WQD, 1999; Henry, 1993; USGS, 2008
1976, August	VTDEC WQD, 1999
1987, May	VTDEC WQD, 1999
2000, Dec 17-18	USGS, 2008

2.6 Ecology

In 1991, "the Vermont Water Resources Board designated all Vermont portions of the Batten Kill mainstem and the West Branch of the Batten Kill as Outstanding Resource Waters…for their exceptional natural, recreational, cultural, and scenic values…including "exceptional wildlife habitat" and a "high quality trout stream" (VTDEC, 2002).

Beginning in the 1990s, a decline in the brown trout population of the Batten Kill main stem and tributaries was noted. Several studies are underway to determine the causes for these declines, as further detailed in the *Batten Kill Trout Management Plan: 2007-2012* (VTFW, 2006). The predominant factor theorized for brown trout population decline is the loss of adequate riparian and instream fish cover linked to past channelization and armoring of the Batten Kill and tributaries, as well as the reduction in woody vegetation along streambanks and riparian areas. "Lack of adequate cover increases fish vulnerability to predators, flood events, winter ice formation, and other environmental stresses which in turn can lower survival" (VTFW, 2006).

2.7 Land Use

Current (1993) land use / land cover within the Fayville and Roaring Branch tributary subwatersheds is estimated as follows (Jaquith *et al*, 2004):

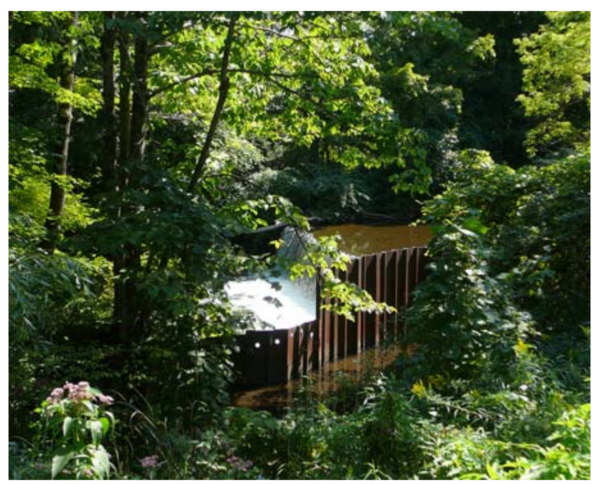
Table 4. Land Use / Land Cover Summary, Fayville and Roaring Branches, Batten Kill

Watershed	Drainage Area (sq mi)	Commercial / Industrial	Residential	Agricultural	Forest / Shrub	Water / Wetland
Fayville Branch	13.9	0.0%	3.7%	2.4%	89.7%	4.2%
Roaring Branch	53.4	0.0%	3.9%	5.1%	86.5%	4.5%

While agricultural and developed uses comprise a relatively small percentage of the overall watershed area, these activities tend to be concentrated along the valleys of the Batten Kill tributaries. Development centers currently include the villages of East Arlington (Fayville Branch, T2S1S1.02, T2S1S1.01) and Chiselville (Roaring Branch, T2.03).

Historically, Chiselville and East Arlington were centers of more intensive industrial and manufacturing activities (Beers, 1869; Henry, 1993; Child, 1880). Several dams were present on the Fayville and Roaring Branches to provide power to these manufacturing interests. Today, dams are no longer present on the six assessed reaches; however, two dams persist on adjacent reaches and influence present-day base levels in the assessed Fayville Branch reaches:

- Ice Pond Dam – located on the Warm Brook 2,500 ft upstream of Fayville Branch confluence (Figure 7a).
- Hale Company Dam – located on the Warm Brook 650 ft downstream of Fayville Branch confluence (Figure 7b).



(a) *(b)*

Figure 7. Existing Dams in vicinity of Fayville Branch confluence with Warm Brook.
(a) Ice Pond Dam, view to south from Ice Pond Road, 11 August 2008.
(b) Hale Company Dam, view to south from Hale Road, 22 August 2008.

Widespread deforestation of Vermont's landscape occurred by the early- to mid-1880s to support subsistence farming and lumber industries. Forest cover in the highlands began to regenerate in the late

1800s and early 1900s, during the industrial age and abandonment of upland farms and sawmills (Thompson & Sorensen, 2000).

3.0 ASSESSMENT METHODOLOGY

Phase 2 Stream Geomorphic Assessments and Bridge and Culvert Assessments conducted on the Fayville and Roaring Branch reaches utilized protocols published by the Vermont Agency of Natural Resources (2007a) and available at: http://www.vtwaterquality.org/rivers/htm/rv_geoassesspro.htm.
Reference is made to these protocols for a description of specific methods.

3.1 Phase 2 Stream Geomorphic Assessment

Phase 2 Stream Geomorphic Assessment protocols are field procedures for geomorphic and habitat assessment. Reach-specific and cross-section data gathered during Phase 2 characterize the present geomorphic condition of the river reach and the dominant process(es) of adjustment (i.e., degradation, widening, aggradation and/or planform adjustment). Phase 2 results, along with Phase 1 assessment results, define the natural and human disturbances to the watershed and channel over time and the composite response or adjustment of the channel to these stressors.

The six Batten Kill tributary reaches were assessed from 16 July through 22 August 2008. Specific features and channel positions were located using a Garmin™ 76CSx model global positioning system (GPS) unit. Pictures were recorded with a digital camera.

In accordance with protocols, select features were digitized in ArcView© 3.x and referenced to the Vermont Hydrography Dataset (VHD), using the Feature Indexing Tool, a component of the Stream Geomorphic Assessment Tool (SGAT, v. 4.59). Certain parameters documented during the original Phase 1 Stream Geomorphic Assessment were updated based on field observations in Phase 2 (see Section 3.2). Phase 2 assessment data were entered into the online Data Management System (DMS, v.4.56) maintained by the VTANR. Phase 2 reach summary reports are compiled in Appendix A.

Seven road crossing structures and one footbridge were encountered during Phase 2 assessments. Spans, clearance and width measurements were conducted at each structure. The span of each crossing was compared to measured or predicted bankfull widths (VTDEC WQD, 2006) 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). Appendix B of this report provides a summary of the bridge and culvert assessments completed for these bridge crossings in accordance with Appendix G of the VTANR protocols (April 2008). Bridge and culvert data were entered into the Structures portion of the DMS (under the "Batten Kill" database).

3.2 Phase 1 Updates

Original Phase 1 assessment data (Jaquith *et al*, 2004) for the six tributary reaches 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. As appropriate, GIS shape files were corrected or updated (using the Feature Indexing Tool). Phase 1 data in the DMS was updated, and the metadata for each Phase 1 step in the database were reviewed and updated (where necessary) to reflect that data were supported by field observations. Phase 1 reach summary reports are presented in Appendix A.

The position of the reference (Phase 1) valley walls was updated, based on field observations and following clarifications to valley wall delineation procedures articulated in protocol updates between 2004 and 2007. Also, a shape file of the modified (Phase 2) valley wall was generated; typically, this Phase 2 valley wall represents artificial fill for semi-permanent structures such as major roads and railroads. Updated valley wall shape files are contained on the Project CD.

3.3 Quality Assurance / Quality Control

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

The following considerations and limitations apply to the Phase 2 data for the Batten Kill tributary reaches:

- Where applicable, reaches were segmented using the Segmentation Tool contained in SGAT (v. 4.59). Segmentation was necessary to:
    - Capture subreaches of a stream type (after Montgomery & Buffington, 1997; and Rosgen, 1996) that was different than the reference stream type of the overall reach;
    - Identify sections of a reach that were of distinctly different geomorphic condition;
    - Identify sections of a reach undergoing a different channel management or land use; and
    - Define bedrock channel sections, defined as "gorges" by protocols;

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

- Select Phase 2 features (including, grade control locations, stormwater inputs, streambank erosion, revetment locations, and more) were geo-located using the Feature Indexing Tool (FIT) in SGAT. Using FIT, these features are indexed to the available Vermont Hydrography Dataset (VHD) for the Batten Kill. In many cases, surface waters depicted on the VHD were significantly offset from their actual position on 2000 orthophotos available for the study area. In some cases, the actual channel position has moved from its 2000 position as a result of natural channel migrations. These cases were revealed by comparison of the 2000 orthophotos with the 2003 aerial imagery (NAIP, 2003), or by review of 2008 channel positions recorded with a hand-held GPS receiver. Thus, locations and lengths of features indexed to the VHD should be considered approximate – particularly for Segment T2.04-B, as this segment is braided into multiple threads that are represented as a single channel in the VHD.

4.0 PHASE 2 ASSESSMENT RESULTS

Geomorphic and habitat assessments were completed on 6 reaches (7 river miles) of the Roaring Branch and Fayville Branch tributaries to the Batten Kill. Phase 2 assessment results are discussed below for each tributary (Sections 4.1 and 4.2). Reach and segment summary reports are provided in Appendix A.

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

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

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

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

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

4.1 Roaring Branch

The Roaring Branch subwatershed has an upstream drainage area of 53.4 square miles at its confluence with the Batten Kill main stem (T2.01). The three reaches assessed as part of this study (T2.05 through T2.03) have upstream drainage areas ranging from 20.5 to 25.9 square miles, respectively.

T2.05

Reach T2.05 crosses the Green Mountains from the confluence of a LB tributary (T2S2.01) for a distance of nearly three miles downstream to the junction of Kelley Stand Rd and Kansas Rd (which continues as North Rd) (see Figure 8).

Figure 8. Reach T2.05, Roaring Branch
(flow is from picture right to left)

The reference valley setting is a Narrow to occasionally Broad valley flanked by steep, bedrock-controlled, forested slopes. At the very upstream and downstream extents of the reach, the valley walls close in on the channel to create a Semi-Confined channel. Bedrock is exposed at several locations along the left valley wall, which is coincident with the LB along nearly the full reach length. In a few locations, bedrock is visible along the right valley wall. Channel-spanning bedrock provides vertical grade control at five separate locations in the downstream half of the reach.

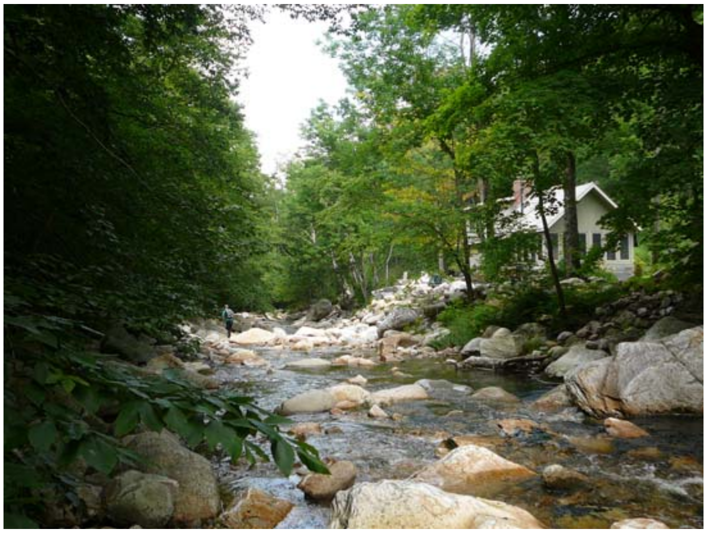


Figure 9. (T2.05) Boulder step/pool channel with occasional encroachment along RB by residences.

Inside these very steep bedrock valley walls are terraces comprised of unconsolidated materials (boulders, cobbles) – occasionally flanking both the LB and RB, often along only one bank (typically the RB). In the narrowest sections of the reach (i.e., in the upstream 1000 ft and the downstream 2000 ft), only one terrace set is typically present, usually along the RB and coincident in elevation with the Kelley Stand Road. These terraces are typically, 2.5 to 3.5 times the bankfull depth of the channel. (Average bankfull depth of the channel is 3.4 ft, based on three cross sections measured in the reach). VTANR protocols (p. 27, 2007) instruct the user to ignore higher-elevation terraces (especially, those higher than 3 times the bankfull depth) as likely representing older terraces formed during incisional processes that pre-date colonial times. It would not be unusual to see post-glacial terraces in this Narrow valley setting that resulted from base level changes either locally or further downstream in the Batten Kill main stem during the draining of high-level glacial lakes several thousands of years before present (see Section 2.2)

Where valley widths are slightly wider, these higher-elevation terraces are joined by a lower-elevation set. These lower terraces range from a thalweg height of 5 to 6.5 ft (or 1.5 to 1.9 times the bankfull depth). Based on available data, there is uncertainty if these lower-elevation terraces represent a recently abandoned floodplain by virtue of incision that has occurred in recent times (less than 200 years before present). It is possible that these lower terraces represent a post-glacial erosional terrace. It is also possible that these terraces represent more recently-abandoned floodplain surfaces since gravel was reportedly extracted from the channel during recovery efforts from the 1927 and 1938 floods (and possibly the 1973 flood) and may have initiated incision. And it is possible that the elevation of RB terraces have been reworked, leveled and even elevated during flood recovery efforts to reinforce base materials of the Kelley Stand Rd and to protect houses along this road.

Pebble count data suggest that given the steepness of the slope (3.74%) and the compactness of the cross sectional area, a majority of the bed materials are mobile at bankfull flow – all but the largest boulders. Flood chutes are frequent – especially where the bedrock-controlled valley walls are locally widened. LB and especially RB terraces are dissected by flood chutes. Absence of vegetation, and presence of imbricated cobbles and gravels in these flood chutes suggest that they are frequently occupied at bankfull and higher flow stages. This fact was confirmed by a local resident who owns a camp on the Kelley Stand Rd (Jones, 2008).

A Cb – step/pool channel was selected as the reference stream type to describe the overall reach. There are brief sections of apparent B–step/pool stream type at the upstream and downstream extents of the reach; however, given the uncertainty concerning the degree of historic floodplain filling / modification to maintain the Kelley Stand Rd, these short sections were not separately delineated as subreaches of an alternate reference stream type.

Kelley Stand Road (gravel) follows the channel along the RB for the full reach length. Often this road is at an elevation coincident with the RB terrace, which is itself at a thalweg height of 9 to 11 feet (or 2 to 2.4 times the average thalweg depth of the channel). Encroachment by this road reduces the valley width somewhat to create a modified Semi-Confined to Narrow valley confinement.

A few seasonal and year-round residences are located on the fluvial terraces along the RB, on both sides of the Kelley Stand Rd (Figure 9). Berms have been constructed along RB to protect the residences and Kelley Stand Rd (Figure 10). One camp was observed on the LB valley side slope, accessed by a wooden footbridge. Possible straightening of the channel is inferred at the downstream end of the reach, upstream of the Kansas Rd bridge crossing. Gravel extraction/dredging is inferred from extensive berming and from anecdotal accounts (especially post-1973 flood).

Figure 10. (T2.05) Example of berm along RB adjacent to residence along Kelley Stand Rd..

Several stormwater inputs were indexed in this three-mile reach: 11 turnouts directing overland flow along the margin of Kelley Stand Rd toward the channel and 11 culverts conveying road ditch contents (see Figure 11). While the number of fine gravel sediment inputs was high, fine sediment was not noted to have accumulated in the channel to a significant degree. It is likely these finer sediments are being transported through the reach to downstream channel sections.

Three cross sections conducted in the reach revealed varying valley confinement, entrenchment, and incision ratios. Cross section XS-3 is located in a short section of channel exhibiting a B2-S/P stream type. Cross sections XS-2 and XS-1 are more representative of the reach as a whole and indicate a C2b-S/P stream type, consistent with the reference stream type. Incision is suggested by the moderate degree of vertical separation of the channel from the floodplain at these two cross section sites (IR = 1.7 to 1.9). Absence of rejuvenating tributaries, active head cutting, or recently exposed tree roots suggests that the incision is historic in nature.

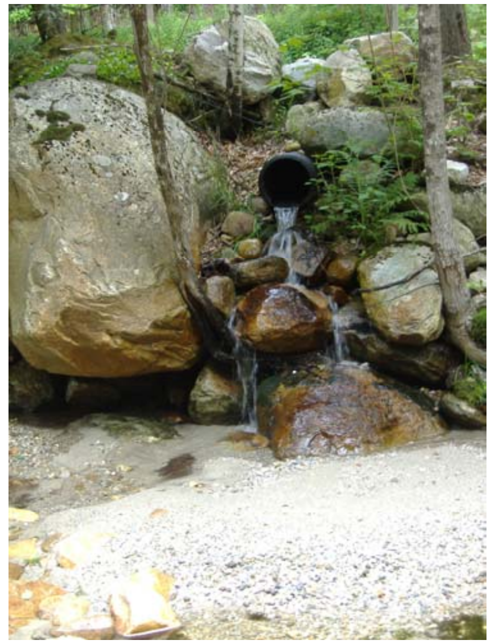


Figure 11. (T2.05) Frequent road turnouts (above) and culverts (right) deliver sediment and stormwater runoff directly to the Roaring Branch, or to flood chutes which are occupied at bankfull stage (or higher flows).

Incision may partly be due to post-glacial stream dissection, and may possibly have been re-invigorated by post-flood channelization, windrowing/dredging and berming within recent centuries. Bedrock exposures in the lower half of the reach have likely moderated incision. Widening and lateral adjustments (meander extension) have been moderated by the coarseness of bed and bank materials as well as periodic exposures of bedrock, especially along the LB. Maintenance of mature forested buffers along both banks has also contributed to channel stability. Given the steepness of the slope, flood chutes are frequent and active at bankfull and higher flow stages, especially where valley confinement broadens locally. A geomorphic condition rating of Fair was assigned indicating a moderate degree of adjustment overall. Planform adjustment was noted as the dominant active adjustment process. A channel evolution stage of II [F-stage] is inferred. VTANR protocols note that a "Low" sensitivity rating is to be assigned to a C2b channel in Fair geomorphic condition.

T2.04

Within reach T2.04, the Roaring Branch transitions from a Semi-confined and Narrow-confinement, steep channel to a Very Broad valley setting (where the radial pattern of topographic contours suggests an alluvial fan feature). Surficial deposits in this area are mapped as an alluvial fan (DeSimone, 2000). This alluvial fan has a segmented, or prograded morphology. The topographic apex of the fan is located at the upstream reach break, where the channel emerges from the upstream narrow, bedrock-constrained valley out onto the broad, unconfined plain (Figure 12). The upper third of the reach is, however, entrenched below the fan surface; this "fan head trench" is a relatively common feature of alluvial fans (Schumm, 2005; Ritter, 1978). Approximately one-half river mile below this topographic apex is the hydrographic apex of the fan, where the channel is no longer entrenched and flows diverge and begin to exhibit the braided and anastamosing forms characteristic of deposition-dominated conditions. Another half-mile downstream from this hydrographic apex, flows converge to a single-thread channel, also entrenched below the surrounding floodplain (though to a lesser degree than the fan head trench).

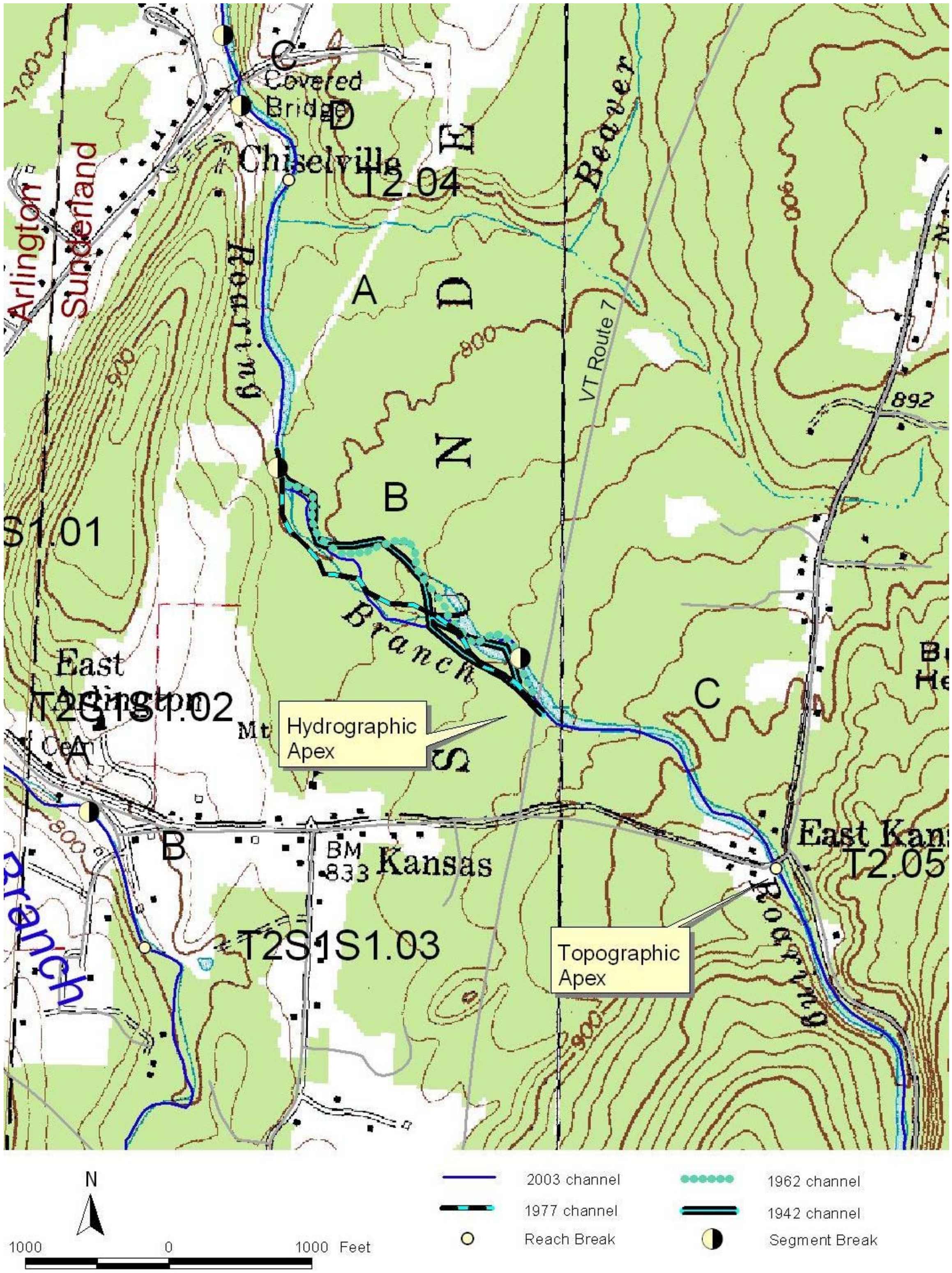


Figure 12. Segmentation of reach T2.04, Roaring Branch.
(See text for discussion of geomorphic features. VT Route 7 was constructed in the early 1980s, post-dating the 1967/1968 topographic base maps. This highway is marked as a light gray north-south line that crosses T2.04 near the hydrographic apex).

More detailed studies would be required to characterize the nature of past depositional and erosional cycles that have resulted in the present-day morphology of this fan and the Roaring Branch channel. It is hypothesized that the principal alluvial fan feature formed in post-glacial times (late Pleistocene or early Holocene), when sediment supply and stream flows were much higher than they are today (see Section 2.2). As the landscape vegetation regenerated, and sediment supply from the upstream catchment gradually decreased, the Roaring Branch incised below the fan surface in the upstream third of reach T2.04. Headward incision would have been constrained longitudinally by the exposures of bedrock in the channel in upstream reach T2.05. With progressive entrenchment of the upper end of reach T2.04, the location of active deposition would have been transferred downstream to the current hydrographic apex. It is possible that depositional processes on this alluvial fan were rejuvenated during deforestation in the early- to mid- 1800s, and would subsequently have decreased during reforestation. Deposition now occurs primarily during major flood events. Based on a review of historic aerial photographs (1977, 1962, 1942) the approximate position of the hydrographic apex of the fan has remained in its present location dating back to at least 1942 (see Figure 13).

Reach T2.04 was segmented to capture the variable geomorphology and a subreach of alternate reference stream type. A multi-thread D-braided reference stream type was assigned to the upper two thirds of the reach to span the alluvial fan feature marked by the transition in valley confinement and gradient. A single-thread, C-riffle/pool reference stream type (subreach, Segment A) was assigned to the downstream third of the reach, due to the significantly lesser gradient and the position of this single-thread channel along the bedrock-controlled left valley wall. The upper two thirds of the reach was further segmented to reflect a vertical stream type departure in the upper third (Segment C).

Segment C

Segment C exhibits a single-thread channel, in contrast to the inferred reference stream type of D-braided. The channel dissects the alluvial fan surface. Valley width is reduced somewhat by Kansas Rd to the southwest and North Rd to the northeast, but not significantly enough to change the confinement ratio (Very Broad). A few residential homes are located along both banks; otherwise land cover in the corridor is young-growth forest.

Berms are present along both banks in vicinity of the two road crossings (Kansas Rd bridge and VT Route 7) which serve as flood-prone-width constrictors. Berms on approach to the VT Route 7 bridge are armored with rip-rap. Limited straightening of the channel is inferred in vicinity of these bridge crossing locations. The present alignment of VT Route 7 was constructed between 1980 and 1986, based on review of historic aerial photographs. The VTrans inventory table indicates that the bridge was constructed in 1982. A small apparent irrigation withdrawal site was noted along LB approximately 950 ft downstream of the Kansas Rd bridge.

A cross section measured mid-segment indicated a stream type departure (from D-braided to F-plane bed) by virtue of a channel that has incised below the surrounding floodplain resulting in an IR = 3.3, and entrenchment ratio (ER) of 1.2. Available data do not define the origin, timing and sequence of incision (or off-setting aggradation) processes that have resulted in the present net degree of entrenchment in this channel segment. It is likely that primary incision to form this fan head trench occurred several thousand years ago driven by climate (and hydrologic, sediment, and vegetation regime) changes during the transition from glacial to post-glacial environments. Some degree of incision may also have resulted during more recent flood events (e.g., 1927, 1936, 1938, 1973) and/or as a result of possible channelization during flood recovery efforts. At present, dominant adjustment processes include planform adjustment (multiple flood chutes, bifurcations) and aggradation (steep riffle).

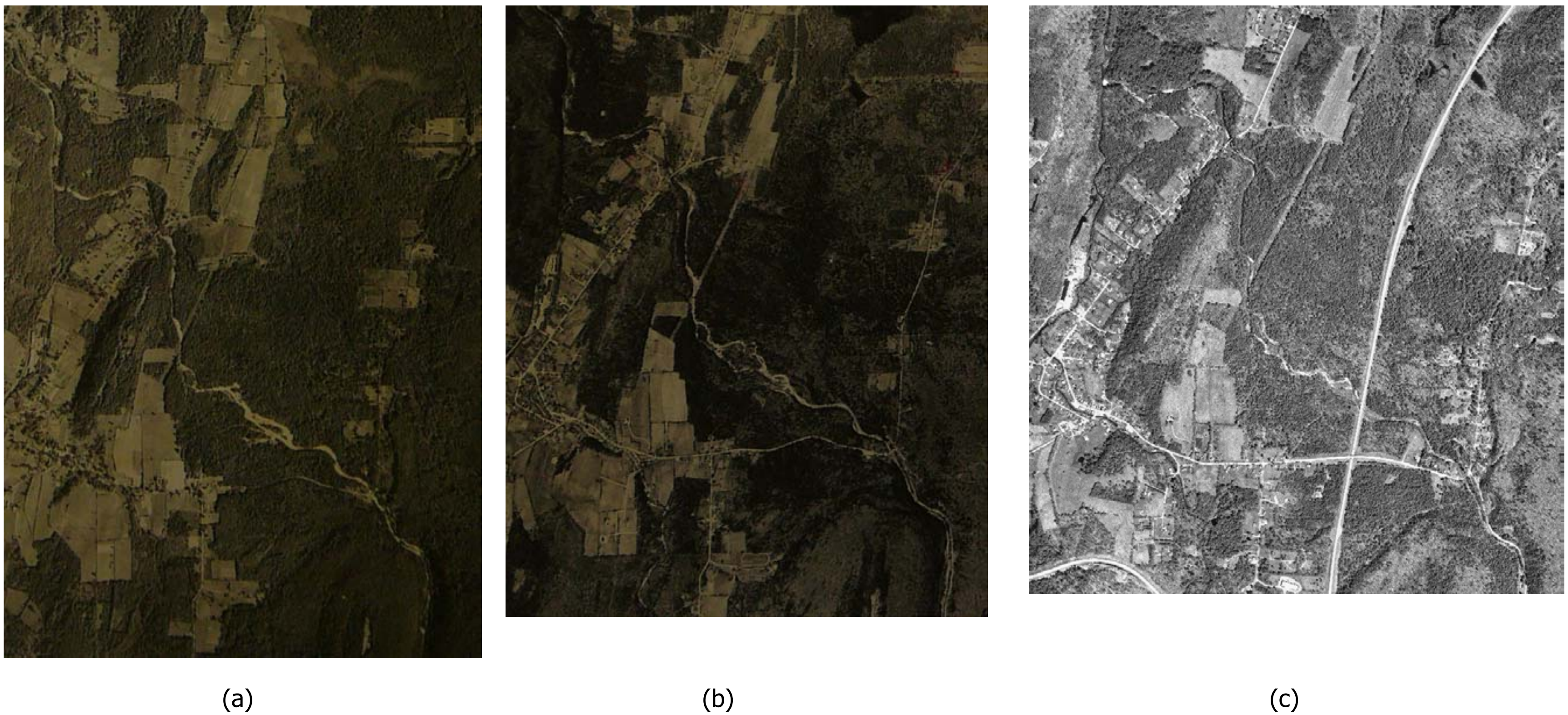


Figure 13. Aerial view of alluvial fan, reach T2.04, Roaring Branch: (a) 1942; (b) 1962; (c) 2000. Divergent flows in segment T2.04-B have occupied various positions during past decades. See Figure 12 for superposition of main flow channels from each year. Degree of deposition appears somewhat more significant in 1942 and 1962, as compared to recent years – perhaps due to floods of 1936 / 1938 and 1948 (see Figure 6, Section 2.4).

Segment B

Within Segment B of reach T2.04, flow splits into multiple, sinuous channels trending generally from southeast to northwest across the alluvial fan. The observed multi-thread channel is consistent with a reference stream type of D-braided. Valley width is reduced somewhat by Kansas Rd to the southwest and VT Route 7 to the north, but not significantly enough to change the confinement ratio (Very Broad). Two new residential homes are located along the LB corridor within 150 ft of active flood chutes; otherwise land use is dense, young-growth forest. Just upstream of the segment, the present alignment of VT Route 7 was constructed between 1980 and 1986, based on review of historic aerial photographs. A short straightening length and berm length are associated with the VT Route 7 bridge crossing at the upstream end of segment.

To follow each individual channel thread and log individual features (i.e. bars, debris jams, erosion, etc.) would have required resources beyond the approved scope of work. Moreover, these features could not have been adequately indexed using the FIT, since the FIT operates on a single channel thread represented on the VHD. After consultation with Shannon Pytlik, VTANR River Management Section (who accompanied the assessors on this reach), it was determined that this braided section of reach T2.04 should be treated as an individual segment with limited assessment. A cross section was not measured since to encompass the full breadth of the multiple active channels would require a land survey with multiple setups. Also, any one channel would contain only a portion of the overall flow through the segment, and not correspond to VT Regional Hydraulic Geometry curve data (VTDEC, 2001; VTDEC, 2006) which are established for single-thread B and C channels.

Figure 14. (T2.04-B) Braided, multi-channel flows across the alluvial fan surface.

Select features along T2.04-B have been indexed using the FIT, and tallied in the DMS. However, the following limitations apply:

- Debris jams – one was noted on a RB channel braid; however, since not all the channel threads were walked, it is likely that more DJs were present on this segment.
- Erosion – many of the channel threads exhibited erosion on one or both banks; and total segment erosion of 60% on each bank was estimated and arbitrarily indexed so that values for LB and RB erosion could be uploaded to the DMS.
- Depositional bars – several diagonal bars, point bars, mid-channel bars and side bars were noted during reconnaissance through the segment corridor, crossing several channel threads. An arbitrary number of bars has been entered in the DMS under each category to reflect that multiple bars were present. However, these numbers should not be interpreted as accurate tallies.
- Ford – one ford was noted crossing a single channel thread. It is likely that this ford crossed other channel threads, but the path (possibly logging or recreational use) was not followed in its entirety. It is likely that if the channel were single-thread, this path would have crossed the channel only once; so, one ford was indexed to the surface water coverage in an approximated location.

- Steep Riffles – several were noted, and indexed to the surface water coverage in somewhat arbitrary locations. It is likely that more steep riffles exist within the full span of this multi-thread channel.
- Berms / Gravel Extraction – two short sections of berms, and a mid-channel depression suggestive of recent gravel extraction were noted in channel braids / flood chutes in close proximity to a LB house near the upstream end of the segment. A berm was indexed along a short segment of the main channel and a point location of gravel extraction was indexed to capture the presence of these channel management features in the DMS for this segment; however, it should be noted that the location of these features is not on the main channel.

An administrative judgment stream type of D3-braided was entered for Segment T2.04-B, consistent with the reference stream type for the reach. A very high W/D ratio is inferred for this reach, based on the presence of multiple parallel channels spanning a maximum approximate distance of 560 feet (GIS estimate; see Figure 12). The floodplain adjacent to these channel threads was typically at a height within 1.0 to 2.5 feet of the thalweg suggesting adequate floodplain connection (i.e., low incision ratios). Based on observation of depositional and erosional features, minor encroachments, and absent evidence of significant channelization, dredging, or planform modifications, the segment was assessed (provisionally) in Fair condition. The dominant active adjustment process is planform adjustment due to the multiple active flood chutes and multi-thread channel. Moderate aggradation is also suggested by the presence of multiple side, point, and mid-channel bars, steep and diagonal riffles. Given the dominance of lateral over vertical adjustments observed in this segment and good floodplain connection, a I [F] Channel Evolution Stage was assigned. Neither the F-stage or D-stage channel evolution models available in VTANR protocols (Appendix C, May 2007) adequately apply to D-braided segments. Stage I [F] was selected to indicate the potential to incise (i.e., no shallow bedrock), and the good floodplain connection. A D3-braided channel in Fair (or even good to reference) condition is assigned an Extreme sensitivity rating under VTANR protocols (2007) due to the multi-thread nature of the channels and propensity for forming and occupying flood chutes.

Segment A

Segment A of T2.04 extends from a power line crossing to the downstream end of reach T2.04 which is located approximately 785 feet upstream from the Chiselville covered bridge. Within this segment, flows converge to a single-thread channel which is "pinned" along a steep, bedrock-controlled, left valley wall. Historic deposition on the alluvial fan would have been constrained by the valley walls which begin to narrow in this segment on approach to the bedrock gorge at Chiselville.

Given the single-thread channel and a lesser channel gradient (<2%) in contrast to the assigned reference stream type of the overall reach (D-braided, >2%), Segment A was identified as a subreach of C-riffle/pool stream type. The degree of incision (IR > 2) below the floodplain along the RB corridor, captured at a mid-segment cross section, indicates a vertical stream type departure from C to F-plane bed.

One camp (tree house) was identified along the left valley wall mid-segment, with a forest trail (ATV accessible) identified as an "Improved Path" leading to this camp. The segment was otherwise undeveloped and forested. A historic photograph depicts an impoundment at the bedrock outcropping under the Chiselville covered bridge approximately 800 feet downstream of this segment (see T2.03-C). Historically, this downstream impoundment may have artificially controlled base levels local to the downstream end of reach T2.04.

Figure 15. (T2.04-A) View downstream below the cross section site, 31 July 2008.

The channel in T2.04-A has a very linear planform, as it is pinned against the bedrock-controlled left valley wall, and incised below the RB terrace. No data have been uncovered to suggest anthropogenic activities in this segment to channelize the river along the bedrock-controlled left valley wall. Historic maps (Beers, 1869; Walling, 1856) do not indicate residential, commercial or industrial buildings in the RB corridor adjacent to this length of channel, and berms were not noted along the RB. A channel can naturally incise to some degree and "pin itself" along a linear bedrock wall, since vertical scour energies are enhanced as the bedrock resists laterally-directed scour. If net deposition of coarse sediment fractions occurred historically in upstream Segment B (or episodically during more recent major flood events), the channel may have locally increased scour energies due to the reduced bedload at Segment A. Incision in this reach may also have been enhanced by breaching of the dam(s) at Chiselville (perhaps in the 1927 flood?). If the base level of this historic dam dropped catastrophically (estimated 65-foot head; Child, 1880), incision may have migrated head-ward within Segment T2.04-A.

At present, this moderately overwidened, incised, plane-bed channel is undergoing a moderate degree of aggradation and minor planform adjustment (flood chutes). Widening appears to be historic in nature, due to the absence of actively leaning trees and undercutting banks on both sides of the linear channel. An RGA score of Fair was calculated with an assigned Sensitivity of "Extreme" due to the vertical stream type departure. An early Stage IV (or late Stage III) of the F-stage channel evolution model is inferred due to the nature of aggradational and planform adjustment processes which appear to be forming persistent and partially-vegetated side bars, allowing for a weak riffle/pool form to develop (including one diagonal riffle), and resulting in a slight narrowing of the channel. A secondary sinuosity of the low-flow channel is evident. Still, the entrenched status of the channel and the unconsolidated nature of stream bed and bank materials means that they are susceptible to sudden, catastrophic erosion in a larger flood event.

T2.03

Reach T2.03 is approximately two-thirds of a mile long, crosses under the Chiselville covered bridge past Chiselville and extends to the LB confluence of Warm Brook. Within this reach, the Roaring Branch turns to the northwest and transitions from a broader valley setting to flow through a valley pinch point where the vertical and lateral position of the channel is controlled by exposed bedrock. At this location, the Roaring Branch crosses a northeast-trending higher-elevation ridge underlain by more weather-resistant Monkton quartzite.

Reach T2.03 was segmented to capture the variability in valley confinement, and geomorphic condition. Segmentation is illustrated in Figure 16 and includes:

- Segment D – 710-foot subreach of reference C3b-riffle/pool which has undergone a stream type departure to F3b-plane bed;
- Segment C – 509 ft of bedrock gorge;
- Segment B – 790 ft of reference C-riffle/pool which has undergone a STD to F-plane bed;
- Segment A – 1,629 ft of reference (and existing) C3-riffle/pool.

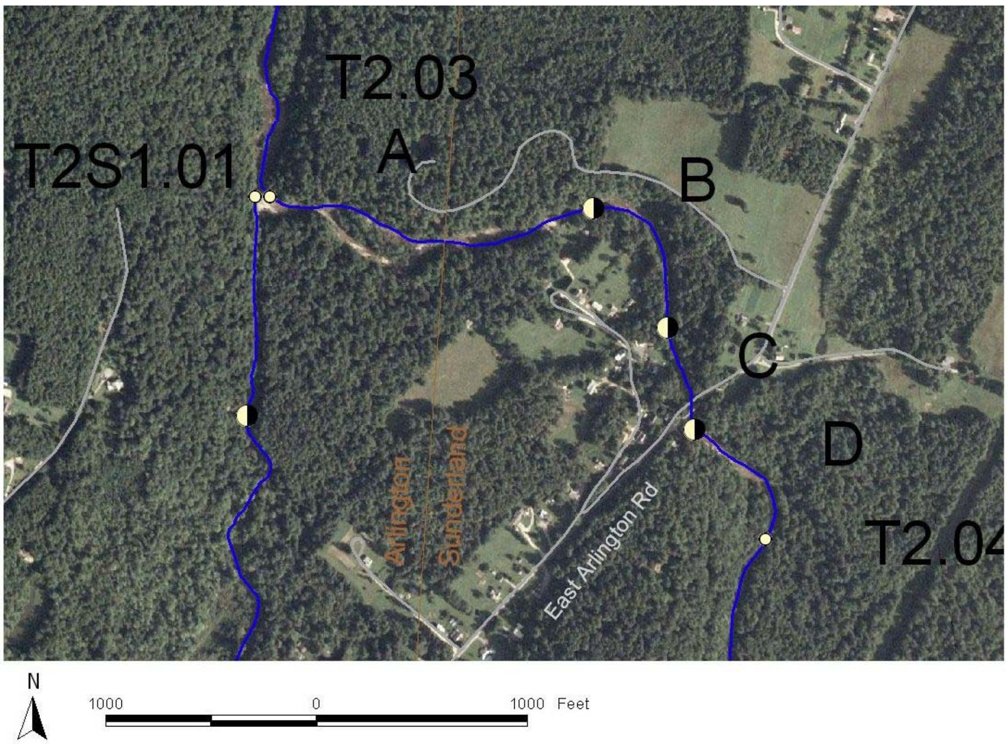


Figure 16. Segmentation of reach T2.03, Roaring Branch.

Segment D

T2.03 Segment D is small section of channel analogous to upstream segment T2.04-A. Ideally, the downstream reach break for T2.04-A would have been placed at the downstream end of this segment T2.03-D. However, the VHD incorrectly depicted a RB tributary confluence 700 ft upstream of this location. The actual confluence of the RB tributary is at or near the downstream end of this segment T2.03-D. Characteristics of this segment are very similar to upstream segment T2.04-A, whose cross section data have been ascribed directly to T2.03-D. The assigned Phase 2 stream type of F3b-PB, represents a vertical stream type departure from the inferred reference stream type of C3b-riffle/pool.

The valley narrows in this segment on approach to the bedrock-controlled gorge of segment T2.03-C. A driveway was observed along the LB corridor at the top of a steep valley side slope. Otherwise, segment corridors were forested with foot trails for recreational access to the river. Flow bifurcates around a large, tree-covered island near the downstream end of the segment. Historic incision is inferred – possibly due to breaching of the mill dam(s) located in segment T2.03-C c. 1880s (and associated drop in local base level).

An RGA score of Fair was calculated with an assigned Sensitivity of "Extreme" due to the vertical stream type departure. Like upstream segment T2.04-A, an early Stage IV (or late Stage III) of the F-stage channel evolution model is inferred, although the degree of planform adjustment and number of depositional bars is less than in the upstream segment. The channel is susceptible to sudden, catastrophic erosion in flood events, due to the entrenched status of the channel and the unconsolidated nature of stream bed and bank materials.

Segment C

Segment T2.03-C is a section of narrowly-confined, bedrock-controlled channel extending from just above the Chiselville covered bridge to a point approximately 450 feet downstream of the bridge. This segment has been classified as a "bedrock gorge" according to protocols (VTANR, 2007). Channel banks are comprised of bedrock; channel bed consists of bedrock with a veneer of boulders/cobbles/gravel. One mostly submerged channel-spanning exposure of bedrock ("ledge") was indexed within the segment. No cross section was completed (per protocols); an administrative judgment stream type of A3b-PB and Sensitivity of "Low" were assigned.

The Chiselville covered bridge crosses the segment but is elevated well above the flood prone stage, with foundation supports on bedrock. One mid-channel pier was apparently added sometime after 1966 (picture on cover of Vermont Life magazine, vol. 20, no. 4). The VTrans bridge and culvert inventory table indicates that the covered bridge was constructed in 1870 and repaired in 1972.

A historic mill dam is depicted in a c.1880s photograph just downstream of the Chiselville covered bridge (Figure 17, left). Based on comparison to the adjacent mill building in this photograph, the dam was at least one story high (> 8 feet). The 1869 Beers Atlas identifies this building as a "Chisel Fact'y". A *History of Arlington* (Child, 1880) identifies this industry as the Arlington Edge Tool Company (formerly Douglas Manufacturing Company) and notes that two dams were present in this vicinity with a combined head of 65 feet. "The upper dam is thirty-five feet high by seventy-five feet long, firmly built between solid ledges of rocks. A reservoir of fifteen or twenty acres can be obtained if needed." (Child, 1880). Two impoundments are also noted on the Beers Map (1869), though not of an area that would suggest a reservoir of the size noted by Child (1880).

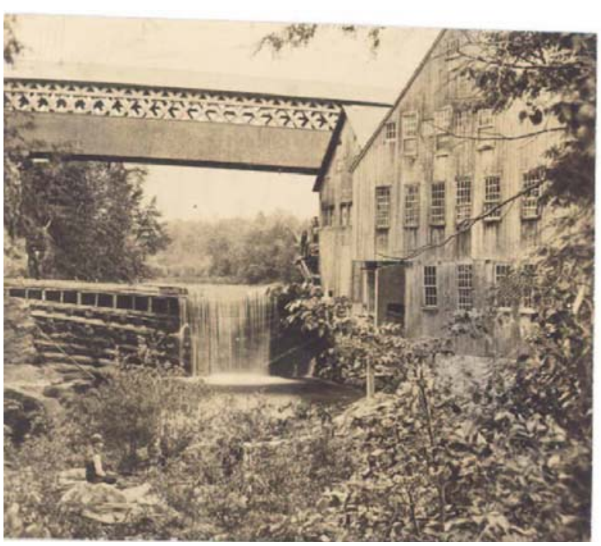


Figure 17. (T2.03-C) (Left) Dam at Chiselville below Chiselville covered bridge, c. 1880s. Reference Jaquith et al, 2004.
(Right) Chiselville covered bridge, view upstream, 1 August 2008.

Segment B

Segment T2.03-B is a short channel segment which is distinguished from downstream Segment A by the degree of vertical stream type departure (C to F). Valley confinement broadens in this segment downstream of the bedrock gorge. Channel gradient (1.8%) is transitional between the upstream bedrock gorge (2.2%) and the downstream segment (1.5%). Chiselville Rd passes through the LB corridor causing a minor human-caused change in valley width; however, this road is only slightly elevated above the floodplain. Historic resources (Beers, 1869; Walling, 1856; Child, 1880) depict active mills and industrial activity in Chiselville along the LB corridor of this segment. A diversion is mapped leading from the lower dam in Segment C along the intervale southwest of the channel to supply a "Chisel Fact." Water is then returned to the channel just below the Arlington-Sunderland town line (Beers, 1869). It is possible that grading and fill activities in this LB corridor raised the adjacent floodplain elevation and/or increased the degree of channel entrenchment. Today land use in the LB corridor is residential in nature.

The cross section measurement in this segment indicated a degree of historic incision of the channel below a narrow RB floodplain (IR_{RAF} = 2.0). This RB terrace is discontinuous along the length of the segment. More often a steep, forested valley wall is continuous with the RB, rising to a high terrace (approx 80 feet above the channel). Two, mostly healed (vegetated) mass failures were observed along this steep RB valley wall. The LB floodplain is at an approximate height three times the channel thalweg, although this height gradually decreases with distance downstream.

A plane-bed form dominates within the segment. A high degree of (historic) widening is suggested by the high W/D ratio (39.4). Historically, incision and widening may have been moderated by bedrock lateral controls, upstream bedrock vertical controls (Segment C), and the relative coarseness of bed and bank materials and maintenance of tree buffers. A moderate degree of aggradation is suggested by the presence of plane-bed morphology (filled pools) and occasional depositional bars (mid-channel, point, and side). Planform adjustment appears limited by the lateral constraints of bedrock and other relatively cohesive bank materials (e.g. till). An RGA score of Fair was calculated with an assigned Sensitivity of "Extreme" due to the vertical stream type departure. A late channel evolution stage of III [F] is inferred (or early stage IV). The channel is susceptible to sudden, catastrophic erosion in flood events, due to the entrenched status of the channel.

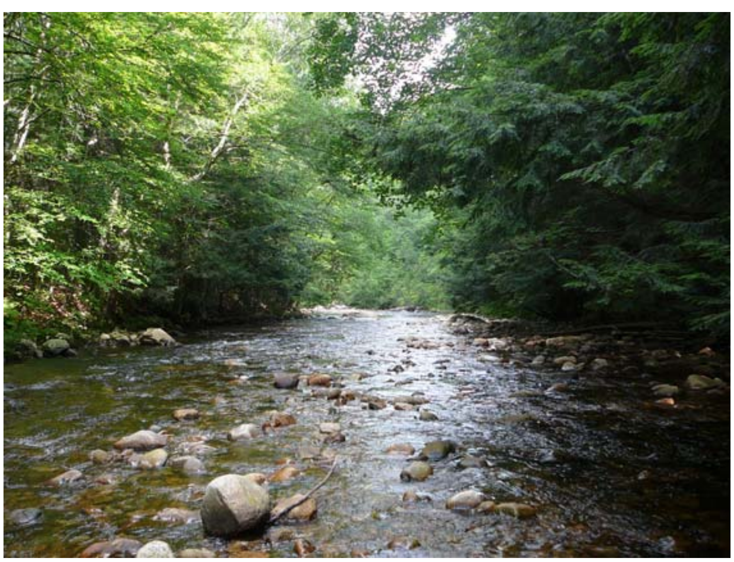


Figure 18. (T2.03-B)
1 August 2008.
View downstream below the cross section site.

Segment A

Segment A is the downstream-most segment of reach T2.03, leading from Chiselville to the confluence of Warm Brook (T2S1). A Very Broad valley confinement and somewhat reduced gradient (1.5%) is evident leading toward this confluence, suggesting a reference C-riffle/pool stream type. No channel-spanning bedrock grade controls were noted in the segment, although bedrock was exposed at several locations along the RB.

A large tributary confluence bar of cobbles and gravels was observed at the point where Warm Brook joins the Roaring Branch. Based on the relative elevations of these two channels, the sediments appear to have originated from the Roaring Branch and not the tributary Warm Brook. It is likely that coarse sediments have accumulated at this point due to a reduction in transport capacity as the Roaring Branch gradient decreases and the channel makes a sharp turn to the north to flow along a bedrock-constrained left valley wall.

The LB corridor in Segment T2.03-A is largely forested. Sparse development (Roaring Branch Camps - recreational cabins) is located along the top of the high RB terrace. This camp was constructed c. 1912 (Henry, 1993).

Segment A exhibits a weak riffle / pool bedform with intermediate stretches of plane bed morphology. Pools are mostly filled. Several recent debris jams have been cut free with chain saws. Several active flood chutes are located in the downstream end of the segment. The segment cross section indicates a C3-riffle/pool stream type, consistent with the reference stream type. A moderate degree of historic incision is evident (IR = 1.7) where the channel has lost some connection to the LB floodplain.

A moderate degree of aggradation is suggested by the presence of depositional bars (mid-channel, point, and side bars), one diagonal riffle, and two steep riffles. Ongoing planform adjustment is indicated by the prevalence of active flood chutes. Widening is suggested by the high W/D ratio (63) – though this was a relatively localized phenomenon in vicinity of the cross section at the upper end of the segment. An RGA score of Fair was calculated with an assigned Sensitivity of "High" as prescribed by protocols (VTANR, 2007a). A channel evolution stage of IV [F] is inferred.

*Figure 19. (T2.03-A)
1 August 2008.
View upstream from confluence of Warm Brook. Increased sediment attenuation in the segment is contributing to formation of flood chutes and channel bifurcation.*

Table 5. Results of Phase 2 Geomorphic Assessments, Roaring Branch reaches assessed in 2008.

Roaring Branch (Batten Kill) - Sunderland, Arlington

Reach	Seg-ment	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq mi)	Stream Type	Incision Ratio	RHA Condition	RGA Condition	Adjustment	Channel Evolution Stage	Stream Type Departure?	Sensitivity
T2.05	--	15,500	3.7	20.6	C2b-S/P	1.88 [RAF]	0.79 Good	0.61 Fair	Mod PF	II [F]	No	Low
T2.04	C	2,549	***3.3***		F2b-PB	3.34 [RAF]	0.60 Fair	0.48 Fair	Mod PF, aggr	IV [F]	D to F	High
	B	2,563	***2.1***		D3b-Br	NM	0.74 Good	0.59 Fair	Extreme PF, aggr	I [F]	No	Extreme
	A *	2,092	***1.9***	25.7	F3-PB	2.2 [RAF]	0.68 Good	0.54 Fair	Mod aggr, min PF	IV [F]	C to F	Extreme
T2.03	D *	710	***2.8***		F3b-PB	2.2 [RAF]	0.71 Good	0.55 Fair	Mod aggr	IV [F]	C to F	Extreme
	C *	509	***2.2***		A3b-PB	NM	NM	NM	NM	I [D]	No	Low
	B	790	***1.8***		F3-PB	2.0 [RAF]	0.72 Good	0.53 Fair	Mod aggr	III [F]	C to F	Extreme
	A	1,629	***1.5***	25.9	C3-R/P	1.7 [RAF]	0.75 Good	0.50 Fair	Mod aggr, wid, PF	IV [F]	No	High

Abbreviations:

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

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

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

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

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

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

* Subreach of alternate reference stream type.

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

4.2 Fayville Branch

Fayville Branch, historically known as Peters Branch, drains a 13.9-square-mile area in the south-central region of the Roaring Branch subwatershed. Fayville Branch flows into Warm Brook at East Arlington, which then flows north to meet the Roaring Branch downstream of Chiselville.

T2S1S1.03

Reach T2S1S1.03 is nearly one mile long and begins at a point 1.8 miles upstream of the Fayville Branch confluence with Warm Brook. In this reach, Fayville Branch flows to the north, parallel to South Rd, crosses VT Route 313 and ends approximately 700 feet upstream of the Prouty Hill Road crossing (see Figure 20). The overall slope of the reach is estimated as 1.05% – a "c" subclass slope category (see Appendix D). Locally, the slope is somewhat steeper (approximately 1.4%) in the downstream quarter of the reach.

Soil mapping indicates that the channel flows over sediments of glacio-fluvial origin in this reach, bounded on either side by higher-elevation terraces of glacial till / dense till (USDA, 2005; USDA, 1998). The Phase 1 (reference) valley walls consist of high terraces along both banks: measured thalweg heights for the LB terraces ranged from 8 to 21 feet along the reach length (or 3 to 7.8 times the maximum bankfull depth of the channel); thalweg heights of the RB terraces ranged from 8 to 15 feet (or 3 to 5.6 times the maximum bankfull depth). The reference valley width between these LB and RB terraces ranged from approximately 180 feet (Narrow) to 440 feet (Very Broad). It is anticipated that these terraces would tend to constrain lateral movement of the channel, however, some erosion, including one mass failure, was observed where the channel has impinged against the terrace face. Bank erosion appears to have been moderated by the relatively mature tree cover and relatively cohesive terrace materials.

Lower terraces are present within this Narrow to Very Broad floodplain that in some locations limit the channel's access to the floodplain at bankfull and low to moderate flood stages. These lower terraces have heights ranging from 1.1 to 2.5 times the thalweg and appear to be comprised of more erodible materials (cobbles, gravels) and are likely of glaciofluvial or more recent alluvial origin. Based on the size of deciduous (e.g., yellow birch) and coniferous (i.e., hemlock) trees growing on these terraces, they have been stable for at least several decades. The channel appears to have access to a relatively narrow incipient floodplain, inside these lower terraces. The terraces are often dissected by flood chutes that split off from the main channel, follow the valley wall (at distances up to 3 bankfull widths away from the channel) for a down-valley distance of 5 to 10 bankfull widths, before rejoining the channel. Fine gravel and sand deposits at the downstream end of these flood chutes, and elevation of the flood chutes relative to the main channel, suggest that they are occupied at bankfull flows (and larger flood stages).

Observed features suggest a channel in the later stages of evolution following past incision. The exact nature and timing of incisional events that likely formed the terrace sets is uncertain; incision may have been post-glacial (several hundreds to thousands of years before present) or historic (100 to 250 years ago) – or both. More extensive surficial geologic mapping would be required to determine the timing and origin of these terraces with more certainty.

Development along the reach is limited to a few residential homes, generally located on the tops of adjacent high terraces. Based on review of historic aerial photographs, the floodplain, terraces, and valley walls surrounding the channel in this reach have been forested since at least 1942. The Route 313 highway access to VT Route 7 that crosses the channel mid-reach was constructed between 1977 and 1980, based on review of aerial photographs. The Route 313 embankment serves as an encroachment

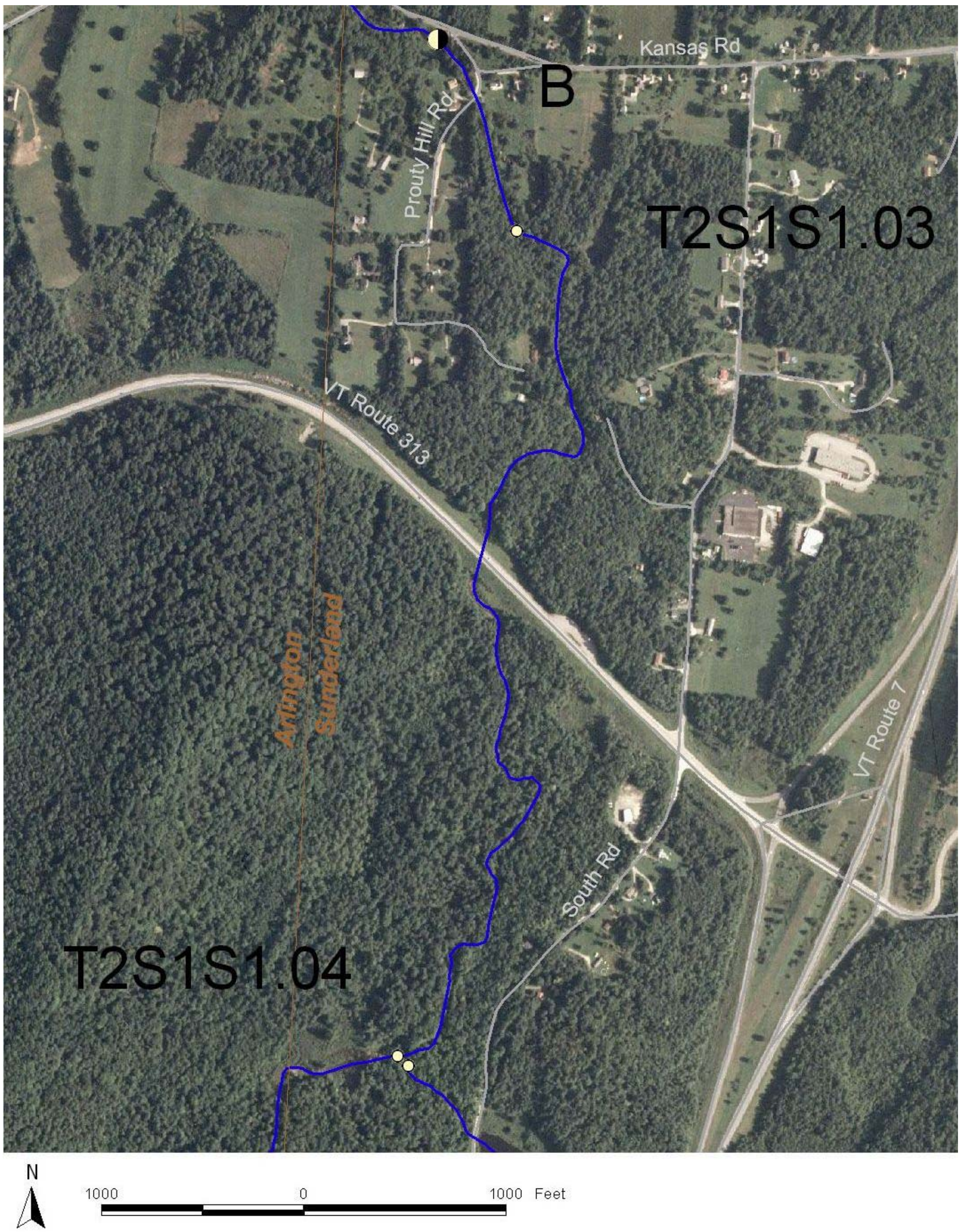


*Figure 20. Reach T2S1S1.03, Fayville Branch.
(flow is from bottom to top of picture).*

along the RB of the channel upstream of the crossing for a short distance. Road base materials fill the floodplain to a height of at least 30 feet above the channel, which is directed under Route 313 via a side-by-side, concrete box-culvert structure (Figure 21). An old road possibly utilized for logging was observed along RB near the downstream end of the reach and was indexed as an "Improved Path".

Figure 21. (T2S1S1.03) 22 August 2008. (Left) Inlet to double box culvert under Route 313, partially blocked by large woody debris. (Right) Interior of LB box culvert (view upstream).

The Route 313 double box culvert is 210 ft long, with each box culvert measuring 10 ft high by 11.9 ft wide. The crossing span (a combined 23.8 ft) is only 57% of the regime bankfull width of 41.4 ft (VTDEC, 2006). Large woody debris has collected at the inlet of the double box culvert that is not visible from the road. A wide, but relatively shallow, scour pool has developed on the downstream end of the culvert. Wooden cribbing / baffles are constructed along the inside edge of each box culvert; these are partially filled with fine to coarse gravel sediments. While design drawings for these structures were not available, they would appear to concentrate flows at low stage so that an adequate water depth can be maintained in the culvert at low flows for fish passage. The intermittent baffles, oriented perpendicular to flow, may have been designed to provide fish resting areas at high flows.

Evidence of historic dams was noted in the next downstream reach (see T2S1S1.02). Moderate beaver activity (including a breached dam) was evident in the upstream half of the reach. Two RB tributaries depicted on the VHD within the reach actually have their point of confluence with the Fayville Branch a few hundred feet downstream of the position shown on the VHD. A moderate-sized delta of fine gravel and sands was present at the confluence of each of these tributaries.

LWD recruitment within the reach is quite active (DJ = 2; LWD = 94). Two channel-spanning debris jams were recorded; other examples of breached DJs were also noted. Frequent submerged logs, boulders and occasional undercut roots provide epiphaunal substrates and fish refuge, especially in the upstream half of the reach above Route 313. LWD recruitment is contributing to small shifts in channel planform and the formation of flood chutes.

Two cross sections were completed in the reach, one upstream and one downstream of Route 313. At both cross sections, the channel has good access to a relatively narrow floodplain that is forested with mid-growth trees. The downstream cross section is located where valley walls are closing in as the channel transitions to a downstream bedrock-controlled valley pinch point (reach T2S1S1.02). Due to the narrowed floodplain, this cross section had an Entrenchment Ratio in the range characteristic of a B stream type (i.e, ER = 1.78). Bed material in this downstream half of the reach is also somewhat coarser (dominated by small cobbles) which may be due to the slightly steeper gradient.

The upper cross section was chosen as representative of the reach as a whole and indicated a C-riffle/pool stream type dominated by coarse gravels, consistent with the reference stream type. The entrenchment ratio was on the cusp between a B and C stream type (ER = 2.01), but can be classified as a C stream type by considering the +/- 0.2 value permitted by protocols. Prevalence of depositional bars (mid, point, side, and diagonal) as well as frequent flood chutes and steep riffles suggest aggradation and planform change are the dominant active adjustment processes within the reach. Frequency of depositional bars decreases with distance downstream in the reach as the gradient steepens slightly and the valley narrows. Many of the depositional bars were vegetated by grasses and young shrubs. The reach was classified in Fair geomorphic condition with an assigned "Very High" sensitivity and a channel evolution stage of V [F].

*Figure 22. (T2S1S1.03)
View upstream,
22 August 2008.
Typical point bar formation (picture right) and LWD (picture left).*

T2S1S1.02

Reach T2S1S1.02 is approximately one third of a mile long, and crosses under Prouty Hill Road to flow along Old Mill Road into the village of East Arlington. The downstream end of the reach is located at the bedrock falls next to the former grist mill. Within this reach, Fayville Branch turns to the northwest and transitions from a broader valley setting to flow through a valley pinch point where the vertical and lateral position of the channel is controlled by the exposed bedrock. At this location, the Fayville Branch crosses the northeast-trending higher-elevation ridge underlain by more weather-resistant Monkton quartzite.

Reach T2S1S1.02 was segmented to capture this subreach of alternate reference stream type (Figure 23):

- Upstream Segment B (1,035 ft long, segment slope of 1.4%) ends just downstream of the Prouty Hill Road crossing, and is in a reference Broad to Narrow valley setting.
- Downstream Segment A (895 ft long, segment slope of 2.8%) is a bedrock channel in a semi-confined to narrowly-confined setting.

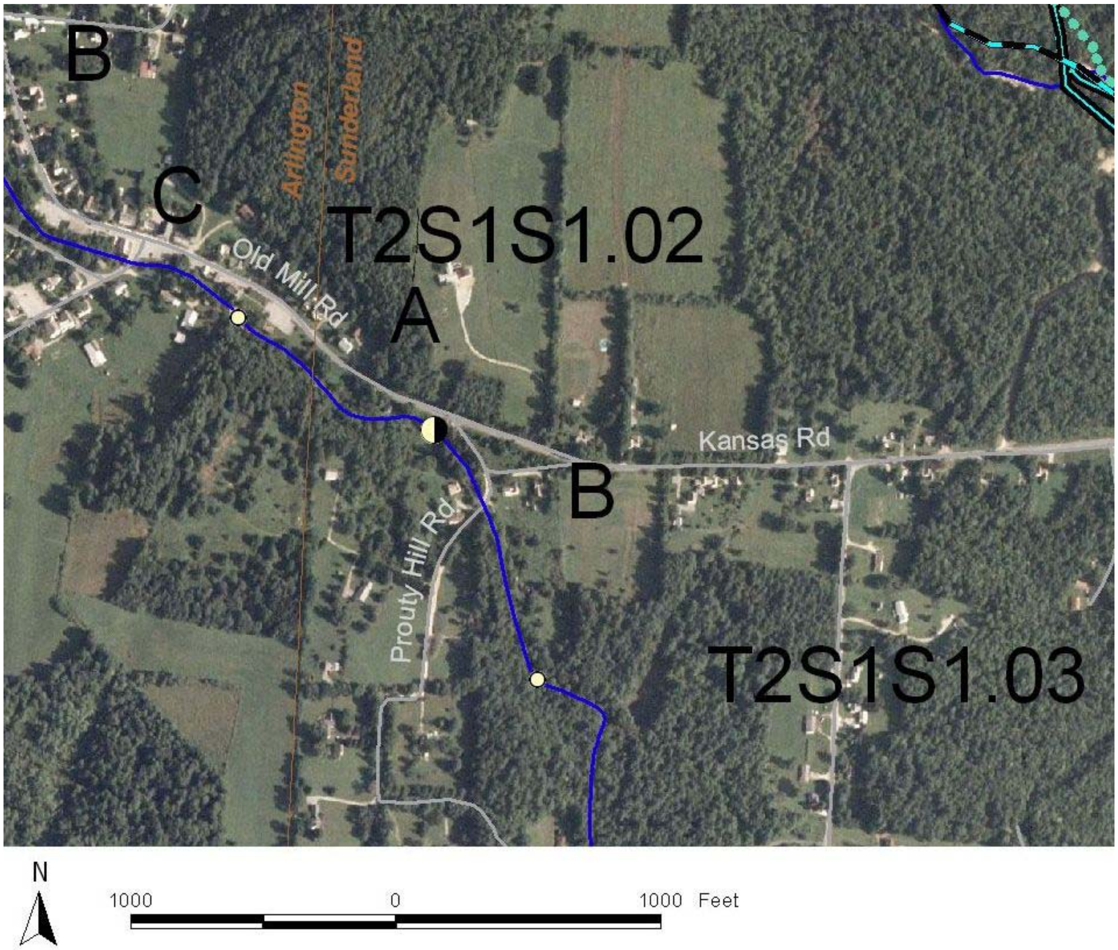


Figure 23. Segmentation of reach T2S1S1.02, Fayville Branch.
(flow is from bottom to top of picture)

Segment B

Segment B is located in an unconfined valley setting. Valley width has been reduced somewhat by the encroachment of Kansas Rd and Prouty Hill Rd along RB, as well as historic mill development along RB. A driveway along RB leading south from Prouty Hill Rd. is not significantly elevated above the floodplain surface. Average valley confinement has been modified from a reference "Broad" to an existing "Narrow" confinement. The channel flows along the LB valley wall upstream of the Prouty Hill Rd culvert crossing and is incised (historically) below the RB floodplain. Channel-spanning bedrock is exposed near the upstream end of the segment (and frequently in the downstream Segment A); otherwise, a cobble plane-bed form dominated.

Straightening is inferred within the segment due to the linear planform, and the historic impoundments and encroachments. Remnants of a possible dam were noted on the LB and RB in vicinity of the channel-spanning bedrock at the upstream end of the segment. Historic photographs and the Beers Atlas (1869) document a historic mill dam (Saffords Mill) at the downstream end of the segment (see Segment A). Foundation remnants are present at the RB near the upstream end of the segment and comprise a section of "Hard Bank" armoring which continues as rip-rap downstream to the Prouty Hill Rd crossing (Figure 24). The Beers Atlas notes the “A. Wallace Clothes Pin Factory” in this general vicinity.

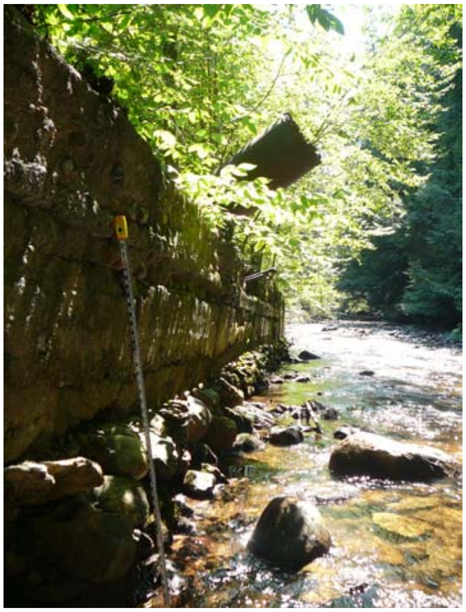


Figure 24. (T2S1S1.02-B)
View upstream on 21 August 2008.
Remnants of a mill building foundation serve as hard bank armoring for the Fayville Branch. The base of the foundation is revealed approximately 2 feet above the current channel bed, suggesting historic incision.

The Prouty Hill Rd crossing is an arch-pipe culvert with a bankfull-constricting span (Figure 25); a scour pool greater than four feet deep has developed below the culvert. A stormwater input (road ditch runoff) was documented along LB near the downstream end of the culvert.

Figure 25. (T2S1S1.02-B)
21 August 2008.
View downstream to inlet of arch-pipe culvert under Prouty Hill Road - 70 ft long, 9.5 ft high, and 15.1 ft wide.
Span (15.1 ft) is only 36% of the regime bankfull width (41.5 ft – VTDEC, 2006)

A vertical stream type departure (from reference C to F) is suggested by the measured incision ratio of 2.5. Despite the degree of incision and channel entrenchment, widening and planform adjustment processes appear to have been moderated by the erosion-resistant bed and bank materials, streambank armoring, and largely intact tree buffers. Minor, localized, aggradation is suggested by the slightly widened cross section (w/d = 25.4) and relative absence of pools; medium gravels were observed to have accumulated at the inlet of the Prouty Hill Rd culvert while elsewhere the bed is dominated by cobbles. The segment was scored in Fair condition, with an Extreme sensitivity rating due to the stream type departure. This segment may have persisted in channel evolution stage II [F] for some time. Still, it is susceptible to sudden and catastrophic erosion in a flood event and/or in the case of a debris jam at the Prouty Hill Rd culvert inlet.

Segment A

There are frequent exposures of bedrock in the bed and banks of Segment A, and this section of reach T2S1S1.02 has a steeper slope (est. 2.8%) than the remainder of the reach (C-riffle/pool, 1.4%); therefore, it was identified as a subreach of alternate reference stream type. Given the bedrock channel, Segment A was classified as a "bedrock gorge" under protocols. A provisional reference and existing stream type of B1-step/pool were assigned, along with a "Low" sensitivity.

Figure 26. (T2S1S1.01-A). Bedrock falls at the grist mill on Old Mill Road, East Arlington, VT.

The most prominent bedrock falls in the Segment is the cascade below the historic grist mill (Figure 26). Old Mill Road follows the channel along RB; however, it is essentially at grade where elevations are controlled by the underlying shallow bedrock. Therefore, no human-caused change in valley width was recorded. The reference valley confinement was estimated as Semi-confined. The left valley wall (steep forested slope) is coincident with the LB; the right valley wall (shallow, moderately-sloped bedrock surface) is sometimes coincident with RB and otherwise within one bankfull width of the channel. Several residential and commercial buildings are developed along the RB corridor, including the former grist mill. Historically, three dams with associated impoundments were located within Segment A (Beers, 1869; Chase, 1880; Henry, 1993), including the Safford's Mill Dam (Figure 27) and a log crib dam at the grist mill falls. See Section 5.1.1 for more details of these historic dams.

Figure 27. (T2S1S1.02-B, A) (Left) Historic location of Safford's Mill Dam (late 1800s) at channel-spanning bedrock just downstream of junction Prouty Hill Rd and Kansas Rd. (Perkins Landscape Change web site) (Right) Present day view from same vantage point.

T2S1S1.01

Below the grist mill falls, Fayville Branch transitions into a Very Broad valley setting on deposits of glacio-fluvial origin (USDA, 1998; DeSimone, 2000) on approach to the confluence with Warm Brook. The historic village of East Arlington has been developed within this broad valley setting.

Generally, the degree of channel incision decreases along the length of this reach from an incision ratio (IR_{RAF}) greater than 2 to a value of 1.0. Reach T2S1S1.01 was segmented to capture: (1) this variability in the degree of vertical departure; (2) presence of encroachments (berms) which locally enhance the degree of entrenchment; and (3) a general fining-downstream sequence of bed materials (Figure 28).

- Segment C – 1,237 ft long, 1.8% gradient, C stream type, IR_{RAF} = 1.9
- Segment B – 685 ft long, 0.9% gradient, C to F stream type departure, with IR_{HEF} of 2.0
- Segment A – 374 ft long, 0.5% gradient, C stream type, IR_{RAF} = 1.0.

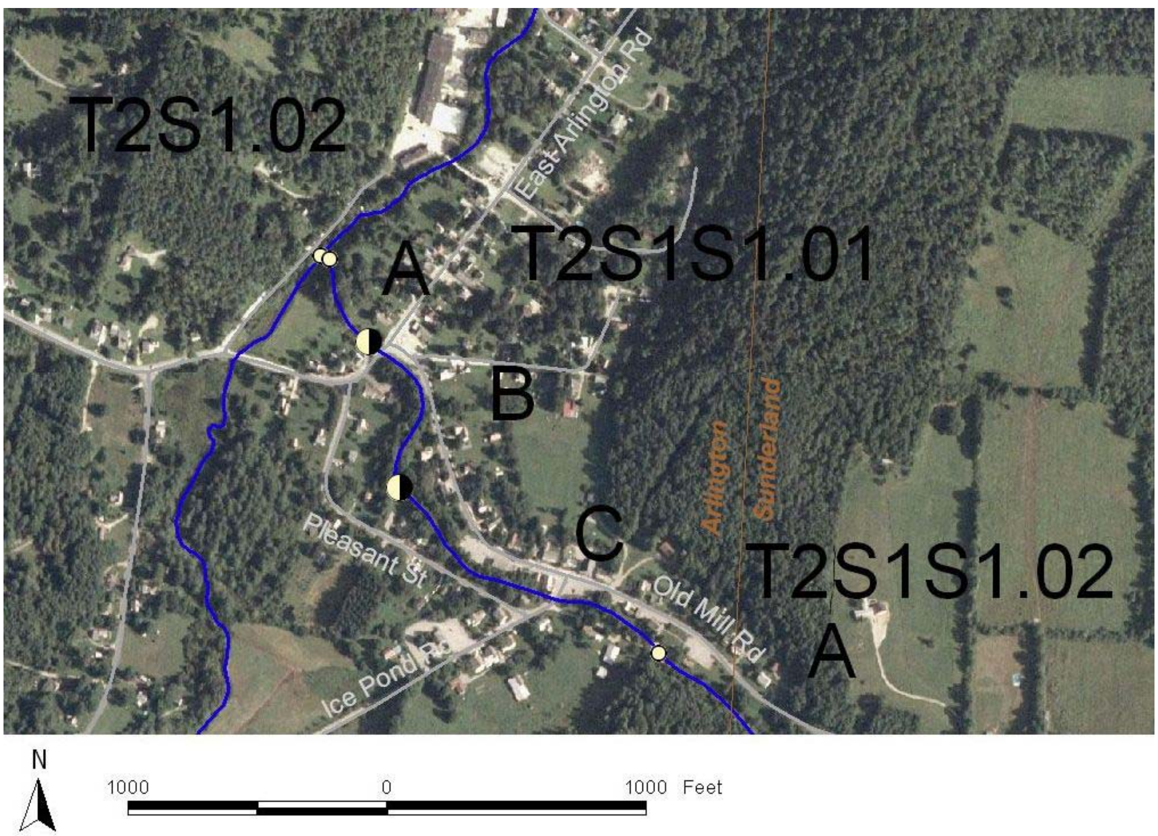


Figure 28. Segmentation of reach T2S1S1.01, Fayville Branch.

Segment C

Segment C extends from the grist mill waterfall downstream to a point half-way between the Ice Pond Rd crossing and the East Arlington Rd crossing. Topographic contours indicate a transition from a Semi-confined to Very Broad valley and decrease in slope from 2.8% in upstream segment T2S1S1.02-A to 1.8% in T2S1S1.01-C (and 0.9% in Segment B, 0.5% in Segment A). Two channel-spanning exposures of bedrock ("waterfall") were noted within Segment C. The upstream-most exposure is actually the base of the grist mill falls. Technically, this waterfall would be grouped with the upstream segment of bedrock channel; however, it was indexed within this segment T2S1S1.01-C due to a slightly mis-located Phase 1 reach break. The second exposure of channel-spanning bedrock was noted mid-way between the grist mill falls and the Ice Pond Rd bridge.

Old Mill Rd follows the channel in the RB corridor and Pleasant St follows within the LB corridor. Both roads are slightly elevated above the surrounding floodplain, and therefore resulted in a slight human-caused change in valley width - enough to change the valley type (from Very Broad to Broad), but not sufficient to change the confinement type (unconfined). The floodplain along both sides of the channel is developed with residential, municipal, and commercial buildings (village of East Arlington). Development is historic dating back to the mid- to late-1700s (Child, 1880). Straightening is inferred from the linear planform. Channel margins have likely been graded and reworked during historical development and during recovery from past flood events. Historic annual reports for Arlington note "flood repair…[to the] East Arlington dikes" following the 1927 flood; "diking [the] East Arlington River" following the 1936 flood, working on the "East Arlington dike" and "dredging and diking [in] East Arlington [with a] steam shovel" after the 1938 flood. Streambanks have been heavily armored with rip-rap and incorporate building foundations as "hard bank" armoring along the RB. Trees rooted in the streambank armoring provide further bank protection. A short section of berm is present along LB downstream of the grist mill waterfall. Ice Pond Rd crosses the channel mid-segment via a bridge with concrete wing walls; this bridge has a bankfull-constricting span and aggradation is noted at the bridge inlet. Stormwater runoff occurs directly from a paved parking area along RB upstream of the bridge and through urban stormwater pipes along RB elsewhere in the segment.

*Figure 29. (T2S1S1.01-C)
21 August 2008.
View downstream of Ice Pond Road bridge. Commercial and residential properties encroach along both banks (outside a narrow but relatively mature tree buffer). Channel is moderately incised and somewhat entrenched below surrounding floodplain.
Rip-rap armors the banks.*

The channel is moderately incised below the floodplain (IR = 1.9) and would appear to have floodplain access only at moderate to high flood stages. Based on the absence of active headcuts or undercut banks, incision is inferred to be historic in nature, possibly enhanced by floodplain filling / regrading during past flood recovery efforts. A coarse-cobble-dominated C-plane bed stream type is evident. The channel is slightly entrenched (ER = 2.37) with a low W/D ratio (12.5).

Channel adjustments are negligible, due to boundary resistance and the conversion of the channel to a transport-dominated sediment regime. Due to the minimal channel adjustments the segment was scored in the "Good" quadrant of the RGA, with a corresponding "Moderate" sensitivity due to the coarseness of bed materials (D50 = cobble, on the cusp of the boulder range). It is likely that this segment has persisted in a channel evolution stage of II [F] since the last major post-flood channelization and "stream cleaning" efforts. Despite the seemingly stable condition, the channel remains susceptible to catastrophic erosion during flood events, especially in the case of debris jams lodged at the bridge inlet or armored narrows of the channel cross section.

Segment B

Segment B of T2S1S1.01 extends from a point mid-way between the Ice Pond Rd crossing and the East Arlington Rd crossing downstream to the East Arlington Rd bridge. This segment was delineated on the basis of berms along both banks that enhance the degree of incision and entrenchment of the channel (estimated IR_{HEF} from 2.4 to 2.0), leading to a stream type departure (C to F).

Old Mill Rd in the RB corridor and Pleasant St in the LB corridor are slightly elevated above the surrounding floodplain, and therefore resulted in a slight human-caused change in valley width - enough to change the valley type (from Very Broad to Narrow), but not sufficient to change the confinement type (unconfined). No bedrock grade controls were noted in the segment. Similar to upstream segment C, the reference stream type is inferred to be C-riffle/pool. Dominant bed materials have decreased in size to gravel.

As in upstream Segment C, the floodplain along both sides of the channel is developed with residential and commercial buildings (village of East Arlington). Streambanks are armored with rip-rap. Channelization and dredging are inferred due to the extensive berming / armoring. Channel margins have likely been graded and reworked during historical development and during recovery from past flood events. The historic channel management activities described under Segment C are likely to have occurred within Segment B. Berms are present along both banks for nearly the entire segment length (with an occasional break in the RB berm). The age of trees rooted in and along the berms would be consistent with a post-1973 flood origin for the berms. The berms effectively constrict the channel, since the distance between them (34 ft) is undersized with respect to the regime bankfull width (42 ft).

The channel is partly incised (IR_{RAF} = 1.4). While the degree of incision below the floodplain has decreased from 1.9 in upstream segment C, the berms along both banks in Segment B have enhanced the degree of channel entrenchment (IR_{HEF} = 2.0, ER = 1.47) to cause a stream type departure (C to F).

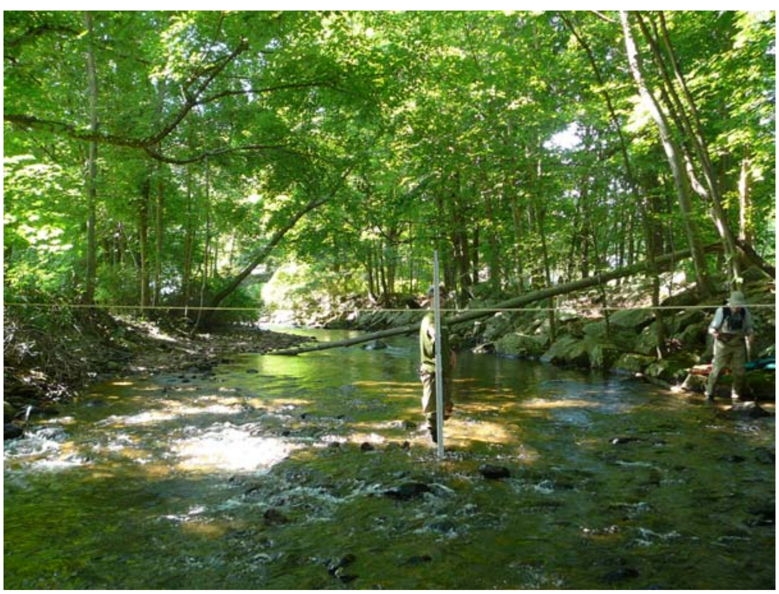


Figure 30. (T2S1S1.01-B) 22 August 2008. View upstream at cross section site in Segment B. Berms lining both stream banks have enhanced the degree of channel entrenchment resulting in loss of floodplain connection and increased erosional scour energies.

A vertical concrete retaining wall exists along RB at the downstream end of the segment to protect Old Mill Rd; this wall encroaches significantly on the channel, which effectively becomes constricted between the LB berm and the RB retaining wall at the apex of the channel meander. A scour pool has developed along the RB coincident with the retaining wall. Three stormwater pipes were observed penetrating the retaining wall and directing drainage to the channel. The concrete wall has significant cracking and spalling and is scoured at the interface with the channel bed (Figure 31). East Arlington Rd bridge crosses the channel at the downstream end of the segment; this bridge has a bankfull-constricting span and minor aggradation was noted at the inlet.

Figure 31. (T2S1S1.01-B) 21 August 2008. View downstream of RB retaining wall near East Arlington Rd bridge crossing.

Moderate aggradation in the segment is suggested by the presence of side and point bars (one each) and a diagonal riffle. A minor degree of planform adjustment is also occurring (i.e. localized meander extension). Incision is historic in nature. The moderate to minor channel adjustments resulted in an RGA score in the "Fair" quadrant. Due to the somewhat greater degree of observed channel adjustment, finer bed materials (gravel-dominated rather than cobble-dominated), and the vertical stream type departure, this Segment T2S1S1.01-B has a higher assigned sensitivity ("Extreme") than upstream Segment C. It is likely that Segment B has persisted in a II [F] channel evolution stage since the last major post-flood channelization and "stream cleaning" efforts (i.e., 1973?). Like upstream Segment C, Segment B remains very susceptible to catastrophic erosion in future flood events.

Segment A

Segment A of Reach T2S1S1.01 extends from the East Arlington Rd bridge downstream to the confluence with Warm Brook. A very broad valley setting is defined by the merging of Warm Brook and Fayville Branch floodplains. A slight reduction in valley width is caused by the East Arlington Rd in the LB corridor; enough to cause a change in valley type (Very Broad to Narrow), but not sufficient to change the reference confinement type (unconfined). Gradient of this segment (0.5%) is considerably less than upstream segments. Bed materials are dominated by coarse gravels, in contrast to small cobbles and boulders of upstream segments. Some sediment has accumulated to form a mid-channel bar upstream of a debris jam in the middle of the segment. A reference C4-riffle/pool stream type is inferred.

Light-density residential development is present in both LB and RB corridors. The Hale Co. dam, located approximately 650 ft downstream of the confluence with Warm Brook, appears to have an impoundment effect that extends upstream into the segment. Historic resources (Beers, 1869; Henry, 1993) indicate that a dam was located in this vicinity at least back to the mid-1800s. Historic dredging and straightening is inferred from the linear planform and anecdotal accounts.

*Figure 32. (T2S1S1.01-A)
22 August 2008.
View upstream from cross section site toward East Arlington Rd bridge crossing. Segment A exhibits a gravel C-plane bed stream type with good floodplain access (IR = 1.2)*

The channel is slightly incised (historically) and exhibits a plane bed form. Minor aggradation is suggested by the overwidened plane-bed morphology and the mid-channel bar; other adjustment processes are minor to negligible. Channel widening and planform adjustment may have been moderated by a reduction in flow velocities (i.e., reduction in gradient) in this segment which appears influenced by impoundment effects of the downstream dam. The segment was assigned a geomorphic condition rating of "Good" due to the minimal degree of adjustment. A C4 channel in "Good" geomorphic condition is prescribed a sensitivity of "High" under VTANR protocols (2007a). A channel evolution stage of I [D] is inferred.

Table 6. Results of Phase 2 Geomorphic Assessments, Fayville Branch reaches assessed in 2008.

Fayville Branch (Batten Kill) - Sunderland, Arlington

Reach	Seg-ment	Channel Length (ft)	Channel Slope (%)	Drainage Area (sq mi)	Stream Type	Incision Ratio	RHA Condition	RGA Condition	Adjustment	Channel Evolution Stage	Stream Type Departure?	Sensitivity
T2S1S1.03	--	5,224	***1.1***	13.7	C4-R/P	1.0 [RAF]	0.71 Good	0.63 Fair	Mod aggr, PF	V [F]	No	Very High
T2S1S1.02	B	1,035	***1.4***		F3-PB	2.5 [RAF]	0.53 Fair	0.60 Fair	Min aggr	II [F]	C to F	Extreme
	A *	895	***2.8***	13.8	B1-S/P	NM	NM	NM	NM	I [D]	No	Very Low
T2S1S1.01	C	1,237	***1.8***		C3-PB	1.9 [RAF]	0.52 Fair	0.70 Good	None	II [F]	No	Moderate
	B	685	***0.9***		F4-PB	1.4 [RAF]	0.56 Fair	0.61 Fair	Mod aggr, min PF	II [F]	C to F	Extreme
	A	374	***0.5***	13.9	C4-PB	1.2 [RAF]	0.52 Fair	0.78 Good	Min aggr	I [F]	No	High

Abbreviations:

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

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

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

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

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

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

* Subreach of alternate reference stream type.

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

5.0 DEPARTURE ANALYSIS, STRESSOR IDENTIFICATION & SENSITIVITY

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

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

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

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

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

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

5.1 Departure Analysis

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

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

5.1.1 Watershed Scale Hydrologic and Sediment Regime Stressors

Data are not sufficient to know with certainty whether (and to what extent and in what locations) a given change in the water or sediment inputs to a river corridor will cause the channel to incise or aggrade, widen or shift its planform. However, potential influences on the hydrology of the Roaring Branch watershed (including Fayville Branch) can be identified in a qualitative sense as a possible contributor(s) to channel dis-equilibrium. Watershed-level hydrologic and sediment regime stressors are identified through a review of existing Phase 1 and Phase 2 stream geomorphic data and include deforestation, stormwater inputs, dams, flow regulations, land use (degree of urbanization), ditching, and wetland loss. Watershed stressors are summarized in Table 4 and described further in the sections below.

It should be noted that Nislow and Magilligan (2005) analyzed longterm USGS flow records from Batten Kill and other regional gages and found "no evidence of long-term change in the timing, duration or magnitude of flows in the Batten Kill basin…over time in the last century."

Deforestation

Widespread deforestation of Vermont's landscape occurred by the early- to mid-1880s (Thompson & Sorensen, 2000) to support subsistence farming and lumber industries. Deforestation is inferred to have caused increased water and sediment loads to be mobilized from the Roaring Branch watershed. Rainfall, which would previously have been intercepted by tree leaves and branches, and which would have been taken up by tree roots and evapo-transpired, instead ran off the land surface. Infiltrative capacities of the soils would have been reduced by compaction of the soils during harvesting. Increased volumes of stormwater runoff would have had increased capacity for gullying and entrainment of soils and sediments from the land surface, delivering increased sediment loads to the river network. For example, deposition on the alluvial fan in Roaring Branch reach T2.04 may have been rejuvenated during this time of deforestation. Sediment supplies to other reaches of the Roaring and Fayville Branches would also have been increased especially during flood events, leading to aggradation and planform adjustments (with the increased sediment loading), and possibly localized incision and widening (where increased hydrologic loading occurred).

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

Floods

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

Available historic resources indicate that the Roaring Branch watershed was affected by the large events of 1927, 1936, 1938 and 1973, as well as several smaller flood events (see Section 2.5). These flood events would have episodically increased flows and sediment loading in the channels of the Roaring Branch watershed.

Urbanization

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

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

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

Table 7. River Stressor Identification Table (Watershed Level)

	Watershed Input Stressors	
Stressor Type	**Hydrologic Regime**	**Sediment Regime**
Floods	Events (such as the floods of 1973, 1938, 1936, and 1927) imparted event-based **increase** in hydrologic loading to the watershed (see Section 2.5).	**Increased** sediment loading from active channel adjustments in upstream reaches, would be expected as a result of major flood events, such as the 1973, 1938, 1936, and 1927 (see Section 2.5).
Deforestation	**Increased** hydrologic loading due to deforestation in mid- to late-1800s; subsequent **decreased** hydrologic loading as slopes reforested through the 1900s.	**Increased** sediment loading due to deforestation in mid- to late-1800s; subsequent **decreased** sediment loading as slopes reforested through the 1900s.
Urbanization	**Insignificant** increased hydrologic loading inferred due to development and increased road densities of reach subwatersheds and upstream drainage areas in recent decades. Upstream watershed development percentages (1.1 to 3.7%) are less than the threshold of concern (5%) noted in VTANR guidance (11 July 2007).	**Insignificant** increased sediment loading inferred due to development and increased road densities of reach subwatersheds and upstream drainage areas in recent decades. Upstream watershed development percentages (1.1 to 3.7%) are less than the threshold of concern (5%) noted in VTANR guidance.
Stormwater Inputs	**Minor increased** hydrologic loading inferred due to road ditch, field ditch, and engineered stormwater inputs. Drainage area of assessed reaches (14 to 26 square miles) equal or exceed the drainage area (0 - 15 sq mi) likely to be influenced by stormwater inputs (as noted in VTANR guidance, 11 July 2007).	**Minor increased** sediment loading inferred due to road ditch, field ditch, and engineered stormwater inputs. Drainage area of corridor reaches (14 to 26 square miles) equal or exceed the drainage area (0 - 15 sq mi) likely to be influenced by stormwater inputs (as noted in VTANR guidance, 11 July 2007).
Dams / Impoundments	No dams are currently located on the six assessed Fayville & Roaring Branch reaches. Closest downstream dam is 650 ft downstream of the Fayville Branch confluence with Warm Brook. This Hale Co. dam appears to have a run-of-river operation and a limited impoundment area; thus, should not significantly influence hydrologic regimes on the Fayville Branch.	No dams are currently located on the six assessed Fayville & Roaring Branch reaches. Closest downstream dam is 650 ft downstream of the Fayville Branch confluence with Warm Brook. This Hale Co. dam appears to have a run-of-river operation and a limited impoundment height. Sediments may be trapped in this impoundment and accumulate in the lower Fayville Branch due to the decreased sediment transport capacity imparted by reduced velocities.
Diversions / Water Withdrawals	Not Applicable	Not Applicable
Loss of Wetlands	**Insignificant** increase in hydrologic loading to the assessed reaches as a result of conversion of wetlands (hydric soils) to agricultural uses through tributary channelization and ditching.	Insignificant increase in sediment loading to the assessed reaches as a result of conversion of wetlands (hydric soils) to agricultural uses through tributary channelization and ditching.
Crop Lands	**Insignificant** increase in hydrologic loading to the corridor reaches as a result of crop land use (implying possible ditching, tile networks). Crop land use is very low (0.4 to 1.4%) in the the upstream watershed. Potential significance also tempered by the size of the upstream watershed (14 to 26 square miles).	Insignificant increase in sediment loading to the corridor reaches as a result of crop land use (implying exposed soils and erosion). in the upstream watershed. Crop land use is very low (0.4 to 1.4%) in the the upstream watershed. Potential significance also tempered by the size of the upstream watershed (14 to 26 sq mi).

The upstream watersheds draining to each of the assessed reaches have urbanized land percentages ranging from approximately 3.4 to 4.4% (Phase 1 data, Jaquith *et al*, 2004). This range of values is below the percentage (5%) suggested as a threshold of concern in VTANR guidance (2007b).

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

Road Networks / Ditches

In rural watersheds, particularly on upland slopes, road and driveway ditches can be a significant contributor of stormwater and sediment to receiving tributaries and rivers. Often road ditch networks terminate at stream crossings without provision for sediment and stormwater retention, detention or treatment.

While a full inventory of these tributary road crossings was beyond the scope of Phase 2 assessments to date, the potential impact of road ditch networks on the watersheds draining to the assessed reaches can be qualitatively evaluated by summing the total length of roads in each sub-watershed and calculating road density. Field (2007) determined that road network density in the Roaring Branch watershed (including Fayville Branch) was very low (page 3 and Table 5b of Field, 2007).

Stormwater inputs

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

Table 8 notes the stormwater inputs identified in the assessed reaches of Roaring Branch (T2) and Fayville Branch (T2S1S1). Because the upstream drainage area of these reaches is quite large (ranging from 14 to 26 square miles), the potential influence of these stormwater inputs on the hydrologic and sediment regimes of the river is considered minor to negligible. VTANR guidance suggests that stormwater inputs are significant only for drainage areas less than 15 square miles. In particular, several points of stormwater runoff were noted along the three-mile upstream reach of Roaring Branch, T2.05. The frequency of stormwater inputs was also relatively high in the short segments of the Fayville Branch through the East Arlington village (reach T2S1S1.01, Segments C and B).

Table 8. Stormwater Inputs in the Assessed Reaches

Reach/ Seg	Field Ditch	Road Ditch	Tile Drain	Urb Stmwtr Pipe	Overland Flow	Other	Total #
	No. of Features						
Roaring Branch							
T2.05	0	**11**	0	0	**11**	0	22
T2.04-C	0	0	0	0	**1**	0	1
T2.04-B	0	0	0	0	0	0	0
T2.04-A	0	0	0	0	0	0	0
T2.03-D	0	0	0	0	0	0	0
T2.03-C	0	0	0	**1**	0	0	1
T2.03-B	0	0	0	0	0	0	0
T2.03-A	0	0	0	0	0	0	0
Favyille Branch							
T2S1S1.03	0	0	0	0	0	**1**	1
T2S1S1.02-B	0	**1**	0	0	0	0	1
T2S1S1.02-A	0	0	0	0	0	0	0
T2S1S1.01-C	0	0	0	**2**	**1**	0	3
T2S1S1.01-B	0	0	0	**3**	0	0	3
T2S1S1.01-A	0	0	0	0	0	0	0

Dams

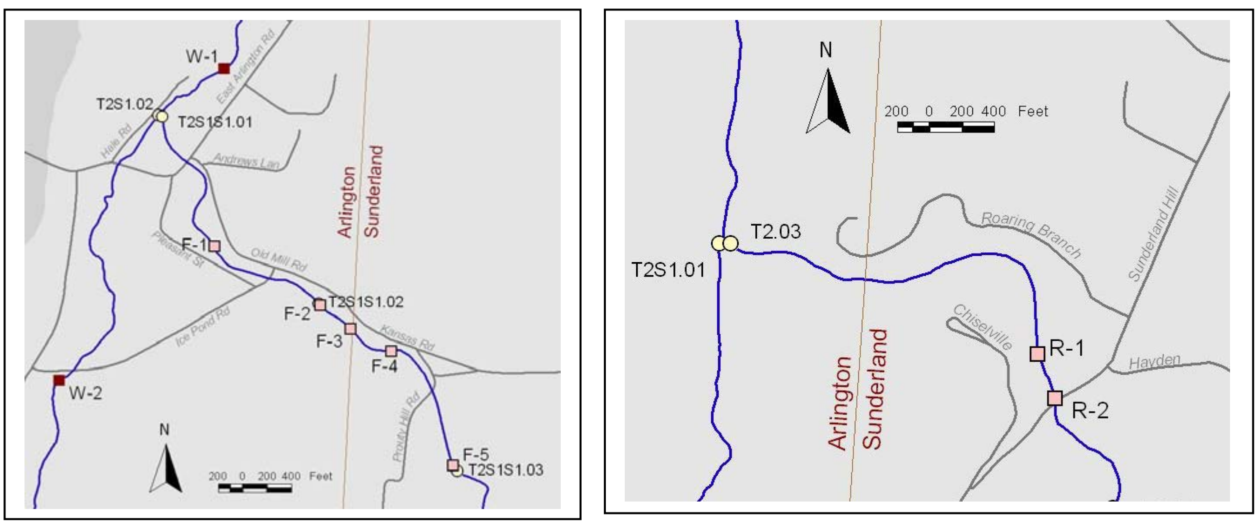
Dams disrupt the flow dynamics (and sediment transport continuity) of rivers to varying degrees and extents, depending on their size, height, topographic setting, and operational status, and depending on the hydrologic, geomorphic and geologic characteristics of the river being impounded (Williams and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

There are presently no dams on the Fayville Branch or Roaring Branch in the six reaches assessed in 2008. Two dams exist on the Warm Brook – 650 ft downstream of the Fayville Branch confluence (Hale

Company dam) and 2,500 ft upstream of the Fayville Branch confluence (Ice Pond dam). These are depicted in Figure 7 in Section 2.7 and on the maps in Figure 33 below. Historically, several dams were present on the assessed reaches of the Fayville and Roaring Branches in support of various manufacturing interests. These are depicted on Figure 33 and summarized in Table 9.
Further details of the construction specifications or length of operation of these historic dams were not available.

While these past structures no longer impound the tributary channels, knowledge of their historic presence aids in characterizing the overall sensitivity of the river reaches and their degree of departure from reference condition, where applicable. In some cases, the present morphology and sediment regime of the river channel can still be influenced by the historic disruption of fluvial and sediment transport processes imparted by a dam(s).

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



(a) (b)

Figure 33. Location of existing (dark square) and historic (light square) dams on Fayville Branch, Warm Brook (a) and Roaring Branch (b).

As further detailed in Section 4.1, the historic dam(s) near the Chiselville covered bridge are reported to have had a significant impoundment height (together, some 65 feet) and a large impoundment area (Child, 1880). Thus, their removal (possibly 1927 flood?) may have contributed to the degree of upstream historic incision noted in T2.03-D and T2.04-A. Sediment impounded at these dams would have been flushed downstream to contribute to aggradation in T2.03-A and T2.02 and T2.01. These downstream reaches were apparently channelized, dredged and bermed following the 1927 flood, the 1938 flood and possibly other events (e.g., 1973) (Field, 2007).

Table 9. Summary of Available Data,
Historic and Existing Dams On and Near the Assessed Reaches

Dam No.	Reach/ Segment	Dam	Date Constructed	Date Breached	Associated Use / Industry	Data Source
Fayville Branch						
F-5	T2S1S1.02-B	At upstream end of reach	Unknown	Unknown	Unknown	Visible dam foundation remnants; nearby mill foundation.
F-4	T2S1S1.02-A	Safford's Saw Mill	c. 1805	Unknown	Saw mill	Historic photo viewed at Perkins Landscape Change web site; Beers, 1869; Child, 1880.
F-3	T2S1S1.02-A	Safford's Washboard Factory	c. 1830	Unknown	Handle & pump factory; washboard factory	Beers, 1869; Walling, 1856; Child, 1880.
F-2	T2S1S1.02-A	Meerworth Bros. Grist Mill	c. 1789	1927	Grist mill	Child, 1880; Beers, 1869; Henry, 1993
F-1	T2S1S1.01-C	Judson & Billings Judson & Demming	c. 1852	Unknown	Saw-frame, saw-buck & washboard factory	Beers, 1869; Child, 1880
Warm Brook						
W-2	T2S1.02	Ice Pond Dam Aka Barney's Dam	c. 1860s	Existing	Early: diversion channel to power brush handle & clothespin factory. Later: Ice Harvest	Beers, 1869; Henry, 1993; VT Dam Inventory
W-1	T2S1.01	Hale Company	Before 1869	Existing	Early: diversion channel to power washboard factory. Later: Hale Furniture Co.	Beers, 1869; VT Dam Inventory
Roaring Branch						
R-2	T2.03-C	At Chiselville Bridge	Before 1869	Unknown	"Chisel Factory" "Douglas Manuf'g Co."	Beers, 1869; Child, 1880; historic photo c.1880s (Jaquith et al, 2004)
R-1	T2.03-C	Below Chiselville Bridge	Before 1869	Unknown	Diversion channel across intervale to "Chisel Factory"	Beers, 1869; Child, 1880

Similarly, historic dams on the Fayville Branch would have impounded sediments to varying degrees, depending on impoundment size and height. Upon breaching of the dams (perhaps during the floods of 1913, 1927, or the 1930s), sediments would have been released to downstream reaches. The Fayville Branch was reportedly channelized, dredged and bermed following the 1927 and 1936/1938 floods (as well as the 1973 flood). It is likely that sediments dredged from the channel during these periods had their source not only from breached dam impoundments, but also from upstream erosion and avulsions. Breaching of historic impoundments at Safford's Saw Mill (F-4) and upstream dam (F-5) may have contributed to the observed degree of vertical stream type departure in segments T2S1S1.02-B and T2S1S1.03 (local to the dam site). Historic incision upstream of the other Fayville Branch historic dams would likely have been limited, given that these dams were located on or near bedrock controls.

Diversions, Water Withdrawals (flow regulation)

Changes in the flow characteristics of a river imparted by diversion structures or substantial water withdrawal sites can influence the magnitude of flows and interrupt the sediment transport functions of rivers, potentially resulting in areas of exacerbated erosion or system-wide instability in the river. No significant withdrawal or diversion sites were present in the assessed reaches. A historic diversion site was noted spanning segments T2.03-B and T2.03-A. Possible lasting impacts of this diversion channel on the present condition of these segments is difficult to predict and would be difficult to distinguish from the effects of dam breaching and naturally enhanced deposition at this tributary confluence. One very small apparent irrigation withdrawal was noted along the LB of Roaring Branch in reach T2.04-C downstream of the Kansas Road bridge. Based on the size of the observed pump, this withdrawal would be very small compared to the total flow in Roaring Branch, and was therefore deemed "Not Significant".

Loss of Wetlands / Agricultural Ditching

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

While ditching and conversion of wetlands to agricultural uses appears to be a significant hydrologic stressor in some of the Batten Kill main stem reaches (Field, February 2007), this land-use conversion is not prevalent in the six upstream tributary reaches of the Roaring and Fayville Branches assessed in 2008. Wetlands (NWI, VSWI) comprise a minor aerial extent of the upland watershed in each tributary, and agricultural land use ranges only from 1.7 to 2.4% in the upstream watershed containing the assessed reaches.

Crop Lands – Exposed Soils

VTANR guidance (2007b) states that the area of cultivated lands draining to each reach can suggest the potential for land surface erosion and sediment mobilization to assessed reaches. Caution should be applied, as such an evaluation does not take into account the degree of hydrologic connection of the noted crop lands to the receiving waters. Nor does it adjust for potential erosion prevention measures or practices in place on the indicated crop lands. Further limitations of this methodology are related to the scale, accuracy, and currency of the land cover / land use data sets utilized to summarize the data:

(*Landcover / Landuse for Vermont and Lake Champlain Basin (LandLandcov_LCLU, edition 2003). Source dates of 1991 to 1993. Available at: http://www.vcgi.org/metadata/LandLandcov_LCLU.htm.)*

Phase 1 stream geomorphic data (Jaquith *et al*, 2004) indicate that crop land use in the upstream watersheds draining to assessed reaches of the Roaring and Fayville Branches is quite low (ranging from 0.4 to 1.4%) and less than the threshold considered to be of significance in VTANR guidance (2007b).

5.1.2 Sediment Regime Stressors (Watershed and Reach Scale)

Sediment regime stressors for the assessed Roaring Branch and Fayville Branch reaches are summarized in Table 7 (Watershed Level Stressors) and in Tables 10-a and 10-b, respectively (Reach Level Stressors); they are discussed briefly in the following sections. The purpose of this section is to evaluate the "cumulative impact of erosion and subsequent deposition at the watershed scale" through review of reach-based features (VTANR 2007b). Features were compiled from a review of Phase 1 and Phase 2 Stream Geomorphic Assessment data and included: (1) depositional bars / planform migration features; (2) bank erosion; (3) mass wasting sites; and (4) gully sites or rejuvenating tributaries.

Depositional bars and planform migration features

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

Along the Fayville Branch upstream of Prouty Hill Road crossing (reach T2S1S1.03) the numbers and variety of depositional features (steep riffles, mid-channel bars, and delta bars) as well as active planform migration features (flood chutes, and channel bifurcations) are particularly noteworthy. These features are suggestive of increased sediment loading from upstream and instream erosion (apparently enhanced by beaver activity), and may also result from localized reductions in sediment transport capacity at the undersized double-box-culvert crossing of VT Route 313 and at the transition to narrower valley confinement at the downstream end of the reach.

Along the Roaring Branch, two segments show a relatively high density of depositional and planform migration features:

- Segment T2.04-B on the alluvial fan where an increased prevalence of such features is entirely consistent with the divergence of flows and multi-thread channel in this valley setting; and

- Segment T2.03-A at the confluence of Warm Brook, where bedrock constraints in the left valley wall force a sharp-angled turn of the channel, which appears to have locally decreased the sediment transport capacity.

In both of these cases, aggradational tendencies and lateral channel adjustments may be enhanced by an increase in sediment supply from erosion in nearby upstream reaches which have increased erosional tendencies resulting from partial to substantial incision and entrenchment.

Bank Erosion

Generally, excess stream bank erosion was not noted in the assessed reaches of Fayville and Roaring Branches. Frequent lateral bedrock grade controls and continuous forested buffers have provided erosion resistance along the channel banks. In the few locations where buffers are minimal or absent (e.g., through the village of East Arlington or at road crossings), rip-rap or hard bank armoring features offer temporary stability to the banks. Erosion was of some significance along segments where planform adjustment and/or widening are the dominant adjustment process (e.g., T2.04-C in the fan-head trench of the alluvial fan on Roaring Branch, T2.03-A where sediment attenuation is enhanced and the channel is actively migrating). In turn, these segments may be contributing to increased sediment loading in downstream segments (i.e., the active depositional segment of the alluvial fan at T2.04-B and in downstream reaches of the Roaring Branch (T2.02 and T2.01).

Mass wasting and gully sites or rejuvenating tributaries

No gully sites or rejuvenating tributaries and relatively few (generally healed) mass wasting sites were identified on the assessed reaches of the Fayville and Roaring Branches. Generally, sediments generated at the point of mass failures represent a low percentage of the overall bedload and are not considered to be significant reach-scale or watershed-scale sediment stressors in the Roaring Branch watershed.

5.1.3 Reach Scale Modifiers

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

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

The impacts of reach-scale modifiers on the hydraulic geometry of the channel are complex. The influence of multiple stressors may overlap within a reach. The following sections describe reach-scale modifications in more detail. Tables 10-a and 10-b, respectively, present a summary of the reach-scale modifiers catalogued for each of the assessed Roaring and Fayville Branch reaches / segments, together with the flow and sediment load modifications previously described.

Table 10-a. River Stressor Identification Table (Reach Level) – Roaring Branch reaches

Reach / Segment	Reach-Scale Stressors					
	Stream Power			Boundary Resistance		
T2.05	I	Slope	Encroachment: berms, right bank	I	Bed, Banks	Frequent bedrock exposures in bed and banks.
	I	Slope	Encroachment: Kelley Stand Rd, RB	I	Banks	Maintenance of tree buffers (except in pockets along RB asspciated with residential use and road).
	I	Depth	Stormwater: localized flow increases below road culvert and road turnout outfalls.	I	Bank	Armoring (some, RB)
T2.04-C	I	Slope, Depth	Straightening, berming	I	Bank	Maintenance of tree buffers, limited encroachments.
	D	Slope	VT Route 7 bridge is FPW constrictor with significant upstream aggradation (localized).			
T2.04-B				I	Bank	Maintenance of tree buffers, limited encroachments.
T2.04-A	I	Slope	Historic breaching of downstream dam(s) at Chiselville	I	Bank	Maintenance of tree buffers, limited encroachments.
				I	Bank	Bedrock exposures in channel bank (LB).
T2.03-D	I	Slope	Historic breaching of downstream dam(s) at Chiselville	I	Bank	Bedrock exposures in channel bank (LB).
	D	Slope	Moderate constriction at downstream end of reach as channel transitions from Very Broad to Semi-Confined (bedrock-controlled) confinement.	I	Bank	Maintenance of tree buffers, limited encroachments.
T2.03-C				I	Bed, Banks	Bedrock exposures in channel bed.
T2.03-B	I	Slope	Straightening: possible historically associated with industry at Chiselville	I	Banks	Bedrock exposures along streambanks.
	I	Slope	Encroachment: (LB) - historic industry	I	Bank	Maintenance of tree buffers, limited encroachments.
	I	Slope	Historically, localized reduction in sediment supply below dam(s) at Chiselville.			
T2.03-A	D	Slope	Sharp turn of channel at downstream confluence of Warm Brook forced by lateral bedrock constraint.	I	Banks	Bedrock exposures along streambank (RB).
				I	Bank	Maintenance of tree buffers, limited encroachments.

Abbreviations:
I = Increase; D = Decrease (of Stream Power or Boundary Resistance)

Notes:
Text in blue denotes a natural stressor or modifier. Text in black indicates a human-caused modification.

Table 10-b. River Stressor Identification Table (Reach Level) – Fayville Branch reaches

Reach / Segment	Reach-Scale Stressors: Stream Power			Boundary Resistance		
T2S1S1.03	I	Slope	Local flow increase resulting in scour pool downstream of VT Route 313 double box culvert.	I	Bank	Armoring (some, both banks)
	D	Slope	VT Route 313 culvert is bankfull constrictor with significant upstream aggradation (localized).	I	Bank	Maintenance of tree buffers, limited encroachments.
	D	Depth	Localized increases in sediment supply at tributary confluences.			
	D	Slope	Historic dam/impoundment at downstream end reach.			
T2S1S1.02-B	I	Slope	Encroachment: Prouty Hill Rd and driveway, RB	D	Bank	Localized removal of woody vegetation related to residential use and road encroachments (RB).
	I	Slope	Historic channelization	I	Bed, Banks	Localized bedrock exposures in bed and banks.
	I	Slope	Historic localized reduction in sediment supply below dam at upstream end segment			
	I	Slope	Local flow increase resulting in scour pool downstream of Prouty Hill Rd culvert.			
	D	Slope	Prouty Hill Rd culvert is bankfull constrictor with significant upstream aggradation (localized).			
	D	Slope	Downstream bedrock grade controls			
	D	Slope	Historic downstream dam(s)/ impoundment at Saffords Mills	I	Bank	Armoring (RB)
T2S1S1.02-A	D	Slope	Historic downstream dam(s)/ impoundment at grist mill.	D	Bank	Localized removal of woody vegetation related to residential/commercial use (RB).
				I	Bed, Banks	Frequent bedrock exposures in bed and banks.
				I	Bank	Armoring (some, RB)
T2S1S1.01-C	I	Slope	Encroachment: berm, LB	D	Bank	Localized removal of woody vegetation related to residential use and road encroachments (both banks).
	I	Slope	Encroachment: parking lot, commercial properties, RB	D	Bed, Banks	Reported historic dredging
	I	Depth	Stormwater: localized flow increases from stormwater outfalls	I	Bed, Banks	Localized bedrock exposures in bed and banks.
	I	Slope	Historic channelization	I	Bank	Armoring
	I	Depth	Historic dredging			
	D	Slope	Ice Pond Rd bridge is bankfull constrictor with significant upstream aggradation (localized).			
T2S1S1.01-B	I	Slope	Encroachment: berms, both banks; retaining wall, RB	D	Bank	Localized removal of woody vegetation related to residential use and road encroachments (RB).
	I	Depth	Stormwater: localized flow increases from stormwater outfalls	D	Bed, Banks	Reported historic windrowing, dredging
	I	Slope	Historic channelization	I	Bank	Armoring (extensive, both banks)
	I	Depth	Historic dredging			
	I	Slope	Localized flow increase downstream of constriction at RB retaining wall and LB berm, leading to scour pool along retaining wall.			
	D	Slope	Sharp approach angle and constriction between LB berm and RB retaining wall near downstream end of segment has contributed to upstream aggradation.			
T2S1S1.01-A	I	Slope	Historic channelization	D	Bank	Localized removal of woody vegetation related to residential use and bridge crossing.
	I	Depth	Historic dredging	D	Bed	Reported historic dredging
	D	Slope	Impoundment effects of Hale Co. dam appear to extend upstream into the segment.			

Stream Power Modifiers

Channel Slope

Channel slope modifiers include stressors that lead to an ***increase*** in stream power, such as:

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

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

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

Channel Depth

Channel depth modifiers include stressors that lead to an ***increase*** in stream power, such as:

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

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

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

(VTANR guidance, 2007b)

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

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

Erosion Resistance Modifiers (Boundary Conditions / Riparian Vegetation)

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

Channel Bed

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

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

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

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

<u>Streambank and Near-bank Riparian Area</u>

Bank and riparian modifications that lead to a ***decrease*** in erosion resistance include:
- removal of vegetation.

Bank and riparian modifications that lead to an ***increase*** in erosion resistance include:
- bank armoring (rip-rap, gabion baskets, revetments, large woody debris).

(VTANR guidance, 2007b)

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

5.1.4 Sediment Regime Departure, Constraints to Sediment Transport & Attenuation

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

The **Departure Analysis Table** (Table 11) summarizes the apparent status of each of the assessed reaches/segments as either transport- or attenuation-dominated. Table 11 also indicates the natural constraints (e.g., bedrock) and human constraints (e.g., roads, development, land uses) to channel adjustment that are, in part, influencing the current transport or attenuation status.

Two bedrock-controlled segments of the assessed reaches (T2.03-C, Roaring Branch; and T2S1S1.02-A, Fayville Branch) are natural transport-dominated reaches, due to the erosion resistance offered by the bedrock. It is likely that the sediment entering these channel segments is balanced by the sediment carried out of the reach (steady-state, dynamic equilibrium conditions).

Reach T2.05 along Kelley Stand Rd on the Roaring Branch is also a natural transport-dominated reach. The Semi-confined to Narrow confinement and steep gradient (3.7%) of this reach govern a transport-dominated condition. Some localized attenuation occurs in flood chutes and areas of wider valley confinement; however, this is probably a short-term sediment storage occurring between flood events. The natural transport-dominated function of this reach appears to have been enhanced somewhat in recent history (last 150 to 200 years) due to a degree of incision and increased encroachment by berms / roads.

The remaining reaches/ segments are in unconfined, low- to moderate-gradient valley settings (0.5 to 1.8%: Fayville; 1.5 to 2.8%: Roaring), and contain limited or no channel-spanning exposures of bedrock. Under dynamic equilibrium conditions these reaches might be expected to deposit fine sediments in their floodplains through periodic bankfull and flood-stage flows, and balance the transport of coarser sediments (bed load), such that the bedload volumes entering the reach would be similar to bedload volumes leaving the reach averaged over a one- to two-year period.

Table 11-a. Departure Analysis Table, Roaring Branch reaches Assessed in 2008.

	Constraints		Transport		Attenuation (storage)			
Reach / Segment	Vertical	Lateral	Natural	Converted	Natural	Decreased	Increased	Asset
T2.05	Channel-spanning bedrock - several locations	H: Road - Kelley Stand Rd (RB) H: Berms H: Footbridge, wooden (FPW) - minor N: Bedrock lateral control, LB (localized)	(x)	**X** (enhanced)		**X** Due to historic partial incision, floodplain encroachment (berms, road), and residential development.		
T2.04-C		H: Berms H: Bridge - Kansas Rd (FPW) H: Bridge - VT Route 7 (FPW)		**X**	Transition to VB confinement at Alluvial Fan	**X** Due to post-glacial and possible historic incision (possible straightening), entrenchment, limited floodplain encroachment (berms).		
T2.04-B		H: Berm (short section) H: Residential Development (LB)			Alluvial Fan, expansion of flow into multiple threads.		(X) Due to upstream sediment sources (erosion, tributary sources, road runoff), enhanced locally at debris jams and by active LWD recruitment - and episodically during major floods.	**X**
T2.04-A		N: Bedrock lateral control, LB (localized)		**X**		(X) Due to historic incision, entrenchment, and convergence of flow to single channel.		

Abbreviations:
H = Human constraint; N = Natural constraint; RB = right bank; LB = left bank; VW = valley wall; BFL = bankfull; FPW = Flood Prone Width; VB = Very Broad; SC = Semi-Confined; LWD = large woody debris.

Table 11-a. Departure Analysis Table, Roaring Branch reaches Assessed in 2008 - Continued.

	Constraints		Transport		Attenuation (storage)			
Reach / Segment	Vertical	Lateral	Natural	Converted	Natural	Decreased	Increased	Asset
T2.03-D		N: Bedrock lateral control, LB (localized)		**X**	Upstream of bedrock grade controls; VB to SC transition.	(X) Due to historic incision, entrenchment		
T2.03-C	Bedrock channel, gorge	N: Bedrock lateral control, both banks	**X**					
T2.03-B				**X**		(X) Due to historic incision, entrenchment		
T2.03-A		N: Bedrock lateral control, RB (localized)		(X)	Locally, upstream of sharp turn at bedrock-controlled left VW at Warm Bk confluence.	(X) Due to historic (partial) incision.	**X** Due to upstream sediment sources (erosion, tributary sources, road runoff), enhanced locally at debris jams and active LWD recruitment.	**X**

Abbreviations:
H = Human constraint; N = Natural constraint; RB = right bank; LB = left bank; VW = valley wall; BFL = bankfull; FPW = Flood Prone Width; VB = Very Broad; SC = Semi-Confined; LWD = large woody debris.

Table 11-b. Departure Analysis Table, Fayville Branch reaches Assessed in 2008.

	Constraints		Transport		Attenuation (storage)			
Reach / Segment	Vertical	Lateral	Natural	Converted	Natural	Decreased	Increased	Asset
T2S1S1.03		H: Encroachment: Route 313, RB (localized) H: Residential Development (localized) H: VT Rt 313 double box culvert (BFL)			Locally, upstream of valley pinch point, BD to NW confinement.		(X) Due to upstream sediment sources (erosion, tributary sources, beaver activity), enhanced locally at debris jams, by active LWD recruitment, and undersized crossings.	**X**
T2S1S1.02-B	Channel-spanning bedrock - one location	H: Road, Prouty Hill Rd H: Residential Development H: Culvert, Prouty Hill (BFL) H: remant mill foundation, RB		**X**	Locally, upstream of bedrock grade controls; NW to SC transition.	(X) Due to historic channelization and incision / entrenchment		
T2S1S1.02-A	Bedrock channel, falls	H: Residential Development, RB N: bedrock lateral control (both banks)	**X**					
T2S1S1.01-C	Channel-spanning bedrock - two locations	H: Residential/Comm. Development H: Roads, Old Mill & Pleasant St H: Culvert, Ice Pond Rd (BFL)		**X**	Locally, at slope reduction at base of Falls	(X) Due to historic (partial) incision, straightening, dredging and armoring.		
T2S1S1.01-B		H: Roads, Old Mill & Pleasant St H: Residential/Comm. Development H: Culvert, E. Arlington Rd (BFL) H: Berms, Retaining Wall		**X**		(X) Due to historic (partial) incision, straightening, dredging, armoring and enhanced entrenchment (berms).	(x) Locally, at constrictions (berm-to-berm, and berm-to-retaining wall).	
T2S1S1.01-A		H: Residential/Comm. Development					(X) Due to impounding effects of downstream Hale Co. dam.	**X**

<u>*Abbreviations:*</u>
H = Human constraint; N = Natural constraint; RB = right bank; LB = left bank; VW = valley wall; BFL = bankfull; FPW = Flood Prone Width; VB = Very Broad; SC = Semi-Confined; LWD = large woody debris.

Three exceptions to this generalization are:

1). The alluvial fan in reach (T2.04) of the Roaring Branch. Due to the sudden transition from a Semi-confined and Narrow confinement to a Very Broad alluvial fan in T2.04, a natural attenuation zone would be expected in this reach. In fact, a braided channel was observed with frequent depositional bars and steep riffles in the middle third of this reach (segment T2.04-B). Yet, the immediately upstream and downstream segments of T2.04 were incised and entrenched. Sediment deposition on this alluvial fan was probably much more active in earlier post-glacial environments (1,000s of years before present), under more intense hydrologic and sediment regimes, and prior to widespread vegetation of the landscape. This location may also have seen renewed sedimentation and lateral adjustments during colonial times, during widespread deforestation of upland slopes in the 1800s.

2). The sharp turn of Roaring Branch (T2.03-A) at the Warm Brook confluence constrained by bedrock along the left valley wall. Due to the sharp meander constrained by bedrock along the left valley wall, sediment deposition would be expected (and was observed) at this location.

3). The point of slope reduction at the base of the grist mill falls on Fayville Branch (T2S1S1.01-C, T2S1S1.01-B). Attenuation of sediments would be expected at this notable decrease in gradient below the bedrock falls near the grist mill on Fayville Branch. As discussed in the next section, it appears that a conversion of these downstream segments to transport-dominated conditions has locally modified this expected attenuation zone. Instead coarse bedload appears to have been transferred through these converted segments to further downstream sections of the Fayville Branch and Warm Brook.

Several unconfined segments have been converted from depositional or equilibrium conditions to transport-dominated conditions by virtue of various channel and watershed disturbances (Tables 11-a and 11-b). Equilibrium transport of coarse sediment fractions that might be expected in these unconfined valley settings has been compromised substantially, and these segments have been converted to a transport-dominated condition as a result of:

- channelization, removal of meanders (T2S1S1.02-B, T2S1S1.01-C, and T2S1S1.01-B; possibly T2.03-B and T2.04-C);
- dredging, windrowing (1927, 1936/38, 1973 floods) (T2S1S1.01-C, and T2S1S1.01-B);
- historic incision and the resultant decrease in degree of floodplain connection (T2.05, T2.04-C, T2.04-A, T2.03-D, T2.03-B, T2.03-A, T2S1S1.02-B, T2S1S1.01-C, and T2S1S1.01-B);
- floodplain encroachments (berming and roads) (T2.05, T2.04-C, and T2S1S1.01-B);
- corridor development (residential and commercial) (T2S1S1.02-B, T2S1S1.01-C, T2S1S1.01-B and T2.03-B).

Some reaches/segments have experienced increased sediment attenuation in recent years, related to the upstream and in-reach production of sediments: T2.04-B (braided segment on the alluvial fan) and T2.03-A on the Roaring Branch; and T2S1S1.03 and T2S1S1.01-A on the Fayville Branch. These segments are minimally constrained or largely unconstrained by infrastructure such as roads and development. They have maintained reasonable access to the floodplain (IR_{RAF} = 1.0 to 1.7; ER = 2.2 to 19.7). And sediment loading has been enhanced by erosion in the incised and entrenched upstream segments. In the case of T2.04-B, aggradation and planform adjustments have been driven by the sudden emergence of the channel out of the upstream fan head trench at the hydrographic apex of the alluvial fan. At segment T2.03-A, sediment loading from upstream entrenched channel segments has enhanced aggradation upstream of the sharp turn in the channel at the bedrock-controlled left valley wall. In T2S1S1.03, sediment attenuation has increased in vicinity of debris jams, submerged LWD, and local to the undersized Route 313 double box culvert. Sediment deposition in T2S1S1.01-A may be enhanced by impounding effects of the Hale Company dam approximately 650 ft downstream of the confluence with Warm Brook.

The current geomorphic condition of these reaches/segments, as modified by human factors, is summarized in the Sediment Regime Departure Maps in Figures 34 and 35.

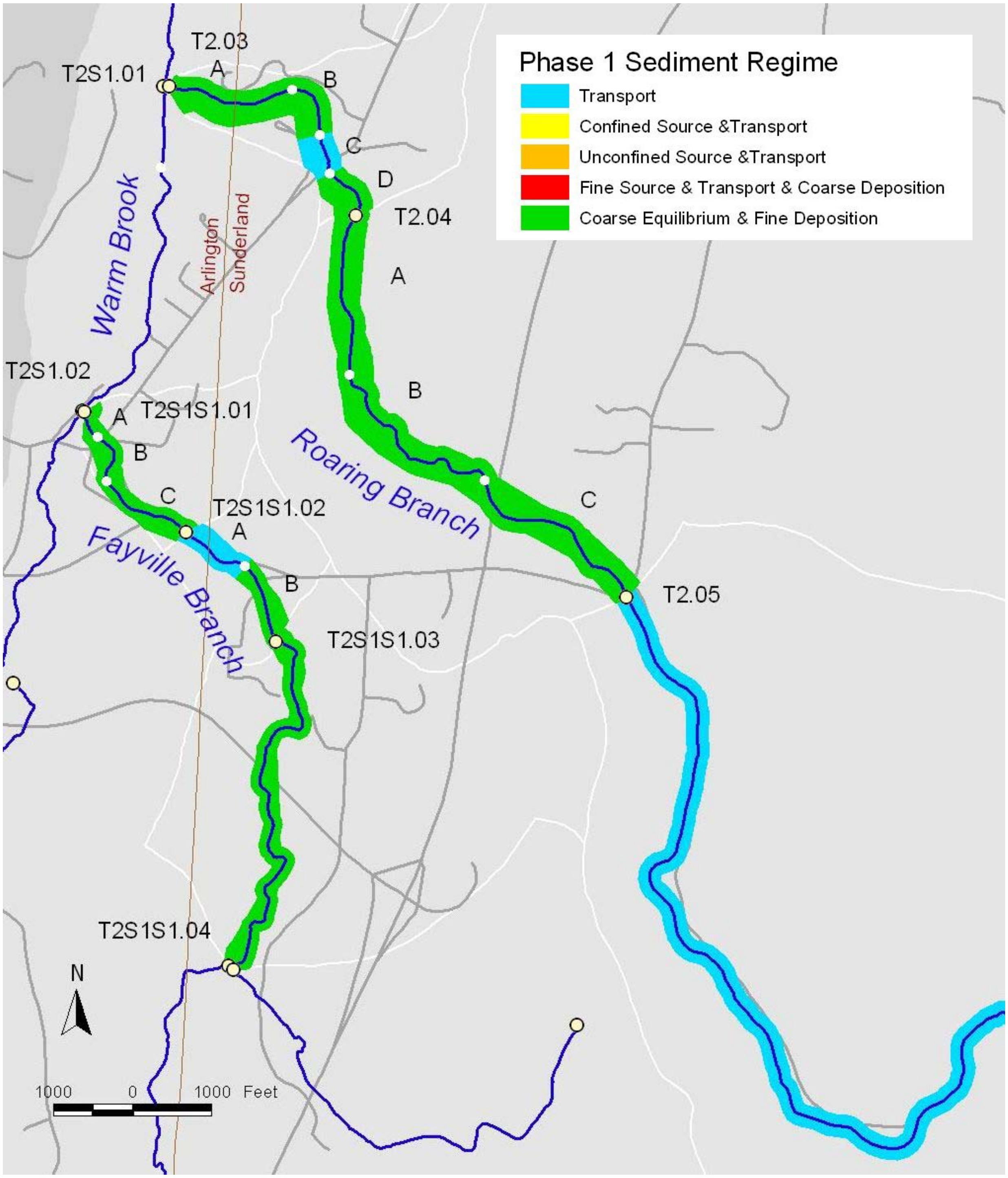


Figure 34. Phase 1 (Reference) Sediment Regime Map
Assessed Reaches of the Fayville and Roaring Branches, Batten Kill watershed.

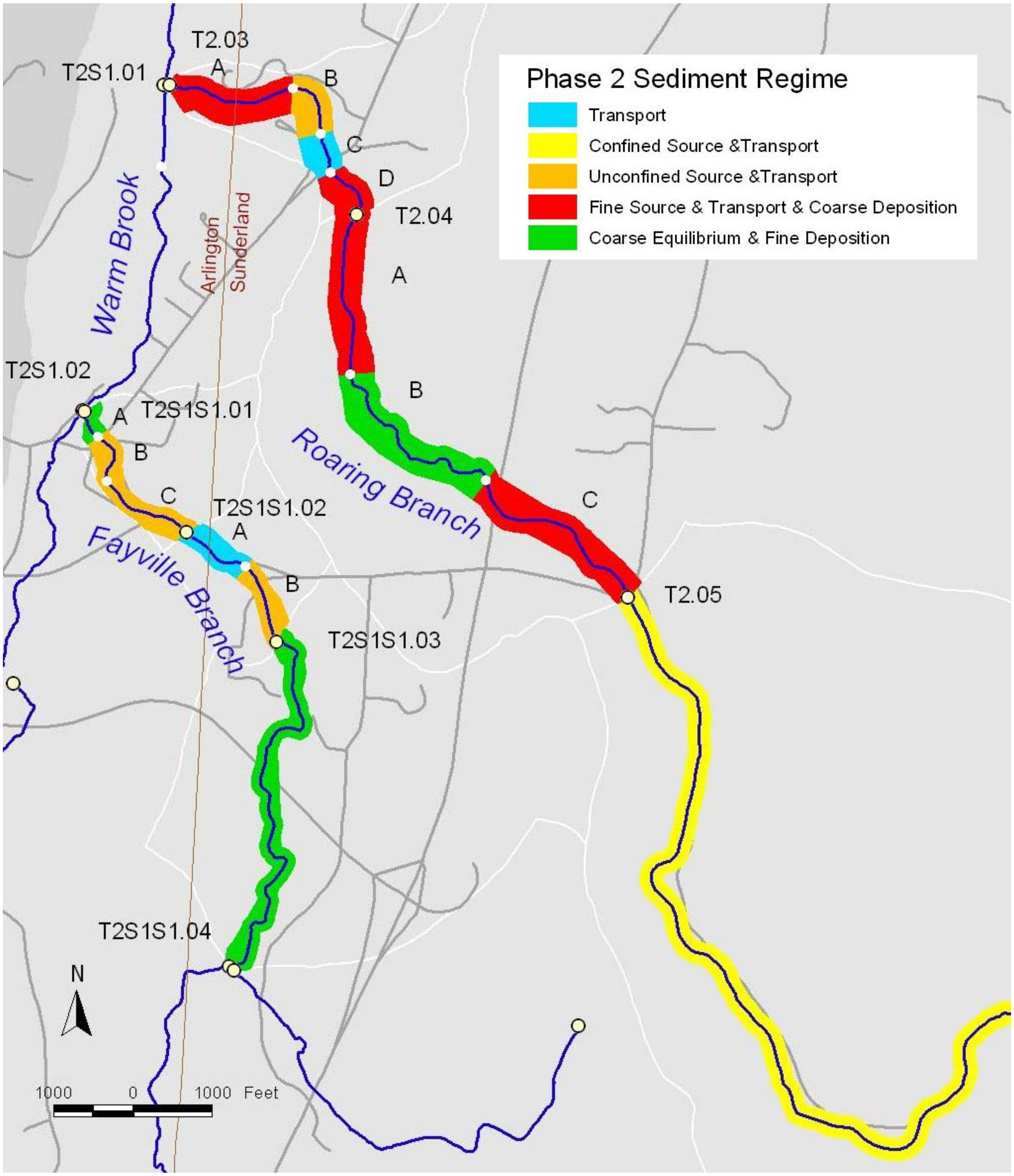


Figure 35. Phase 2 (Existing) Sediment Regime Map
Assessed Reaches of the Fayville and Roaring Branches, Batten Kill watershed.

Phase 1 (Reference) Sediment Regime

Figure 34 displays the reference sediment regimes that are characteristic of the assessed Fayville Branch and Roaring Branch reaches in a pre-disturbed state (say, 300 years before present).

Transport (coded blue in Figure 34)
Bedrock-controlled Segments T2.03-C (gorge beneath Chiselville covered bridge on the Roaring Branch) and T2S1S1.02-A (near the grist mill on the Fayville Branch) have been assigned a *Transport* classification for the reference (Phase 1) sediment regime. In reach T2.05 (along Kelley Stand Rd on the Roaring Branch), while the channel is generally dominated by a Narrow reference valley confinement with occasional pockets of available floodplain, there are long sections of Semi-confined reference confinement with narrow or non-existent floodplain. The steepness of the slope (3.7%) prevents significant storage of sediment. And the erosion resistance of coarse glacial erratics and glaciofluvial boulders in the stream bed and banks, as well as mature forested buffers, means that this channel (in a pre-disturbed state) would not be a significant source of coarse and fine sediments. Therefore, this reach was also classified with a *Transport* reference sediment regime.

Coarse Equilibrium & Fine Deposition (coded green in Figure 34)
Between these bedrock reaches, it is theorized that the Fayville Branch and Roaring Branch channels would have had a more meandering planform (constrained locally by exposures of bedrock and variable sediment types in the stream bed and banks). Each channel would have had access to the surrounding floodplain. Fine sediments would be deposited in the floodplains through periodic bankfull and flood-stage flows, and the transport of coarser sediments (bed load) would be balanced, such that the bedload volumes entering the reach would be similar to bedload volumes leaving the reach averaged over a one- to two-year period. Deposition and erosion cycles would have been balanced, such that there would be no net change in overall channel dimensions, gradient and planform (i.e., a channel in dynamic equilibrium). The channel would have moved within its floodplain in its reference (pre-disturbed) condition, but there would be no net change in average, reach-wide geometry such as slope and average meander width and amplitude.

Some uncertainty surrounds the assignment of reference sediment regime to the post-glacial alluvial fan reach (T2.04). In sections of this fan which have good floodplain access (T2.04-B), fine deposition is permitted during overbank events at bankfull and flood stages since. The prevalence of depositional bars and steep riffles suggests that storage of coarser sediment fractions is also occurring. Therefore, this segment (and the one below it) was classified with a reference sediment regime of *Coarse Equilibrium & Fine Deposition*. With the significant reduction in sediment transport capacity (given the divergence of flows into multiple threads, and associated decreases in individual-channel width, depth and discharge), it is possible that the volume of coarse sediment entering the segment *exceeds* the volume leaving the segment, resulting in a net *deposition* of coarse sediment fractions – particularly during episodic flood events. Also, it is unclear whether the upstream fan head trench (Segment T2.04-C) represents a historic entrenchment (occurring within the last 300 years) as a result of anthropogenic factors such as channelization and deforestation, or a post-glacial entrenchment (occurring within the last 10,000 years as a result of changing climate and natural transition of the hydrologic/sediment regimes). If it is the latter, then a reference sediment regime might be more accurately described as *Confined Source and Transport* – where storage of both coarse and fine sediment fractions would be limited by the significant degree of entrenchment and natural armoring of the stream banks by glacially-derived boulders and large cobbles – vestiges of a more intensive postglacial hydrologic and sediment regime.

Phase 2 (Existing) Sediment Regime

Figure 35 displays the existing sediment regimes that are hypothesized based on Phase 2 assessment results and the departure analysis previously described. The contrast in coding of the reaches between the two figures illustrates the degree of departure from reference that is inferred.

Transport (coded blue in Figure 35)
The segments of bedrock channel (T2.03-C on the Roaring Branch and T2S1S1.02-A on the Fayville Branch) have not undergone significant lateral or vertical adjustments in response to channel and watershed disturbances, given the stability offered by the underlying bedrock. Thus, a *Transport* classification has been assigned for the Phase 2 (Existing) sediment regime of these segments.

Coarse Equilibrium & Fine Deposition (coded green in Figure 35)
Based on Phase 2 assessments, three reaches/ segments appear not to have undergone a significant sediment regime departure: (1) the downstream-most segment of the Fayville Branch (T2S1S1.01-A); (2) reach T2S1S1.03 of the Fayville Branch spanning the VT Route 313 crossing; and (3) segment T2.04-B of the Roaring Branch (the segment of braided channel flowing across the alluvial fan). A minimal degree of net lateral and vertical adjustment in response to channel and watershed disturbances is apparent in these three segments. Therefore, a *Coarse Equilibrium & Fine Deposition* classification has been assigned for the Phase 2 (Existing) sediment regime of these segments.

These segments have good floodplain connection during bankfull events ($IR_{RAF} < 1.2$). A minor increase in sediment attenuation from upstream sediment sources is evident in T2S1S1.03 (local to debris jams and the undersized culvert crossing). Similarly, some increase in sediment attenuation is apparent in segment T2S1S1.01-A. The presence of a mid-channel bar and plane bed morphology suggests that limited storage of coarser sediment fractions is occurring within the bankfull channel (though at the expense of pool depths and riffle/pool diversity). Increased sediment storage in this segment may be occurring as a result of decreased transport capacity imparted by the decreased valley gradient and impoundment effects of the Hale Co. dam. However, such attenuation is not substantial enough to have resulted in dis-equilibrium conditions or a sediment regime departure.

On the other hand, a degree of sediment regime departure is theorized for the remaining segments of Fayville and Roaring Branches:

Confined Source & Transport (coded yellow in Figure 35)
The transport function of Roaring Branch reach T2.05 has been enhanced by a degree of historic incision, as well as residential and road encroachments along the RB and berms constructed to protect these investments. As a consequence, erosional energies of bankfull and flood events have been increased. This reach has also become more of a source of coarse and fine sediments by virtue of these encroachments and historic incision. Fine sediments are also directed off the Kelley Stand Road and ditches by concentrated stormwater flows to the Roaring Branch – both directly, and indirectly (via flood chutes). In the few locations where mature forested buffers have been removed or reduced in the RB corridor along the road or in vicinity of residences, bank erosion has been enhanced. A sediment regime departure from *Transport* -dominated to *Confined Source & Transport* is inferred.

Unconfined Source & Transport (coded orange in Figure 35)
One segment of the Roaring Branch (T2.03-B) and three segments of the Fayville Branch (T2S1S1.02-B, .01-C, and .01-B) are classified in this category. Due to the vertical stream type departure (C to F) of two segments (T2.03-B and T2S1S1.02-B) and loss of floodplain connection (IR_{RAF} values ranging from 1.4 to 2.5), these segments have been converted to a transport-

dominated condition. These segments are inferred to have persisted in channel evolution stage II [F] following historic channelization, dredging, armoring, and/or berming. Plane-bed morphologies dominate. Both fine and coarse sediment fractions are exported through the segments due to the minimal available floodplain and enhanced velocities of the incised and entrenched cross section. Extensive bank armoring, often narrow but continuous tree buffers, coarse bed materials, and lateral exposures of bedrock (T2.03-B) provide erosion resistance which has moderated the degree of lateral and vertical adjustments. Width/depth ratios are generally low (12.6, 18.4, 25.4, and 39.6). The existing sediment regime for these segments has been classified as *Unconfined Source & Transport.*

Fine Source & Transport / Coarse Deposition (coded red in Figure 35)
Segments T2.04-C, T2.04-A, T2.03-D, and T2.03-A are moderately to substantially incised (IR_{RAF} values ranging from 1.7 to 3.3). Three of these four segments (all but T2.03-A) have undergone a vertical stream type departure to an F or Fb stream type. Late stage III [F] and early stage IV [F] channel evolution is inferred. Like the other incised and entrenched segments, these segments have experienced increased velocities of bankfull and flood-stage flows, with enhanced scour energies, and have been converted to a *Fine Source & Transport* condition by virtue of the reduced frequency of overbank flooding. However, these segments are generally more prone to lateral adjustments, given the relative lack of armoring, extensive berms and encroachments. Historic (T2.04-C, T2.04-A) and active (T2.03-A) widening and planform adjustments (flood chutes, bifurcations) have begun to create narrow, discontinuous pockets of floodplain at an elevation below the recently abandoned floodplain. Well-developed tree buffers are present along both banks of these segments and provide some measure of erosion resistance. On the other hand, historic recruitment of trees and debris jams probably contributed to the formation of flood chutes, bifurcations, and localized meander development. A low to moderate degree of coarse sediment deposition is occurring (perhaps between major flooding episodes), leading to a shallow and overwidened bankfull cross section with little pool definition. Plane-bed dominated morphology is beginning to be replaced by a weak riffle/pool bedform, characterized by diagonal riffles and a secondary, low-flow sinuosity. Generally, width/depth ratios of these segments are greater than their *Unconfined Source & Transport* counterparts (ranging from 30 to 64). Channel widening may have contributed to a reduction in sediment transport capacity that has begun to drive deposition. In-segment and upstream erosion is contributing to coarse sediment deposition within these segments, particularly associated with entrained large woody debris. Thus, these segments have been converted from a *Coarse Equilibrium* condition to *Coarse Deposition*.

Recovery of equilibrium conditions in these Roaring Branch segments may be long term. Materials in the streambanks have a glaciofluvial origin (often kame moraine) and while unconsolidated in nature they are often quite large in diameter (frequent boulders and large cobbles) and are thought to be relicts of a more intense fluvial regime. The coarseness of these streambed and bank materials, along with persistent well-developed forested buffers will tend to moderate channel adjustments. Extensive lateral bedrock exposures along LB (T2.04-A, T2.03-D) and RB (T2.03-A) will continue to naturally limit the overall sinuosity of these channels.

Recovery of segment T2.04-C, in particular, may be very long term and this segment may persist in channel evolution stage IV [F] and in this modified sediment regime state for some time. Post-glacial and possibly historic incision (IR > 3) has disconnected the channel from the surrounding floodplain (alluvial fan) surface, such that deposition of finer sediment fractions (small cobbles and gravels) in annual to fifty-year overbank flooding has been essentially eliminated. However, the steep gradient and flashy nature of flows in this entrenched channel segment has not permitted significant vegetation of the few depositional bars (side, point, mid) that have formed (Figure 36). The relative coarseness of bed and bank materials (boulders, cobbles with a post-glacial alluvial fan and/or glaciofluvial origin) means that they are resistant to erosion at bankfull and lower flow stages under current hydrologic regimes, and the channel cannot easily adjust to form a new floodplain at this lower elevation.

Figure 36. (T2.04-C) View downstream from cross section site, 31 July 2008.

5.2 Sensitivity Analysis

The **Stream Sensitivity Map** (Figure 37) identifies the sensitivity classification for each of the assessed reaches / segments. Inherent in the stream sensitivity rating are:

- the natural sensitivity of the reach given the topographic setting (confinement, gradient) and geologic boundary conditions (sediment sizes) – as reflected in the reference stream type classification (after Rosgen, 1996 and Montgomery & Buffington, 1997); and
- the enhanced sensitivity of the reach given by the degree of departure from reference (or dynamic equilibrium) condition – as reflected in the existing stream type classification and the condition (Reference, Good, Fair to Poor ratings in the Rapid Geomorphic Assessment).

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

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

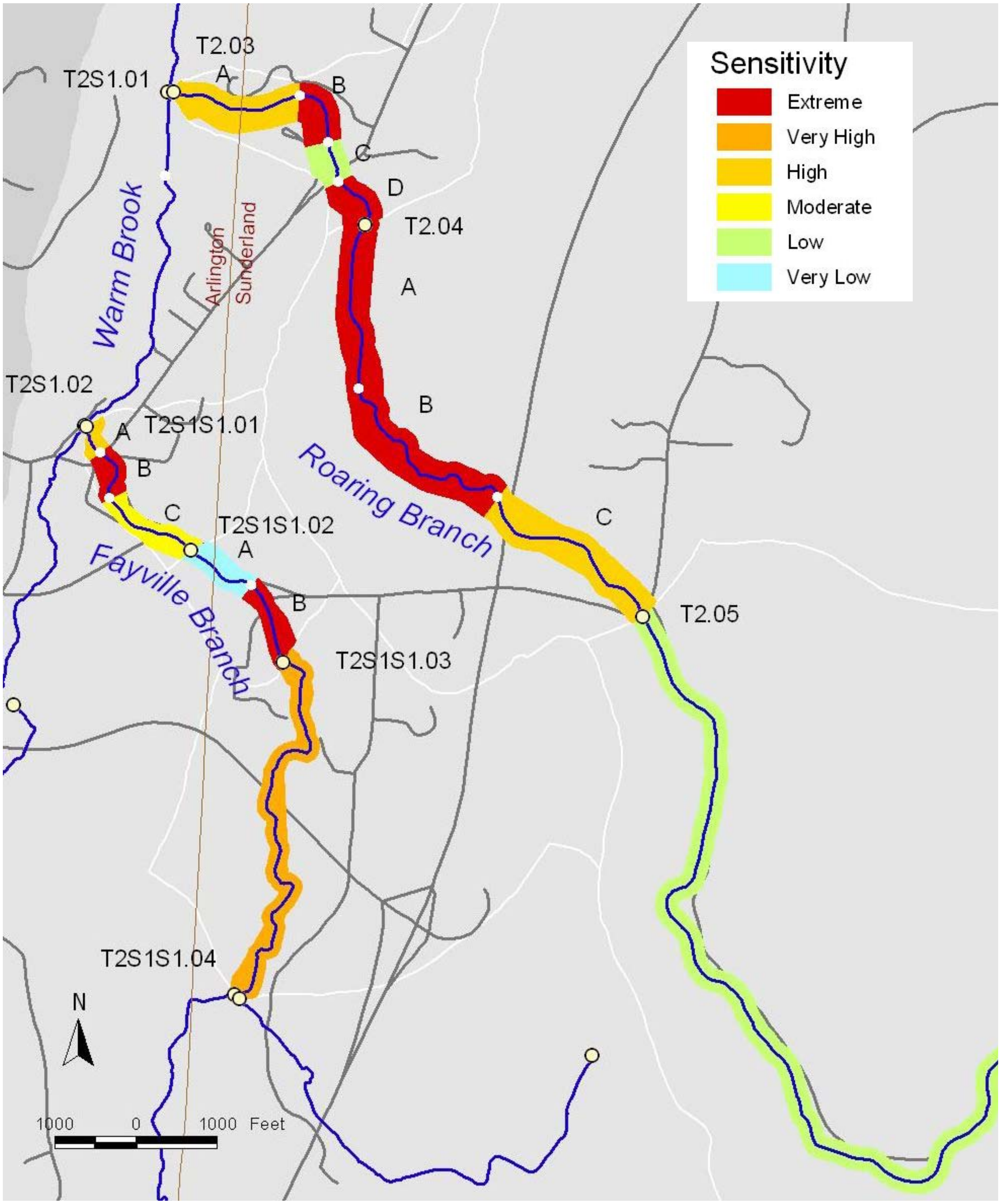


Figure 37. Stream Sensitivity Map
Assessed Reaches of the Fayville and Roaring Branches, Batten Kill watershed.

6.0 PRELIMINARY PROJECT IDENTIFICATION (Reach & Corridor Scale)

Landowners, community members, and resource agencies, including the Bennington County Regional Commission, the Bennington County Conservation District, Batten Kill Watershed Alliance, and Vermont Agency of Natural Resources, can use geomorphic data to inform future management strategies for the assessed reaches of Fayville and Roaring Branches. For a given reach or segment, the active adjustment processes, degree of departure from reference, and sensitivity ranking will define the short-term compatibility and long-term sustainability of various restoration or conservation options and future land use or channel management activities.

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

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

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

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

Each broad category of restoration and conservation strategies identified in VTANR guidance (2007b) is discussed in Sections 6.1 through 6.8. An additional category (mitigating point sources of stormwater and sediment loading) is presented in Section 6.9. Section 6.10 then summarizes recommended strategies by reach and segment.

The work scope for this Phase 2 assessment has not included public outreach or analysis to determine the technical, financial and social feasibility of these listed project opportunities. Instead, this listing will form the basis for future project development and implementation efforts in the context of watershed, community, and corridor planning projects. A few of these projects (e.g., buffer plantings) can be considered for immediate implementation, independent of other watershed projects, and will require only minimal feasibility analysis and project development activities. Other identified projects may require further evaluation and efforts to perform alternatives analyses, conduct landowner outreach and negotiations, and identify potential stakeholders and funding sources.

6.1 Protecting River Corridors

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

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

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

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

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

- T2.03-C - the bedrock gorge segment along Roaring Branch which is afforded stability by the underlying bedrock and which was assigned a Low sensitivity; and
- T2S1S1.02-A – the bedrock channel along Old Mill Road in East Arlington (Fayville Branch); Very Low sensitivity.

Highest priority reaches for river corridor protection include "highly sensitive reaches critical for flow and sediment attenuation from upstream sources or sensitive reaches where there is a major departure from equilibrium conditions and threats from encroachment (VTANR, 2007b)". Limited term or permanent corridor easements are possible mechanisms for corridor protection, with the willingness of landowners. Protection of the river corridor in these reaches can serve the functions listed above. As summarized in Table 12, there are additional strategic factors that may raise the priority of corridor protection for a given reach, including:

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

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

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

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

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

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

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

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

Table 12. River Corridor Protection opportunities
Fayville and Roaring Branch tributary reaches

Reach / Segment	Town	Priority	Protection Upstream of Constrained or Altered Reaches	Protection Downstream of Constrained or Altered Reaches	Key Sediment Attenuation Area	Channel-contiguous wetlands	Alluvial Fan or Point of Marked Valley Slope Reduction	Downstream from Major Tributary or Other Large Sediment Source	Moderate or Major Departure from Equilibrium	Accompany Passive or Active Restoration, Incised/Aggraded
Roaring Branch										
T2.05	Sunderland	Low							√	
T2.04-C	Sunderland	Very High		√			√		√	√
T2.04-B	Sunderland	Very High		√	√		√			
T2.04-A	Sunderland	High	√						√	
T2.03-D	Sunderland	High	√						√	
T2.03-C	Sunderland	Low								
T2.03-B	Sunderland	High		√					√	
T2.03-A	Arlington	Very High		√	√				√	
Fayville Branch										
T2S1S1.03	Sunderland	Very High	√		√			√		√
T2S1S1.02-B	Sunderland	High							√	√
T2S1S1.02-A	Arlington	Low		√						
T2S1S1.01-C	Arlington	Low							√	
T2S1S1.01-B	Arlington	High							√	√
T2S1S1.01-A	Arlington	Very High		√	√	√	√			

6.2 Planting Stream Buffers

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

Tree buffers are largely intact along both banks of the assessed reaches. It is a very important to maintain these buffers, not only for streambank stability, but also for the shading and organic matter that the tree canopy provides to aquatic organisms. Where they are absent (e.g., along Old Mill Road in East Arlington), buildings, roads and parking lots have encroached upon the channel and buffer plantings would not be feasible. One high-priority opportunity to increase buffer widths and continuity is located along the downstream-most segment of Fayville Branch (T2S1S1.01-A). Segment T2S1S1.02-B upstream and downstream of the Prouty Hill Road crossing could also benefit from greater buffer protections; however, the degree of channel and floodplain encroachments by roads, driveways, the instream culvert crossing, and residential buildings reduces the feasibility (and therefore the priority) of buffer treatments in this segment.

6.3 Stabilizing Stream Banks

Streambank stabilization can be considered in "laterally-unstable, [but vertically stable] reaches where human-placed structures are at high risk and not taking action may result in increased risk of erosion, to not only the structure, but lands that would provide the opportunity to establish a buffer" (VTANR, 2007b). Any bank stabilization project should be considered in the broader context (both in time and space) for the channel adjustment processes such management will set in motion and for the consequences to upstream and downstream reaches. No bank stabilization projects have been identified along the Fayville and Roaring Branch tributary reaches at this time. (An existing bank-stabilization structure – the concrete retaining wall along Old Mill Rd in T2S1S1.01-B – is discussed in the context of constricting structures, section 6.6.2).

6.4 Arresting Head Cuts and Nick Points

No head cut sites or significant sections of actively incising channel were noted in the study reaches on the Fayville and Roaring Branches.

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

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

A possible berm removal project has been identified in the Fayville and Roaring Branch tributary reaches assessed in 2008:

T2.05 – Roaring Branch reach along Kelley Stand Rd. Several lengths of berms are present along the RB of this reach, reportedly installed during flood recovery efforts following the 1927, 1936 / 1938 and 1973 floods. In some locations, these berms are placed for the protection of a nearby house or section of the Kelley Stand Road. In other locations, they block the river's access to adjacent flood chutes and pockets of floodplain. Feasibility assessments could evaluate the potential for berm removal in discrete sections that would allow the river to access the floodplain and flood chutes to dissipate energies of flood flows and permit storage of sediments. Evaluations should focus on specific locations where berm removal will not significantly increase risk of inundation of nearby homes, or substantially increase the risk of road failure. In the watershed context, this project is considered a relatively low priority. Due to the steep channel gradient and relatively narrow valley confinement, opportunities for flow and sediment attenuation are limited. Also, berm removal in most cases would involve the removal of large trees, which offer deep root systems and roughness elements to the overbank channel that tend to decrease streambank erosion and dissipate flow energies.

A second possible berm removal is discussed in the context of constricting structures (Section 6.6.2) – adjacent to the concrete retaining wall along Old Mill Rd in T2S1S1.01-B.

6.6 Removing / Replacing Structures

Human-placed structures which span and "constrain the vertical and lateral movement of the channel and/or result in a significant constriction of the floodplain" can be considered for removal or replacement to support dynamic equilibrium of the channel (VTANR, 2007b)". In the Roaring and Fayville Branch reaches, constraining structures include bridge and culverts (section 6.6.1), and a berm/retaining wall constriction (section 6.6.2).

6.6.1 Bridge and Culvert Crossings

Several bridge and culvert crossings are present on the assessed reaches. Their status as either a bankfull or flood-prone-width constrictor is summarized in Table 13. These data can be utilized by landowners, town road crews, VTrans, and regional planning commissions when establishing schedules and budgets for rehabilitation and replacement.

Table 13. Potential Bridge & Culvert Structure Replacements
Fayville and Roaring Branch tributary reaches

Reach / Segment	Town	Road	Structure Type	Constriction Status	Replacement Priority
T2.05	Sunderland	Footpath	Timber footbridge	FPW	Low
T2.04-C	Sunderland	Kansas Rd	Bridge	FPW	Low
T2.04-C	Sunderland	VT Route 7	Bridge	FPW	Moderate (a)
T2.03-C	Sunderland	Sunderland Hill Rd	Bridge (covered)	None	Not Applicable
T2S1S1.03	Sunderland	VT Route 313	Double-box culvert	BFL	Low (b)
T2S1S1.02-B	Sunderland	Prouty Hill Rd	Arch pipe Culvert	BFL	High (c)
T2S1S1.01-C	Arlington	Ice Pond Rd	Bridge	BFL	Low
T2S1S1.01-B	Arlington	East Arlington Rd	bridge	BFL	Low

Abbreviations: BFL = Bankfull Width constrictor; FPW = Flood-prone-width constrictor.

(a) VT Route 7 bridge is positioned just below the hydrographic apex of the alluvial fan where divergent flows are a strong tendency of the Roaring Branch. Rip-rap-armored berms have been constructed on approach to the bridge inlet to constrain channel flows; substantial sediment has aggraded upstream of the structure. While the bridge itself has a wide span (greater than bankfull width), this crossing location is highly sensitive and subject to increased lateral adjustment. A crossing positioned further upstream of this apex (i.e., over the fan head trench) might be subject to fewer erosion hazard conflicts over the long term.

(b) The VT Route 313 double-box culvert is a significant constrictor of the bankfull flow. The combined span of the two box culverts (23.8 ft) is only 57% of the regime bankfull width of 41.4 ft (VTDEC, 2006). Large woody debris has collected at the inlet of the double box culvert that is not visible from the road. A wide, but relatively shallow, scour pool has developed on the downstream end of the culvert. While this a likely debris jam site, the substantial height and width of the VT Route 313 embankment and base materials suggest that avulsion at this crossing would be a rare and unlikely event. Replacement of this crossing with a wider-span bridge would mitigate this source of localized channel instability. The cost/benefit ratio of replacement is likely to be very high. Trash racks installed upstream of the inlet would trap LWD in a location more readily visible from the road and may help to reduce the potential for debris jams. Structures within the box culvert appear to have been designed to benefit passage of fish and other aquatic organisms (see Section 4.2). Data regarding the efficacy of these structures were not available.

(c) The Prouty Hill Rd arch-pipe culvert is a significant constrictor of the bankfull flow. The span (15.1 ft) is only 36% of the regime bankfull width. A scour pool greater than four feet deep has developed below the culvert; medium gravels have accumulated at the inlet of the culvert. This a likely debris jam site and potential channel avulsion site. In the event of a culvert blockage, water would accumulate to a great depth behind the fill for Prouty Hill Rd; a catastrophic failure of this culvert would release a substantial volume of flood water downstream to the village of East Arlington. Replacement of this crossing with a wider-span bridge would reduce the likelihood of channel avulsion and mitigate this source of localized channel instability.

Replacement of the Prouty Hill Rd culvert is also advisable from a habitat perspective. Flow is quite shallow inside the culvert, and continuity of natural substrates and flow depths is not maintained through this long structure. These conditions can inhibit the movement of benthic organisms and fish as well as other species (e.g., salamander, crayfish, muskrat, etc). An open-bottom structure (i.e., arch or bridge) or an embedded culvert (with natural substrates comprising the bottom 20% of the structure) would provide more optimal conditions for fish and wildlife passage. The cost of replacing the Prouty Hill Rd culvert would be quite high. However, there may be some lesser-cost enhancements or retrofitting options that might improve sediment transport continuity and fish passage.

6.6.2 Other constrictions

Berm-to-retaining wall constriction

T2S1S1.01-B – Fayville Branch, downstream of Ice Pond Rd, upstream of East Arlington Rd bridge.

A local constriction of the Fayville Branch occurs at the upstream end of the concrete retaining wall along Old Mill Road where the channel is constrained between this wall and a LB berm (Figure 38). This retaining wall / berm constriction is at a highly sensitive location along the river network, at a point where the channel is transitioning from highly managed, incised and entrenched sections to a unconfined, low-gradient profile with floodplain access (downstream segment T2S1S1.01-A). These man-made features constrain the channel at a point in the modified landscape where lateral adjustments are a strong tendency. The immediately upstream channel has an undersized cross section (constrained by high, armored berms on both banks) that tends to increase flow velocities and scour energies directed at the retaining wall. The constriction is also located at the apex of a meander bend. A scour pool has developed along the RB adjacent to the wall. Relief between the upstream channel bed and downstream scour pool is significant; this step accelerates flow locally and enhances the degree of vertical scour. A narrow depositional bar is forming on the LB at this turn, which also diverts flow to the RB and exacerbates the degree of scour at the wall. The concrete wall has significant cracking and spalling and is scoured at the interface with the channel bed. Streambank erosion is occurring along the RB immediately upstream of the retaining wall, where rip-rap armoring has been placed to stabilize the bank. Overland stormwater runoff may also be contributing to bank instability in this location. Collectively, these observations suggest a high likelihood of retaining-wall failure during the next major flood event.

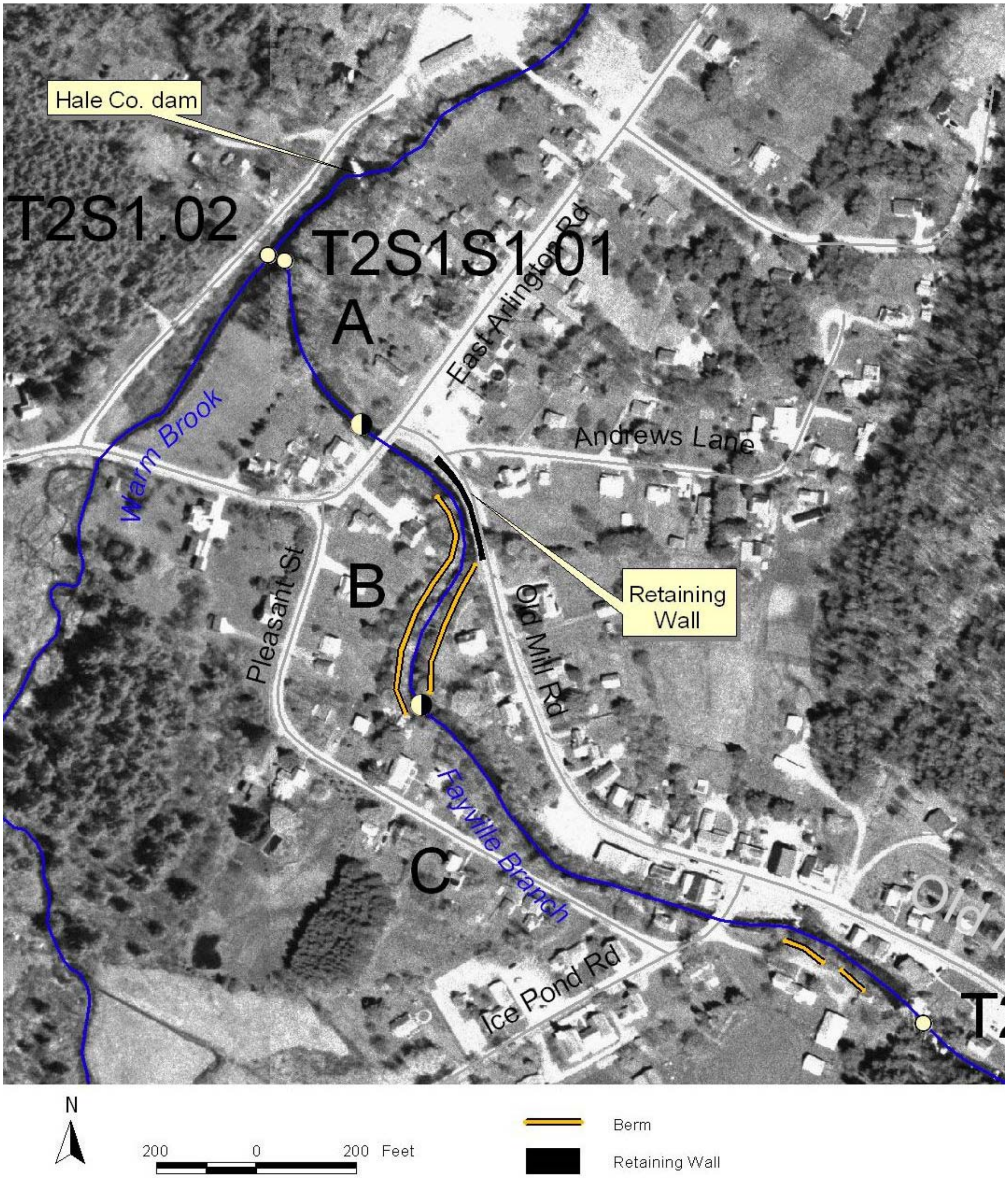


Figure 38. Berm / retaining-wall constriction on Fayville Branch, segment T2S1S1.02-B, East Arlington village.

The degree of floodplain development at and downstream of this retaining wall is somewhat less dense than in upstream segments through the center of East Arlington village. There may be some room to accommodate a wider channel and LB floodplain for overbank flows on the inside of this meander. For example, the LB berm across from the retaining wall could be removed, if it could be determined that flooding of area homes and businesses would not be unduly exacerbated by this modification. A complicating factor is the second bankfull-constricting feature (the East Arlington Rd bridge) located within 150 feet downstream of the retaining wall, which further constrains the planform of the channel and reduces the available floodplain. It may be more feasible to install structures that protect the Old Mill Road and direct flows through this section and under the East Arlington Rd bridge to focus on dissipation of flows and attenuation of sediments immediately downstream of the bridge. In either case, repairs or replacement of the retaining wall will be required in the near term to avoid catastrophic failure of this structure.

An alternatives analysis should be undertaken to evaluate possible rehabilitation or replacement of this retaining wall and restoration of the channel in this location. Possible alternatives may include:

- Removing the LB berm and (if needed) lowering the LB floodplain surface to reconnect the channel with the adjacent flood plain to provide flow and sediment attenuation locally;

- Moving the Old Mill Road (and the retaining wall) further to the northeast to permit a wider channel cross section at this location;

- Removing the East Arlington Road bridge crossing and the northern end of Old Mill Road including the retaining wall; directing traffic to alternate routes (e.g., Pleasant St.); directing traffic to alternate crossings (e.g., Ice Pond Road). The gradient is somewhat steeper in this upstream segment (T2S1S1.01-C) and the channel's propensity for laterally adjusting may be less. Also, historic modifications to the Fayville Branch in this upstream segment appear to have resulted in channel features (boulders, tree buffers, hard bank and rip-rap armoring) that are more in balance with the increased stream power of the channelized segment. Therefore, a crossing in this upstream location may be more sustainable and less subject to conflicts with an adjusting Fayville Branch.

- Longitudinally extending the retaining wall or other bank armoring further upstream beyond the apex of the meander bend;

- Vertically extending the wall or other bank armoring to greater depths (i.e., below likely scour depths);

- Redirecting or treating stormwater runoff along Old Mill Road and vicinity to avoid concentrated storm flows to this location;

- Adding a secondary overflow channel (probably to the southwest) to accommodate flood flows and reduce the volume of water (and scour energies) in the main channel. (This alternative would likely require a second road crossing and involve a high cost/benefit ratio).

- Identifying and preserving opportunities to attenuate sediments and flows in upstream reaches (e.g., corridor protection in T2S1S1.03).

An additional factor that should be considered within the context of this alternatives analysis is the Hale Company dam located on the Warm Brook 650 ft downstream of the Fayville Branch confluence (and approximately 850 feet downstream of the retaining wall). Impoundment effects of this dam appear to extend upstream into the lower Fayville Branch and will constrain the profile of the Fayville Branch regardless of which restoration alternative is chosen. Operational status and use of the Hale Company dam was not available at the time of reporting; if this dam is no longer in use, analysis of restoration in this segment should consider alternatives with and without dam removal.

If repair / rehabilitation of the retaining wall involves maintaining or increasing channel bed and bank armoring in the wall vicinity, then protection of downstream segment T2S1S1.01-A (and in Warm Brook reach T2S1.01) becomes of greater importance for the flow and sediment attenuation functions this area can provide.

6.7 Restoring Incised Reaches

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

Based on the Phase 2 geomorphic assessments in the tributary reaches to date, two possible historically-incised candidates for restoration have been identified where floodplain connection could be restored through a combination of structures to induce channel-bed aggradation and/or excavation to lower the elevation of the adjacent floodplain:

T2.04-A / T2.03-D on the Roaring Branch, downstream of the alluvial fan and upstream of the Chiselville covered bridge. These segments flow along the LB valley wall where bedrock is often exposed, and are incised below the floodplain along RB. A limited upstream sediment supply is inferred due to enhanced deposition on the upstream alluvial fan (Segment T2.04-B). Therefore, floodplain development and reconnection through natural aggradational processes (passive restoration) may take a very long time. Active restoration methods may accelerate a return to dynamic equilibrium. A disadvantage of such an active approach is that lowering of the adjacent RB terrace to create floodplain access would involve removal of a well-established tree buffer, which could increase erosion and sediment loading to downstream reaches over the short term. A long-term advantage of restored floodplain access in these two segments would be increased sediment and flow attenuation in an area that presently has very little development. This would reduce the pressure of increased flows and sediment loading on downstream reaches (T2.02 and T2.01) near the confluence of the Batten Kill where development is more extensive.

T2S1S1.02-B on the Fayville Branch, spanning the Prouty Hill Rd culvert. This segment flows along the LB valley wall (till with occasional bedrock exposure), and is incised (historically) below the floodplain along RB. Active restoration methods may accelerate a return to dynamic equilibrium. However, several constraints exist within the reach that would complicate the technical feasibility (and lower the priority) of active restoration approaches to reconnect the channel with the floodplain – including residences within the corridor, a RB driveway, and the Prouty Hill Rd culvert crossing.

A more feasible approach might involve restoring the incised reach with bedforms and floodplain features that are more in balance with the channelized planform (i.e., create a modified reference stream type). At the same time, greater emphasis should be placed on protecting the next downstream opportunity for flow and sediment attenuation – in segment T2S1S1.01-A at the confluence with Warm Brook (and in Warm Brook reach T2S1.01).

6.8 Restoring Aggraded Reaches

Further study is sometimes warranted to evaluate the feasibility of various active geomorphic and engineering techniques to restore aggraded reaches which could accelerate a return to dynamic equilibrium of the channel, by restoring equilibrium of sediment transport processes.

T2.03-A of the Roaring Branch, is an aggraded segment that exhibits channel braiding and frequent depositional bars. The moderate aggradation in this segment can be addressed through passive restoration techniques in the context of river corridor protection (Section 6.1 above). The channel in this reach is reasonably free to adjust its planform, dimensions and profile in response to changes in sediment and water loading. Active restoration of the moderately-aggraded condition might be feasible (e.g., placement of structures to restore equilibrium W/D ratio and reconnect the channel with its floodplain). However, such an approach is not recommended at this time, because upstream (watershed-scale) sediment loading is thought to be a contributing stressor governing adjustment processes in this reach, along with natural bedrock constraints constraining the planform at the downstream end.

6.9 Mitigating Point Sources of Increased Stormwater and Sediment Loading

Stormwater runoff along Kelley Stand Road is contributing to sediment loading in reach T2.05. While the valley shared by this road and Roaring Branch is quite narrow in spots, there are opportunities to improve management of the stormwater runoff and reduce erosion along the road ditches and at culvert outlets. Road maintenance practices to mitigate for stormwater and sediment runoff may include: stabilization of road surfaces (different gravel materials), improvement of roadside ditches (excavation, stone lining and/or seeding and mulching), alternative grading practices (turnouts, check-basins); re-orientation of culvert crossings; protection of culvert headers; and gully stabilization. Technical and financial resources are available to the towns through the Better Back Roads program (Northern Vermont Resource Conservation and Development Council) as well as the VT Department of Transportation.

6.10 Summary of Recommended Strategies by Reach / Segment

In summary, the reach- and corridor-specific strategies identified for the Roaring Branch and Fayville Branch reaches are presented in Tables 14a and 14b, respectively. Refer to previous sections 6.1 through 6.9 for more detailed explanations.

Table 14a. Summary of Recommended Strategies by Reach /Segment
Roaring Branch tributary reaches

Reach / Segment	Town	Project Description	Technical Feasibility	Priority	Discussed In Section
Roaring Branch					
T2.05	Sunderland	River Corridor Protection	High	Low	6.1
		Possible Berm Removal – *feasibility assessment required*	Moderate	Low	6.5
		Mitigate Point Sources of Stormwater Runoff / Road Sediment Loading	Moderate (overall); High (locally)	High	6.9
T2.04-C	Sunderland	River Corridor Protection	High	Very High	6.1
		Replace FPW-constricting Kansas Rd bridge	Moderate	Low	6.6.1
		Replace FPW-constricting Route 7 bridge	Moderate	Moderate	6.6.1
T2.04-B	Sunderland	River Corridor Protection	High	Very High	6.1
T2.04-A	Sunderland	River Corridor Protection	High	High	6.1
		Restore Incised Reach *(active geomorphic approach – feasibility assessment required)*	Low	Low	6.7
T2.03-D	Sunderland	River Corridor Protection	High	High	6.1
		Restore Incised Reach *(active geomorphic approach – feasibility assessment required)*	Low	Low	6.7
T2.03-C	Sunderland	River Corridor Protection	High	Low	6.1
T2.03-B	Sunderland	River Corridor Protection	High	High	6.1
T2.03-A	Arlington, Sunderland	River Corridor Protection	High	Very High	6.1
		Restore Aggraded Reach – *passive approach through Corridor Protection*	High	High	6.8, 6.1
		Restore Aggraded Reach – *(active geomorphic approach – feasibility assessment required)*	Very Low	Low	6.8

Abbreviations: BFL = Bankfull Width constrictor; FPW = Flood-prone-width constrictor.

Table 14b. Summary of Recommended Strategies by Reach /Segment
Fayville Branch tributary reaches

Reach / Segment	Town	Project Description	Technical Feasibility	Priority	Discussed In Section
Fayville Branch					
T2S1S1.03	Sunderland	River Corridor Protection	High	Very High	6.1
		Replace BFL-constricting Route 313 double-box culvert	Moderate	Low	6.6.1
T2S1S1.02-B	Sunderland	River Corridor Protection	High	High	6.1
		Replace BFL-constricting Prouty Hill Rd arch-pipe culvert	High	High	6.6.1
		Restore Incised Reach – Possible formation of Modified Reference Stream Type - *(active geomorphic approach – feasibility assessment required)*	Low	Low	6.7
		Plant Stream Buffers	High	Low (limited opportunity)	6.2
T2S1S1.02-A	Arlington, Sunderland	River Corridor Protection	High	Low	6.1
T2S1S1.01-C	Arlington	River Corridor Protection	High	Low	6.1
		Replace BFL-constricting Ice Pond Rd bridge	Moderate	Low	6.6.1
T2S1S1.01-B	Arlington	River Corridor Protection	High	High	6.1
		Retaining Wall Rehabilitation / Replacement / Removal – *alternatives analysis required*	Pending Alternatives Analysis	Pending Alternatives Analysis	6.6.2
		Possible Berm Removal – *alternatives analysis required*	Pending Alternatives Analysis	Pending Alternatives Analysis	6.6.2
		Possible Replacement / Removal BFL-constricting E Arlington Rd bridge - *alternatives analysis required*	Pending Alternatives Analysis	Pending Alternatives Analysis	6.6.1, 6.6.2
T2S1S1.01-A	Arlington	River Corridor Protection	High	Very High	6.1
		Plant Stream Buffers	High	High	6.2

Abbreviations: BFL = Bankfull Width constrictor; FPW = Flood-prone-width constrictor.

7.0 WATERSHED-LEVEL MANAGEMENT STRATEGIES

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

7.1 Town Planning incorporating Fluvial Erosion Hazards

To avoid infrastructure conflicts with an adjusting river channel, and to protect lives and reduce loss of property in flooding events, geomorphic assessment data can be used to support fluvial erosion hazard planning. The present degree of residential and commercial development along the assessed Fayville and Roaring Branch reaches (excluding East Arlington village) is relatively minor. This presents the opportunity for communities to discuss the hazards associated with fluvial erosion along the river corridor and to incorporate geomorphic data into town plans and zoning documents. A proactive planning process can support the river's ability to move toward an equilibrium condition and reduce losses and expensive repairs in future flood events. Planning efforts can include "avoidance" strategies to ensure that new development does not further encroach on the river corridor, reduce the sediment and flow attenuation functions of the floodplain area, and place infrastructure at risk of fluvial erosion losses. Currently, funding and technical resources are available to the towns through the Bennington County Regional Commission (State of Vermont Emergency Management funds) as well as the VTDEC River Management Section to support a public planning process to review the possible role of a corridor overlay district in town planning and to develop a viable draft ordinance for public review.

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

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

A river corridor overlay district with the objective of reducing fluvial erosion hazards can be developed along the Roaring and Fayville Branches for the towns of Arlington (T2.03-A; T2S1S1.01; T2S1S1.02-A) and Arlington (remaining reaches /segments). Generally, speaking this corridor delineation method relies on the meander belt-width concept as outlined in various guidance documents from VTANR (for example, see VTANR, 2008a; VTANR, 2008b).

Definitions

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

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

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

A meander belt is defined by connecting the outside point of meander bends along the left and right banks of a channel. In a river system in dynamic equilibrium that has not been subjected to intensive floodplain encroachment and channel management, the meanders will theoretically have full expression, and connecting the outside points of each meander will approximate an area through which the river channel can be expected to migrate laterally and longitudinally.

Since many of Vermont's streams have been channelized and straightened with the meanders removed or significantly reduced in amplitude, connecting the points at the outside edge of these straightened meanders would result in a narrow "meander belt" that was insufficient in width to describe the area of likely future adjustments. Therefore, Vermont guidance calls for a meander belt width to be buffered at a specified distance off a meander center line (or stream center line). The meander center line, is a line connecting each successive meander cross-over point, proceeding down-valley (see the above VTANR guidance documents for more detailed explanation).

The distance buffered off the meander center line is determined by the (1) approximate channel width in the reach and (2) by the present geomorphic condition and sensitivity of that reach to further adjustments. Channel widths and sensitivity ratings are determined during Phase 1 and Phase 2 Stream Geomorphic Assessments. The Sensitivity ranking (from Very Low to Extreme) is dependent on the stream type (e.g., steep, narrow channels in mountainous settings versus shallow, meandering channels in broader valley settings) and the geomorphic condition of the reach (Reference, Minor Adjustment, Major Adjustment, Stream Type Departure). Further details are provided in the Phase 1 and 2 Stream Geomorphic Assessment protocols (VTANR, 2007a).

Depending on the Sensitivity rating, a channel is buffered to varying widths, which increase with increasing sensitivity (Table 15).

Table 15. Meander Belt Width Dimensions based on Geomorphic Sensitivity

Sensitivity	Meander Belt Width, based on reference channel width
Very Low	Equal to the reference channel width
Low	Two (2) channel widths
Moderate	Four (4) channel widths
High	Six (6) channel widths Eight (8) channel widths for E stream types
Very High	Six (6) channel widths Eight (8) channel widths for E stream types
Extreme	Six (6) channel widths Eight (8) channel widths for D & E stream types

<u>Reference:</u> *River Corridor Protection Guide*
VT Agency of Natural Resources, 2008 November

In the assessed reaches of the Fayville and Roaring Branch reaches, therefore, FEH corridors would be developed as follows (Table 16):

Table 16. Meander Belt Width Dimensions for the Roaring and Fayville Branches

Reach/Segment	Town	Stream Type	Sensitivity	Meander Belt Width
Roaring Branch				
T2.05	Sunderland	C2b	Low	Two (2) channel widths
T2.04-C	Sunderland	F2b	High	Six (6) channel widths
T2.04-B	Sunderland	D3b	Extreme	Eight (8) channel widths
T2.04-A	Sunderland	F3	Extreme	Six (6) channel widths
T2.03-D	Sunderland	F3b	Extreme	Six (6) channel widths
T2.03-C	Sunderland	A3b	Low	Two (2) channel widths
T2.03-B	Sunderland	F3	Extreme	Six (6) channel widths
T2.03-A	Arlington	C3	High	Six (6) channel widths
Fayville Branch				
T2S1S1.03	Sunderland	C4	Very High	Six (6) channel widths
T2S1S1.02-B	Sunderland	F3	Extreme	Six (6) channel widths
T2S1S1.02-A	Arlington	B1	Very Low	Equal to the reference channel width
T2S1S1.01-C	Arlington	C3	Moderate	Four (4) channel widths
T2S1S1.01-B	Arlington	F4	Extreme	Six (6) channel widths
T2S1S1.01-A	Arlington	C4	High	Six (6) channel widths

The process of corridor delineation in GIS, as prescribed in VTANR protocols, will identify where the above meander belt width impinges on a valley wall. In those cases, the meander belt width is clipped to the valley wall and the clipped area is re-distributed to the opposite side of the channel (where available).

In some cases, (e.g., in some sections of reach T2.05), the valley walls are so narrowly-confining, that the full dimension of the meander belt width is not expressed, and the corridor width may become defined by the left and right valley walls. The corridor delineation process also provides for manual adjustments of the corridor taking into account site-specific knowledge of channel migration zones or avulsion sites (e.g., in T2.04-B, Figure 12) that may extend outside of the corridor generated based on regional hydraulic geometry relationships.

The meander belt width is a close *approximation* of the area surrounding an alluvial channel which is at risk of fluvial erosion hazards in the short term. To comprehensively map fluvial erosion hazard risk with greatest confidence and accuracy would require detailed survey work along the entire river section of interest; field-based evaluation of soil types, geotechnical properties and erodibilities; analysis of historic channel positions; as well as hydrologic and hydraulic modeling (FEMA, 2003; Rapp & Abbe, 2003). Such an intensive study would be cost-prohibitive for most towns, and such an endeavor Statewide would require resources beyond what is reasonably available at the present time.

The meander belt width provides a first approximation that can be quickly derived with reasonably limited resources. As suggested in *Defining River Corridors: Fact Sheet #2*, the belt-width derived corridors "provide an area within which channel adjustments may occur, in order to re-establish an equilibrium condition, and there can be a reasonable expectation that fluvial erosion hazards will be minimized" (VTDEC WQD River Management Section, 2005, p.3).

Two specific recommendations are offered with regard to FEH corridor development based on the Phase 2 assessment results for Fayville and Roaring Branches:

1). T2.05 - During FEH corridor definition, a "Low" sensitivity channel would be buffered at 2 times the channel width (clipped to the confining valley walls in this case). It is likely that in some locations along reach T2.05, a Low-sensitivity FEH corridor would not fully encompass locations of active flood chutes recorded along the reach. Often, flood chute channels surround residences such that they are cut off at high flows. While the Kelley Stand Rd has been restored after major flood events, past evidence would confirm that this road (and houses located beyond the road) is at risk of fluvial erosion. Therefore, manual adjustments to the FEH corridor along this reach would be prudent, relying on local knowledge of avulsion locations in past flood events.

2). T2.04-B - A D3-braided channel in Fair (or even good to reference) condition is assigned an Extreme sensitivity rating under VTANR protocols (2007a) due to the multi-thread nature of the channels and propensity for forming and occupying flood chutes. The FEH corridor along a D3-braided, Extreme-sensitivity segment is generated by buffering the meander center line (or stream center line) at a distance 4 times the channel width on either side, for a total meander belt width of 8 channel widths (Table 16). It is possible that such a corridor generated for Segment T2.04-B would not fully encompass the known positions of the channel recorded on historic aerial photographs. The risk of fluvial erosion hazards may exist outside the boundaries of the FEH corridor on this alluvial fan, and manual adjustments to expand protections would be advised.

7.2 Buffers for waterways not covered by FEH Overlay District

With completion of this Phase 2 geomorphic assessment, data sufficient for the development of a Fluvial Erosion Hazard (FEH) overlay district exists for these six assessed reaches of the Fayville and Roaring Branches. (Additional data are available for other reaches of the Batten Kill main stem and major tributaries – e.g., see Field, 2007).

Several additional tributaries exist in the towns of Sunderland and Arlington (and surrounding towns of the Batten Kill watershed). These tributaries are typically small enough in size that complete geomorphic assessment is either not practical or affordable in the near term. Yet, protection of these smaller tributaries from encroachment, channelization, dredging, berming and other impacts is still critical to the overall watershed goals of mitigating for increased flows and sediment loading. While impacts to any one small tributary may be small in degree, impacts to several small-order tributaries can accumulate in the watershed to result in significant impacts to the Fayville and Roaring Branch (and the Batten Kill).

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

7.3 Additional Planning / Zoning Strategies to Mitigate Stormwater / Sediment Impacts

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

- Implement Low Impact Development techniques:
    - Establish or Increase Minimum Lot Sizes
    - Establish or Reduce Maximum Lot Coverages / Minimize Percent Impervious
    - Minimize land disturbance / compaction during construction
    - Prevent stormwater outfalls from crossing vegetated buffers and entering rivers and streams without treatment or energy dissipation.
    - Specify maximum road and driveway widths.
    - Review parking space ratios for minimum impacts.
- Incorporate practices for area-based zoning, transfer-of-development rights and clustering into zoning and subdivision regulations to encourage protection of river corridors.
- Add relevant language to zoning and subdivision regulations for protection against fluvial erosion hazards – Special Flood Hazard Area regulations established for floodways defined on FEMA-FIRM maps are designed to protect against inundation (rising water) flooding. These practices do not necessarily adequately protect against erosion hazards (or sudden streambank erosion, avulsion) during flooding events.
- Consider forested (vegetative) buffers and erosion control along tributaries and unnamed streams that are not covered by corridor plans and/or Fluvial Erosion Hazard overlay districts.
- Consider local-level stormwater ordinances for development projects that fall under the thresholds for triggering Act 250 review or the States Stormwater Management rule (e.g., Charlotte – ½ acre disturbed).
- Consider local road & driveway and bridge & culvert ordinances or review standards.

7.4 Improved Road Maintenance Practices to Mitigate Stormwater/Sediment Impacts

Several stormwater runoff / road maintenance concerns were identified along the Fayville and Roaring Branch reaches. Similar road encroachments are dispersed through the watersheds on smaller tributaries draining to these reaches and ultimately to the Batten Kill. Collectively, these sites contribute to the accumulation of sediments in the Fayville and Roaring Branches and the Batten Kill.

Road maintenance practices to mitigate for stormwater and sediment runoff to all surface waters 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 culvert header protection.

7.5 Maintenance and Replacement of Crossing Structures

Undersized bridge crossing structures were identified as contributors to localized channel instabilities in the Fayville and Roaring Branch reaches (Section 6.6.1). Similar conditions likely exist at crossings sites dispersed throughout the watershed on smaller tributaries ultimately draining to these reaches and the Batten Kill.

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

- New or replacement bridges and culverts should ideally have openings which pass the bankfull width without constriction.
- Bridges and culverts should be designed to cross the river without creating channel approaches at an angle to structures. Such sharp angles can lead to undermining of fill materials and structural components.
- The historic channel migration pattern of the river should be considered when installing new or replacement crossing structures (and when constructing new roads, driveways, and buildings). Corridor protection strategies that prevent or limit placement of infrastructure within the corridor will protect structures from future erosion and flood losses.
- Planned build-out for watershed communities and resultant channel enlargement (from increased percent imperviousness) should be considered when designing new or replacement bridges and crossing structures.
- Road ditch runoff should be diverted to side-slopes where energy can be dissipated, stormwaters can infiltrate, and sediment / detritus loads can be deposited on the land and not directly to streams.

8.0 REFERENCES

Beers, F. W., 1869, Atlas of Bennington County, Vermont. New York, NY: F. W. Beers, A. D. Ellis & C.G. Soule.

Behling, Robert E., 1966, *Surficial Geology of the Equinox, Londonderry, and Pawlet quadrangles*.

Bierman, Paul, Andrea Lini, Paul Zehfuss, Amy Church, 1997, *Postglacial Ponds and Alluvial Fans: Recorders of Holocene Landscape History*. GSA Today, vol. 7, no. 10.

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

Chapman, D. H., 1937, *Late-glacial and postglacial history of the Champlain Valley*, American Journal of Science, 5th series, vol. 34, no. 200, pp 89-124.

Child, 1880. *Gazetteer and Business Directory of Bennington County, Vermont: Town of Arlington*.

Connally, G. Gordon and Parker E. Calkin, 1972, Woodfordian Glacial History of the Champlain Lowland, Burlington to Brandon, Vermont. New England Intercollegiate Geological Conference, 64th Annual Meeting Guidebook for Field Trips in Vermont, pp. 389-397.

Connally, G. Gordon and L. A. Sirkin, 1969, *Deglacial history of the Lake Champlain – Lake George Lowland*, distributed during field trip, 41st Annual meeting, NY State Geological Association, 20 p.

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

DeSimone, D., 2000. Surficial geologic map of the Arlington and Vermont portion of the Shushan quadrangle. Vermont Geological Survey Open File Report VG00-2.

DeSimone, D. and R. G. LaFleur, 1986. *Glaciolacustrine Phases in the Northern Hudson Lowland and Correlatives in Western Vermont*. Northeastern Geology, v. 8, no. 4, pp. 218-229.

DeSimone, D. and R. G. LaFleur, 1985, *Glacial Geology and History of the Northern Hudson Basin, New York and Vermont*. New York State Geological Association Guidebook, 57th Annual Meeting, Trip A-10, pp 82-116.

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

FEMA, 2003. Riverine Erosion Hazard Areas Mapping Feasibility Study. Available at: http://www.fema.gov/fhm/ft_reha.shtm

Field, John, 2007 February, River Corridor Planning on the Batten Kill, Vermont. Submitted to River Management Program, Dept of Environmental Conservation, VT Agency of Natural Resources. Available at: http://www.anr.state.vt.us/dec/waterq/rivers/docs/FinalReports/23_CPA.pdf

Field, John, 2005 December, Phase 2 Geomorphic Assessment of the Batten Kill, Vermont. Submitted to River Management Program, Dept of Environmental Conservation, VT Agency of Natural Resources. Available at: http://www.anr.state.vt.us/dec/waterq/rivers/docs/FinalReports/23_P2A.pdf

Field, John, no date, Changes on the Batten Kill, Vermont Since 1860 as Documented by Historic Ground Photographs. Available at: http://www.battenkillalliance.org/PDFs/BK_Paired_Photos.pdf

Fitzgerald, Evan P., 2007, Linking Urbanization to Stream Geomorphology and Biotic Integrity in the Lake Champlain Basin, Vermont. Masters Thesis, University of Vermont, M. Sc. Natural Resources.

Henry, Hugh, 1993. Arlington Along the Battenkill: Its Pictured Past. Arlington, Vermont: Arlington Townscape Association, Inc.

Hewitt, Philip C. and Richard F. LaBrake, Geology of the Equinox quadrangle and vicinity, Vermont. Vermont Geological Survey Bulletin #18.

Jaquith, S., M. Kline, J. Field, & J. Henderson, 2004 February, Phase 1 Geomorphic Assessment of the Batten Kill Main-Stem and Major Tributaries, Vermont. Available at: http://www.anr.state.vt.us/dec/waterq/rivers/docs/FinalReports/23_P1A.pdf

Jones, Coleen, 2008, personal interview, riparian landowner, Kelley Stand Rd, Sunderland, VT.

Kondolf, G. M., 1997, Hungry Water: Effects of Dams and Gravel Mining on Rivers. Environmental Management, 21 (4) pp 533-551.

Lyttle, Peter T., Digital bedrock geologic map of the Arlington quadrangle and a Vermont portion of the Shushan quadrangle, Vermont. USGS Open-File Report 950483.

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.

Mulvihill, Christiane I., Amy Filopowicz, Arthur Coleman, and Barry P. Baldigo, 2007, *Regionalized Equations for Bankfull Discharge and Channel Characteristics of Streams in New York State – Hydrologic Regions 1 and 2 in the Adirondack Region of Northern New York*. US Geological Survey Scientific Investigations Report 2007-5189.

Nislow, Keith H. and Frank J. Magilligan, 2005, Analysis of Hydrologic Regimes in the Batten Kill Basin. Poster presentation at Batten Kill Scientific Open House hosted by the Batten Kill Watershed Alliance. Available at: http://www.battenkillalliance.org/PDFs/Hydrologic_Regions.pdf

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

Pair, D. L. and Rodrigues, C. G., 1993, Late Quaternary deglaciation of the southwestern St. Lawrence Lowland, New York and Ontario, *Geological Society of America Bulletin*, v. 105, pp. 1151-1164.

Perkins Landscape Change Program website (http://www.uvm.edu/perkins/landscape)

Rapp, Cygnia & Timothy Abbe, 2004. A Framework for Delineating Channel Migration Zones.Washington State Department of Ecology, Washington State Department of Transportation, Ecology Publication #03-06-027. http://www.ecy.wa.gov/biblio/0306027.html

Ridge, John C., 2003, *The Last Deglaciation of the Northeastern United States: A Combined Varve, Paleomagnetic, and Calibrated ^{14}C Chronology*, in Geoarchaeology of Landscapes in the Glaciated Northeast. Cremeens, David L. and Hart, John P, Ed. Albany, NY: New York State Museum Bulletin 497.

Ritter, Dale F., 1978, Process Geomorphology. Dubuque, Iowa: Wm. C. Brown Publishers.

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

Schumm, Stanley A., 2005. River Variability and Complexity. New York, NY: Cambridge University Press.

Severson, J. P., 1991, Patterns and causes of 19th and 20th century shoreline changes of the Winooski Delta. University of Vermont, Field Naturalist Program, M.S. Thesis.

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

Thomas, P. A., 1985, Archeological and geomorphological evaluation; M5000 (3) northern connector material supply/disposal area, Howe Farm flood plain: Burlington, VT: University of Vermont, Department of Anthropology, no. 54, 41 pp.

Thompson, E. H. and E. R. Sorensen, 2000. Wetland, Woodland, Wildland: A Guide to the Natural Communities of Vermont. The Nature Conservancy and Vermont Department of Fish and Wildlife. University Press of New England.

USDA Natural Resource Conservation Service, 2005, State Data Table Top 20, published by the United States Department of Agriculture, NRCS; available at: ftp://ftp-fc.sc.egov.usda.gov/VT/Soils/top20/

USDA Natural Resource Conservation Service, 1998, Soil Survey Geographic (SSURGO) database for Bennington County, Vermont, available at: http://www.vcgi.org/dataware/default.cfm?layer=GeologicSoils_SO

USGS, 2008, on-line surface water data, <http://waterdata.usgs.gov/vt/nwis>.

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

VT Agency of Natural Resources, 2008a, River Corridor Protection Guide: Fluvial Geomorphic-Based Methodology to Reduce Flood Hazards and Protect Water Quality. Available at: http://www.anr.state.vt.us/dec/waterq/rivers/docs/rv_RiverCorridorProtectionGuide.pdf

VT Agency of Natural Resources, 2008b, Municipal Guide to Fluvial Erosion Hazard Mitigation. Available at: http://www.anr.state.vt.us/dec/waterq/rivers/docs/rv_municipalguide.pdf

VT Agency of Natural Resources, 2007a, 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, 2007b (11 July draft). *River Corridor Planning Guide to Identify and Develop River Corridor Protection and Restoration Projects*. Available at: http://www.anr.state.vt.us/dec/waterq/rivers/docs/rv_rivercorridorguide.pdf

VT Center for Geographic Information, 2005, Vermont Dam Inventory (EmergencyOther_DAMS) viewed June 2005 online at: http://www.vcgi.org/metadata/EmergencyOther_DAMS.htm

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

VT DEC Water Quality Division, 2005, Defining River Corridors: Fact Sheet #2. Available at: http://www.anr.state.vt.us/dec/waterq/rivers/docs/Educational%20Resources/rv_DefiningRiverCorridorsFactSheet.pdf

VT DEC Water Quality Division, 2002 August, Batten Kill, Walloomsac River & Hoosic River Watersheds: Water Quality and Aquatic Habitat Assessment Report. (Available online at: http://www.anr.state.vt.us/dec//waterq/planning/docs/pl_basin1.assessment_report.pdf)

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

VT DEC Water Quality Division, February 1999, 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 Fish & Wildlife Department, 2006 January 8, Batten Kill Trout Management Plan: 2007-2012.

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.

Walling, H. F., 1856, Map of Bennington County, Vermont. New York, NY: C.B. Peckham & H.F. Walling.

Williams, G. P. and M. G. Wolman, 1984, *Downstream effects of dams on alluvial rivers*. United States Geological Survey Professional Paper 1286, 83 pp.