River Corridor Plan for the Saxtons River Watershed
Windham County, Vermont

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Prepared by:

Fitzgerald Environmental Associates, LLC.
316 River Road
Colchester, VT 05446

Fitzgerald Environmental Associates, LLC.
Applied Watershed Science & Ecology

Prepared under contract to:

Windham County Natural Resources Conservation District
28 Vernon Street, Suite 332
Brattleboro, VT 05301

Windham Regional Commission
139 Main Street, Suite 505
Brattleboro, Vermont 05301

WINDHAM COUNTY CONSERVATION DISTRICT

WINDHAM REGIONAL COMMISSION

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Executive Summary

In 2008, the Windham County Natural Resources Conservation District (WCNRCD), the Windham Regional Commission (WRC), and the Vermont Department of Environmental Conservation (VTDEC) identified the Saxtons River watershed in southeastern Vermont for the assessment of fluvial geomorphic and aquatic habitat conditions. Fitzgerald Environmental Associates, LLC. (FEA) was retained by WCNRCD in 2008 to carry out Phase 1 and 2 assessments following the Stream Geomorphic Assessment (SGA) Protocols developed by the Vermont River Management Program (RMP). The Phase 1 SGA covered 77 river miles, while the Phase 2 SGA covered 32 river miles. Funding for this project was secured through a FEMA Pre-Disaster Mitigation grant administered by WRC. Funding for subsequent river corridor planning activities was provided by a VTDEC Clean and Clear grant administered by WRC.

The Saxtons River drains a 78 square mile watershed spanning 5 towns in Windham County. Tributary to the Connecticut River, the Saxtons River is one of three major watersheds considered part of Vermont Basin 11 (Williams and West Rivers are also included in Basin 11). Four major named tributaries drain to the river, including Leach Brook, Weaver Brook, Bull Creek and the South Branch. The river corridors of the watershed support a diversity of forms and conditions, including upland cascading reaches, alluvial fans, areas of braiding at tributary junctions, and meandering channels in the valley along Route 121. Like many river systems in New England, past floods, defunct dams and various types of human land use in the river corridor have all left a lasting imprint on the morphology and stability of the channel network. The following is a summary of the Phase 2 SGA findings and corridor planning effort.

- A total of 29 river reaches (32 river miles) were assessed using the VTDEC Phase 2 SGA Protocols. Due to the varied topographic terrain and valley setting, especially in the tributaries, the reaches were further subdivided into 37 segments for field data collection. Two reaches, one on Howe Brook and one on Willie Brook, were segmented and partially assessed to characterize the alluvial fans at their confluence with the South Branch.
- The stressor identification analysis revealed low to moderate watershed-scale impacts from recent land use changes and wetland loss; only isolated areas of urban and agricultural land use appear to be affecting the hydrologic and sediment regimes. However, abundant reach-scale stressors such as corridor encroachments and channel straightening have impacted many miles of river corridor in the watershed. Thirteen (13) segments have departed from reference conditions primarily due to channel incision and/or straightening. These departures result in a conversion of river segments to effective transporters of sediment to downstream areas, with a subsequent loss of storage of sediment and floodwaters within the floodplain.
- With the exception of two key areas at tributary junctions (Reaches M06 and M09), the main stem of the Saxtons River from Grafton to Bellows Falls has lost significant floodplain function and aquatic habitat due to encroachment from Route 121. Some reaches of the main stem are found in naturally entrenched valley settings; however numerous reaches in unconfined valley settings have been indirectly straightened due to bank armoring and floodplain modifications (e.g., fill from road embankments). Hard bank armoring and reduced riparian vegetation limits input of woody debris and pool formation. Most reaches of the main stem had woody debris densities well below 50 pieces/mile (commonly “fair” and “poor” ratings), and pool densities were also very low. Over-widened channels on the main stem also degrade habitat through bed

sedimentation from ongoing bank erosion and a high degree of solar-thermal loading which raises summer temperatures above thresholds tolerated by salmonids.

- Bull Creek is found in a wide alluvial valley and has a natural propensity for fluvial erosion and channel migration. In addition, historical impacts to the channel (e.g., straightening) have heightened its sensitivity. Nevertheless, of all the study reaches Bull Creek has the greatest potential for habitat restoration. The combination of a wide alluvial valley, limited corridor development, coarse gravel substrate, and high bedload allows for dynamic channel processes with excellent formation of habitat features (e.g., pools and undercut banks). Riparian corridor restoration for habitat improvement is very promising in the lower part of Bull Creek.
- The South Branch of the Saxtons River and its tributaries, found to the south of Grafton Village, are situated in an unconfined valley. Channel and floodplain functions have been severely impacted by encroachment on the corridor from Townshend Road. The alluvial fans noted on the tributaries to the South Branch in Grafton have been severely channelized over the last 50 to 100 years, and it is well known that significant debris originated from these areas during the 1996 flood. This debris caused a bridge failure and other damage to private property. Dam removal is currently being pursued on the South Branch near Kidder Hill Road in Grafton. Improved aquatic organism passage (AOP) at this location will result in better access to many miles of habitat upslope.
- A total of 51 structures at road crossings were assessed using the VTDEC methods, including 49 bridges and 2 culverts. The results of a structure analysis indicate that 54% of the assessed bridges and culverts are adequately sized to accommodate stream equilibrium conditions. However, many bridges had spans that approximate the bankfull channel width; only 6 (12%) of the 51 structures have spans less than 75% of measured bankfull widths. Both of the assessed culverts (2 total) have widths less than 50% of bankfull channel width and cause significant flood constrictions and reduced AOP. Eight (8) bridges and two (2) culverts have been identified as "moderate" or "high" priorities for replacement or retrofit to address their incompatibility with channel stability and/or AOP.
- Watershed-level approaches to restoration of dynamic equilibrium conditions were evaluated, including mitigation of stormwater runoff, implementation of Fluvial Erosion Hazard (FEH) zones, and the above-described analysis of structure data. FEH zones are recommended for the five towns in the watershed to encourage long-term channel stability, reduce flood recovery and infrastructure maintenance costs, and increase public safety. Other recommendations include stormwater management regulations at the local level that would help avoid future runoff problems.
- Site level approaches to restoration of dynamic equilibrium conditions were evaluated in detail at the reach scale using a step-wise procedure developed by VTANR. This resulted in the identification of 32 unique projects for the study area, including 22 projects that do not require significant further study (i.e., passive approaches such as buffer plantings and corridor protection), and 10 projects requiring further feasibility study or engineering design (i.e., active restoration approaches such as culvert replacements).
- Five (5) restoration projects were selected for further alternatives analysis and landowner outreach. These included three corridor protection and buffer planting projects, one berm removal project, and one dam removal project. As part of a pre-design effort, FEA conducted cursory Phase 3 SGA surveys for the two "active" restoration projects. FEA also summarized potential partners, permitting requirements and cost estimates for each project.

1.0 Project Background

1.1 Introduction and Study Goals

In 2008, the Windham County Natural Resources Conservation District (WCNRCD), the Windham Regional Commission (WRC), and the Vermont Department of Environmental Conservation (VTDEC) identified the Saxtons River watershed in southeastern Vermont for the assessment of fluvial geomorphic and aquatic habitat conditions. The study is part of a larger effort to characterize the physical and biological conditions of the Saxtons River watershed and aid in the identification of stressors on aquatic biota communities. In addition, the study results provide the basis for future river corridor and Fluvial Erosion Hazard (FEH) planning efforts in the watershed. Fitzgerald Environmental Associates, LLC. (FEA) was retained by WCNRCD in 2008 to carry out Phase 1 and 2 assessments following the Stream Geomorphic Assessment (SGA) Protocols developed by the Vermont River Management Program (RMP). The Phase 1 SGA study covered 77 river miles (FEA, 2008), while the Phase 2 SGA covered 32 river miles. Funding for this project was secured through a FEMA Pre-Disaster Mitigation grant administered by WRC. Funding for subsequent river corridor planning activities was provided by a VTDEC Clean and Clear grant administered by WRC.

Watershed restoration projects are most successful when carried out within a context for understanding how reach and watershed-scale stressors cause channel instability. The VTANR River Corridor Planning Guide provides sound, scientifically-defensible methods for identifying stressors on channel stability and restoration projects that will address them appropriately (VTANR, 2010a). The overall goal of the VTDEC RMP is to "manage toward, protect, and restore the fluvial geomorphic equilibrium condition of Vermont rivers by resolving conflicts between human investments and river dynamics in the most economically and ecologically sustainable manner," (VTANR, 2010a) achieved through:

- Fluvial erosion hazard mitigation
- Sediment and nutrient load reduction, and
- Aquatic and riparian protection and restoration

The goal of the SGA and river corridor planning effort for the Saxtons River watershed is to provide:

1) A basis for understanding the overall causes of channel instability and habitat degradation
2) The data needed to develop FEH Zones for the study area
3) A list of preliminary corridor restoration projects that can be further developed in the future to mitigate flood and erosion hazards in the watershed
4) Progress on the development of 5 high-priority restoration projects identified by the project partners

1.2 Project Partners

The planning team for the development of the Saxtons River Corridor Plan included representatives from the following organizations:

- Windham Regional Commission (WRC)
- Windham County Natural Resources Conservation District (WCNRCD)
- Vermont Department of Environmental Conservation (VTDEC)

In addition, various community members and landowners from the towns in the watershed participated in the planning process through landowner meetings and a public forum. Other organizations active in river restoration and land conservation were involved in project planning such as the Vermont River Conservancy (VRC), Vermont Land Trust (VLT), the Natural Resources Conservation Service (NRCS) and the Farm Service Agency (FSA).

1.3 Previous Studies

Several studies of the Saxtons River watershed have been completed over the last 20 years. VTDEC has developed a Comprehensive Management Plan for Basin 11 encompassing the West, Williams, and Saxtons River watersheds (VTDEC, 2008). This document summarizes an extensive effort to engage the stakeholders in a process to protect and enhance the health of the basin. The plan includes a review of previous studies, historical data, and restoration projects within the basin. The plan characterizes the basin's water quality conditions and stressors, and the current and future challenges to protecting and restoring the health of the basin's waterways. The plan asserts that the greatest concerns to water quality and aquatic habitat are, in order of priority: 1) thermal modification, 2) sedimentation, 3) physical habitat alterations, 4) flow alterations, and 5) pathogens. The stressors pertinent to the Saxtons River watershed are discussed below.

- **Thermal modification** affects 107 miles of Basin 11, impacting the aquatic biota community by increasing metabolism rates and decreasing dissolved oxygen. Thermal modification has been identified in the Saxtons River watershed as a possible stressor to the biological community in the lower Saxtons River. Restoration projects to address this stressor can be identified using the SGA data, including riparian buffer plantings and stream corridor conservation.

- **Sedimentation** affects many river reaches in Basin 11, impacting the aquatic biota community and increasing nutrient loading to downstream waters. Sedimentation has been identified in the lower Saxtons River as a possible stressor on the biological community. Restoration projects to address this stressor can be identified using the SGA data, including stream bank stabilization, replacement of undersized stream crossings, and conservation of sediment attenuation zones within the stream corridor.

- **Physical habitat alterations** are directly impacting the biological communities in Basin 11, including those in the lower Saxtons River. The collection of geomorphic assessment data is recommended to identify areas where habitat can be improved or restored using passive or active stream channel management approaches.

The Saxtons River watershed has been sampled periodically by the VTDEC Biomonitoring Section, with the most recent sampling occurring in 2008. The results of the sampling indicated that the upper and lower Saxtons River supported good to excellent macroinvertebrate communities within the sampled riffles (Table 1.1). In addition, sampling on the lowermost reach of Leach Brook (Reach T1.03) indicated an excellent macroinvertebrate community. Fish sampling also indicated a healthy community in the upper and lower Saxtons River; however the fish community in Leach Brook was rated as poor due to low densities of fish, especially native brook trout (*Salvelinus fontinalis;* Table 1.2)

Table 1.1 Macroinvertebrate sampling data for the Saxtons River and Leach Brook

Date Sampled	VTDEC Site ID	Location	River Mile	SGA Reach	Mean Density	Mean Species Richness	Mean EPT* Richness	Community Assessment
10/1/2003	60000000038	Saxtons River	3.8	M05	1,624	39	23	Very Good
10/4/1993	60000000045	Saxtons River	4.5	M05	2,100	44	22	Good
10/5/1993	60000000062	Saxtons River	6.2	M06	1,892	50	28	Excellent
10/4/1994	60000000062	Saxtons River	6.2	M06	2,526	59	36	Excellent
10/2/1995	60000000062	Saxtons River	6.2	M06	2,346	47	27	Excellent
9/20/2006	60000000094	Saxtons River	9.4	M09	3,256	55	31	Excellent
9/22/2008	60000000203	Saxtons River	20.3	M20-A	2,004	55	34	Excellent
9/25/2008	60000000045	Saxtons River	4.5	M05	3,640	52	30	Good
9/25/2003	60500000001	Leach Brook	0.1	T3.01	485	42	23	Excellent

* EPT: Pollution sensitive families of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)

Table 1.2 Fish sampling data for the Saxtons River and Leach Brook

Date Sampled	VTDEC Site ID	Location	River Mile	SGA Reach	IBI†	Community Assessment
10/4/1994	60000000062	Saxtons River	6.2	M06	33	Good
10/2/1995	60000000062	Saxtons River	6.2	M06	31	Good
9/20/2006	60000000094	Saxtons River	9.4	M09	33	Good
9/20/2006	60000000144	Saxtons River	14.4	M15	37	Very Good
9/25/2008	60000000203	Saxtons River	20.3	M20-A	36	NA
9/25/2008	60000000045	Saxtons River	4.5	M05	31	Fair
9/25/2003	60500000001	Leach Brook	0.1	T3.01	9	Poor
9/20/2006	60500000001	Leach Brook	0.1	T3.01	18	Poor

† Index of Biological Integrity: Mixed Water (MW) index for Saxtons River, Cold Water (CW) index for Leach Brook

2.0 Background Watershed Information

2.1 Geographic Setting and Land Use History

The Saxtons River watershed is located in Basin 11 in northern Windham County, Vermont (Figure 2.1). The watershed has a drainage area of 77.9 square miles and outlets into the Connecticut River east of the Route 5 river crossing, just downstream of Bellows Falls Village in the town of Rockingham. The main stem of Saxtons River flows in an easterly direction along Route 121, with the headwaters of the main stem located in Windham. The watershed in its entirety spans the towns of Rockingham, Westminster, Grafton, Athens, Windham and Townshend. The Saxtons River has several significant tributaries that make up much of the total area of the watershed. In the Town of Grafton the main stem meets the South Branch (T6) entering from the south. Continuing east from Grafton, the main stem is joined with Weaver Brook (T5) and Bull Creek (T4) in the area of Cambridgeport. Downstream of Cambridgeport, Leach Brook (T3) enters the main stem from the north about a mile upstream of the Village of Saxtons River. An unnamed tributary (T2) enters the main stem from the south about two-thirds of a mile upstream of the Westminster Street Bridge in the Village of Saxtons River. East of Saxtons River Village the main stem meets the confluence with Bundy Brook (T1) entering from the south at one mile upstream of the river mouth.

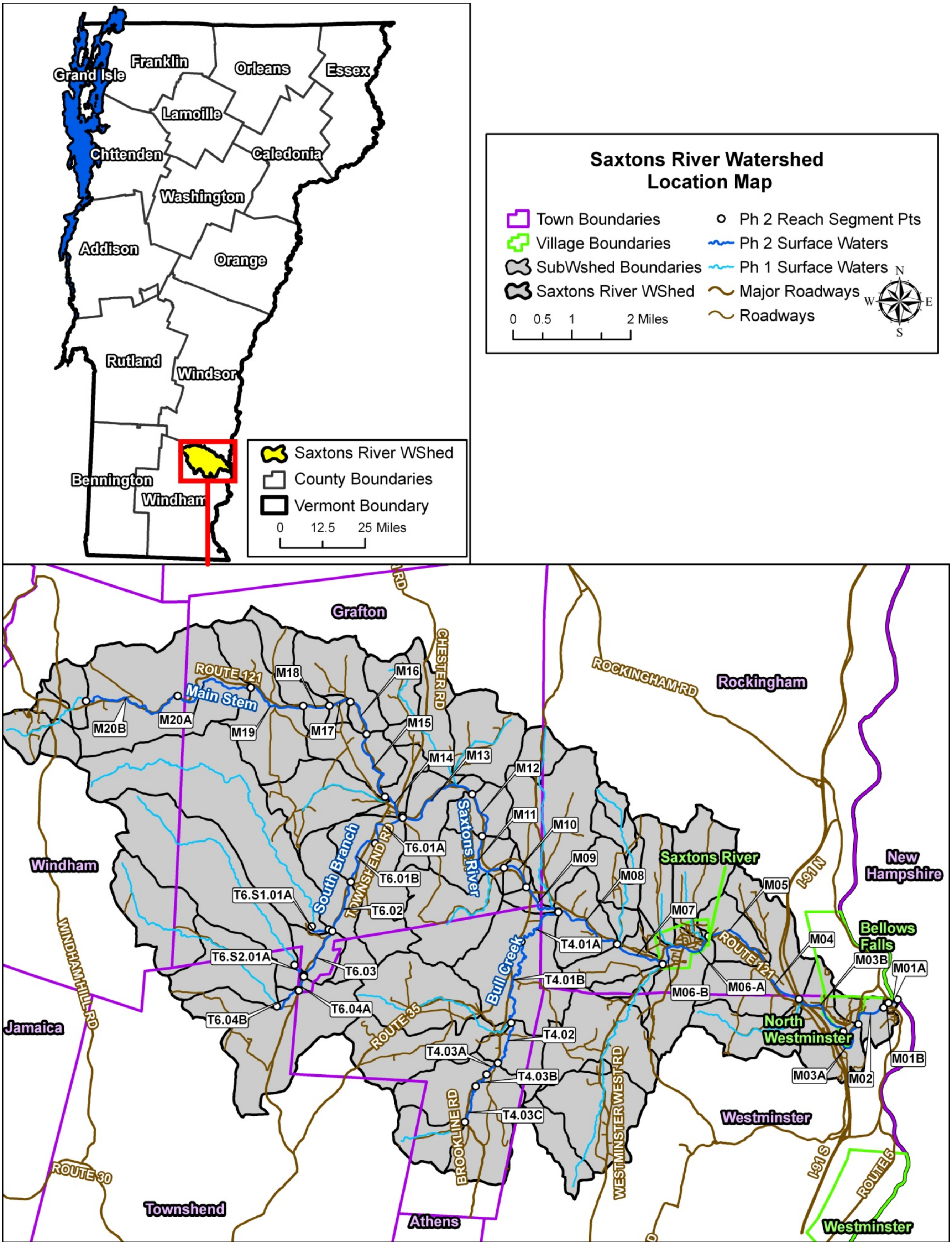

Figure 2.1 Saxtons River Watershed Locus Map; Windham County, Vermont

Land cover data based on imagery from 2006 (NOAA, 2008a) are summarized in Table 2.1. The Saxtons River is drained by a rural watershed, with forest representing the dominant cover type. Agricultural lands only cover 6.0% of the watershed, with a majority of larger farmlands found in the lower watershed downstream of the intersection of Route 121 and Route 35 in Cambridgeport. The wide, alluvial valleys of Bull Creek and the South Branch continue to support extensive agricultural lands, including hayfields and pasture for cows, horses and sheep. There is limited developed in the watershed, with only 1.6% coverage. Concentrated areas of residential development are found primarily around the three main villages along Route 121: Saxtons River, Grafton, and Cambridgeport.

Table 2.1 Land cover/land use (LCLU) data for the Saxtons River Watershed

Land Cover Type	Main Stem (M01-M20)	Bull Creek (T4)*	South Branch (T6)**	Entire Watershed
Agriculture	7.4%	6.3%	2.7%	6.0%
Development	4.0%	0.5%	0.1%	1.6%
Forest	86.0%	90.5%	94.1%	89.6%
Open Water	0.0%	0.4%	0.2%	0.1%
Scrub/Shrub	1.2%	1.1%	1.8%	1.3%
Wetland	1.4%	1.2%	1.2%	1.4%

* Includes Athens Brook; ** Includes Styles, Willie, and Howe Brook

Land Use History

Historically, the impacts of agricultural practices on the Vermont landscape played an important role in the legacy effects on waterways like the Saxtons River. Prior to the deforestation associated with human settlement, the watershed would have been a mixture of deciduous forest on the valley floors, coniferous forest along the mountain spines, and a mixture of both along the slopes. Deforestation and grazing, largely from sheep farms, likely left over 80 percent of the watershed devoid of trees at one time or another (Albers, 2000). This landscape change had a tremendous impact on waterways like the Saxtons River. Exposed, highly-erodibe soils (e.g., glacial tills) on steep slopes was carried to the valley floors where it aggraded on river bottoms; a legacy that still influences the way Vermont's rivers are managed today.

As Vermont's farmers began to move to the Midwest in search of more productive farmland in the mid to late 1800's, the deciduous forests along the mountain slopes began to recover (Albers, 2000). Throughout the early and mid 1900's, as more family farms found on marginal lands were given up, the forests continued to recover. Today, approximately 90 percent of the Saxtons River watershed is covered by forest. With the increasing tourism sector in the state, and the need for lumber for second-homes and construction, forestry has replaced agriculture in many of the rural hill slopes of Vermont.

2.2 Geologic Setting

The underlying geology of the Saxtons River watershed is comprised of mixture of rock types from the Devonian, Ordivician, and Precambrium eras (Doll et al., 1961). The Waits River Formation, which contains a mixture of schist and marble, is found in the eastern section of the watershed. The Missisquoi formation, found mainly in the western section of the watershed, contains a mixture of quartzites, schists and phyllites. The weathering of calcium carbonate rich (sea bottom) sediments in these formations results in basic soils that typically support communities of rich woods species.

The presence of Glacial Lake Hitchcock also had a significant effect on the surficial geology of the lower watershed, perhaps as far upslope as reach M09 (Figure 2.2). This lake occupied the Connecticut River Valley from central Connecticut north to St. Johnsbury during the retreat of the Laurentide ice sheet beginning approximately 18,000 years ago (Ridge and Larson, 1990). The great size of the lake, combined with the erosive forces of the glacier moving over bedrock surfaces allowed for the development of annual layering of fine sediments (e.g., varves) throughout the area affected by the lake.

Figure 2.2 Extent of Glacial Lake Hitchcock in New England (NPS, 2010)

Surficial geologic deposits of the Saxtons River watershed were governed largely by glacial activity. During the Wisconsin glaciation, glaciers one mile in thickness extended across New England, reaching their maximum extents approximately 20,000 years ago. This glacial event left the Green Mountains with a physical imprint that is clearly evident today. In the Saxtons River watershed, dense till and outwash areas reflect the dynamic nature with which glaciers shaped the landscape (Figure 2.3). However, most of the surficial geology of the Saxtons River watershed is dominated by glacial tills. The resultant soils in steeper sloped areas formed on these rocky tills are thin by nature. On the valley floors, fine sandy loams and silty loams associated with recent alluvium and glacial lake deposits provide good to excellent soils for agriculture.

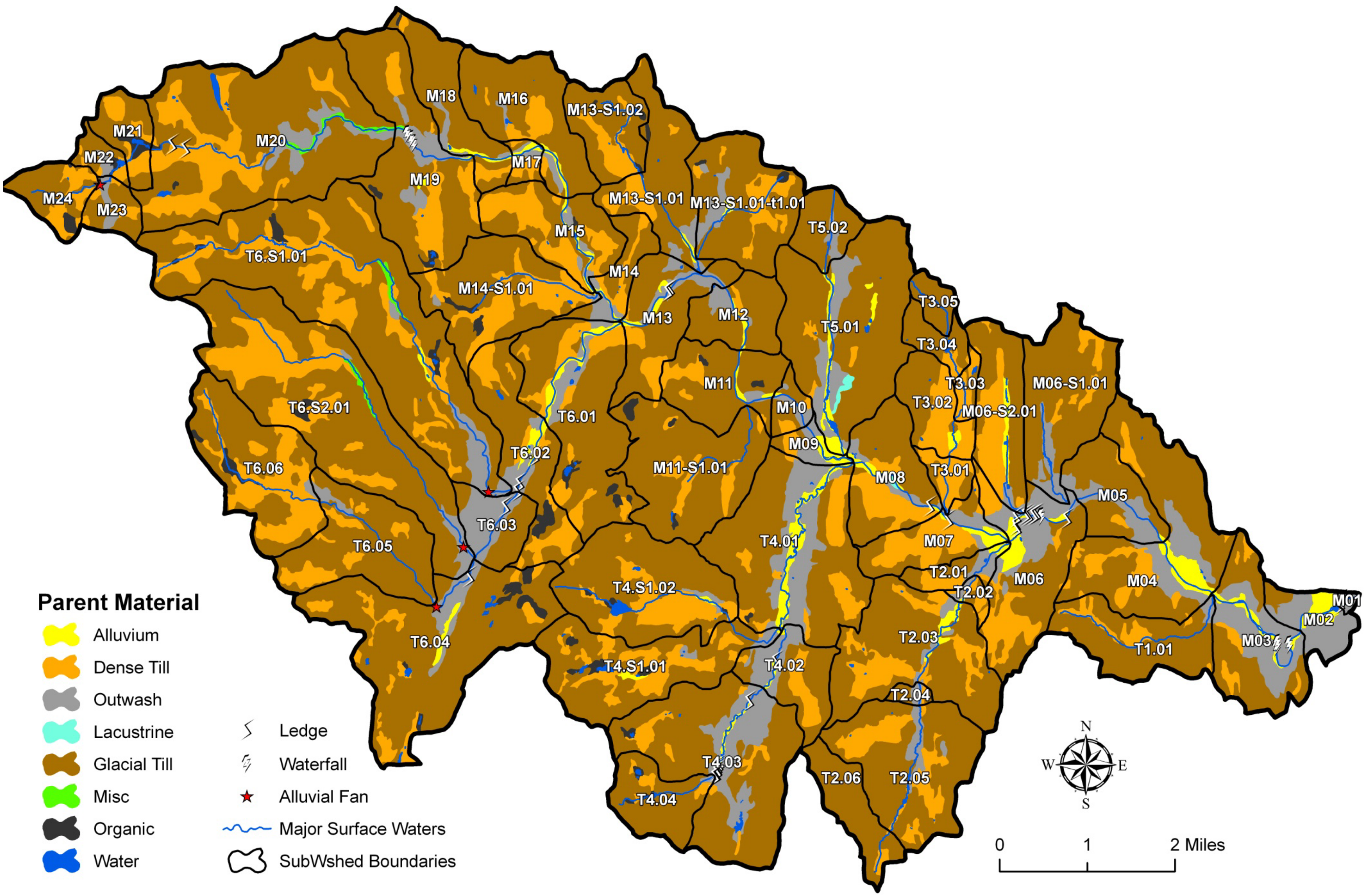

Figure 2.3 Surficial parent materials and grade controls in the Saxtons River watershed (Source: NRCS, 2008)

2.3 Geomorphic Setting

The Saxtons River has two main branches and a minimum of four significant tributaries. The main stem of the Saxtons River has an overall channel slope of 1.8%, with significant differences in the reference valley and channel morphology between the upper and lower watershed. The lower Saxtons River (Reaches M01 – M08) has an overall channel slope of 0.8%, and most of the reaches are found in unconfined valley settings with significant alluvial deposits. The upper Saxtons River (Reaches M09 – M24) has an overall channel slope of 2.4%, and the reaches are found in both unconfined and confined valley settings typical of Vermont headwaters channels.

The first major tributary stemming southward from the main stem in the Saxtons River Basin is Bull Creek (T4). Bull Creek is found in an unconfined, alluvial valley and has an overall channel slope of 1.0%. The final reach of Bull Creek (T4.04) is a headwaters reach found in a steep, confined valley with a slope of approximately 7%. The South Branch of the Saxtons River (T6) has an overall channel slope of 1.5%, and the channel is found in a very broad, unconfined alluvial valley. Entering the South Branch from the west are three steep, headwaters tributaries known as Howe, Willie, and Styles Brooks. The reaches associated with these tributaries all have gradients above 3% and are found in confined valley settings.

The river reaches assessed in this study are found in varied topographic terrain. Variation in topography and valley slope influences the channel morphologies that would be expected under reference (i.e., undisturbed) conditions. The Phase 1 SGA study carried out by FEA included summary data of the topographic characteristics that influence valley and channel morphology, including watershed area, channel/valley slopes, predicted channel widths, and sinuosity. Following the Phase 2 SGA work done in this study, reference reach characteristics for some of the reaches were refined based on improved knowledge of the reach and valley setting. The reach characteristics were used to classify natural channels using two classification systems developed by Rosgen (1994) and Montgomery and Buffington (1997).

The Rosgen system (Figure 2.4) uses measurements of channel and floodplain dimensions to make predictions about river processes. This classification system is used widely by federal and state agencies as a way of communicating about river form and function in the context of restoration management. The Montgomery and Buffington classification system is based on a river's "bedform", whereby the shape of the bed and its features (e.g., riffle and pools) are used to understand the dominant hydraulic and sediment processes of the river. This system is also used widely in Vermont and other states as part of geomorphic assessment methods.

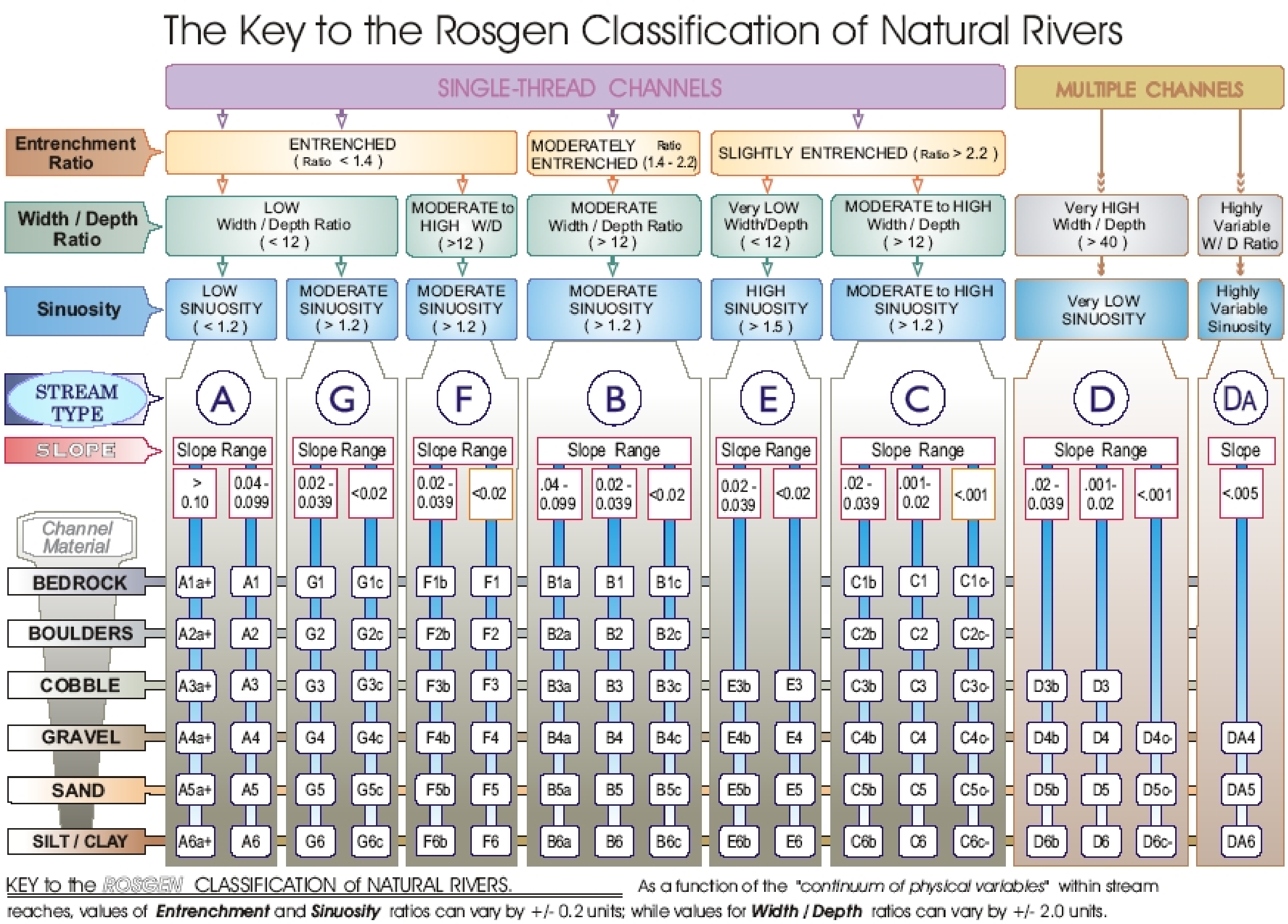

Figure 2.4 The Rosgen (1994) classification of streams based on channel morphology. Key parameters for classification include 1) the entrenchment ratio (floodprone width / bankfull channel width), 2) width to depth ratio (bankfull width / mean channel depth), and 3) channel sinuosity (channel length / straight-line valley length). Entrenched channels are typically dominated by sediment transport processes, whereas slightly entrenched channels (C and E types) have sediment transport and depositional processes.

Table 2.2 provides a summary of the reference reach data for the 29 reaches assessed in the watershed. The Saxtons River main stem reaches are found in a variety of settings, from broad and alluvial to the more confined, mountainous headwaters. Where the valley is unconfined C-type reference channels are found. Areas with a more confined setting were found throughout the basin and were most often B-type by reference. Riffle-pool reference bedform was dominant throughout the watershed because of the lower slopes and coarse gravel to cobble sized substrate. Bull Creek had a very wide valley setting and low slope and was subsequently C-type by reference with riffle-pool bedform. A few reaches on the main stem were C-type by reference with finer substrate. The South Branch had similar valley dimensions as Bull Creek and channel type is also C-type. However, substrate is likely to be coarser than Bull Creek. The lower portions of Howe and Willie Brook along with Styles Brook are alluvial fans by reference with D-type morphology. Howe and Willie Brook both extend up several miles toward Windham. Their reference condition reflects a steep channel with a narrow valley and A or B-type morphology.

Table 2.2 Reference reach characteristics for the Saxtons River and selected tributaries

Surface Water	Reach ID	Watershed Area (Mi^2)	Channel Length (Mi)	Channel Width (ft)	Channel Slope	Sinuo-sity	Valley Type*	Reference Stream Type†	Bedform‡
Saxtons River Main Stem	M01	77.9	0.3	89.0	1.4	1.1	NC	F	Plane Bed
	M02	77.9	0.6	89.0	0.3	1.1	BD	C	Riffle-Pool
	M03	77.3	1.9	88.7	1.0	1.2	SC	B	Riffle-Pool
	M04	74.7	0.9	87.4	0.4	1.1	BD	C	Riffle-Pool
	M05	72.3	1.3	86.1	0.5	1.1	NC	B	Riffle-Pool
	M06	71.4	1.2	85.7	1.0	1.3	VB	C	Riffle-Pool
	M07	61.6	0.9	80.3	1.1	1.0	NW	B	Plane Bed
	M08	59.1	1.3	78.8	0.5	1.1	BD	C	Riffle-Pool
	M09	46.7	0.8	71.1	0.8	1.0	BD	C	Riffle-Pool
	M10	43.1	0.6	68.6	0.9	1.1	SC	B	Riffle-Pool
	M11	42.9	1.0	68.5	0.9	1.0	NW	C	Riffle-Pool
	M12	39.8	0.8	66.3	0.9	1.1	NW	C	Riffle-Pool
	M13	39.0	1.6	65.7	1.3	1.0	BD	C	Riffle-Pool
	M14	14.2	0.5	42.1	1.2	1.1	VB	C	Riffle-Pool
	M15	12.0	1.3	39.1	1.3	1.1	BD	C	Riffle-Pool
	M16	10.9	0.7	37.4	0.8	1.1	SC	B	Riffle-Pool
	M17	9.4	0.4	35.1	1.3	1.0	VB	C	Riffle-Pool
	M18	9.2	0.5	34.8	1.6	1.1	NW	B	Riffle-Pool
	M19	8.2	1.1	33.1	3.4	1.1	SC	B	Step-Pool
	M20	5.9	3.6	28.7	2.5	1.1	BD	C	Riffle-Pool
Bull Creek	T4.01	11.2	3.1	37.9	0.6	1.4	VB	C	Riffle-Pool
	T4.02	4.4	0.9	25.2	1.3	1.1	VB	C	Riffle-Pool
	T4.03	3.6	1.4	23.0	1.6	1.2	BD	C	Riffle-Pool
South Branch	T6.01	20.0	1.8	49.0	1.0	1.2	VB	C	Riffle-Pool
	T6.02	17.8	0.9	46.4	1.1	1.0	VB	C	Riffle-Pool
	T6.03	11.2	0.9	38.0	1.1	1.1	VB	C	Riffle-Pool
Styles Brk**	T6.04	6.7	0.8	30.3	3.6	1.0	VB	D	Braided
Howe Brk	T6.S1.01	5.1	6.9	26.9	3.4	1.1	NC	B	Step-Pool
Willie Brk	T6.S2.01	3.9	4.7	23.7	4.5	1.1	NC	A	Step-Pool

* NC = Narrowly Confined; SC= Semi-confined; NW= Narrow; BD=Broad; VB=Very Broad; † per Rosgen, 1994
‡ per Montgomery and Buffington, 1997; **T6.04 occupies part of the South Branch and Styles Brook; segmentation was done in Phase 2

2.4 Hydrology and Flood History

USGS Gaging Data

The United States Geological Survey (USGS) operates a real-time flow monitoring gage on the lower Saxtons River approximately 3.9 miles upstream of the confluence with the Connecticut River (USGS, 2010). The gage is found within SGA reach M05, and has an upslope drainage area of 72.2 square miles. The gage was operated by USGS from 1940 to 1982 and then abandoned from 1983 until 2002. It has been operating from 2002 until present. Thus, the period of record spans a total of 48 years. The Saxtons River flow data from 1940 to 1982 was included in a USGS study to summarize the flow-frequency characteristics of Vermont Rivers and Streams (Oslon, 2002). The magnitude and return frequency data produced from this study for the Saxtons River gage are included below in Table 2.3.

Table 2.3 Peak discharge for given recurrence intervals on the Saxtons River, VT

Recurrence Interval	Discharge Q (cfs)
2-Year	2,640
5-Year	4,180
10-Year	5,420
25-Year	7,270
50-Year	8,860
100-Year	10,600
500-Year	15,700

*Data obtained from Olson, 2002

Flooding history

Figure 2.5 summarizes the annual peak discharges on the Saxtons River during the period of record. There are several historical flood events that are noteworthy: The June 1 flood of 1953 was a 10-year flow event that was widespread throughout southern Vermont (USGS, 2010). The September 12, 1960 storm was also a 10-year event that caused flooding in other basins throughout the state. The two larger events in the 1970's both exceeded the 25-year magnitude, and caused widespread flooding and damage throughout Vermont. The 1976 event, a result of heavy rainfall associated with Hurricane Belle, caused tremendous damage throughout the state. In June of 1996 approximately 11 inches of rain fell in 24 hours in the vicinity of Grafton, causing widespread road and infrastructure failures (including the destruction of a covered bridge) that exceeded $1,000,000. Major damage from road and culvert washouts was concentrated along Fire Pond, Middletown, and Hinkley Brook roads to the southwest of Grafton village (Doherty, 2008). No streamflow data was available for this event because the USGS gage was not in operation.

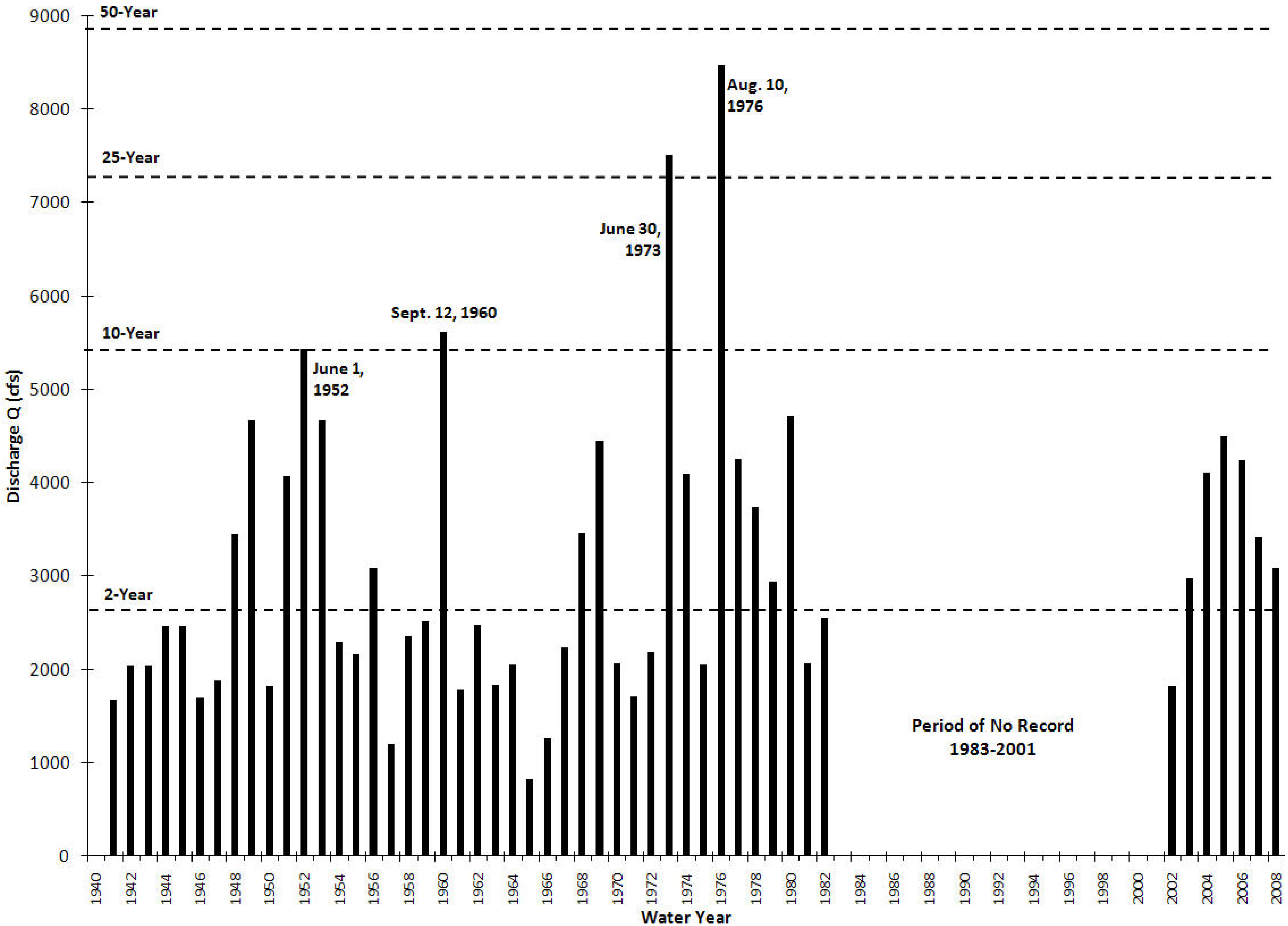

Figure 2.5 Annual peak discharges for USGS Gage # 01154000 on the Saxtons River in Windham County, Vermont; Recurrence intervals from Olson (2002)

The Flood of 1927

The flood of 1927 occurred in early November after leaf-fall. The rain storm was unprecedented in intensity and spatial extent (Figure 2.6). Almost the entire state received between 5 and 8 inches of rain over the course of a few days time. The volume of rainfall in combination with the time of year made the perfect conditions for severe devastation throughout the state. Although there is no gage record for this time on the Saxtons River, the severity of the storm event caused significant channel adjustments, which are still observed today.

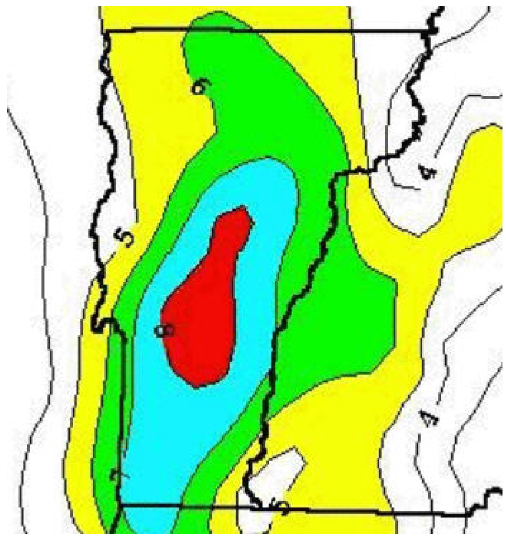

Figure 2.6 NWS Northeast River Forecast Center's predicted rainfall distribution during the 1927 flood in inches (NOAA, 2007)

Historical Channel Modification

The Saxtons River was an essential power source during the turn of the last century. Although a complete record of dam history is not available, historical photographs from the UVM Landscape Change Program reveal extensive dam activity in the Village of Saxtons River (UVM, 2009). Three (3) large crib dams once impounded the main stem for power in a variety of mill settings, most notably the Saxtons River Woolen Mill (Figure 2.7). This structure was located on Maple Street and only a foundation remains today. Upstream of the Woolen Mill two other dams were present, built on channel spanning grade controls (Figure 2.8). These structures were up and downstream of what is now the Westminster Street Crossing in downtown Saxtons River. All of these structures have led to significant aggradation of sediment upstream and altered the hydrology of the river system. We could not locate records indicating when these structures were removed or breached by flood events. The flood of 1927 could have very well been the event that demolished all three of these crib dams.

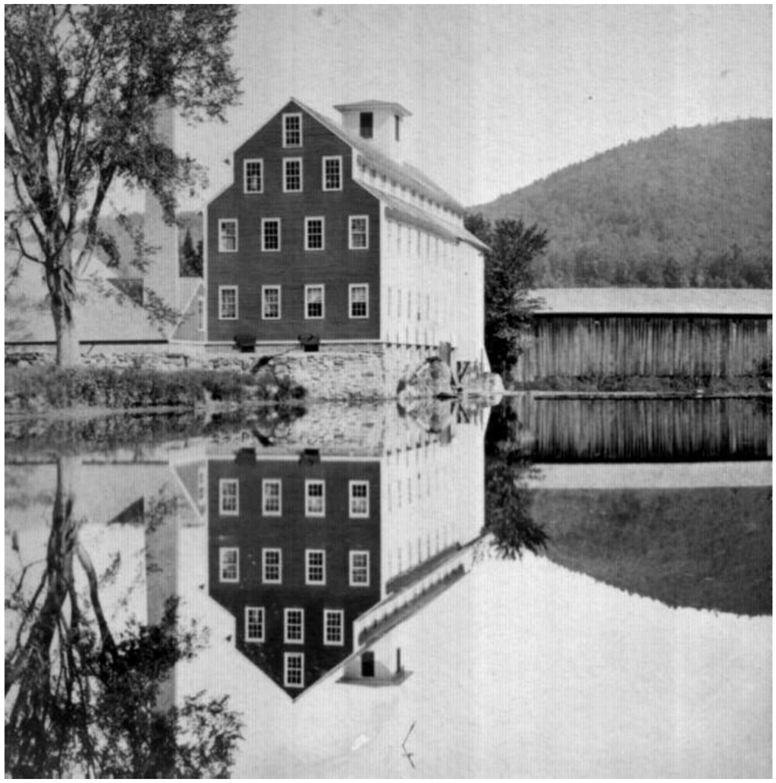

Figure 2.7 Downstream view of Saxtons River Woolen Mill and former Maple St. Bridge crossing dam located just upstream of bridge crossing (*c.* 1860 to 1890)

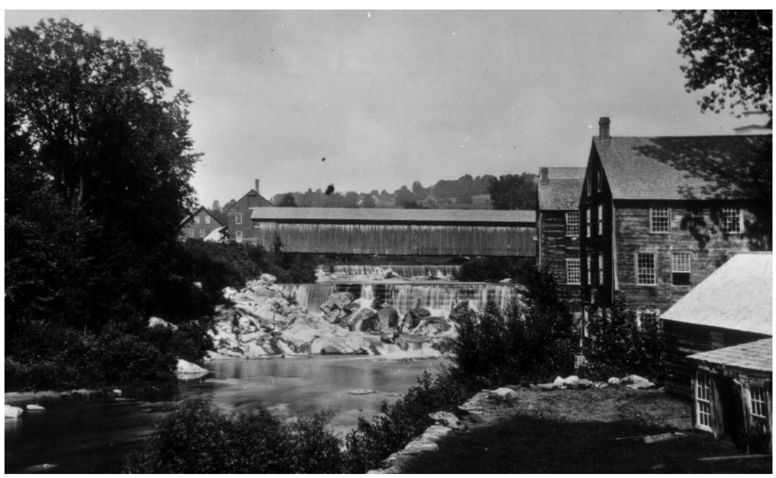

Figure 2.8 Upstream view of Westminster Street crossing and two crib dams (*c.* 1870 to 1949)

2.5 Ecological Setting

With the exception of the upper headwaters reaches west of Grafton village, the Saxtons River watershed is found within the Southern Vermont Piedmont (SP) Biophysical Region (Thompson and Sorenson, 2000). The headwaters reaches upstream of Reach M17, as well as Styles, Willie, and Howe Brooks are found within the Southern Green Mountain (SM) Biophysical Region. This SP region is found along the eastern border of Vermont and extends from White River Junction down to Massachusetts. It is characterized by gentle rolling hills and bedrock geology that supports Northern Hardwood Forest communities. Some areas of igneous intrusions (e.g., granitic plutons), such as

Ascutney Mountain and Black Mountain to the west of Brattleboro, support rare communities such as the Pitch Pine-Oak-Heath community. Rich soils of loam and silt along the Connecticut River that once supported extensive areas of silver maple (*Acer saccharinum*) and ostrich fern (*Matteuccia struthiopteris*) were converted to agricultural use during European settlement in the late 18^{th} century. Post-glacial deposits of sand and gravel are common in the river valleys of the SP region, including the main stem and tributary valleys in the Saxtons River watershed.

Elevations within the watershed range from 228 feet at the confluence with the Connecticut River, up to approximately 2,870 feet in the headwaters area north of Windham village. With an average annual rainfall of 40.2 inches (NOAA, 2008b) and a temperate climate, the forest cover is comprised primarily of mixed hardwood tree species, with areas of white pine (*Pinus strobus*) and eastern hemlock (*Tsuga canadensis*) found within younger growth and along steeper slopes, respectively.

Extensive wetlands occupy large areas within the watershed along the main stem and tributaries (NWI, 2003). Along the main stem a series of significant wetlands are found along Reach M09 just upstream of the confluence of Bull Creek and Weaver Brook. Along headwaters reaches M20, M21, and M22 there is another stretch of significant wetlands through which a low gradient channel flows. Along the low gradient tributary reaches of Bull Creek (T4.01 and T4.02) there are extensive wetlands in the wide alluvial valley. In addition, significant wetlands are found along the lower reach of Weaver Brook (T5.01) upstream of Route 121. These large wetland areas provide important flood control and water quality protection functions. Large wetlands also support continued inputs of subsurface and groundwater during the low flow periods of the year. These functions are maximized in areas where the wetland is contiguous with the channel and undisturbed by agricultural ditching or development, such as in reaches M09, M20 through M22, T5.01, and the middle section of T4.01

3.0 Methods

The Vermont River Management Program (RMP) has invested many years of effort into developing state-of-the-art Stream Geomorphic Assessment (SGA) protocols (VTANR, 2009a). The SGA protocols are intended to be used by resource managers, community watershed groups, municipalities and others to identify how changes to land use affect fluvial geomorphic processes at the landscape and reach scale, and how these changes alter the physical structure and biotic habitat of streams in Vermont. The SGA protocols have become a key tool in the prioritization of restoration projects that will 1) reduce sediment and nutrient loading to downstream receiving waters such as Lake Champlain and the Connecticut River, 2) reduce the risk of property damage from flooding and erosion, and 3) enhance the quality of in-stream biotic habitat. The protocols are based on defensible scientific principles and have been tested widely in many watersheds throughout the state.

3.1 Phase 1 and 2 SGA Methods

Phase 1 assessments employ remote sensing techniques, along with limited field verification, to identify background conditions in the watershed (VTANR, 2007). The Phase 1 approach results in watershed-scale data about the landscape (e.g., soils and land cover) and the stream channel (e.g., slope and form), providing a basis for understanding the natural and human-impacted conditions within the watershed. The Phase 2 approach builds upon Phase 1 data through the collection of reach-specific data about the current physical conditions. Characterization of reach conditions utilizes a suite of quantitative (e.g., channel geometry, pebble counts) and qualitative (e.g., pool-riffle habitat) measurements to calculate two indices: Rapid Geomorphic Assessment (RGA) Score; Rapid Habitat Assessment (RHA) score. Using the RGA scores in conjunction with knowledge about the background or "reference" conditions, a sensitivity rating is developed to describe the degree to which the channel is likely to adjust to human impacts in the future.

Phase 1 data were previously collected by Fitzgerald Environmental Associates, LLC. for the entire watershed in 2008 and summarized in the VTDEC Database Management System (DMS). A total of 20 main stem reaches were identified for initial Phase 2 assessment conducted in the summer of 2008. In the summer of 2009, 9 additional reaches recommended for Phase 2 assessment were assessed. A total of 37 segments were assessed for Phase 2 data, and data were entered into the Data Management System (DMS). All major human impacts and natural features noted during the Phase 2 surveys were indexed in a GIS using the Stream Geomorphic Assessment Tool (SGAT) and Feature Indexing Tool (FIT; VTANR, 2009a).

The Phase 2 SGA work conducted by FEA also included collection of habitat data following the New RHA protocols (VTANR, 2008a). The new protocols were developed to better describe the total available habitat in a reach by classifying different size classes of large woody debris, pools, undercut banks, and refuge areas. The protocols also put more emphasis on how land use practices and geomorphic changes can impact the habitat condition. When the current habitat condition has changed from what would be expected under reference conditions that is referred to as a stream type habitat departure (STHD). Given the timing of the SGA data collection on the Saxtons River, the new habitat parameters were collected during Phase 2 assessments, however, the DMS could not accommodate the new data. A systematic data conversion was developed by FEA to convert the New RHA data into the Legacy RHA format so it could be entered into the DMS. Table 3.1 provides the methods used to convert the data between New and Legacy RHA formats. The overall habitat condition (e.g., "fair", "good", etc.) remained the same before and after conversion. Individual parameter scores for the New and Legacy RHA can be found in Appendix B.

Table 3.1 Methods used to derive Legacy RHA data from data collected using the New RHA protocol

New RHA Step	Description	Legacy RHA Step	Description	How Legacy Data Was Derived
6.1	Woody Debris Cover	**6.1**	Epifaunal Substrate and Cover	New 6.1 = Old 6.1
6.2	Bed Substrate Cover	**6.2**	Embeddedness	New 6.2 = Old 6.2
6.3	Scour and Deposition Features	**6.3***	Velocity/Depth Patterns	New 6.3 = Old 6.3
6.4	Channel Morphology	**6.4***	Sediment Deposition	New 6.3 = Old 6.4
6.5	Hydrologic Characteristics	**6.5**	Channel Flow Status	New 6.5 = Old 6.5
6.6	Connectivity	**6.6**	Channel Alteration	New 6.4 = Old 6.6
6.7	Left River Bank	**6.7***	Riffle/Step Frequency	Avg(New 6.3 & New 6.4) =Old 6.7
6.7	Right River Bank	**6.8**	Left Bank Stability	New 6.7 = Old 6.8
6.8	Left Riparian Area	**6.9**	Right Bank Stability	New 6.7 = Old 6.8
6.8	Right Riparian Area	**6.9***	Left Bank Vegetation Protection	Avg(Old 6.8 & Old 6.10) =Old 6.9
*Note: Legacy Score Values in these steps were further modified in some reaches to individual parameter values recorded in the New RHA to better align the data.		**6.9***	Right Bank Vegetation Protection	Avg(Old 6.8 & Old 6.10) =Old 6.9
		6.10	Left Riparian Zone Width	New 6.8 = Old 6.10
		6.10	Left Riparian Zone Width	New 6.8 = Old 6.10

3.2 Phase 3 SGA Methods

FEA completed cursory Phase 3 assessments following the VTANR protocols (VTANR, 2009b) on Upper M06 and Lower T6.01-A in August of 2010. These assessments were conducted to better describe the hydraulic and hydrologic conditions of two areas identified in the project development section. More detail about the assessment can be found in Appendices E and F.

3.3 Phase 2 Quality Assurance

The RMP Quality Assurance (QA) protocols outlined in the SGA protocols (VTANR, 2009a) were followed in order to ensure a complete and accurate dataset. FEA and RMP shared responsibility for QA for the SGAT shapefiles and the finalized Phase 2 dataset. All metadata describing the data sources were entered in the Data Management System (DMS), with extraordinary sources noted in the comments section in Step 5 and Step 7. The DMS database for all assessed reaches in the watershed was finalized in August, 2010. The QA summary is included in Appendix G.

3.4 Bridge and Culvert Assessments

FEA conducted bridge and culvert surveys on all significant private and public bridges and culverts within the selected Phase 2 reaches. The Bridge and Culvert Assessment and Survey Protocols specified in Appendix C of the Vermont Stream Geomorphic Assessment Handbook (VTANR, 2009a) were followed. Latitude and Longitude at each of the structures was determined using a GPS unit. The assessment included various photos documenting the conditions of each structure.

The Vermont Culvert Geomorphic Screening Tool (MMI, 2008a) and the Vermont Culvert Aquatic Organism Passage Screening Tool (MMI, 2008b) developed by Milone and MacBroom, Inc. for VTANR were used to identify culverts within the study area that have a higher priority for replacement/retrofit due to geomorphic incompatibility and/or for being potential barriers to movement and migration of aquatic organisms.

3.5 Stressor and Departure Analysis

FEA followed the VTANR methods for developing stream corridor plans outlined in the Vermont River Corridor Planning Guide (VTANR, 2010a). This technical guide is directed towards river scientists, planners, and engineers engaged in finding economically and ecologically sustainable solutions to the conflicts between human investments and river dynamics. The guide provides explanations for the following:

- River science and societal benefits of managing streams in a sustainable manner toward equilibrium conditions
- Methods for assessing and mapping stream geomorphic conditions, and identifying and prioritizing river corridor protection and restoration projects
- Methods for examining project feasibility and negotiating management alternatives with stakeholders
- Information on current programs available to Vermont landowners, towns, and other interested parties to implement river corridor protection and restoration projects

Included in this approach is an extensive mapping exercise to lay the foundation for understanding stressors on stream channel stability at the watershed and reach scales. These maps are compiled as part of the stressor and departure analysis, and illustrate a gradient of human impacts and stream response across the watershed. The maps provide a basis for identifying projects through a step-wise procedure to screen potential projects for compatibility with equilibrium conditions.

3.5.1 Stressor Analysis

The data collected through the Phase 1 and 2 SGA studies provides the basis for assessing the impacts to the hydrologic and sediment regimes, and the channel riparian and boundary conditions. This data, when combined with other watershed-scale data developed in this study, allows for the assessment of physical departure from reference conditions, and serves to validate watershed-scale patterns and stream conditions observed in the field.

Stressor, departure and sensitivity maps have been prepared to depict the effects of significant physical processes occurring within the Saxtons River study area. These maps provide an indication of where channel adjustment processes watershed have been altered, at both the watershed scale and the reach scale. The analysis of existing and historic departures from equilibrium conditions along a stream network allows for the prediction of future channel adjustments within the watershed. This is helpful in developing and prioritizing potential river corridor protection and restoration projects.

3.5.2 Departure Analysis

Much research has shown that alluvial river channels in wide valleys will adjust their geometry and planform to accommodate changes in the discharge and sediment loading from the upslope watershed (Dunne and Leopold, 1978). This concept was summarized by Lane (1955) to show that stream power and sediment (size and distribution) will seek a dynamic equilibrium condition in the absence of anthropogenic disturbance or catastrophic natural storm events. Slight changes from one year to another, such as variation in rainfall amounts (and a resulting variation in discharge), may cause subtle changes in channel form. However, the cross-sectional shape and profile of a river is typically stable under reference watershed conditions, and predictable given knowledge about: 1) the geologic conditions of the watershed and corridor, 2) the topography of the watershed, and 3) the regional climate.

Analysis of a watershed’s sediment regime is a useful approach for summarizing the reach and watershed-scale stressors affecting the equilibrium conditions of river channels. Sediment regime mapping provides a context for understanding the sediment transport and channel evolution processes (Schumm, 1977) which govern changes in geometry and planform for river channels in a state of disequilibrium. The VTANR River Corridor Planning Guide (VTANR, 2010a) outlines a methodology for understanding the reference and altered sediment regimes of reaches according to data collected during the Phase 2 field assessments. The sediment regime types used in this analysis are summarized below in Table 3.2.

Table 3.2 Sediment regime types for corridor planning (VTANR, 2010a)

Sediment Regime	Narrative Description
Transport	Steeper bedrock and boulder/cobble cascade and step-pool stream types; typically in more confined valleys, do not supply appreciable quantities of sediments to downstream reaches on an annual basis; little or no mass wasting; storage of fine sediment is negligible due to high transport capacity derived from both the high gradient and/natural entrenchment of the channel.
Confined Source and Transport	Cobble step pool and steep plane bed streams; confining valley walls, comprised of erodible tills, glacial lacustrine, glacial fluvial, or alluvial materials; mass wasting and landslides common and may be triggered by valley rejuvenation processes; storage of coarse or fine sediment is limited due to high transport capacity derived from both the gradient and entrenchment of the channel. Look for streams in narrow valleys where dams, culverts, encroachment (roads, houses, etc.), and subsequent channel management may trigger incision, rejuvenation, and mass wasting processes.
Unconfined Source and Transport	Sand, gravel, or cobble plane bed streams; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to entrenchment or incision and associated bed form changes; these streams are not a significant sediment supply due to boundary resistance such as bank armoring, but may begin to experience erosion and erosion and supply both coarse and fine sediment when bank failure lead to channel widening; storage of coarse or fine sediment is negligible due to high transport capacity derived from the deep incision and little or no floodplain access. Look for straightened, incised or entrenched streams in unconfined valleys, which may have been bermed and extensively armored and are in Stage II or early Stage III of channel evolution.
Fine Source and Transport & Coarse Deposition	Sand, gravel, or cobble streams with variable bed forms; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to vertical profile and associated bed form changes; these streams supply both coarse and fine sediments due to little or no boundary resistance; storage of fine sediment is lost or severely limited as a result of channel incision and little or no floodplain access; an increase in coarse sediment storage occurs due to a high coarse sediment load coupled with the lower transport capacity that results from a lower gradient and/or channel depth. Look for historically straightened, incised, or entrenched streams in unconfined valleys, having little or no boundary resistance, increased bank erosion, and large unvegetated bars. These streams are typically in late Stage III and Stage IV of channel evolution.
Coarse Equilibrium (in = out) & Fine Deposition	Sand, gravel, or cobble streams with equilibrium bedforms; at least one side of the channel is unconfined by valley walls; these streams transport and deposit coarse sediment in equilibrium (stream power—produce as a result of channel gradient and hydraulic radius—is balanced by the sediment load, sediment size, and channel boundary resistance); and store a relatively large volume of fine sediment due to the access of high frequency (annual) floods to the floodplain. Look for unconfined streams, which are not incised or entrenched, have boundary resistance (woody buffers), minimal bank erosion, and vegetated bars. These streams are Stage I, late IV, and Stage V.
Deposition	Silt, sand, gravel, or cobble streams with variable and braided bed forms; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to changes in slope and/or depth resulting in the predominance of transient depositional features; storage of fine and coarse sediment frequently exceeds transport**. Floodplains are accessed during high frequency (annual) floods. Look for unconfined streams, which are not incised or entrenched, have become significantly over-widened, and if high rates of bank erosion are present, it is offset by the vertical growth of unvegetated bars. These regimes may be located at zones of naturally high deposition (e.g., active alluvial fans, deltas, or upstream of bedrock controls), or may exist due to impoundment and other backwater conditions above weirs dams and other constrictions.

** Use of the "Deposition" regime characterization may be rare, but valuable as a planning tool, where the reach is storing far more than it is transporting during some defined planning period. The extreme example would be that of an impounded reach where all of the coarse and a great percentage of the fine sediments are being deposited, rather than transported downstream. This man-made condition may change, thereby changing the sediment regime, but is not likely over the period at which the corridor plan will be used.

Channel evolution models (CEM) also provide a basis for understanding the temporal scale of channel adjustments and departure in the context of SGA Phase 2 results. Both the "D" stage and "F" stage CEMs (VTANR, 2009a) are helpful for explaining the channel adjustment processes underway in the Saxtons River watershed. The "F" stage CEM is used to understand the process that occurs when a stream degrades (incises) its bed. The more dominant adjustment process for the "D" stage channel evolution is aggradation, widening and planform change. D-stage CEM typically occurs where grade controls prevent severe channel incision and abandonment of the adjacent floodplain. The common stages of both CEMs are depicted in Figure 3.1 below.

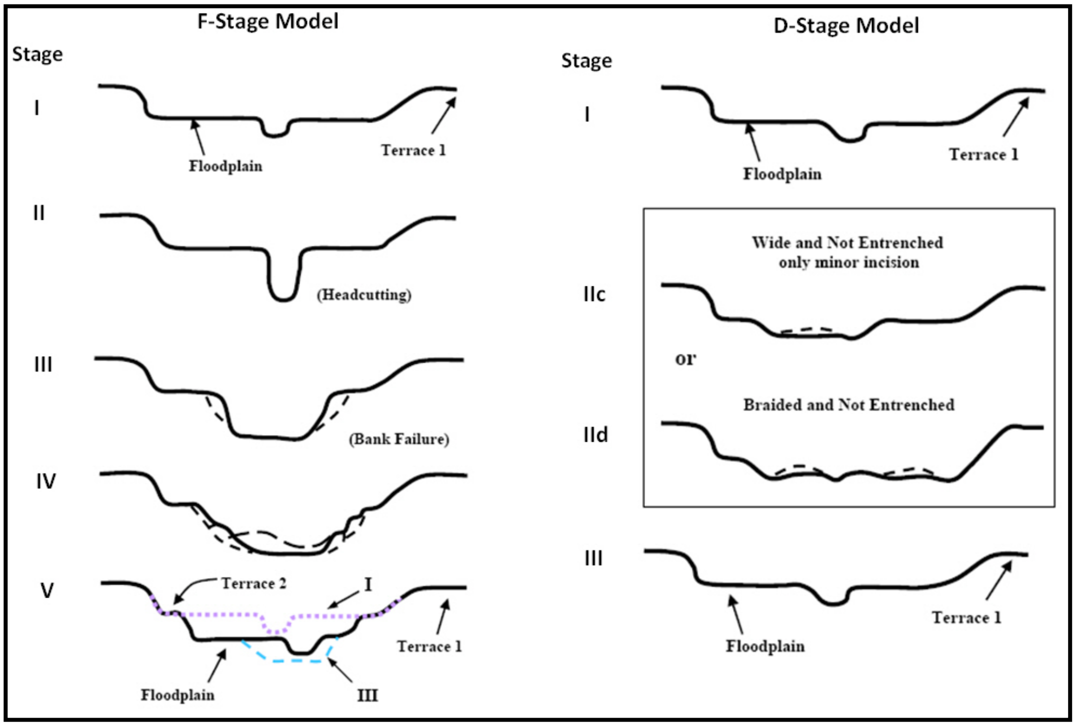

Figure 3.1 Typical channel evolution models for F-stage and D-stage (VTANR, 2009a)

3.5.3 Sensitivity Analysis

The following description of the sensitivity of various stream types to changes in sediment and flow regimes, boundary conditions and channel morphology, is included from the most recent version of the VTANR River Corridor Planning Guide (VTANR, 2010a).

> Certain geomorphic stream types are inherently more sensitive than others, responding readily through lateral and/or vertical adjustments to high flow events and/or influxes of sediment. Other geomorphic stream types may undergo far less adjustment in response to the same watershed inputs. In general, streams receiving a large supply of sediment, having a limited capacity to transport that sediment, and flowing through finer-grained, non-cohesive materials are inherently more sensitive to adjustment and likely to experience channel evolution processes than streams with a lower sediment supply, higher transport capacity and flowing through cohesive or coarse-grained materials (Montgomery and Buffington, 1997). The geometry and roughness of the stream channel and floodplain (i.e., the width, depth, slope, sediment sizes, and floodplain relations) dictate the velocity of flow, how much erosive power is produced, and whether the stream has the competence to transport the sediment delivered from upstream (Leopold, 1994). If the energy produced by the depth and slope of the water is either too little or too great in relation to the sediment available for transport, the stream may be out of equilibrium and channel adjustments are likely to occur, especially during flood conditions (Lane, 1955).

Stream sensitivity maps have been prepared for the Saxtons River study area. Sensitivity ratings were assigned using the VTANR Protocols (VTANR, 2009a).

3.6 Project Identification

Site-specific projects were identified using methods outlined by VTANR in Chapter 6 Preliminary Project Identification and Prioritization (VTANR, 2010a). This planning guide is intended to aid in the development of projects that protect and restore river equilibrium conditions. The projects identified for the study reaches can be classified under one of the following categories: Active Geomorphic Restoration, Passive Geomorphic Restoration, and Conservation.

Active Geomorphic Restoration implies the management of rivers to a state of geomorphic equilibrium through active, physical alteration of the channel and/or floodplain. Often this approach involves the removal of human constructed constraints or the construction of meanders, floodplains or stable banks. Riparian buffer re-vegetation and long-term protection of a river corridor is essential to this alternative.

Passive Geomorphic Restoration allows rivers to return to a state of geomorphic equilibrium by removing factors adversely impacting the river and subsequently using the river's own energy and watershed inputs to re-establish its meanders, floodplains and equilibrium conditions. In many cases, passive restoration projects may require varying degrees of active measures to achieve ideal results. Riparian buffer re-vegetation and long-term protection of a river corridor (e.g., corridor easements) is essential to this alternative.

Conservation is an option to consider when stream conditions are generally "good" or "reference" and the channel is in a state of dynamic equilibrium. Typically, conservation is applied to minimally disturbed reaches where river structure and function and vegetation associations are relatively intact, and/or where high quality aquatic habitat is found.

3.7 Project Development

Following the review of the preliminary projects by the corridor planning partners the list was narrowed to 5 total projects. Each project was considered in-depth and summary information found in Appendix F includes:

- A description of the site location (including a site map)
- A summary of the stressors on channel stability
- An analysis of restoration alternatives (including conceptual restoration designs)
- A list of current and potential funding and technical partners
- A review of regulatory requirements
- Cost estimates for the selected alternative
- A summary of contacts made during project development
- A discussion of next steps for project implementation

4.0 Results

The following section includes narratives describing the Phase 2 results and a summary of the watershed and reach-scale stressors on channel stability. Detailed summaries of geomorphic data for each segment, as well as a map of assessed segments, are provided in Appendix A. Habitat assessment summary data is provided in Appendix B.

4.1 Reach Narratives and Phase 2 Results

4.1.1 Saxtons River Main Stem Reaches (M01-M20)

M01-A

Reach M01 was segmented to highlight the differences in channel form below and above the grade control at the Blake and Higgins dam. Segment A is 0.2 miles in length and begins at the confluence with the Connecticut River about 800 feet downstream of the Route 5 crossing. Some structural components of the Blake and Higgins dam remain intact despite the dam being breached. The dam buttresses are situated on a bedrock outcrop, so it continues to act as a grade control (Figure 4.1). Downstream of the dam the channel is largely influenced by the backwaters of the Connecticut River during high flow events. The channel is widened and has an abundance of mid-channel bars (Figure 4.2). The channel has F-type morphology due to the additional hydraulic forces associated with the Connecticut River backwaters. The width-to-depth (WDR) and entrenchment ratios (ER) are 48.4 and 1.1, respectively. The segment has a braided bedform and predominately gravel with a median particle size of 30mm. The valley setting is narrowly confined, and both valley side slopes area extremely steep.

Figure 4.1 Blake and Higgins dam buttresses on a grade control

Figure 4.2 Several mid-channel bars in the widened channel

This segment has a unique geomorphic morphology because it is so heavily influenced by the Connecticut River. The major adjustment processes observed were aggradation and widening. The segment is considered to be in stage IId of the D channel evolution model (CEM). However, the narrowly confined valley results in an extremely low entrenchment value and the channel reflects F-type geometry with braided bedform (RGA score = "Fair"'). Much of the habitat in this segment has been compromised by the excess in sediment (RHA score = "Fair"), but large woody debris (LWD/mile = 56) and pools (pools/mile = 22) were still common.

M01-B

Segment B of reach M01 is 0.1 miles in length and set in a narrowly confined bedrock gorge (Figure 4.3). It was segmented because of the gorge setting and no cross-section was taken because of the stability of the bedrock (Figure 4.4). Administrative judgment was used to determine the geomorphic state (RGA score "good")

Figure 4.3 Upstream view from the dam at the bedrock gorge

Figure 4.4 Looking downstream at the gorge toward Route 5

M02

Reach M02 is 0.6 miles in length and extends from the reach break of M01 at the end of the bedrock gorge upslope through a wide, alluvial valley. Under reference conditions this channel is predicted to be a C-type channel with riffle-pool bedform. The channel slope of this reach is 0.3, which would suggest a slow meandering profile. However, past and present incision has led to a stream type departure from C-type to F-type channel geometry with a plane bedform. The width-to-depth ratio is 27.8, the incision ratio (IR = 2.6) and entrenchment ratio (ER = 1.2) all are indicative of the F-type morphology (Figure 4.5). The current channel geometry prohibits floodplain access, giving the reach high sediment transport capacity. The dominant substrate in M02 is cobble (47%) with a median particle size of 180mm. At the downstream reach break with M01, the bedrock gorge constricts the channel, which has caused sediment to be deposited in the form of large bars, while the rest of the reach remains relatively featureless (Figure 4.6). Upstream of the cross-section location a stream ford was observed just below the abutments of what used to be a covered bridge.

The present and historic incision has disconnected this reach from its floodplain, so any large flow event causes substantial bed scour and substrate is transported downstream. Following the F-type channel evolution model this reach shows the characteristics of stage II. Bank erosion and changes in planform are likely as this channel tries to regain stability and develop a new floodplain at a lower elevation. The geomorphic condition of M02 was “Fair” due to the extreme incision and departure from reference stream type. The transport conditions typical of F-type stream channels limits the ability for large woody debris to snag in the channel, although there were several pieces on the channel margins (LWD/mile = 33). Pools were infrequent, with one rank 7 pool downstream of the old bridge abutments (pools/mile = 8). The overall habitat condition was influenced by the geomorphic instability of this reach (RHA score = “Fair”).

It should be noted that the high incision ratio in the reach may be exaggerated by the height of a glacial terrace (not a recently abandoned floodplain) above the current bankfull channel. Although the soils surrounding this reach are mapped by NRCS as “alluvium”, it is unclear whether this apparent floodplain was formed by recent river processes (hundreds of years old), or whether it is a relict of older, glacial processes (thousands of years old).

Figure 4.5 M02 cross-section location w/ F-type geometry

Figure 4.6 Sediment aggradation at steep riffle near M01

M03-A

Reach M03 was segmented because of several grade controls that altered the channel morphology upstream of the Covered Bridge Road crossing. Segment A is 0.8 miles in length and extends upstream from the change in confinement at the reach break with M02, up to the segment break just upstream of the Covered Bridge Road crossing. The average channel slope of this segment is about 1.8%, but a lot of the slope change occurs at the three grade controls (including Twin Falls), which account for 41 feet of the elevation differences (Figure 4.7). The segment is semi-confined by its valley and the channel geometry is characteristic of B-type channels (WDR = 29.0, IR = 1.5, ER = 2.2) with a subclass slope of c, because of the low slope. The segment exhibits plane bedform and cobble is the dominant substrate (64%). The median substrate size from the pebble count was 90 mm. One mass failure was observed in the downstream end of this segment. The failure was approximately 81 feet high and 100 feet in length (Figure 4.8).

Figure 4.7 The grade control downstream of Covered Bridge Rd

Figure 4.8 Mass failure located on right bank

The segment is mostly a transport-based channel. Unlike downstream reach M02, these characteristics are more natural for this system given its confinement and slope. No stream type departure from reference conditions was observed for this segment. Only minor aggradation of sediment from the mass failure and some historical degradation, along with some widening and planform shifts reduced the geomorphic stability of the segment (RGA score = “Fair”). The channel is in stage II of the F-model of channel evolution. Potential for woody debris to remain in the channel was reduced by the geomorphic conditions of the segment (LWD/mile = 20). Pools were present and predominantly ranks 6 and 7 (pools/mile =9). The habitat condition was negatively influenced by the lack of woody debris and the lack of connectivity caused by Twin Falls (RHA score = “Fair”).

M03-B

Segment M03-B begins just upstream of the Covered Bridge Road crossing and extends upstream about 1.1 miles to the reach break about 800 feet upstream of the I-91 crossing. The channel geometry is indicative of C-type morphology and the bedform is plane bed. The bed slope is approximately 0.5% and the confinement type is narrow. The bed substrate is predominately cobble (46%) and coarse gravel (28%) with gravel median substrate (55mm). The width-to-depth ratio observed at the cross-section seems to be slightly lower than widening observed in other parts the segment (WDR = 30.8; Figure 4.9). The entrenchment ratio is characteristic of C-type channel morphology (ER = 2.9) and the incision ratio suggests moderate degradation (IR = 1.5). The lower end of this segment has significant aggradation upstream of the grade control at the road crossing. There, the sediment has formed several large bar features suggesting past incision, widening, and now a shift in planform (Figure 4.10).

Figure 4.9 Widening looking upstream at cross-section location

Figure 4.10 Diagonal bar upstream of segment break

The geomorphic stability seems to be reduced by the extensive degradation and planform changes throughout the segment and aggradation in the lower-segment (RGA score = “Fair”). The current stream channel has a slightly disconnected floodplain and the channel is in stage III of the CEM. This has impacted the availability of habitat and the normal spacing of pools and riffles expected with a riffle-pool bedform has been replaced by relatively featureless plane bed form (RHA score = “Fair”). In several areas along both banks buffer widths less than 25 feet and bank erosion were observed. Limited woody debris was found within the bankfull area (LWD/mile = 15). Pools were limited as well (pools/mile = 8).

M04

M04 is approximately 0.9 miles in length. The reach extends from the break with M03-B near I-91 at the confluence with T1.01 up to the change in confinement and slope upstream of Town Highway 99. The morphology reflects F-type channel morphology with plane bedform. The substrate observed in this segment was predominately coarse gravel (44%) and cobble (43%). The reach has a slope of 0.39% and a broad confinement. However, incision has disconnected the channel from its floodplain and the stream has departed from a reference C-type channel to its current morphology (IR = 2.2). The channel has historically been straightened (85%). The width-to-depth and entrenchment ratios are both characteristic of the stream type designation (WDR = 33.3; ER = 1.3) The tributary entering the right side of the channel mid-reach is rejuvenating and causing sediment to be washed downstream and deposit in the form of a mid-channel and diagonal bar (Figure 4.11; Figure 4.12).

Figure 4.11 Rejuvenating tributary located mid-reach

Figure 4.12 Diagonal riffle located mid-reach

The geomorphic stability of this reach has been greatly altered by the down-cutting of the channel and subsequent aggradation and widening (RGA score = “Poor”). The CEM stage is III; it appears that most incision has already taken place and widening and changes in planform will continue to drive the channel evolution process. The plane bedform and unstable geomorphic condition has greatly altered the habitat structure as well. This reach had very few prominent pools (pools/mile = 9), and little woody debris (LWD/mile = 9). The coarse substrate was embedded by fines and silt making this reach one of the lowest scoring reaches in the watershed (RHA score = “Poor”).

M05

Reach M05 is approximately 1.3 miles in length with a channel slope of 0.5%.The downstream end of the reach begins at the change in confinement and slope upstream of Town Highway 99 and ends about 420 feet downstream of the Main Street Road crossing in the Village of Saxtons River along Oak Street. The valley in M05 is semi-confined and the channel has a plane bedform. The channel exhibits B-type channel morphology with a subclass slope of c (Figure 4.13). The width-to-depth ratio of the channel reflects constant bank scour (WDR=33.2) and the channel is moderately entrenched (ER = 1.4) but still considered a B-type channel. Incision was observed (IR = 1.6) at the cross-section where a small floodplain remains. The substrate composition is predominately gravel (44%) and cobble (37%) with a median substrate size is 48 mm. The USGS gage is located on this reach just upstream of the Hall Bridge Road crossing. At the crossing the channel is constricting the floodprone flow, which is leading to some minor deposition at the gage location upstream of the bridge.

About 30% of the right corridor is developed and the residential buildings found within the corridor could be at risk during extreme events, especially where the valley wall broadens in the upper reach (Figure 4.14). The geomorphic condition is “Fair” and widening is the dominant adjustment process. The channel is in stage III of the CEM because of its moderate widening and incision. The habitat condition has been reduced by the availability of wood (LWD/Mile = 2) and pools (Pools/Mile = 5; RHA score = “Fair”). The buffer and bank condition is adequate for much of the reach keeping the condition “Fair” despite the low woody debris and pool densities.

Figure 4.13 Looking upstream at B-Type channel

Figure 4.14 Development on the RB along Route 121

M06

Reach M06 begins at the reach break near Oak Street and extends upstream 1.2 miles to the confluence with Tributary T2.01 north of Westminster West Road. The average channel slope of M06 is approximately 1.0% and the confinement is narrow. The current stream type is C and the dominant bedform is riffle-pool (WDR = 45.2, ER = 2.7, IR = 1.5). The stream type observed in this reach fluctuates, and human impacts from encroachments have caused some areas to become significantly entrenched. In the lower reach the channel is very similar to that of M05. This section of the reach was not segmented because of its short length. The substrate is predominately cobble (48%) and the median substrate size is 95mm. Many grade controls were noted during the field assessment. Downstream of the Westminster Street Crossing a large waterfall grade control was present, but the rest of the grade controls were small ledges either at grade or only a few feet above the height of water.

The channel is developed and encroached upon on both banks for a large portion of its length. Encroachment and development spans 90% and 75% of the channel's length, respectively. There are also several areas that have been straightened historically. The impacts associated with anthropogenic activities on this channel are very evident. Historical photographs indicate that at least 3 crib dams were once located in this reach (Figure 4.15). These dams caused significant aggradation of sediment which may explain why this reach has such a high width-to-depth ratio. Following the removal of the dams the channel most likely down-cut, leading to some incision observed in all cross-sections. The primary adjustments in this reach widening and aggradation (RGA score = "Fair"). The grade controls observed on this reach offer considerable vertical stability to the channel and have halted any further down-cutting that may have occurred after the crib dams were removed. Two berms can be found on the left bank at the upstream end of the channel. These features protect the hay field along Route 121 from flooding and prevent the channel from fully accessing its floodplain (Figure 4.16). A cursory Phase 3 survey was completed at the berm area to explore the possibility of removal. This is discussed in detail in Appendices E and F. Two road crossings at Main Street and Westminster West Road both have some deposition upstream of the structures, which led to a decreased aggradation score for the RGA. The channel is currently in stage III of the CEM and it is unlikely that evolution will continue until substantial planform adjustments take place. Woody debris was observed at a density of 17 LWD/mile and pools were infrequent (pools/mile =6). The habitat condition rating was considered to be "Fair".

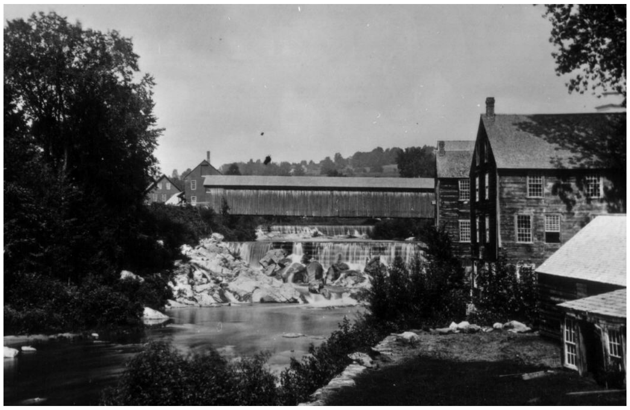

Figure 4.15 Crib dams located at the old Westminster Street crossing

Figure 4.16 Berm observed along the left bank in upper reach

M07

Reach M07 begins at the confluence of the Main stem with Tributary T2.01 and extends upstream 0.9 miles to the confluence with Leach Brook (T3.01). The channel slope is approximately 1.1% and the confinement is narrow. The current and reference stream type for this channel is B_c and the dominant bedform is plane bed (Figure 4.17). The substrate type is gravel, with 28% coarse gravel and 10% fine gravel. The median substrate size recorded at the cross-section location was 50mm. The channel geometry reflects the B-type designation (WDR = 22.8, ER = 1.6, IR = 1.2). Minor bank erosion was observed on both banks, but the bank margins were largely stabilized by deciduous species and shrubs. (Figure 4.18)

Figure 4.17 Plane bedform with little habitat

Figure 4.18 Bank erosion on the right bank

Although development and encroachment are common in this reach the channel is well buffered on both sides. The dense riparian cover has aided in the geomorphic stability of this reach. M07 only has some minor aggradation and widening in areas where the riparian buffer reduced. The overall geomorphic condition is stable and in stage I of F-model of the CEM (RGA score = “Good”). However, the nature of the stream type and bedform limits the habitat availability (RHA score = “Fair”). The reach is primarily transport based, which limits the potential for woody debris to attenuate (LWD/mile = 21). Pools were very limited (pools/mile = 6)

M08

M08 begins just upstream of the confluence with T3.01 (Leach Brook) and extends upstream 1.3 miles to the reach break at the confluence with T4.01 (Bull Creek). This reach has an average slope of 0.5% and a narrow confinement. The channel exhibits C-type morphology and the bedform is riffle-pool. The dominant substrate observed was cobble (43%) and the median substrate size was 60mm. Channel geometry reflects some widening (WDR = 28.5), with minor incision (IR = 1.6), and C-type entrenchment (ER = 3.2; Figure 4.19). One channel crossing, at McBride Road, seemed to be causing some bank scour and deposition above. The upstream end of the reach on the left bank had reduced buffer width because cattle are allowed to graze up to the channel's edge.

Upstream, in reach M09, channel migration and widening is causing sediment to be transported downstream. Reach M08 is aggrading the coarse substrate from upstream and its channel is also widening (RGA score "Fair"). The channel is currently in stage III of the CEM. M08's habitat condition does not seem to be seriously impacted by the aggrading sediment. However, the excessive widening and lack of woody debris (LWD/mile = 15) is reducing the habitat condition (RHA score = "Fair"). Pools were limited (pools/mile = 10), but several nice habitat features including undercut banks were noted (Figure 4.20).

Figure 4.19 Channel geometry indicative of C-type morphology

Figure 4.20 Undercut bank located in area of migration

M09

M09 is 0.8 miles in length and has an average slope of 0.8%. This reach begins at the confluence with T4.01 (Bull Creek) and extends up to about 650 feet upstream of the Route 121 crossing. This reach has changed significantly over the last half a century. Figure 4.21, shows some of the migration features that have been discerned using aerial photography from 1962 and 1999. The background imagery is the 2008 NAIP imagery, showing the channel's current location. M09 is unconfined and set in a broad alluvial valley, which has made these abrupt changes in planform possible. The channel geometry reflects D-type morphology with riffle-pool bedform. The high width-to-depth ratio is indicative of this stream-typing (WDR = 44.5; ER =4.0; IR = 1.3). This channel has moved extensively through the valley and the bar and bed features are rapidly changing. The dominant substrate observed was cobble (48%) with a median particle size of 98mm. It is likely that the dominant channel could avulse and permanently head south and enter into T4.01 (Bull Creek) about 500 feet west of the current confluence point.

The upper section of this reach transitions into a more straightened and confined setting similar to upstream reach M10. The Phase 1 reach break would have been better placed approximately 500 feet downstream of the Route 121 crossing. This reach as not segmented because: 1) the upper, straightened section represented a minority of the reach length, and 2) the Phase 2 valley walls, rather than a potentially different stream type, will determine the extents of the FEH zone in the upper reach.

The multiple flood chutes present, along with aggradation and side bar development indicates widening and planform changes. The geomorphic condition is highly unstable and the lack of grade controls has likely led to the advanced stage of the CEM (RGA score = "Fair"; CEM stage = IId, D-model). Some restoration efforts were made on the right bank (Figure 4.21). There, willow plantings and rip-rap were installed to prevent further channel migration and potential avulsions out into the hay field to the southeast. The habitat was influenced by the shallow nature of the channelized flow (Figure 4.22). Pools were limited (pools/mile = 9), and the channel was often too shallow to support a diverse assemblage of aquatic species. Woody debris was quite low (LWD/mile = 17) and the habitat condition seemed to reflect the geomorphic condition (RHA score = "Fair").

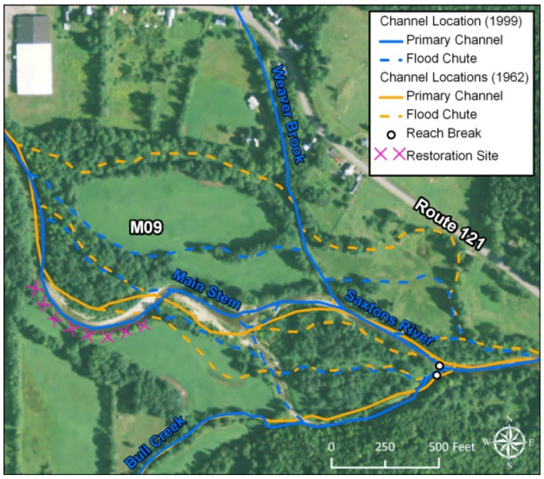

Figure 4.21 Channel migration and braiding in the last 50 years

Figure 4.22 Wide, shallow channel with little available habitat

M10

Reach M10 begins just upstream of the Route 35 and Route 121 intersection and extends upstream 0.6 miles to the reach break downstream of the next Route 121 crossing. The channel slope is approximately 0.9% and the valley is semi-confined. The substrate in M10 is predominately gravel with 25% coarse gravel and 12% fine gravel. The median particle size is 70mm. M10's morphology reflects B_c-type channel geometry and the bedform is plane bed. There was no incision at the cross-section location (IR = 1.0), but in the lower reach where the channel is encroached upon by Rt. 121 there is a slightly elevated human floodplain (Figure 4.23). The width-to-depth ratio and entrenchment ratios were both indicative of the B-type channel geometry (WDR = 27.2; ER = 1.5). In addition to the encroachment by Route 121, some areas of the reach had development along the right bank and buffer widths that were less than 25 feet (Figure 4.24).

Figure 4.23 Human elevated floodplain in lower reach

Figure 4.24 Buffer width <25ft and development on right bank

The geomorphic condition of the reach was negatively influenced by degradation resulting from bank armoring and encroachment, mostly in the lower reach (RGA score = “Fair”). The encroachment and armoring, as well as the presence of large boulders on the banks have limited the channel’s ability to widen in response to historical degradation and the reach is in stage II of the CEM. The habitat condition has been reduced by the degradation of the channel and the bank and buffer conditions (RGA score = “Fair”). This reach had the lowest woody debris density in the main stem (LWD/mile = 7). The low woody debris count can be attributed to the plane bedform and the limited buffer width. Pools were present at a higher density in the upper portion of the reach than the lower (pools/mile = 30).

M11

M11 is one mile long and has an average channel slope of 0.9%. The reach begins downstream of the Route 121 crossing near The Dug Road and extends upstream to just downstream of the next crossing of Route 121. The channel exhibits C-type morphology with riffle-pool bedform (Figure 4.25). The width-to-depth ratio of this reach is 25.8, the entrenchment ratio is 2.8, and the incision ratio is 1.4. The substrate is predominately cobble (50%) with some coarse gravel (23%), and the median particle size is 75mm. The riffles and pool sequences are well spaced but the riffles themselves are sedimented by more mobile substrate. The upper and lower sections of this reach are encroached on both sides. The Dug Road and Route 121 encroach upon the lower portion of M11, and an unnamed driveway and Route 121 encroach on the upper part of the reach. The encroachment totals about 47% of the channel’s length. Some development and reduced buffer widths were also noted along this reach. A large flood chute was observed along the left bank mid-reach. This feature could have been an old road that got scoured out during a large flow event. The abutments of a historic channel crossing remain downstream of the current Route 121 crossing near The Dug Road. There the channel has several well developed pools that exceeded 4 feet in depth (Figure 4.26).

Figure 4.25 Cross-section looking upstream at C-type geometry

Figure 4.26 Deep pool feature downstream of Rt 121 crossing

The channel is in a state of widening due to past incision. The reach is currently in stage III of the D-channel evolution model. The current geomorphic condition is impacted by the limited access to floodplain throughout the reach caused by the road encroachments (RGA score = “Fair”). Habitat was limited due to low sinuosity, woody debris (LWD/mile = 15) and pool/ riffle formation (pools/mile = 18). The areas of the reach with limited buffer width and poor riparian species also reduced the habitat condition (RGA score = “Fair”).

M12

Reach M12 begins just downstream of the Route 121 crossing and extends upstream 0.8 miles, ending about 600 feet downstream of the dairy farm operation that is located in the right corridor. The channel exhibits B-type morphology with a slope of 0.9%, so a subclass slope designation of c was used. The width-to-depth ratio and entrenchment ratios are consistent with the type (WDR = 30.4; ER = 1.5). Human elevated floodplain associated with Route 121 has led to an incision ratio of 1.3 and a human elevated incision ratio of 2.1. The valley is semi-confined and the bedform is plane bed (Figure 4.27). The substrate in M12 is mostly gravel (42%) and cobble (40%), with a median particle size of 70mm.

The channel is encroached upon entirely by Route 121, which has led to substantial changes in the natural geomorphic adjustment processes. Incision caused by road encroachment has caused a stream type departure, from C to B_c due to lack of extensive floodplain (RGA score = "Fair"). The stream is in stage II of the F-model of CEM. Some meandering profile and habitat formation was noted in the lower reach, but extensive historical channel encroachment has led to a simplified form with limited habitat. Fine sediment deposition also reduces the viable habitat (RHA score = "Fair"; Figure 4.28).

Figure 4.27 Plane bed, featureless channel along Route 121

Figure 4.28 Fine sediment deposition near Route 121 crossing

M13

M13 begins at the reach break along Route 121 and extends upstream to the confluence with the South Branch (T6.01). This reach totals 1.6 miles in length and has an average slope of 1.2%. The valley is semi-confined due to human-caused changes in the valley width associated with Route 121. By reference this reach is C-type with a riffle-pool bedform, but the encroachment from the road has caused the stream to incise and the current stream type is B (Figure 4.29). The channel has a subclass slope type of c (slope = 1.3%) and the bedform is plane bed. The stream type departure was induced by degradation and a human elevated floodplain (HEIR = 2.5; IR = 1.8). The width-to-depth and entrenchment ratios are 20.8 and 2.1, respectively. The substrate in this reach is predominately cobble (43%), with some gravel (29%).

Figure 4.29 M13 cross-section with human elevated floodplain on right

The encroachment from Route 121 has reduced the floodprone width and led to channel incision and loss of habitat. The reach is primarily adjusting by degradation and the channel is in stage II of the CEM (RGA score = "Fair"). Additional clearing in the buffer and along the left bank has further reduced LWD recruitment potential (LWD/mile = 29; Figure 4.30). Two large mass failures on right bank are supplying a moderate amount of sediment downstream. Also, a road ditch/tributary input off the left bank is rejuevenating and causing significant sediment to be washed downstream. Fine sediment in pools (pools/mile=22) and the loss of bank and buffer stability through encroachment and development has led to a decrease in the habitat quality (RHA score = "Fair").

Figure 4.30 Buffer clearing and development in the left corridor

M14

M14 begins at the confluence with the South Branch (T6), and extends up through the village of Grafton. The channel is 0.5 miles in length and has a slope of 1.2%. The valley confinement is broad, with evidence that the valley wall has been reduced slightly due to human structures in the village such as roads and houses. By reference, the reach is C-type with riffle-pool bedform. The encroachment and development within the village has caused the bedform to become plane-bed, but the stream type remains C. The width-to-depth (WDR = 20.9) and entrenchment (ER = 2.8) ratios are indicative of the stream typing. Substrate in this reach is predominantly cobble (49%), with a median particle size of 68mm. Rip-rap and hard bank armoring were observed from the reach break to about 200 feet upstream of the Main Street crossing (Figure 4.31). The total armoring spanned 46.5% and 17.5% of the channel length for the right and left banks, respectively (Figure 4.32). The armoring has limited the channel from its floodplain in some places natural floodplain is slightly raised (IR = 1.3). The Main Street crossing in Grafton Village is constricting the channel and causing some fine sediment to deposit upstream in a steep riffle.

Figure 4.31 Rip-rap on the right bank downstream of Main St

Figure 4.32 Hard bank upstream of the Main Street

M14 has considerable historic planform changes that have been caused by human activity in the form of straightening, armoring and floodplain development. The stream in this reach is largely channelized; the armoring led to past degradation and sediment from upslope is aggrading (RGA score = “Fair”). The extensive management of the stream banks and buffers has essentially stalled the reach in stage II of the CEM. It is unlikely that any further channel evolution will take place unless those structures are removed. Since the reference bedform of riffle-pool has been replaced by plane bed much of the channel’s capacity to support aquatic species has diminished (RHA score = “Poor”). Any significant pool feature has been filled in by fine sediment (pools/mile = 4) and woody debris is limited (LWD/mile = 16).

M15

Reach M15 extends 1.3 miles along Route 121 from the reach break with M14 to about 700 feet upstream of the third crossing near an Alpaca Farm. The average slope of the channel is 1.3% and the valley has a broad confinement. The channel exhibits C-type morphology with riffle-pool bedform. The width-to-depth and entrenchment ratios are 19.0 and 5.5, respectively. In areas that the channel abuts the road the channel has become incised by the human raised floodplain (HEIR = 2.0; IR = 1.4). The dominant substrate is cobble (72%) and the median particle size is 85mm. The entire channel is encroached upon by Route 121 and 36% of the right bank has a buffer width less than 25 feet (Figure 4.33). State sources indicate that gravel mining took place along this reach. Although the exact location is unknown, some incision could be attributed to the removal of sediment from the channel.

The encroachment has affected the natural channel form significantly, but not as much as it did in M14. M15 still retains a riffle-pool bedform with some regularity in its riffle spacing. The geomorphic condition is “Fair” and the large number of side bar features (13 total) indicates that the channel is beginning to change its planform and is in stage III of the CEM. The alpaca farm in the upper reach has a dredged farm ditch to divert water coming off the steep valley wall into the channel and prevent ponding in the fields (Figure 4.34). This feature could be adding significant amounts of fine sediment downstream that has been deposited as bar features. The habitat could improve in the future as more pool features form (pools/mile = 4) and more woody debris attenuates along the bar features (LWD/mile = 10; RHA score = “Fair”).


Figure 4.33 No buffer and encroachment on the left bank


Figure 4.34 Farm ditch that drains water from steep slope

M16

Like M15, M16 also runs along Route 121. The reach begins north of the alpaca farm and extends 0.7 miles upstream to the reach break by a snowmobile bridge. Reach M16 is set in a semi-confined valley. The low slope for this setting (slope = 0.8%) is causing sediment to aggrade and give the channel a plane bedform. The channel exhibits C-type morphology, with a width-to-depth and entrenchment ratio of 21.3 and 1.8, respectively (Figure 4.35). The entire length of the channel is encroached upon by Route 121, which has limited the ability of the channel to shift its planform and redevelop sinuosity. The substrate is predominately gravel (45%) and cobble (42%), with a median particle size of 60mm. Some incision on this reach can be attributed to the encroachment of Route 121 (IR = 1.6). The human elevated floodplain in the form of fill from Route 121 has made the natural floodplain much smaller (HEIR = 2.8).


Figure 4.35 M16 Cross-section looking upstream

The geomorphic adjustment process is primarily aggradation now, after historic degradation (RGA score = “Fair”). The encroachment from the road in combination with the valley’s natural confinement has created a static channel morphology with limited lateral migration. Some minor widening and planform changes are currently taking place in conjunction with the aggradation and the channel in stage III of the CEM. A stream ford mid-reach at a change of slope has a significant amount of fine sediment depositing upstream with very high embeddedness (Figure 4.36; Figure 4.37). Limited pools (pools/mile = 10) and woody debris (LWD/mile = 12), along with the encroachment reduced the habitat condition (RHA score = “Fair”).

Figure 4.36 Looking upstream at area with aggradation

Figure 4.37. Deposition of fines and high embeddedness

M17

M17 is a short reach, 0.4 miles in length that extends from a snowmobile crossing to about 1,400 feet upstream of the Route 121 crossing. This reach has a slope of 1.3% and is narrowly confined because of the encroachment and fill associated with Route 121. The fill and rip-rap has a dramatic effect on the channel geometry and led to a stream type departure (Figure 4.38). The low width-to-depth (WDR = 12.6) and entrenchment ratios (ER = 1.5) are indicative of G-type morphology. The incision ration is 2.3 and the human elevated incision ratio is 2.8. A subclass slope of c was assigned to account for the slope less than 2.0%. Channel bedform in M17 is plane bed because the steep side slopes prohibit any major riffle/pool features from forming. The dominant substrate is cobble (62%) and the median particle size is 95mm.

Figure 4.38 Rip-rap and road fill on the right bank

This segment has been heavily manipulated and historical aerial photographs indicate that the channel has been moved and pressed against the valley wall (Figure 4.39). For most problematic erosion areas in this reach the management solution has been bank armoring. A mass-failure mid-reach at a stormwater outfall was recently filled with large boulders to arrest the slope failure. The geomorphic condition reflects historic and present degradation, aggradation of fine sediment, and historic changes in planform (RGA score = “Poor”). Given the extensive armoring the reach is likely to remain in stage II of the CEM. However, in the event of a powerful flood and accumulation of debris from upslope, the channel could potentially avulse to its former (natural) location across the road to the north. The chosen stream type and stream sensitivity of "extreme" reflect this future erosion hazard. The habitat has also been influenced by the anthropogenic impacts in this reach (RHA score = "Poor"). Pools are almost non-existent (pools/mile = 2) and woody debris is scarce (LWD/mile = 17).

Figure 4.39 Mass failure on the right bank that has been heavily armored

M18

Reach M18 is 0.5 miles in length and extends up Route 121 until the change in slope. The stream has B-type morphology and a subclass slope of c (slope = 1.6%). The width-to-depth and entrenchment ratios both reflect the stream typing (WDR = 22.3; ER = 1.6). No incision (IR = 1.0) was observed at the cross-section (Figure 4.40). M18's valley is narrowly confined and has human-caused change from Route 121. The encroachment and change to the valley width has not affected the bedform, which remains riffle-pool. The reach's substrate is predominately gravel (43%) and cobble (36%), with a median particle size of 55mm. Off the left bank mid-reach there is a flood chute that extends downstream about 1,100 feet and parallels the road (Figure 4.41). The flood chute had some water in it at the time of the survey, but flows through it are likely quite large during spring snowmelt.

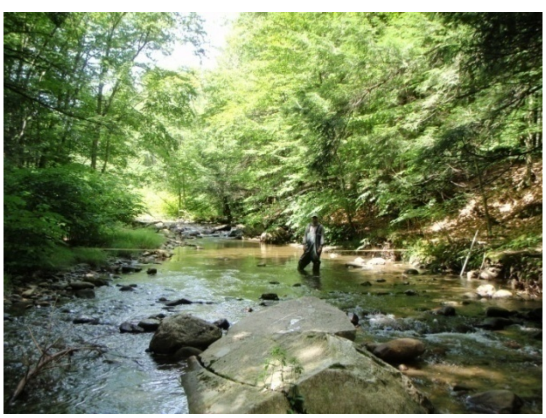

Figure 4.40 M18 cross-section looking upstream.

Figure 4.41 Flood chute off left bank that parallels Rt 121

The geomorphic condition of this reach was relatively stable (RGA score = "Good"). The stream type was consistent with phase 1 predictions with no departures and the riffle-pool formations were complete. The channel evolution stage reflects the slight narrowing of the valley from Route 121 with minor incision (CEM stage = I). A dead sculpin (*Cottus sp.*) was found in a shallow area where water remained in the flood chute. The habitat was lacking slightly because there weren't many high-quality pools (pools/mile =15) or woody debris (LWD/mille = 26; RHA score = “Fair”).

M19

M19 is 1.1 miles long, with an average channel slope of about 3.4%. This reach begins at the change in confinement near the open field and continues along Route 121. Although the reach follows the road, the channel is not encroached heavily like most of the reaches downstream. The channel exhibits B-type morphology with step-pool bedform. The width-to-depth and entrenchment ratios are both indicative of the stream type, with no incision observed (WDR = 21.9; ER = 1.3; IR = 1.0). The dominant substrate is cobble (44%), with a median particle size of 63mm. There seems to be more of a plane bedform and a shallower slope on the downstream end of this reach, however, no segmentation was made because the downstream channel shared the same geometry as the area where the cross-section was taken upstream. The crossing at Cabell Road acts as a constriction to both the bankfull and the floodprone channel width and it is causing sediment to deposit upstream. The left bank both up and downstream of the structure is heavily rip-rapped and the buffer width is less than 25 feet (Figure 4.42).

Figure 4.42 Armoring and no buffer upstream of the Cabell Road Crossing on the left bank

While Phase 2 assessments were underway a stream bank revetment project was completed on 750 feet of channel mid-reach. The land owners were concerned about the banks receding into their field and received the permits necessary to work in the channel. The reach was assessed prior to installation, and then reexamined after rip-rap lined a good portion of both banks. Prior to construction this area had the best habitat in the reach, with deep pools (pools/mile = 22), overhung banks, and woody debris (LWD/mile = 12) that slumped into the channel (Figure 4.43). The habitat features that were present in the reach prior to the revetment project yielded a “Good” RHA score. After the rip-rap was installed most of the quality habitat features were removed and all wood was removed from the channel (Figure 4.44). The current RHA score is not known, but given the extent of rip-rap and pool filling, it is likely that it would score in a lower category. Shifts in planform associated with eroding banks and some minor widening were observed. The reach scored “Fair” for the RGA. Much of the upper reach is controlled vertically by bedrock outcrops, but the majority of the channel is in stage IV of the CEM.

Some historical channel straightening was noted in the lower reach where a hay field is found in between Route 121 and the channel. Given the extensive bank armoring upstream, and the high bedload from the naturally-steep reaches above, this area could be susceptible to lateral migration in the future.

Figure 4.43 The left bank prior to rip-rapping

Figure 4.44 Rip-rap and the removal of vegetation on the LB

M20-A

M20 was segmented because of changes in the valley wall and slope observed mid-reach. Segment M20-A is 1.6 miles in length and extends up from the reach break with M19, upstream to the first crossing of Route 121. The segment has a channel slope of 4.0% and the valley is semi-confined. Channel morphology is indicative of a B-type stream and the bedform is step-pool (Figure 4.45). Width-to-depth and entrenchment ratios are both characteristic to the stream type (WDR = 20.5; ER =2.1) and some moderate incision was observed (IR = 1.5). The substrate is predominantly cobble (44%) and boulder (25%), with a median particle size of 145mm. Minor aggradation of fine substrate was noted in pebble count. Step-pool features were complete and spaced adequately in lower reach.

Figure 4.45 M20-A cross-section looking downstream

Several mass failures were noted on this segment, which can be attributed to the steep slope of the channel and the adjacent slope side (Figure 4.46). The large failures are contributing substantial amounts of fine sediment to channel and may be responsible for migration features in lower reach. An avulsion was observed where a tipped tree caused significant sediment aggradation, forcing the channel to find a new course. The role of woody debris to stabilize and to create change to the channel bed is apparent in this headwater reach. The channel is in stage II of the CEM and slightly unstable given the high energy gradient of the headwaters reach (RGA score “Fair”). The entire reach is well buffered by dense deciduous and coniferous species. Slope instability associated with the mass failures and erosion contributed lots of woody debris to the channel making for excellent habitat (LWD/mile = 104). Some pools were filled in from the excess in sediment (Pools/mile = 18), but the RHA condition was not affected (RHA score “Good”).

Figure 4.46 Large slope failure on the left valley wall

M20-B

M20-B is a long segment (2.0 miles) that extends from segment break near first Route 121 crossing in lower reach up to reach break with M21 at the beaver dam. The lower slope (1.6%) and the broad confinement of the segment made it a sub-reach with a different reference stream type. The segment exhibits C-type geometry with riffle-pool bedform. The width-to-depth ratio (WDR = 9.7) is a bit lower than what would be expected for a C-type channel because the segment is encroached upon frequently by Route 121 (Figure 4.47). The road has also elevated the floodplain (IR = 1.6), and cut off some of the channel’s ability to access the natural floodprone area on the north side (ER = 7.0). The substrate is predominantly cobble (39%) with a median particle size of 68mm. Some stretches of the stream bank in this segment were armored to protect the roadway from channel erosion or to protect a structure at a road crossing. In total, this segment had 6 bridge crossings and 1 culvert crossing. Often these structures were constrictions to both the channel and floodprone widths, and scour was noted frequently.

There are two large beaver dams on this reach. The first is located in the portion of the channel that runs between Route 121 and White Road (Figure 4.48). The second can be found in a fairly confined area upstream of the Mercy Lane Crossing. These areas were not segmented because of their short length but both actively trap sediment and change the natural fluvial condition. The major adjustment processes in M20-B are degradation and incision induced by historical channel straightening and road encroachment from Route 121 (RGA score = “Fair”). The historic incision from the road has put this segment in stage II of the CEM. It is unlikely that it will advance any further due to the rip-rap and road encroachment. The woody debris in this segment was less frequent (LWD/mile = 42) but still high compared to downstream reaches. Rt. 121 has cut off meander bends and floodplains that exist on the other side of the road over approximately 30-40% of the segment. The habitat would have been better with more pools (pools/mile = 16) and if the channel was able to take on a more natural meandering profile with the valley (RHA score = “Fair”).

Figure 4.47 M20-B cross-section looking upstream

Figure 4.48 Beaver dam downstream of White Road

4.1.2 Bull Creek Tributary Reaches (T4.01-T4.03)

T4.01-A

Segment T4.01-A is the lower most reach of Bull Creek that meets the Saxtons River main stem at an area of active channel aggradation and planform changes (Reach M09). The segment is 1.1 miles in length and has an average slope of 0.5%. The flat land of the stream corridor lends itself to agriculture and has likely been farmed and/or grazed since the Cambridgeport village area was settled in the 1700 or 1800's (Beers, 1869). The stream corridor has been continuously grazed and the channel has been manipulated and straightened since that time (Figure 4.49). The segment is situated in a wide alluvial valley with a well-formed floodplain (Figure 4.50). Under reference conditions, the channel would likely have E-type dimensions with high sinuosity, low width-to-depth ratio, and a high gravel bed load.

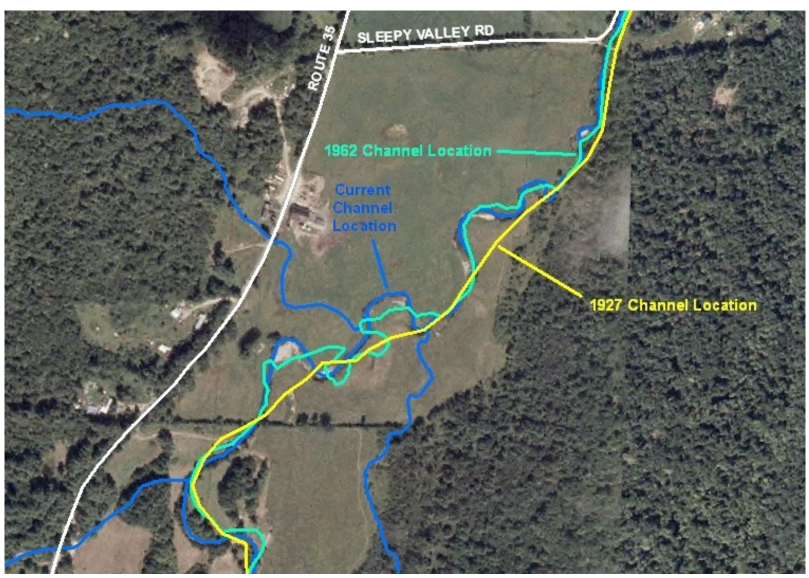

Figure 4.49 Historical channel straightening and redevelopment of meanders in T4.01-A, lower Bull Creek

Due to impacts to the channel boundaries (loss of woody vegetation) and historical straightening, the channel currently has C-type dimensions with a greater than expected width-to-depth ratio of 17.4. Segment T4.01-A remains unentrenched in the wide alluvial valley (ER = 12.6) with only minor incision (IR = 1.2). The channel bed is dominated by coarse gravel (42%); however there is an increase in fine sands (30%) that is attributable to the high degree of bank erosion (Figure 4.51).

Figure 4.50 Wide alluvial valley of T4.01-A

Figure 4.51 Bank erosion and widening in lower T4.01-A

Because the channel has a high bed load and is actively redeveloping a sinuous planform, there is potential for pool formation and undercut banks. However, the unstable banks and lack of woody vegetation limit the formation of good habitat features. The LWD and pool densities were 37 and 17 per mile respectively, both in the fair category for riffle-pool stream types. Undercut banks were also limited, and the overall habitat condition was rated as "Fair". Despite the current habitat conditions, this segment has excellent potential for habitat restoration in the long term if revegetation and corridor protection strategies are pursued. The aggradation, widening and planform processes indicate a response to historical channel straightening (stage III of CEM), and the overall RGA condition was "Fair".

T4.01-B

Segment T4.01-B begins at the segment break just upstream of a farm road crossing off Brookline Road and ends at the confluence with tributary Athens Brook (T4.S1.01). The segment is 2.0 miles in length and an average slope of 0.6%. The channel exhibits C-type morphology with a width-to-depth ratio and entrenchment ratio of 12.9 and 15.8, respectively (Figure 4.52). The substrate is predominately gravel (39%) and cobble (34%) with a median particle size of 30mm (gravel). The segment showed signs of minor incision, but not enough to drastically reduce the floodplain connectivity (IR = 1.2). Bedform in this segment was predominately riffle-pool, with some areas resembling plane bed because of historic channel straightening and armoring (Figure 4.53).

Figure 4.52 Cross-section location looking upstream

Figure 4.53 Straightened area along Brookline Road

T4.01-B is a dynamic channel with a high bed load, active meander bends, and excellent pool formation (pools/mile = 35). Most pools had good cover over a large portion of the pool area or were in conjunction with undercut banks (Figure 4.54). Existing habitat potential is very high and could be improved in the lower segment with reforestation and planting projects. The area with historical channel straightening mid-segment where the bedform is plane bed had limited habitat and slightly lowered the overall score (RHA score = "Good"). Large woody debris was common (LWD/Mile = 62). The lower segment lacks woody buffer in some areas, which has led to some moderate erosion on the outside of meander bends. Shifting planform is the dominant geomorphic adjustment observed in this segment. The overall geomorphic score was influenced because of a neck-cutoffs and other areas of possible avulsion (RGA score = "Fair"). Evidence of historic incision and some widening are good indicators of stage III of the CEM.

Figure 4.54 Pool and undercut bank located in the upper segment

T4.02

T4.02 is 0.9 miles in length with an average slope of 1.3%. The reach begins at the confluence with Athens Brook (T4.S1.01) and ends just upstream of the Tenneyville Drive channel crossing. The width-to-depth (WDR = 13.0) and entrenchment ratios (ER = 10.0) suggest C-type channel morphology and the bedform is riffle-pool. Moderate incision was observed on this reach (IR = 1.5). The substrate is predominately cobble (43%) and gravel (36%) with a median particle size of 30mm (gravel). Fine substrates were observed throughout the reach, especially in the slack water and behind woody debris (Figure 4.55). Likely sources of the increased sand and fine gravel include a large mass failure on the right bank and two blown out beaver dams observed in the upstream reach T4.03 (Figure 4.56).

Figure 4.55 Fine substrate deposits behind a boulder

Figure 4.56 Looking downstream at the mass failure

Geomorphically, this reach is nearly stable but responding to the increase in sediment from upslope sources. The reach is in stage II of the F model CEM and the RGA score is “Fair”. The lower part of this reach had good habitat features despite the increase in fine sediment from the mass failure and breached beaver dams. (LWD/mile =75; pools/mile = 28) The quality of habitat in the lower reach can be attributed to the adequate bank and buffer vegetation, as well as accessible floodplain (RHA score = “Fair”). However, the upper reach had some extensive development in the left corridor. The land was cleared there, exposing surficial material and fill. At the time of the Phase 2 survey no silt fences or sediment management practices were in place to protect the channel from sedimentation (Figure 4.57). Upstream, a pile of fill soil was within 25 feet of the channel, again with no management practices in place (Figure 4.58).

Figure 4.57 Exposed surficial material with no sediment BMPs

Figure 4.58 Fill and excavator within 25 feet of channel

The upstream end of this reach has extensive impacts to the banks and riparian zone because of development within the stream corridor. A trailer park straddles the channel and many trailers are within the floodprone area, sitting very close to the bankfull channel elevation (Figure 4.59). Structures in this area are at risk during flood events and the low buffer width has impacted the channels banks. One stream crossing in the upper reach is acting as a bankfull channel constriction. The clearance of this structure is also very low and could pose a problem during high flow events and washout (Figure 4.60).

Figure 4.59 Development and low buffer width in upper reach

Figure 4.60 Bridge with low clearance; 22 ft constriction

T4.03-A

Reach T4.03 was segmented twice to highlight differences in valley confinement and because of beaver activity. Segment T4.03-A is 0.3 miles in length with a slope of about 1.5%. The segment begins at the reach break just downstream of Valley Cemetery Road and extends upstream to the segment break where the valley width changes from narrow to very broad at the site of a large blown-out beaver dam. The channel is C-type by reference but human caused change to the valley width from Brookline Road encroachment has caused a departure and it is now an entrenched (ER = 1.3), F-type channel with a human elevated floodplain (HEIR = 2.7; IR = 2.0). The width-to-depth ratio is also slightly lower because of the impact of road encroachment on stream power and incision (WDR = 12.7; Figure 4.61). The channel exhibits plane bedform and the substrate is predominately gravel (44%) and cobble (27%) with a median particle size of 30mm (gravel).

Figure 4.61 Cross-section looking upstream with Brookline Road in the left corridor (Photo Right)

There is little evidence of continued incision and degradation; the stream type departure from C to F-type likely happened when the road was built and is an historic adjustment. The channel is in stage III of the CEM because some widening is occurring now in areas that the stream bank is not armored by the road embankment. Planform changes are occurring now as the channel tries to develop some sinuosity in the confined setting (RGA score = “Fair”). Habitat quality in this segment is reduced because of the poor buffer width and bank condition on the left side (RHA score = “Fair”).

The woody debris and pool densities are both moderate with 41 LWD/mile and 20 pools/mile, respectively.

T4.03-B

Segment B is 0.3 miles in length and was segmented because it is set in an unconfined, very broad setting and the entire channel is either currently impounded by beaver activity or recovering from the recent breaching of beaver dams. The segment has a slope of approximately 0.8% and it is located in the beaver meadow mid-reach along Brookline Road. The channel exhibits C-type channel geometry with a riffle-pool bedform. The width-to-depth and entrenchment ratios are 17.0 and 3.1, respectively. The segment does have some incision (IR =1.5), because the cross-section was taken upstream of the breached beaver dams. The current channel morphology is the result of incision through sediment that had aggraded behind the beaver dams. Substrate in this segment is predominately gravel (46%) and sand (24%) with a median particle size of 10mm (gravel).

In total, T4.03-B has 4 beaver dams (Figure 4.62). Two of them have been breached by humans or have been blown out during a large storm event (Figure 4.63). The other two dams are intact and trapping extensive amounts of sediment upstream. The channel is responding to the base water level drop following the loss of the two major dams. The changes in channel state have occurred rapidly, because in 2008 both lower dams were intact.

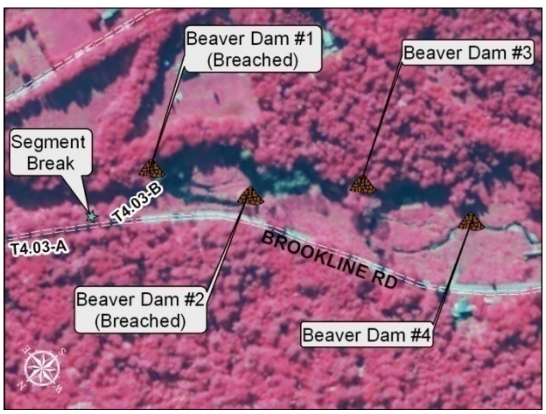

Figure 4.62 Infrared aerial imagery of the beaver dam area


Figure 4.63 Looking downstream at the second breached dam

The channel appears to be in stage III of the CEM. After the two dams were breached a headcut must have rapidly migrated upstream and slightly incised the channel, because the soft clay and sand observed in the upstream dams was not observed where the dams were breached. Now, the channel is widening and trying to develop a planform that is suitable for a stable channel morphology (Figure 4.64). At the third beaver dam the channel becomes impounded and remains impounded for the rest of the segment (Figure 4.65). The beaver dams in this segment have had a profound impact on the geomorphic condition. The removal of the beaver dams in the lower portion of the segment has triggered channel evolution to take place. The current widening of the channel is the greatest adjustment to the channel's current condition (RGA score = "Fair"). Wood was present in abundance (LWD/mile = 234) and pools were common (pools/mile = 43). The habitat in this reach was diverse because of the presence of beaver dams in the upper segment and recent loss of them in the lower segment (RHA score = "Fair").

Figure 4.64 Widening channel upstream of the second dam

Figure 4.65 3rd beaver dam causing extensive ponding

T4.03-C

Segment C is 0.7 miles long and extends up to the reach break with T4.04 just upstream of the Brookline Road crossing. T4.03-C has Cb-type geometry with width-to-depth, entrenchment, and incision ratios of 17.0, 2.4, and 1.6, respectively. The segment is set in an unconfined, very broad valley but does not have any impacts associated with beaver activity. The slope is approximately 2.6%, giving the segment a subclass slope (b). The substrate is predominately cobble (45%) and gravel (41%) with a median substrate size of 60mm (gravel). The dominate bedform was riffle-pool, but areas in the upper reach had step-pool features (Figure 4.66).

This segment is quite dynamic geomorphically and it appears to be in stage IV of the CEM. Several debris jams and slope changes move the channel between flood chutes and a new terrace seems to be present. This segment is active because of the high slope in the upstream reach and surrounding tributaries. The geomorphic condition is “Fair” because the channel is still undergoing planform shifts and recovering from the widening that occurred during stage III of the CEM. The upper section has a greater slope than the rest of the segment, but it was not separated out because of its short length. The Brookline Road crossing just downstream of the reach break is undersized, and observations in the field indicate that a large flow event recently crossed the road (Figure 4.67). The alignment issues of the culvert and constriction must have backed up the culvert and water followed the road for about 75 feet then poured down in the left floodplain of the channel. The habitat in this segment is on the threshold of good, but the dynamic nature of the channel and some impacts to riparian area have lowered its condition (RHA score = “Fair”). Woody debris is common (LWD/mile = 85) and a variety of smaller sized pools were observed (pools/mile = 27).

Figure 4.66 The start of well-formed riffle-pool in stage IV CEM

Figure 4.67 Area where channel crossed Brookline Road

4.1.3 South Branch Tributary Reaches (T6.01-T6.04)

T6.01-A

Segment T6.01-A is the lower most segment of the South Branch of the Saxtons River. It is found from the confluence with the main stem in Grafton up to a sharp 90 degree bend in the channel approximately 500 feet downstream of the Townshend Road crossing. The segment is 0.8 miles long and has an overall channel slope of 0.9%. The wide, alluvial valley and low slope would typically allow for channel and floodplain depositional processes; however historical manipulation of the river corridor has resulted in an incised channel (HEIR = 1.7; IR = 1.3) with reduced floodplain access. The channel has C-type geometry, but historical straightening (approximately 30% of the segment length) has simplified the meander profile (WDR = 21.5; ER = 4.0). By reference we would expect a channel with greater sinuosity and development of riffle-pool features. A plane bedform was noted as dominant during the field surveys, with limited development of quality pools and undercut banks. The substrate is dominated by cobble (54%). Pool, LWD, and undercut banks densities were all in the "Fair" range for riffle-pool streams. The RGA condition was rated as "Fair" due to the historical impacts from channel straightening and the incised state of the channel (CEM stage II). The RHA score was also "Fair" on account of the scarcity of habitat features for biota.

Figure 4.68 Breached dam upstream of Kidder Hill Road

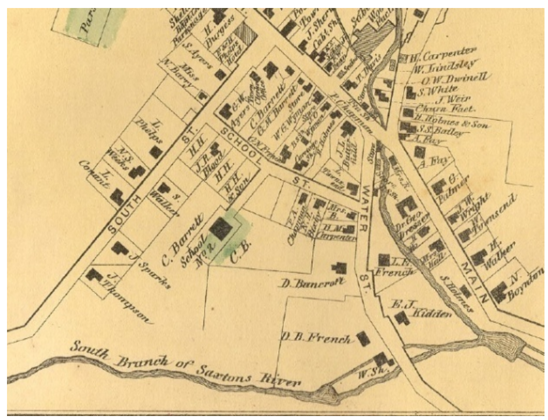

Figure 4.69 1869 Beer's Atlas showing dam and sluiceway

A section of a breached dam remains in place in the lower reach approximately 300 feet upstream of the covered bridge at the Kidder Hill Road crossing (Figure 4.68). This structure was part of a raceway diversion to a mill located along the north bank (Figure 4.69) just west of Kidder Hill Road (previously called Water Street). The structure was constructed on a grade control that spans at least half of the channel. Although the structure is partially breached, the concentration of flow and debris around the structure may limit the passage of juvenile fish into the upper reaches of the South Branch. In addition, sediment deposition occurring upstream of the structure is causing minor bank instability on the left bank. The removal of this structure to improve fish passage and channel stability is explored further in the project development summary in Appendix F.

T6.01-B

Segment T6.01-B begins 500 feet downstream of the Townshend Road crossing and continues up to the reach break with T6.02 west of Turner Hill Road. The segment is approximately one mile long and has an overall channel slope of 0.7%. Like the lower segment of this reach, the channel is situated in a wide alluvial valley that was likely occupied at least in part by the channel beltwidth prior to human settlement. The channel is highly incised due to historical channel straightening (75% of segment length) to accommodate agriculture and Townshend Road within the river corridor. Under reference conditions we would expect C-type channel geometry and greater sinuosity. Due to severe channel incision (HEIR = 2.8; IR = 2.2) resulting from straightening, bank armoring and encroachment of the road along the river corridor (Figure 4.70), a stream type departure was noted from C to F-type geometry (WDR = 13.1; ER = 1.5; Figure 4.71). The bed substrate is dominated by cobble (43%) and coarse gravel (34%), with limited fining noted in the riffles.


Figure 4.70 Bank armoring and development in the upper reach


Figure 4.71 Cross-section location looking upstream

The available habitat in this segment is severely limited by the incised channel state and lack of sinuosity. Increased stream power has caused erosion of channel features (e.g., riffles and undercut banks) and limits the retention of LWD. Density of LWD was fair, while undercut bank and pool densities were poor and well below expected levels for riffle-pool stream types. Overall RHA condition was noted as “Fair”.

Degradation was noted as the dominant process as the channel remains in an incised state (CEM stage II) following the historical impacts, and RGA condition was noted as “Fair”. Stream sensitivity is classified as “extreme” for FEH purposes due to the departure in stream type. It is unclear whether future lateral adjustments within the segment would ever cause the river meanders to reoccupy the wide valley on the east side of Townshend Road. The FEMA flood mapping indicates that the extents of the 100 year flooding are bound by the western edge of the Townshend Road embankment. However, to conservatively map the FEH zone for future channel adjustments, the valley wall limits have been extended beyond Townshend Road since extreme channel adjustments and/or avulsions to the east cannot be ruled out.

T6.02

T6.02 begins at the reach break just downstream of the Townshend Road crossing near Zeller Camp Road up to the confluence with Howe Brook (T6.S1.01). The reach is 0.9 miles in length with an average channel slope of 1.1%. By reference T6.02 would be a C-type channel with riffle-pool bedform. However, extensive straightening and encroachment by Townshend road has caused a departure from reference channel morphology and now it has Bc-type channel geometry with plane bedform (WDR = 20.9; ER = 2.1; Figure 4.72). The channel is incised currently (IR = 2.0), but fill associated with Townshend Road has led to a human elevated floodplain and a higher incision ratio (HEIR = 2.5). The substrate is predominately cobble (67%) and the median particle size is 103 mm (cobble). The valley is still considered to be unconfined and very broad, because the Townshend road encroachment may not act as a valley wall in the largest flooding events and the height of the road encroachments are variable (Figure 4.73).

Figure 4.72 Cross-section location looking upstream

Figure 4.73 Townshend Rd. encroachment with HEF and B<25ft

Degradation and planform changes are the primary adjustments that have taken place as a result of the human manipulation of the channel. The extensive straightening and encroachment to this channel has negatively impacted its geomorphic condition and the channel will likely remain in stage II of the CEM (RGA score = “Fair”). A mass failure was observed in the lower reach where the channel is adjacent to the left valley wall (Figure 4.74). The failure is starting to re-vegetate on one end, but the other end is still actively contributing sediment to the downstream reach. The channelized nature of the reach, with plane bedform has limited the available habitat (RHA condition = “Fair”). The altered channel morphology also lowers the channels ability to attenuate LWD (LWD/mile = 26) and pools were mostly small and with poor cover (pools/mile = 12).

Figure 4.74 Large mass failure located in the lower reach on the left valley wall

T6.03

Reach T6.03 is 0.9 miles in length and begins at the confluence with Howe Brook (T6.S1.01) and ends at the confluence with Willie Brook (T6.S2.01). The reach is very similar to that of T6.02; it is almost entirely encroached upon by Townshend road and has a slope of 1.1% (Figure 4.75). The upslope drainage area is smaller because Howe Brook has a watershed area of 5.1 square miles. By reference T6.03 would be a meandering C-type channel with riffle-pool bedform, but impacts from encroachments and straightening have caused a stream type departure. T6.03 now exhibits Bc-type channel geometry with a width-to-depth ratio of 20.4 and an entrenchment ratio of 2.1 (Figure 4.76). The substrates are predominately cobble (42%) and gravel (33%) and the median particle size is 60mm (gravel). The straightening and encroachment have led to a change in bedform; T6.03 currently has plane bedform.


Figure 4.75 Straightened channel with encroachment


Figure 4.76 Cross-section location looking upstream

The geomorphic condition of this reach has been severely degraded by human impacts to the corridor. The current valley width is very broad, because Townshend Road may not act as a permanent confining feature in the largest storm events. The loss of floodplain connectivity (HEIR = 2.9; IR = 1.7) through historic degradation and planform shifts (straightening) have trapped this reach in stage II of the CEM (RGA score = "Fair"). The upper reach has some aggradation of sediment that washed down Willie Brook during the two floods in the late 1990's. Evidence of dredged boulders and cobbles remain on the left bank (Figure 4.77). Habitat conditions have been reduced due to the plane bed nature of the channel. Wood (LWD/mile = 19) and pools are limited (16 pools/mile), but the right bank and riparian buffer has good vegetation and no human impacts (RHA condition = "Fair").


Figure 4.77 Dredged materials on the left bank near the confluence with Willie Brook in the upper reach

T6.04-A

Reach T6.04 was segmented to account for the impact of encroachment from Townshend Road in the lower reach, as well as the alluvial fan characteristics in the upper reach. Segment T6.04-A begins at the confluence with Willie Brook and ends upstream at the Townshend Road crossing. The segment is 0.25 miles in length with a channel slope of 0.7%. As with downstream reaches influenced by the presence of Townshend Road in the stream corridor, channel straightening was noted for a majority of this segment. Under reference conditions, the channel would likely have greater sinuosity and development of riffle and pool features. Sinuosity and development of these habitat features is nearly absent due to the road impacts. C-type channel geometry was noted in the cross-section survey (Figure 4.78), however the channel remains in an incised state (HEIR = 1.9; IR = 1.2) due to road impacts. The width-to-depth and entrenchment ratios are 22.5 and 5.8, respectively. Significant sediment deposition was noted within the Townshend Road Bridge at the segment break (Figure 4.79). During the 1996 flood, the build-up and failure of a debris jam behind this structure resulted in a flood wave in downstream reaches that caused significant flooding.

Figure 4.78 Cross-section mid-segment in T6.04-A

Figure 4.79 Sediment deposition within undersized bridge

Some channel aggradation and widening were noted in the cross-section mid-segment. Straightening within the alluvial fan in the upstream segment may be causing excess sediment transport into this area. Some fining in the bed substrate was noted, and the overall RGA condition for the segment was noted as “Fair” with a CEM stage of III. Pool and LWD densities were within the expected ranges for riffle-pool stream types; however a majority of these features fell within the smaller size classes, indicating a lack of habitat diversity. Impacts to the bank and buffer conditions resulted in an overall rating of “Fair”.

T6.04-B (Styles Brook)

Upstream of the final Townshend Road crossing the South Branch is known locally as Styles Brook. Segment T6.04-B was delineated at the road crossing to capture the tendency of this segment to act as an alluvial fan similar to downstream segments for Howe and Willie Brook. T6.04-B begins at the Townshend Road Bridge and extends 0.6 miles upstream to the confluence with another significant tributary entering from the south. The overall channel slope is 3.0%; however the slope lessens in the downstream section proximate the Townshend Road crossing. This lower section of Styles Brook would be a highly depositional area under reference conditions. Sediment transported down the steep, confined headwaters channels to the west would have been deposited over a large, 10-acre area west of Townshend Road. Historic stone walls built along the south banks of Styles Brook (Figure 4.80) provide evidence that the planform of this segment was likely manipulated when the land was settled in the 1800’s. Since this time, the channel has been dredged multiple times following flood events in the 1970’s and 1990’s, and recent windrowing was evident in the lower segment.

Figure 4.80 Old stone walls along the left bank of Styles Brook

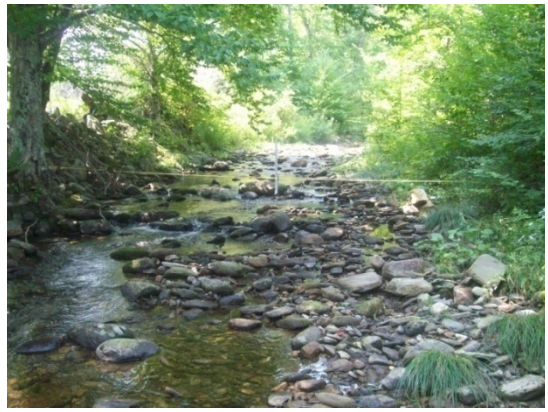

Figure 4.81 Cross-section mid-segment on T6.04-B

Due to the severe manipulation of the channel geometry from dredging and straightening, the channel has departed from its reference condition. Under natural conditions, we would expect a braided stream form (D-type) that would have flooded frequently and flowed diffusely into the South Branch downstream. Berms have been constructed to contain flood flows from the largest flow events; the structures result in F-type channel geometry (Figure 4.81). The width-to-depth, entrenchment, and incision ratios are 16.9, 1.4, and 1.1, respectively. Human-caused change to the floodplain has caused a human elevated incision ratio of 2.4 (Figure 4.82). This channel manipulation has resulted in a simplified bedform that will be stable only until the next large flood event. Habitat conditions are extremely degraded as a result the major channel modifications, limited pool development, and reduced woody debris density (RHA score = “Poor”)

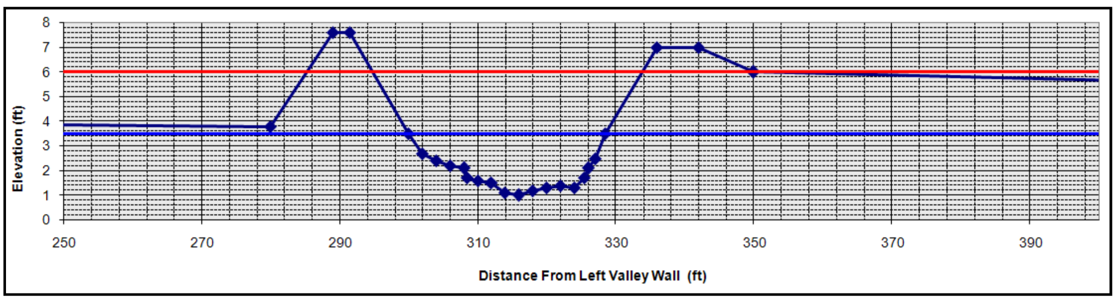

Figure 4.82 Cross-section of Willie Brook, showing berms along both channel banks

The RGA condition for the segment was assessed as “Poor” due to the extensive channel alteration and propensity for future channel migration (FEH sensitivity is “extreme”). The berm constructed along the left (north) bank of the lower segment is not robust and future flood events could cause property loss and road damage downstream. The extensive channel modifications, including berming, straightening, and windrowing, have kept this channel in stage II of the CEM.

T6.S1.01-A (Howe Brook)

Howe Brook, reach T6.S1.01 is a long reach (6.2 miles) that extends up to the northwest toward Burt Hill. The high slope of the reach transitioning into the flat valley of the South Branch of the Saxtons River made it a probable location for an alluvial fan. For our Phase 2 assessments only the portion of the reach considered to be an alluvial fan was assessed. This area was segmented to distinguish it from the upslope channel that was not assessed. This segment has had significant dredging and straightening throughout the alluvial fan; the channel bed elevation is likely much lower than the pre-straightened elevation. Segment T6.S1.01-A is 0.4 miles long and has a slope of 3.7%. The current channel geometry for this segment is indicative of B-type channel morphology (Figure 4.83).

The width-to-depth, entrenchment, and incision ratios are 16.2, 1.5, and 2.0 respectively. The abandoned floodplain is high above the active channel, occurring at the same elevation of the hay field to the south. The substrate is predominately cobble (42%) with a median substrate size of 95mm (cobble). Bedform in T6.S1.01-A is plane bed, and the valley is semi-confined. Reference conditions were kept as B-type, because the alluvial fan must have been straightened so long ago that no visible remains of historical channels and floodchutes were observed.

Figure 4.83 Cross-section with B-type channel geometry looking upstream

The Townshend Road crossing at the reach break is undersized and potentially problematic. Following the floods in the late 1990's the crossing became blocked by sediment and dredging was done to clear the structure (Figure 4.84). The planform is much more dynamic in the upper segment. There are some braided flows and more evidence of the alluvial fan. A historic berm on the right bank that prevents water from flowing out to the south where the channel bends to the north has led to a mass failure on the left bank downstream (Figure 4.85). The geomorphic condition of this reach has been impacted by the past land use and human modification of the channel (RGA score = "Fair"). It seems that the straightening and berming have resulted in tremendous degradation (with no stream type departure) and the channel does not seem to be able to advance from stage II of the CEM. Bank and buffer width is adequate in the upper segment, but the lower area near Townshend road has mowed lawn up to hard bank armoring on the left bank. Pools (pools/mile = 25) and large woody debris (LWD/mile = 78) were more common in the upper segment and the over RHA condition was "Fair".

Figure 4.84 Townshend Road crossing; dredging location

Figure 4.85 Mass failure on the left bank

T6.S2.01-A (Willie Brook)

Willie Brook, reach T6.S2.01 is a long reach (4.5 miles) that extends up to the northwest toward Burt Hill. The high slope of the reach transitioning into the flat valley of the South Branch of the Saxtons River made it a probable location for an alluvial fan. For Phase 2 analysis only the portion of the reach impacted by the alluvial fan was assessed. This area was segmented to distinguish it from the upslope channel that was not assessed. This segment has significant dredging and straightening throughout the alluvial fan; the channel bed elevation is likely much lower than the pre-straightened elevation. The lower portion of Willie Brook has extensive evidence of previous channels that suggest a past history as an alluvial fan (Figure 4.86). The segment is 0.3 miles in length and as a channel slope of approximately 4.0%. Currently, T6.S2.01-A exhibits F-type channel morphology with width-to-depth and entrenchment ratios of 14.0 and 1.3, respectively. Incision from the natural floodplain to the right of the right berm is 1.6. The median substrate size is 110mm with 53% cobble and the bedform is plane bed. By reference this segment would be a braided D-type channel with an unconfined setting. However, the modifications to the channel have reduced the valley width to 107 feet, which is a semi-confined valley.

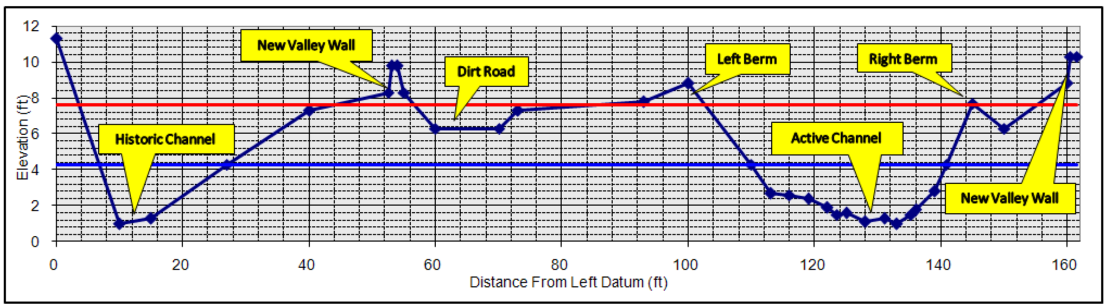

Figure 4.86 Cross-section of Willie Brook, showing historic channel and modified valley width

Human modification through straightening and berming has increased transport capacity and made the Townshend Road crossing in the lower reach a problematic area for debris jams during flooding events. Field observations and interviews with local land owners indicate that the bridge is undersized and was problematic during the large floods in the late 1990's. Following the flood, the bridge was completely clogged with sediment and the channel was extensively dredged (Figure 4.87). Stone pilings from the dredging remain on either side of the channel downstream of the crossing (Figure 4.88; Figure 4.89)

Figure 4.87 Looking upstream from the Townshend Road crossing at the dredged and straightened channel

Figure 4.88 Dredging pilings on the right bank

Figure 4.89 Undersized crossing at Townshend Road

The impacts observed along the entire channel from straightening and berming have jeopardized the long-term stability of the segment. The loss of a multiple thread channel decreases the system's ability to attenuate sediment and dissipate flood flows and debris; what was once a setting for significant aggradation has been converted to a transport reach. Only at the constricted road crossing in the lower reach does sediment deposition occur. The geomorphic condition score is "Poor" because of its modified and extremely sensitive state. Channel adjustments are not likely to move forward from stage II of the F model if current management practices (e.g., dredging) continue. Habitat in T6S2.01-A was "Fair"; in the upper segment many downed trees from poor bank stability created pools and other habitat features (LWD/mile = 80; pools/mile = 20).

A complete summary of the individual Rapid Habitat Assessment (RHA) and Rapid Geomorphic Assessment (RGA) scores is shown below (Table 4.1). Additional, segment specific data can be obtained in Appendix A.

Table 4.1 RHA and RGA scores for Phase 2 assessed segments

Stream Name	Reach/ Segment ID	RHA Score	RHA Condition	RGA Score	RGA Condition
Saxtons River Main Stem	M01-A	43%	Fair	40%	Fair
	M01-B*	NA	NA	NA	Good
	M02	42%	Fair	40%	Fair
	M03-A	51%	Fair	60%	Fair
	M03-B	36%	Fair	41%	Fair
	M04	33%	Poor	33%	Poor
	M05	55%	Fair	55%	Fair
	M06	45%	Fair	45%	Fair
	M07	56%	Fair	74%	Good
	M08	62%	Fair	58%	Fair
	M09	37%	Fair	44%	Fair
	M10	55%	Fair	58%	Fair
	M11	52%	Fair	54%	Fair
	M12	50%	Fair	54%	Fair
	M13	50%	Fair	58%	Fair
	M14	33%	Poor	43%	Fair
	M15	45%	Fair	50%	Fair
	M16	50%	Fair	50%	Fair
	M17	33%	Poor	35%	Poor
	M18	56%	Fair	65%	Good
	M19	77%	Good	51%	Fair
	M20-A	75%	Good	63%	Fair
	M20-B	54%	Fair	60%	Fair
Bull Creek	T4.01-A	39%	Fair	41%	Fair
	T4.01-B	70%	Good	56%	Fair
	T4.02	60%	Fair	56%	Fair
	T4.03-A	49%	Fair	41%	Fair
	T4.03-B	64%	Fair	54%	Fair
	T4.03C	64%	Fair	49%	Fair
South Branch Saxtons River	T6.01-A	51%	Fair	56%	Fair
	T6.01-B	42%	Fair	49%	Fair
	T6.02	48%	Fair	49%	Fair
	T6.03	50%	Fair	44%	Fair
	T6.04-A	45%	Fair	43%	Fair
Styles Brook	T6.04-B	26%	Poor	30%	Poor
Howe Brook	T6.S1.01-A	52%	Fair	40%	Fair
Willie Brook	T6.S2.01-A	48%	Fair	34%	Poor

*Note: RGA condition was determined by professional judgment for segments that were not fully assessed

4.2 River Corridor Planning

The following sections summarize the results of the stressor identification and departure effort (watershed scale maps are found in Appendix D). The mapping of physical stressors and natural or human constraints allowed for 1) a process-based approach to understanding stream conditions at different scales, and 2) an evaluation of the connectivity of stressors along the channel network. The maps were referenced during the project identification process summarized in Section 5.0.

4.2.1 Stressor Maps

Land Use

The Saxtons River watershed contains a mixture of land cover types (Table 4.2; NOAA, 2008a), including significant amounts of forest cover throughout. The entire upslope watershed is approximately 89.6 % forested, with approximately 6.0% covered by agricultural lands. Lands classified as scrub/shrub are typically in transition from old field to forest, and cover 1.3% of the watershed. Developed lands (including road corridors) occupy only 1.6% of the watershed, with lesser amounts occupied by wetlands (1.4%) and open water (0.1%). Land use distribution is fairly consistent across each of the assessed tributaries.

The Phase 1 river corridor (SGAT output "S09") has a much higher degree of agriculture and development land use for the main stem, because the Saxtons River corridor has historically been a valuable resource for fertile farmlands and other anthropogenic uses. Bull Creek and the South Branch both have extensive corridor agriculture, but little development.

Table 4.2 Land cover/land use (LCLU) data for the Saxtons River Watershed for reach subwatersheds and river corridor

Land Cover Type	Main Stem (M01-M20)		Bull Creek (T4)		South Branch (T6)		Entire Watershed	
	Reach	Corridor	Reach	Corridor	Reach	Corridor	Reach	Corridor
Agriculture	7.4%	17.8%	6.3%	19.6%	2.7%	13.9%	6.0%	14.2%
Development	4.0%	14.5%	0.5%	1.0%	0.1%	0.8%	1.6%	7.3%
Forest	86.0%	49.8%	90.5%	54.6%	94.1%	78.4%	89.6%	62.5%
Open Water	0.0%	0.2%	0.4%	3.5%	0.2%	0.4%	0.1%	0.8%
Scrub/Shrub	1.2%	6.1%	1.1%	9.3%	1.8%	2.2%	1.3%	4.4%
Wetland	1.4%	11.5%	1.2%	12.1%	1.2%	4.3%	1.4%	10.9%

* Includes Athens Brook; ** Includes Styles, Willie, and Howe Brook

Hydrologic Regime Stressors

The following description of the hydrologic regime of a watershed, and the general response to watershed-scale land use changes and stressors is included from the most recent version of the VTANR River Corridor Planning Guide (VTANR, 2010a).

> The hydrologic regime may be defined as the timing, volume, and duration of flow events throughout the year and over time. The hydrologic regime may be influenced by climate, soils, geology, groundwater, watershed land cover, connectivity of the stream, riparian, and floodplain network, and valley and stream morphology. The hydrologic regime, as addressed in this section, is characterized by the input and manipulation of water at the watershed scale and should not be confused with channel and floodplain "hydraulics," which describes how the energy of flowing

> water affects reach-scale physical forms and is affected by reach-scale physical modifications (e.g., bridges modify channel and floodplain hydraulics).

When the hydrologic regime has been significantly altered, stream channels will respond by undergoing a series of channel adjustments. Where hydrologic modifications are persistent, the impacted stream will adjust morphologically (e.g., enlarging when stormwater peaks are consistently higher) and often result in significant changes in sediment loading and channel adjustments in downstream reaches. The current day stressors to the hydrologic regime have been mapped using the variables extracted from the Phase 2 field dataset, watershed-scale loss of wetlands, and density of the road network within each subwatershed. Wetland loss was mapped as the area where hydric soils (NRCS mapping) and National Wetland Inventory (NWI) mapped areas intersected with urban or agricultural land uses in the watershed, with the remaining areas assumed to be intact wetland (NRCS, 2008; NWI, 2003). This approach allows for the interpretation of loss of hydrologic attenuation of surface runoff at the reach and watershed scale. In addition, stormwater outfall locations mapped during the Phase 2 assessments are included to depict areas of increased stormflows. Flow regulating structures (e.g., dams) are also depicted on the maps. A summary of the local (reach-scale) and upslope impacts to the hydrologic regime for each segment based on the map in Appendix D is provided in Table 4.5 at the end of this section.

Sediment Load Indicators

The following description of the sediment regime of a watershed, and the general response to watershed-scale land use changes and stressors is included from the most recent version of the VTANR River Corridor Planning Guide (VTANR, 2010a).

> The sediment regime may be defined as the quantity, size, transport, sorting, and distribution of sediments. The sediment regime may be influenced by the proximity of sediment sources, the hydrologic regime, and valley, floodplain and stream morphology. Understanding changes in sediment regime at the reach and watershed scales is critical to the evaluation of stream adjustments and sensitivity. The sediment erosion and deposition patterns, unique to the equilibrium conditions of a stream reach, create habitat. In all but the most dynamic areas (e.g., alluvial fans), they provide for relatively stable bed forms and bank conditions.

The current day stressors to the sediment regime have been mapped using the variables extracted from the Phase 2 field dataset, and the percent of agriculture within each subwatershed. Four classes of percent agriculture were mapped to depict the relative impact of sediment delivery from agricultural lands at the reach and watershed scales. In addition, depositional and migration features mapped during the Phase 2 assessments are included to depict areas of increased vertical and lateral channel adjustments due to aggradation. Mass failures, gullies and bank erosion depict where sediment delivery from the channel boundaries is occurring. A summary of the local and upslope impacts to sediment loading for each reach based on the maps in Appendix D is provided in Table 4.5.

Channel Slope and Depth Modifiers

Many of Vermont’s rivers and streams have been historically manipulated and straightened to maintain an unnaturally steep slope, allowing for a short term sense of security from flooding and subsequent encroachment of infrastructure in the floodplain. Over time, many alluvial rivers will seek to redevelop a sinuous planform through the deposition of sediments in unconfined valleys. Following flood events when alluvial rivers become energized enough to transport large amounts of coarse sediment into depositional zones of the watershed, lateral channel migration intensifies and further channel straightening is required to protect infrastructure found in the floodplain. In larger alluvial rivers of Vermont, straightening and channelization typically ranges between 25 and 75 percent of the total river channel length in Vermont (VTANR, 2010a).

In addition to historic alterations to channel slope in Vermont's alluvial rivers, the lowering of stream beds (e.g., dredging) and the raising of floodplains (e.g., berming) have resulted in an increase in channel depth (VTANR, 2010a). Channel depths have typically been increased through the encroachment on the floodplain by roads and railroads and subsequent filling and armoring required to construct and maintain this infrastructure. Increases in impervious cover have also led to the deepening and eventual widening of channels throughout urbanized areas of Vermont (Fitzgerald, 2007).

Alterations to channel slope and depth in the Saxtons River study area have been mapped using the variables extracted from the Phase 2 field dataset (see maps in Appendix D). Areas of channel straightening mapped during the Phase 1 and 2 assessments are included to depict areas of increased channel slope. Corridor encroachment data highlights where roads and development have reduced the floodplain area, typically resulting in increased stream power and channel deepening. Additional data showing the location of natural channel features (e.g., ledges and waterfalls) depict areas that have a resistance to vertical channel change. The presence of beaver activity in each reach indicates where temporary controls on vertical adjustments may be found. A summary of the local impacts to channel depth and slope for each reach is provided in Table 4.5.

Modifications to Channel Boundary and Riparian Conditions

The boundary conditions of a river encompass the bed and bank substrate, and the vegetation and root material found along the riverbank. Human alterations to the river boundary conditions are often made to increase the resistance of the banks and bed to reduce lateral and vertical adjustments. In addition, the removal of riparian vegetation can cause a decrease in boundary resistance, and lead to increased lateral migration. Other natural and human-installed features within the channel, such as bedrock ledges and dams, affect boundary resistance in an upstream and downstream direction by controlling vertical adjustment processes.

Alterations to the channel boundary conditions and riparian areas in the Saxtons River study area have been mapped using the variables extracted from the Phase 2 field dataset (see maps in Appendix D). Relative bank armoring (e.g., rip-rap) highlights areas of increased resistance to lateral migration, whereas relative bank erosion highlights reaches where significant lateral adjustments are found. Additional data showing the location of natural channel features (e.g., ledges and waterfalls) depict areas that have a resistance to channel change. A summary of the local impacts to channel boundary conditions, including impacts to riparian vegetation, is provided in Table 4.5.

4.2.2 Departure Analysis

The reference and existing sediment regime types have been mapped using data from the Phase 1 and 2 assessments (Figure 4.90). Many segments have undergone a departure in sediment regime type due to channel incision and/or widening as a result of: 1) historical land uses, 2) encroachments or development in the river corridor, or 3) extensive straightening and bank armoring. Reach stream type departures are summarized below to help better describe the reaches where physical changes in channel morphology have accompanied sediment regime change (Table 4.3). The most common stream type departures observed were C to B and C to F.

Table 4.3 Summary of Departures from Reference Conditions

Surface Water	Reach/ Segment ID	Stream Type Departure	Dominant Adjustment(s)
Saxtons River Main Stem	M02	C to F	Degradation
	M04	C to F	Degradation
	M09	C to D	Aggradation
	M12	C to B	Degradation
	M13	C to B	Degradation
	M17	C to G	Degradation
Bull Creek	T4.01A	E to C	Aggradation; Widening
	T4.03A	C to F	Degradation
South Branch Saxtons River	T6.01B	C to F	Degradation
	T6.02	C to B	Degradation
	T6.03	C to B	Degradation
	T6.04B	D to F	Degradation
Willie Brook	T6.S2.01A	D to F	Degradation

Saxtons River Main Stem (M01-M20): The majority of the main stem segments have become greater sources of coarse and fine sediments due to historical incision resulting from channel straightening and encroachments from Route 121. Five (5) segments continued to exhibit transport-based sediment regimes under the current conditions (M01-A, M01-B, M07, M018, and M20-A).

Bull Creek (T4.01-T4.03): Bull Creek has gone from a fine depositional system to a sediment regime driven by fine source and transport. Only one reach (T4.02) had an unconfined source and transport regime. Many of the geomorphic adjustments noted in these reaches were planform shifts. The finer gravel-sized substrate offered less boundary resistance and channel migration was common.

Saxtons River South Branch (T6.01-T6.04-A): The South Branch segments have become greater sources of unconfined coarse sediment due to historical incision resulting from channel straightening and encroachments from Townshend Road.

Howe Brook (T6.S1.01-A): The assessed portion of Howe Brook is a source of sediment to downstream reaches. Although alluvial fan processes were present in the segment, historic manipulation of the tributary has channelized it into a confined setting.

Willie Brook (T6.S2.01-A) and *Styles Brook (T6.04-B):* Both segments have departed from a coarse equilibrium condition typical of alluvial fans through channel straightening, dredging, and incision; these reaches are now unconfined sources of sediment to downstream areas.

4.2.3 Sensitivity Analysis

The methods outlined in the Corridor Planning Guide have been used to describe the stream sensitivities of the segments in the Saxtons River study area. Using the stream geometry and substrate data in conjunction with overall geomorphic stability (RGA score) as determined during the Phase 2 surveys, stream sensitivity ratings have been assigned to each segment (Figure 4.91).

Additional, larger maps are provided in Appendix D to depict segment sensitivity ratings. Eight (8) segments have heightened sensitivities of "Extreme" due to human impacts and 12 segments have heightened sensitivities of "Very High". The "Extreme" and "Very High" segments and descriptions of impacts are presented in Table 4.4. The heightened stream sensitivity ratings are most often due to stream type departures (STD) and channel degradation through incision and straightening. Otherwise, impacts associated with planform shifts and encroachments are common.

Table 4.4 Very High and Extremely sensitive segments and descriptions of the specific impacts and adjustments

Surface Water	Reach/ Segment ID	Stream Sensitivity	Description of Impact(s)
Saxtons River Main Stem	M01-A	Very High	Aggradation and high turbulent flows from backwater of Connecticut River
	M02	Extreme	*STD C to F; Straightening and Incision
	M03-B	Very High	Aggradation downstream and historic planform changes around I-91
	M04	Extreme	STD C to F; Straightening and Incision
	M05	Very High	Narrowly confined setting with high transport capacity
	M08	Very High	High sediment load from upstream D-type channel leading to instability
	M09	Extreme	STD C to D; Aggradation and Planform Changes
	M16	Very High	Impacts from M17's highly channelized state; incision and encroachments
	M17	Extreme	STD C to G; Channelized and encroached with extensive armoring
Bull Creek	T4.01-A	Very High	STD E to C; Fine substrate aggradation and planform changes
	T4.01-B	Very High	Aggradation from upslope reaches and planform changes
	T4.02	Very High	Aggradation because of slope failures and from upstream reach
	T4.03-A	Extreme	STD C to F; Encroachment and incision
	T4.03-B	Very High	Breaching of 2 large beaver dams; planform shifts, degradation, aggradation
	T4.03-C	Very High	Transport of sediment from steeper upper segment; planform shifts
South Branch	T6.01-B	Extreme	STD C to F; historic channel degradation (straightening and incision) and planform shifts
	T6.03	Very High	STD C to B; Sediment from T6.S2 aggrading; historic degradation (straightening and incision)
	T6.04-A	Very High	Sediment from T6.04-B aggrading in reach; degradation (straightening and incision)
Styles Brook	T6.04-B	Extreme	STD D to F; Extensive channel modification and adjustments of former alluvial fan (straightening, incision, planform shifts)
Willie Brook	T6.S2.01-A	Extreme	STD D to F; Extensive channel modification and adjustments of former alluvial fan (straightening, incision, planform shifts)

Note: STD = Stream Type Departure

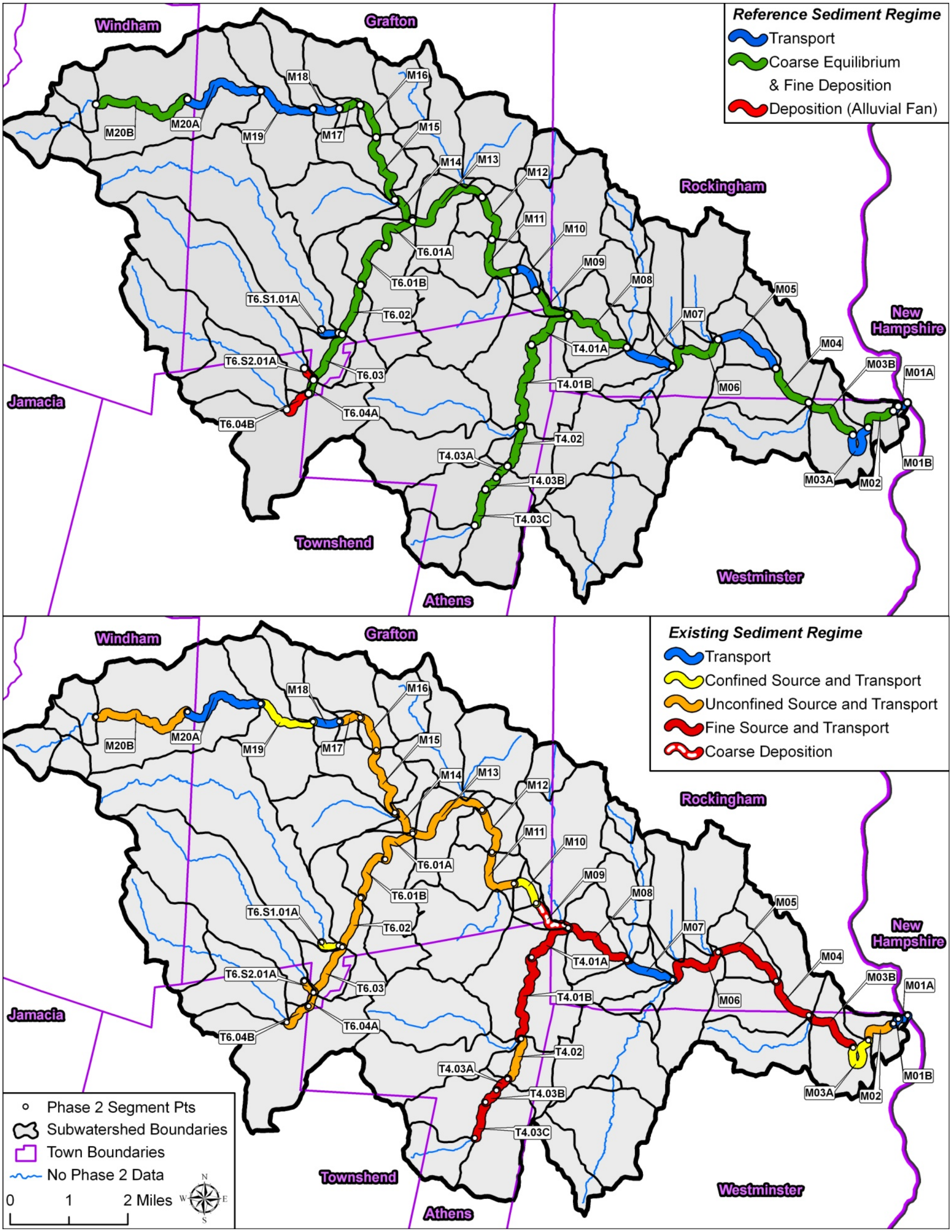

Figure 4.90 Reference and Existing Sediment Regime Maps for the Saxtons River

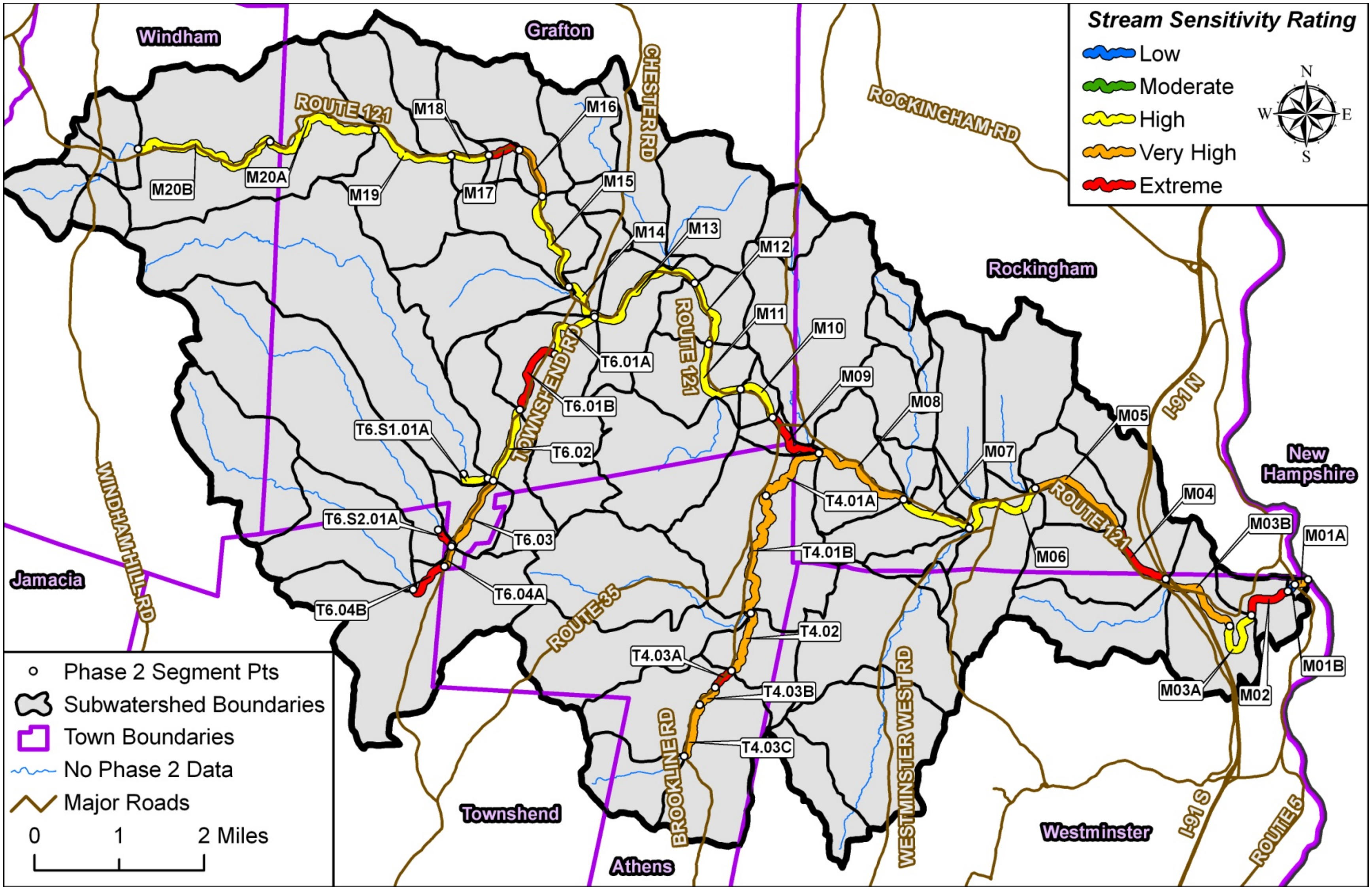

Figure 4.91 Stream Sensitivity Rating Map for the Saxtons River

Table 4.5 Watershed and Reach-Scale Stressors Impacting Equilibrium Conditions of Phase 2 Assessed Saxtons River Segments

Stream Segment (CEM; RGA)*	Regime Stressors		Reach Scale Stressors	
	Hydrologic	**Sediment**	**Stream Power**	**Boundary Resistance**
Saxtons River Main Stem M01A (IId; Fair)	*Increased Flows* • At confluence with the Connecticut River; affected by large flow events and stage differences • Extreme development in the Village of Bellows Falls (>20%) • Very high local road density (>5 Miles/Mile^2)	*Increased Load* • Bar formation likely from additional sediment from Connecticut River backwater • Abundant depositional/channel migration features *Decreased Load* • Some sediment attenuation upstream behind Blake and Higgins Dam (Breached)	*Increase* • Moderately high impervious area in the Village of Bellows Falls • High stormwater inputs within segment (10 - 15) • Extreme corridor encroachment and development (>50%) • Channel incised, F-type *Decrease* • Abundant depositional/channel migration features • Channel widened • Backwater effect	*Increase* • Grade control in upper segment
Saxtons River Main Stem M01B (I; Good)	*Increased Flows* • Some upslope wetland loss • Very high road density in reach (>5 Miles/Mile^2) • Extreme development in the Village of Bellows Falls (>20%)	*Increased Load* • Some sediment attenuation upstream behind Blake and Higgins Dam (Breached) • Extreme agricultural land use upslope (>20%) • Moderate Bank Erosion upstream (5-20%)	*Increase* • Blake and Higgins Dam breached • Banks bedrock, in a gorge setting *Decrease* • Blake and Higgins dam still impeding flow slightly	*Increase* • Grade control in upper segment *Decrease* • Moderate Bank Erosion (5-20%)
Saxtons River Main Stem M02 (II; Fair)	*Increased Flows* • Some local wetland loss • High local road density in reach (3-5 Miles/Mile^2) • High local development (10-20%)	*Increased Load* • Some sediment attenuation upstream behind Blake and Higgins Dam (Breached) • Extreme local agricultural land use (>20%) • Moderate Bank Erosion (5-20%) • Extreme corridor agricultural land use (>50%)	*Increase* • Channel incised and departed to F-type • Moderate corridor encroachment (5-20%) *Decrease* • Abundant depositional and migration features	*Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%) • Moderate Bank Erosion (5-20%)
Saxtons River Main Stem M03A (II; Fair)	*Increased Flows* • Very high local road density (>5 Miles/Mile^2) • High local development (10-20%)	*Increased Load* • Mass failure in segment • Moderate depositional and migration features	*Increase* • High corridor encroachment (20-50%) moderate development (5-20%) *Decrease* • Moderate depositional/channel migration features	*Increase* • Multiple grade controls in segment *Decrease* • Mass failure in segment

Table 4.5 Watershed and Reach-Scale Stressors Impacting Equilibrium Conditions of Phase 2 Assessed Saxtons River Segments

Stream Segment (CEM; RGA)*	Regime Stressors		Reach Scale Stressors	
	Hydrologic	Sediment	Stream Power	Boundary Resistance
Saxtons River Main Stem M03B (III; Fair)	*Increased Flows* • Very high local road density (>5 Miles/Mile^2) • High local development (10-20%)	*Increased Load* • Moderate Bank Erosion (5-20%) • Mass failure in reach • Abundant depositional/channel migration features	*Increase* • High corridor encroachment (20-50%) moderate development (5-20%) • High straightening (20 - 50%) *Decrease* • Abundant depositional/channel migration features	*Increase* • High bank armoring (> 20%) *Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%) • Moderate Bank Erosion (5-20%) • Mass failure in reach
Saxtons River Main Stem M04 (III; Poor)	*Increased Flows* • High local road density (3-5 Miles/Mile^2) • Moderate local development (5-10%)	*Increased Load* • Moderate depositional and migration features	*Increase* • Extreme corridor encroachment (>50%) and high development (20 - 50%) • High straightening (20 - 50%) • Channel incised and departed to F-type *Decrease* • Moderate depositional/channel migration features	*Increase* • Moderate bank armoring (5 - 20%) *Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%)
Saxtons River Main Stem M05 (III; Fair)	*Increased Flows* • High development in upslope reach (10-20%)	*Increased Load* • Moderate depositional and migration features	*Increase* • Extreme corridor encroachment and development (>50%) • High straightening (20 - 50%) • Channel incised and departed to F-type *Decrease* • Moderate depositional/channel migration features	*Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%)
Saxtons River Main Stem M06 (III; Fair)	*Increased Flows* • Moderately high impervious area in the Village of Saxtons River • High local road density (3-5 Miles/Mile^2) • High local development (10-20%)	*Increased Load* • Moderate depositional and migration features • Mass failure in reach • High local agricultural land use (10-20%)	*Increase* • Extreme corridor encroachment and development (>50%) • High straightening (20 - 50%) *Decrease* • Moderate depositional/channel migration features	*Increase* • Multiple grade controls in reach *Decrease* • Mass failure in reach

Table 4.5 Watershed and Reach-Scale Stressors Impacting Equilibrium Conditions of Phase 2 Assessed Saxtons River Segments

Stream Segment (CEM; RGA)*	Regime Stressors		Reach Scale Stressors	
	Hydrologic	Sediment	Stream Power	Boundary Resistance
Saxtons River Main Stem M07 (I; Good)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Moderate Bank Erosion (5-20%) • Abundant depositional/channel migration features • Moderate depositional and migration features • Mass failure in reach • Extreme local agricultural land use (>20%) • High corridor agricultural land use (20-50%)	Increase • Extreme corridor encroachment (>50%) and high development (20 - 50%) *Decrease* • Moderate depositional/channel migration features	*Increase* • Grade control in reach *Decrease* • Moderate Bank Erosion (5-20%) • Multiple mass failures in reach
Saxtons River Main Stem M08 (III; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Moderate depositional and migration features • Moderate Bank Erosion (5-20%) • Multiple mass failures in reach • Gully in reach • Extreme agricultural land use upslope (>20%)	*Increase* • High corridor encroachment (20-50%) *Decrease* • Moderate depositional/channel migration features	*Increase* • Grade control in reach *Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%) • Moderate Bank Erosion (5-20%) • Multiple mass failures in reach • Gully in reach
Saxtons River Main Stem M09 (IId; Fair)	*Increased Flows* • High local road density (3-5 Miles/Mile^2) • Moderate local development (5-10%)	*Increased Load* • Moderate Bank Erosion (5-20%) • Abundant depositional/channel migration features • Extreme local agricultural land use (>20%) • High corridor agricultural land use (20-50%)	*Increase* • High corridor encroachment and development (20-50%) • High straightening (20 - 50%) *Decrease* • Abundant depositional/channel migration features	*Increase* • Moderate bank armoring (5 - 20%) *Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%) • Moderate Bank Erosion (5-20%)
Saxtons River Main Stem M10 (II; Fair)	*Increased Flows* • Very high local road density (>5 Miles/Mile^2) • Moderate local development (5-10%)	*No Significant Increase or Decrease in Sediment*	*Increase* • Extreme corridor encroachment and development (>50%) • Dredging noted in reach	*Increase* • Moderate bank armoring (5 - 20%) *Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%)
Saxtons River Main Stem M11 (III; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Moderate depositional and migration features • Moderate Bank Erosion (5-20%) • Mass failure in reach	*Increase* • High corridor encroachment (20-50%) moderate development (5-20%) *Decrease* • Moderate depositional/channel migration features	*Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%) • Moderate Bank Erosion (5-20%) • Mass failure in reach

Table 4.5 Watershed and Reach-Scale Stressors Impacting Equilibrium Conditions of Phase 2 Assessed Saxtons River Segments

Stream Segment (CEM; RGA)*	Regime Stressors		Reach Scale Stressors	
	Hydrologic	Sediment	Stream Power	Boundary Resistance
Saxtons River Main Stem M12 (II; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Moderate depositional and migration features • Mass failure in reach	*Increase* • Extreme corridor encroachment (>50%) and moderate development (5 - 20%) • Moderate straightening (5 -20%) *Decrease* • Moderate depositional/channel migration features	*Increase* • Moderate bank armoring (5 - 20%)
Saxtons River Main Stem M13 (II; Fair)	*Increased Flows* • Moderate development in upstream reach (5-10%); the Village of Grafton	*Increased Load* • Moderate depositional and migration features • Moderate Bank Erosion (5-20%) • Multiple mass failures in reach • Extreme agricultural land use upslope (>20%) • High corridor agricultural land use (20-50%)	*Increase* • Extreme corridor encroachment (>50%) and high development (20 - 50%) • Extreme straightening (>50%) *Decrease* • Moderate depositional/channel migration features	*Increase* • Moderate bank armoring (5 - 20%) • Multiple grade controls in reach *Decrease* • High reduction in riparian vegetation; Buffer < 25 (20 - 50%) • Moderate Bank Erosion (5-20%)
Saxtons River Main Stem M14 (II; Fair)	*Increased Flows* • Moderate local development (5-10%); the Village of Grafton • High local road density (3-5 Miles/Mile^2)	*Increased Load* • Abundant depositional/channel migration features • Mass failure in reach • Extreme local agricultural land use (>20%) • High corridor agricultural land use (20-50%)	*Increase* • High corridor encroachment (20-50%) and extreme development (>50%) • High straightening (20 - 50%) *Decrease* • Abundant depositional/channel migration features	*Increase* • High bank armoring (> 20%) *Decrease* • High reduction in riparian vegetation; Buffer < 25 (20 - 50%) • Mass failure
Saxtons River Main Stem M15 (III; Fair)	*Increased Flows* • High local road density (3-5 Miles/Mile^2)	*Increased Load* • Moderate depositional and migration features • Moderate Bank Erosion (5-20%) • Mass failure in reach • Gully in reach • High local agricultural land use (10-20%) • High corridor agricultural land use (20-50%)	*Increase* • Extreme corridor encroachment (>50%) and moderate development (5 - 20%) • High straightening (20 - 50%) • Dredging noted in reach *Decrease* • Moderate depositional/channel migration features	*Increase* • Moderate bank armoring (5 - 20%) *Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%) • Moderate Bank Erosion (5-20%) • Gully and Mass failure in reach
Saxtons River Main Stem M16 (III; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Abundant depositional/channel migration features • Extreme agricultural land use upslope (>20%)	*Increase* • Extreme corridor encroachment (>50%) and high development (20 - 50%) *Decrease* • Abundant depositional/channel migration features	*Increase* • Moderate bank armoring (5 - 20%)

Table 4.5 Watershed and Reach-Scale Stressors Impacting Equilibrium Conditions of Phase 2 Assessed Saxtons River Segments

Stream Segment (CEM; RGA)*	Regime Stressors		Reach Scale Stressors	
	Hydrologic	**Sediment**	**Stream Power**	**Boundary Resistance**
Saxtons River Main Stem M17 (II; Poor)	*Increased Flows* • Very high local road density (>5 Miles/Mile^2)	*Increased Load* • Moderate depositional and migration features • Multiple mass failures in reach • Extreme local agricultural land use (>20%)	*Increase* • Extreme corridor encroachment (>50%) • Extreme straightening (>50%) • Channel incised and departed to G-type *Decrease* • Moderate depositional/channel migration features	*Increase* • High bank armoring (> 20%) *Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%)
Saxtons River Main Stem M18 (I; Good)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Moderate Bank Erosion (5-20%) • Abundant depositional/channel migration features	*Increase* • High corridor encroachment (20-50%) • Moderate straightening (5 -20%) *Decrease* • Abundant depositional/channel migration features	*Increase* • Moderate bank armoring (5 - 20%) *Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%) • Moderate Bank Erosion (5-20%)
Saxtons River Main Stem M19 (IV; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Moderate Bank Erosion (5-20%) • Abundant depositional/channel migration features	*Increase* • High straightening (20 - 50%) *Decrease* • Abundant depositional/channel migration features	*Increase* • Multiple grade controls in reach *Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%) • Moderate Bank Erosion (5-20%)
Saxtons River Main Stem M20A (I; Good)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Moderate Bank Erosion (5-20%) • Abundant depositional/channel migration features • Multiple mass failures in segment	*Increase* • Moderate corridor encroachment (5-20%) *Decrease* • Abundant depositional/channel migration features	*Decrease* • Multiple mass failures in segment • Moderate Bank Erosion (5-20%)
Saxtons River Main Stem M20B (II; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Moderate depositional and migration features • Multiple mass failures in segment	*Increase* • Extreme corridor encroachment (>50%) and moderate development (5 - 20%) • Moderate straightening (5 -20%) *Decrease* • Beaver Activity • Moderate depositional/channel migration features	*Increase* • Moderate bank armoring (5 - 20%) • Multiple grade controls in segment *Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%) • Multiple mass failures in segment
Bull Creek T4.01A (III; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Moderate Bank Erosion (5-20%) • High corridor agricultural land use (20-50%) • Abundant depositional/channel migration features	*Increase* • High straightening (20-50%) • Moderate corridor encroachment (5-20%) *Decrease* • Abundant depositional/channel migration features	*Decrease* • Extreme reduction in riparian vegetation; Buffer < 25 (>50%) • Moderate Bank Erosion (5-20%)

Table 4.5 Watershed and Reach-Scale Stressors Impacting Equilibrium Conditions of Phase 2 Assessed Saxtons River Segments

Stream Segment (CEM; RGA)*	Regime Stressors		Reach Scale Stressors	
	Hydrologic	Sediment	Stream Power	Boundary Resistance
Bull Creek T4.01B (III; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Moderate Bank Erosion (5-20%) • Abundant depositional/channel migration features • Mass failure in segment • Gully in segment • Breached beaver dams upstream (T4.03-B) • High corridor agricultural land use (20-50%)	*Increase* • High straightening (20-50%) • Moderate corridor encroachment (5-20%) *Decrease* • Abundant depositional/channel migration features	*Increase* • Moderate bank armoring (5 - 20%) *Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%) • Moderate Bank Erosion (5-20%)
Bull Creek T4.02 (IIc; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Mass failure in reach • Breached beaver dams upstream (T4.03-B) • Abundant depositional and migration features	*Increase* • Moderate corridor encroachment (5-20%) *Decrease* • Abundant depositional and migration features	*Increase* • Grade control in reach *Decrease* • High reduction in riparian vegetation; Buffer < 25 (20 - 50%) • Mass failures in reach
Bull Creek T4.03A (III; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Moderate Bank Erosion (5-20%) • Abundant depositional/channel migration features • Breached beaver dams upstream (T4.03-B)	*Increase* • Extreme corridor encroachment (>50%) and high development (20 - 50%) • Channel incised and departed to F-type *Decrease* • Abundant depositional/channel migration features	*Increase* • Moderate bank armoring (5 - 20%) • Grade control in segment *Decrease* • High reduction in riparian vegetation; Buffer < 25 (20 - 50%) • Moderate Bank Erosion (5-20%)
Bull Creek T4.03B (III; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Moderate Bank Erosion (5-20%) • Abundant depositional/channel migration features • Breached beaver dams in segment	*Increase* • High corridor encroachment (20-50%) moderate development (5-20%) • Moderate straightening (5 -20%) • Beaver Activity, 2 breached beaver dams in lower segment *Decrease* • Abundant depositional/channel migration features • Beaver Activity, 2 intact beaver dams in upper segment	*Decrease* • Moderate Bank Erosion (5-20%)

Table 4.5 Watershed and Reach-Scale Stressors Impacting Equilibrium Conditions of Phase 2 Assessed Saxtons River Segments

Stream Segment (CEM; RGA)*	Regime Stressors		Reach Scale Stressors	
	Hydrologic	**Sediment**	**Stream Power**	**Boundary Resistance**
Bull Creek T4.03C (IV; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Moderate Bank Erosion (5-20%) • Abundant depositional/channel migration features	*Increase* • Moderate corridor encroachment and development (5-20%) • Moderate straightening (5 -20%) *Decrease* • Abundant depositional/channel migration features	*Increase* • Multiple grade controls in segment *Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%) • Moderate Bank Erosion (5-20%)
Saxtons River South Branch T6.01A (II; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Abundant depositional/channel migration features • Mass failure in segment • High corridor agricultural land use (20-50%)	*Increase* • High corridor encroachment (20-50%) moderate development (5-20%) • High straightening (20 - 50%) *Decrease* • Abundant depositional/channel migration features	*Increase* • Moderate bank armoring (5 - 20%) *Decrease* • High reduction in riparian vegetation; Buffer < 25 (20 - 50%) • Mass failures in segment
Saxtons River South Branch T6.01B (II; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Abundant depositional/channel migration features • Multiple mass failures in segment • Gully in segment • High corridor agricultural land use (20-50%)	*Increase* • High corridor encroachment and development (20-50%) • Extreme straightening (>50%) • Channel incised and departed to F-type *Decrease* • Abundant depositional/channel migration features	*Increase* • Moderate bank armoring (5 - 20%) *Decrease* • High reduction in riparian vegetation; Buffer < 25 (20 - 50%) • Multiple mass failures in segment
Saxtons River South Branch T6.02 (II; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Multiple mass failures in reach • High agricultural land use upslope (10-20%) • High corridor agricultural land use (20-50%)	*Increase* • Extreme corridor encroachment (>50%) and high development (20 - 50%) • Extreme straightening (>50%) • Dredging noted in reach	*Increase* • Moderate bank armoring (5 - 20%) • Multiple grade controls in reach *Decrease* • High reduction in riparian vegetation; Buffer < 25 (20 - 50%) • Multiple mass failures in reach
Saxtons River South Branch T6.03 (II; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Moderate depositional and migration features • High local agricultural land use (10-20%) • High corridor agricultural land use (20-50%)	*Increase* • Extreme corridor encroachment (>50%) and moderate development (5 - 20%) • Extreme straightening (>50%) • Dredging noted in reach *Decrease* • Moderate depositional/channel migration features	*Decrease* • High reduction in riparian vegetation; Buffer < 25 (20 - 50%) *Increase* • Grade control in reach

Table 4.5 Watershed and Reach-Scale Stressors Impacting Equilibrium Conditions of Phase 2 Assessed Saxtons River Segments

Stream Segment (CEM; RGA)*	Regime Stressors		Reach Scale Stressors	
	Hydrologic	**Sediment**	**Stream Power**	**Boundary Resistance**
Saxtons River South Branch T6.04A (III; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Abundant depositional/channel migration features • High corridor agricultural land use (20-50%)	*Increase* • Extreme corridor encroachment (>50%) and high development (20 - 50%) • Extreme straightening (>50%) *Decrease* • Abundant depositional/channel migration features	*Increase* • Moderate bank armoring (5 - 20%) • Grade control in segment *Decrease* • Extreme reduction in riparian vegetation; Buffer < 25 (>50%)
Styles Brook T6.04B (II; Poor)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Alluvial Fan • Moderate Bank Erosion (5-20%) • Abundant depositional/channel migration features • High corridor agricultural land use (20-50%)	*Increase* • Moderate development (5-20%) • Extreme straightening (>50%) • Dredging noted in reach • Channel incised and departed to F-type *Decrease* • Abundant depositional/channel migration features	*Decrease* • High reduction in riparian vegetation; Buffer < 25 (20 - 50%) • Moderate Bank Erosion (5-20%) • Alluvial fan
Howe Brook T6.S1.01A (II; Fair)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Alluvial Fan • Abundant depositional/channel migration features • Mass failure in segment	*Increase* • Moderate development (5-20%) • Extreme straightening (>50%) • Dredging noted in reach *Decrease* • Abundant depositional/channel migration features	*Increase* • Moderate bank armoring (5 - 20%) *Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%) • Alluvial fan • Mass failure in segment
Willie Brook T6.S2.01A (II; Poor)	*No Significant Increase or Decrease in Flows*	*Increased Load* • Alluvial Fan • Moderate Bank Erosion (5-20%) • Abundant depositional/channel migration features • Mass failure in segment	*Increase* • Moderate development (5-20%) • High straightening (20-50%) • Dredging noted in reach • Channel incised and departed to F-type *Decrease* • Abundant depositional/channel migration features	*Increase* • High bank armoring (> 20%) *Decrease* • Moderate reduction in riparian vegetation; Buffer < 25 (5 - 20%) • Moderate Bank erosion (5-20%) • Mass failure in segment

* CEM = Channel Evolution Model; RGA = Rapid Geomorphic Assessment Score

5.0 Preliminary Project Identification

5.1 Watershed Level Opportunities

5.1.1 Stormwater Runoff

Increased stormwater runoff, even in rural areas of Vermont, can increase peak flood flows and the erosive power of the streams. Stormwater runoff originating from gravel roads and exposed soil during development, or over farm fields can add significant sediment inputs to streams. Increasing development results in more driveways and roads, which transport sediment and runoff directly to streams. Sediment from roads and driveways can be addressed with improved drainage ditch networks, limiting future driveway lengths in sensitive areas, and other approaches. The Vermont Better Back Roads program provides assistance for towns seeking ways to reduce rural stormwater problems.

The Saxtons River watershed generally had limited stormwater impacts because of the largely forested watershed. However, several localized areas had stormwater outfalls that were clearly impacting the condition of the receiving channel. One area of impact was downstream of the Village of Grafton at the town garage. This site had an exposed gravel and sand used for road maintenance and limited buffer width along the channel allowing for sediment and excess stormwater to flow directly into the channel. The other area where stormwater impacts were directly influencing channel dynamics was upstream of Grafton along Route 121. There, the valley toe of a farm pasture was dredged to drain into the channel and get water out of the grazing pasture. The dredging has caused significant soil loss of the exposed soil, forming a bar downstream.

Towns can use local planning to improve development standards and enact local stormwater control standards and guidelines for stormwater treatment or mitigation. Local planning efforts are important to control and monitor stormwater and development impacts on natural resources. By planning proactively, towns can reduce long-term costs and risks associated with stormwater runoff. Options that the towns along the Saxtons River could consider at the local level include:

- Requiring stormwater controls for development projects which are not large enough in scale to fall under state regulatory permits (less than 1 acre impervious cover), but likely have a measurable impact on adjacent water bodies.
- Incorporating more rigorous requirements for stormwater control of new development in headwaters areas. Research in Vermont has shown that physical and biotic conditions in small watersheds (< 5 square miles in area) are impacted by very low levels of impervious cover (as low as 5 percent; Fitzgerald, 2007).
- Encouraging Low Impact Development (LID) by offering development density incentives for those projects which result in reduced footprints of impervious cover.

5.1.2 Fluvial Erosion Hazard Zones and Risk Assessments

Many Vermont communities found along large rivers have faced significant property losses and risks to public safety during past flood events. While inundation-related flood loss is a significant component of flood disasters, the predominant mode of damage during floods is fluvial erosion.

Fluvial erosion hazards have been increased and exacerbated by historical channel management practices in Vermont such as channel straightening, berming, and floodplain encroachment.

Towns can reduce flood recovery and infrastructure maintenance costs and increase public safety by limiting development in areas adjacent to rivers with a high potential for vertical and lateral adjustment. The Fluvial Erosion Hazard (FEH) zone can be thought of as the corridor a river requires to redevelop or maintain equilibrium conditions over the long term. FEH zones also indicate which reaches have a higher propensity for severe migration during flood events. These reaches, which are given elevated ratings of "very high" or "extreme", are high priority reaches for protection, especially when there is little existing protection afforded by wetlands or conservation easements. One component of the Saxtons River Corridor Plan is the development of Fluvial Erosion Hazard (FEH) corridors for reaches surveyed for Phase 2 data. FEH corridor development methods are explained in detail in the following sections.

FEH Corridor Analysis

FEA used the Stream Geomorphic Assessment Tool (SGAT) to develop Phase 1 data for 59 reaches along 77 stream miles during 2008. In 2009 and 2010, FEA used the data developed during Phase 1 in conjunction with the Phase 2 SGA data for 29 reaches (37 total segments) to determine appropriate FEH corridor widths for each reach or segment. FEA and VTDEC developed FEH corridors following the Vermont Department of Environmental Conservation FEH approach found in the document titled "River Corridor Protection Guide" (VTANR, 2008b). The FEH corridor width is determined by the inherent sensitivity of the reach to adjustments and the current condition of reach stability as determined through the Phase 2 field surveys (Table 5.1). The reach-specific ratings determine the corridor width needed to accommodate fluvial geomorphic equilibrium conditions (Table 5.2). Further background information about the FEH approach at the municipal level is provided in the VTANR publication "Municipal Guide to Fluvial Erosion Hazard Mitigation" (VTANR, 2010b).

Table 5.1 Stream Sensitivity Ratings Based on Geomorphic Stream Type and Condition

Existing Geomorphic Stream Type[1]	Stream Sensitivity		
	Reference or Good Condition	Fair-Poor Condition in Major Adjustment	Poor Condition, Stream Type Departure
A1, A2, B1, B2,	Very Low	Very Low	Low
C1, C2	Very Low	Low	Moderate
G1, G2	Low	Moderate	High
F1, F2	Low	Moderate	High
B3, B4, B5	Moderate	High	High
B3c, C3, E3	Moderate	High	High
C4, C5, B4c, B5c	High	Very High	Very High
A3, A4, A5, G3, F3	High	Very High	Extreme
G4, G5, F4, F5	Very High	Very High	Extreme
D3, D4, D5	Extreme	Extreme	Extreme
C6, E4, E5, E6	High	Extreme	Extreme

[1] Geomorphic stream types from the Rosgen (1994) Classification System.

Table 5.2 FEH Ratings and Corridor Widths Based on Typical Setting and Impact

Sensitivity Rating	Corridor Width in Relation to Reference Channel Width	Typical Setting & Impact
Very Low	Equal	Steep, bedrock or boulder-bottomed stream with no impacts
Low	Two (2) channel widths	Steep, bedrock or boulder-bottomed stream with limited human impacts
Moderate	Four (4) channel widths	Moderate gradient stream with limited human impacts
High	Six (6) channel widths Eight (8) channel widths for E-type	Low to moderate gradient stream with limited to moderate human impacts
Very High	Six (6) channel widths Eight (8) channel widths for E-type	Low to moderate gradient stream with high human impacts
Extreme	Six (6) channel widths Eight (8) channel widths for D and E-type	Severe departure from reference conditions; Stream types with high natural sensitivity

FEH Risk Assessments

FEA used the FEH corridor to analyze the implications of an FEH Overlay District within the study area for the towns of Westminster, Rockingham, Athens, Grafton, Windham, and Townshend. The purpose of this analysis is to 1) provide the Towns, WRC, and WCNRCD, and VTDEC with a summary of the built and natural capital within the corridor, and 2) highlight areas of potential conflict and opportunities for corridor protection. The analysis also assessed the planning and zoning districts (where available) and other protected parcels within the corridor (e.g., conserved lands).

ArcGIS® software was used to summarize the land cover and zoning acreages within the FEH corridor at the reach-scale. A reach-scale approach to analyzing and managing fluvial erosion hazards is imperative given the varying sensitivities to adjustment exhibited by different stream types under the influence of human impacts. A summary of the GIS data utilized in the analysis is provided below in Table 5.3. Most of the GIS data were acquired through the Vermont Center for Geographic Information (VCGI), while others were obtained through the WRC.

Table 5.3 GIS Data Utilized in Saxtons River FEH Risk Assessments

Data Layer	Description	Source
FEH Corridor	Corridor based on VTDEC FEH approach	Phase 1 & 2 SGA
Town Zoning	Zoning Districts adopted by Towns for future growth	WRC
Roads	Public road locations for Vermont	VCGI
Buildings	Building locations for Vermont	VCGI
Conserved Parcels	Conserved by Towns, Land Trusts, or other partnerships	WRC
Wetland Boundaries	National Wetland Inventory (NWI) data for Vermont	VCGI
Wetland Soils	Hydric soils mapped by NRCS for State of Vermont	VCGI

Tables 5.4a, b, and c summarize the results of the analysis of the zoning data for each town where zoning data is available. Table 5.5 summarizes all of the structure data as well as conservation

data such as wetlands and conserved lands. Maps of these features and the FEH corridor are available in Appendix D.

Town Zoning

Town Zoning Districts were summarized based on the percent area coverage of the FEH corridor. This summary aids in understanding the potential for future conflicts where lands zoned for future growth fall within the FEH corridor. The towns within the study area have different zoning designations, depending on the level of development. For each town the specific districts that were found within the FEH corridor were listed, although others do exist outside the FEH zone.

In the town of Westminster the zoning within the FEH corridor was predominately residential although industrial zoned land was observed in segment M01-A (Table 5.4a). Rockingham was predominately zoned rural residential with some agriculture and forest. Reach M06 was mostly agriculture and forest; however, portions of the FEH zone were within the Village of Saxtons River and zoned accordingly (Table 5.4b). In Windham, very few zoning districts were present and all of the FEH zone was designated rural zoning (Table 5.4c).

Structures

Building locations discerned from aerial photographs and the E-911 structures database were used to identify the number of adjacent structures within the FEH corridor. The number of stream crossings (e.g., bridges and culverts) tallied during the Phase 2 surveys are also summarized by reach. This summary aids in understanding the potential for future erosion conflicts within the FEH corridor.

Building locations and stream crossings were most dense around town centers and villages. North Westminster Village, Saxtons River Village, Cambridgeport, and Grafton (town center) had the highest number of adjacent buildings within the FEH zone and often the most stream channel crossings. The headwaters reach M20 of the main stem had very limited buildings, but many stream crossings (Table 5.5).

Conserved Lands

A conserved lands database maintained by WRC was used to summarize the percent coverage of lands protected against future development within the FEH corridor for each reach. Additionally, wetlands data from the US Fish and Wildlife Service's National Wetland Inventory and hydric soils mapped by the Natural Resources Conservation Service were included in the analysis to represent areas within the FEH corridor where land is generally unsuitable for structural development.

Conserved land is limited within the Saxtons River watershed. Most large conserved parcels are located on mountainous forested land and are not in the river corridor. Only three (3) reaches/segments have conserved land within the river corridor (Table 5.5). Reach M02 and segment M03-A have land conserved by the Vermont Land Trust for the Basin Farm and the FEH zone of reach M06 is within the Saxtons River Village forest. Wetlands are found throughout the FEH corridors of the main stem and tributary reaches, however they often take up only small portions of the FEH zone area (Table 5.5).

Summary Tables of Fluvial Erosion Hazard (FEH) Corridor Data and Risk Assessments for the Saxtons River Watershed

**Note: Zoning Data only availible in Westminster, Rockingham, and Windham*

Table 5.4a Summary of FEH corridor zoning in Westminster, VT

Surface Water	Reach/ Segment	FEH Rating	FEH Zone Area* (acres)	Town Zoning Districts**	
				Industrial	Residential
Saxtons River	M01-A	Very High	4.4	84.9%	15.1%
	M02	Exetreme	32.4	0.0%	100.0%
	M03-A	High	26.0	0.0%	100.0%
	M03-B	Very High	38.6	0.0%	100.0%
	M04	Exetreme	10.1	0.0%	100.0%

*FEH Zone area clipped by towns; may not include entire reach FEH corridor

**Several other zoning districts exist within the Westminster town boundary, but not within the FEH corridor

Table 5.4b Summary of FEH corridor zoning in Rockingham, VT

Surface Water	Reach/ Segment	FEH Rating	FEH Zone Area* (acres)	Town Zoning Districts**		
				Rural Residential 1	Agricultural & Forest	Saxtons River District
Saxtons River	M04	Extreme	41.5	100.0%	0.0%	0.0%
	M05	Very High	36.9	94.8%	5.2%	0.0%
	M06	High	57.5	5.5%	3.3%	91.2%
	M07	High	31.1	94.2%	0.0%	5.8%
	M08	Very High	59.9	71.0%	29.0%	0.0%
	M09	Extreme	32.5	100.0%	0.0%	0.0%
Bull Creek	T4.01-A	Extreme	11.1	100.0%	0.0%	0.0%

*FEH Zone area clipped by towns; may not include entire reach FEH corridor

**Several other zoning districts exist within the Rockingham town boundary, but not within the FEH corridor

Table 5.4c Summary of FEH corridor zoning in Windham, VT

Surface Water	Reach/ Segment	FEH Rating	FEH Zone Area* (acres)	Town Zoning Districts**
				Rural
Saxtons River	M20-A	High	2.3	100.0%
	M20-B	High	28.8	100.0%

*FEH Zone area clipped by towns; may not include entire reach FEH corridor

**Several other zoning districts exist within the Rockingham town boundary, but not within the FEH corridor

Table 5.5 Summary of Fluvial Erosion Hazard (FEH) structures and conservation lands in the Saxtons River watershed

Surface Water	Town(s)†	Reach/ Segment	FEH Rating	FEH Zone Area‡ (acres)	Structures Within FEH Zone*		Conserved Lands** (Percent)		
					Adjacent Buildings	Stream Crossings	Conservation	Wetlands	Total
Saxtons River Main Stem	We	M01-A	Very High	4.4	0	2	0.0%	24.2%	24.2%
	We	M02	Extreme	32.4	1	0	99.9%	14.8%	99.9%
	We	M03-A	High	26.0	1	1	32.1%	3.3%	35.3%
	We	M03-B	Very High	38.6	2	3	0.0%	6.5%	6.5%
	We, Ro	M04	Extreme	51.6	6	1	0.0%	0.0%	0.0%
	Ro	M05	Very High	36.9	5	1	0.0%	0.0%	0.0%
	Ro	M06	High	57.5	17	2	3.2%	8.3%	11.5%
	Ro	M07	High	31.1	1	1	0.0%	0.0%	0.0%
	Ro	M08	Very High	59.9	3	1	0.0%	0.1%	0.1%
	Ro, At, Gr	M09	Extreme	56.0	5	1	0.0%	19.5%	19.5%
	Gr	M10	High	18.8	10	0	0.0%	0.0%	0.0%
	Gr	M11	High	31.0	3	1	0.0%	4.1%	4.1%
	Gr	M12	High	24.0	0	1	0.0%	0.0%	0.0%
	Gr	M13	High	48.8	9	2	0.0%	8.2%	8.2%
	Gr	M14	High	14.6	15	1	0.0%	0.0%	0.0%
	Gr	M15	High	33.9	6	3	0.0%	1.4%	1.4%
	Gr	M16	Very High	12.3	2	2	0.0%	0.0%	0.0%
	Gr	M17	Extreme	6.2	0	1	0.0%	13.0%	13.0%
	Gr	M18	High	10.2	0	0	0.0%	0.0%	0.0%
	Gr	M19	High	23.4	5	1	0.0%	0.0%	0.0%
	Gr, Wi	M20-A	High	26.4	0	1	0.0%	0.0%	0.0%
	Wi	M20-B	High	28.8	2	7	0.0%	12.7%	12.7%
Bull Creek	Ro, At	T4.01-A	Extreme	32.0	0	2	0.0%	16.6%	16.6%
	At	T4.01-B	Very High	49.0	4	1	0.0%	36.3%	36.3%
	At	T4.02	Very High	14.3	6	3	0.0%	7.9%	7.9%
	At	T4.03-A	Extreme	4.6	3	2	0.0%	0.0%	0.0%
	At	T4.03-B	Very High	5.4	1	0	0.0%	0.9%	0.9%
	At	T4.03-C	Very High	11.8	2	2	0.0%	1.9%	1.9%
South Branch Saxtons River	Gr	T6.01-A	High	28.1	4	2	0.0%	0.0%	0.0%
	Gr	T6.01-B	Extreme	33.2	4	2	0.0%	0.0%	0.0%
	Gr	T6.02	High	30.3	7	1	0.0%	0.0%	0.0%
	Gr	T6.03	Very High	25.4	3	0	0.0%	1.3%	1.3%
	Gr, To	T6.04-A	Very High	6.3	2	2	0.0%	0.0%	0.0%
Styles Brook	At, Gr, To	T6.04-B	Extreme	16.6	1	0	0.0%	0.0%	0.0%
Howe Brook	Gr	T6.S1.01-A	High	5.8	0	1	0.0%	0.0%	0.0%
Willie Brook	Gr, To	T6.S2.01-A	Extreme	3.8	1	1	0.0%	0.0%	0.0%

†Towns: We = Westminster, Ro = Rockingham, Gr = Grafton, At = Athens, Wi = Windham, To = Townshend; ‡FEH Zone area includes entire reach extent; *Stuctures within FEH Zone: Adjacent buildings = number of buildings found in FEH zone, Stream Crossings = Number of bridges or culverts that cross the channel; **Conserved lands: Conservation = conservation land area shapefiles obtained from WRC, Wetlands = National wetland inventory and hydric soils (NRCS Soil polygon) obtained from VCGI

5.2.3 Stream Crossings

Throughout Vermont, undersized bridges and poorly aligned culverts prevent critical sediment and woody debris transport processes and fish and wildlife migration. These conditions result in 1) channel instability and/or damage to infrastructure and personal property, 2) increased flooding, and 3) decreased fish and wildlife population health. Two (2) assessed culverts in the Saxtons River study area are currently undersized and causing various problems such as upstream deposition, excessive erosion, downstream bed degradation, and aquatic organism passage problems. As such structures come up for replacement, resizing them to accommodate expected discharge and sediment loads and placing them in proper alignment with stream channels is recommended.

Detailed summary data and a structure location map for all bridges and culverts in the study area are included in Appendix C. Assessments were completed on 51 structures in the study area. Tables 5.6 and 5.7, found below, summarize key data collected for all structures. Both Tables include a relative priority ranking for replacement or retrofit. For culverts the priority ranking is based on a review of the following three criteria: structure width in relation to bankfull channel width; aquatic organism passage (AOP); geomorphic compatibility. For bridges priority ranking is based on a review of: structure width in relation to bankfull channel width; structural problems; vertical clearance. Two (2) culverts and 8 bridges have been assigned a “moderate” or “high” priority for replacement or retrofit. Additional information about the recommended actions to address high priority structures is provided in the site-specific project identification summary in Table 5.8.

Table 5.6 Aquatic organism passage (AOP) and geomorphic compatibility for culverts assessed in the Saxtons River Basin

Stream Name	Reach/ Segment; Map ID	Road Name	Percent Bankfull Width	Condition or Observations	Geomorphic Compatibility[1]	Aquatic Organism Passage[2] (AOP)	AOP Retrofit Potential
Saxtons River	M20-B; 32	Mercy Lane	35%	Human-built grade control (not permanent) downstream of structure causing ponding and deposition of fine sediments downstream.	Partially Compatible	Reduced AOP	Moderate
Bull Creek	T4.03-C; 42	Brookline Road	28%	In a recent flood channel has crossed over and followed the road for about 75 ft. The structure is a sig. channel constriction with major alignment issues.	Mostly Incompatible	No AOP Including Adult Salmonids	Moderate

[1] Scores and Ratings developed with the VTANR Geomorphic Compatibility Screening Tool; [2] Aquatic organisms Passage ratings developed with the VTANR methodology;

Table 5.7 Bridge summary data for the Ph2 assessed surface waters in the Saxtons River Watershed, VT

Surface Water	Town	Map ID	Reach/ Segment ID	Road Name	% Bankfull Width*	Priority for Replacement or Retrofit
Saxtons River Main Stem	**Westminster**	**1**	**M01-A**	Railroad Trestle	128%	Low
		2	**M01-A**	Route 5	92%	Low
		3	**M03-A**	Covered Bridge Road	120%	Low
		4	**M03-B**	Route 121	195%	Low
		5	**M03-B**	Interstate 91 SB	455%	Low
		6	**M03-B**	Interstate 91 NB	455%	Low
	Rockingham	**7**	**M04**	Barbers Park Road	100%	Low
		8	**M05**	Hall Bridge Road	96%	Low
		9	**M06**	Main Street	153%	Low
		10	**M06**	Westminster Street	112%	Low
		11	**M08**	McBride Road	79%	Low
	Grafton	**12**	**M09**	Route 121 East	99%	Low
		13	**M11**	Route 121 East	124%	Low
		14	**M12**	Route 121 East	170%	Low
		15	**M13**	Route 121 East	214%	Low
		16	**M13**	TH 52	92%	Low
		17	**M14**	Main Street	109%	Low
		18	**M15**	TH 9	79%	Moderate
		19	**M15**	Houghtonville Road	169%	Low
		20	**M15**	Houghtonville Road	99%	Low
		21	**M16**	Private Driveway	95%	Low
		22	**M16**	Snow Mobile Bridge	162%	Low
		23	**M17**	Houghtonville Road	373%	Low
		24	**M19**	Cabell Road	78%	Moderate
	Windham	**25**	**M20-A**	Route 121	100%	Low
		26	**M20-B**	Route 121	110%	Low
		27	**M20-B**	Logging Access Road	242%	Low
		28	**M20-B**	Route 121	176%	Low
		29	**M20-B**	White Road	88%	Low
		30	**M20-B**	Route 121	93%	Low
		31	**M20-B**	Route 121	123%	Low
Bull Creek	**Rockingham**	**33**	**T4.01-A**	Driveway off Sleepy Valley Rd	68%	Moderate
	Athens	**34**	**T4.01-A**	Farm Road	84%	Low
		35	**T4.01-B**	Ober Road	78%	Low
		36	**T4.02**	Miller Road	100%	Low
		37	**T4.02**	Private Driveway	142%	Low
		38	**T4.02**	Private Driveway	92%	High
		39	**T4.03-A**	Private Driveway	119%	Low
		40	**T4.03-A**	Valley Cemetery Road	105%	Low
		41	**T4.03-C**	Private Driveway	123%	Low
South Branch Saxtons River	**Grafton**	**43**	**T6.01-A**	Kidder Hill Road	95%	Low
		44	**T6.01-A**	Covered Bridge Crossing	86%	Low
		45	**T6.01-B**	Townshend Road	169%	Low
		46	**T6.01-B**	Private Farm Road	157%	Low
		47	**T6.02**	Townshend Road	155%	Low
		48	**T6.04-A**	Private Foot Bridge	**49%**	Moderate
Styles Brk		**49**	**T6.04-A**	Townshend Road	**42%**	High
Howe Brk		**50**	**T6.S1.01-A**	Townshend Road	74%	Moderate
Willie Brk		**51**	**T6.S2.01-A**	Townshend Road	97%	Moderate

*Bolded for width less than 50% of bankfull width

5.2 Site-Level Project Opportunities

The site-level projects developed for the Saxtons River watershed on the main stem, Bull Creek and South Branch are provided below in Table 5.8. The project strategy, technical feasibility, and priority for each project are listed by project number and reach/segment. A total of 32 projects were identified to promote the restoration or protection of channel stability and aquatic habitat. The table summarizes key information for each project, including the site stressors and constraints, project strategy, priority, relative costs, and potential partners.

The project locations and categories identified for the study area are included on a map in Appendix D. The 32 projects are further broken down by category as follows: 9 active geomorphic restoration projects; 22 passive geomorphic restoration projects; and 1 project involving both active and passive geomorphic restoration.

Table 5.8 Site-Level Project Identification for the Saxtons River Main Stem, Bull Creek, and the South Branch

Project #, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
#1: Blake & Higgins Dam Saxtons River Segment M01-A 43.12406 N 72.44069 W	**Active Restoration** *Dam Removal*	Remains of breached dam are a moderate barrier to aquatic organism passage (for weak swimmers); Dam is not currently maintained; Large bridge footings (Route 5) nearby; Locally important swimming hole upstream.	Remove dam remains to restore aquatic organism passage; Channel restoration or sediment removal in upstream reach would not be necessary	Low	Moderate	Increased AOP and potential for ~1.0 miles of restored habitat upstream up to Twin Falls.	Moderate construction & permitting costs for structure removal	VTDEC; USFW; NOAA & American Rivers; CRWC; CRJC
#2: East of Basin Farm Road Saxtons River Reach M02 43.12145 N 72.44610 W	**Passive Restoration** *Buffer Plantings*	Areas of limited woody vegetation along river edge – south (right) bank (815 ft with buffer less than 25ft wide). Approx. 500 feet bank erosion contributing to degraded habitat and elevated stream temperatures due to limited near-bank canopy	Plant stream buffer with native woody vegetation in areas lacking canopy cover; Coordinate with adjacent landowners to assess interest and cooperation	Moderate	Moderate	Improved biotic habitat within reach (overhanging vegetation) and downstream (shading for lower water temp.)	Relatively low costs for native plant materials and labor	WCNRCD; NRCS (CREP or Tress for Streams)
#3: East of Basin Farm Road Saxtons River Reach M02 43.12146 N 72.44600 W	**Passive Restoration** *Corridor Protection*	Channel likely historically straightened and manipulated upstream of Blake & Higgins Dam. Channel currently incised with bank erosion. Lateral migration predicted in future in lower reach.	Protect stream corridor and plant buffer with native woody vegetation as described in project #2. CREP project easement would cover both approaches.	**High**	Moderate	Potentially reduced property loss from erosion; Mitigation of floodplain loss upslope	Easements may already be in place under current ownership - needs further investigation	WCNRCD; NRCS (CREP)
#4: North and South of Route 121 (south bank) Saxtons River Segment M03-B 43.12347 N 72.46379 W	**Passive Restoration** *Buffer Plantings*	Areas of limited woody vegetation along river edge – south (right) bank (720 ft with buffer less than 25ft wide), Approx. 250 feet bank erosion contributing to degraded habitat and elevated stream temps	Plant stream buffer with native woody vegetation in areas lacking canopy cover; Coordinate with adjacent landowners to assess interest and cooperation	Moderate	Moderate	Improved biotic habitat within reach (overhanging vegetation) and downstream (shading for lower water temp.)	Relatively low costs for native plant materials and labor	WCNRCD; NRCS (CREP or Tress for Streams)

Table 5.8 Site-Level Project Identification for the Saxtons River Main Stem, Bull Creek, and the South Branch

Project #, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
#5: North and south of Route 121 Saxtons River Segment M03-B 43.12334 N 72.46613 W	**Passive Restoration** *Corridor Protection*	Channel historically straightened and manipulated around I-91 crossing. Channel currently incised and widening. Lateral migration predicted in future.	Protect stream corridor and plant buffer with native woody vegetation as described in project #4.	Moderate	Moderate	Potentially reduced property loss from erosion; Mitigation of floodplain loss upslope and within reach.	Potentially moderate to high costs for easements due to private ownership; Needs further investigation	WCNRCD; NRCS (CREP); VRC
#6: East of Route 121 Saxtons River Segment M04 43.12956 N 72.48003 W	**Passive Restoration** *Corridor Protection*	Channel historically straightened and manipulated upstream of I-91 crossing. Channel currently incised and widening. Lateral migration predicted in future.	Protect stream corridor, especially mid-reach where adjacent agricultural fields encroach on river corridor from the east.	**High**	Moderate	Potentially reduced property loss from erosion; Mitigation of floodplain loss upslope and within reach.	Potentially moderate to high costs for easements due to private ownership; Needs further investigation	WCNRCD; NRCS (CREP); VRC
#7: East of Route 121 - west of Saxtons River Village Saxtons River Reach M06 43.13598 N 72.51519 W	**Active Restoration** *Berm Removal*	Berm extends 700 feet along left bank, disconn-ecting floodplain. Berm elevated 3.5 feet above floodplain on average. Healthy established trees along berm. 10-year storm discharge would access adjacent floodplain with berm removed.	Remove berm or puncture short segments of the berm and re-grade near bank floodplain to encourage overbank flooding in adjacent hay field.	**High**	Moderate	Reduced fine sediment loading to channel and downstream areas; Reduced property loss from high flow events and ongoing erosion	Potentially high construction & permitting costs for berm removal and floodplain restoration; Needs further landowner investigation.	VTANR
#8: Downstream of Bull Creek Confluence Saxtons River Reach M08 43.14438 N 72.54657 W	**Passive Restoration** *Corridor Protection*	Main stem confluence with Bull Creek is very active depositional area; Downstream reach (M08) is in state of channel widening and is an attenuation zone for sediment transported from upstream reaches.	Protect stream corridor from development and further channel management (i.e., armoring or encroachment).	Moderate	Moderate	Important sediment and floodwater attenuation reach due to channelization in upstream reaches and high bed load in Bull Creek.	Potentially moderate to high costs for easements due to private ownership and reach length; Needs further investigation	VTANR, VRC, VLT

Table 5.8 Site-Level Project Identification for the Saxtons River Main Stem, Bull Creek, and the South Branch

Project #, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
#9: Restoration West of Mandigo Road Saxtons River Reach M08 43.14657 N 72.55009 W	**Passive Restoration** *Buffer Plantings; Corridor Protection*	Upper section of reach west of Mandigo Road along north bank has cattle actively grazing in river corridor and along banks. Banks and vegetation are degraded.	Exclude cattle from grazing within 25 feet of banks. Plant buffer with native woody vegetation where vegetation has been grazed.	Low	Moderate	Reduced fine sediment loading to channel and downstream areas; Improved biotic habitat within reach	Relatively low costs for native plant materials and labor; CREP easement possible along entire north bank.	WCNRCD; NRCS (CREP)
#10: Confluence with Bull Creek Saxtons River Reach M09 43.14721 N 72.55561 W	**Passive Restoration** *Corridor Protection*	Main stem confluence with Bull Creek is very active depositional area; Lateral migration and spring flooding are problematic for landowner. Landowner interested in public access and possibly easement.	Protect stream corridor and plant buffer with native woody vegetation. Provide public access trail to river – area should have excellent fish habitat in long term as corridor vegetation recovers.	**High**	**High**	Important sediment and floodwater attenuation reach for protection of downstream areas. Improved biotic habitat within reach.	Potentially high costs for easements due to private ownership; Needs further investigation	VTANR, VRC, VLT
#11: West of Route 121 and The Dug Road in Grafton Saxtons River Reach M11 43.15747 N 72.57822 W	**Passive Restoration** *Corridor Protection*	Undeveloped corridor along inside of meander bend in between river and Route 121 upstream of the road crossing. Large flood chute noted in this area, and channel predicted to migrate laterally in future.	Long-term stream corridor protection to avoid conflict with river migration and development. FEH zone would cover this area.	Moderate	Low	Important sediment and floodwater attenuation section of reach downstream of channelized area.	Potentially moderate to high costs for easements due to private ownership; Needs further investigation	VTANR, VRC, VLT
#12: East of Route 121 in Grafton Saxtons River Reach M12 43.16977 N 72.57587 W	**Passive Restoration** *Corridor Protection*	Undeveloped corridor along inside of meander bend in between river and Route 121 upstream of the road crossing. Large depositional features suggest channel is active along only meander noted in reach.	Long-term stream corridor protection to avoid conflict with river migration and development. FEH zone would cover this area.	Moderate	Low	Important sediment and floodwater attenuation section of reach downstream of channelized area.	Moderate costs for easements due to private ownership; Needs further investigation	VTANR, VRC, VLT

Table 5.8 Site-Level Project Identification for the Saxtons River Main Stem, Bull Creek, and the South Branch

Project #, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
#13: Grafton Town Garage Saxtons River Reach M13 43.17383 N 72.59488 W	**Passive & Active Restoration** *Buffer Plantings; Stormwater Management;*	Grafton Town Garage impacts stream buffer along north bank and discharges uncontrolled stormwater directly to channel. Mass failure along south bank across from site likely aggravated by bank/buffer impacts.	Develop stream buffer restoration plan for immediate near bank along north bank. Re-route stormwater runoff to a small BMP (e.g., bioretention basin or rain garden) to reduce fine sediment loading to channel.	Moderate	**High**	Reduced fine sediment loading to channel and downstream areas; Improved canopy cover in reach for habitat.	Low to moderate costs for planting materials and labor. Low costs for design and installation of stormwater BMP.	WCNRCD; WRC; VTDEC Watershed Grants; VTRANS Municipal Stormwater Mitigation Funds
#14: Confluence with South Branch Saxtons River Reach M14 43.17013 N 72.60470 W	**Passive Restoration** *Corridor Protection*	Main stem confluence with South Branch is an active depositional area; Channel migration and spring flooding are likely. Significant channel encroachment and floodplain development upstream in Grafton Village.	Protect stream corridor and plant buffer with native woody vegetation upstream of confluence on right bank. FEH zone would cover this area.	Moderate	Moderate	Reduced fine sediment loading to channel and downstream areas; Potentially reduced property loss from erosion; Mitigation of floodplain loss upslope	Moderate costs for easements due to private ownership; Needs further investigation; Low costs for buffer planting	VTANR, VRC, VLT
#15: Upstream of Grafton Village Saxtons River Reach M14 43.17445 N 72.60865 W	**Passive Restoration** *Corridor Protection*	Section of right bank armored upstream of Village, but channel avulsion exists upstream and erosion found throughout. Limited floodplain access in downstream areas makes this a high priority area.	Protect stream corridor and plant buffer with native woody vegetation along right bank upstream of Grafton Village center at various locations.	**High**	Moderate	Potentially reduced property loss from erosion; Mitigation of floodplain loss downstream	Moderate costs for easements due to private ownership; Needs further investigation; Low costs for buffer planting	VTANR, VRC, VLT
#16: Farm North of Grafton Village Saxtons River Reach M15 43.18783 N 72.61782 W	**Active Restoration** *Stormwater Management*	Farm in the upper reach has dredged a deep farm ditch to divert water coming off the steep valley wall into the channel to avoid ponding in their fields. Ditch is delivering fine sediment to downstream channel.	Improve ditch by installing properly spaced check dams to encourage settling of fine sediment prior to reaching channel. Possible use of vegetation along check dams for nutrient uptake.	Low	**High**	Reduced fine sediment loading to channel and degradation of aquatic habitat.	Low costs to retrofit channel with check dams and vegetation.	VTANR

Table 5.8 Site-Level Project Identification for the Saxtons River Main Stem, Bull Creek, and the South Branch

Project #, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
#17: Downstream of Cabell Road in Houghtonville Saxtons River Reach M19 43.19652 N 72.63982 W	**Passive Restoration** *Corridor Protection*	Historical channel straightening noted in the lower reach where a hay field is found in between Route 121 and the channel. Given the extensive bank armoring upstream and high bed load from naturally-steep reaches above, this area could be susceptible to lateral migration in the future.	Long-term stream corridor protection to avoid conflict with river migration and development. FEH zone would cover this area.	Moderate	Moderate	Important sediment and floodwater attenuation section of reach downstream of channelized area.	Moderate costs for easements due to private ownership; Needs further investigation	VTANR, VRC, VLT
#18: Cabell Road in Houghtonville Saxtons River Reach M19 43.19709 N 72.64703 W	**Active Restoration** *Bridge Retrofit/ Replacement*	Bridge beneath Cabell Road is undersized (78% of Wbkf) and causing sediment deposition upstream and minor bank erosion downstream.	As structure comes up for replacement, it should be replaced and resized according to the RMP recommendations as well as redesigned to eliminate current problems.	Moderate	Low	Reduced risk of debris catchment during large flood which could cause severe flooding and erosion.	High cost for structure redesign and replacement.	VTRANS; VTDEC
#19: Mercy Lane Saxtons River Segment M20-B 43.19901 N 72.69727 W	**Active Restoration** *Culvert Retrofit/ Replacement*	Culvert beneath Mercy Lane is undersized (35% of Wbkf) and causing scour below – structure is partially compatible with geomorphic stability. Increased velocities through the culvert are reducing aquatic organism passage (AOP).	Replace culvert with an open-bottomed arch or bridge to improve AOP and reduce risks of erosion and flooding of adjacent home and roads.	Moderate	Moderate	Improved AOP in headwaters reach where high densities of brook trout were observed. Reduced risk of flooding and erosion.	Potentially high costs for design, permitting, and construction.	VTANR, USFW, Town of Windham
#20: Upstream of Mercy Lane Saxtons River Segment M20-B 43.19902 N 72.69812 W	**Passive Restoration** *Buffer Plantings*	Approximately 300 feet of channel lacks buffer – lawn mowed up to channel edge. Quality habitat with high brook trout densities noted upstream.	Plant stream buffer with native woody vegetation in areas lacking canopy cover; Coordinate with adjacent landowners to assess interest and cooperation.	Moderate	Moderate	Improved habitat in headwaters reach where high densities of brook trout were observed.	Relatively low costs for native plant materials and labor	WCNRCD; NRCS (CREP or Tress for Streams)

Table 5.8 Site-Level Project Identification for the Saxtons River Main Stem, Bull Creek, and the South Branch

Project #, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
#21: East of Route 35 Bull Creek Segment T4.01-A 43.14110 N 72.56025 W	**Passive Restoration** *Buffer Plantings*	Lack of native woody buffer for approx. 3,700 feet of stream bank along active farm. Stream type departure from C to E due to bank instability. Reduced habitat and high thermal loading. Reference habitat was likely excellent due to channel type and sinuosity.	Plant stream buffer with native woody vegetation in areas lacking canopy cover; Coordinate with adjacent landowners to assess interest and cooperation; Potential CREP project or "Trees for Streams"	**High**	**High**	Reduced fine sediment loading to channel and downstream areas; Reduced property loss from erosion; Improved biotic habitat within reach	Relatively low costs for native plant materials and labor, however it is a long stretch of channel; CREP easement potentially costly due to length	WCNRCD; NRCS (CREP)
#22: East of Route 35 Bull Creek Segment T4.01-A 43.14110 N 72.56025 W	**Passive Restoration** *Corridor Protection*	Channel historically straightened and manipulated. Channel currently has high rates of bank erosion. Additional lateral migration predicted throughout segment.	Protect stream corridor and plant buffer with native woody vegetation as described in project #21. CREP or VTDEC project easement would cover both approaches.	**High**	**High**	Potentially reduced property loss from erosion; Mitigation of floodplain loss upslope	Easements may already be in place under current ownership - needs further investigation	WCNRCD; NRCS (CREP); VTDEC
#23: North of Ober Road Bull Creek Segment T4.01-B 43.13099 N 72.56539 W	**Passive Restoration** *Buffer Plantings*	Lack of native woody buffer for approx. 1,000 feet of stream bank north of Ober Road. Channel has a high bed load and has active lateral migration. Long term bank erosion could be partially mitigated with buffer plantings.	Plant stream buffer with native woody vegetation in areas lacking canopy cover; Coordinate with adjacent landowners to assess interest and cooperation.	Moderate	Moderate	Reduced fine sediment loading to channel and downstream areas; Reduced property loss from erosion; Improved biotic habitat within reach	Relatively low costs for native plant materials and labor	WCNRCD; NRCS
#24: North and South of Tenneyville Road Trailer Park Bull Creek Segment T4.02 43.11057 N 72.57070 W	**Passive Restoration** *Buffer Plantings*	Multiple areas in upper reach are impacted by existing trailer park and on-going expansion to the north. Approx. 1,000 feet of channel length lacking healthy buffer.	Plant stream buffer with native woody vegetation in areas lacking canopy cover	Moderate	Moderate	Reduced fine sediment loading to channel and downstream areas; Improved biotic habitat within reach; Improved aesthetics	Relatively low costs for native plant materials and labor	WCNRCD; NRCS

Table 5.8 Site-Level Project Identification for the Saxtons River Main Stem, Bull Creek, and the South Branch								
Project #, Location, Reach, Lat/Long	**Type of Project**	**Site Description Including Stressors and Constraints**	**Project or Strategy Description**	**Hazard Mitigation Priority**	**Ecological Benefits Priority**	**Project Benefits**	**Costs**	**Potential Partners & Funding**
#25: East of Brookline Road in Athens Bull Creek Segment T4.03-B 43.10465 N 72.57761 W	**Passive Restoration** *Corridor Protection*	Depositional section of Bull Creek in unconfined valley setting. Extensive historical and current beaver activity, causing flooding and active channel processes when dams breach.	Long-term stream corridor protection to avoid conflict with river migration and development. FEH zone would cover the area's most susceptible to erosion and flooding.	Moderate	Moderate	Important sediment and floodwater attenuation section of reach downstream of channelized area.	Moderate costs for easements due to private ownership; Needs further investigation	VTANR
#26: Brookline Road Bull Creek Segment T4.03-B 43.09484 N 72.58301 W	**Active Restoration** *Culvert Retrofit/ Replacement*	Culvert beneath Brookline Road is undersized (28% of Wbkf) and causing scour below – structure is mostly incompatible with geomorphic stability. There is no aquatic organism passage (AOP). Bedrock present on downstream end.	Replace undersized culvert with an open-bottomed arch or bridge to improve AOP and reduce risks of erosion and flooding of adjacent home and roads.	Moderate	Moderate	Improved AOP in headwaters reach where high densities of brook trout are likely. Reduced risk of flooding and erosion.	High costs for design, permitting, and construction.	VTANR, USFW, Town of Athens
#27: Kidder Hill Dam South Branch Segment T6.01-A 43.16872 N 72.60636 W	**Active Restoration** *Dam Removal*	Old breached dam is a potential barrier to aquatic organism passage (esp. juvenile fish); Dam is not currently maintained; Aggradation, widening and bank erosion upstream.	Remove structure to restore aquatic organism passage; Channel restoration and/or sediment removal in upstream reaches would probably not be necessary.	Moderate	**High**	Increased AOP and potential for many miles of restored spawning habitat upstream	Moderate construction & permitting costs for structure removal	VTDEC; USFW; NOAA & American Rivers
#28: West of Townshend Rd in Grafton South Branch Segment T6.01-B 43.16235 N 72.61821 W	**Passive Restoration** *Corridor Protection*	70% of channel length historically straightened. Armoring in upper end of reach has increased stream power. Lower end of reach predicted to migrate laterally in future.	Long-term stream corridor protection to avoid conflict with river migration and development. FEH zone would cover the entire area most susceptible to erosion and flooding.	Moderate	Moderate	Important sediment and floodwater attenuation section of reach downstream of channelized area.	Moderate to high costs for easements due to private ownership and length of channel; Needs further investigation	VTANR, VRC, VLT

Table 5.8 Site-Level Project Identification for the Saxtons River Main Stem, Bull Creek, and the South Branch								
Project #, Location, Reach, Lat/Long	**Type of Project**	**Site Description Including Stressors and Constraints**	**Project or Strategy Description**	**Hazard Mitigation Priority**	**Ecological Benefits Priority**	**Project Benefits**	**Costs**	**Potential Partners & Funding**
#29: Townshend Rd Howe Brook Segment T6.S1.01-A 43.14198N 72.62799 W	**Active Restoration** *Bridge Retrofit/ Replacement*	Bridge beneath Townshend Road on Howe Brook is undersized (74% of Wbkf). Bank erosion upstream. Deposition occurred upstream during 1996 flood and could worsen in future flood events.	Replace undersized bridge with an appropriately-sized structure to reduce risks of erosion and flooding of adjacent home and roads.	**High**	Low	Reduced localized erosion. Reduced risk of flooding and erosion.	High costs for design, permitting, and construction.	Town of Grafton; FEMA
#30: East of Townshend Road in Grafton South Branch Segment T6.03 43.13255 N 72.63500 W	**Passive Restoration** *Corridor Protection*	95% of channel length historically straightened. Upper reach has floodplain area that is partially disconnected, but the road is not an encroachment to the channel as it is downstream, making it ideal for corridor protection.	Long-term stream corridor protection to avoid conflict with river migration and development. FEH zone would encompass the entire area most susceptible to erosion and flooding.	Moderate	Low	Important sediment and floodwater attenuation section of reach upstream of channelized area.	Moderate costs for easements due to private ownership; Needs further investigation	VTANR, VRC, VLT
#31: West of Townshend Road in Grafton Willie Brook T6.S2.01-A 43.13172 N 72.63880 W Styles Brook T6.04-B 43.12670 N 72.64075 W	**Passive Restoration** *Corridor Protection*	Both areas were once alluvial fans that have been straightened and armored. Now, sediment can be delivered downstream with little resistance, putting homes and Townshend Road at risk.	Long-term stream corridor protection to avoid conflict with river migration and development. Reconnect some of the alluvial fan functions that have been lost because of channel straightening, rip-rap and berming.	**High**	Moderate	Important sediment and floodwater attenuation section of reach;	Moderate to high costs for easements due to private ownership; Needs further investigation	VTANR, VRC, VLT

Table 5.8 Site-Level Project Identification for the Saxtons River Main Stem, Bull Creek, and the South Branch								
Project #, Location, Reach, Lat/Long	**Type of Project**	**Site Description Including Stressors and Constraints**	**Project or Strategy Description**	**Hazard Mitigation Priority**	**Ecological Benefits Priority**	**Project Benefits**	**Costs**	**Potential Partners & Funding**
#32: Townshend Rd South Branch Segment T6.04-A 43.12709 N 72.63906 W	**Active Restoration** *Bridge Retrofit/ Replacement*	Bridge beneath Townshend Road on Styles Brook is undersized (42% of Wbkf) and was problematic during 1996 flood. Sediment and debris created a jam at structure that forced a large volume of floodwaters and debris downstream, causing damage to houses in floodplain	Replace undersized bridge with an appropriately-sized structure to reduce risks of erosion and flooding of adjacent and downstream home and roads.	**High**	Moderate	Reduced localized erosion. Reduced risk of flooding and erosion downstream.	High costs for design, permitting, and construction.	Town of Grafton; FEMA

6.0 Conclusions & Recommendations

The Saxtons River and its tributaries vary significantly from east to west and along gradients from higher elevations to valley floors. The river corridors of the watershed support a diversity of forms and conditions, including upland cascading reaches, alluvial fans, areas of braiding at tributary junctions, and meandering channels in the valley along Route 121. Like many river systems in New England, past floods, defunct dams and various types of human land use in the river corridor have all left a lasting imprint on the morphology and stability of the channel network. While it is challenging to succinctly summarize the overall state of the river reaches included in this study, some general themes are summarized below that will be useful for future planning and management efforts.

Channel Forms and Stability

- With some minor exceptions, the upper reaches of the Saxtons River main stem west of Grafton are found in steeper gradients and more confined valley settings. Channel stability was generally “good” to “fair” in these reaches, and the potential for corridor restoration opportunities was lower than other areas in the watershed to the east.
- The South Branch of the Saxtons River and its tributaries, found to the south of Grafton Village, are situated in an unconfined valley. Channel and floodplain functions have been severely impacted by encroachment on the corridor from Townshend Road. Several areas along the South Branch have been identified for corridor restoration potential, including tributaries to the South Branch found along two alluvial fans (Styles and Willie Brooks), and the removal of a dam near Kidder Hill Road.
- Bull Creek is found in a wide alluvial valley and has a natural propensity for fluvial erosion and channel migration. In addition, historical impacts to the channel (e.g., straightening) have heightened its sensitivity. The highest ranking corridor protection project in the watershed, found on the lowest segment of Bull Creek, is currently being pursued by VTANR and VLT and will protect a critical floodplain prior to the confluence with the river’s main stem.
- With the exception of two areas at tributary junctions, the main stem of the Saxtons River from Grafton to Bellows Falls has lost significant floodplain function due to corridor encroachment from Route 121. Some reaches of the main stem are found in naturally entrenched valley settings; however numerous reaches in unconfined valley settings have been indirectly straightened due to bank armoring and floodplain modifications (e.g., fill from road embankments). The two exceptions are Reaches M06 and M09, where wider alluvial valleys present opportunities for river corridor restoration.

Aquatic Habitat

- As described above, the effect of Route 121 encroachment on the river corridor has reduced channel stability and degraded habitat. Many miles of river are “locked in place” with little room for natural lateral migration. This effect, in combination with bank armoring (e.g., rip-rap) and reduced riparian vegetation, severely limits input of woody debris and pool formation. Most reaches of the main stem had woody debris densities well below 50 pieces/mile (commonly “fair” and “poor” ratings), and pool densities were also very low. Over-widened channels on the main stem also degrade habitat through 1) a high degree of bed sedimentation from ongoing bank erosion, and 2) a high degree of solar-thermal loading which raises summer temperatures above thresholds tolerated by salmonids.

- Of all the study reaches, Bull Creek has the greatest potential for habitat restoration. The combination of a wide alluvial valley, limited corridor development, coarse gravel substrate, and high bedload allows for a dynamic channel with excellent formation of habitat features (e.g., pools and undercut banks). Riparian corridor restoration for habitat improvement is very promising in the lower part of Bull Creek.
- Few aquatic organism passage (AOP) problems associated with road crossings were noted in the study reaches. One culvert on the upper study reach of the main stem (M20-B), and one on upper Bull Creek (Reach T4.03-C) had reduced AOP. All other road crossings were bridges (49 total) with no AOP limitations.
- Dam removal is currently being pursued on the South Branch near Kidder Hill Road in Grafton. Improved AOP at this location will result in better access to many miles of habitat upslope.

Flood and Erosion Hazard Management Recommendations

- As noted above, two alluvial areas associated with tributary junctions in and around villages present opportunities for corridor protection and restoration. Reach M09, found at the confluence with Bull Creek, is a key sediment and floodwater attenuation asset. An effort is currently underway with the landowner to conserve the river corridor in this reach. Similarly, Reach M06 is found in a wide alluvial valley immediately upstream of the Village of Saxtons River. A berm along the river has prevented full floodplain function in this reach, which presents an opportunity for restoration and mitigation of downstream flooding.
- Ongoing lateral migration is predicted for many of the study reaches in the future. Adoption of Fluvial Erosion Hazard (FEH) zoning ordinances are highly recommended to prevent unsustainable river maintenance costs and increase public safety by limiting development within the active river corridor.
- The alluvial fans noted on the tributaries to the South Branch in Grafton have been severely channelized over the last 50 to 100 years. It is well known that significant debris originated from these areas during the 1996 flood, causing a bridge failure and other damage to private property. The development of a long-term management plan, one which includes a corridor protection component, is highly recommended for these areas.

The watershed management strategies and specific projects areas identified in this plan were developed to address the challenges and problems noted in the above summary. Long-term impediments to river restoration, such as the location of major roadways within the river corridor, have also been considered within the prioritization of strategies and project areas. The strategies are consistent with VTANR's goals of river corridor restoration, and when used within the context of the geomorphic and habitat data, provide a holistic framework for long-term restoration of river corridor functions.

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8.0 Glossary of Terms

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Restoration Terms, by Craig Fischenich, February, 2000, USAE Research and Development Center, Environmental Laboratory, 3909 Halls Ferry Rd., Vicksburg, MS 39180

And

Vermont Stream Geomorphic Assessment Handbook, 2007, Vermont Agency of Natural Resources, Waterbury, VT
http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_geoassesspro.htm

Acre -- A measure of area equal to 43,560 ft ^{2} (4,046.87 m^2). One square mile equals 640 acres.
Adjustment process --or type of change, that is underway due to natural causes or human activity that has or will result in a change to the valley, floodplain, and/or channel condition (e.g., vertical, lateral, or channel plan form adjustment processes)
Aggradation -- A progressive buildup or raising of the channel bed and floodplain due to sediment deposition. The geologic process by which streambeds are raised in elevation and floodplains are formed. Aggradation indicates that stream discharge and/or bed-load characteristics are changing. Opposite of degradation.
Algae -- Microscopic plants that grow in sunlit water containing phosphates, nitrates, and other nutrients. Algae, like all aquatic plants, add oxygen to the water and are important in the fish food chain.
Alluvial -- Deposited by running water.
Alluvium -- A general term for detrital deposits make by streams on riverbeds, floodplains, and alluvial fans; esp. a deposit of silt or silty clay laid down during time of flood. The term applies to stream deposits of recent time. It does not include subaqueous sediments of seas or lakes.
Anadromous -- Pertaining to fish that spend a part of their life cycle in the sea and return to freshwater streams to spawn.
Aquatic ecosystem -- Any body of water, such as a stream, lake, or estuary, and all organisms and nonliving components within it, functioning as a natural system.
Armoring -- A natural process (compare with unnatural "streambank armoring" defined later) where an erosion-resistant layer of relatively large particles is established on the surface of the streambed through removal of finer particles by stream flow. A properly armored streambed generally resists movement of bed material at discharges up to approximately 3/4 bank-full depth. Augmentation (of stream flow) – Increasing flow under normal conditions, by releasing storage water from reservoirs.
Avulsion -- A change in channel course that occurs when a stream suddenly breaks through its banks, typically bisecting an overextended meander arc.
Backwater -- (1) A small, generally shallow body of water attached to the main channel, with little or no current of its own, or (2) A condition in subcritical flow where the water surface elevation is raised by downstream flow impediments.
Backwater pool -- A pool that formed as a result of an obstruction like a large tree, weir, dam, or boulder.
Bank stability -- The ability of a streambank to counteract erosion or gravity forces.
Bankfull channel depth -- The maximum depth of a channel within a riffle segment when flowing at a bank-full discharge.
Bankfull channel width -- The top surface width of a stream channel when flowing at a bank-full discharge.
Bankfull discharge -- The stream discharge corresponding to the water stage that overtops the natural banks. This flow occurs, on average, about once every 1 to 2 years and given its frequency and magnitude is responsible for the shaping of most stream or river channels.
Bankfull width -- The width of a river or stream channel between the highest banks on either side of a stream.
Bar -- An accumulation of alluvium (usually gravel or sand) caused by a decrease in sediment transport capacity on the inside of meander bends or in the center of an overwide channel.
Barrier -- A physical block or impediment to the movement or migration of fish, such as a waterfall (natural barrier) or a dam (man-made barrier).
Base flow -- The sustained portion of stream discharge that is drawn from natural storage sources, and not affected by human activity or regulation.
Bed load -- Sediment moving on or near the streambed and transported by jumping, rolling, or sliding on the bed layer of a stream. See also suspended load.
Bed material -- The sediment mixture that a streambed is composed of.
Bed material load -- That portion of the total sediment load with sediments of a size found in the streambed.
Bed roughness -- A measure of the irregularity of the streambed as it contributes to flow resistance. Commonly expressed as a Manning "n" value.
Bed slope -- The inclination of the channel bottom, measured as the elevation drop per unit length of channel.
Bedform -- Individual patterns which streams follow that characterize the condition of the stream bed into several categories. (*See*: braided, dune-ripple, plane bed, riffle-pool, step-pool, and cascade)

Benthic invertebrates -- Aquatic animals without backbones that dwell on or in the bottom sediments of fresh or salt water. Examples: clams, crayfish, and a wide variety of worms.
Berms -- mounds of dirt, earth, gravel, or other fill built parallel to the stream banks designed to keep flood flows from entering the adjacent floodplain.
Biota -- All living organisms of a region, as in a stream or other body of water.
Boulder -- A large substrate particle that is larger than cobble, between 10 and 160 inches in diameter.
Boundary resistance -- The ability a stream bank has to withstand the erosional forces of the flowing water at varying intensities. Under natural conditions boundary resistance is increased due to stream bank vegetation (roots), cohesive clays, large boulder substrate, etc.
Braided -- A stream channel characterized by flow within several channels, which successively meet and divide. Braiding often occurs when sediment loading is too large to be carried by a single channel.
Braiding (of river channels) -- Successive division and rejoining of riverflow with accompanying islands.
Buffer strip -- A barrier of permanent vegetation, either forest or other vegetation, between waterways and land uses such as agriculture or urban development, designed to intercept and filter out pollution before it reaches the surface water resource.
Canopy -- A layer of foliage in a forest stand. This most often refers to the uppermost layer of foliage, but it can be used to describe lower layers in a multistoried stand. Leaves, branches and vegetation that are above ground and/or water that provide shade and cover for fish and wildlife.
Cascade -- A short, steep drop in streambed elevation often marked by boulders and agitated white water.
Catchment -- (1) The catching or collecting of water, especially rainfall. (2) A reservoir or other basin for catching water. (3) The water thus caught. (4) A watershed.
Channel -- An area that contains continuously or periodically flowing water that is confined by banks and a streambed.
Channelization -- The process of changing (usually straightening) the natural path of a waterway.
Channel evolution model (CEM) -- A series of stages used to describe the erosional or depositional processes that occur within a stream or river in order to regain a dynamic equilibrium following a disturbance.
Clay -- Substrate particles that are smaller than silt and generally less than 0.0001 inches in diameter.
Coarse gravel -- Substrate that is smaller than cobble, but larger than fine gravel. The diameter of this stream-bottom particulate is between 0.63 and 2.5 inches.
Cobble -- Substrate particles that are smaller than boulders and larger than gravels, and are generally between 2.5 and 10 inches in diameter.
Confinement -- *see* Valley confinement
Confluence -- (1) The act of flowing together; the meeting or junction of two or more streams; also, the place where these streams meet. (2) The stream or body of water formed by the junction of two or more streams; a combined flood.
Conifer -- A tree belonging to the order Gymnospermae, comprising a wide range of trees that are mostly evergreens. Conifers bear cones (hence, coniferous) and have needle-shaped or scalelike leaves.
Conservation -- The process or means of achieving recovery of viable populations.
Contiguous habitat -- Habitat suitable to support the life needs of a species that is distributed continuously or nearly continuously across the landscape.
Cover -- “cover” is the general term used to describe any structure that provides refuge for fish, reptiles or amphibians. These animals seek cover to hide from predators, to avoid warm water temperatures, and to rest, by avoiding higher velocity water. These animals come in all sizes, so even cobbles on the stream bottom that are not sedimented in with fine sands and silt can serve as cover for small fish and salamanders. Larger fish and reptiles often use large boulders, undercut banks, submerged logs, and snags for cover.
Critical shear stress -- The minimum amount of shear stress exerted by stream currents required to initiate soil particle motion. Because gravity also contributes to streambank particle movement but not on streambeds, critical shear stress along streambanks is less than for streambeds.]
Cross-section -- A series of measurements, relative to bankfull, that are taken across a stream channel that are representative of the geomorphic condition and stream type of the reach.
Crown -- The upper part of a tree or other woody plant that carries the main system of branches and the foliage.
Crown cover -- The degree to which the crowns of trees are nearing general contact with one another.
Cubic feet per second (cfs) -- A unit used to measure water flow. One cubic foot per second is equal to 449 gallons per minute.
Culvert -- A buried pipe that allows flows to pass under a road.
Debris flow -- A rapidly moving mass of rock fragments, soil, and mud, with more than half of the particles being larger than sand size.
Deciduous -- Trees and plants that shed their leaves at the end of the growing season.
Degradation -- (1) A progressive lowering of the channel bed due to scour. Degradation is an indicator that the stream's discharge and/or sediment load is changing. The opposite of aggradation. (2) A decrease in value for a designated use.
Detritus -- is organic material, such as leaves, twigs, and other dead plant matter, that collects on the stream bottom. It may occur in clumps, such as leaf packs at the bottom of a pool, or as single pieces, such as a fallen tree branch.

Dike -- (1) (Engineering) An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of lowlands; a levee. (2) A low wall that can act as a barrier to prevent a spill from spreading. (3) (Geology) A tabular body of igneous (formed by volcanic action) rock that cuts across the structure of adjacent rocks or cuts massive rocks.
Dissolved oxygen (DO) -- The amount of free (not chemically combined) oxygen dissolved in water, wastewater, or other liquid, usually expressed in milligrams per liter, parts per million, or percent of saturation.
Ditch -- A long narrow trench or furrow dug in the ground, as for irrigation, drainage, or a boundary line.
Drainage area -- The total surface area upstream of a point on a stream that drains toward that point. Not to be confused with watershed. The drainage area may include one or more watersheds.
Drainage basin -- The total area of land from which water drains into a specific river.
Dredging -- Removing material (usually sediments) from wetlands or waterways, usually to make them deeper or wider.
Dune-ripple -- A bedform associated with low-gradient, sand-bed channels; the low gradient nature of the channel causes the sand to form a sequence of dunes and small ripples; significant sediment transport typically occurs at most stream stages.
Ecology -- The study of the interrelationships of living organisms to one another and to their surroundings.
Ecosystem -- Recognizable, relatively homogeneous units, including the organisms they contain, their environment, and all the interactions among them.
Embankment -- An artificial deposit of material that is raised above the natural surface of the land and used to contain, divert, or store water, support roads or railways, or for other similar purposes.
Embeddedness -- is a measure of the amount of surface area of cobbles, boulders, snags and other stream bottom structures that is covered with sand and silt. An embedded streambed may be packed hard with sand and silt such that rocks in the stream bottom are difficult or impossible to pick up. The spaces between the rocks are filled with fine sediments, leaving little room for fish, amphibians, and bugs to use the structures for cover, resting, spawning, and feeding. A streambed that is not embedded has loose rocks that are easily removed from the stream bottom, and may even "roll" on one another when you walk on them.
Entrenchment ratio --The width of the flood-prone area divided by the bankfull width.
Epifaunal – "epi" means surface, and "fauna" means animals. Thus, "epifaunal substrate" is structures in the stream (on the stream bed) that provide surfaces on which animals can live. In this case, the animals are aquatic invertebrates (such as aquatic insects and other "bugs"). These bugs live on or under cobbles, boulders, logs, and snags, and the many cracks and crevices found in these structures. In general, older decaying logs are better suited for bugs to live on/in than newly fallen "green" logs and trees.
Ephemeral streams -- Streams that flow only in direct response to precipitation and whose channel is at all times above the water table.
Equilibrium Condition -- The state of a river reach in which the upstream input of energy (flow of water) and materials (sediment and debris) is equal to its output to downstream reaches. Natural river reaches without human impacts tend towards a "stable" state where predictable channel forms are maintained over the long term under varying flow conditions.
Erosion -- Wearing away of rock or soil by the gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical, chemical, or biological forces.
Eutrophic -- Usually refers to a nutrient-enriched, highly productive body of water.
Eutrophication -- The process of enrichment of water bodies by nutrients.
Fine gravel -- Is substrate which is larger than sand, but smaller than coarse gravel. It is between 0.08 and 0.63 inches in diameter.
Flash flood -- A sudden flood of great volume, usually caused by a heavy rain. Also, a flood that crests in a short length of time and is often characterized by high velocity flows.
Floodplain -- Land built of fine particulate organic matter and small substrate that is regularly covered with water as a result of the flooding of a nearby stream.
Floodplain (100-year) -- The area adjacent to a stream that is on average inundated once a century.
Floodplain Function – Flood water access of floodplain which effects the velocity, depth, and slope (stream power) of the flood flow thereby influencing the sediment transport characteristics of the flood (i.e., loss of floodplain access and function may lead to higher stream power and erosion during flood).
Flow -- The amount of water passing a particular point in a stream or river, usually expressed in cubic feet per second (cfs).
Fluvial -- Migrating between main rivers and tributaries. Of or pertaining to streams or rivers.
Fluvial Geomorphology—The study of how rivers and their landforms interact over time through different climatic conditions.
Ford -- A shallow place in a body of water, such as a river, where one can cross by walking or riding on an animal or in a vehicle.
Fry -- A recently hatched fish.
Gabion -- A wire basket or cage that is filled with gravel or cobble and generally used to stabilize streambanks.
Gaging station -- A particular site in a stream, lake, reservoir, etc., where hydrologic data are obtained.
Gallons per minute (gpm) -- A unit used to measure water flow.
Geographic information system (GIS) -- A computer system capable of storing and manipulating spatial data.

Geomorphology -- A branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and the buildup of erosional debris.
Glide -- A section of stream that has little or no turbulence.
Grade control -- A fixed feature on the streambed that controls the bed elevation at that point, effectively fixing the bed elevation from potential incision; typically bedrock, dams. or culverts.
Gradient -- Vertical drop per unit of horizontal distance.
Grass/forb -- Herbaceous vegetation.
Gravel -- An unconsolidated natural accumulation of rounded rock fragments, mostly of particles larger than sand (diameter greater than 2 mm), such as boulders, cobbles, pebbles, granules, or any combination of these.
Groundwater -- Subsurface water and underground streams that can be collected with wells, or that flow naturally to the earth's surface through springs.
Groundwater basin -- A groundwater reservoir, defined by an overlying land surface and the underlying aquifers that contain water stored in the reservoir. In some cases, the boundaries of successively deeper aquifers may differ and make it difficult to define the limits of the basin.
Groundwater recharge -- Increases in groundwater storage by natural conditions or by human activity. See also artificial recharge.
Groundwater Table -- The upper surface of the zone of saturation, except where the surface is formed by an impermeable body.
Habitat -- The local environment in which organisms normally live and grow.
Habitat diversity -- The number of different types of habitat within a given area.
Habitat fragmentation -- The breaking up of habitat into discrete islands through modification or conversion of habitat by management activities.
Headcut -- A sharp change in slope, almost vertical, where the streambed is being eroded from downstream to upstream.
Headwater -- Referring to the source of a stream or river.
High gradient streams -- typically appear as steep cascading streams, step/pool streams, or streams that exhibit riffle/pool sequences. Most of the streams in Vermont are high gradient streams.
Hydraulic gradient -- The slope of the water surface. See also streambed gradient.
Hydraulic radius -- The cross-sectional area of a stream divided by the wetted perimeter.
Hydric -- oil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper horizon.
Hydrograph -- A curve showing stream discharge over time.
Hydrologic balance -- An accounting of all water inflow to, water outflow from, and changes in water storage within a hydrologic unit over a specified period of time. Hydrologic region -- A study area, consisting of one or more planning subareas, that has a common hydrologic character.
Hydrologic Unit Code (HUC) -- A distinct watershed or river basin defined by an 8-digit code.
Hydrology -- The scientific study of the water of the earth, its occurrence, circulation and distribution, its chemical and physical properties, and its interaction with its environment, including its relationship to living things.
Hyporheic zone -- The area under the stream channel and floodplain where groundwater and the surface waters of the stream are exchanged freely.
Impoundment -- An area where the natural flow of the river has been disrupted by the presence of human-made or natural structure (e.g. weir or beaver dam). The impoundment backwater extends upstream causing sediment to be deposited on the stream bottom.
Improved paths – Paths that are maintained and typically involve paved, gravel or macadam surfaces.
Incised river -- A river that erodes its channel by the process of degradation to a lower base level than existed previously or is consistent with the current hydrology.
Incision ratio -- The low bank height divided by the bankfull maximum depth.
Infiltration (soil) -- The movement of water through the soil surface into the soil.
Inflow -- Water that flows into a stream, lake,
Instream cover -- The layers of vegetation, like trees, shrubs, and overhanging vegetation, that are in the stream or immediately adjacent to the wetted channel.
Instream flows -- (1) Portion of a flood flow that is contained by the channel. (2) A minimum flow requirement to maintain ecological health in a stream.
Instream use -- Use of water that does not require diversion from its natural watercourse. For example, the use of water for navigation, recreation, fish and wildlife, aesthetics, and scenic enjoyment.
Intermittent stream -- Any nonpermanent flowing drainage feature having a definable channel and evidence of scour or deposition. This includes what are sometimes referred to as ephemeral streams if they meet these two criteria.
Irrigation diversion -- Generally, a ditch or channel that deflects water from a stream channel for irrigation purposes.
Islands -- mid-channel bars that are above the average water level and have established woody vegetation.

Kame – a deposit of stratified glacial drift in isolated mounds or steep-sided hills.
Lake -- An inland body of standing water deeper than a pond, an expanded part of a river, a reservoir behind a dam
Landslide -- A movement of earth mass down a steep slope.
Large woody debris (LWD) -- Pieces of wood at least 6 ft. long and 1 ft. in diameter (at the large end) contained, at least partially, within the bankfull area of a channel.
Levee -- An embankment constructed to prevent a river from overflowing (flooding).
Limiting factor -- A requirement such as food, cover, or another physical, chemical, or biological factor that is in shortest supply with respect to all resources necessary to sustain life and thus "limits" the size or retards production of a population.
Low gradient -- streams typically appear slow moving and winding, and have poorly defined riffles and pools.
Macroinvertebrate -- Invertebrates visible to the naked eye, such as insect larvae and crayfish.
Macrophytes -- Aquatic plants that are large enough to be seen with the naked eye.
Main Stem -- The principal channel of a drainage system into which other smaller streams or rivers flow.
Mass movement -- The downslope movement of earth caused by gravity. Includes but is not limited to landslides, rock falls, debris avalanches, and creep. It does not however, include surface erosion by running water. It may be caused by natural erosional processes, or by natural disturbances (e.g., earthquakes or fire events) or human disturbances (e.g., mining or road construction).
Mean annual discharge -- Daily mean discharge averaged over a period of years. Mean annual discharge generally fills a channel to about one-third of its bank-full depth.
Mean velocity -- The average cross-sectional velocity of water in a stream channel. Surface values typically are much higher than bottom velocities. May be approximated in the field by multiplying the surface velocity, as determined with a float, times 0.8.
Meander -- The winding of a stream channel, usually in an erodible alluvial valley. A series of sine-generated curves characterized by curved flow and alternating banks and shoals.
Meander amplitude -- The distance between points of maximum curvature of successive meanders of opposite phase in a direction normal to the general course of the meander belt, measured between center lines of channels.
Meander belt width -- the distance between lines drawn tangential to the extreme limits of fully developed meanders. Not to be confused with meander amplitude.
Meander length -- The lineal distance down valley between two corresponding points of successive meanders of the same phase.
Mid-channel Bars – bars located in the channel away from the banks, generally found in areas where the channel runs straight. Mid-channel bars caused by recent channel instability are unvegetated.
Milligrams per liter (mg/l) -- The weight in milligrams of any substance dissolved in 1 liter of liquid; nearly the same as parts per million by weight.
Moraine – a mass of till either carried by an active glacier or deposited on the land after a glacier recedes.
Natural flow -- The flow past a specified point on a natural stream that is unaffected by stream diversion, storage, import, export, return flow, or change in use caused by modifications in land use.
Neck cutoff -- A channel migration feature where the land that separates a meander bend is cut off by the lateral migration of the channel. This process may be part of the equilibrium regime or associated with channel instability.
Outfall -- The mouth or outlet of a river, stream, lake, drain or sewer.
Outwash – water-transported material carried away from the ablation zone of a melting glacier.
Oxbow -- An abandoned meander in a river or stream, caused by cutoff. Used to describe the U-shaped bend in the river or the land within such a bend of a river.
Peat -- Partially decomposed plants and other organic material that build up in poorly drained wetland habitats.
Perched groundwater -- Groundwater supported by a zone of material of low permeability located above an underlying main body of groundwater with which it is not hydrostatically connected.
Perennial streams -- Streams that flow continuously.
Permeability -- The capability of soil or other geologic formations to transmit water.
pH -- The negative logarithm of the molar concentration of the hydrogen ion, or, more simply acidity.
Planform -- The channel shape as if observed from the air. Changes in planform often involve shifts in large amount of sediment, bank erosion, or the migration of the channel. A channel straightened for agricultural purposes has a highly impacted planform.
Point bar -- The convex side of a meander bend that is built up due to sediment deposition.
Pond -- A body of water smaller than a lake, often artificially formed.
Pool -- A reach of stream that is characterized by deep, low-velocity water and a smooth surface.
Potential plant height -- the height to which a plant, shrub or tree would grow if undisturbed.
Probability of exceedence -- The probability that a random flood will exceed a specified magnitude in a given period of time.
Railroads – Used or unused railroad infrastructure.
Rapids -- A reach of stream that is characterized by small falls and turbulent, high-velocity water.

Reach -- A section of stream having relatively uniform physical attributes, such as valley confinement, valley slope, sinuosity, dominant bed material, and bed form, as determined in the Phase 1 assessment.
Rearing habitat -- Areas in rivers or streams where juvenile fish find food and shelter to live and grow.
Reference stream type --Uses preliminary observations to determine the natural channel form and process that would be present in the absence of anthropogenic impacts to the channel and the surrounding watershed.
Refuge area -- An area within a stream that provides protection to aquatic species during very low and/or high flows.
Regime theory -- A theory of channel formation that applies to streams that make a part of their boundaries from their transported sediment load and a portion of their transported sediment load from their boundaries. Channels are considered in regime or equilibrium when bank erosion and bank formation are equal.
Restoration -- The return of an ecosystem to a close approximation of its condition prior to disturbance.
Riffle -- A reach of stream that is characterized by shallow, fast-moving water broken by the presence of rocks and boulders.
Riffle-pool ratio -- The ratio of surface area or length of pools to the surface area or length of riffles in a given stream reach; frequently expressed as the relative percentage of each category. Used to describe fish habitat rearing quality.
Riffle-step ratio-- ratio of the distance between riffles to the stream width.
Riparian area -- An area of land and vegetation adjacent to a stream that has a direct effect on the stream. This includes woodlands, vegetation, and floodplains. Riparian buffer is the width of naturally vegetated land adjacent to the stream between the top of the bank (or top of slope, depending on site characteristics) and the edge of other land uses. A buffer is largely undisturbed and consists of the trees, shrubs, groundcover plants, duff layer, and naturally uneven ground surface. The buffer serves to protect the water body from the impacts of adjacent land uses. Riparian corridor includes lands defined by the lateral extent of a stream's meanders necessary to maintain a stable stream dimension, pattern, profile, and sediment regime. For instance, in stable pool-riffle streams, riparian corridors may be as wide as 10-12 times the channel's bankfull width. In addition the riparian corridor typically corresponds to the land area surrounding and including the stream that supports (or could support if unimpacted) a distinct ecosystem, generally with abundant and diverse plant and animal communities (as compared with upland communities).
Riparian habitat -- The aquatic and terrestrial habitat adjacent to streams, lakes, estuaries, or other waterways.
Riparian -- Located on the banks of a stream or other body of water.
Riparian vegetation -- The plants that grow adjacent to a wetland area such as a river, stream, reservoir, pond, spring, marsh, bog, meadow, etc., and that rely upon the hydrology of the associated water body.
Ripple -- (1) A specific undulated bed form found in sand bed streams. (2) Undulations or waves on the surface of flowing water.
Riprap -- Rock or other material with a specific mixture of sizes referred to as a "gradation," used to stabilize streambanks or riverbanks from erosion or to create habitat features in a stream.
River channels --Large natural or artificial open streams that continuously or periodically contain moving water, or which form a connection between two bodies of water.
River miles --Generally, miles from the mouth of a river to a specific destination or, for upstream tributaries, from the confluence with the main river to a specific destination.
River reach -- Any defined length of a river.
River stage -- The elevation of the water surface at a specified station above some arbitrary zero datum (level).
Riverine -- Relating to, formed by, or resembling a river including tributaries, streams, brooks, etc.
Riverine habitat -- The aquatic habitat within streams and rivers.
Roads -- Transportation infrastructure. Includes private, town, state roads, and roads that are dirt, gravel, or paved.
Rock -- A naturally formed mass of minerals.
Rootwad -- The mass of roots associated with a tree adjacent to or in a stream that provides refuge for fish and other aquatic life.
Run (in stream or river) -- A reach of stream characterized by fast-flowing, low-turbulence water.
Runoff -- Water that flows over the ground and reaches a stream as a result of rainfall or snowmelt.
Sand -- Small substrate particles, generally from 0.002 to 0.08 in diameter. Sand is larger than silt and smaller than gravel.
Scour -- The erosive action of running water in streams, which excavates and carries away material from the bed and banks. Scour may occur in both earth and solid rock material and can be classed as general, contraction, or local scour.
Sediment -- Soil or mineral material transported by water or wind and deposited in streams or other bodies of water.
Sedimentation -- (1) The combined processes of soil erosion, entrainment, transport, deposition, and consolidation. (2) Deposition of sediment.
Seepage -- The gradual movement of a fluid into, through, or from a porous medium. Segment: A relatively homogenous section of stream contained within a reach that has the same reference stream characteristics but is distinct from other segments in the reach in one or more of the following parameters: degree of floodplain encroachment, presence/absence of grade controls, bankfull channel dimensions (W/D ratio, entrenchment), channel sinuosity and slope, riparian buffer and corridor conditions, abundance of springs/seeps/adjacent wetlands/stormwater inputs, and degree of channel alterations.

Sensitivity -- of the valley, floodplain, and/or channel condition to change due to natural causes and/or anticipated human activity.
Shear -- equal and opposite tangential forces (stream flow force and bed/bank resistance) that cause bed and bank material to slide in a downward and/or downstream direction.
Shoals -- unvegetated deposits of gravels and cobbles adjacent to the banks that have a height less than the average water level. In channels that are over-widened, the stream does not have the power to transport these larger sediments, and thus they are deposited throughout the channel as shoals.
Silt -- Substrate particles smaller than sand and larger than clay; between 0.0001 and 0.002 inches in diameter.
Siltation -- The deposition or accumulation of fine soil particles.
Sinuosity -- The ratio of channel length to direct down-valley distance. Also may be expressed as the ratio of down-valley slope to channel slope.
Slope -- The ratio of the change in elevation over distance.
Slope stability -- The resistance of a natural or artificial slope or other inclined surface to failure by mass movement.
Snag -- Any standing dead, partially dead, or defective (cull) tree at least 10 in. in diameter at breast height and at least 6 ft tall. Snags are important riparian habitat features.
Spawning -- The depositing and fertilizing of eggs (or roe) by fish and other aquatic life.
Spillway -- A channel for reservoir overflow.
Stable channel -- A stream channel with the right balance of slope, planform, and cross section to transport both the water and sediment load without net long-term bed or bank sediment deposition or erosion throughout the stream segment.
Stone -- Rock or rock fragments used for construction.
Straightening -- the removal of meander bends, often done in towns and along roadways, railroads, and agricultural fields.
Stream -- A general term for a body of water flowing by gravity; natural watercourse containing water at least part of the year. In hydrology, the term is generally applied to the water flowing in a natural narrow channel as distinct from a canal. Stream banks are features that define the channel sides and contain stream flow within the channel; this is the portion of the channel bank that is between the toe of the bank slope and the bankfull elevation. The banks are distinct from the streambed, which is normally wetted and provides a substrate that supports aquatic organisms. The top of bank is the point where an abrupt change in slope is evident, and where the stream is generally able to overflow the banks and enter the adjacent floodplain during flows at or exceeding the average annual high water.
Stream channel -- A long narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.
Stream condition -- Given the land use, channel and floodplain modifications documented at the assessment sites, the current degree of change in the channel and floodplain from the reference condition for parameters such as dimension, pattern, profile, sediment regime, and vegetation.
Stream gradient -- A general slope or rate of change in vertical elevation per unit of horizontal distance of the bed, water surface, or energy grade of a stream.
Stream morphology -- The form and structure of streams.
Stream order -- A hydrologic system of stream classification. Each small unbranched tributary is a first-order stream. Two first-order streams join to make a second-order stream. A third-order stream has only first-and second-order tributaries, and so forth.
Stream reach -- An individual segment of stream that has beginning and ending points defined by identifiable features such as where a tributary confluence changes the channel character or order.
Stream type -- Gives the overall physical characteristics of the channel and helps predict the reference or stable condition of the reach.
Stream type departure -- When the current stream type differs from the reference stream type as a response to anthropogenic or severe natural disturbances. These departures are often characterized by large-scale incision, deposition, or changes in planform.
Streambank armoring – The installation of concrete walls, gabions, stone riprap, and other large erosion resistant material along stream banks.
Streambank erosion -- The removal of soil from streambanks by flowing water.
Streambank stabilization -- The lining of streambanks with riprap, matting, etc., or other measures intended to control erosion.
Streambed -- (1) The unvegetated portion of a channel boundary below the baseflow level. (2) The channel through which a natural stream of water runs or used to run, as a dry streambed.
Streamflow -- The rate at which water passes a given point in a stream or river, usually expressed in cubic feet per second (cfs).
Step (in a river system) --A step is a steep, step-like feature in a high gradient stream (> 2%). Steps are composed of large boulders lines across the stream. Steps are important for providing grade-control, and for dissipating energy. As fast-shallow water flows over the steps it takes various flow paths thus dissipating energy during high flow events.
Substrate -- (1) The composition of a streambed, including either mineral or organic materials. (2) Material that forms an attachment medium for organisms.

Surface erosion -- The detachment and transport of soil particles by wind, water, or gravity. Or a group of processes whereby soil materials are removed by running water, waves and currents, moving ice, or wind.
Surface water -- All waters whose surface is naturally exposed to the atmosphere, for example, rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc., and all springs, wells, or other collectors directly influenced by surface water.
Suspended sediment -- Sediment suspended in a fluid by the upward components of turbulent currents, moving ice, or wind.
Suspended sediment load -- That portion of a stream's total sediment load that is transported within the body of water and has very little contact with the streambed.
Tailwater -- (1) The area immediately downstream of a spillway. (2) Applied irrigation water that runs off the end of a field.
Thalweg -- (1) The lowest thread along the axial part of a valley or stream channel. (2) A subsurface, groundwater stream percolating beneath and in the general direction of a surface stream course or valley. (3) The middle, chief, or deepest part of a navigable channel or waterway.
Tractive Force --The drag on a streambed or bank caused by passing water, which tends to pull soil particles along with the streamflow.
Transpiration -- An essential physiological process in which plant tissues give off water vapor to the atmosphere.
Tributary -- A stream that flows into another stream, river, or lake.
Turbidity -- A measure of the content of suspended matter that interferes with the passage of light through the water or in which visual depth is restricted. Suspended sediments are only one component of turbidity.
Urban runoff -- Storm water from city streets and gutters that usually carries a great deal of litter and organic and bacterial wastes into the sewer systems and receiving waters.
Valley confinement -- Referring to the ratio of valley width to channel width. Unconfined channels (confinement of 4 or greater) flow through broader valleys and typically have higher sinuosity and area for floodplain. Confined channels (confinement of less than 4) typically flow through narrower valleys.
Valley wall -- The side slope of a valley, which begins where the topography transitions from the gentle-sloped valley floor. The distance between valley walls is used to calculate the valley confinement.
Variable-stage stream -- Stream flows perennially but water level rises and falls significantly with storm and runoff events.
Velocity -- In this concept, the speed of water flowing in a watercourse, such as a river.
Washout -- (1) Erosion of a relatively soft surface, such as a roadbed, by a sudden gush of water, as from a downpour or floods. (2) A channel produced by such erosion.
Water quality -- A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.
Waterfall -- A sudden, nearly vertical drop in a stream, as it flows over rock.
Watershed -- An area of land whose total surface drainage flows to a single point in a stream.
Watershed management -- The analysis, protection, development, operation, or maintenance of the land, vegetation, and water resources of a drainage basin for the conservation of all its resources for the benefit of its residents.
Watershed project -- A comprehensive program of structural and nonstructural measures to preserve or restore a watershed to good hydrologic condition. These measures may include detention reservoirs, dikes, channels, contour trenches, terraces, furrows, gully plugs, revegetation, and possibly other practices to reduce flood peaks and sediment production.
Watershed restoration -- Improving current conditions of watersheds to restore degraded habitat and provide long-term protection to aquatic and riparian resources.
Weir -- A structure to control water levels in a stream. Depending upon the configuration, weirs can provide a specific "rating" for discharge as a function of the upstream water level.
Wetland -- Areas adjacent to, or within the stream, with sufficient surface/groundwater influence to have present hydric soils and aquatic vegetation (e.g. cattails, sedges, rushes, willows or alders).
Width/depth ratio -- The ratio of channel bankfull width to the average bankfull depth. An indicator of channel widening or aggradation, and used for stream type classification.