Crosby Brook Watershed
Stream Corridor Restoration Plan

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Executive Summary

- Crosby Brook is drained by a small, urbanizing watershed found within the Towns of Brattleboro and Dummerston. It is classified as a Class B/Coldwater fishery per the Vermont Water Quality Standards. Biotic sampling done by the Vermont Department of Environmental Conservation (VTDEC) indicated that the aquatic community in the lower watershed is stressed by elevated stream temperature, siltation of the bed substrate with fine sediments, and habitat degradation resulting from channel and floodplain alterations.

- Crosby Brook was identified for geomorphic assessment in 2007 as part of an effort to understand the watershed and reach-scale impacts on channel stability and the aquatic community. Fitzgerald Environmental Associates, LLC (FEA) was retained by the Windham County Natural Resources Conservation District (WCNRCD) in 2007 to carry out Phase 1 and 2 assessments following the Stream Geomorphic Assessment (SGA) Protocols developed by VTDEC, and in 2008 to develop a Stream Corridor Plan.

- In order to develop a science-based corridor plan for long term restoration purposes, FEA used RMP River Corridor Planning Guide to identify restoration projects in the watershed. This effort built on the SGA Phase 1 and 2 data. FEA completed an analysis of stressors to the hydrologic and sediment regimes and riparian/boundary conditions, including the mapping of channel and floodplain features identified during the field surveys. The data and mapping formed the basis for developing a list of potential restoration and protection projects using a step-wise procedure developed by VTDEC.

- The results of the stressor and departure analysis indicated specific areas of the watershed where recent increases in impervious cover and man-made drainage infrastructure, and historical channel straightening and floodplain encroachment have adversely impacted the sediment and hydrologic regimes. Channel incision and widening processes dominate much of the channel network in the lower watershed, resulting in many reaches with high sediment transport capacity, and bank and bed erosion.

- A total of 19 unique restoration project opportunities were identified for the Crosby Brook reaches, including 4 corridor protection sites, 6 riparian buffer planting sites, 5 active channel restoration sites, and 4 structure replacements. Based on input from the corridor planning partners, three projects were selected for further development.

- The three selected projects included: 1) buffer enhancement and bank/floodplain restoration east of Route 9 (behind Bickford's restaurant); 2) buffer enhancement and bank stabilization east of Putney Road (behind Motel Six); 3) slope and channel stabilization along Black Mountain Road. An alternatives analysis was carried out for each project to determine the feasibility of each alternative in terms of land use constraints, landowner/stakeholder support, restoration and protection activities required, cost estimates, and regulatory requirements.

1.0 Background

1.1 Project Overview

In 2007, the Windham County Natural Resources Conservation District (WCNRCD) and the Vermont Department of Environmental Conservation (VTDEC) identified the Crosby Brook watershed in Dummerston and Brattleboro, Vermont for assessment of fluvial geomorphic conditions. The study was part of a larger effort to characterize the physical and biotic conditions of the watershed and to aid in the identification of stressors on aquatic biota communities. Crosby Brook is classified as a Class B/Coldwater fishery per the Vermont Water Quality Standards. VTDEC undertook an extensive, 3-year sampling effort in the watershed beginning in 2002 to better understand the environmental stressors on the aquatic community (VTDEC, 2005). The findings indicated that the upper reaches of both branches have adequate habitat conditions to support the expected macroinvertebrate communities. However, the biotic communities in the lower watershed appear to be stressed by elevated stream temperature, siltation of the bed substrate with fine sediments, and habitat alterations resulting from channel and floodplain alterations.

Fitzgerald Environmental Associates, LLC (FEA) was retained by WCNRCD in 2007 to carry out Phase 1 and 2 assessments following the Stream Geomorphic Assessment (SGA) Protocols developed by the Vermont Department of Environmental Conservation (VTDEC, 2007). Further background on the Phase 1 and 2 study objectives specific to the watershed can be found in Phase 1 and 2 summaries prepared by FEA (FEA, 2007; FEA, 2008). Additional background information about the geologic, geomorphic, and ecological setting of the Crosby Brook watershed can be found in the Phase 2 summary.

The Phase 2 results indicated that the lower zone of the watershed is experiencing the greatest degree of channel adjustment and decline in physical habitat. These adjustments, in conjunction with riparian buffer loss and increased stormwater runoff, are leading to a decline in biotic integrity. A large gully on the main stem has had a severe impact on the lower watershed conditions (e.g., supply of fine sediment to the channel), and the deleterious effects of recent commercial development and floodplain encroachment in this zone of the watershed are also evident.

1.2 Corridor Planning Goals and Objectives

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, 2007).

The overall goal of the River Management Program (RMP) is to “manage toward, protect, and restore the fluvial geomorphic equilibrium condition of Vermont rivers by resolving conflicts between human investments and river dynamics in the most economically and ecologically sustainable manner," (VTANR, 2007) achieved through:

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

The goal of the Crosby Brook Stream Corridor Restoration Plan was to develop projects with the following objectives: (a) to improve the long-term stability of Crosby Brook; (b) to reduce sediment and nutrient pollution loading of the Crosby Brook and therefore the Connecticut River; (c) to reduce over time landowner vulnerability and infrastructure damage from flood and fluvial erosion hazards. WCNRCD, VTDEC, Windham Regional Commission (WRC) and the Town of Brattleboro intend to use this plan for project implementation and stakeholder outreach to work towards achieving long-term stream channel stability.

1.3 Corridor Planning Tasks

1.3.1 Stressor/Departure Analysis and Project Identification

A stressor identification analysis was completed following the VTDEC approach (VTANR, 2007). This approach uses Phase 1 and 2 SGA data to develop watershed and reach-scale mapping of natural and built features that influence river stability. A step-wise procedure has been developed by VTDEC to identify projects that would be compatible with geomorphic adjustments and managing the stream toward equilibrium conditions. FEA used this approach to identify potential stream restoration projects that were compatible with the project goals.

Types of projects include:

- Protecting river corridors from channel management and future encroachment
- Planting stream buffers with woody vegetation
- Stabilizing stream banks if it will achieve the stated goals
- Arresting channel erosion such as head cuts and nick points
- Removing berms and other barriers to geomorphic processes
- Removing or replacing structures following VTDEC recommendations
- Restoring incised reaches through "passive" or "active" measures.

1.3.2 Project Development

Following the preliminary project identification phase, Evan Fitzgerald toured potential high priority projects within the watershed with the corridor planning partners. The partners then reviewed and commented on the list of projects, and three projects were identified for further development. As part of the project development process, FEA documented the feasibility of each project in terms of land use constraints, landowner/municipal/stakeholder support, restoration and protection activities required, rough cost estimates, and regulatory requirements. Project feasibility was based on the following key evaluation criteria:

- Does the overall project or activity contribute to and accommodate the stream equilibrium conditions?
- Does the project alternative or management activity chosen result in an overall reduction of sediment/nutrient production from within the river corridor and increase in sediment and nutrient storage in the watershed?
- If the project is completed, is there likelihood that it will fail because of unmitigated constraints or anticipated channel adjustment processes in the river reach or in the watershed?
- Will the project or management activity lead to or contribute to instability in upstream or downstream reaches?

The project descriptions included in Section 5 serve as a status report to document 1) the level of "readiness" of the project, 2) the tasks that will need to be completed before the project can be implemented, and 3) The contacts made during project development.

1.3.3 Fluvial Erosion Hazard Analysis

A separate component of the corridor planning effort involved the analysis of Fluvial Erosion Hazard (FEH) zones of Crosby Brook for the Phase 2 study reaches. Using Phase 1 data previously developed using the Stream Geomorphic Assessment Tool (SGAT), FEA developed FEH corridors following the VTDEC FEH approach (VTDEC, 2008). The FEH corridor is determined by the inherent sensitivity of the reach to adjustments (e.g., lateral migration) and the current condition of reach stability as determined through Phase 2 field surveys. The FEH corridor represents the estimated area surrounding the channel needed to accommodate fluvial geomorphic equilibrium conditions. The corridor can be used by municipalities to develop protection strategies that will reduce property loss and infrastructure damage from flooding and long-term bank erosion.

Using the FEH corridor, we analyzed the implications of an FEH Overlay District within the towns of Brattleboro and Dummerston. The purpose of this analysis was to provide the Towns, WCNRCD and DEC with a summary of the built and natural capital within the corridor, and highlight opportunities for corridor protection. The analysis also assessed the towns' planning and zoning districts in the context of development patterns and other protected parcels within the corridor (e.g., town-owned parcels and conserved lands). The complete results of the FEH analysis are provided in Appendix C.

2.0 Methods

The Vermont River Management Program (RMP) has invested many person-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. Data collected for the Crosby Brook watershed using the protocols forms the basis for the preliminary project identification carried out as part of the Stream Corridor Planning effort.

2.1 Phase 1 and 2 SGA Methods

Phase 1 assessments employ remote sensing techniques, along with limited field verification, to identify background conditions in the watershed. 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 will adjust to human impacts in the future.

Phase 1 data were collected by FEA for the entire watershed in 2007 and summarized in a final report (FEA, 2007). A total of 16 reaches were identified during the Phase 1 analysis for the 10.1 mile channel network, and 9 reaches were selected for further Phase 2 assessment in 2008, including 6 reaches on the main stem and 3 reaches on the SB (See Figure 1). A total of 16 segments were assessed for Phase 2 data, and data were entered into the Data Management System (DMS). All major human impacts and natural features noted during the Phase 2 surveys were indexed in a GIS using the Feature Indexing Tool (FIT; VTDEC, 2007).

2.2 Bridge and Culvert Assessments

FEA conducted bridge and culvert surveys on all private and public bridges and culverts within the selected Phase 2 reaches. The Bridge and Culvert Assessment and Survey Protocols specified in Appendix G of the Vermont Stream Geomorphic Assessment Handbook (VTANR, 2007) were followed. Latitude and Longitude at each of the structures was determined using a GPS unit. The assessment included various photos documenting the conditions of each structure.

The Vermont Culvert Geomorphic Screening tool (MMI, 2008a) and the Vermont Culvert Aquatic Organism Passage Screening Tool (MMI, 2008b) developed by

Milone and MacBroom, Inc. for VTDEC were used to identify culverts within the Crosby watershed that have a higher priority for replacement/retrofit due to geomorphic incompatibility and/or for being potential barriers to movement and migration of aquatic organisms.

2.3 River Corridor Planning

FEA followed the VTDEC methods for developing stream corridor plans outlined in the Vermont River Corridor Planning Guide (VTANR, 2007). This technical guide is directed towards river scientists, planners, and engineers engaged in finding economically and ecologically sustainable solutions to the conflicts between human investments and river dynamics. The guide provides explanations for the following:

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

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

3.0 Stressor Identification and Departure 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 and using relationships derived from recently completed research in the region (Fitzgerald, 2007), also allows for the assessment of physical departure from reference conditions, and serves to validate watershed-scale patterns and stream conditions observed in the field.

The stream segments studied in the Crosby Brook watershed have a diversity of natural forms and sensitivities (Table 1). Many segments have undergone severe channel adjustments, resulting in a departure from reference conditions. The average score from the Rapid Geomorphic Assessment (RGA) stability assessment was 0.58, or within the range of fair conditions; indicating that the impacts of urbanization and historic channel straightening have resulted in many segments that are not in regime and have channels experiencing some degree of floodplain disconnection. Similarly, the Rapid Habitat

Assessment (RHA) results indicate fair conditions overall, with degraded conditions typically reflective of increased substrate embeddedness (due to excess fine substrate), limited pool variability and depth, limited presence of coarse and large woody debris, and poor bank vegetation. Ten (10) of the 16 study segments in the watershed are in a state of channel incision (stage II of channel evolution; VTANR, 2006b), or channel widening (stage III) due primarily to vertical adjustments brought on by the urbanization and corridor encroachment.

Table 1. Crosby Brook Reference Reach Characteristics

Reach	Phase 2 Data	Drainage Area (sq. mi.)	Channel Length (mi)	Channel Slope (%)	Channel Width (ft.)	Sinuosity	Valley Width§ (ft.)	Confinement		Stream Type**	Bedform†
								Ratio	Type*		
M01	Yes	5.7	0.7	1.2	28.2	1.07	150	5.3	NW	C	Riffle-Pool
M02	Yes	3.7	0.5	0.7	23.3	1.03	227	9.7	BD	C	Riffle-Pool
M03	Yes	2.8	0.6	1.1	20.6	1.07	200	9.7	BD	C	Riffle-Pool
M04	Yes	2.6	0.6	1.4	19.9	1.10	100	5.0	NW	C	Riffle-Pool
M05	Yes	2.4	0.5	0.3	19.4	1.20	400	20.7	VB	E	Riffle-Pool
M06	Yes	2.2	0.7	2.5	18.4	1.05	150	8.1	BD	C	Riffle-Pool
M07	No	1.6	1.0	3.1	16.1	1.03	*50*	3.1	SC	B	Step-Pool
M08	No	0.5	0.7	7.4	9.4	1.00	*15*	1.6	NC	A	Step-Pool
M09	No	0.1	0.3	3.6	4.9	1.06	*25*	5.1	NW	B	Step-Pool
T1.01	Yes	1.8	0.5	1.4	17.1	1.03	120	7.0	BD	C	Riffle-Pool
T1.02	Yes	1.7	0.8	4.5	16.5	1.01	40	2.4	SC	B	Step-Pool
T1.03	Yes	1.1	0.8	0.2	13.5	1.06	381	28.2	VB	E	Dune-Ripple
T1.04	No	0.8	0.2	4.3	11.9	1.20	*40*	3.4	NC	B	Step-Pool
T1.05	No	0.4	1.0	4.9	8.9	1.03	*15*	1.7	NC	A	Step-Pool
T2.01	No	0.5	0.5	3.4	9.7	1.02	*55*	5.7	SC	B	Step-Pool
T2.02	No	0.1	0.7	4.8	5.3	1.01	*15*	2.8	SC	A	Step-Pool

* NW = Narrow; SC = Semi-confined; BD = Broad; VB = Very Broad

§ Valley Width estimated remotely for *italicized* values

** per Rosgen (1994)

† per Montgomery & Buffington (1997)

The following sections summarize the methods used to develop the stressor identification and departure maps found in Appendix A. 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 4.

3.1 Hydrologic Regime Stressors

The following description of the hydrologic regime of a watershed, and the general response to watershed-scale land use changes and stressors is included from the most recent version of the VTANR River Corridor Planning Guide (VTANR, 2007b).

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 changed, 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 Crosby Brook watershed contains a mixture of land cover types (Table 2), including significant amounts of forest cover (mostly in the upper watershed). The watershed is currently 60% forested, with approximately 10% covered by agricultural lands (including extensive orchards). Residential lands occupy 10% of the watershed, with lesser amounts occupied by commercial/industrial lands (4.4%) and transportation corridors (6.4%). The watershed has a low to moderate degree of impervious cover (8.7%), below levels typically associated with degraded stream conditions at the national level (CWP, 2003), but above the 5% impact threshold noted in urbanizing watersheds in Chittenden County (Fitzgerald, 2007). Figure 2 depicts land cover types at the watershed-scale categorized by general cover types: forest, agriculture, urban, water/wetland.

Table 2. Land Cover for Crosby Brook Watershed

Land Cover Type*	Entire Watershed	North Branch†	South Branch
Forested	60.2%	63.5%	53.2%
Agriculture	10.7%	6.6%	19.6%
Residential	9.9%	9.4%	10.8%
Commercial/Industrial	4.4%	6.3%	0.4%
Transportation	6.4%	6.4%	6.3%
Water & Wetland	8.4%	7.8%	9.7%

* 2002 LandSat Data from UVM Spatial Analysis Lab (SAL, 2005)
† Upslope watershed beginning at Reach M02

Vertical and lateral channel adjustments caused by upslope urbanization have been shown to be a significant source of fine sediment loading in watersheds around the world (Trimble, 1997; Simon and Rinaldi, 2006), and are known to have a deleterious effect on aquatic biota in Vermont (Fitzgerald, 2007). Due to ongoing channel adjustments in small Vermont watersheds in response to urbanization, VTANR asserts that endogenous sources of sediment (e.g., channel bed and banks) far outweigh the exogenous sources (e.g., colluvial and runoff-generated) in these settings (VTDEC, 2006).

The current day stressors to the hydrologic regime have been mapped using the variables extracted from the Phase 2 field dataset, watershed-scale loss of wetlands, and the degree of impervious cover at the subwatershed scale (Figure 3). Wetland loss was mapped as the area where hydric soils (NRCS mapping) and National Wetland Inventory (NWI) mapped areas intersected with urban or agricultural land uses in the watershed, with the remaining areas assumed to be intact wetland. This approach allows for the interpretation of loss of hydrologic attenuation of surface runoff at the reach and watershed scale. In addition, stormwater outfall densities mapped during the Phase 2 assessments are included to depict areas of increased stormflows. A summary of the local (reach-scale) and upslope impacts to the hydrologic regime for each main stem reach based on Figure 3 is provided in Table 5 at the end of this section.

3.2 Sediment Regime Stressors

The following description of the sediment regime of a watershed, and the general response to watershed-scale land use changes and stressors is included from the most recent version of the VTANR River Corridor Planning Guide (VTANR, 2007).

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

The current day stressors to the sediment regime have been mapped using the variables extracted from the Phase 2 field dataset, and the percent of agriculture within each subwatershed (Figure 4) using land use data from 2006. Four classes of percent agriculture were mapped to depict the relative impact of sediment delivery from agricultural lands at the reach and watershed scales. In addition, depositional and migration features mapped during the Phase 2 assessments are included to depict areas of increased vertical and lateral channel adjustments due to aggradation. Mass failures, gullies and bank erosion depict where sediment delivery from the channel boundaries is occurring. A summary of the local and upslope impacts to sediment loading for each main stem reach based on Figure 4 is provided in Table 5.

3.3 Channel Slope and Depth Modifiers

Many of Vermont's rivers and streams have been historically manipulated and straightened to maintain an unnaturally steep slope in a state of sediment transport, allowing for a short term sense of security from flooding and subsequent encroachment of infrastructure in the floodplain. Over time, alluvial rivers seek to redevelop a sinuous planform through the deposition of sediments in unconfined valleys. Following flood events when alluvial rivers have become energized enough to transport large amounts of coarse sediment into depositional zones of the watershed, lateral channel migration ensues 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, 2007).

In addition to historic alterations to channel slope in Vermont's alluvial rivers, the lowering of stream beds (e.g., dredging) and the raising of floodplains (e.g., berming) have resulted in an increase in channel depth (VTANR, 2007). 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 Crosby Brook watershed have been mapped using the variables extracted from the Phase 2 field dataset (Figure 5). 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. Areas with "high" encroachment indicate those reaches where at least 20 percent of the reach is affected by encroachment. Additional data showing the location of natural channel features (e.g., ledges) depict areas that have a resistance to vertical channel change. The presence of beaver activity in each reach indicates where temporary controls on vertical adjustments may be found. A summary of the local and upslope impacts to channel depth and slope for each reach is provided in Table 5.

3.4 Modifications to Channel Boundary and Riparian Conditions

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

Alterations to the channel boundary conditions and riparian areas in the Crosby Brook watershed have been mapped using the variables extracted from the Phase 2 field dataset (Figure 6). 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) depict areas that have a resistance to channel change. A summary of the local impacts to channel boundary conditions, including impacts to riparian vegetation, for each main stem reach based on Figure 6 is provided in Table 5.

In the Crosby Brook watershed, three low-gradient segments along the main stem and south branch (M01-B, T1.02-D, T1.03) have a combination of fine bed substrate and limited bank cohesiveness. In addition, no natural grade controls were noted in these segments during the field surveys, making them susceptible to vertical adjustments (e.g., nickpoints). Channel armoring was found to be significant only around those areas where corridor encroachments (e.g., berms and roads) were located; only 5 of the 16 main stem segments had bank armoring exceeding 5 percent of the total segment length. Many segments (7 of 16 segments) had significant reductions in woody riparian vegetation, leading to decreased boundary resistance.

3.5 Sediment Regime 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 shape and profile of a river is typically stable under reference watershed conditions, and predictable given knowledge about 1) the geologic conditions of the watershed and corridor, 2) the topography of the watershed, and 3) the regional climate.

Analysis of a watershed's sediment regime is a useful approach for summarizing the reach and watershed-scale stressors affecting the equilibrium conditions of river channels. Sediment regime mapping provides a context for understanding the sediment transport and channel evolution processes (Schumm, 1977; see supporting materials in Appendix B) which govern changes in geometry and planform for river channels in a state of disequilibrium. The VTANR River Corridor Planning Guide (2007) 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.

Table 3. Sediment Regime Types (VTANR, 2007)

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/or 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 supply both coarse and fine sediment when bank failure leads 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 bed forms; 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); storage of fine sediment as a result of floodplain access for high frequency (annual) floods. 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 Stage IV, and Stage V of channel evolution.

The reference and existing sediment regime types have been mapped using data from the Phase 1 and 2 assessments. Figures 7 and 8 summarize the sediment regime types for reference and existing conditions for the 16 study segments. The analysis of sediment regime types reveals that the main stem and south branch channels of Crosby Brook have experienced many areas of departures from the reference regime conditions. All of the segments with channel slopes less than 2 percent are assumed to have been fine or coarse-bottomed streams in equilibrium, where there was a balance between sediment transport and supply. Only three segments with these characteristics were found to be “in regime” under existing conditions (M04, M05, and M06-C), with the remaining segments having reduced floodplain deposition of fine sediments, and increased bank erosion. Segments with channel slopes greater than 2 percent are assumed to have been dominated by sediment transport processes. Only 5 of the 16 Phase 2 segments were characterized by these conditions, and none were shown to have severely altered processes during the Phase 2 surveys.

Table 4. Crosby Brook Departure Analysis Summary							
River Segment	Constraints		Transport		Floodplain Sediment and Flow Attenuation (Storage)		
	Vertical	Lateral	Natural	Converted	Natural	Increased	Asset
M01-A	Ledges; Waterfalls (N)	Development; Roads (H)	X				
M01-B		Development; Roads (H)		X	X		future
M02		Development; Roads (H)		X	X		
M03	Ledges (N)	Roads (H)		partially	X	X	X
M04	Ledges; Beaver Activity (N)	Roads (H)			X		X
M05					X		X
M06-A				partially	X		X
M06-B	Ledge (N)	Roads (H)	X				
M06-C		Development (H)			X		X
T1.01		Development; Roads (H)		X	X		
T1.02-A	Waterfall (N)	Roads (H)		X	X		future
T1.02-B	Ledges (N)	Roads (H)	X				
T1.02-C	Ledges; Waterfalls (N)		X				
T1.02-D		Development (H)			X		future
T1.02-E	Ledges (N)		X				
T1.03		Berms (H)		partially	X		future

N = Natural
H = Human Constructed
“future” indicates a segment with potential for sediment attenuation if corridor is managed sustainably.
“partially” indicates a portion of the segment has been converted to a transport reach.

Table 4 summarizes both the departure of sediment regime conditions based on the transport and storage capacity, as well as the constraints to the connectivity of the adjustment processes along the channel network, and the redevelopment of equilibrium conditions in the reach. The summary of transport regimes (transport versus storage) indicates whether the regime is naturally dominated by sediment transport processes, or whether it has been converted to this state due to human constraints (with a resulting attenuation decrease). The flow and sediment attenuation summary indicates where streams have an inherent tendency to store sediment (natural), where sediment deposition is increasing, and whether the reach has potential for future sediment deposition (asset).

Segments that have been converted from depositional regimes to transport regimes include: M01-B, M02, M03, M06-A, T1.01, T1.02-A, T1.02-D and T1.03. Segments M01-B, M02, T1.01, and T1.02-D have had their sediment regimes converted to transport processes through a combination of historic channel straightening, and the encroachment of development on the floodplain that prohibits the natural meandering profile of the channel. Reach T1.03 has been converted to a transport regime due to channel straightening and deepening that has persisted over time. Reach M03 has been impacted by the historic migration of a headcut upstream along the channel from the I-91 crossing, and from the excess sediment loading from the gully.

3.6 Stream 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, 2007).

> 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).

The methods outlined in the Corridor Planning Guide have been used to describe the stream sensitivities of the studied segments of Crosby Brook. Using the stream geometry and substrate data (Rosgen, 1994; see supporting materials in Appendix C) and overall geomorphic stability (RGA score) as determined during the Phase 2 surveys, stream sensitivity ratings have been assigned to each segment. In addition, the active adjustment processes described during the field effort have been summarized. An adjustment process was considered "active" if it received a score in the fair to poor range during the RGA scoring process. Figure 9 summarizes the current stream sensitivities and adjustment processes for the Crosby Brook watershed.

Due to the inherent propensity of meandering sand and gravel bed channels to adjust in response to watershed and reach-scale impacts, 11 out of 16 segments have a stream sensitivity rating of very high or above. Many of the main stem and south branch segments are going through the initial stages of channel evolution (stage II; incision), while some and are beginning to aggrade fine and coarse sediments (stage III). Only one study reach, M05, showed signs of floodplain redevelopment that typically follows a prolonged period of channel incision (stage IV). This reach is likely readjusting to historic impacts from channel straightening, and has redeveloped some floodplain geometry in the absence of intensive agriculture in the stream corridor.

Three reaches have experienced a departure of channel morphology from reference conditions (see Appendix C for further description of the Rosgen classification system), resulting in a stream sensitivity rating of extreme. In addition, two reaches with E-type geometry and a "fair" geomorphic rating have also been rated with an extreme sensitivity. This is due to the inherent sensitivity of sand-bottomed, E-type channels to adjust to human impacts.

> **M02:** Extensive channel straightening (approximately 90% of reach length) from the construction of I-91 and more recent encroachments from commercial development along Route 5 has reduced the channel to a simplified form with no floodplain access and limited habitat diversity. M02 is found in an altered, semi-confined valley setting with a very low entrenchment ratio (ER = 1.5). Channel and floodplain measurements indicated the reach has undergone a stream type departure from C-type geometry with riffle-pool bedform to F-type geometry dominated by plane bed features. There is very limited habitat diversity due to extensive straightening, increase in fine sediments, and limited buffer and corridor protection (RHA condition "Poor"). VTDEC sampling data indicate that the fish and macroinvertebrate communities have been highly impacted, supporting fair to poor conditions. The LWD density for this reach was the lowest for any of the main stem reaches (30 pieces/mile).
>
> **T1.01**: Extensive channel straightening (approximately 50% of reach length) from the construction of I-91 and encroachments along Black Mountain Road has reduced the channel to a simplified form with no floodplain access and limited habitat diversity. Channel and floodplain measurements indicated the reach has undergone a stream type departure from C-type geometry with riffle-pool bedform to F-type geometry dominated by plane bed features. There is very limited habitat diversity due to extensive straightening and limited buffer and corridor protection (RHA condition "Fair"). VTDEC sampling data indicate that the fish and macroinvertebrate communities have not been impacted by the historic impacts to the channel, as good to excellent conditions were noted during two years of

sampling. The LWD density for this reach was average for the south branch reaches (47 pieces/mile).

T1.02-B: Extensive channel encroachment (95% of segment length) from the road bed and berm along Black Mountain Road has reduced the channel to a simplified form with no floodplain access and limited habitat diversity. The channel currently has an unnaturally low entrenchment ratio (ER = 1.3), and a disconnected, human elevated floodplain (IR/HEF = 2.6). Channel and floodplain measurements indicated the reach has undergone a stream type departure from B-type to F-type geometry (Figure 36). Step-pool bed morphology was dominant, but large stretches of channel also exhibited plane bedform. Severe bank erosion is extensive along the right bank, but is limited along the left bank due to road bed armoring.

T1.02-D: This short segment (700 feet) was delineated to describe the change in channel and valley dimensions that occur immediately downstream of the Dickinson Road crossing. At this point the valley widens to an unconfined setting, and the channel slope decreases to approximately 0.5%. The channel dimensions indicate E-type channel geometry with some riffle-pool formation in the upper segment. Minor channel incision was noted in the cross section mid-segment (IR = 1.6). A small terrace is forming along the lower banks that suggests stage II of channel evolution. Due to the incision and lack of a healthy riparian buffer, fair physical stability and habitat was noted (RGA/RHA conditions “Fair”). Due to limited recruitment potential, the LWD density for this segment was well below the average for south branch reaches (16 pieces/mile).

T1.03: This reach is found from a drastic change in valley confinement up to Scott’s Farm on Kipling Road. The very broad valley and low width-to-depth ratio of the channel indicated E-type geometry with dune-ripple bedform. The wide alluvial valley probably formed in conjunction with channel meandering processes over time, however historic channel straightening appears to have relocated the channel in the lower reach along the left valley wall to make way for pasture or hay fields, and now athletic fields. A cross section taken in the lower reach indicates good floodplain connectivity with minor channel incision (IR=1.3; Figure 44). A berm follows the left bank within 20 to 25 feet of channel for much of lower and middle reach. This berm may have been part of old farm road, and does not severely disconnect channel from floodplain, since a majority of floodplain width is on the right bank. The channel stability and floodplain connectivity was fair, with some evidence of incision in lower reach (RGA condition “Fair”, CEM stage II). The LWD density for this reach was very low due to the lack of a healthy riparian buffer on the right bank and limited recruitment potential (18 pieces/mile).

Table 5. Watershed and Reach-scale Stressors Impacting Equilibrium Conditions				
Stream Segment (CEM;RGA†)	**Regime Stressors**		**Reach-Scale Stressors**	
	Hydrologic	**Sediment**	**Stream Power**	**Boundary Resistance**
M01-A (I;Fair)	*Increased Flows* • Very high local and upslope TIA* • Major stormwater inputs in upstream, incised reaches	*Increased Load* • Moderate increase in fine deposition (without increase in bar features) affecting biological habitat	*Increase* • Major stormwater inputs in upstream, incised reaches • High corridor encroachment and development	*Increase* • Multiple grade controls in reach *Decrease* • Reduced riparian vegetation
M01-B (II;Fair)	*Increased Flows* • Very high local and upslope TIA* • Extreme stormwater inputs within reach and upslope	*Increased Load* • Multiple mass failures • Limited sediment loading due to moderate bank armoring	*Increase* • Extreme stormwater inputs within reach • High corridor encroachment • High channel straightening	*Increase* • Mod. Bank Armoring (5-20%) *Decrease* • Highly reduced riparian vegetation • High erodibility potential of bed/bank substrate**
M02 (II;Poor)	*Increased Flows* • Very High local and upslope TIA* • Extreme stormwater inputs within reach • Moderate local wetland loss	*Increased Load* • Multiple mass failures • Abundant depositional and channel migration features • Mod. bank erosion (5-20%) • Large gully in upstream reach	*Increase* • Extreme stormwater inputs within reach • High corridor encroachment and development • High channel straightening *Decrease* • Abundant depositional and migration features	*Decrease* • Reduced riparian vegetation • Mod. bank erosion (5-20%)
M03 (III, Fair)	*Increased Flows* • High local TIA* • Moderate local wetland loss	*Increased Load* • Multiple mass failures • Abundant depositional and channel migration features • Mod. bank erosion (5-20%) • Large gully entering reach	*Increase* • Minor corridor encroachment • Moderate channel straightening *Decrease* • Abundant depositional and migration features	*Increase* • Multiple grade controls in reach *Decrease* • Highly reduced riparian vegetation
M04 (I;Good)	*Increased Flows* • Increased local and upslope TIA* • Moderate local wetland loss	*Increased Load* • Abundant depositional features • Channel migration features present • Limited sediment loading due to moderate bank armoring	*Increase* • High corridor encroachment • High channel straightening *Decrease* • Abundant depositional and migration features • Beaver activity (historic)	*Increase* • Multiple grade controls • Mod. Bank Armoring (5-20%) *Decrease* • Highly reduced riparian vegetation
M05 (IV;Good)	*Increased Flows* • Increased local TIA* • High local wetland loss	*Increased Load* • High local and upslope agricultural land uses • Mass failure present	*Increase* • High channel straightening *Decrease* • Abundant depositional features	*Decrease* • Highly reduced riparian vegetation • Mod. bank erosion (5-20%)

Table 5. Watershed and Reach-scale Stressors Impacting Equilibrium Conditions

Stream Segment (CEM;RGA†)	Regime Stressors		Reach-Scale Stressors	
	Hydrologic	Sediment	Stream Power	Boundary Resistance
		• Abundant depositional features • Mod. bank erosion (5-20%) • Large gully entering reach		
M06-A (II;Fair)	*No Significant Increase or Decrease in flows*	*Increased Load* • Moderate local and upslope agricultural land uses • Mass failure present *Decreased Load* • Dredging noted in reach	*Increase* • Moderate channel straightening • Dredging noted in reach	*Increase* • Mod. Bank Armoring (5-20%)
M06-B (II;Good)	*Increased Flows* • Moderate stormwater inputs within reach	*Increased Load* • Moderate local and upslope agricultural land uses • Moderate depositional features • Channel migration features present	*Increase* • Moderate stormwater inputs • High corridor encroachment *Decrease* • Depositional and migrational features present	*Increase* • Grade control in reach
M06-C (I;Good)	*No Significant Increase or Decrease in flows*	*Increased Load* • Moderate local and upslope agricultural land uses • Abundant depositional features • Channel migration features present	*Increase* • Minor corridor development • Moderate channel straightening *Decrease* • Abundant depositional and migration features	*No Significant Increase or Decrease in Boundary Resistance*
T1.01 (II;Fair)	*Increased Flows* • High local and upslope TIA* • Very high stormwater inputs	*Increased Load* • Moderate local and high upslope agricultural land uses • Mass failure present • Abundant depositional features • Mod. bank erosion (5-20%)	*Increase* • Very high channel straightening • Very high stormwater increases • High corridor encroachment *Decrease* • Abundant depositional features	*Increase* • Mod. Bank Armoring (5-20%) *Decrease* • Highly reduced riparian vegetation
T1.02-A (II;Fair)	*Increased Flows* • High local and upslope TIA* • Very high stormwater inputs • Moderate upslope wetland loss	*Increased Load* • Moderate local and high upslope agricultural land uses • Multiple large mass failures • Abundant depositional and channel migration features • High bank erosion (>20%)	*Increase* • High channel straightening • Moderate corridor encroachment • Very high stormwater increases • Head cuts present *Decrease* • Abundant depositional features	*Decrease* • High bank erosion (>20%) *Increase* • Grade control in reach
T1.02-B (II;Poor)	*Increased Flows* • High local and upslope TIA*	*Increased Load* • Moderate local and high upslope agricultural land uses	*Increase* • High channel straightening	*Decrease* • Mod. bank erosion (5-20%)

Table 5. Watershed and Reach-scale Stressors Impacting Equilibrium Conditions				
Stream Segment (CEM;RGA†)	**Regime Stressors**		**Reach-Scale Stressors**	
	Hydrologic	**Sediment**	**Stream Power**	**Boundary Resistance**
	• Very high stormwater inputs • Moderate upslope wetland loss	• Multiple mass failures • Moderate depositional features • Mod. bank erosion (5-20%)	• High corridor encroachment • Very high stormwater increases *Decrease* • Moderate depositional features	• Highly reduced riparian vegetation *Increase* • Grade controls in reach • Mod. Bank Armoring (5-20%)
T1.02-C (I;Reference)	*Increased Flows* • Mod. local and upslope TIA* • Moderate upslope wetland loss	*Increased Load* • Moderate local and high upslope agricultural land uses • Abundant depositional features	*Increase* • Minor corridor development	*Increase* • Grade controls in reach
T1.02-D (II;Fair)	*Increased Flows* • Mod. local and upslope TIA* • High upslope and moderate local wetland loss • Increased stormwater inputs	*Increased Load* • Moderate local and high upslope agricultural land uses	*Increase* • Minor stormwater increases • High corridor encroachment • High channel straightening	*Decrease* • Highly reduced riparian vegetation • High erodibility potential of bed/bank substrate**
T1.02-E (II;Fair)	*Increased Flows* • Mod. local TIA* • High upslope and moderate local wetland loss	*Increased Load* • Moderate local and high upslope agricultural land uses • Moderate depositional features	*Decrease* • Moderate depositional features	*Increase* • Grade controls in reach
T1.03 (II;Fair)	*Increased Flows* • Very high local wetland loss	*Increased Load* • High local and upslope agricultural land uses	*I Increase* • Berm adjacent channel in lower reach (high impact) • Moderate corridor development • High channel straightening	*Decrease* • Highly reduced riparian vegetation • High erodibility potential of bed/bank substrate**

*Total Impervious Area
** Reaches with high erodibility potential having fine bed substrate and limited bank cohesiveness (e.g., sands)
Note: local scale for wetland loss and road density/TIA includes the corridor and the adjacent subwatersheds draining directly to the reach
† Channel evolution stage (F model for all reaches) and Rapid Geomorphic Assessment categorical score

4.0 Preliminary Project Identification

4.1 Watershed Level Opportunities

4.1.1 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 funneling sediment and runoff directly to streams. Sediment from roads and driveways can be addressed with improved ditches, 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.

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

- Requiring stormwater controls for development projects which are not large enough in scale to fall under state regulatory permits (less than 1 acre impervious cover), but likely have a measurable impact on adjacent waterbodies.
- Incorporating more rigorous requirements for stormwater control of new development in headwaters areas. Recent 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.

4.1.2 Fluvial Erosion Hazard Zones

Most lowland Vermont communities such as Brattleboro have faced significant property losses and risks to public safety during past flood events. While inundation-related flood loss is a significant component of flood disasters, the predominant mode of damage during floods is associated with fluvial erosion. Fluvial erosion hazards have been increased and exacerbated by historical channel management practices in Vermont such as channel straightening, berming, and floodplain encroachment. In small, urbanizing watersheds such as Crosby Brook, watershed scale modifications to the hydrologic regime due to increases in impervious cover have further energized the erosion potential of the stream.

FEH corridors were developed for the Crosby Brook reaches where Phase 2 data was collected. FEH corridors represent the estimated area surrounding the channel needed to accommodate fluvial geomorphic equilibrium conditions. Using the FEH corridor, we analyzed the implications of an FEH Overlay District within the towns of Brattleboro and Dummerston. The purpose of this analysis was to provide a summary of the built and natural capital within the corridor, and highlight opportunities for corridor protection. The analysis also assessed the towns' planning and zoning districts in the context of development patterns and other protected parcels within the corridor (e.g., town-owned parcels and conserved lands). The complete results of the FEH analysis, including corridor maps (Figures 10 and 11), are provided in Appendix B.

Towns can reduce future flood recovery and infrastructure maintenance costs and increase public safety by limiting development in areas adjacent to rivers with a high potential for vertical and lateral adjustment. These reaches, which are given elevated ratings of "Very High" or "Extreme", are high priority reaches for protection, especially when there is little existing protection afforded by wetlands or conservation easements. Reaches or segments with elevated ratings and limited protected lands in the corridor have the highest risk for future conflicts, and include: M01-B, M06-A, T1.01, T1.02-A, T1.02-B, and T1.02-D.

4.2.3 Stream Crossings

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

Summary data for all structures in the watershed, including bridges, was included in the Phase 2 Summary (FEA, 2008). In order to make use of the VTANR culvert screening tools for structure prioritization, Table 6 summarizes data collected for 10 culverts in the Crosby Brook watershed. The final column of the table includes a prioritization of structures for replacement or retrofit based on a review of the following three criteria: structure width in relation to bankfull channel width; aquatic organism passage; geomorphic compatibility. Four (4) culverts have been assigned a high priority for replacement or retrofit. Photographs of each high priority structure are provided below. Additional information about the recommended actions to address problematic structures is provided in Table 7.

Table 6. Priority Rankings for Crosby Brook Culverts

Reach/ Segment	Road Name	Condition/ Observation	Percent Bankfull Channel Width[1]	Aquatic Organism Passage[2]	Geomorphic Compatibility[3]	Relative Priority for Replacement or Retrofit
M03	Ryan Road	Minor failing of bank armoring on downstream end; Lack of vegetated buffer downstream	29%	None	Mostly incompatible	**High**
M04	Middle Road	Culvert height is 7.0 ft. but due to aggraded material in structure clearance is only 4.3 ft	33%	Full	Partially compatible	Low
M06-A	Middle Road	Minor bank erosion downstream of structure; Road well armored and erosion not yet problematic	44%	None	Mostly incompatible	**High**
M06-B	Houghton Road	Minor failing of armoring on downstream end; Erosion not yet problematic	56%	Reduced	Partially compatible	Low
M06-C	Houghton Road	Scour and deposition on the left bank downstream; minor channel incision.	36%	Reduced	Mostly compatible	Low
T1.01	I-91 North	High degree of bank erosion on right bank downstream of structure.	24%	Reduced	Mostly incompatible	Moderate
T1.01	Black Mountain Road	High degree of bank erosion on right bank downstream of structure.	65%	None	Mostly incompatible	**High**
T1.02-B	Black Mountain Road	Minor scour at upstream end on left bank, but nearby grade controls limit vertical adjustments.	40%	Reduced	Partially compatible	Low
T1.02-D	Dickinson Road	Town officials note that culvert is undersized and headwall is failing on upstream end.	33%	None	Partially compatible	**High**
T1.03	NA (Trail)	Severe bank erosion on downstream end of culvert due to limited boundary resistance	43%	Reduced	Mostly compatible	Moderate

[1] Shaded for bankfull width percentage less than 50% ; [2] Aquatic Organisms Passage ratings developed with the VTANR methodology (not applicable to bridges); [3] Scores and ratings developed with the VTANR Geomorphic Compatibility Screening Tool

Ryan Road crossing (Reach M03). Perched downstream end (left) and inlet (right).

Upper Middle Road crossing (Segment M06-A).
Upstream end (left) and lack of riparian buffer downstream (right).

Black Mountain Road crossing (Reach T1.01).
Perched outlet (left) and headwall at inlet (right).

Dickinson Road crossing (Segment T1.02-D).
Downstream end (left) and road runoff into upstream end (right).

4.2 Site Level Project Opportunities

4.2.1 Considerations for Active Channel Restoration Projects

Much research in the field of urban stream geomorphology has been carried out in the Pacific Northwest in recent years, in settings with land use pressures similar to those in the Crosby Brook watershed. The clear strategy advocated as a result of these studies is the restoration of the hydrologic regime **prior** to "active" restoration of stream channel forms and habitats (Booth et al., 2002; Booth, 2005). From these studies, it is also clear that the failure to work towards restoration of the hydrologic regime will lead to watershed conditions which may preclude stream ecosystem recovery (e.g., lack of controls on increased impervious cover, failure to implement best management practices). The VTDEC strategy for restoration in the other stormwater impaired watersheds in Chittenden County accounts for this knowledge, as outlined in the VTDEC TMDL approach (VTDEC, 2006). A similar sequencing of restoration actions is recommended for the Crosby Brook watershed.

The restoration projects summarized in the following section have accounted for the stated goal of the VTANR TMDL approach to watershed-scale restoration. This approach considers the altered hydrologic regime as a key factor influencing hydraulic geometry and stream power, and thus the physical habitat that supports aquatic biota (VTDEC, 2006). Certain active channel restoration projects, such as natural channel design, are generally discouraged in the short term due to the recognition that watershed-scale restoration of the hydrologic regime is likely to occur over a long-term period (greater than 10 years). However, other active restoration projects that will aid in the reduction of sediment loading and/or the reestablishment of channel equilibrium conditions regardless of the timing of watershed-scale restoration (e.g., berm removal, culvert replacement, floodplain restoration, etc.) are summarized and prioritized accordingly.

4.2.2 Project Descriptions and Priorities

The site level projects developed for the Crosby Brook watershed are provided below in Table 7. The project strategy, technical feasibility, and priority for each project are listed by project number and reach. A total of 19 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 project strategy, technical feasibility, and priority based on scientific data and stakeholder input. The project locations and categories identified for the Crosby Brook watershed are depicted below in Figure 12. The 19 projects are further broken down by category as follows: 9 active geomorphic restoration; 10 passive geomorphic restoration. The three highest priority projects selected by the project partners for further development are described in further detail in Section 5.

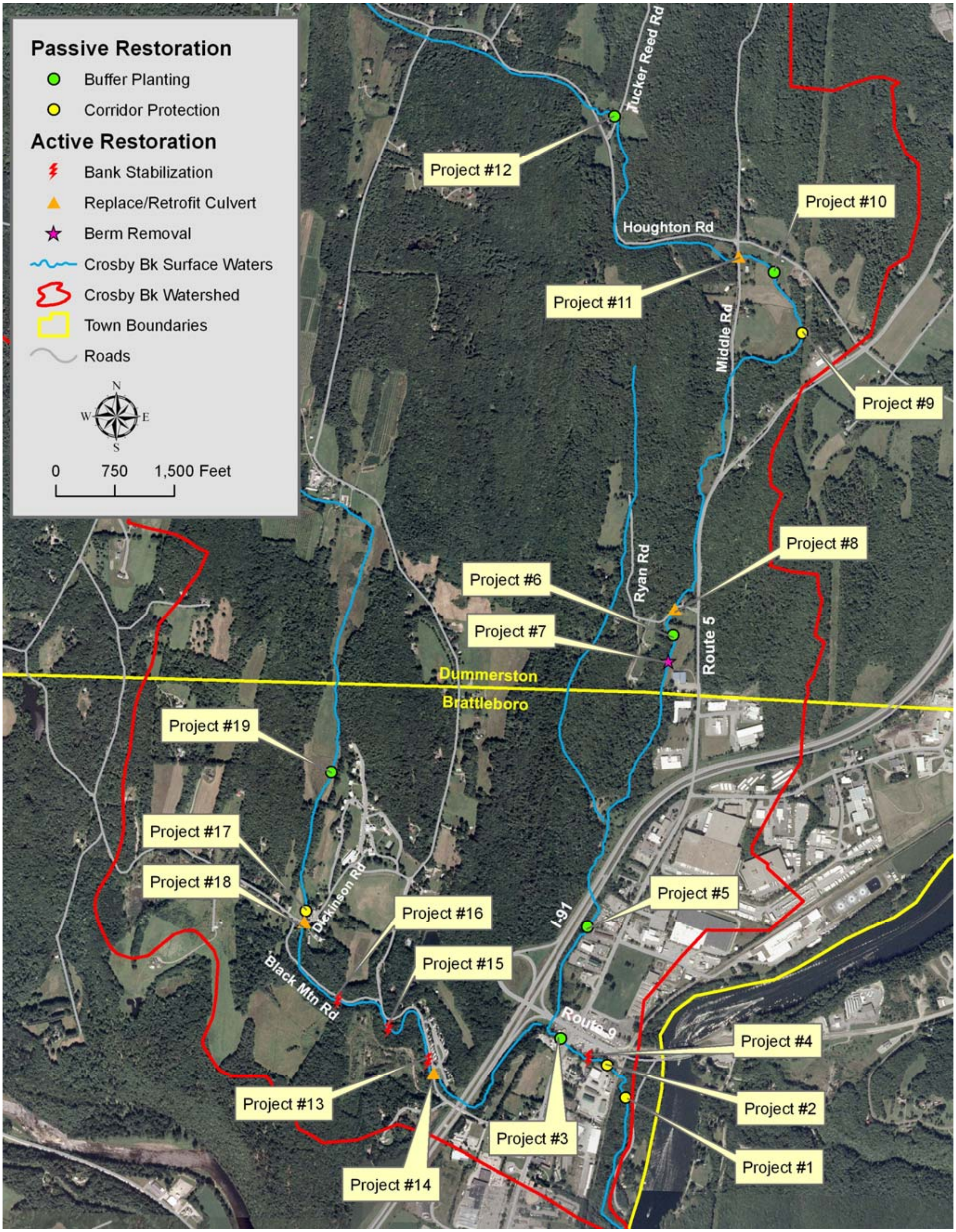


Figure 12. Project Location Map

Table 7. Crosby Brook Watershed Project Descriptions and Prioritization					
Project #, Reach, Stream Type, CEM†, RGA/RHA†	**Site Description and Importance, Including Stressors and Constraints**	**Project Type and Strategy**	**Priority, Technical Feasibility & Relative Costs**	**Other Social Benefits**	**Potential Partners**
#1 M01-A, A, I, Good/Good	Reach is vertically stable due to bedrock controls. Increased sedimentation from upstream sources has degraded biological habitat. Upper segment has short section of channel with hilly side slopes (~5%) that could be marginally suitable for corridor development.	**Passive Restoration** Develop conservation easement for parcels on left bank in upper segment where adjacent land could be suitable for future development.	**Moderate priority** Reach has good riparian buffer and undeveloped corridor. Feasibility depends on land ownership (two parcels within left corridor). Relatively high costs due to proximity to river and high land values.	Allowing for fine deposition to occur will further protect water quality in the Connecticut River. Wildlife habitat conservation is additional benefit.	Town of Brattleboro; VLT; VTDEC
#2 M01-B, C, II, Fair/Fair	Encroachment from railroad in lower segment, and development in middle and upper segment. Narrow floodplain not filled by adjacent development is not accessible to channel (incision ratio =1.5). High degree of sedimentation of fines, and poor riparian buffer. Adjacent parking lots are a direct source of fine sediment in summer (runoff) and in winter due to snow removal.	**Passive Restoration** Plant stream buffer in 2 areas of segment: 1) lower segment above railroad bridge where banks lack woody vegetation and there are numerous bank failures; 2) upper segment above Route 5 crossing adjacent gas station and bus station.	**High priority** Channel is currently incising and vertical adjustments are likely to continue over next 10-20 years. Higher priority in upper segment where vertical controls from road crossings have limited bank failures. Relatively low cost for native plant materials and labor.	Improved biotic habitat and increased shading. Reduced erosion risks, especially in lower reach upstream of railroad bridge.	WCNRCD; VYCC; Town of Brattleboro; Landowner
#3 M01-B, C, II, Fair/Fair	See above general segment description. Lower part of segment corridor from railroad bridge up to Bickford's restaurant is partially undeveloped. Numerous mass failures noted in this section indicating lateral channel adjustments.	**Passive Restoration** Protect stream corridor (3) in lower segment to allow channel to maintain and redevelop meandering profile.	**Moderate priority** FEH corridor implementation could address this site. Relatively high costs due to high land values in commercial district.	Allowing for fine deposition to occur will further protect water quality in the Connecticut River and downstream reach with degraded habitat.	WCNRCD; Town of Brattleboro; Landowner
#4 M01-B, C, II, Fair/Fair	See above general segment description. Lower part of segment from railroad bridge up to Bickford's restaurant has numerous large failing banks.	**Active Restoration** Stabilize stream banks in lower and middle part of segment. Use soft engineering (e.g., wood revetments) to stabilize banks.	**High priority** Further investigation of banks and properties beyond eroding banks needed to assess technical feasibility. Costs for stabilization could be moderate to high depending on scope.	Reduced sediment supply from ongoing bank erosion, and potential to improve biological habitat within segment and downstream.	WCNRCD; VYCC; Town of Brattleboro; Landowner

Table 7. Crosby Brook Watershed Project Descriptions and Prioritization

Project #, Reach, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project Type and Strategy	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
#5 M02, F, II, Poor/Poor	Approx. 90% of reach affected by channel straightening from construction of I-91 in the 1950's. Corridor encroachment and floodplain filling has caused a stream type departure. Despite higher channel slope, sediment supply from upslope gully (in M03) is exceeding transport capacity. High degree of sedimentation observed in reach.	**Passive Restoration** Plant stream buffer in 2 areas of segment: 1) mid-reach immediately downstream of I-91 crossing behind car dealership; 2) at sharp bend ~500 feet downstream of I-91 crossing behind Motel 6. Discourage mowing and snow removal within riparian buffer at both sites.	**High priority** Bank erosion is occurring, especially at lower site behind Motel 6. Behind car dealership, riparian buffer is used for depositing snow from plowed lot and is a source of sediment to channel in spring. Relatively low cost for native plant materials and labor.	Improved biotic habitat and increased shading. Reduced erosion risks, especially in vicinity of Motel 6.	WCNRCD; VYCC; Town of Brattleboro; Landowner
#6 M03, C, III, Fair/Fair	Upper section of reach has limited riparian buffer along the left bank where a historical hay/pasture area is now meadow.	**Passive Restoration** Plant stream buffer along left bank for ~600 ft to encourage long-term restoration of upper reach as it regains equilibrium conditions.	**Moderate priority** Single parcel for site. Planting should be completed in conjunction with corridor protection. Relatively low cost for native plant materials and labor.	Improved biotic habitat through increased shading and input of coarse woody debris and organic matter.	WCNRCD; VYCC; Town of Dummerston
#7 M03, C, III, Fair/Fair	See above for general reach description. Upper section of reach has limited floodplain access due to a berm that extends ~350 ft along the left bank. Additional armoring and channel incision noted along berm.	**Active Restoration** Remove berm to increase floodplain access along left bank where no development exists currently. Enhance adjacent floodplain wetlands.	**Low priority** Done in conjunction with the corridor protection and riparian buffer plantings noted above. Feasibility depends on landowner willingness (1 parcel). Relatively high costs due to excavation work and design fees.	Further protection of water quality in downstream reaches. Wildlife habitat conservation and restoration additional benefit with enhanced wetlands.	WCNRCD; VTDEC
#8 M03, C, III, Fair/Fair	See above for general reach description. Ryan Road culvert is not compatible with geomorphic stability and has no aquatic organism passage. Crossing creates a discontinuity in habitat from upstream to downstream reaches.	**Active Restoration** Replace structure with adequately-sized culvert or bridge that accommodates 100% of bankfull channel width (24 ft).	**High priority** If restoration of native trout fishery is a restoration goal. Relatively high costs due to change in channel slope at structure. Alternative could be construction of weirs at outlet to improve fish passage.	Improved biotic habitat and enhancement of trout fishery in upper reaches.	WCNRCD; Town of Dummerston

Table 7. Crosby Brook Watershed Project Descriptions and Prioritization

Project #, Reach, Stream Type, CEM†, RGA/RHA†	Site Description and Importance, Including Stressors and Constraints	Project Type and Strategy	Priority, Technical Feasibility & Relative Costs	Other Social Benefits	Potential Partners
#9 M05, C, IV, Good/Fair	Channel historically straightened against valley wall. Some evidence of terraces noted in middle and upper reach. Channel has redeveloped some sinuosity in lower and middle reach. Large gully and mass failure present along left bank mid-reach.	**Passive Restoration** Corridor protection through conservation easements. Corridor is currently undeveloped and adjusting towards equilibrium conditions.	**Low priority** Important sediment attenuation asset reach. High loss of local wetlands. Three parcels occupy the corridor. Relatively high costs for conservation due to productive agricultural lands.	Further protection of water quality in downstream reaches. Wildlife habitat conservation an additional benefit.	WCNRCD; Town of Dummerston; Landowner
#10 M05, C, IV, Good/Fair	See above for general reach description. Upper and lower sections of reach has limited riparian buffer where a historical hay/pasture area is now meadow. Planting area spans three (3) parcels.	**Passive Restoration** Plant stream buffer in 2 areas of reach: 1) along right bank for ~100 ft in lower reach just above reach break where bank erosion is occurring. 2) along both banks for ~600ft in upper reach from Middle Rd crossing downstream.	**Moderate priority** Long stretches of stream without cover that likely leads to increased stream temperatures. Relatively low cost for native plant materials and labor.	Improved biotic habitat through increased shading and input of coarse woody debris and organic matter.	WCNRCD; VYCC; Landowner
#11 M06-A, C, II, Fair/Good	See above general segment description. Culvert beneath Middle Road in lower reach is incompatible with geomorphic stability and has no aquatic organism passage.	**Active Restoration** Replace structure with adequately-sized culvert or bridge that accommodates 100% of bankfull channel width (24 ft).	**Moderate priority** If restoration of native trout fishery is a restoration goal. Relatively high costs due to change in channel slope at structure. Alternative could be construction of weirs at outlet to improve fish passage.	Improved biotic habitat and enhancement of trout fishery in upper reaches.	WCNRCD; Town of Dummerston
#12 M06-C, C, I, Good/Good	Immediately upstream of the Tucker Reed Road crossing are direct channel impacts associated with a residence on the right bank. Lack of woody buffer vegetation is causing bank erosion on the right bank.	**Passive Restoration** Plant riparian buffer on right bank upstream of Tucker Reed Road.	**Moderate priority** Achievable buffer planting due to relatively low costs for implementation.	Improved biotic habitat through increased shading and input of coarse woody debris and organic matter.	VYCC

Table 7. Crosby Brook Watershed Project Descriptions and Prioritization					
Project #, Reach, Stream Type, CEM†, RGA/RHA†	**Site Description and Importance, Including Stressors and Constraints**	**Project Type and Strategy**	**Priority, Technical Feasibility & Relative Costs**	**Other Social Benefits**	**Potential Partners**
#13 T1.01, F, II, Fair/Fair	Floodplain filled by road berms and beds, constricting channel and reducing meander development. Riffle-pool features replaced by plane bedform through ~70% of the reach. Approx. 260 feet of eroding bank on left side within 5-10 feet of Black Mountain Road.	**Active Restoration** Stabilize banks along road using a combination of hard and soft engineering techniques: wood and rock revetments in conjunction with willow plantings. Vigorous, low growing woody species (e.g., willows) recommended for compatibility with road maintenance.	**High priority** Due to threatened integrity of the road. Moderate to high costs associated with materials and labor. Do nothing alternative would lead to higher long term costs if road failed due to ongoing channel adjustments.	Reduced sediment supply to downstream impaired reaches from ongoing bank erosion. Improved biotic habitat through increased shading and input of coarse woody debris and organic matter.	WCNRCD; Town of Brattleboro
#14 T1.01, F, II, Fair/Fair	See above general segment description. Culvert beneath Black Mountain Road is incompatible with geomorphic stability and has no aquatic organism passage.	**Active Restoration** Replace structure with adequately-sized culvert or bridge that accommodates 100% of bankfull channel width (17 ft), or at least 75% of width (13 ft).	**Moderate priority** Relatively high costs due to excavation work in tight setting, and design fees. Alternative improvement could be construction of weirs at outlet to improve fish passage alone.	Improved biotic habitat and enhancement of trout fishery in upper reaches.	WCNRCD; Town of Brattleboro
#15 T1.02-A, C, II, Fair/Fair	One nick point noted in the lower reach causing a disconnect between the channel and floodplain. One cross section in the lower segment below the nickpiont revealed severe incision (IR = 1.9); another above the nickpiont indicated only minor incision (IR = 1.1).	**Active Restoration** Conduct Phase 3 survey at site to determine degree of departure. Potentially use combination of hard and soft controls (i.e., wood and rock) to create grade controls.	**High priority** Due to important sediment attenuation asset. High costs due to design fees and labor/materials. Cost of no action could lead to increased incision in upper segment, exacerbating the slope failures. Hydraulic analysis should determine whether grade controls will increase aggradation and lateral adjustments in upper segment near the mass failure.	Allowing for fine deposition to occur in this segment will aid in mitigating degradation of biological habitat in downstream reaches near mouth.	WCNRCD; Town of Brattleboro; VTDEC; VTRANS

Table 7. Crosby Brook Watershed Project Descriptions and Prioritization					
Project #, Reach, Stream Type, CEM†, RGA/RHA†	**Site Description and Importance, Including Stressors and Constraints**	**Project Type and Strategy**	**Priority, Technical Feasibility & Relative Costs**	**Other Social Benefits**	**Potential Partners**
#16 T1.02-B, F, II, Poor/Fair	Historically channel had a small floodplain along the left bank within the semi-confined valley. Currently the lack of floodplain is causing excess stream power during runoff events, resulting in bank failure along right bank. Many new slope failures observed in 2008 (new since fall 07). Left bank armoring along road is mostly intact.	**Active Restoration** Develop long-term management plant to restore incised reach through the decommissioning of Black Mountain Road. Ongoing bank erosion on right bank will worsen over time unless historical floodplain is at least partially restored along the left bank.	**Moderate priority** Mitigation needed over long term due to increased fine sediment (e.g., clays and silts) from right bank failures. Project not feasible in short-term due to road constraints and landowner access, but should be considered in the long term.	Large reduction in sediment loading to downstream reaches and improved trout fishery. Potential for creating a conserved park where fishery could be restored for recreation close to Brattleboro.	Town of Brattleboro; VTDEC
#17 T1.02-D, E, II, Fair/Fair	Channel geometry indicates E-type channel geometry with some riffle-pool formation in the upper segment. A small terrace is forming along the lower banks that suggests stage II of channel evolution. Lack of a healthy riparian buffer, limited recruitment potential, low LWD density.	**Passive Restoration** Protect stream corridor in area upstream of Dickinson Road crossing along right bank. This area of floodplain is flat and may be suitable for development. Plant stream buffer with native woody vegetation	**Low priority** Due to depositional reach. Development of corridor may be unlikely under current owner. Relative costs of conservation possibly moderate to high due to high land value.	Allowing for fine deposition to occur in this segment will aid in mitigating degradation of biological habitat in downstream reaches near mouth.	WCNRCD; Town of Brattleboro; VTDEC; WLC
#18 T1.02-D, E, II, Fair/Fair	See above general segment description. Culvert beneath Dickinson is incompatible with geomorphic stability and has no aquatic organism passage, except for salmonids.	**Active Restoration** Replace structure with adequately-sized culvert that accommodates 100% of bankfull channel width (9 ft).	**High priority** Due to limited current channel adjustments upslope, and hydraulic constriction that may increase floodplain connectivity upslope of crossing.	Improved biotic habitat and enhancement of trout fishery in upper reaches.	Town of Brattleboro
#19 T1.03, E, II, Fair/Fair	Lower end of segment lacks native woody buffer along athletic fields. Some bank erosion mid-reach is attributable to reduced boundary resistance from lack of vegetation.	**Passive Restoration** Plant stream buffer with native woody vegetation in lower and middle reach where buffer would not interfere with fields.	**Moderate priority** Due to long stretch of channel without canopy cover, leading to increased stream temperatures in downstream reaches during summer months.	Improved aesthetics of stream channel along recreation fields.	WLC; WCNRCD; VYCC

† Channel evolution stage, Rapid Geomorphic Assessment, and Rapid Habitat Assessment Scores.

5.0 Project Development

The corridor planning partners reviewed and commented on the list of preliminary projects following a watershed tour in October, 2008. The corridor planning team included Jolene Hamilton (WCNRCD), Shannon Pytlik (VTDEC), Rod Francis (Town of Brattleboro), and John Bennett (WRC). Three projects from the initial list of 30 total projects were chosen for further development. Project summaries are included below for the three projects. Each summary includes:

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

5.1 Segment T1.02-A: Black Mountain Road Site

Reach Location and Condition

This segment was delineated to capture the short, unconfined section of channel associated with the large mass failure along Black Mountain Road (Figure 13). It is found from the sharp bend in the channel along Black Mountain Road up to 200 feet south of the intersection with Kipling Road (Figure 14). The segment is 0.2 miles long (1,000 feet), and the field measured channel slope was 2.2%. One nickpoint was noted in the lower reach that may have caused a disconnect between the channel and floodplain in the lower segment. Two channel cross sections were measured to better understand the variability in channel incision within the segment. One cross section in the lower segment below the nickpoint revealed an incised channel morphology (IR = 1.9), while another above the nickpoint indicated only minor incision (IR = 1.1). The incised section of the segment represents a majority (approximately 70%), and has likely been exacerbating the increased supply of sediment to lower reaches from the mass failure and other bank failures.

Figure 13. Large mass failure in upper segment.

The large mass failure is found along the right bank, and measures approximately 90 feet in length by 35 feet in height. Based on observations by Brattleboro Town officials, the slope failure has become worse in recent years. A review of historical photography from 1962 suggests that the failure did not exist at that time, and has perhaps developed as a result of increased incision at the site since that time period. Due to the channel incision and adjustment features, this segment is considered highly sensitive to further human impacts (RGA condition “Fair”, CEM stage II). The habitat diversity is compromised by aggradation of fine sediments from the slope failure, and a loss of bed features due to the channel incision (RHA condition “Fair”).

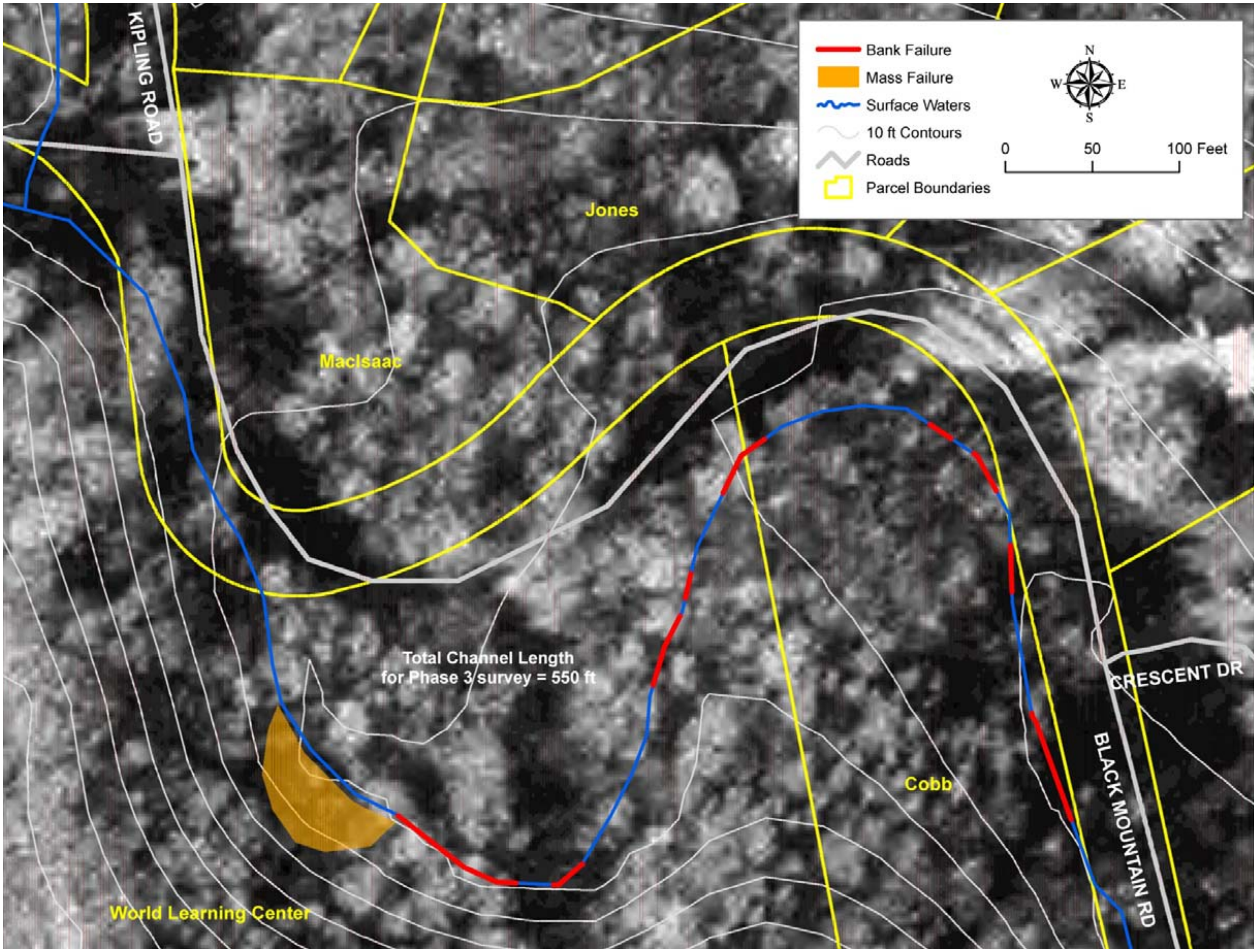


Figure 14. Site location map.

Stressors

1) Channel adjustments: The main stressor from upslope reaches is increased stream power due to loss of floodplain (encroachment) along Black Mountain Road, resulting in low wood densities within this reach, and reduced coarse sediment storage. Unfortunately, any large woody debris (LWD) that has fallen into the stream around the failure has been removed by the Town Department of Public works, further aggravating the issue. Due to the age and vigor of the floodplain forest, and the bank armoring upslope, there are few other sources of wood from the channel boundaries. Following a site visit in October 2008 to further review the nickpoint in the lower segment (Figure 15), it appears that this moderate change in channel slope downstream of the mass failure is not an imminent threat to the upslope mass failure. The nickpoint is not migrating rapidly, and could be monitored before a large effort is made to address it with structural means (e.g., rock weirs). Long term stabilization of this feature may not be necessary at all following a natural channel restoration approach to restore LWD to the channel.

2) Sheer at toe of failure: Ongoing sheer at toe of failure will continue to undercut and aggravate the failure. A combination of “soft” and “hard” armoring could reduce the stress at the toe. An approach using a log deflector in combination with rock rip-rap is one possibility.

1) Top-down slope failure: Due to the steep slope of the valley wall, the failure is now active in a top-down direction. One option to address this (described further below) is the use of root wads with boles anchored into stream bed edge (above the bankfull elevation) would address the long term instability of the slope by mimicking and enhancing the natural process of fallen trees stabilizing the structure-less soil. Future plantings along the slope would add further stability and reduce sediment loading directly to channel.

Figure 15. Nickpoint in lower segment.

Restoration Alternatives

Three alternatives are evaluated below for the Black Mountain Road restoration site. The narratives describe the general approach and landowner constraints. Table 8 summarizes the technical feasibility of each alternative with respect to the overall objectives of the VTDEC approach to watershed restoration.

1) Do Nothing

This approach should be considered given the moderate to high costs associated with corridor protection and channel restoration. Although the mass failure may be a natural process for this setting, the channel incision downstream of the failure is the result of hydrologic and floodplain alterations (described above in stressors section). The mass failure will continue to be a source of fine sediment to the channel over the long-term, and may prevent restoration of the reference biological community despite efforts made by the project partners to address sediment supply at other locations throughout the watershed.

The parcel is currently owned by the World Learning Center (WLC), and the Town is responsible for maintenance of Black Mountain Road. The WLC has expressed interest in the long-term protection of the parcel, possibly through a conservation easement or the sale of the property to an entity such as the Town. The "do nothing" approach may result in ongoing erosion and deposition along the road. The possibility that this erosion along the road could worsen and present ongoing maintenance costs to the Town is worrisome.

2) Stream Corridor Protection

As described above, the parcel owners may be open to the possibility of corridor protection around channel. However, corridor protection is somewhat of a moot issue due to the constraints that would limit any further development or channel management for this segment. The channel is bound to the south by a very steep slope that would limit future development along the right bank. In addition, floodplain and wetland constraints (as well as other Act 250 criteria) would likely prevent development to the north within the small stretch of evenly sloped land in between the channel and Black Mountain Road.

3) Channel Restoration

Given the active nature of the channel and slope adjustments, conceptual designs for the stabilization of the slope have been developed. Initial plans for dealing with the mass failure have been re-evaluated and a new design is proposed. The new conceptual design proposes to address the three adjustment processes outlined in the stressors section above.

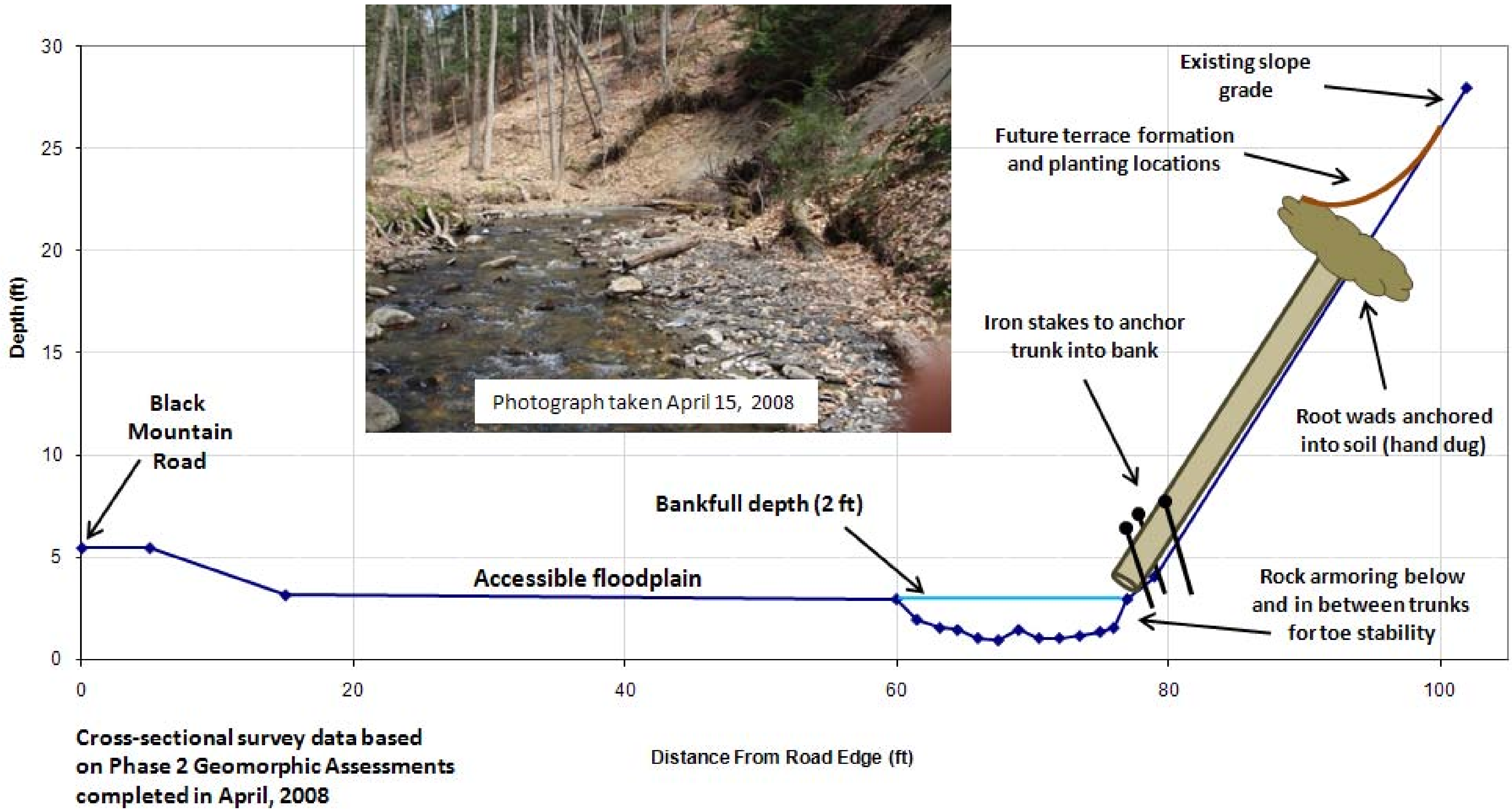


Figure 16. Concept sketch (in cross-section) to address slope failure.

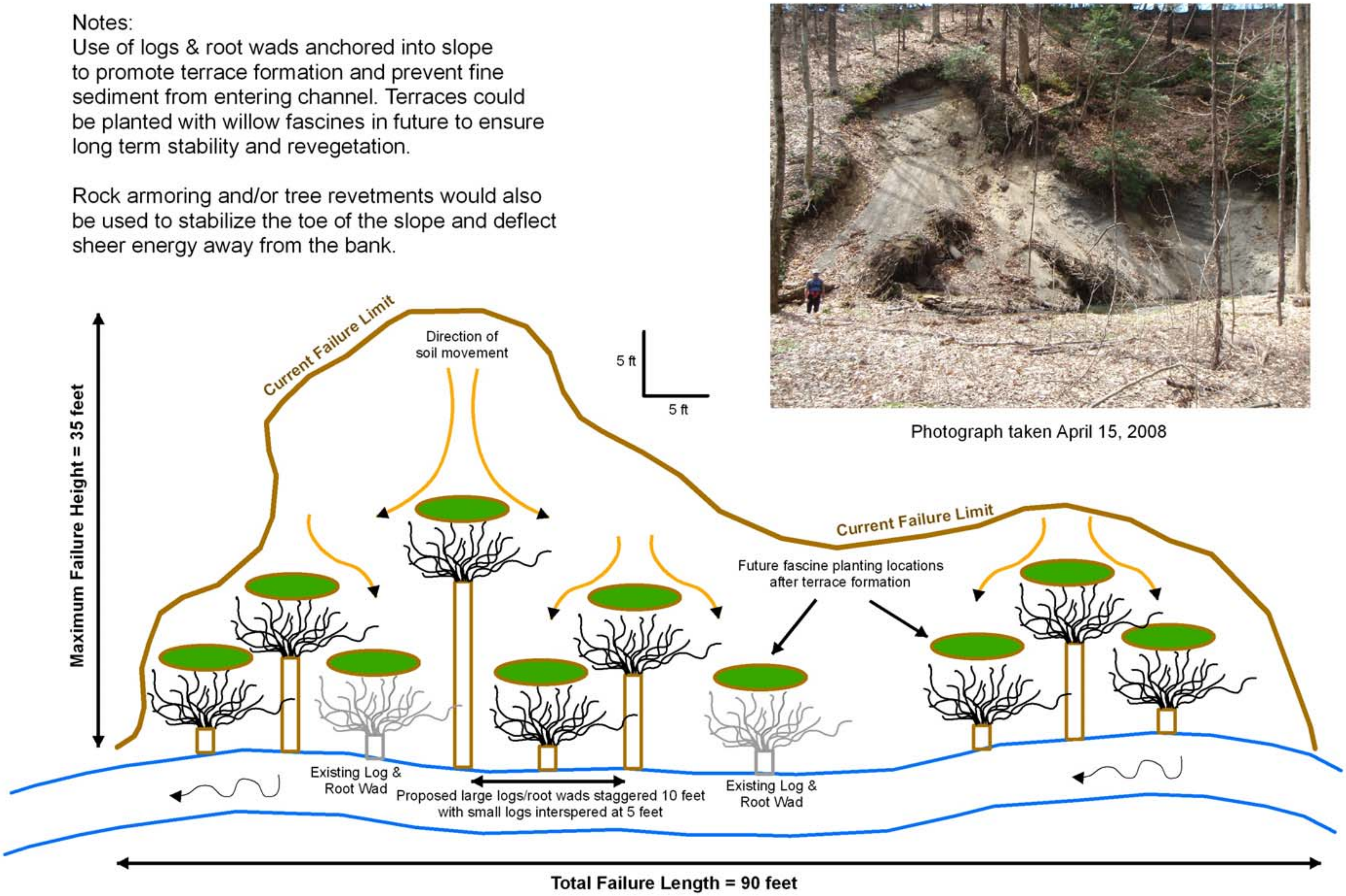


Figure 17. Concept sketch (direct view) to address slope failure

The mass failure, which is being caused by three forces - top-down slope failure, sheer at toe of failure and downstream channel adjustments - will be stabilized with an innovative technique using large tree trunks with rootwads placed on the slope with the cut trunk (top) anchored in the stream bank and the root wad oriented upslope and partially buried in the bank. The root wad will act as a trap for soil falling from above to address the top-down slope failure. These will accumulate into a series of benches that will build up soil and later be planted with fast growing shrubs (e.g., willows) to anchor the soil in place. Trunk tops in the stream will either be held in place with rock or be cabled into the ground (see Figures 16 and 17). The toe of the slope will be stabilized with log deflectors or rock to protect from sheer failure at the toe of the slope. The downstream channel adjustments will be addressed using a series of LWD dams. Sediment from upstream will accumulate behind each structure to promote vertical stability. The stream will then have greater access to the floodplain during high flow events. Floodwaters will spread out over the healthy floodplain, velocity will decrease and sediment will attenuated. This will help mitigate impacts downstream of both excess sediment and stream power.

Table 8. Alternatives Analysis for Segment T1.02-A

Restoration Alternative	Does the project accommodate stream equilibrium conditions?	Does the project result in an overall reduction of sediment/nutrient production from within the river corridor and increase storage of sediment/nutrients?	Could the project fail due to unmitigated constraints and/or future channel adjustments?	Will the project lead to instability in upstream or downstream reaches?
#1 Do Nothing	Perhaps over the very long-term. In the short-term channel adjustments will continue within the reach and downstream.	No. Ongoing channel adjustments will increase sediment and nutrient loading to the channel and downstream reaches, further exacerbating habitat degradation at the watershed-scale.	Not applicable.	No action could lead to instability in the downstream reaches due to excess sediment supply from the slope failure.
#2 Stream Corridor Protection	Over the very long-term, corridor protection is key to equilibrium conditions. However, the short segment is well protected against future development.	See above answer	Corridor protection as a stand-alone strategy could be ineffective due to downstream effects of ongoing channel adjustments.	See above answer.
#3 Channel Restoration	Yes. This approach is aimed at restoring equilibrium conditions with the use of a naturalized design approach to address the 3 processes currently in motion.	Yes. Project will seek to reduce excess sediment loading from the slope failure, and promote storage of sediment within the floodplain using LWD structures.	Upslope urbanization or further loss of floodplain function could reduce stability of slope and/or LWD structures in the channel.	No. The project will promote stability in downstream reaches by reducing excess sediment loading.

Based on input from the project team throughout the project development process, the channel restoration alternative (#3) has been chosen for this site. A VTRANS grant was acquired by the Town of Brattleboro for restoration work associated with the mass failure and road drainage problems on Black Mountain Road upstream of the site.

Funding and Technical Partners

The project partners described in the project development introduction have been involved from the start in this project. Rod Francis from the Town of Brattleboro and Marie Caduto of VTDEC initially applied for and received funding through the VTRANS administered SAFETEA-LU program. Marie Caduto has been responsible for submitting a re-design proposal to VTRANS for the proposed approach described above.

In addition, Shannon Pytlik, Mike Kline, and Chris Brunelle of VTDEC have reviewed the conceptual designs and provided feedback on the technical feasibility of the approach. This feedback was incorporated into the revised conceptual designs, and will be further considered during subsequent design and implementation work.

The Vermont Youth Conservation Corps (VYCC) could also be a potential partner in the construction work. Marie Caduto is exploring the possibility of hiring a VYCC crew for the 2009 summer to assist in the restoration work throughout the Crosby Brook watershed. This could significantly reduce the implementation costs.

Regulatory Requirements

- US Army Corps of Engineers (USACE) Category 2 Permit - May be required if over 100 linear feet of bank is proposed for stabilization with the final design, or if the construction work takes place outside of the recommended timeframe of July 15 to October 1.
- VTANR Stream Alterations Permit- May be required but depends on the need for a USACE Category 2 permit.

Cost Estimates

Cost for Project Design & Permitting:	$8,000 – $10,000*
Cost for Topographic Survey:	$1,000
Cost for Construction & Oversight:	$10,000 - $12,000
Estimated Total Costs:	**$19,000 – $23,000**

* Some of the costs of advancing the design and permitting have been covered under the current corridor planning grant.

Next Steps

The project partners are currently seeking approval of the re-design through VTRANS. If the conceptual re-design is approved for the allocated funding, the Town of Brattleboro will seek consulting services to develop the restoration design. A Phase 3 SGA survey will be conducted by a consultant with cooperation from VTDEC staff to develop the baseline survey data needed for the design. Additional topographic survey data (for CAD drawing purposes) may need to be collected, as the Town of Brattleboro does not have the capability to produce this base mapping.

The design process will include hydrologic and hydraulic modeling to determine the magnitude of the sheer stresses at the toe of the slope, and the existing frequency of flooding within the channel and floodplain. These calculations will form the basis for the type of materials needed to stabilize the slope toe, and the frequency of LWD structures along the channel bed to encourage sediment storage and increased floodplain access.

Once the proposed design is prepared in a format acceptable for review by the USACE and VTANR permitting staff, a site visit will take place to review the design. If the USACE staff decide that the project meets the Category 2 requirements, a permit application will need to be prepared. In this scenario, it is likely that a VTANR stream alterations permit application will also need to be prepared. However, given the nature of the project (restoration focus), it is not expected that the permit application process will be time consuming, if it is necessary at all.

The following table summarizes the contacts made to date by Evan Fitzgerald regarding the design, costs, and permitting of the channel restoration project.

Table 9. Contacts made for T1.02-A Restoration Project

Name/Affiliation/Contact	Role	Date(s) Contacted	Discussion
Bill Guenther, VTDF 802.227.7967	Advice on materials sourcing and contractors	12/1/2008	Sources of LWD for design. Potential local contractors. Slope stabilization techniques.
Tim Hamilton, 802.257.0597	Potential contractor for site work	12/19/2008; 2/20/2009	Cost estimate for one week of work at site and hauling stumps to site.
Steve Roy, USFWS 802.747.6739	Technical advice on restoration design	12/19/2008	LWD densities for channel restoration per previous work on Griffith Brook in the West River basin.
Dan Redondo, Vermont Wetland Plant Supply 802.948.2553	Technical advice on restoration design	11/19/2008, 12/22/2008, 1/05/2009	Slope and channel restoration approaches based on previous designs in alluvial channels in VT and Mass.
Ethan Swift, VTDEC 802.786.2503	Technical advice on restoration design	11/26/2008	Slope and channel restoration approaches based on previous designs in the Poultney River watershed.
Mike Tkaczyk, MT3 Unlimited 802.254.1688	Potential contractor for site work	1/02/2009; 2/20/2009	Cost estimate for one week of work at site and hauling stumps to site.

Name/Affiliation/Contact	Role	Date(s) Contacted	Discussion
Chris Brunelle, VTDEC 802.879.5631	VTDEC stream alterations permitting	1/5/2008	Permitting requirements based on re-design proposal.
Chris Smith, USFWS 802.827.0629 x20	Technical advice on restoration design	1/06/2009	Slope and channel restoration approaches based on previous designs in alluvial channels in VT.
Justin Kenney, VYCC 802.434.3969 x140	Coordinator of summer VYCC crews	1/06/2009	Potential for VYCC crew to carry out hand-building techniques for LWD jams and root wads on slope.
Lance Goreman, NRCS 802.254.5323	Technical advice on materials sourcing	1/08/2009	NRCS contacts and literature for aggressive willow plantings.
Marty Abair, USACE 802.872.2893	US Army Corps permitting	1/30/2009	Permitting requirements based on re-design proposal.

5.2 Segment M01-B: Bickford's Site

Reach Location and Condition

Segment M01-B is found from a break in slope near the railroad tracks up to the confluence with the South Branch at the Exit 3 ramp (see Figure 19). The segment is approximately 1,500 feet long and has an overall channel slope of approximately 0.5%. Under reference conditions we would expect this segment to be found in a broad, alluvial valley. Gravel stream channels in this setting and watershed zone typically have a meandering profile with riffle-pool bed features. However, encroachments on the channel from the railroad, Route 9, and commercial development have reduced the available floodplain area. As a result, the channel is found in an altered (semi-confined) valley setting with a lower than expected entrenchment ratio (ER = 2.8). Due to the diminished floodplain access, greater stream power is concentrated in the channel and has led to incision and numerous bank failures. Large failures were noted along the south bank of the segment, some reaching heights of 12 feet (Figure 18).

Figure 18. Bank failure in fill soils along south bank.

The bed is dominated by sand (49%), with lesser amounts of fine gravel (27%) and silts (13%). A very high degree of fine sedimentation was observed throughout segment, which is likely leading to impacts on the biotic habitat. Due to the change in valley morphology and the moderate to high channel incision noted throughout, the segment is moderately unstable with a high degree of vertical and lateral adjustment processes (RGA condition "Fair", CEM stage II). The increase in fine sediments and limited buffer and corridor protection resulted in a decreased habitat score (RHA condition "Fair"). The large woody debris (LWD) density for this reach was well below the average for Crosby Brook reaches (47 pieces/mile).

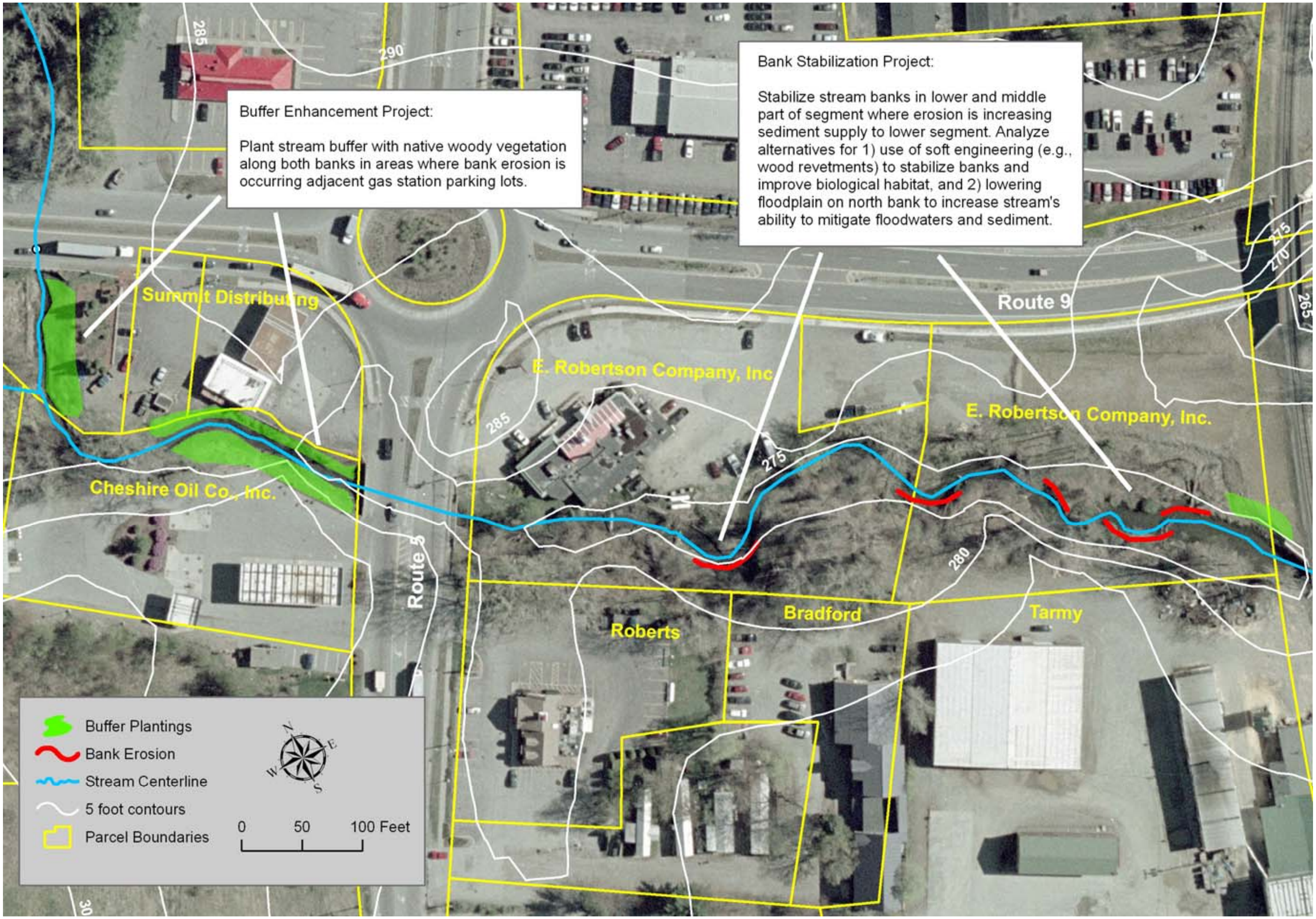


Figure 19. Project location and approach.

Stressors

1) Channel adjustments: Channel encroachment has led increased stream power due to loss of floodplain along both banks. Historical aerial photographs indicate that fill was placed in the floodplain to serve adjacent commercial building lots as early as the 1960's around the time that I-91 was constructed. Since the 1960's there has been little new development within the stream corridor, however additional riprap has likely been added to the banks to protect the adjacent infrastructure. Increasing development along the Route 5 corridor has led to greater stormwater discharges to lower Crosby Brook. Over time, this has triggered the channel to vertically and laterally adjust within its manipulated, narrow corridor. Cross-section measurements within this segment indicated an incised channel morphology (incision ratio = 1.5). Due to the presence of fill along the floodplain margins, the channel has begun to cut into the fill, releasing large amounts of sediment into the channel and adversely affecting habitat downstream where VTDEC biomonitoring data has shown impaired conditions.

2) In-stream habitat: Under reference conditions we would expect this channel to have a riffle-pool morphology with gravel-dominated substrate. Currently, the bed is dominated by sand (49%), with lesser amounts of fine gravel (27%) and silts (13%). A large amount of sediment continues to work its way down the north branch of Crosby Brook from the gully on Pepsi's property. This sediment will continue to be deposited in this segment over time. In addition, due to a lack of wood sources along the channel margins, the LWD density for this reach was well below the average for Crosby Brook reaches. These factors contributed to a "fair" rating for habitat conditions, which is consistent with the VTDEC biomonitoring data for this segment. Biotic habitat is further degraded by the channel instability; bank failures contribute additional fine sediments to the channel.

Figure 20. Lack of healthy buffer west of Route 5.

3) Riparian Buffer: Lack of riparian vegetation is contributing to elevated stream temperatures in the lower reaches. Among other impacts, lack of tree cover leads to greater sunlight reaching the

water's surface and increases in water temperature. VTDEC monitoring has shown that stream temperatures in the lowest reach (M01) upstream of the Connecticut River exceed 20^{o}C for several days in succession. Brook trout will generally not survive in streams with temperatures above this level. In the upper segment west of Route 5, the impacts on the riparian buffer are extensive and obvious (Figure 20). In the lower segment, there is also a lack of healthy riparian buffer, especially along the north bank near the railroad crossing.

Restoration Alternatives

Three alternatives are evaluated below for the M01-B ("Bickford's") restoration site. The narratives describe the general approach and landowner constraints. Table 10 summarizes the technical feasibility of each alternative with respect to the overall objectives of the VTDEC approach to watershed restoration.

1) Do Nothing

Given the moderate to high costs associated with corridor protection and channel restoration, it is prudent to consider this approach. However, the stressors set in motion will not likely be abated through natural processes without a great deal of further impacts to biotic habitat. Bank erosion would likely increase over time due to the vertical instability in the stream segment, and the lack of natural boundary resistance (e.g., vegetated banks). In addition, the channel has only recently begun to cut laterally into fill along the south banks, and this process will become worse over time without mitigation. Channel incision is resulting from a combination of hydrologic and floodplain alterations (described above in stressors section). It is critical that the systemic stressor of watershed hydrology (e.g., excess stormwater runoff) be addressed in conjunction with any active channel restoration measures.

The parcels to the west of Route 5 are currently owned by Scenic State Oil and TSR Realty. There are only limited channel adjustments west of Route 5 due to bank armoring; these landowners may not be as concerned about property loss as those downstream. Adjacent landowners downstream (east of Route 5) include the E. Robertson Company on the north bank, and three other landowners along the south bank (see Figure 2). These landowners will likely have a vested interest in channel stability, since ongoing bank erosion could threaten their property and adjacent infrastructure. Although property losses may not be imminent, the "do nothing" approach may not be feasible for south bank landowners in the near future. In addition, further development may be possible along the north bank just west of the railroad crossing. Development in this location may not be avoided with this approach

2) Stream Corridor Protection and Buffer Planting

Corridor protection would only apply to a small section of the segment along the north bank, just west of the railroad crossing. This is the only undeveloped section of the corridor and it is owned by a single landowner (E. Robertson Co). Bank erosion is concentrated in this section, making it a high priority for corridor protection to avoid future fluvial erosion conflicts. Floodplain and wetland constraints (as well as other Act 250 criteria) may prevent development to the north within this small stretch of stream corridor. Buffer plantings will play be a critical role in reducing thermal loading, and could be used as a stand-along measure in specific parts of the segment as part of a corridor protection approach. Targeted areas should include the heavily impacted area immediately west of Route 5, and the north bank just west of the railroad crossing. Combined, these areas cover approximately 7,800 square feet (0.2 acres). Given the highly impacted urban setting, a higher density of 675 stems per acre (8 feet spacing on center) is recommended.

3) Bank and Floodplain Restoration; Buffer Planting

Due to the active nature of the channel and slope adjustments, a bank restoration approach with floodplain re-grading should be considered for this site. Conceptual designs used from other stream stabilization projects have been compiled below to illustrate the range of techniques available for this site. In addition, a typical channel cross-section from the Phase 2 surveys illustrates the degree of channel incision, and how floodplain re-grading could increase floodplain function.

The failures along the south bank are caused by channel adjustments and a lack of structure and vegetative protection in the fill soils. Compared to the Black Mountain Road failure site, there is a greater amount of space to work within at these failure sites beyond the banks; therefore a wider range of stabilization techniques can be considered. A soft engineering approach using natural materials in combination with some rock armoring could be applicable. In addition, the steep banks of the fill soils could be peeled back, with the final bank profile taking on a moderated slope that would allow planted vegetation to become established. Examples of combinations of rock riprap with wood and/or tree revetments are provided below (Figure 21) from the Federal Interagency Stream Restoration Working Group’s publication on Stream Corridor Restoration (FISRG, 2001).

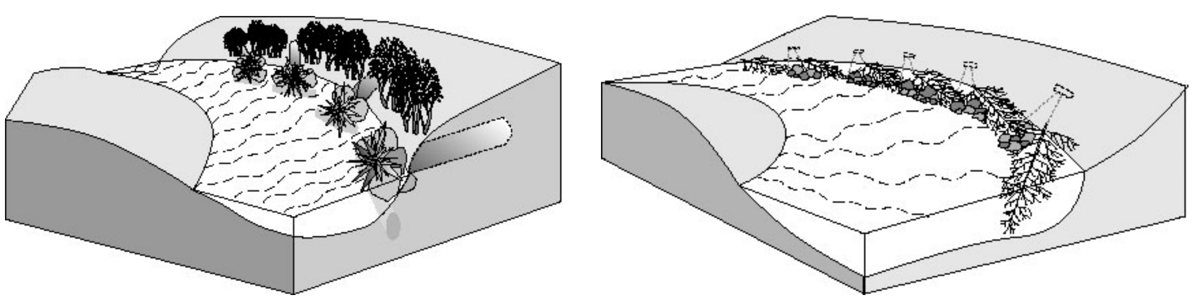
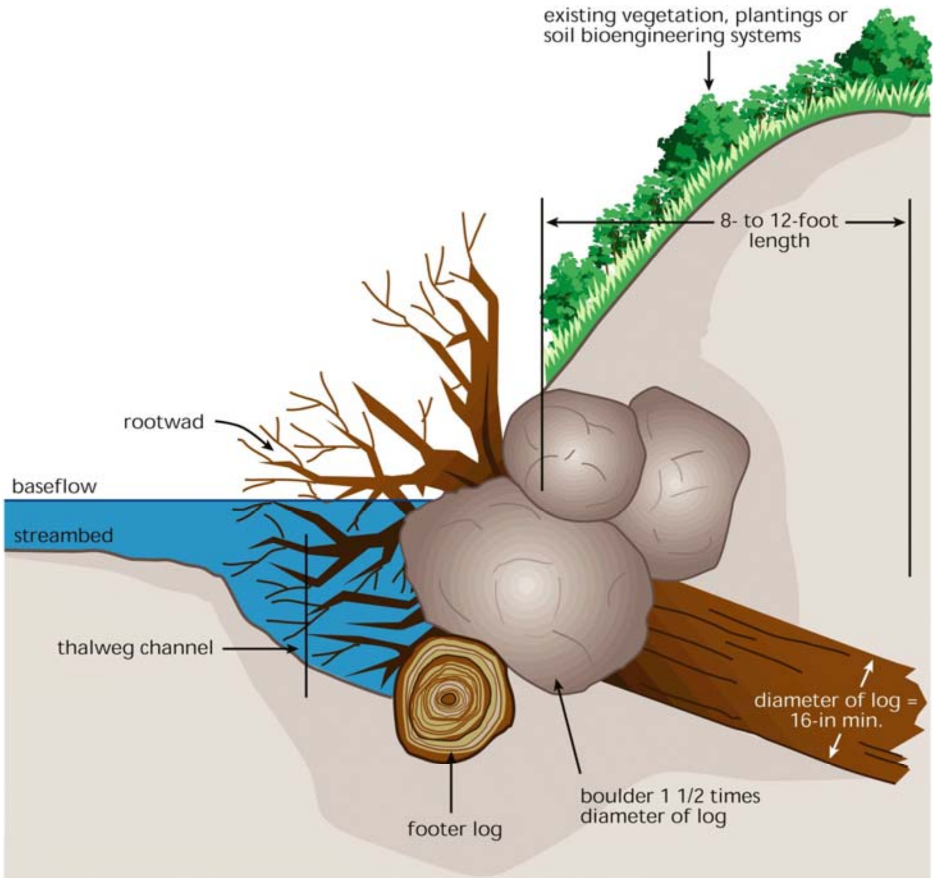


Figure 21a. Potential rootwad-boulder (left) and tree revetment (right) approaches for bank stabilization. Rootwad-boulder approach in greater detail (below)



Source: Chapter 16 Engineering Handbook, USDA-NRCS, 1997.

Fig. 8.42 -- Revetment systems. Details of rootwad and boulder technique.
In Stream Corridor Restoration: Principles, Processes, and Practices, 10/98.
Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the US).

Figure 21b. Combination rootwad and boulder technique.

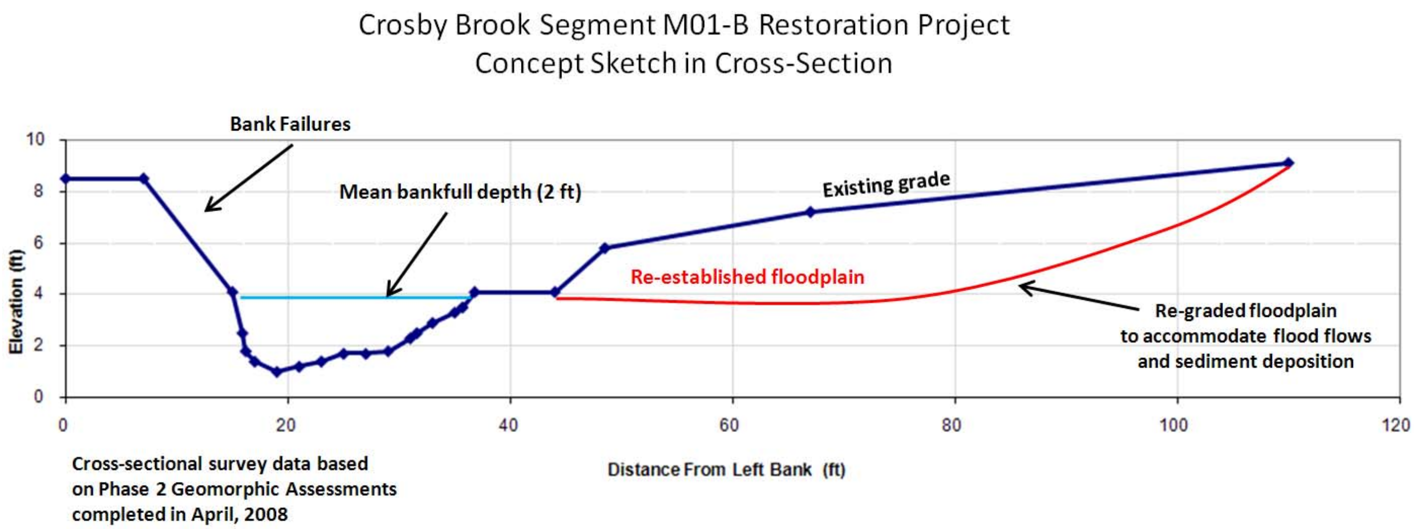


Figure 22. Floodplain re-grading to increase flood flow and sediment attenuation.

Table 10. Alternatives Analysis for Segment M01-B

Restoration Alternative	Does the project accommodate stream equilibrium conditions?	Does the project result in an overall reduction of sediment/nutrient production from within the river corridor and increase storage of sediment/nutrients?	Could the project fail due to unmitigated constraints and/or future channel adjustments?	Will the project lead to instability in upstream or downstream reaches?
#1 Do Nothing	Only over the very long-term. In the short-term channel adjustments will continue within the reach and downstream.	No. Ongoing channel adjustments will increase sediment and nutrient loading to the channel and downstream reaches, further exacerbating habitat degradation at the watershed-scale.	Not applicable.	No action could lead to further instability in the downstream reaches due to excess sediment supply from the bank failures.
#2 Stream Corridor Protection & Buffer Planting	Corridor is mostly developed. Channel instability likely over next 20-30 years as channel adjusts to narrow valley.	Only over the very long term. In short term sediment loading will increase. Also see above answer	Yes. Lateral channel adjustments could threaten adjacent infrastructure and require more bank armoring.	See above answer.
#3 Bank Stabilization & Floodplain Re-grading	Yes. This approach is aimed at restoring quasi-equilibrium conditions with the use of a naturalized design approach to address channel instability.	Yes. Project will seek to reduce excess sediment loading from the bank failures, and promote storage of sediment within the floodplain by increasing access for small to moderate flood events.	Continued urbanization along the Route 5 corridor without mitigation of hydrologic regime could jeopardize strategy.	No. The project will promote stability in downstream reaches by reducing excess sediment loading.

Cost Estimates for Alternative #2

Conservation Easement for Parcels:	$10,000 - $15,000
Buffer Planting (inc. labor and materials):	$1,000 - $2,000
Estimated Total Costs:	**$11,000 – $17,000**

Cost Estimates for Alternative #3

Cost for Project Design & Permitting:	$20,000 – $25,000
Cost for Topographic Survey:	$1,500
Cost for Construction & Oversight:	$25,000 – $35,000
Estimated Total Costs:	**$46,500 – $61,500**

Funding and Technical Partners

The project partners described in the project development introduction has been involved from the start in the review of this project. These partners include the Town of Brattleboro, WCNRCD, and VTDEC. The Vermont Youth Conservation Corps (VYCC) could also be a partner in the construction work. Marie Caduto is exploring the possibility of hiring a VYCC crew for the 2009 summer to assist in the restoration work throughout the Crosby Brook watershed.

Regulatory Requirements

- US Army Corps of Engineers (USACE) Category 2 Permit - May be required if over 100 linear feet of bank is proposed for stabilization with the final design, or the floodplain re-grading approach is selected.
- VTANR Stream Alterations Permit- May be required but depends on the need for a USACE Category 2 permit.

Next Steps

Fitzgerald Environmental conducted outreach in early 2009 to introduce the conceptual plans for the Bickford's site to the adjacent landowners. These meetings helped the project partners assess the feasibility of the project in terms of landowner support and cooperation. Additional meetings with landowners will be needed in the future to further develop the project. Based on these meetings and further input from the project partners, an alternative will be selected for further development and implementation in the future.

If alternative 3 is selected, a Phase 3 SGA survey will need to be conducted by a consultant with cooperation from VTDEC staff to develop the baseline survey data needed for the design. Additional topographic survey data (for CAD drawing purposes) will need to be collected. The design process will include hydrologic and hydraulic modeling to determine the magnitude of the sheer stresses at the toe of the slope, and the existing frequency of flooding within the channel and floodplain. These calculations will form the basis for the type of materials needed to stabilize the slope toe, and the extent of floodplain re-grading to encourage sediment storage and increased floodplain access.

Once the proposed design is prepared in a format acceptable for review by the USACE and VTANR permitting staff, a site visit will take place to review the design. If the USACE staff decide that the project meets the Category 2 requirements, a permit application will need to be prepared. In this scenario, it is likely that a VTANR stream alterations permit application will also need to be prepared.

The following table summarizes the contacts made to date by Evan Fitzgerald regarding the design, costs, and permitting of the channel restoration project.

Table 11. Contacts made for M01-B Restoration Project

Name/Affiliation/Contact	Role	Date(s) Contacted	Discussion
Steve Roy, USFWS 802.747.6739	Technical advice on restoration design	12/19/2008	LWD densities for channel restoration per previous work on Griffith Brook in the West River basin.

Name/Affiliation/Contact	Role	Date(s) Contacted	Discussion
Dan Redondo, Vermont Wetland Plant Supply 802.948.2553	Technical advice on restoration design	1/05/2009	Slope and channel restoration approaches based on previous designs in alluvial channels in VT and Mass.
Ethan Swift, VTDEC 802.786.2503	Technical advice on restoration design	11/26/2008	Slope and channel restoration approaches based on previous designs in the Poultney River watershed.
Mike Tkaczyk, MT3 Unlimited 802.254.1688	Potential contractor for site work	1/02/2009; 2/20/2009	Cost estimate for one week of work at site and hauling stumps to site.
Justin Kenney, VYCC 802.434.3969 x140	Coordinator of summer VYCC crews	1/06/2009	Potential for VYCC crew to carry out hand-building techniques for LWD jams and root wads on slope.
Lance Goreman, NRCS 802.254.5323	Technical advice on materials sourcing	1/08/2009	NRCS contacts and literature for aggressive willow plantings.
Jim Roberstson, Cheshire Oil 603.352.0001	Landowner in upper reach	5/1/2009; 5/27/2009	Potential for willow plantings and bank stabilization in upper reach.
Fred Backo, Summit Distributing Co. 603.448.4427	Landowner in upper reach	5/1/2009; 5/14/2009	Potential for willow plantings and bank stabilization in upper reach.

5.3 Reach M02: Putney Road Site

Reach Location and Condition

Reach M02 is found from the confluence with the south branch up to the confluence with the next major tributary (T2) upslope of the I-91 crossing. The reach is 0.5 miles long and has an overall channel slope of 0.7%. Under reference conditions we would expect this reach to be found in a broad, alluvial valley that supports a meandering channel profile. Extensive channel straightening (approximately 90% of reach length) from the construction of I-91 (see Figure 23) and more recent encroachments from commercial development along Route 5 has reduced the channel to a simplified form. The channel currently has limited floodplain access and habitat diversity. This reach is now found in an altered, semi-confined valley setting with a very low entrenchment ratio (ER = 1.5). Channel and floodplain measurements indicated a stream type departure from C-type geometry with riffle-pool bedform to F-type geometry dominated by plane bed features. Despite the increased channel slope, sediment supply from upslope sources (especially the gully on Pepsi property) appears to be exceeding transport capacity, as a high degree of sand and fine gravel sedimentation was observed below the I-91 crossing.

Figure 23. Historical channel straightening during construction of I-91 (left), and resulting plane bed morphology in the lower reach (right)

Due to the departure in valley and channel morphology and the high channel incision, the segment is considered extremely sensitive to further human impacts (RGA condition “Poor”, CEM stage II). There is very limited habitat diversity due to extensive straightening, increase in fine sediments, and limited buffer and corridor protection (RHA condition “Poor”). VTDEC sampling data indicate that the fish and macroinvertebrate communities have been highly impacted, supporting fair to poor conditions. The LWD density for this reach was the lowest for any of the main stem reaches (30 pieces/mile).

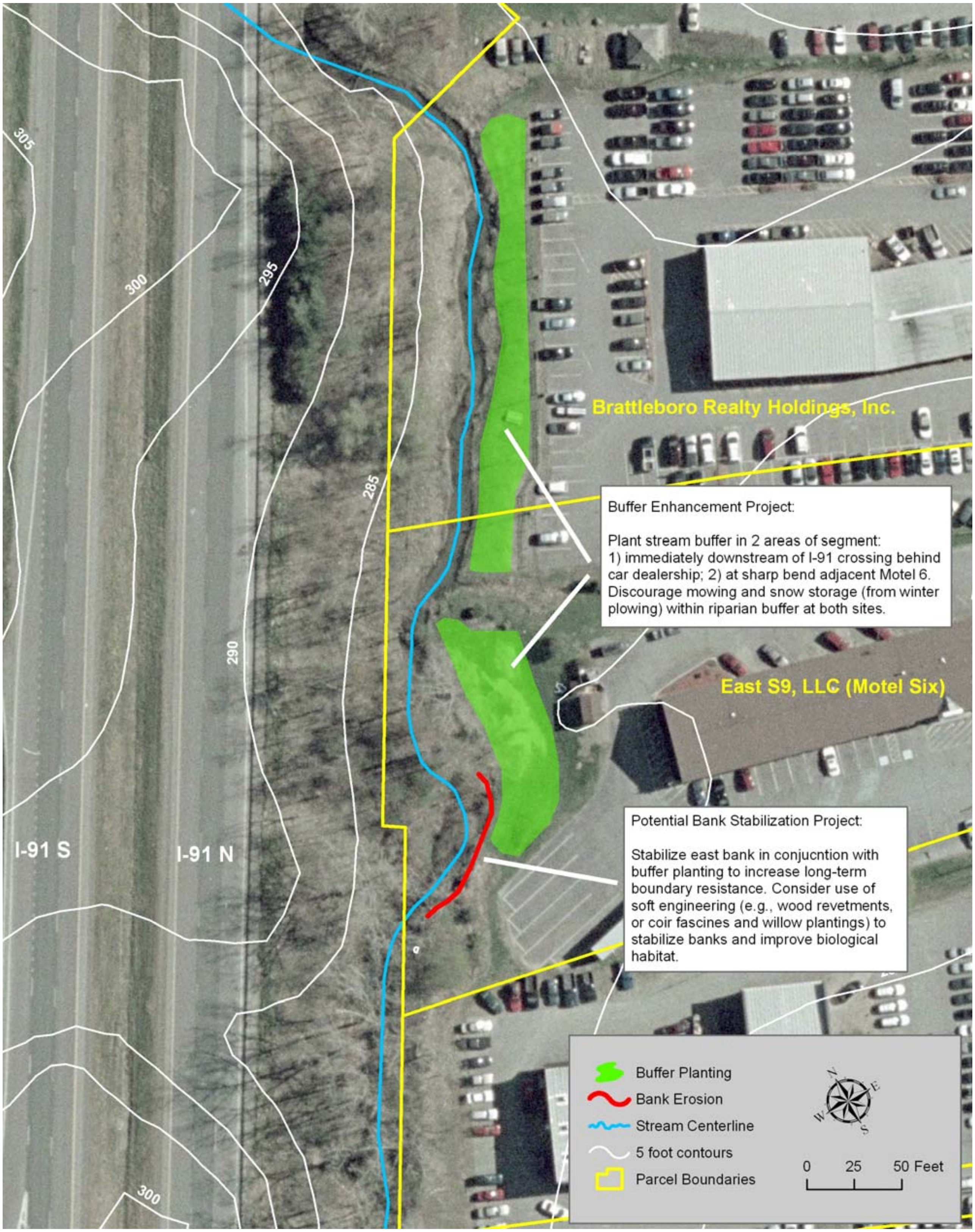


Figure 24. Site location and strategy map.

Stressors

1) Channel adjustments: Channel straightening and encroachment has led increased stream power due to loss of floodplain along both banks, and a much simplified channel form. Historical aerial photographs indicate that the channel had an extensive, meandering form and flowed across the wide valley that is now occupied to the west by I-91 and to the east by commercial development along Route 5. Significant amounts of fill were placed in the floodplain to serve adjacent commercial building lots as early as the 1960's around the time that I-91 was constructed. Since that time, there has been additional development within the stream corridor, and the channel has been further straightened to allow for adjacent development (Figure 25). In addition, increasing adjacent development has led to greater stormwater discharges directly to this section of Crosby Brook. The loss of channel meanders from recent development has also led to decreased storage capacity of sediment coming down the channel from upslope. The sediment originating from the gully upstream of I-91 appears to be overwhelming the storage capacity of the channel south of this project site. While there is some channel incision and entrenchment due to floodplain encroachment, there are also areas of severe aggradation. This has led to very poor habitat conditions in this reach. Due to severity of floodplain encroachment in this reach, there is little hope for recovery of reference channel geometry.

Figure 25. Channel straightening and floodplain encroachment. 1962 aerial photograph (left), and 2008 (right). Note location of historic meanders (dashed blue) and current straight channel (solid blue).

2) In-stream habitat: Under reference conditions we would expect this channel to have a riffle-pool morphology with gravel-dominated substrate. Currently, the bed is dominated by fine gravel (35%), sands (32%), with lesser amounts of silts (16%). Sediment continues to work its way down the Crosby Brook from the gully on Pepsi's property. Given the reduced sediment storage capacity in this reach, sediment will continue to be deposited over the long term. Lack of in-stream woody debris and other habitat features such as pools and riffles contributed to a "fair" rating for habitat conditions, which is consistent with the VTDEC biomonitoring data for this reach.

Figure 26. Lack of buffer and bank erosion behind Motel 6.

3) Riparian Buffer: Lack of riparian vegetation in this reach is contributing to elevated stream temperatures downstream. Lack of tree cover leads to greater sunlight reaching the water's surface and increases in water temperature. VTDEC monitoring has shown that stream temperatures in the lowest reach (M01) upstream of the Connecticut River exceed $20^{o}C$ for several days in succession. Brook trout will generally not survive in streams with temperatures above this level. In the lower reaches such as M02, any and all opportunities for re-planting the buffer with native woody vegetation should be explored. At this project site (Figure 26), approximately 400 linear feet of bank is recommended for buffer planting to increase shading of the stream channel and promote long term bank stability.

Restoration Alternatives

Three alternatives are evaluated below for the Putney Road restoration site. The narratives describe the general approach and landowner constraints. Table 12 summarizes the technical feasibility of each alternative with respect to the overall objectives of the VTDEC approach to watershed restoration.

1) Do Nothing

Inaction at this site will result in ongoing thermal loading to the stream, and elevated stream temperatures in the downstream reaches where VTDEC biomonitoring stations are located. In addition, bank erosion at the sharp bend behind Motel 6 would continue since the area is maintained as lawn. Snow storage in the riparian buffer from adjacent parking lots will continue to add fine sediments to the channel during winter thaws and spring runoff events.

2) Buffer Planting (stand-alone treatment)

Figure 24 shows the two areas where the buffer planting is recommended. Combined, these areas cover approximately 8,400 square feet (0.2 acres). NRCS buffer planting guidelines (NRCS-VT, 2009) for planting density would result in a total of 60 trees for this site (300 stems/acre). Given the highly impacted urban setting, a higher density planting plan that includes a combination of trees and shrubs would aid in the reestablishment of a healthy buffer in a shorter time frame. A higher density of 675 stems per acre (8 feet spacing on center) is recommended. The estimated cost range below includes materials and labor. The project costs could be further lowered if the VYCC or other volunteers were to help in the planting effort. Given the presence of beavers in the area, stem protectors are recommended for the tree plantings.

Estimated Total Costs: $500 - $1,000

3) Buffer Planting and Bank Stabilization

In addition to the buffer planting, approximately 90 linear feet of eroding bank could be stabilized to further reduce sediment loading to downstream areas. As described in previous project descriptions (see sections 5.1 and 5.2), "soft" engineering approaches to bank stabilization could be used for this site. This could include a rootwad-boulder approach, coir logs and willow plantings, or simply a tree revetment approach like VYCC has used in the past for stabilizing banks of small streams. The estimated cost range below includes materials and labor, including a small excavator on site for one day and 5 cubic yards of rock for bank stabilization in combination with tree revetments. The project costs could be further lowered if the VYCC or other volunteers were to help stabilization and planting efforts.

Estimated Total Costs: $2,000 - $3,000

Table 12. Alternatives Analysis for Reach M02

Restoration Alternative	Does the project accommodate stream equilibrium conditions?	Does the project result in an overall reduction of sediment/nutrient production from within the river corridor and increase storage of sediment/nutrients?	Could the project fail due to unmitigated constraints and/or future channel adjustments?	Will the project lead to instability in upstream or downstream reaches?
#1 Do Nothing	No. Lack of boundary resistance will result in ongoing bank erosion.	No. Ongoing erosion will increase sediment and nutrient loading to the channel and downstream reaches, further exacerbating habitat degradation at the watershed-scale.	Not applicable.	No action could lead to instability in the downstream reaches due to excess sediment supply from the bank erosion.
#2 Buffer Planting	Yes. Increasing boundary resistance will reduce bank erosion and lateral adjustments.	Yes. Reduced bank erosion will decrease sediment/nutrient loading to downstream areas.	Yes. Beavers could threaten plantings. Snow removal or other property maintenance could threaten plantings.	No. The project will promote stability in downstream reaches by reducing excess sediment loading.
#3 Buffer Planting & Bank Stabilization	Yes. See above answer.	Yes. See above answer. Bank stabilization could reduce sediment and nutrient loading more quickly in the short term.	Yes. See above answer.	No. See above answer.

Funding and Technical Partners

The WCNCRD and the Putney Road Business Association could together serve as the local groups for organizing volunteers for the planting effort. The Vermont Youth Conservation Corps (VYCC) could also be a partner in the planting and stabilization work. Marie Caduto is exploring the possibility of hiring a VYCC crew for the 2009 summer to assist in the restoration work throughout the Crosby Brook watershed. This could significantly reduce the implementation costs of this project.

Next Steps

Fitzgerald Environmental conducted outreach in early 2009 to introduce the conceptual plans for the site to the adjacent landowners. These meetings helped the project partners assess the feasibility of the project in terms of landowner support and cooperation. Additional meetings with landowners will be needed in the future to further develop the project. Based on these meetings and further input from the project partners, an alternative will be selected for further development and implementation in the future.

The following table summarizes the contacts made to date by Evan Fitzgerald regarding the design and costs of this project.

Table 13. Contacts made for M02 Restoration Project

Name/Affiliation/Contact	Role	Date(s) Contacted	Discussion
Justin Kenney, VYCC 802.434.3969 x140	Coordinator of summer VYCC crews	1/06/2009	Potential for VYCC crew to carry out hand-building techniques for LWD jams and root wads on slope.
Ben Gabos, NRCS 802.524.6505 x122	Technical advice on materials sourcing and costs	3/5/2009	NRCS contacts and literature for buffer planting costs and specs.
Stacy Kritsas, Stacey Subaru 802.251.1000	Landowner to south of project site	5/14/2009	Stream condition and potential for buffer restoration in parcels to the north.
Samantha Bacon, Motel 6 802.254.6007	Hotel Manager	5/14/2009; 5/27/2009	Stream condition and potential for buffer restoration behind hotel.

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