White Creek and Mill Brook Corridor Plan
Rupert, Vermont

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Executive Summary

The Town of Rupert is nestled in a narrow valley within the steep mountains of the Taconic Range in southwestern Vermont. The mountainous terrain draining the White Creek/Mill Brook watershed creates fluvial erosion hazards throughout the town. While flood damages resulting from inundation occurred in 2011 during Tropical Storm (TS) Irene in New York along the White Creek downstream (west) of Rupert, fluvial erosion has been the principal mode of damage to roadways, homes, and farm fields in Rupert during past flood events. Over the last 20 years, Rupert has experienced numerous floods that have caused severe damage to private and public land and infrastructure, including significant floods in 1996, 1999, 2000, and TS Irene in 2011.

In an effort to understand the root causes of stream channel instability and fluvial erosion hazards in the White Creek/Mill Brook watersheds, the Bennington County Conservation District (BCCD) has sought to develop a database of Stream Geomorphic Assessment (SGA) data for most stream reaches of significant size in the watershed. This effort began in 2005 with a remote, desktop review of the reaches in the watershed, and continued in 2008 with detailed field measurements (i.e., Phase 2 SGA). This data allows for a much more comprehensive erosion hazard planning approach, in contrast to the conventional approach of multiple "spot fixes" with limited knowledge of the river system. In early 2012, BCCD received a grant from the Vermont Agency of Natural Resources (Ecosystem Restoration Program) to develop a River Corridor Management Plan for the Mill Brook/White Creek watershed. Fitzgerald Environmental Associates, LLC (FEA) was hired by BCCD in spring of 2012 to develop the plan. The objectives of the planning study are described below.

1) Develop a basis for understanding the overall causes of channel instability and habitat degradation along the river corridors in the watershed.
2) Produce a list of preliminary corridor restoration projects that can be further developed in the future to mitigate flood and erosion hazards in the White Creek/Mill Brook watersheds.
3) Develop project packets for five (5) high priority projects to support future implementation.

The White Creek and Mill Brook channels are still adjusting their dimensions, patterns, and profiles to impacts from historical sedimentation in the valleys from early European settlement and deforestation that caused hillslope erosion, as well as modern day impacts from channel straightening, dredging and corridor encroachment associated with adjacent railroads, agriculture, and other land uses. Recent flood events over the last 20 years have also triggered channel incision and redevelopment of floodplain access in some reaches. Ongoing vertical and lateral channel migration is likely in the future for many reaches in the watershed. Given these predictions for future channel adjustments, the following watershed-scale and site-specific management observations and approaches are summarized from the corridor plan:

- The stressor identification analysis revealed limited watershed-scale impacts from recent land use changes (i.e., development); however corridor encroachments and channel straightening have significantly impacted the lower reaches of Mill Brook and White Creek. Four (4) river segments in the White Creek watershed have departed from reference conditions due to channel incision. 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.

- Site level approaches to restoration of dynamic equilibrium conditions were evaluated in detail at the reach scale. This effort resulted in the identification of 29 unique projects, including 17 projects that do not require significant further study (i.e., passive approaches such as buffer plantings and corridor protection), and 12 projects requiring further feasibility study or engineering design (i.e., active restoration approaches such as bridge replacements). Five project bundles that were identified by the Rupert steering committee as high-priority were evaluated in further detail. Project summaries are included in Appendix B.
- We recommend the continued use/enforcement of the adopted Fluvial Erosion Hazard (FEH) zone ordinance in Rupert, with consideration of appropriate stream setbacks in areas where the FEH zone is not mapped (e.g., smaller tributaries draining to White Creek and Mill Brook).
- Sediment management has been identified as a key concern in the Rupert community due to ongoing conflicts at structures and road crossings. However, given the state of channel adjustments in many reaches in the White Creek/Mill Brook watershed, bank stabilization is generally not advisable in reaches that are actively incising or redeveloping planform geometry. Numerous riverbank stabilization projects in Vermont and other states have failed due to a lack of understanding of channel adjustment processes.
- In certain reaches where the channel is confirmed to have access to its floodplain, bank stabilization treatments may be viable but should be carefully considered. An example of this is Project 18, which is described in detail in Appendix B.
- Carefully consider those areas of river corridor identified as "high-priority" for added protection (i.e., conservation easements) above and beyond the FEH restrictions to protect upstream floodplains and mitigate downstream effects of fluvial erosion hazards in the Village of Rupert. Refer to "high priority" projects 2, 3, 23, 26, and 27 in Table 5.3.
- Address high-priority areas of channel and floodplain restoration to mitigate the effects of dredging/berming that occurred following TS Irene. These areas, which include projects 2 and 8 (see Appendix B for detailed project descriptions), have elevated risks of future flood damage for both adjacent lands and downstream areas.

1.0 Project Background

1.1 Introduction

The Town of Rupert is situated at the toe of steep mountains of the Taconic Range rising to the east. The mountains east and north of Rupert village are well forested with very limited roadways and development. White Creek and Mill Brook, and their tributaries, begin to the east and north of the village, and find their way into idyllic valleys where the land has been in agricultural use for over two centuries. As with most mountain-valley villages of Vermont, Rupert village is not necessarily prone to prolonged inundation when White Creek and Mill Brooks rise following large rainfall events. Rather, fluvial erosion is primarily what causes damage to roadways, homes, and farm fields in Rupert. Over the last 20 years, the Town of Rupert has experienced four major floods that have caused severe damage to private and public land and infrastructure. The most recent event, Tropical Storm Irene in August 2011, caused widespread damage in southern Vermont, including the Town of Rupert.

In an effort to understand the root causes of stream channel instability and fluvial erosion hazards in the White Creek and Mill Brook watersheds, the Bennington County Conservation District (BCCD) has sought to develop a database of Stream Geomorphic Assessment (SGA) data for most stream reaches of significant size in the watershed. This effort began in 2005 with a remote, desktop review of the reaches in the watershed, and continued in 2008 with detailed field measurements (i.e., Phase 2 SGA). This data allows for a much more comprehensive erosion hazard planning approach, in contrast to the conventional approach of multiple “spot fixes” with limited knowledge of the river system.

In early 2012, BCCD received a grant from the Vermont Agency of Natural Resources (Ecosystem Restoration Program) to develop a River Corridor Management Plan for the Mill Brook and White Creek watersheds. Fitzgerald Environmental Associates, LLC (FEA) was hired by BCCD in spring of 2012 to develop the plan. The goals of the planning study are described below.

1.2 Study Goals

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 (VTDEC, 2010). 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,” (VTDEC, 2010) achieved through:

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

The BCCD completed Phase 1 Stream Geomorphic Assessments (SGA) following the RMP protocols for portions of the White Creek, Mill Brook, and Sandgate Brook in 2005. Fifteen higher priority reaches were selected from the Phase 1 study for further Phase 2 assessments. BCCD hired a consultant, VHB-Pioneer, to collect Phase 2 data on these reaches in 2008. Using this background data as a basis for planning, the goal of the River Corridor Planning effort for these watersheds is to provide:

4) A basis for understanding the overall causes of channel instability and habitat degradation along the river corridors in the watershed.
5) A list of preliminary corridor restoration projects that can be further developed in the future to mitigate flood and erosion hazards in the White Creek/Mill Brook watersheds.
6) Project packets for five (5) high priority projects to support future implementation.

1.3 Project Partners

The planning team for the ongoing SGA and River Corridor Planning work in the White Creek and Mill Brook watersheds includes the following groups:

- Bennington County Conservation District
- Bennington County Regional Commission
- Town of Rupert Representatives
- Vermont Department of Environmental Conservation
- Battenkill Watershed Alliance
- Vermont Department of Fish & Wildlife

2.0 Background Watershed Information

2.1 Geographic Setting and Land Use History

The White Creek/Mill Brook watershed is located in Bennington County in the Southwestern corner of Vermont (Figure 2.1). The 22.5 square mile watershed is the largest subwatershed of the Batten Kill River basin draining into New York State (BCCD, 2006). White Creek discharges into Black Creek, which drains into the Batten Kill, which flows into the Hudson River. The Batten Kill and the Hoosic River watersheds are the only watersheds in Vermont which drain into the Hudson River. The assessed segments and reaches in the watershed are fourth and fifth order systems. The drainage area of White Creek is twice as large as the drainage area for Mill Brook.

Land cover data based on imagery from 2006 (NOAA, 2008) are summarized in Table 2.1. White Creek and Mill Brook are drained by a rural watershed, with forests representing the dominant land cover type (84.2%). Agricultural lands cover 14% of the watershed with a majority of the farmlands found in the Mill Brook watershed. The lower reaches of White Creek (M01A, M01B, and M01T2.01A) also contain a large percentage of agricultural lands. Development is low throughout the study area (0.5%). The developed lands are concentrated along major roads in the Mill Brook and White Creek watersheds and in the town of Rupert in reaches M01T1.02 and M01T1.03.

Table 2.1 Land use/Land cover data for the White Creek/Mill Brook watershed and tributary

Land Cover/Land Use Type	Mill Brook	Sandgate Brook	White Creek	Entire Watershed
Agriculture	32.7%	1.2%	7.5%	14.0%
Development	1.0%	0.0%	0.3%	0.5%
Forest	64.0%	98.2%	91.0%	84.2%
Open Water	0.0%	0.0%	0.0%	0.0%
Scrub/Shrub	1.2%	0.5%	0.8%	0.9%
Wetland	1.0%	0.0%	0.3%	0.4%
Branch Area (Mi^2)	6.38	2.71	13.34	22.43

*Mill Brook: reaches M01T1.01-M01T1.06, T1S1.01; Sandgate Brook: reaches M03T1.01 – M03T1.03; White Creek: reaches M01-M07, M01T2.01-M01T2.02, M03T2.01-M03T2.02

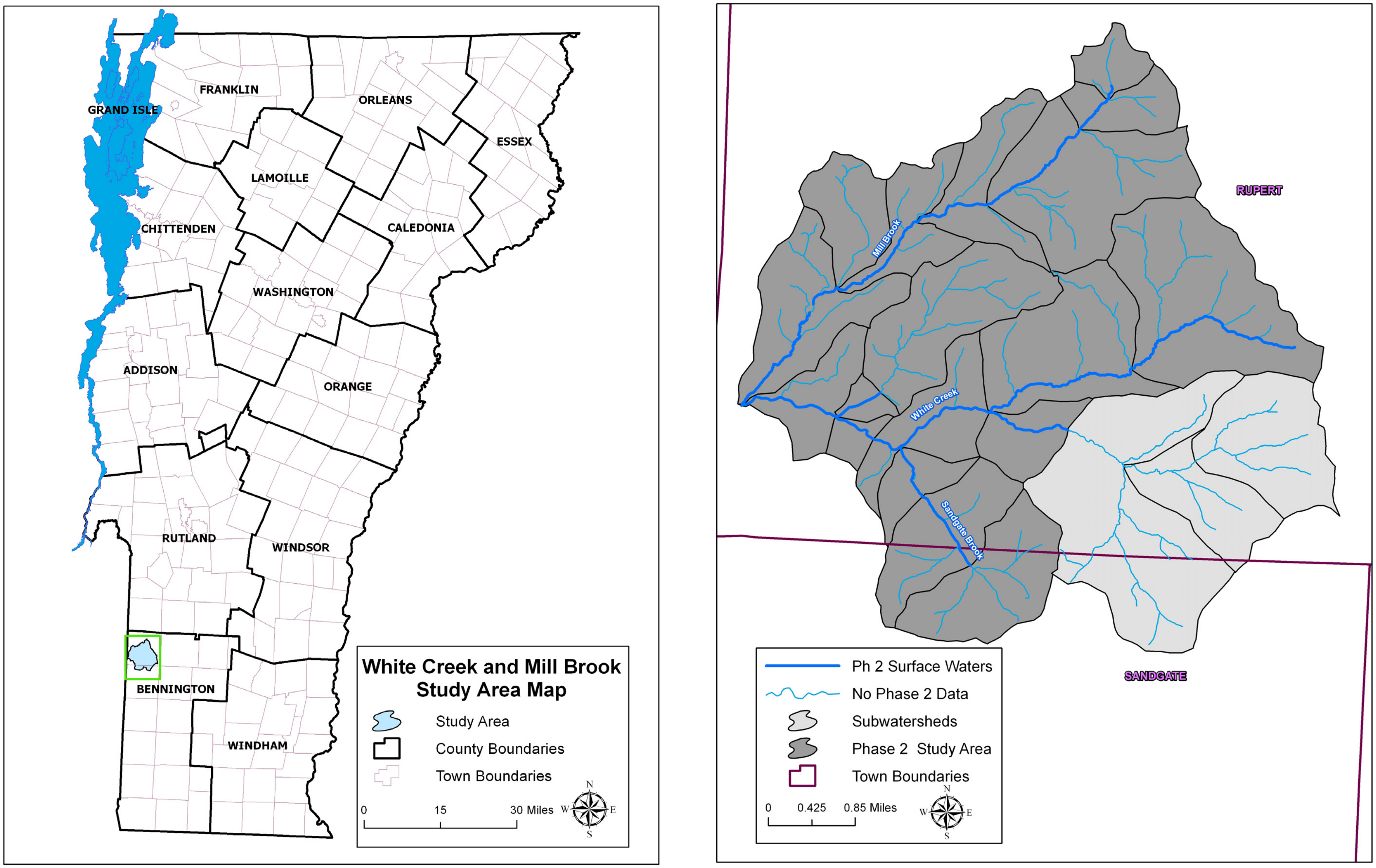


Figure 2.1 White Creek and Mill Brook Watershed Location Map; Southwestern, VT

Land Use History

Historically, the impacts of agricultural practices on the Vermont landscape played an important role in the legacy effects on waterways like White Creek and Mill Brook. Prior to the deforestation associated with human settlement, the watersheds were 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% of the watershed devoid of trees at one time or another (Albers, 2000). This landscape change had a tremendous impact on waterways like White Creek and Mill Brook. Exposed, highly-erodible soil (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 84 percent of the White Creek and Mill Brook watersheds are covered by forest. Only 14% of the watersheds are occupied by agricultural land uses today.

2.2 Geologic Setting

The study watersheds are located in the Taconic Mountain (TM) Biophysical Region (Thompson and Sorenson, 2000). The TM region occupies a small area of southwestern Vermont; however the underlying geology that defines this region extends into eastern New York, western Massachusetts and western Connecticut. The TM biophysical region is characterized by its variability in climate, landform, hydrology, and topography.

The geology of the TM region primarily consists of metamorphosed mudstones that were thrusted over softer limestones during the Taconic Orogeny. The underlying bedrock setting is composed primarily of metamorphosed, clastic sedimentary rocks. The predominant bedrock within the watershed is slate bedrock. The vast majority of surficial geology is till, and some alluvium (Vermont Geologic Survey, 1970; see Figure 2.2 for map of soil parent materials).

The valleys in the TM region have deep postglacial deposits of gravel, lake-bottom, and alluvium sediments. The dominant soil in the White Creek/Mill Brook watershed is loam. The limestone bedrock underlying the TM region transports a large amount of water, creating a wealth of springs that feed clean cold water into the Battenkill and other important streams and rivers for fisheries.

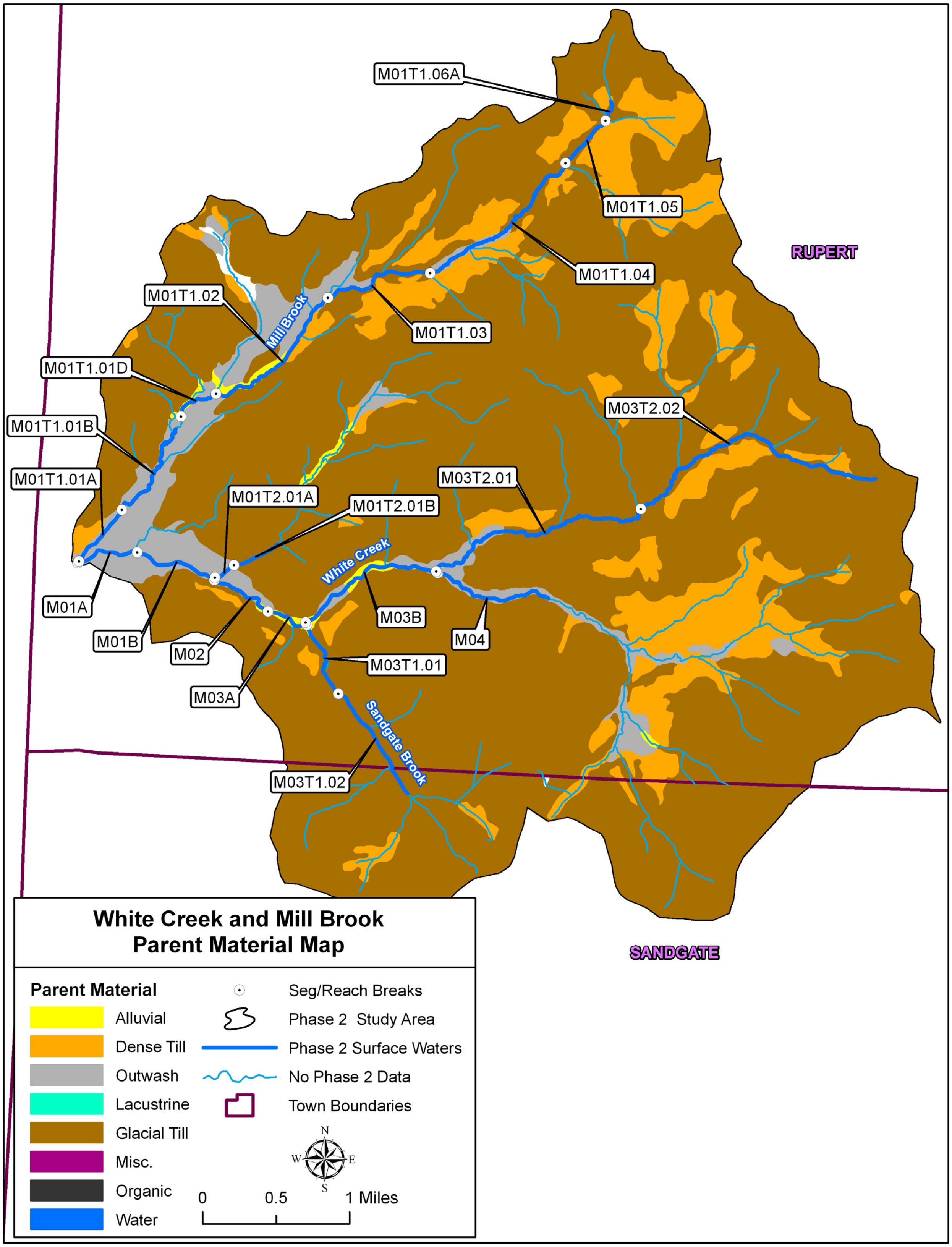


Figure 2.2 Parent surficial materials in the White Creek/ Mill Brook watershed

2.3 Geomorphic Setting

Table 2.2 provides a summary of the reference reach data for the 15 reaches assessed in the watershed. The White Creek/Mill Brook reaches are found in a fairly consistent setting with broad and very broad valleys, B and C-type stream types, and riffle-pool or step-pool bedform.

Table 2.2 Reference reach characteristics for White Creek, Mill Brook, and Sandgate Brook

Surface Water	Reach ID	Watershed Area (Mi^2)	Channel Length (Mi)	Channel Width (ft)	Channel Slope (%)	Sinuosity	Valley Type*	Reference Stream Type†	Bedform‡
White Creek	M01	22.5	1.0	51.5	1.09	1.06	VB	C	Riffle-Pool
	M02	13.7	0.5	41.5	1.83	1.38	VB	C	Riffle-Pool
	M03	13.5	1.4	41.2	1.89	1.08	BD	C	Riffle-Pool
	M04	5.8	0.9	28.4	2.21	1.11	BD	C	Riffle-Pool
	M01T2.01	1.7	0.5	16.5	3.24	1.09	VB	B	Step-Pool
	M03T2.01	4.1	1.7	24.5	4.10	1.10	SC	B	Step-Pool
	M03T2.02	2.5	2.0	19.4	9.32	1.07	SC	A	Step-Pool
Mill Brook	M01T1.01	6.4	1.8	29.7	1.88	1.35	VB	C	Riffle-Pool
	M01T1.02	4.3	1.1	25.0	0.17	1.29	VB	C	Riffle-Pool
	M01T1.03	3.6	0.8	23.1	2.20	1.20	VB	C	Riffle-Pool
	M01T1.04	2.8	1.3	20.5	3.33	1.09	VB	B	Step-Pool
	M01T1.05	0.8	0.4	12.0	4.52	1.05	VB	B	Step-Pool
	M01T1.06	0.3	0.6	8.0	9.35	1.03	NC	E	Riffle-Pool
Sandgate Brook	M03T1.01	2.7	0.6	20.3	3.51	1.07	VB	B	Step-Pool
	M03T1.02	2.3	0.8	19.0	5.15	1.02	BD	B	Step-Pool

* SC= Semi-confined; NW= Narrow; BD=Broad; VB=Very Broad, NC=No Confinement; † per Rosgen, 1994

‡ per Montgomery and Buffington, 1997

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. A Phase 1 SGA study was previously carried out by BCCD, and 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 completed as the basis for 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).

Several parameters including entrenchment, channel dimensions, sinuosity, and slope are factored into stream classifications. The reference stream type classification was determined in the Phase 1 SGA and corroborated in the Phase 2 SGA for potential stream type departures. Out of the 15 assessed reaches, there is one (1) A type stream, six (6) B type streams, seven (7) C type streams, and one (1) E type stream. There are eight (8) riffle-pool, and seven (7) step-pool type reaches. The sinuosity is generally low in the White Creek/Mill Brook watershed, but valley confinement types range significantly between the reaches. The lower reaches of White Creek have slopes ranging from 1.1 to 2.2%. The tributaries to White Creek (M01T2 and M03T2) have higher slopes ranging from 3.2 to 9.3%. Mill Brook shows a gradual increase in slope moving upstream, except for reach M01T1.02 which has a very low slope of 0.2%.

The Rosgen system (Figure 2.3) 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 profile 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.

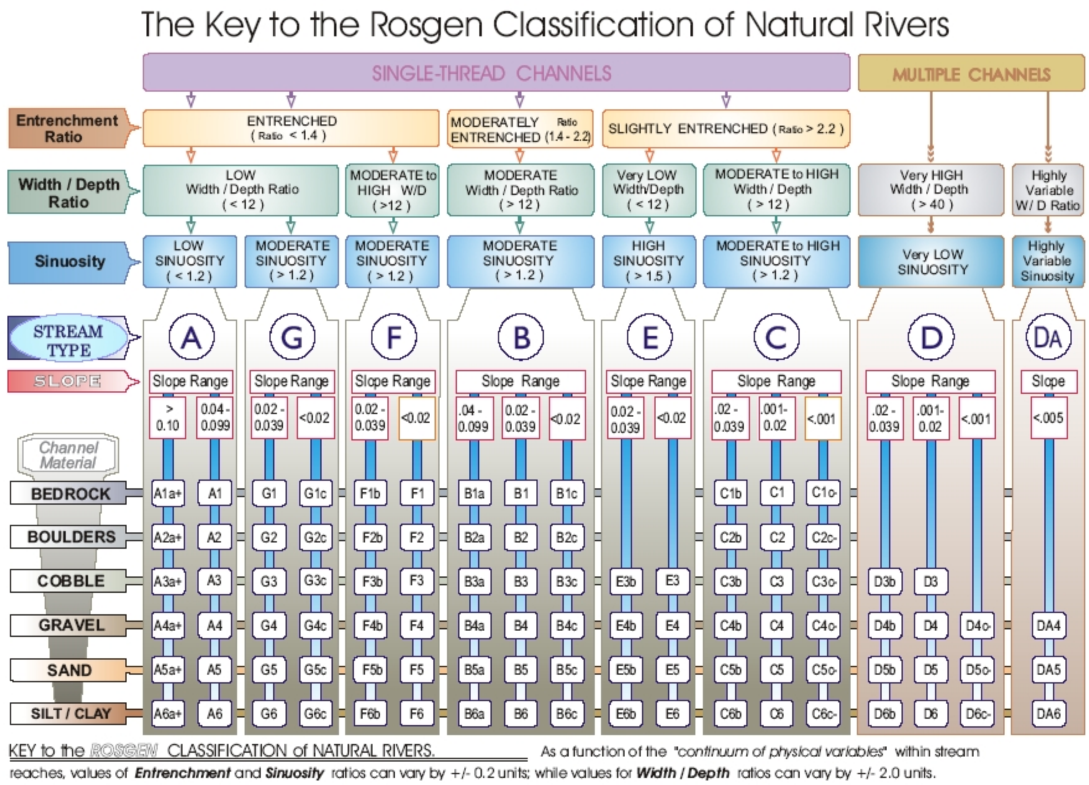


Figure 2.3 The Rosgen (1994) classification of streams based on channel morphology. Key parameters for classification include 1) the entrenchment ratio (floodprone width / bankfull channel width), 2) width to depth ratio (bankfull width / mean channel depth), and 3) channel sinuosity (channel length / 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.

2.4 Hydrology, Flood History and Channel Management

USGS Gaging Data and Flooding History (from VHB-Pioneer Report, 2008)

No stream gage records exist for the White Creek/Mill Brook watershed. However, hydrologic data from the watersheds was derived using the Streamstats program, developed for the state of Vermont by the United States Geological Survey (USGS). Based on the Streamstats summary basin characterization, White Creek has a drainage area of 16.2 square miles and has a slightly higher mean annual precipitation and higher percentage of land above 1200' elevation. Mill Brook has a Streamstats drainage area of 6.4 square miles. The bankfull discharge (two year flow frequency) is approximately 613 cfs for White Creek and 251 cfs for Mill Brook.

The USGS operates a real-time flow monitoring gage on the Batten Kill at Battenville, NY (gage #01329500) that reveals some flood history for the basin. Based on the gage's historical data, there have been flows in excess of the 10 year event in 2000 and 2011, and greater than the 25 year event in 1927, 1936, 1938, 1948, and 1977, 2011. More recently, there have been major floods in the White Creek/Mill Brook watershed in 1996, 1999, and 2000 which damaged public roads, bridges, agricultural fields, and residential infrastructure (BCCD, 2006). The 1999 flood resulted in the declaration of the town of Rupert as a Federal Disaster Area.

Tropical Storm Irene

Tropical storm Irene hit Vermont on August 28th 2011 and dumped 3-5 inches of rain throughout the state with localized areas receiving totals from 7-11 inches. This rainfall coupled with high antecedent soil moisture conditions produced flooding that approached or exceeded the historic flood of 1927 in many large basins. Area normalized discharges of 100-200 csm (cubic feet per second per square mile drainage area) and 100 to 500 year floods were recorded in many major river basins. These catastrophic flows produced severe river channel and floodplain adjustments, including channel widening, deposition, and lateral migration. Transportation infrastructure was particularly susceptible to the flooding with over 500 miles of state highways and 200 bridges damaged, and comparable damage to municipal roads and bridges. Emergency road and bridge repairs were immediately undertaken to reconnect several communities and areas that were completely cut off following the storm. The estimated damages in Vermont alone from Irene may reach 1 billion dollars, with comparable damage tallied in New York State.

In Rupert, damage resulting from Tropical Storm Irene was severe, but less so than other recent flood events such as 1999. For example, a localized downburst that occurred in August, 2010 caused severe flooding and damage along the Mill Brook corridor along VT315. Below in Table 2.3 is a summary of areas that saw the most severe damage or channel adjustments during Tropical Storm Irene.

Table 2.3 Severe Damage Areas in Watershed from Tropical Storm Irene

Road	Reach	Damages and Repairs
Below VT153 Bridge	White Creek - M01-A	Significant deposition of sediments and flooding in adjacent fields and downstream residential areas. Channel dredged to remove gravel.
Downstream of Kent Hollow Road	Tributary A to White Creek - M01T2.01-A	Significant deposition of sediments and flooding in adjacent fields. Channel low flow is now subsurface due to gravel deposits.
Kent Hollow Road	White Creek - M03-B	Bank failure adjacent to Kent Hollow Road; Repair made with stacked stone wall and armoring.
Culvert at Private Driveway off VT315	Mill Brook - M01T1.03	Undersized culvert destroyed. Landowner to replace with bridge.
VT315 near Clark Road	Mill Brook - M01T1.04	Channel bank migrated south to within 10-15 feet of edge of pavement. Stabilization measures needed.
VT315 near Watrous Road	Mill Brook - M01T1.04	Bed erosion within and downstream of bridge; Bed armoring installed to arrest channel incision.

Table 2.3 Severe Damage Areas in Watershed from Tropical Storm Irene

Road	Reach	Damages and Repairs
VT315 on steep road incline	Unnamed tributary to Mill Brook	Severe bed incision in small tributary parallel VT 315. Bed armoring needed to prevent road failure.

Flood Recovery and Channel Management

Common flood recovery efforts in the 1960's and 70's in Vermont involved dredging and deepening river channels to create more hydraulic capacity, armoring embankments even where it resulted in severe river encroachment, and re-channelizing rivers to their pre-flood location. These activities often resulted in greater vulnerability due to the loss of floodplain access, particularly in communities found downstream of long stretches of channel manipulation. In reviewing historical aerial photographs of the White Creek and Mill Brook watersheds, we can see evidence of these management practices and also track how the river channels have changed since that time. The images below include channel centerlines mapped from different years of aerial photography, including the 1962 photographs used as the background image.

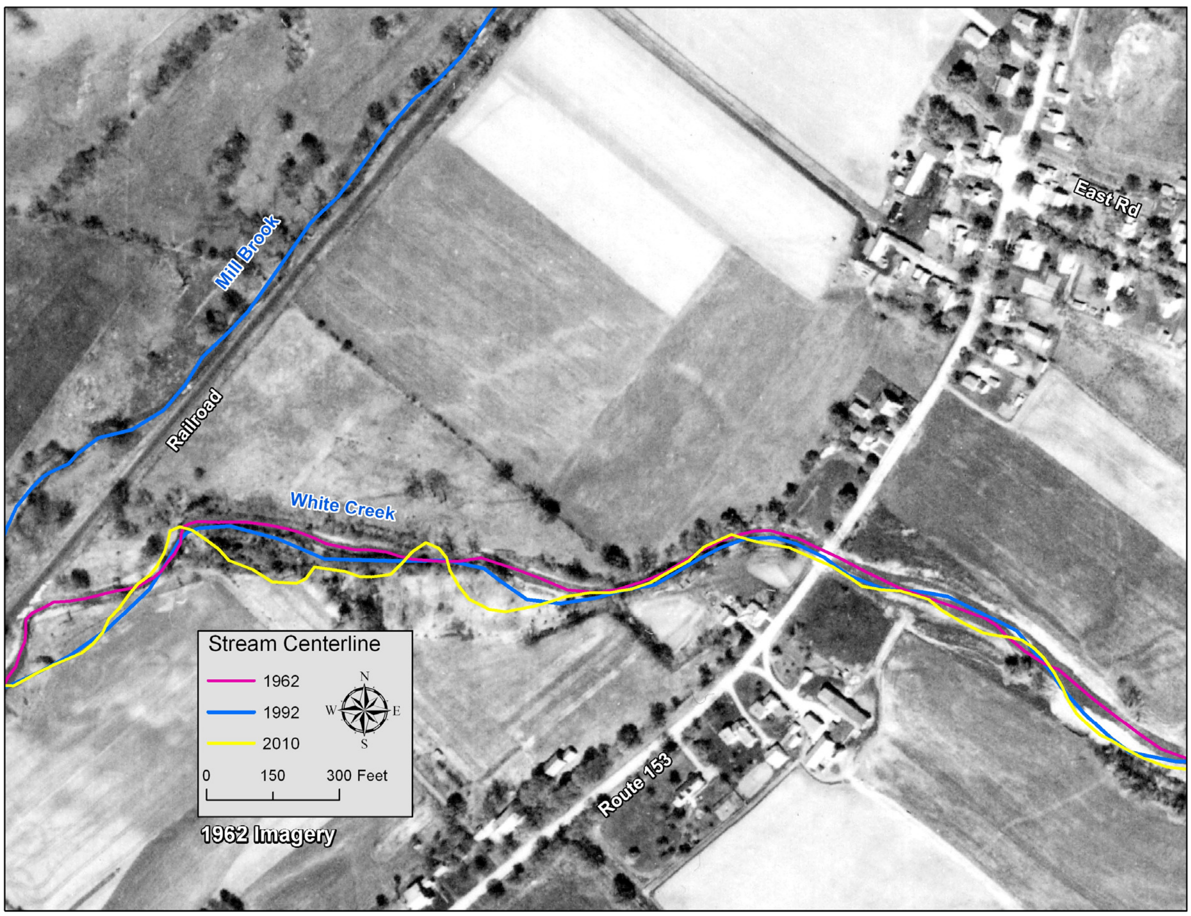
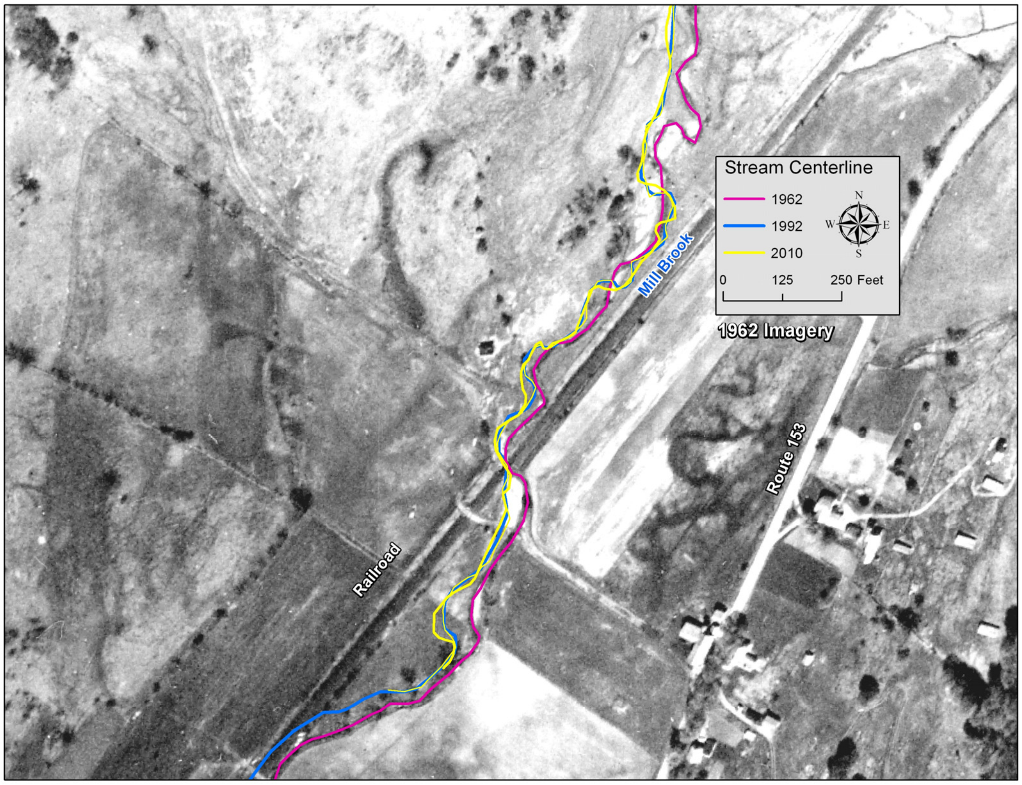


Figure 2.4 Stream centerlines for lower White Creek illustrate the changes in channel planform that have occurred since the 1960's.



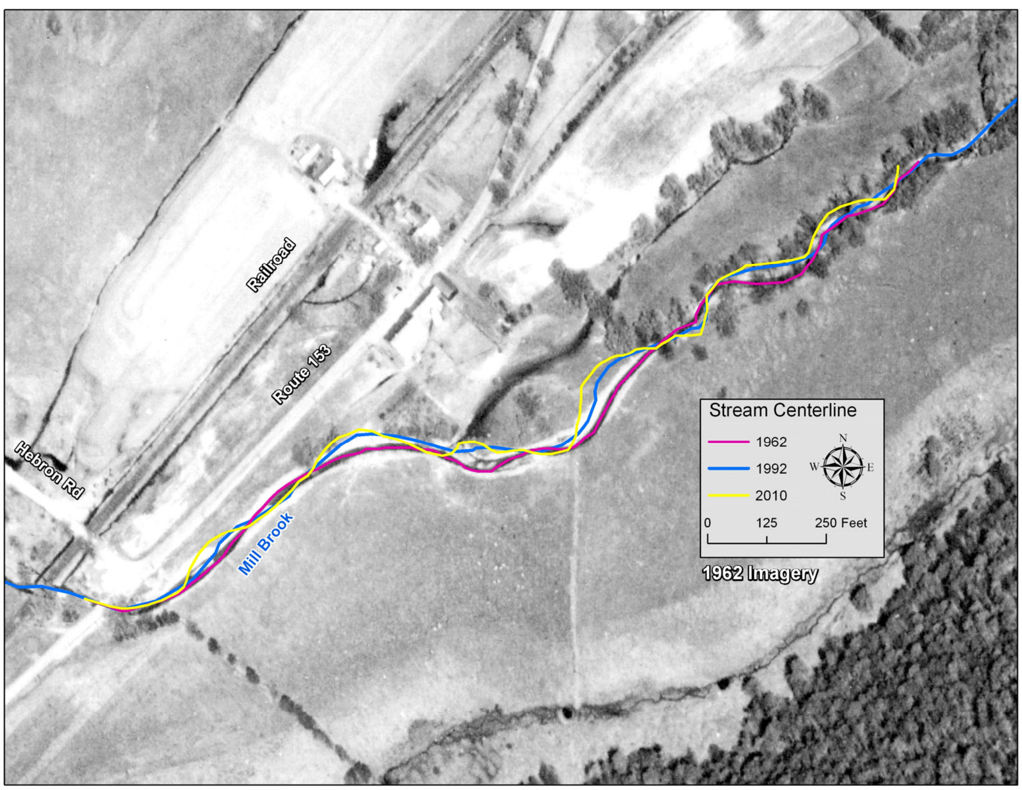


Figure 2.5 Stream centerlines for lower Mill Brook downstream (top image) and upstream (bottom image) of the VT153 bridge near Hebron Road.

2.5 Ecological Setting

Elevations in the White Creek/Mill Brook watershed range from 700 feet in West Rupert, up to approximately 3300 feet in the Bear Mountains. Northern hardwood forests are the most common forest type and wetlands occupy large areas of valleys. The natural vegetation of the TM region is also strongly influenced by southern species at the far extent of their natural range. The study area is primarily characterized by northern hardwood forests with areas of maple/ash/hickory/oak and dry-oak/hickory/hophornbeam. Higher elevation forests in both watersheds are composed of spruce, fir, and pine. Much of the valley riparian maple forests in the TM region were converted to sheep pasture in the 19th century. Slate quarrying was also very important in the region and heavily affected the land in many areas (Thompson and Sorenson, 2000).

VTDEC has collected benthic macroinvertebrate samples and fish surveys at river miles 10.5 and 10.6, located in reach M01-B (Tables 2.5a & 2.5b). Macroinvertebrate samples collected in 1989 indicated major impairment due to nutrient loading, likely from a nearby agricultural area. Dense cover of filamentous algae and high abundance of Oligochaeta worms led to a Fair/Poor community assessment. Reductions in nutrient loading appear to have produced a major improvement in more recent macroinvertebrate community assessment scores. Fish stocking by the VTFWS was last conducted in the 1990's and fish survey data collected in 2008 rated the community as Good/Fair. Biotic sampling has not been conducted following TS Irene, which likely impacted fish and macroinvertebrate communities.

Table 2.5a. Macroinvertebrate sampling data for White Creek

Date Sampled	DEC ID	Location	River Mile	SGA Reach	Mean Density	Mean Species Richness	Mean EPT* Richness	Community Assessment
10/5/1989	590100000105	White	10.5	M01-B	9372	63	32	F-Poor
7/11/1990**	590100000105	White	10.5	M01-B	5208	59	19	Vgood
10/7/1996	590100000105	White	10.5	M01-B	4532	48	25	EXC
10/8/2008	590100000106	White	10.6	M01-B	2032	45	26	EXC

*EPT: Pollution sensitive families of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)
** Sample collected outside of index period

Table 2.5b. Fish survey data for White Creek

Date Sampled	DEC ID	Location	River Mile	SGA Reach	Species Richness	CWIBI*	Community Assessment	Date Sampled
10/8/2008	590100000106	White	10.6	M01-B	5	33	Good/Fair	10/8/2008

*CWIBI: Cold water index of biotic integrity

3.0 Methods

The Vermont River Management Program (RMP) has invested many years of effort into developing a state-of-the-art system of Stream Geomorphic Assessment (SGA) protocols. 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 hydro-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 watersheds. 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 collected in 2005 by BCCD on 21 reaches on White Creek, Mill Brook, and their tributaries, and were summarized in the VTDEC Database Management System (DMS). A total of 15 reaches were identified for Phase 2 assessment conducted by VHB-Pioneer in the summer of 2008. A total of 20 segments on White Creek and Mill Brook 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 Feature Indexing Tool (FIT; VTDEC, 2009).

3.2 Phase 2 Quality Assurance/Quality Control

Vermont's River Management Program conducted quality assurance/quality control (QA/QC) checks on the White Creek/Mill Brook data in October 2008. The QA/QC tools were developed by the VT ANR and are partially built into the online database management system. The spatial (GIS) database of the watershed and uploaded spatial data are also reviewed through the QA/QC process.

3.3 Bridge and Culvert Assessments

Bridge and culvert assessments were simultaneously conducted in accordance with the Bridge and Culvert Assessment (Appendix G) of the Phase 2 SGA protocol.

3.4 Stressor and Departure Analysis

FEA followed the VTDEC methods for developing river corridor plans as outlined in the Vermont River Corridor Planning Guide (VTANR, 2010). 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 long-term equilibrium conditions.

3.4.1 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 White Creek/Mill Brook study area. These maps provide an indication of where channel adjustment processes 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. This is helpful in developing and prioritizing potential river corridor protection and restoration projects.

3.4.2 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 river corridor, 2) the topography of the watershed and river corridor, 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, 2010) 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 3.1.

Table 3.1 Sediment regime types for corridor planning (VTANR, 2010)

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 (VTDEC, 2009) are helpful for explaining the channel adjustment processes underway in the West Branch 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.

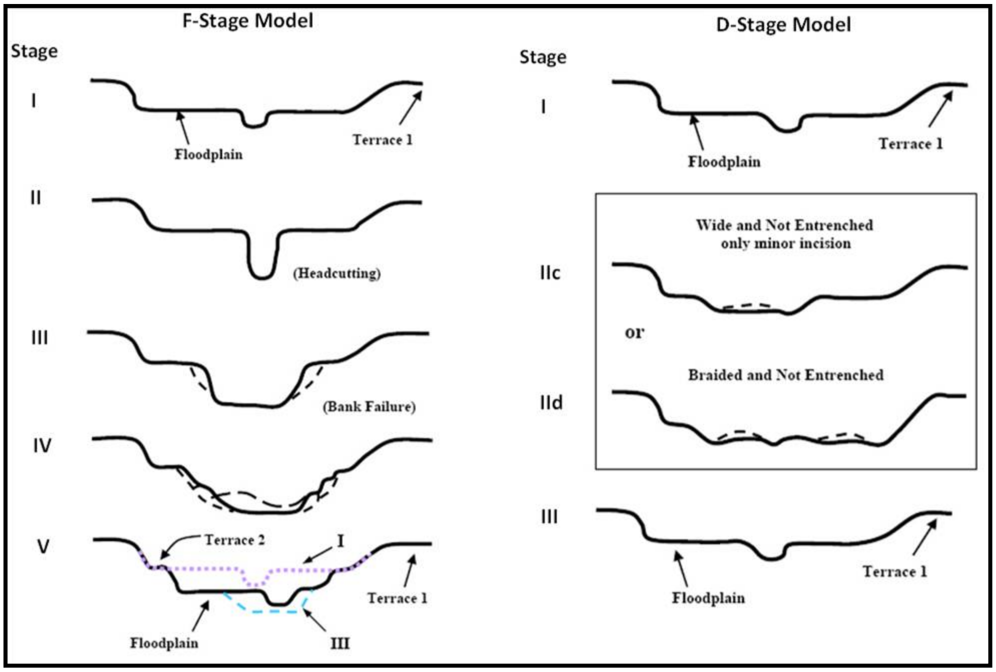


Figure 3.1 Typical channel evolution models for F-stage and D-stage (VTDEC, 2009)

3.4.3 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, 2010).

> 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 White Creek/Mill Brook study area. Sensitivity ratings were assigned using the VTDEC Protocols (VTDEC, 2009).

3.5 Project Identification

Site-specific projects were identified using methods outlined by VTANR in Chapter 6 Preliminary Project Identification and Prioritization (VTANR, 2010). 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.

4.0 Results

The following section includes Phase 2 SGA results and a summary of the watershed and reach-scale stressors on channel stability.

4.1 Phase 2 SGA Results

A complete summary of the individual Rapid Habitat Assessment (RHA) and Rapid Geomorphic Assessment (RGA) scores are shown below (Table 4.1).

Table 4.1 RHA and RGA scores for Phase 2 assessed reaches/segments

Surface Water	Phase 2 Segment ID	RHA Condition	RHA Score	RGA Score	RGA Condition	Stream Sensitivity
White Creek	M01A	Good	0.65	0.75	Good	High
	M01B	Fair	0.65	0.56	Fair	Extreme
	M02	Good	0.65	0.53	Fair	High
	M03A	Good	0.77	0.59	Fair	Very High
	M03B	Good	0.71	0.76	Good	Moderate
	M04	Fair	0.60	0.58	Fair	High
	M01T2.01A	Fair	NA	0.61	Fair	High
	M01T2.01B	Good	0.70	0.71	Good	Moderate
	M03T2.01	Good	0.78	0.64	Fair	High
	M03T2.02	Reference	0.90	0.89	Reference	High
Mill Brook	M01T1.01A	Fair	0.63	0.59	Fair	High
	M01T1.01B	Good	0.66	0.74	Good	High
	M01T1.01D	Fair	0.57	0.70	Good	High
	M01T1.02	Fair	0.50	0.55	Fair	Very High
	M01T1.03	Fair	0.56	0.64	Fair	Very High
	M01T1.04	Fair	0.55	0.54	Fair	High

Table 4.1 RHA and RGA scores for Phase 2 assessed reaches/segments

	M01T1.05	Good	0.73	0.68	Good	Moderate
	M01T1.06A	Good	0.69	0.89	Reference	High
Sandgate Brook	M03T1.01-	Good	0.77	0.80	Good	Moderate
	M03T1.02-	Good	0.75	0.70	Good	Moderate

Note: RHA = Rapid Habitat Assessment; RGA = Rapid Geomorphic Assessment

4.2 River Corridor Planning

The following sections summarize the stressor identification and departure maps. 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 White Creek/Mill Brook watersheds contain a mixture of land cover types (Table 4.2; NOAA, 2008) typical of rural Vermont watersheds. The upslope subwatersheds and highlands are predominately forested, while the river corridors and valley bottoms have much greater agricultural and developed land (Figure 4.1). Lands classified as scrub/shrub are typically found in areas of transition from old field to forest or in telephone/utility line right-of-ways. Developed lands (including road corridors) occupy only 0.5% of the watershed, with less area occupied by wetlands (0.4%). Agricultural lands are concentrated in the valleys of Mill Brook and the lower reaches of White Creek. Developed lands closely follow major roads in both White Creek and Mill Brook.

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 corridors of White Creek and Mill Brook have been valuable resources for fertile farmlands and other anthropogenic uses. Sandgate Brook has a higher percentage of developed land within the corridor.

Table 4.2 Land use/Land cover data for the White Creek/Mill Brook watershed

Land Cover/Land Use Type	Mill Brook	Sandgate Brook	White Creek	Entire Watershed
Agriculture	32.7%	1.2%	7.5%	14.0%
Development	1.0%	0.0%	0.3%	0.5%
Forest	64.0%	98.2%	91.0%	84.2%
Open Water	0.0%	0.0%	0.0%	0.0%
Scrub/Shrub	1.2%	0.5%	0.8%	0.9%
Wetland	1.0%	0.0%	0.3%	0.4%
Branch Area (Mi^2)	6.38	2.71	13.34	22.43

*Mill Brook: reaches M01T1.01-M01T1.06, T1S1.01; Sandgate Brook: reaches M03T1.01 – M03T1.03; White Creek: reaches M01-M07, M01T2.01-M01T2.02, M03T2.01-M03T2.02

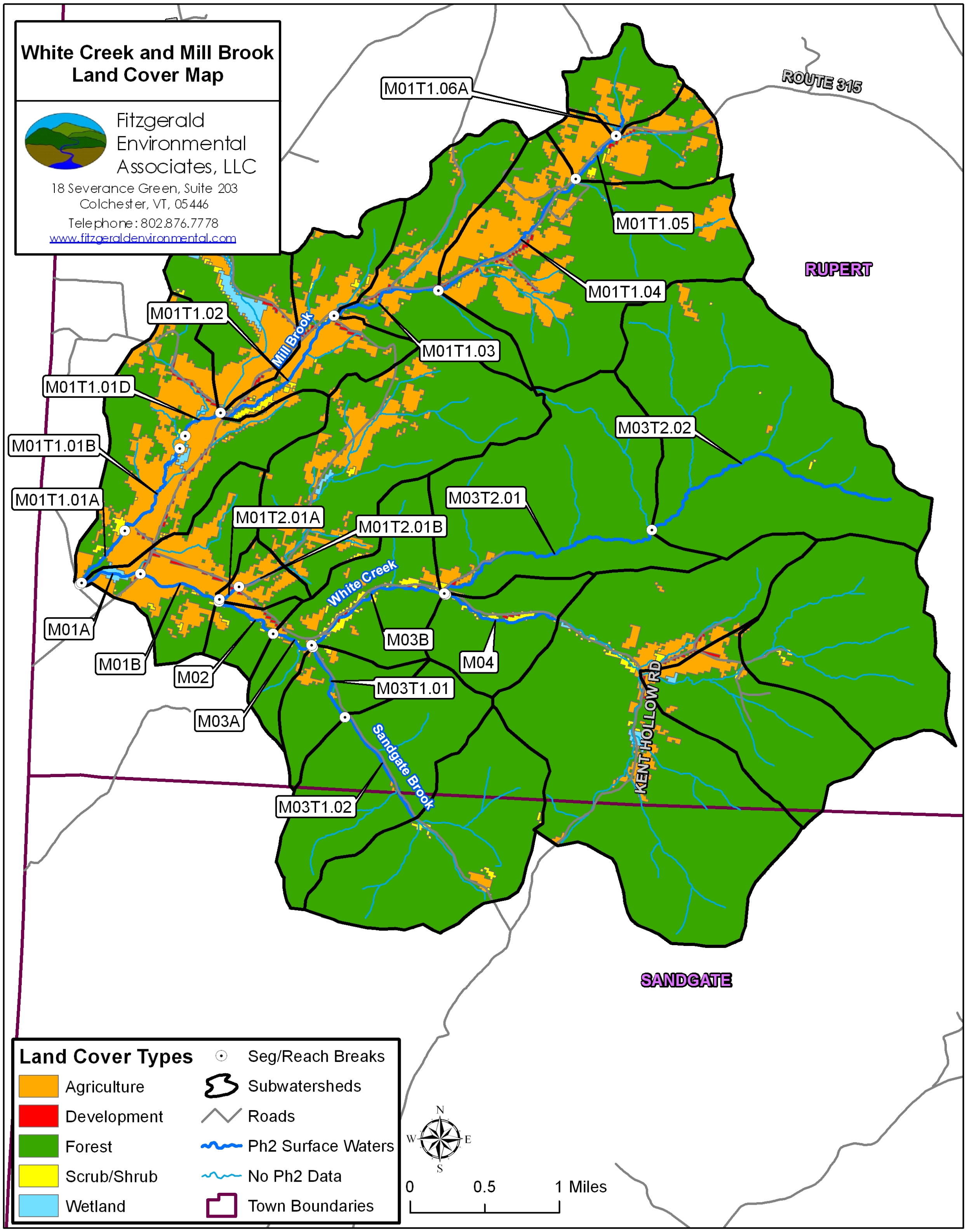


Figure 4.1 Land use/Land cover data for the White Creek/Mill Brook watersheds

Hydrologic Regime Stressors

The following description of the hydrologic regime of a river, 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, 2010).

> 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 (e.g., stormwater outfalls), 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) areas intersected with urban or agricultural land uses in the watershed, with the remaining areas assumed to be intact wetland. Some adjustments to this estimate of loss were made following comments from the Rupert steering committee and additional field observations. Estimating wetland loss is a way to interpret of loss of hydrologic attenuation of surface runoff at the reach and watershed scale. Stormwater outfall locations mapped during the Phase 2 assessments are included to depict areas of increased stormflows (Figure 4.2).

Areas of impact to the hydrologic regime include:

- Moderate localized road density in M01T2.01A subwatershed (4.01 $Mi/Mi1^2$)
- Moderate localized corridor wetland loss in M01T1.01B and M01T1.02 subwatersheds due to agricultural land use
- Moderate to high densities of stormwater inputs from road ditches in M01.T1.05 and M03T1.02

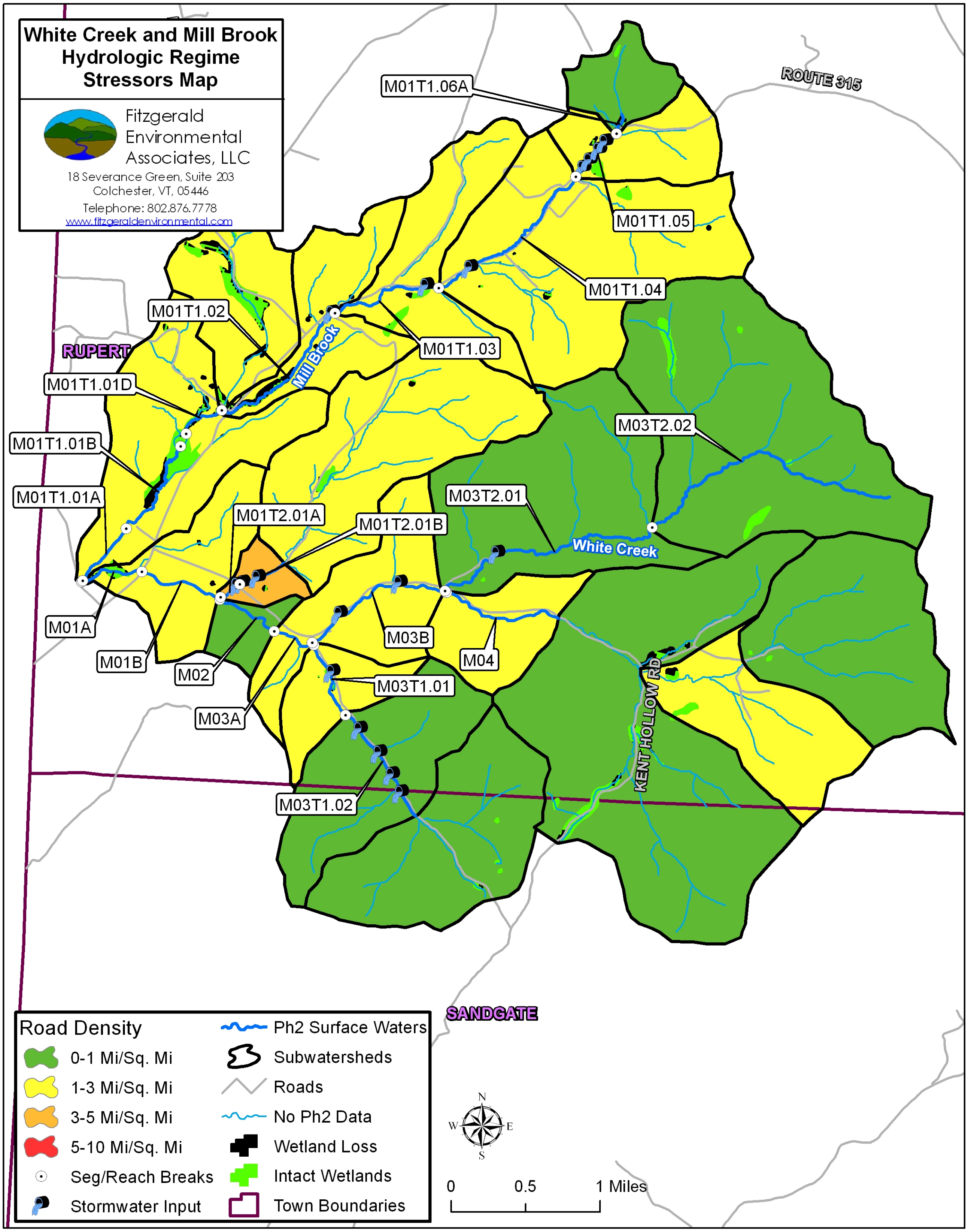


Figure 4.2 Hydrologic Regime Stressors for the White Creek/Mill Brook watersheds

Sediment Load Indicators

The following description of the sediment regime of a river, 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, 2010).

> 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 (cropland and bare land) 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 sediment aggradation. Mass failures, gullies and bank erosion depict where sediment delivery from the channel boundaries is occurring (Figure 4.3).

Areas impacted by high sediment load stressors include:

- High to very high agricultural land use throughout Mill Brook (17%-46%)
- High to very high agricultural land use in lower White Creek (13%-45%)
- Extremely high agricultural land use in subwatershed for M01T2.01A (53%)
- High bank erosion in White Creek Reach M02 and Mill Brook Reach M01T1.04
- Several segments with a high density of depositional features (M01A, M01B, M01T1.01A, M01T1.01B, M01T1.01D, M01T1.03, M01T1.04, M01T1.05, M01T201a, M01T2.01B, M02, and M04). All of these are found in one of three locations:
    - Lower White Creek along Kent Hollow Road down to confluence with Mill Brook
    - Lower Mill Brook from Hebron Road down to confluence with White Creek
    - Upper Mill Brook from Pawlet Mountain Road up to final crossing of VT315
- High density of migration features and mass failures in reach M03T2.01

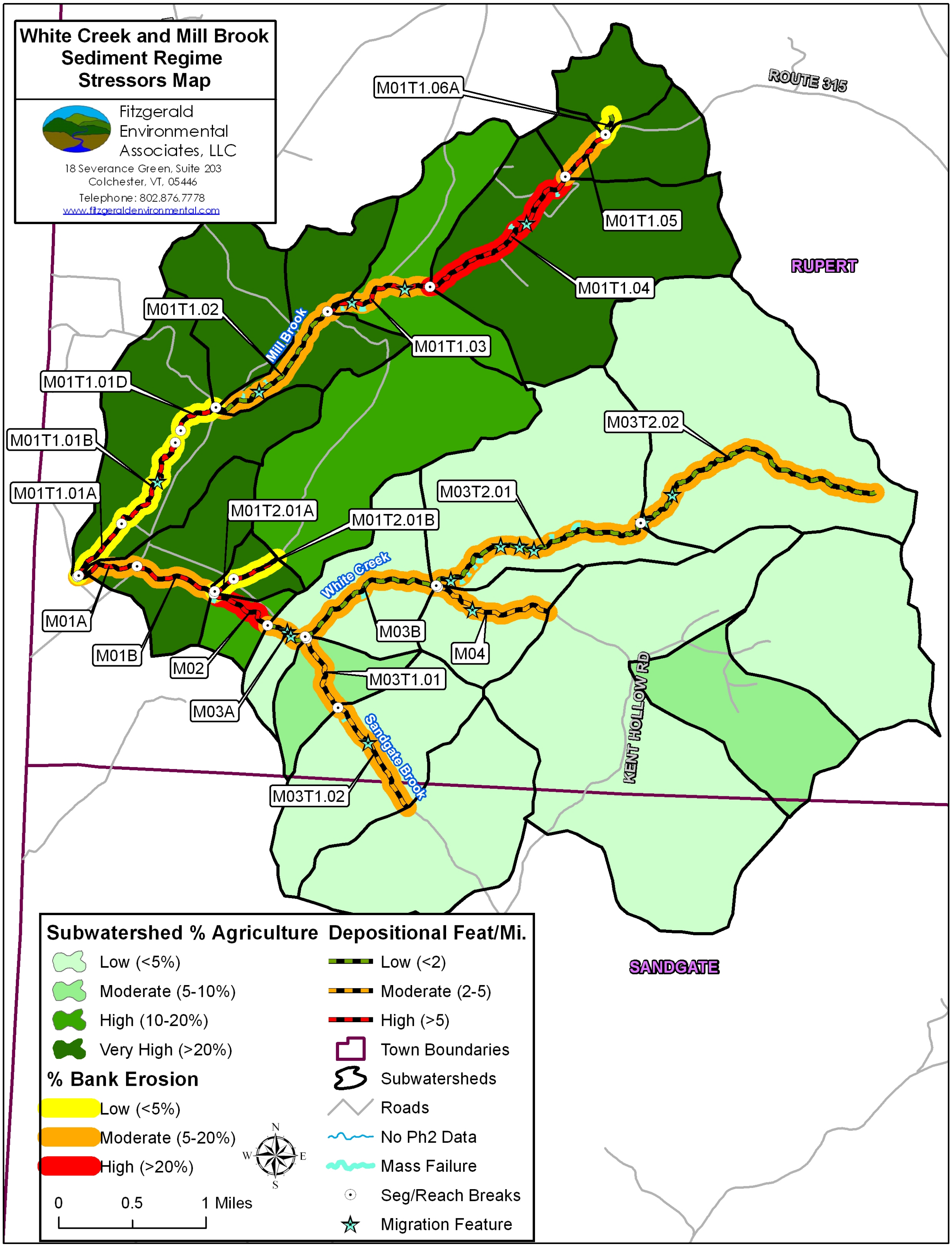


Figure 4.3 Sediment regime stressors for the White Creek/Mill Brook watersheds

Figure 4.4 Looking upstream at hay and corn fields from VT153 bridge. White Creek Segment M01-B.

Figure 4.5 Looking downstream from VT153 bridge at depositional features in White Creek Segment M01-A.

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, 2010).

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., encroachments) have resulted in an increase in channel depth (VTANR, 2010). 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 White Creek/Mill Brook study area have been mapped using the variables extracted from the Phase 2 field dataset (Figure 4.6). 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 natural resistance to vertical channel change.

Areas impacted by increases in slope and depth or influenced by controls on slope and depth include:

Increases in Slope and Depth

- Extreme channel straightening (>50%) in Mill Brook reaches: M01T1.02 and M01T1.04
- Extreme channel straightening (>50%) in White Creek tributary reaches: M01T2.01A, M01T2.01B, and M03T1.02
- High straightening in reaches: M01A, M01B, M03A, M03B, M04, M01T1.05, and M01T1.06A
- Extensive corridor encroachments in areas of White Creek and Mill Brook, primarily from roads (M01T1.03, M01T1.05, M01T2.01, M03A, M03B, M03T1.01, and M03T1.02)

Controls on Slope and Depth

- Some dense areas of grade controls on upper White Creek reaches M03T2.01 and M03T2.02; lower White Creek reaches M01B and M01T2.01A; and Mill Brook reaches M01T1.03 and M01T1.01A.

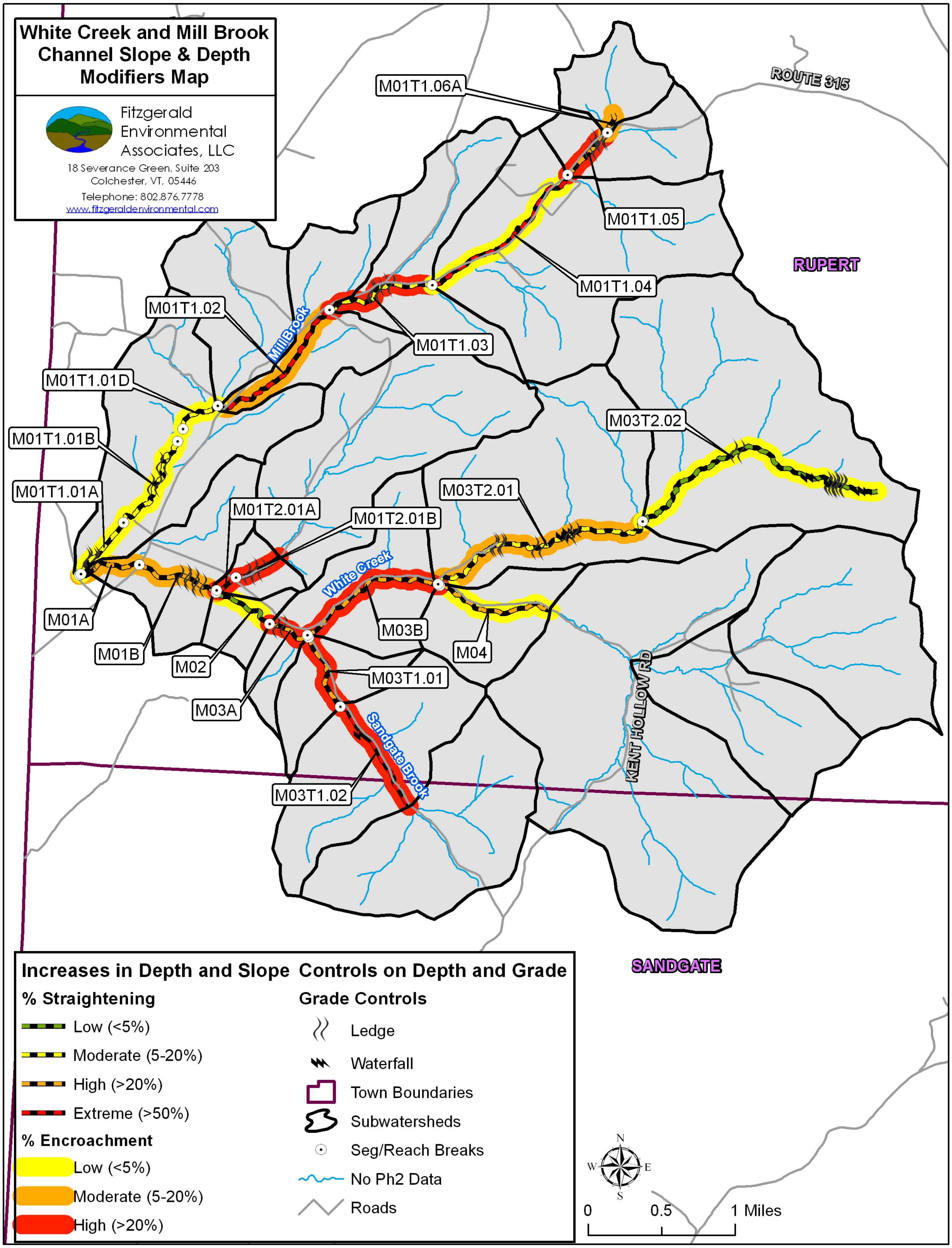


Figure 4.6 Slope and depth modifiers for the White Creek/Mill Brook watersheds

Figure 4.7 Encroachment of VT315 on Mill Brook corridor. Example of using a vertical wall to minimize road encroachment for road-river compatibility. Reach M01T1.03.

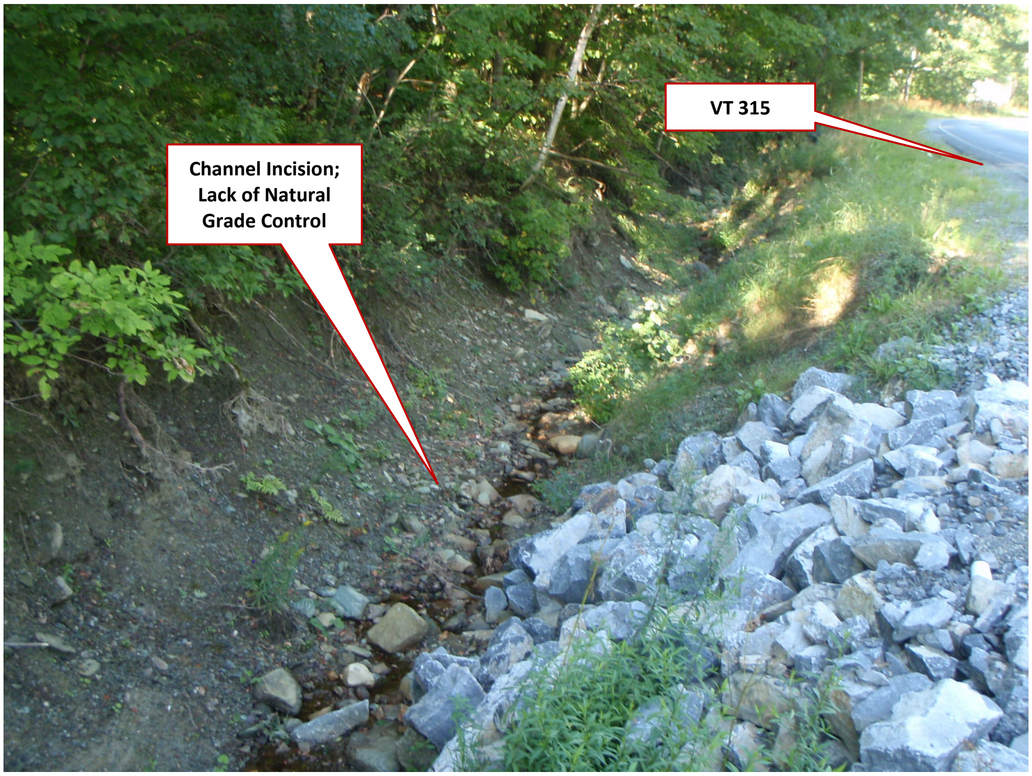


Figure 4.8 Channel downcutting in upper headwaters reaches of Mill Brook due to encroachment of VT315 on channel. Armoring of banks is a temporary solution due to unstable bed.

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. However, extensive removal of riparian vegetation in the absence of bank hardening can cause a decrease in boundary resistance, and lead to increased lateral migration (Figure 4.9). 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 White Creek and Mill Brook study area have been mapped using the variables extracted from the Phase 2 field dataset (Figure 4.9). 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 natural resistance to channel change.

Areas influencing riparian zone and boundary conditions include:

Increased Boundary Resistance

- Some dense areas of grade controls on upper White Creek reaches M03T2.01 and M03T2.02; lower White Creek reaches M01B and M01T2.01A; and Mill Brook reaches M01T1.03 and M01T1.01A.
- Moderate bank armoring on White Creek through the Town of Rupert (M03-A, M03-B, and M04) and on Sandgate Brook (M03T1.02)

Decreased Boundary Resistance

- High bank erosion in segments White Creek reach M02 and Mill Brook reach M01T1.04
- Buffer width impacts throughout the Mill Brook reaches due to agricultural land use in the stream corridor
- Buffer width impacts along Sandgate reaches due primarily to residential land use in the stream corridor
- Buffer width impacts in the middle reaches of White Creek due primarily to agricultural land use in the stream corridor

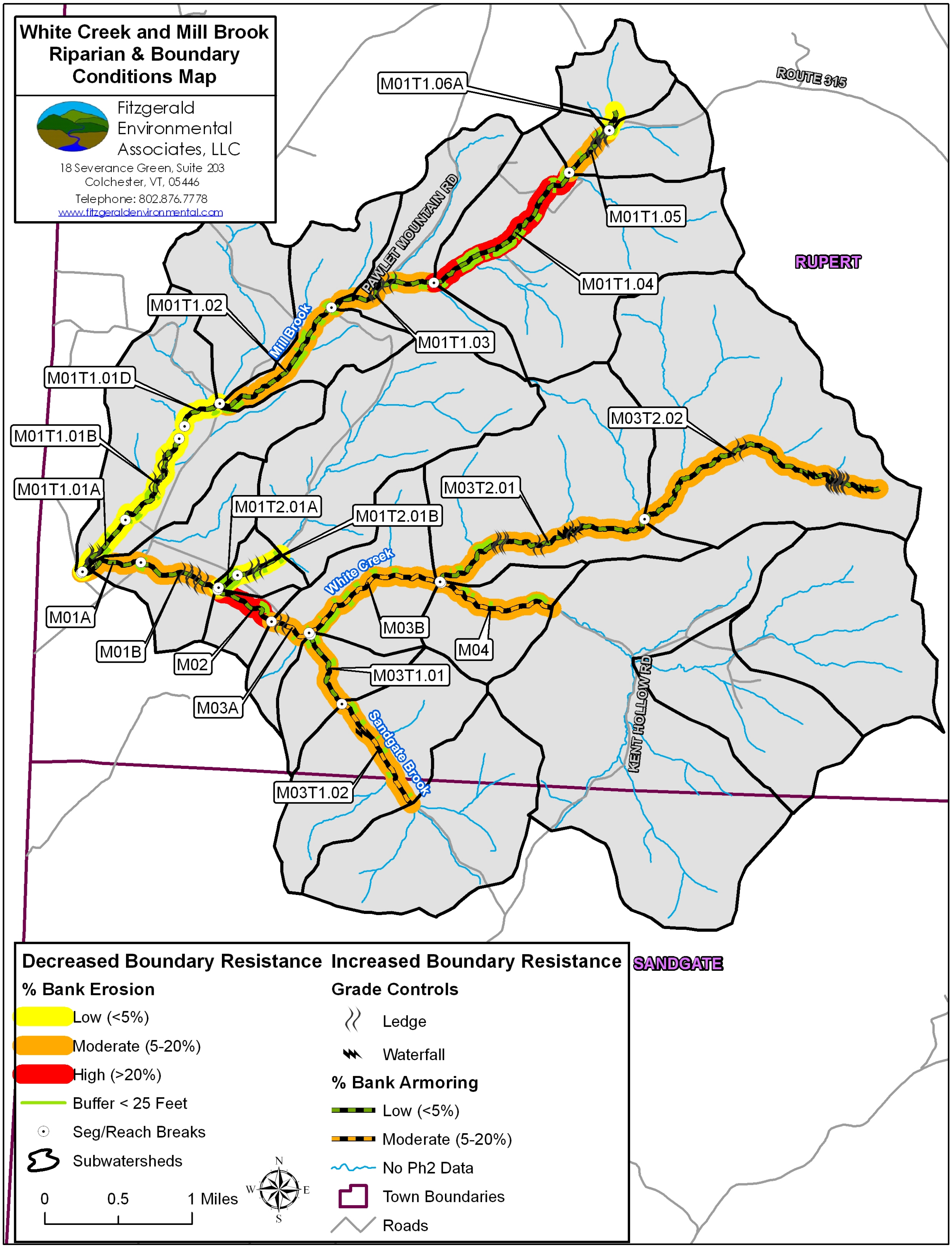


Figure 4.9 Riparian and boundary condition stressors for the White Creek and Mill Brook watersheds

4.2.2 Departure Analysis

The reference and existing sediment regime types have been mapped using data from the Phase 1 and 2 assessments (Figures 4.10 & 4.11). Several segments in the White Creek have undergone a departure in both sediment regime and stream 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. Stream type departures (per Rosgen, 1994) are summarized below (Table 4.3) to better describe the reaches where physical changes in channel morphology have accompanied sediment regime changes.

Table 4.3 Summary of Stream Type Departures from Reference Conditions

Surface Water	Phase 2 Segment ID	Stream Type Departure	Dominant Adjustment Type
White Creek	M01B	C to F	Degradation - Entrenchment
	M02	C to B	Degradation - Entrenchment
	M04	C to B	Degradation - Entrenchment
	M01T2.01A	B to E	Degradation - Straightening

In addition to stream type departures, several reaches/segments of White Creek and Mill Brook have undergone departures in sediment regimes in the absence of stream type departures. These departures are summarized below in Table 4.4.

Table 4.4 Summary of Sediment Regime Departures

Surface Water	Phase 2 Segment ID	Reference Sediment Regime	Existing Sediment Regime	Cause of Departure
White Creek	M01A	Coarse Equilibrium & Fine Deposition	Fine Source & Transport; Coarse Dep.	Historical channel incision; active aggradation/planform
	M01B	Coarse Equilibrium & Fine Deposition	Unconfined Source & Transport	Historical channel incision; channel widening
	M02	Coarse Equilibrium & Fine Deposition	Fine Source & Transport; Coarse Dep.	Historical channel incision; active aggradation/planform
	M03A	Coarse Equilibrium & Fine Deposition	Fine Source & Transport; Coarse Dep.	Historical channel incision; active aggradation/planform
	M04	Transport	Fine Source & Transport; Coarse Dep.	Historical channel incision; active aggradation/planform
	M01T2.01A	Transport	Confined Source & Transport	Channel incision; Aggradation from TS Irene
	M01T2.01B	Transport	Confined Source & Transport	Active channel incision
Mill Brook	M01T1.01A	Coarse Equilibrium & Fine Deposition	Fine Source & Transport; Coarse Dep.	Historical channel incision; active aggradation/planform
	M01T1.02	Coarse Equilibrium & Fine Deposition	Fine Source & Transport; Coarse Dep.	Historical channel incision; active aggradation/planform
	M01T1.03	Coarse Equilibrium & Fine Deposition	Unconfined Source & Transport	Historical channel incision; channel widening
	M01T1.04	Transport	Confined Source & Transport	Historical channel incision; active aggradation/planform

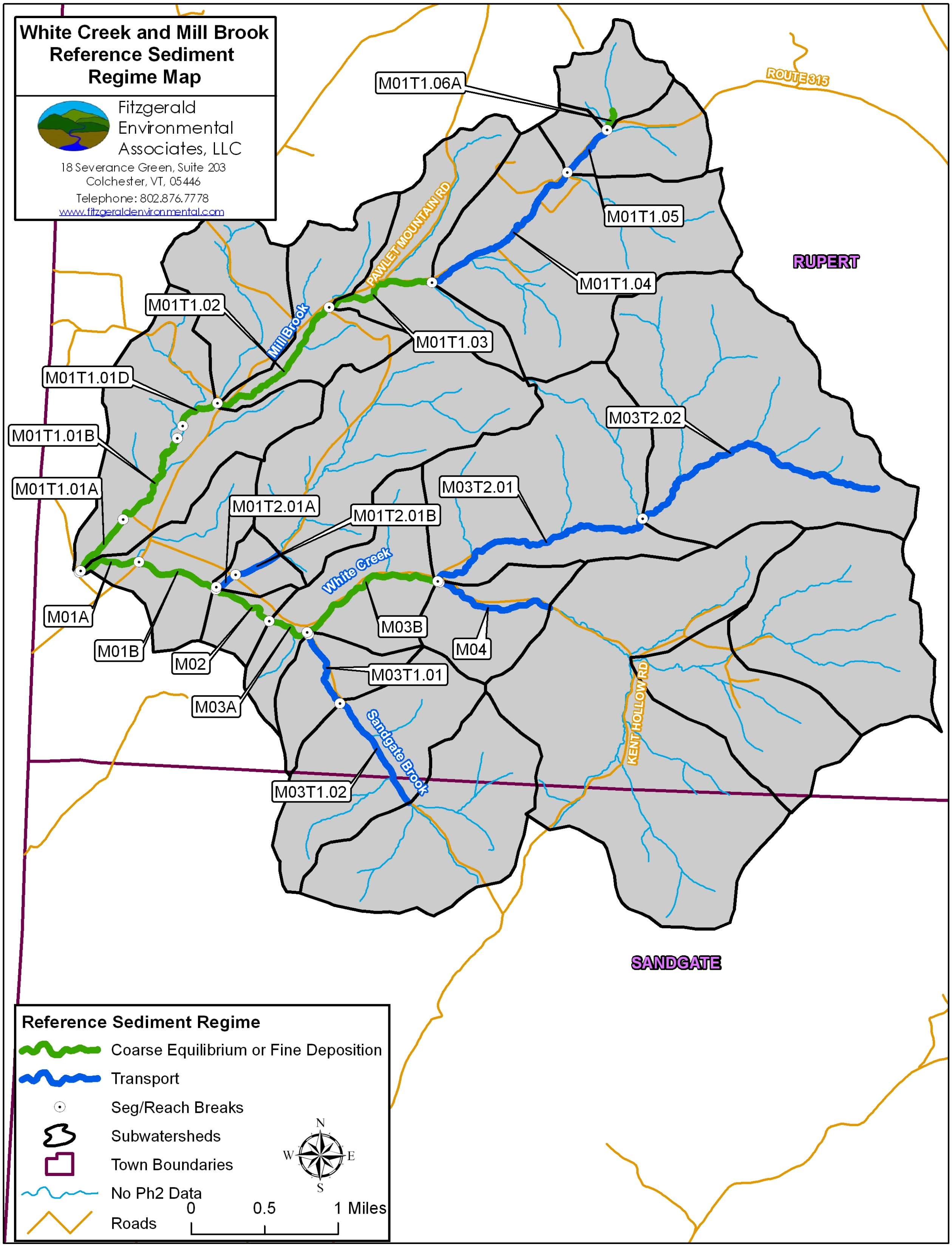


Figure 4.10 Reference sediment regime map for the White Creek and Mill Brook watersheds

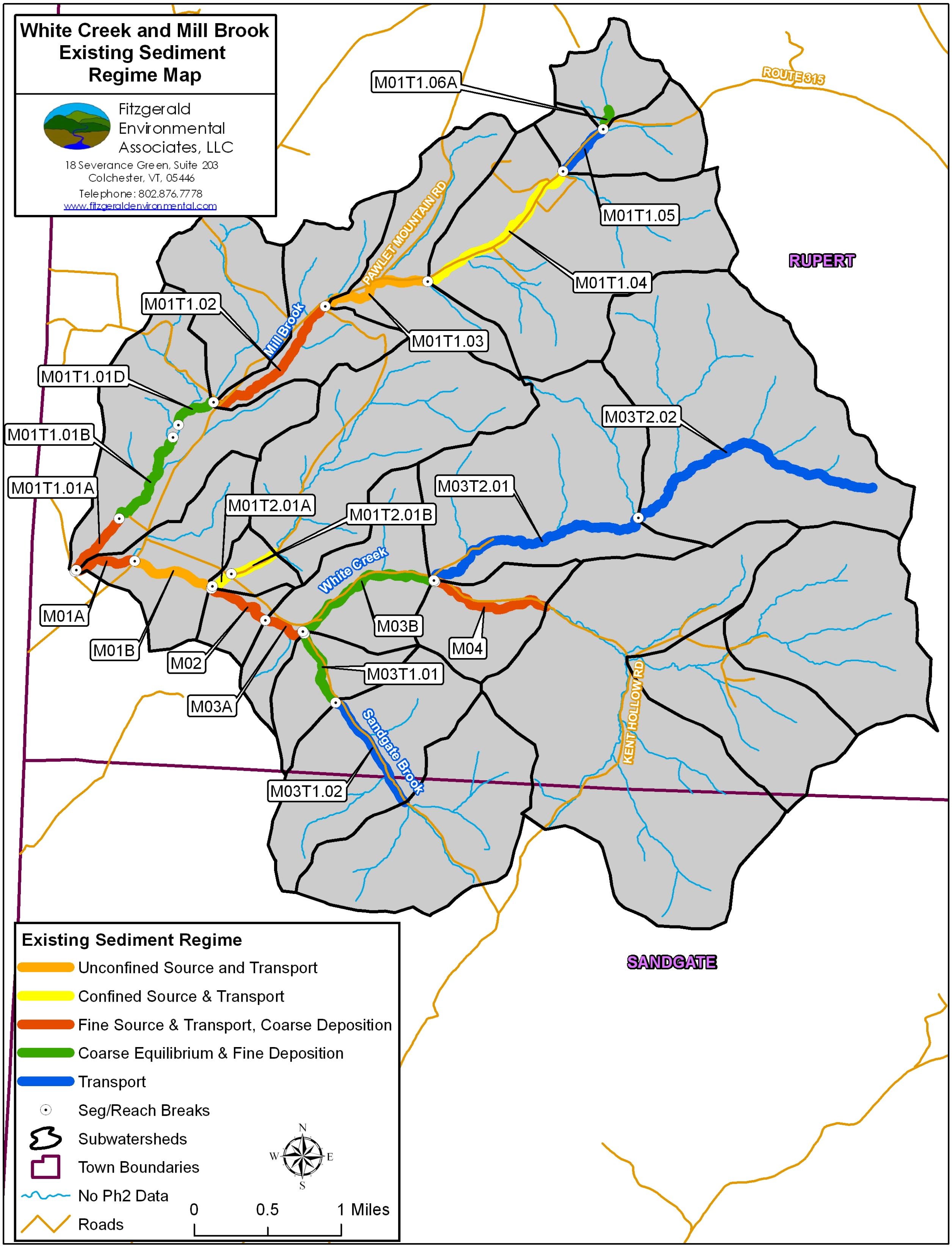


Figure 4.11 Existing sediment regime map for the White Creek and Mill Brook watersheds

4.2.3 Sensitivity Analysis

The methods outlined in the VTANR Corridor Planning Guide have been used to describe the stream sensitivities of the segments in the White Creek/Mill Brook study area (2010). 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 4.12). One segment (M01B) has a heightened sensitivity of "Extreme" due to human impacts. Three segments (M01T1.02, M01T1.03, and M03A) have heightened sensitivities of "Very High" due to human impacts. The heightened stream sensitivity ratings are due to stream type departures (STD) and channel degradation resulting from historical channel straightening, corridor encroachments, and incision (Table 4.5). Reach M01B has a stream type departure from C to F due to incision and entrenchment. Reach M03A is impacted by incision and encroachment from Kent Hollow Road. Reach M01T1.02 has been impacted by incision, historic straightening and encroachment from development and roads. Similarly, reach M01T1.03 has been impacted by encroachments (Rt315) and incision.

Table 4.5 Very High and Extreme sensitivity segments and descriptions of the specific impacts and adjustments that are occurring to the stream

Surface Water	Phase 2 Segment ID	Stream Sensitivity	Description of Impacts
White Creek	M01T1.02	Very High	Encroachment, Incision, and Straightening
	M01T1.03	Very High	Encroachment and Straightening
Mill Brook	M01B	Extreme	Stream type departure, Incision, Straightening
	M03A	Very High	Encroachment, Incision

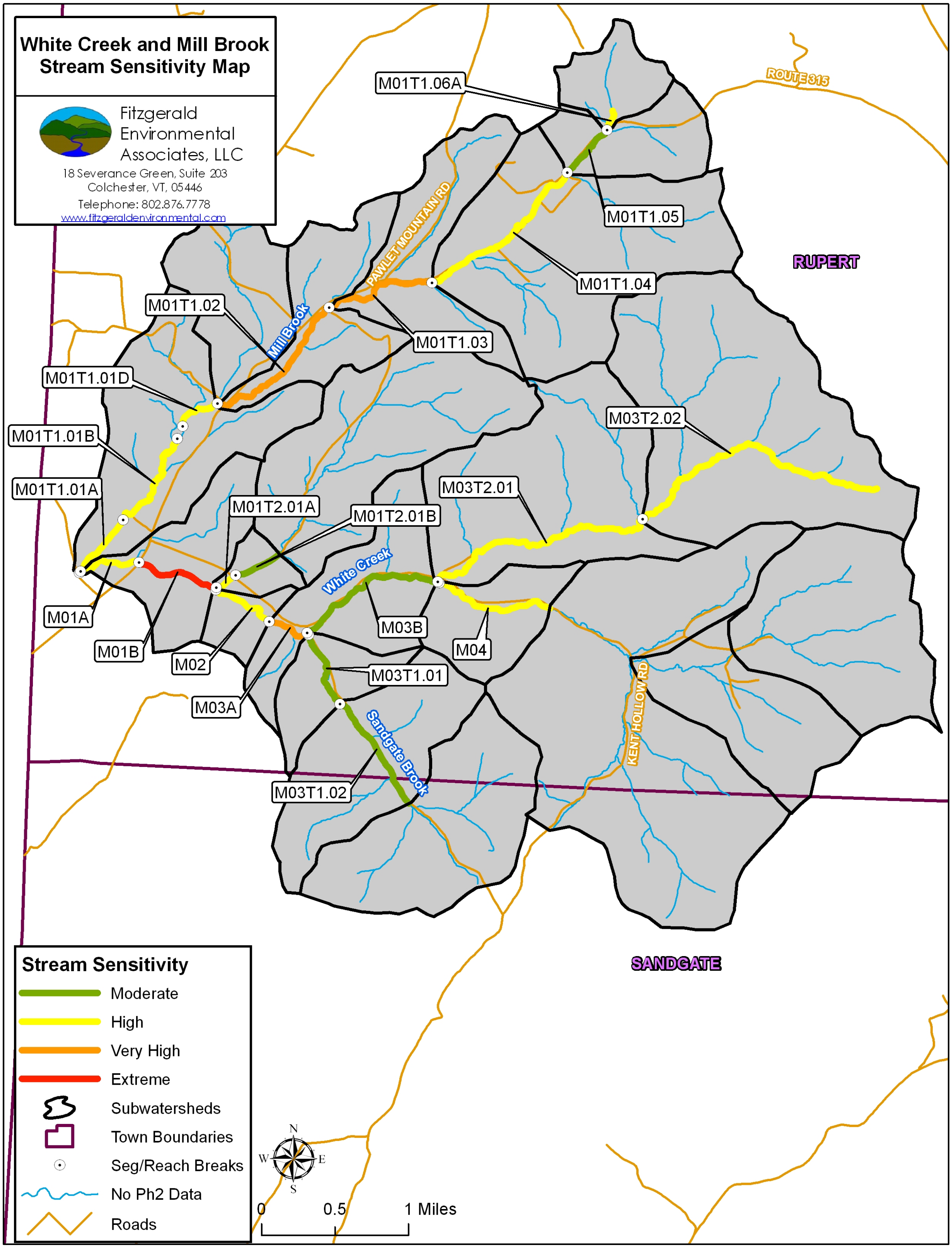


Figure 4.12 Stream Sensitivity map for the White Creek and Mill Brook watersheds

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 funnels sediment and runoff directly into 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 White Creek/Mill Brook watersheds generally have limited stormwater impacts because of the largely forested watersheds and low road densities. In the future, if development pressures heighten concerns about impacts from stormwater runoff, the Town of Rupert could consider enacting local 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 could consider at the local level include:

- Requiring stormwater controls for development projects which are not large enough in size to fall under state regulatory permits (less than 1 acre impervious cover), but likely have a measurable impact on the conditions of adjacent waterbodies (e.g., habitat, water quality).
- 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 Stream Crossings

Throughout Vermont, undersized and poorly aligned river crossings critically interrupt floodflows, sediment and woody debris movement downstream, 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. Some culverts and bridges in the White Creek/Mill Brook study area are currently undersized and causing various problems such as upstream deposition, excessive erosion and downstream bed degradation (Tables 5.1 and 5.2). 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 highly recommended.

Table 5.1 Summary of bridge data in the White Creek/Mill Brook watersheds

Surface Water	Reach/Seg ID	Channel Width (ft)	Structure Width (ft)	Percent of Channel Width*	Location/Comments
White Creek	M01-A	51.5	56.3	109%	State HWY 153 crossing
	M01-A	51.5	22.9	44%	Bike path crossing
	M03-B	41.2	29.6	72%	Saunders Rd crossing
	M03-B	41.2	30	73%	Kent Hollow Rd crossing
	M03-B	41.2	49	119%	Sandgate Rd crossing
	M03-B	41.2	28	68%	Private Drive #1 (up from Saunders)
	M03-B	41.2	34	83%	Kent Hollow Rd crossing
	M03T2.01	41.2	30	73%	Kent Hollow Rd crossing
	M04	41.2	34.5	84%	Private Drive #2
Mill Brook	M01T1.01-B	29.7	36	121%	Bike path crossing
	M01T1.01-B	29.7	28	94%	Bike path crossing
	M01T1.02	29.7	26.5	89%	Hebron Trail crossing
	M01T1.02	29.7	19	64%	State HWY 153 crossing
	M01T1.02	25	22	88%	Youlin Rd crossing
	M01T1.02	25	20	80%	Private Rd crossing
	M01T1.03	23.1	16	69%	Private Rd crossing
	M01T1.03	23.1	16	69%	Private Rd crossing
	M01T1.04	20.5	17	83%	State HWY 153 crossing
	M01T1.04	20.5	30	146%	Private Rd crossing
Sandgate Brook	M03T1.01	19	20	105%	Sandgate Rd crossing
	M03T1.01	20.3	15	74%	Sandgate Rd crossing

Table 5.2 Summary of culvert data in the White Creek/Mill Brook watersheds

Stream Name	Reach	Location	Percent Bankfull Width	Geomorphic Compatibility	Aquatic Organism Passage (AOP)	AOP Retrofit Potential*
Mill Brook	M01T1.03	Private Rd crossing	47%	Mostly Compatible	No AOP except adult salmonids	MLL
	M01T1.04	VT 153 crossing	117%	Fully Compatible	Full AOP	HHH
	M01T1.04	Watrous Rd crossing	91%	Mostly Compatible	Reduced AOP	HHM
	M01T1.06-A	VT 153 crossing	85%	Mostly Compatible	No AOP including adult salmonids	HML
Sandgate Brook	M03T1.01	Sandgate Rd crossing	35%	Partially Compatible	Full AOP	MML
	M03T1.02	Sandgate Rd crossing	150%	Mostly Compatible	Reduced AOP	HHH
	M03T1.02	Sandgate Rd crossing	160%	Fully Compatible	Reduced AOP	HHH

* Notes on AOP Retrofit Potential:
H: High probability the existing culvert can be retrofitted
M: Medium probability the existing culvert can be retrofitted
L: Low probability the existing culvert can be retrofitted

Position 1 (left): For strong swimmers
Position 2 (Center): For moderate swimmers
Position 3 (right): For weak swimmers

5.2 Site-Level Project Opportunities

The site-level projects developed for the White Creek/Mill Brook watersheds are provided below in Table 5.3. The project strategy, technical feasibility, and priority for each project are listed by number and reach/segment. A total of 29 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 (for both hazard mitigation and ecological benefit), relative costs, and potential partners.

Priority assessments were made by Evan Fitzgerald using best professional judgment, with input from the Rupert Corridor Plan steering committee in November, 2012. Priority assignments are intended for planning purposes to distinguish salient areas of risk or degradation from more common problem areas. Hazard mitigation priority refers to the relative risk of the site to erosion or flooding hazards, or the mitigation potential of the project for downstream reaches. Ecological benefits priority refers to the potential for the project to improve riparian and/or aquatic habitat within the reach or downstream. In most cases, projects have multiple benefits in the context of the corridor plan.

The project locations for the study area are included on a map provided in Appendix A. The 29 projects are further broken down by category as follows: twelve (12) active geomorphic restoration projects; seventeen (17 passive geomorphic restoration projects.

Table 5.3 Site-specific Opportunities for River Restoration and Protection

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 **Rail Trail Bridge east of Cross Road** White Creek Segment M01-A 43.23564 N 73.25199 W	**Active Restoration** *Bridge Retrofit/ Replacement*	Steel-timber rail trail bridge is undersized (44% of bankfull width) and concrete footings are undermined. Bridge alignment results in a severe bend in channel with sediment deposition upstream.	As structure comes up for replacement, it should be resized according to the RMP recommendations (design guidance of minimum 120% of bankfull width or 66 feet).	Moderate	Low	Reduced risk of debris catchment during large flood which could cause flooding and erosion.	Potentially high costs for structure redesign and replacement.	VTrans; Town of Rupert, BCCD; VT Recreation Trails Grant Program
#2 **Southwest of VT 153** White Creek Segment M01-A 43.23638 N 73.24762 W	**Active & Passive Restoration** *Floodplain Restoration & Corridor Protection*	Channel incised with berming along south bank in upper segment from post-Irene dredging. Channel incision in lower segment from historical berming (1970's). Forested stream corridor.	Remove portion or all post-Irene berming along south bank. Explore possibility of selectively pushing larger substrates into channel to increase roughness and improve habitat. Explore easement for corridor protection and long-term channel management rights.	**High**	Moderate	Potentially reduced flooding and property damage downstream if significant flood flow and sediment attenuation can be achieved.	Moderate costs for berm removal and channel restoration. Potentially high costs for property easement.	VTDEC Ecosystem Restoration Program (ERP); Town of Rupert; BCCD; Battenkill Watershed Alliance; Landowner
#3 **East of VT 153** White Creek Segment M01-A 43.23538 N 73.24086 W	**Passive Restoration** *Corridor Protection & Buffer Plantings*	Channel historically dredged and straightened following flood events in 1960's and 70's. Channel currently incised with stream type departure. Riparian buffer lacking in lower segment.	Explore easement for corridor protection and long-term channel management rights. Plant riparian buffer in lower segment to improve shading.	**High**	Moderate	Floodplain will attenuate sediment upstream of bridge during flood events. Improved habitat due to shading, etc.	Relatively low costs for native plant materials and labor. Potentially high costs for property easement.	BCCD; VTDEC ERP; VLT; Battenkill Watershed Alliance; Landowner
#4 **South of Kent Hollow Road** White Creek Segment M02 43.23211 N 73.22812 W	**Passive Restoration** *Buffer Plantings*	Channel currently incised with stream type departure. Bank erosion increased on one meander bend during T.S. Irene. Outside of bend along edge of farm field has large root wad in channel and flood chute on inside bend.	Plant stream bank with native woody vegetation in areas lacking canopy cover; Consider using smaller, more vigorous planting stock closer to bank and larger stock >15ft from top of bank.	Low	Moderate	Improved biotic habitat within reach (overhanging vegetation) and downstream (shading for lower water temp.). Increased resistance against bank erosion.	Relatively low costs for native plant materials and labor.	BCCD; NRCS (CREP or Tress for Streams); Battenkill Watershed Alliance; Landowner

Table 5.3 Site-specific Opportunities for River Restoration and Protection

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 of Saunders Lane** White Creek Segment M03-B 43.23179 N 73.21880 W	**Passive Restoration** *Buffer Plantings*	Channel historically straightened but not currently incised per Phase 2 field data. Long stretch (650ft) of channel lacking woody riparian vegetation on east bank.	Plant west bank with native woody vegetation in areas lacking canopy cover; Coordinate with adjacent landowners to assess interest and cooperation.	Low	Moderate	Potentially reduced property loss from erosion; Improved biotic habitat within reach and downstream.	Relatively low costs for native plant materials and labor.	BCCD; NRCS (CREP or Tress for Streams); Battenkill Watershed Alliance; Landowner
#6 **South of Kent Hollow Road erosion** White Creek Segment M03-B 43.23535 N 73.21159 W	**Passive Restoration** *Corridor Protection*	Good channel stability, floodplain connection to the south, and aquatic habitat throughout reach. Road embankment washed out during TS Irene and repaired with stacked stone wall embankment.	Work with landowner to protect stream corridor from further development and channel management (i.e., armoring or encroachment). Assess parcel configuration to determine extents of corridor easement.	Moderate	Low	Important sediment and floodwater attenuation reach to take pressure off erosion along road corridor to north. Protection of good aquatic habitat.	Potentially moderate to high costs for easements due to private ownership and reach length; Needs further investigation.	BCCD; VTDEC ERP; Battenkill Watershed Alliance; Landowner
#7 **South of Kent Hollow Road** White Creek Segment M04 43.23234 N 73.19594 W	**Passive Restoration** *Corridor Protection*	Fair channel stability, and floodplain connection to the north. Floodplain access good in upper reach. Downstream road embankment washed out during TS Irene.	Work with landowner to protect stream corridor from further development and channel management (i.e., armoring or encroachment). Assess parcel configuration to determine extents of corridor easement.	Moderate	Low	Important sediment and floodwater attenuation reach to take pressure off erosion along road corridor to north	Potentially moderate to high costs for easements due to private ownership and reach length; Needs further investigation.	BCCD; VTDEC ERP; Battenkill Watershed Alliance; Landowner
#8 **West of Kent Hollow Road** Tributary A to White Creek Seg. M01T2.01-A 43.23466 N 73.23273 W	**Active Restoration** *Channel & Floodplain Restoration*	Channel historically straightened and ditched. Highly depositional at change in slope. Extreme sediment deposition from TS Irene resulted in dry channel and habitat disconnect from mainstem of White Creek.	Conduct cursory alternatives analysis to determine appropriate restoration approach, including some or all of following practices: Buffer restoration; Channel reconfiguration; Habitat enhancement with large woody debris.	Moderate	**High**	Tributary along Lang Road is known to have quality habitat for brook trout. Combine with outlet improvements on box culvert to restore AOP from White Creek.	Potentially moderate to high costs for channel restoration. Relatively low costs for native plant materials and labor.	VTDEC Ecosystem Restoration Program (ERP); BCCD; Battenkill Watershed Alliance; Landowner

Table 5.3 Site-specific Opportunities for River Restoration and Protection								
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 **Kent Hollow Road Box Culvert** Tributary A to White Creek Seg. M01T2.01-A 43.23528 N 73.23175 W	**Active Restoration** *Culvert Retrofit/ Replacement*	Box culvert beneath Kent Hollow Road is undersized and perched above downstream surface water level. Increased velocities and height above surface water is reducing aquatic organism passage (AOP).	Replace culvert with an open-bottomed arch or bridge to improve AOP; Alternatively, explore potential retrofit of downstream end of culvert to improve AOP with grade control weirs to induce backwater and reduce base flow velocities.	Moderate	**High**	Improved AOP in tributary reach where quality habitat was observed upstream.	High costs for design and installation of new structure; Retrofit would be less costly.	Town of Rupert; BCCD; Battenkill Watershed Alliance; VTRANS; VFWD
#10 **West of Sandgate Road** Sandgate Brook Seg. M03T1.01 43.22906 N 73.22124 W	**Passive Restoration** *Buffer Plantings*	Channel relatively stable per Phase 2 field data. Long stretch (430ft) of channel lacking woody riparian vegetation on both banks in residential area.	Plant both banks with native woody vegetation in areas lacking canopy cover; Coordinate with landowners to assess interest and cooperation.	Low	Moderate	Potentially reduced property loss from erosion; Improved biotic habitat within reach and downstream.	Relatively low costs for native plant materials and labor.	BCCD; NRCS (CREP or Tress for Streams); Battenkill Watershed Alliance; Landowner
#11 **Private Driveway Culvert off Sandgate Road** Sandgate Brook Seg. M03T1.01 43.22709 N 73.21923 W	**Active Restoration** *Culvert Retrofit/ Replacement*	Culvert beneath private driveway has washed out in past. Corrugated metal culvert is undersized (35% of bankfull width). Increased velocities reducing aquatic organism passage (AOP).	Replace culvert with an open-bottomed arch or bridge to improve AOP; Alternatively, explore potential retrofit of downstream end of culvert with weirs to slow velocity, prevent scour, and improve AOP.	Moderate	Moderate	Improved AOP in tributary reach where quality habitat was observed upstream.	High costs for design and installation of new structure; Retrofit would be less costly.	Landowner; BCCD; Battenkill Watershed Alliance; VFWD
#12 **West of Rail Trail** Mill Brook Seg. M01T1.01-A 43.23981 N 73.24750 W	**Passive Restoration** *Buffer Plantings*	Channel incised but locked in place by high banks to west and rail trail to east. Long stretch (600ft) of channel with minimal buffer width (<20ft in some locations).	Plant north buffer with native woody vegetation in areas lacking canopy cover; Coordinate with landowners to assess interest and cooperation.	Low	Moderate	Potentially reduced sediment discharge to channel from field; Improved biotic habitat within reach and downstream.	Relatively low costs for native plant materials and labor.	BCCD; NRCS (CREP or Tress for Streams); Battenkill Watershed Alliance; Landowner

Table 5.3 Site-specific Opportunities for River Restoration and Protection

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 **Rail Trail Bridge near Mill Road** Mill Brook Seg. M01T1.01-B 43.24133 N 73.24750 W	**Active Restoration** *Bridge Retrofit/ Replacement*	Steel-timber rail trail bridge was damaged during TS Irene. Ensure that VTrans redesign is compatible with geomorphic stability and proper alignment is considered.	Use VTDEC RMP design recommendations (guidance of minimum 120% of bankfull width or 36 feet)	Moderate	Low	Reduced risk of debris catchment during large flood which could cause flooding and erosion.	Likely moderate to high costs for structure redesign and replacement.	VTrans; Town of Rupert; BCCD; VT Recreation Trails Grant Program
#14 **East of Rail Trail** Mill Brook Seg. M01T1.01-B 43.24250 N 73.24404 W	**Passive Restoration** *Buffer Plantings*	Channel relatively stable per Phase 2 field data. Long stretch (670ft) of channel lacking woody riparian vegetation on east bank along hay field. There is an active CREP project in reach for riparian plantings and bank armoring.	Plant east buffer with native woody vegetation in areas lacking canopy cover; Coordinate with landowners to assess interest and cooperation.	Low	Moderate	Potentially reduced sediment discharge to channel from field; Improved biotic habitat within reach and downstream.	Relatively low costs for native plant materials and labor.	BCCD; NRCS (CREP or Tress for Streams); Battenkill Watershed Alliance; Landowner
#15 **West of Rail Trail** Mill Brook Seg. M01T1.01-D 43.25177 N 73.23593 W	**Passive Restoration** *Buffer Plantings*	Channel relatively stable per Phase 2 field data. Long stretch (525ft) of channel lacking woody riparian vegetation on west bank along hay field.	Plant west buffer with native woody vegetation in areas lacking canopy cover; Coordinate with landowners to assess interest and cooperation.	Low	Moderate	Potentially reduced sediment discharge to channel from field; Improved biotic habitat within reach and downstream.	Relatively low costs for native plant materials and labor.	BCCD; NRCS (CREP or Tress for Streams); Battenkill Watershed Alliance; Landowner
#16 **VT153 Bridge** Mill Brook Seg. M01T1.02 43.25211 N 73.23305 W	**Active Restoration** *Bridge Retrofit/ Replacement*	Bridge is undersized (64% of reference bankfull width) and has low clearance. Flood constriction noted during TS Irene.	As structure comes up for replacement, it should be resized according to the VTANR River Management Program (RMP) recommendations.	**High**	Low	Reduced risk of debris catchment during large flood which could cause flooding and erosion.	High costs for structure redesign and replacement.	VTrans; Town of Rupert

Table 5.3 Site-specific Opportunities for River Restoration and Protection								
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 **East of VT153** Mill Brook Seg. M01T1.02 43.25307 N 73.23069 W	**Passive Restoration** *Buffer Plantings*	Channel incised in upper reach but less so in lower reach. Stage IV of channel evolution suggests some stabilization that could be improved with plantings. Long stretch (1,400ft) of channel lacking woody vegetation.	Plant both banks with native woody vegetation in areas lacking canopy cover; Coordinate with landowners to assess interest and cooperation.	Low	Moderate	Potentially reduced sediment discharge to channel from field; Improved biotic habitat within reach and downstream.	Low to moderate costs for native plant materials and labor.	BCCD; NRCS (CREP or Tress for Streams); Battenkill Watershed Alliance; Landowner
#18 **East of VT153** Mill Brook Seg. M01T1.02 43.25305 N 73.22983 W	**Active Restoration** *Bank Stabilization*	Channel incised in upper reach but less so in lower reach. Stage IV of channel evolution. Two mass failures (total length approx. 250ft) contributing large sediment load to downstream reaches	Reshape banks from 1:1 slope to 1:1.5 and terrace with bioengineering methods (e.g., coir logs and jute fabric) above bankfull elevation. Plant with vigorous vegetation such as willows.	**High**	Moderate	Potentially reduced sediment discharge to channel from field; Improved biotic habitat within reach and downstream.	Low to moderate costs for native plant materials and labor. Moderate costs for machinery access and labor if required.	BCCD; Battenkill Watershed Alliance; Landowner
#19 **East of VT153** Mill Brook Seg. M01T1.02 43.25848 N 73.22239 W	**Passive Restoration** *Buffer Plantings*	Channel incised in upper reach but less so in middle reach. Stage IV of channel evolution suggests some stabilization that could be improved with plantings. Long stretch (725ft) of channel lacking woody vegetation on both banks	Plant both banks with native woody vegetation in areas lacking canopy cover; Coordinate with landowners to assess interest and cooperation.	Low	Moderate	Potentially reduced sediment discharge to channel from field; Improved biotic habitat within reach and downstream.	Low to moderate costs for native plant materials and labor.	BCCD; NRCS (CREP or Tress for Streams); Battenkill Watershed Alliance; Landowner
#20 **Upstream and Downstream of Youlin Road** Mill Brook Seg. M01T1.02 43.26184 N 73.21941 W	**Passive Restoration** *Buffer Plantings*	Lack of buffer vegetation upstream and downstream of Youlin Road bridge (approx. 150 linear feet) is leading to minor bank instability and lack of shading of channel at two residences.	Plant right (west) bank upstream of bridge, and left (east) bank downstream of bridge with willows interspersed between bank armoring to increase resistance to erosion; Coordinate with landowners to assess interest and cooperation.	Moderate	Moderate	Improved bank stability for homes near stream bank; Improved biotic habitat within reach and downstream.	Low costs for native plant materials and labor.	BCCD; NRCS (CREP or Tress for Streams); Battenkill Watershed Alliance; Landowner

Table 5.3 Site-specific Opportunities for River Restoration and Protection

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 **Upstream of Youlin Road** Mill Brook Seg. M01T1.03 43.26222 N 73.21817 W	**Active Restoration** *Berm Removal*	Berm along right bank just above Youlin Road to protect home on west bank. Berm is 300ft long. Contributes to channel incision in reach and downstream.	Explore possibility of lowering berm to allow some floodplain access while still ensuring protection of adjacent residence (if possible). Cursory alternatives analysis needed.	Moderate	Low	Improve floodplain access in forested corridor immediately upstream of Village area where flooding is a problem.	Moderate to high costs for machinery/labor to move berm material. Some design costs needed to ensure no increased risk to home.	VTDEC Ecosystem Restoration Program (ERP); BCCD; Battenkill Watershed Alliance; Landowner
#22 **South of VT315** Mill Brook Seg. M01T1.03 43.26449 N 73.21078 W	**Passive Restoration** *Buffer Plantings*	Lack of buffer vegetation along left (south) bank south of VT315. (approx. 400 linear feet) is leading to minor bank instability and lack of shading of channel.	Plant left (south) bank downstream of bridge; Coordinate with landowners to assess interest and cooperation.	Low	Moderate	Improved bank stability for homes near stream bank; Improved biotic habitat within reach and downstream.	Low costs for native plant materials and labor.	BCCD; NRCS (CREP or Tress for Streams); Battenkill Watershed Alliance; Landowner
#23 **South of VT315** Mill Brook Seg. M01T1.03 & 04 43.26451 N 73.20478 W	**Passive Restoration** *Corridor Protection*	One of 3 areas of good floodplain access on Mill Brook upstream of Rupert Village. Sediment deposition occurred during TS Irene adjacent hay field in forested stream corridor.	Work with landowner to protect stream corridor from further development and channel management (i.e., armoring or encroachment). Assess parcel configuration to determine extents of corridor easement.	**High**	Low	Important sediment and floodwater attenuation reach to take pressure off erosion along road corridor and village to west.	Potentially moderate to high costs for easements due to private ownership and reach length; Needs further investigation.	BCCD; VTDEC ERP; Battenkill Watershed Alliance; Landowner
#24 **North of VT315** Mill Brook Seg. M01T1.04 43.26780 N 73.1969 W	**Active Restoration** *Roadway Embankment Stabilization*	Channel eroded bank to within 10-15ft of road edge. Length is 50-100ft. Insufficient lateral space to armor bank traditionally without severe stream encroachment. Channel incised with IR between 1.5 - 2.0.	Build a stacked wall at toe of slope with 2-3ft key depth. Shape upper slope to 1:1.5 and plant with vigorous vegetation such as willows.	**High**	Moderate	Roadway stability. Reduced sediment discharge to channel from field.	Moderate costs for materials and labor.	VTrans; Town of Rupert

Table 5.3 Site-specific Opportunities for River Restoration and Protection								
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 **Northwest of VT315** Mill Brook Seg. M01T1.04 43.26449 N 73.21078 W	**Passive Restoration** *Buffer Plantings*	Lack of buffer vegetation along left (east) bank in hay field west of VT315 (approx. 650 linear feet) is leading to bank instability and lack of shading of channel.	Plant left (east) bank. Use a setback of 15ft with larger tree stock to avoid loss from channel migration; Plant smaller, more vigorous stock along near bank.	Low	Moderate	Improved bank stability for structures near stream bank; Improved biotic habitat within reach and downstream.	Low costs for native plant materials and labor.	BCCD; NRCS (CREP or Tress for Streams); Battenkill Watershed Alliance; Landowner
#26 **South of VT315** Mill Brook Seg. M01T1.04 43.27069 N 73.19257 W	**Passive Restoration** *Corridor Protection*	One of 3 areas of good floodplain access on Mill Brook upstream of Rupert Village. Sediment deposition occurred during TS Irene adjacent hay field in forested stream corridor. Limited channel incision for approximately 500ft.	Work with landowner to protect stream corridor from further development and channel management (i.e., armoring or encroachment). Assess parcel configuration to determine extents of corridor easement.	**High**	Low	Important sediment and floodwater attenuation reach to take pressure off erosion along road corridor and village to west.	Potentially moderate to high costs for easements due to private ownership and reach length; Needs further investigation.	BCCD; VTDEC ERP; Battenkill Watershed Alliance; Landowner
#27 **South of Watrous Road** Mill Brook Seg. M01T1.04 43.27460 N 73.18761 W	**Passive Restoration** *Corridor Protection*	One of 3 areas of good floodplain access on Mill Brook upstream of Rupert Village. Limited to minor channel incision for approx. 500ft with hay field on right (west) bank. Sediment deposition occurred during TS Irene.	Work with landowner to protect stream corridor from further development and channel management (i.e., armoring or encroachment). Assess parcel configuration to determine extents of corridor easement.	**High**	Low	Important sediment and floodwater attenuation reach to take pressure off erosion along road corridor and village to west.	Potentially moderate to high costs for easements due to private ownership and reach length; Needs further investigation.	BCCD; VTDEC ERP; Battenkill Watershed Alliance; Landowner
#28 **Watrous Road Culvert** Mill Brook Seg. M01T1.04 43.27516 N 73.18725 W	**Active Restoration** *Culvert Retrofit*	Culvert is a barrier to aquatic organism passage (AOP). Numerous adult brook trout seen in plunge pool at outlet.	Install grade control weirs to downstream channel to raise bed and reduce drop out of perched culvert and velocities through channel.	Low	**High**	Improved AOP for healthy native fishery.	Moderate costs for design and installation of weirs.	Town of Rupert; BCCD; Battenkill Watershed Alliance; Landowner

Table 5.3 Site-specific Opportunities for River Restoration and Protection

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 **VT315 ditch along steep hill** Unnamed and not assessed for Phase 1 or Phase 2 SGA 43.27991 N 73.17508 W	**Active Restoration** *Channel Restoration*	Roadside drainage carrying perennial stream is highly incised and threatens road. No natural grade control present. Channel incised and will undermine road embankment and armoring.	Install grade control weirs and/or bed armoring in channel bottom to prevent further incision and road failure. Minimum key depth of 2ft for rock.	**High**	Moderate	Prevents road failure; Prevents excessive sedimentation of downstream reaches.	Moderate costs for materials and labor.	VTrans; Town of Rupert

6.0 Conclusions & Recommendations

The steep, mountainous terrain draining the White Creek/Mill Brook watershed creates fluvial erosion hazards throughout the Town of Rupert. While flood damages resulting from inundation occurred in 2011 during TS Irene in New York along the White Creek downstream (west) of Rupert, fluvial erosion has been the principal mode of damage to roadways, homes, and farm fields in Rupert. Over the last 20 years, the Town of Rupert has experienced numerous floods that have caused severe damage to private and public land and infrastructure. The Town of Rupert, in cooperation with BCCD and VTDEC, is wise to take a long-term corridor planning approach to better understand, plan for, and mitigate fluvial erosion hazards in the watershed.

The White Creek and Mill Brook channels are still adjusting their width, depth, and planform to the following historical and ongoing impacts: 1) aggradation of sediment in the valleys due to European settlement and deforestation that occurred during the 1700's and 1800's; 2) channel straightening, dredging and corridor encroachment associated with adjacent railroads, agriculture, and other land uses; 3) significant floods in recent years such as those in 1996, 1999, 2000, and TS Irene in 2011.

Within certain areas of the White Creek/Mill Brook corridors, moderate to severe vertical and lateral channel migration is likely in the future. Given the current state of the channel and predicted future adjustments, the following watershed-scale and site-specific management approaches are recommended:

- Continue the use/enforcement of the adopted Fluvial Erosion Hazard (FEH) zone ordinance in Rupert, with consideration of appropriate stream setbacks in areas where the FEH zone is not mapped (e.g., smaller tributaries draining to White Creek and Mill Brook).
- Sediment management has been identified as a key concern in the Rupert community due to ongoing conflicts at structures and road crossings. However, given the state of channel adjustments in many reaches in the White Creek/Mill Brook watershed, bank stabilization is generally not advisable in reaches that are actively incising or redeveloping planform geometry. Numerous riverbank stabilization projects in Vermont and other states have failed due to a lack of understanding of channel adjustment processes and stage of channel evolution.
- In certain reaches where the channel is confirmed to have access to its floodplain, bank stabilization treatments may be viable but should be carefully considered. This is the case for project 18 (see project summary in Appendix B).
- Carefully consider those areas of river corridor identified as "high-priority" for added protection above and beyond the FEH restrictions (i.e., conservation easements) to protect upstream floodplains and mitigate downstream effects of fluvial erosion hazards in the Village of Rupert. Refer to "high priority" projects 2, 3, 23, 26, and 27 in Table 5.3.
- Address high-priority areas of channel and floodplain restoration to mitigate the effects of dredging/berming that occurred following TS Irene. These areas, which include projects 2 and 8 (see Appendix B for detailed project descriptions), have elevated risks of future flood damage for both adjacent lands and downstream areas.

7.0 References

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8.0 Glossary of Terms

Adapted from:

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 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.
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.