Green River Corridor Plan

Guilford and Halifax, VT

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WINDHAM REGIONAL COMMISSION

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Executive Summary

The Green River flows through a scenic and densely forested watershed from the headwaters in Marlboro through the Towns of Halifax and Guilford in southeastern Vermont before crossing the border into Massachusetts. The river valleys in Massachusetts continue to be largely forested with increasing development and agriculture until the river crosses under Interstate 91 and flows through the Town of Greenfield as a heavily managed urban waterway. The Green River flows into the Deerfield River south of Greenfield approximately two miles upstream of the confluence with the Connecticut River. At the mouth, the river drains 89.5 square miles, including approximately 37.3 square miles in Vermont.

Tropical Storm Irene in August of 2011, tracked directly through the Green River watershed causing major damage in Vermont and Massachusetts. Over 7 inches of rain fell in the headwaters of the Green River watershed. Roads and bridges were especially hard hit by the flooding and this damage to the transportation network, particularly along Green River Road in Halifax, slowed recovery efforts and severed access to dozens of homes. Numerous residences were directly impacted by the flood in Guilford and Halifax. As a result of the impacts from this flood, and the increasing severity of rainfall and flood events in the last decade, flooding and erosion hazards are a top concern for residents within the Green River watershed.

As a result of dealing with severe, repeat flood and erosion damage throughout Vermont over the last two decades, Vermont's river scientists and engineers now understand that hazard mitigation and river restoration projects are most successful when carried out within a context of how reach and watershed-scale stressors influence flood and erosion hazards. In an effort to understand the root causes of stream channel instability and flood/fluvial erosion hazards in the Green River watershed, the Windham Regional Commission (WRC) and the Vermont Department of Environmental Conservation (VTDEC) have sought to develop a database of Stream Geomorphic Assessment (SGA) data for river reaches of significant size throughout the watershed. These data allow for a more comprehensive approach to flood and erosion hazard planning, in contrast to the conventional approach of multiple “spot fixes” with limited knowledge of the river system.

Fitzgerald Environmental Associates, LLC. (FEA) was retained by WRC in 2013 to complete river assessments on the Green River and Hinesburg Brook following the Phase 1 SGA Protocols developed by the VTDEC. Following this study, a subset of the Phase 1 reaches was selected for field-based, Phase 2 SGA data collection. FEA collected Phase 2 data in May of 2014 for 10 reaches covering approximately 8.6 miles, and developed a River Corridor Plan (RCP) for these reaches.

Below are the objectives of the Phase 2 SGA and River Corridor Plan:

1) Develop a basis for understanding the overall causes of channel instability and habitat degradation along the river corridors in the watershed.
2) Develop a list of preliminary corridor restoration projects that can be further developed in the future to mitigate flood and erosion hazards.
3) Collect the information needed to map fluvial erosion hazard zones in Halifax and Guilford.

Below is a summary of key findings from the Phase 2 SGA and River Corridor Plan:

There is a distinct transition in the middle of the Phase 2 study area near the Guilford-Halifax town line. The upper reaches in Halifax (reaches M08 through M13) are characterized by higher slope, confined or narrow valleys, and greater sediment erosion and transport capacity. The upper reaches are highly impacted by historic encroachment from roads and associated straightening and bank armoring. The lower reaches in Guilford are characterized by wider valleys, lateral erosion and deposition processes, and planform adjustments. These reaches are dynamic and highly erosive during flood events due to ongoing adjustments to their dimensions, patterns, and profiles. The lateral adjustments in the lower reaches are likely in response to impacts from historical sedimentation in valleys from early European settlement and deforestation that caused hillslope erosion, as well as modern day impacts from channel straightening, dredging, berming, and corridor encroachment associated with adjacent agriculture, development, and roads. Tropical Storm Irene triggered channel incision, mass wasting of valley slopes, major inputs of sediment and woody debris to the channel, and redevelopment of floodplain access in some areas through aggradation. Ongoing vertical and lateral channel migration is likely in the future for many of the lower reaches in Guilford. These changes are less likely in the upper reaches (Halifax) due to extensive armoring and encroachment. Given these predictions for future channel adjustments, the following watershed-scale and site-specific management observations and approaches are summarized from the Phase 2 data and RCP.

- The stressor identification analysis revealed limited watershed-scale impacts from recent land use changes (i.e., development). For example, the overall watershed land cover is 94% forest with very minimal development (<1%) and limited agricultural lands (4%).
- Tropical Storm Irene was likely a 500-year event and triggered severe channel adjustments in many of the Phase 2 reaches. The flooding unleashed an enormous volume of coarse sediment and woody debris into the channel as a result of mass wasting of tall banks and valley side slopes, and stream bed erosion. Mass failure and channel incision were predominantly found in the upper reaches with high encroachment, whereas erosion, deposition, and channel migration were observed in the lower reaches with less encroachment and some floodplain accessibility.
- Several segments in the study area have undergone a departure in both sediment regime and stream type due to channel incision and/or widening as a result of: 1) historical land uses, 2) encroachments or development in the river corridor, or 3) extensive straightening and bank armoring. Many of the channel adjustments caused by these historic stressors were exacerbated by the extreme flood event in 2011, leading to further stream type departures.
- Nine river segments have departed from reference conditions due to channel incision and entrenchment (i.e., floodwaters are contained within a narrow channel without access to the original floodplain). These departures result in a conversion of river segments to effective transporters of sediment and high velocity floodwaters to downstream areas, with a corresponding loss of storage of sediment and floodwaters within the floodplain.
- Seven bridges were assessed for geomorphic compatibility as part of the Phase 2 work. One private bridge in Halifax (reach M11) had an effective span less than the reference bankfull channel width, indicating a high degree of structure vulnerability to flooding and erosion.
- Site level approaches to restoration of dynamic equilibrium conditions were evaluated in detail at the reach scale. This effort resulted in the identification of 23 potential restoration project areas, including 12 projects that do not require significant further study (i.e., passive approaches such as buffer plantings and corridor protection), and 11 projects requiring further feasibility study or engineering design (i.e., active restoration approaches such as berm removal).

1.0 Project and Watershed Background

1.1 Introduction and Study Goals

1.1.1 Project Introduction

In 2012 the Windham Regional Commission (WRC) and the Vermont Department of Environmental Conservation (VTDEC) identified the Green River in southeastern Vermont for assessment of fluvial geomorphic conditions. Prior to this, geomorphic assessment data had been collected for adjacent watersheds, including Whetstone Brook and the West River.

Severe flooding and erosion damage sustained during Tropical Storm Irene (TSI) in the Towns of Guilford and Halifax led to the selection of this watershed for further study. Infrastructure along the river and tributaries was severely impacted by flooding and erosion, and therefore this information will serve to help these towns better understand existing flood vulnerabilities, and plan for future improvements with flood risks in mind.

Fitzgerald Environmental Associates, LLC. (FEA) was retained by WRC in 2013 to complete river assessments on the Green River and Hinesburg Brook following the Phase 1 Stream Geomorphic Assessment (SGA) Protocols (VTDEC, 2009) developed by the VTDEC. FEA used the Stream Geomorphic Assessment Tool (SGAT) to develop the baseline GIS data for the watershed in 2013. A total of 21 reaches along 17.2 river miles were assessed during the Phase 1 analysis.

Following this study, a subset of the Phase 1 reaches was selected for field-based, Phase 2 SGA data collection. FEA completed the Phase 2 field work in 2014 for 10 reaches (approximately 8.6 river miles), and developed a River Corridor Plan (RCP) for these reaches. This report summarizes watershed background information, SGA results, and the RCP into one planning document.

1.1.2 Study Goals

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

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

The Phase 1 SGA approach develops 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 SGA data also aids in the identification of specific stressors affecting the physical conditions of the stream channels and structures (e.g., bridges and culverts). Ultimately, the Phase 1 results help guide planners in selecting reaches for more detailed Phase 2 data collection where this information can be valuable for flood vulnerability mapping, identification of river restoration projects, and long-term river corridor planning. The goal of the Phase 2 and RCP effort is to provide:

1) A basis for understanding the overall causes of channel instability and habitat degradation along the river corridors in the watershed.
2) A list of preliminary corridor restoration projects that can be further developed in the future to mitigate flood and erosion hazards.
3) Information needed to map fluvial erosion hazard zones in Guilford and Halifax.

1.2 Background Watershed Information

1.2.1 Geographic Setting and Land Use History

The Green River watershed is located in the Lower Connecticut River Basin in southeastern Vermont (Figure 1.1). The watershed has a drainage area of approximately 89.5 square miles spanning the border of Vermont into Massachusetts, and outlets to the Deerfield River two river miles upstream of its confluence with the Connecticut River. The lowest reaches are an urban stream flowing through the city of Greenfield, MA, while the headwaters drain the Mount Olga-Hogback ridge to the north in the Green Mountains of Vermont. The watershed covers portions of five towns in Massachusetts: Greenfield, Shelburne, Bernardston, Leyden, and Colrain; and four towns in Vermont: Brattleboro, Guilford, Halifax, and Marlboro. This report describes the approximately 35 square miles of the watershed that drain to the river at the Vermont-Massachusetts border (Figure 1.2).

Land cover data based on imagery from 2006 (NOAA, 2008) are summarized in Table 1.1. The Green River is drained by a rural watershed, with forests representing the dominant land cover type (93.6%). Agricultural lands cover 4.0% of the watershed and are scattered throughout, while wetlands cover 1.4% of the watershed and are predominantly distributed around the headwaters of the watershed especially to the north. Development (0.4%) and open water (0.4%) occupy minimal area within the watershed.

Table 1.1: Percent Land Cover for the Green River in Vermont and Hinesburg Brook watersheds.

Watershed	Drainage Area (mi^2)	Agriculture	Development	Forest	Open Water	Scrub/Shrub	Wetland
Green River*	29.6	3.4%	0.3%	94.0%	0.5%	0.3%	1.5%
Hinesburg Brook	5.1	7.6%	0.5%	91.3%	0.0%	0.0%	0.6%
Entire Watershed*	34.7	4.0%	0.4%	93.6%	0.4%	0.3%	1.4%

*Land cover data for Vermont portion of mainstem and all tributaries are included.

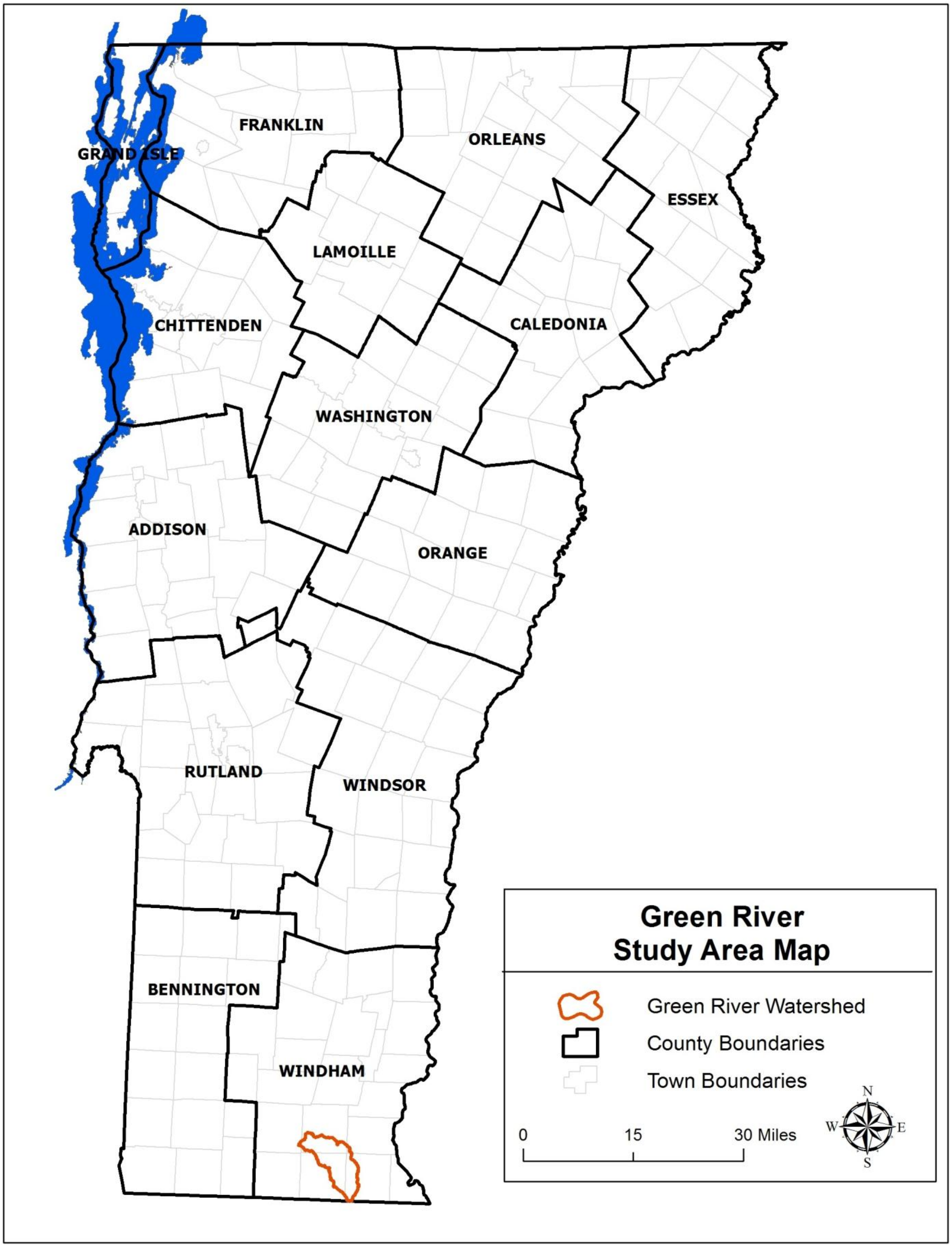


Figure 1.1: Location map for the Green River watershed study area.

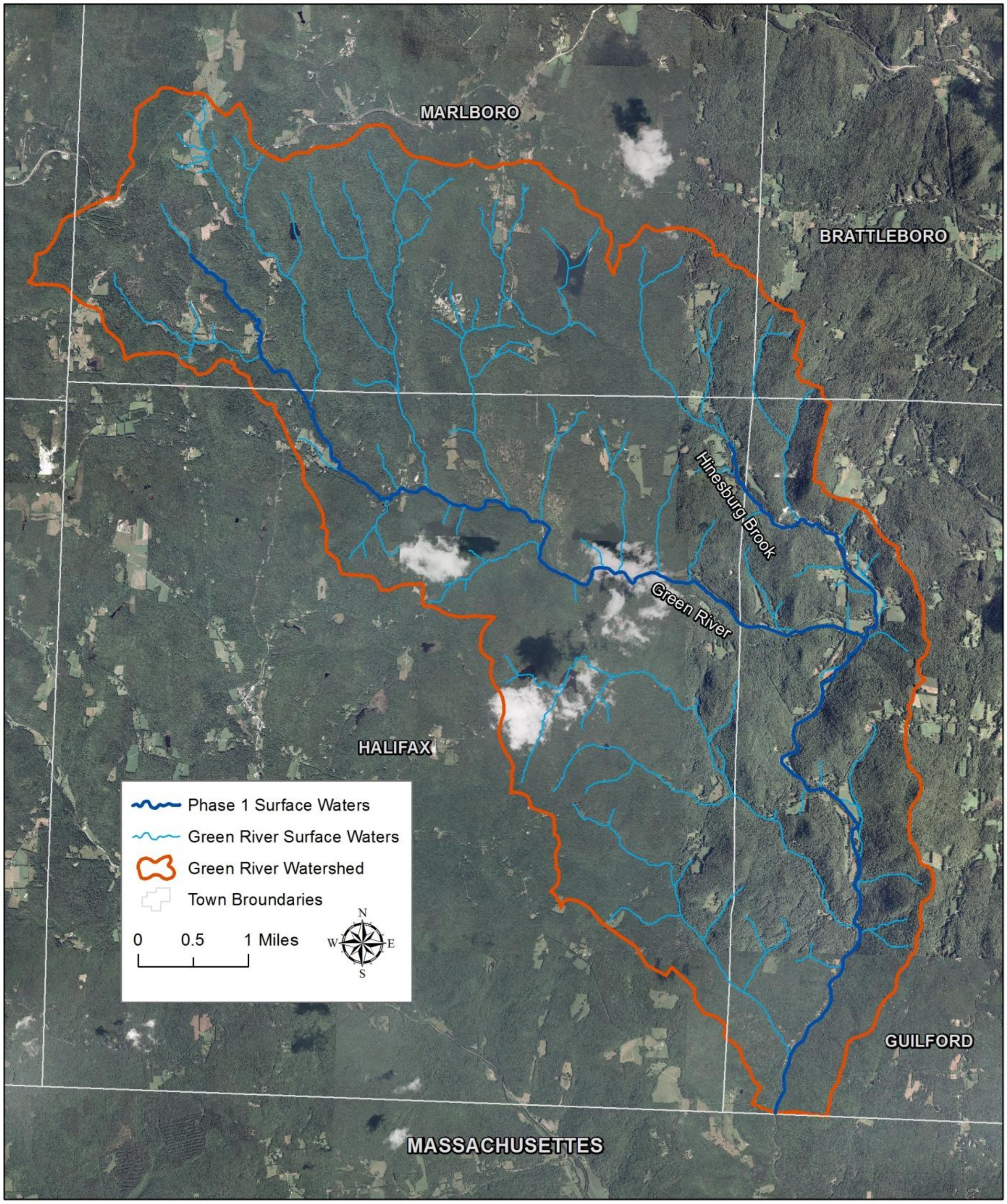


Figure 1.2: Green River watershed in Vermont, Phase 1 surface waters, and town boundaries.

Land Use History

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

As Vermont's farmers began to move to the Midwest in search of more productive farmland in the mid to late 1800's, the deciduous forests along the mountain slopes began to recover (Albers, 2000). Throughout the early and mid-1900's, as more family farms found on marginal lands were given up, the forests continued to recover. Today, approximately 94 percent of the Green River watershed is covered by forest. Only 4% of the watershed is occupied by agricultural land uses today. During the 19^{th} and 20^{th} centuries surrounding areas were heavily settled and developed, while the Vermont portion of the Green River Watershed remains a "rural enclave in a busy world" (Riggs, 1995).

1.2.2 Geologic Setting

The underlying geology of the Green River watershed is comprised of a range of bedrock types. The lower Green River and Hinesburg Brook watersheds contain a mixture of carbonaceous phyllite and limestone members from the Waits River and Northfield formations (Lower Devonian and Upper Silurian periods). The upper Green River watershed transitions to schists, quartzite, granofels, and amphibolites from the Ordovician and Cambrian periods and the Neoproterozoic era as the watershed climbs to the eastern faces of the Green Mountain formations (Ratcliffe et al., 2011 and Riggs, 1995).

Surficial geologic deposits in the Green River watershed were governed largely by glacial activity. During the Wisconsin glaciation, glaciers one mile in thickness extended across New England, reaching their maximum extents approximately 20,000 years ago. This glacial event left the Green Mountains with a physical imprint that is clearly evident today. In the Green River watershed dense till, glacial till, and outwash areas reflect the dynamic nature with which glaciers shaped the landscape (Figure 1.3). Most of the surficial geology of the watershed is dominated by till and the stream corridors are primarily outwash and alluvium. The resultant soils in the Green watershed are primarily fine sandy loams, many of which are very stony (Marlow, Tunbridge-Lyman, Berkshire-Tunbridge, Berkshire-Monandnock, Mundal, and Rawsonville-Hogback). High elevation organic soils (Markey muck and Lupton mucky peat) are scattered throughout the upper drainages.

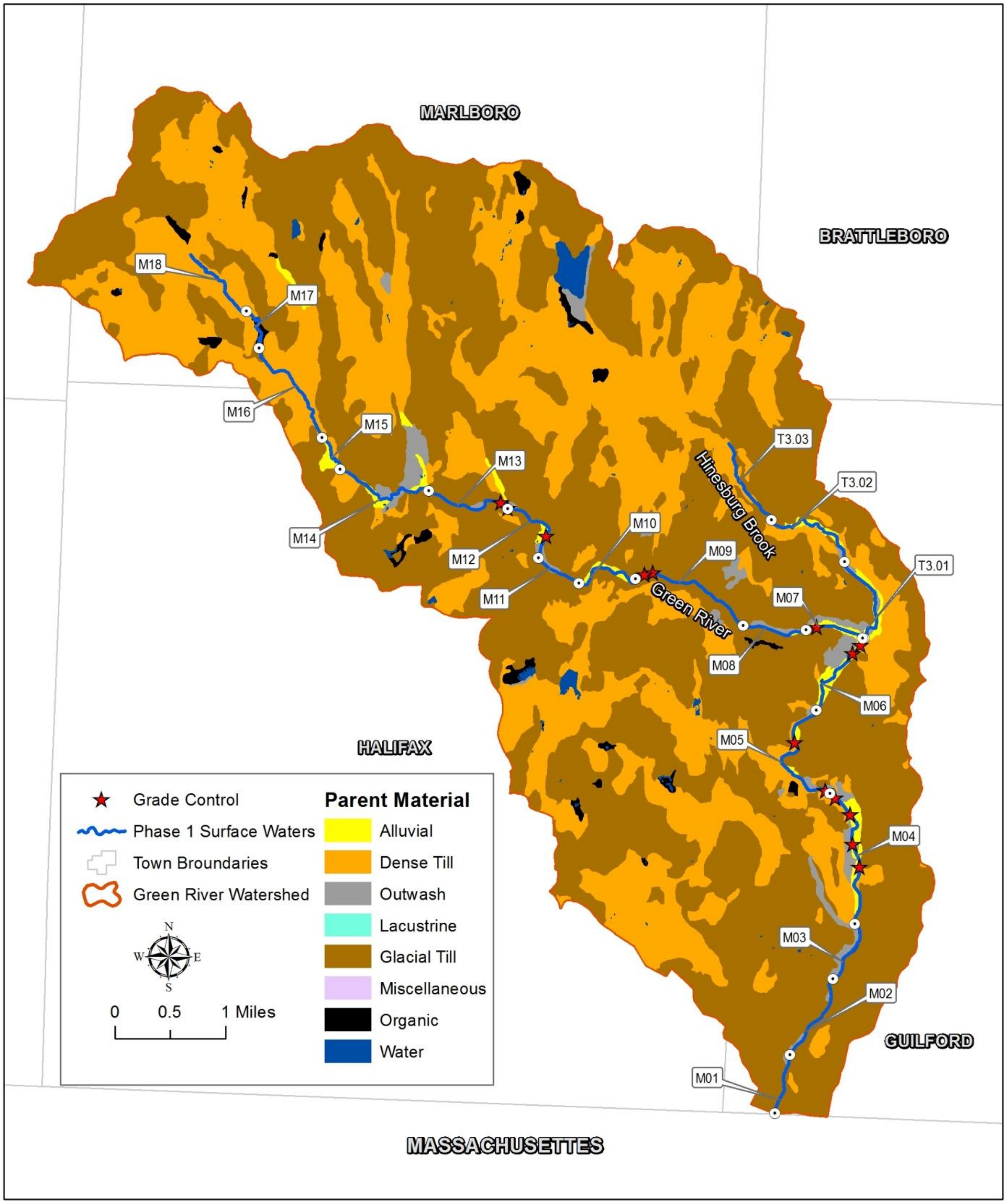


Figure 1.3: Parent surficial materials and grade controls in the Green River watershed.

1.2.3 Geomorphic Setting

The Green River watershed contains four geomorphically different sections of the mainstem and Hinesburg Brook. Average slopes for all of the study reaches are presented in Table 1.2. The first three reaches of the main stem flow through a fairly unique, semi-confined valley with a naturally straight channel having a slope near 1%. Green River Road shares the valley floor and closely follows the river for all of this section.

Slope is consistently near 1% for the middle section but the valley opens to broad and very broad widths. River Road or Green River Road share the unconfined valley for much of this section, however the road is typically located at the base of the valley walls. A large historic timber crib dam is located on reach M05 and directly affects approximately 1,200 feet of channel upstream (i.e., ponding).

Slope increases to approximately 2% and valley widths decrease to narrow or semi-confined through the upper section of Green River. A short stretch of steep and narrowly confined channel is located in the middle of M09. Green River Road closely follows the River and shares the valley for much of this section.

Slope and valley width are variable as the river enters the headwaters section. Reaches M14, M15, and M17 are lower slope (1.4 to 1.5%) and are unconfined. Reaches M16 and M18 are semi-confined and have slopes of 2.6 to 4.5%.

Hinesburg Brook (T3) enters the mainstem at the top of M06 and drains a steeper watershed to the north. Channel slope increases from 2.2 to 4.4% and valley width decreases from very broad to semi-confined as the stream climbs towards the headwaters. Hale Road follows the stream through most of the study area and is adjacent to the channel for most of T3.03.

Table 1.2: Average channel slopes for Green River and Hinesburg Brook.

Channel (SGA Reaches)	Average Slope
Green River (M01-M18)	1.7%
Lower Green (M01-M03)	0.9%
Middle Green (M04-M07)	0.9%
Upper Green (M08-M13)	2.0%
Green Headwaters (M14-M18)	2.4%
Hinesburg Brook (T3.01-T3.03)	3.2%

1.2.4 Hydrology and Flood History

The United States Geological Survey (USGS) currently operates a real-time flow monitoring gage on the Green River in Colrain Massachusetts (Gage #01170100). The river has been gaged at this location since 1968. Long-term flow frequency data from this gage were included in a USGS study to summarize flow-frequency characteristics of Vermont rivers and streams (Olson, 2002). We analyzed all of the available flow data using the USGS PeakFQ software to include a large storm event in October 2005 and TSI in August of 2011, which both occurred after the Olson report (Table 1.3). The results for the 10-year and 100-year storms based on the Olson report and the PeakFQ analysis are shown in Figure 1.4 (Flynn et al., 2006; USGS, 1982).

Table 1.3: Frequency and magnitude of flow events in the Green River watershed based on USGS gage data.

	Discharge (cfs)	
Return Frequency	Olson (1968 - 2000)	PeakFQ (1968-2012)
2 year	2,480	2,343
5 year	3,330	3,738
10 year	3,890	4,991
25 year	4,580	7,040
50 year	5,100	8,969
100 year	5,610	11,310
500 year	6,810	18,820

The shift in flood discharges between the Olson report and the PeakFQ results using current data show the importance of large floods (e.g., TSI) in shaping these relationships. The twelve years of data added since the Olson report contained a near 500-year event (6,540cfs) and TSI (19,400 cfs) which was almost three times larger than the previously estimated 500-year discharge.

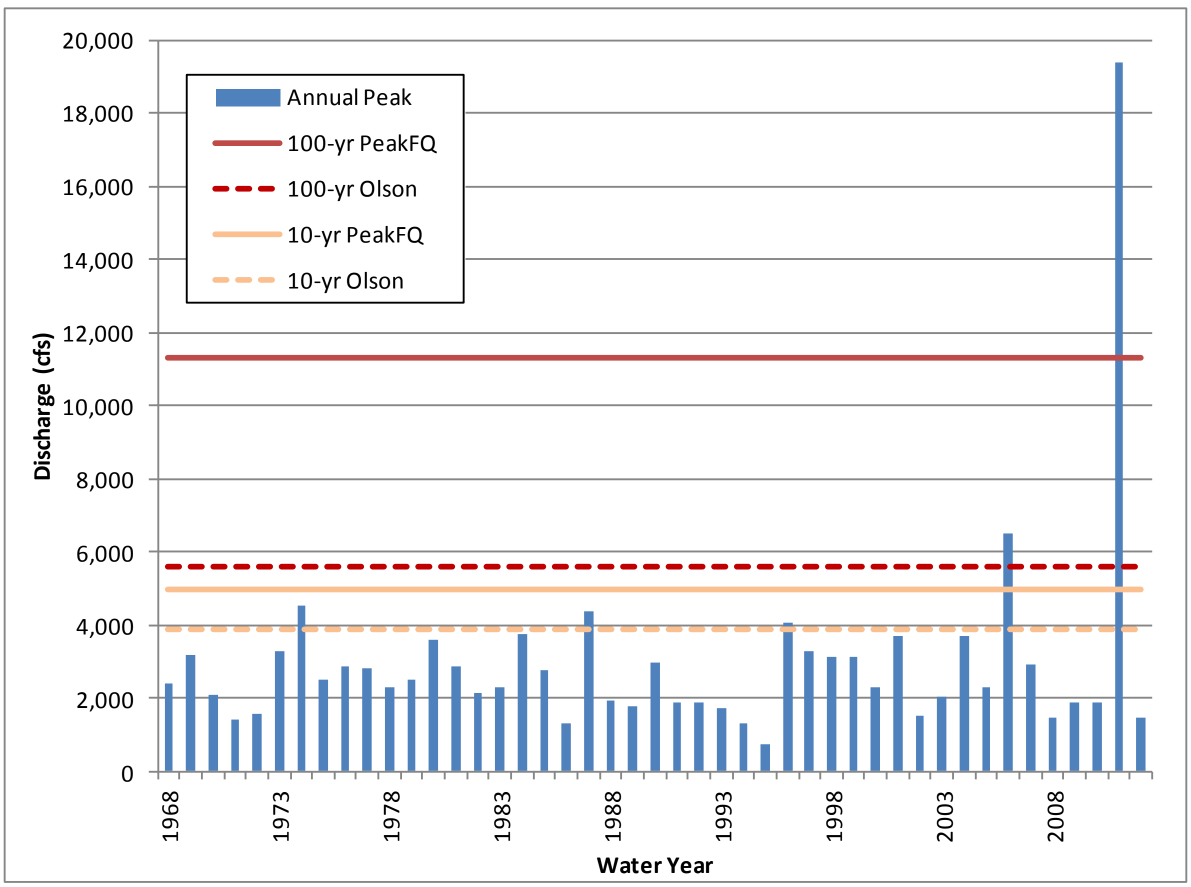


Figure 1.4: Annual peak streamflows from USGS gage on the Green River in Colrain, MA.

The Green River watershed was one of the hardest hit areas in Vermont during TSI. Area rainfall totals from August 28, 2011 recorded approximately 8" of rain and it is likely that higher amounts actually fell within the upper watershed. Huge volumes of water washed off of the steep headwaters and through the tight valleys of the upper mainstem. As the channel slope decreased the river began to spill over its banks and fill the valley. Major sand and silt deposits were left on accessible floodplains (Figure 1.5). Roads were damaged or destroyed throughout the study area as they were undermined or overtopped by floodwaters (Figures 1.6 - 1.8). The flood also caused major erosion and mass failures along the forested banks and valley walls generated huge volumes of fine sediment, filling in many of the deeper pools and the popular swimming area above the timber crib dam (Riggs, 1995).

Figures 1.5-1.8: Clockwise from top left: deep sand and silt deposition on floodplain in reach M05; floowaters overtopping River Road near the Massachusettes border; Green River Road in Colrain MA destroyed after the waters receeded; cyclists surveying damage to Hinesburg Road near the Deer Park Bridge on reach M08B. (All TSI photographs courtesy of Linda Lembke)

1.2.5 Ecological Setting

The majority of the Green River watershed (M01-M13) and the Hinesburg Brook watershed are located in the Southern Vermont Piedmont (SP) biophysical region, and the remainder of the Green River watershed is located in the Southern Green Mountains (SM) biophysical region (Thompson and Sorenson, 2000). The SP region is found along the eastern border of Vermont and extends from White River Junction down to Massachusetts. It is characterized by gentle rolling hills and bedrock geology that supports Northern Hardwood Forest communities. Some areas of igneous intrusions (e.g. granitic plutons), such as Ascutney Mountain and Black Mountain to the west of Brattleboro, support rare communities such as the Pitch Pine-Oak-Heath community. Rich soils of loam and silt along the Connecticut River that once supported extensive areas of silver maple (*Acer saccharinum*) and Ostrich Fern (*Matteuccia struthiopteris*) were converted to agricultural use during European settlement in the late 18th century. Post-glacial deposits of sand and gravel are common in the river valleys of the SP region, including the mainstem and tributaries of the Green River watershed.

The SM region is found along the spine of the Green Mountains and low foothills to the east in the southern half of Vermont. Temperatures are cooler and precipitation is higher in this region. Bedrock is typically metamorphic, acidic, and non-calcareous. The natural communities in this region tend to be those with northern affinities that are best suited for colder temperatures. Boreal communities are found on the highest peaks where winter conditions are harshest. The slopes grade into the Northern Hardwood forest type at elevations of around 2,500 feet. This forest type dominates most of the upper Green River watershed. Deep glacial till deposits cover most of the SM region including the Green River watershed. Glaciofluvial kame and outwash deposits common in the SM region are found throughout the river valleys. Elevations within the study area range from 540 feet at the Massachusetts border to over 2,400 feet at the top of Mount Olga and Hogback Mountain in the headwaters of the mainstem.

Macroinvertebrate and fish community assessments have been completed by the VTDEC Biomonitoring Division on the Green River in reaches M04 and M08 (Tables 1.4 and 1.5). Macroinvertebrate community assessments ranged from "fair" to "excellent". The "fair" condition samples from M04 had very low density in 2011 immediately following TSI, but otherwise represented a diverse community with low pollution tolerance. The 2013 assessment received a fair rating due to dominance of filter feeding caddisflies (Cheumatopsyche sp.). Fish community assessments also found communities that were typically "good" to "excellent".

Table 1.4: Macroinvertebrate Community Assessment Data

Reach	Date	Station ID	Community Assessment	Total Richness	EPT Richness	Biotic Integrity
M04	10/24/1991	670000000166	Excellent	48	26.5	3.44
M04	10/6/1992	670000000166	Excellent	50	29	3.12
M04	10/14/1993	670000000166	Excellent	37	23.5	3.35
M04	10/6/2011	670000000166	Fair	41	28.5	2.54
M04	9/26/2012	670000000166	Excellent	58	36.5	3.22
M04	10/11/2013	670000000166	Fair	38	24	4.25

Table 1.4: Macroinvertebrate Community Assessment Data

Reach	Date	Station ID	Community Assessment	Total Richness	EPT Richness	Biotic Integrity
M08	10/24/1991	670000000199	Excellent	51	28	2.71
M08	10/6/1992	670000000199	Excellent	52.5	29.5	2.88

Table 1.5: Fish Community Assessment Data

Reach	Date	Station ID	Community Assessment	Total Richness	Biotic Integrity
M04	9/26/2012	670000000166	Good	7	35
M04	10/14/2013	670000000166	Excellent	9	41

2.0 Methods

2.1 Data Collection 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 biological 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 instream biological habitat. The protocols are based on defensible scientific principles and have been tested widely in many watersheds throughout the state. Data collected for the Green River using these protocols forms the basis for preliminary project identification carried out during Phase 2 SGA and River Corridor Planning efforts.

The SGA protocols include three phases (VTDEC, 2009):

Phase 1: The Phase 1 SGA approach utilizes the Stream Geomorphic Assessment Tool (SGAT), a GIS extension developed by RMP for the collection of reach and watershed scale data. In addition to the GIS and remote sensing effort, a cursory field assessment (“windshield survey”) is included for the verification of stream and valley forms, significant channel features and the location of man-made infrastructure. The Phase 1 SGA approach results in watershed-scale data about the landscape (e.g., soils and land cover) and the stream channel (e.g., slope and form), which provides a basis for understanding the natural and human-impacted conditions within the watershed. The SGA data also aids in the identification of specific stressors affecting the physical conditions of the stream channels and structures (e.g., bridges and culverts). Table 2.1 summarizes the parameters collected in Phase 1 using the Feature Indexing Tool (FIT), which include those utilized to develop the final impact ratings.

Phase 2: 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 predict the degree to which the channel will adjust to human and natural impacts in the future.

Table 2.1: Parameters collected with the Feature Indexing Tool.

Phase 1 Step	Phase 2 Step	Data Type	Impact	Sub-Impact
3.1	1.2	Point	Alluvial Fan	NA
3.2	1.6	Point	Grade Control	Dam Ledge Waterfall Weir
NA	3.3	Point	Mass Failure	NA
5.5	5.5	Point	Dredging	Dredging Gravel Mining Commercial Mining
NA	4.4	Point	Debris Jam	NA
NA	4.6	Point	Stormwater Input	NA
NA	4.9	Point	Beaver Dam	NA
NA	5.2	Point	Migration	Neck Cut Off Flood chute Avulsion Braiding
NA	5.3	Point	Steep Riffle or Head Cut	Head Cut Steep Riffle
NA	5.4	Point	Stream Crossing	Stream Ford Animal Crossing
NA	3.3	Point	Gully	NA
6.2	1.3	Line	Development	NA
6.1	1.3	Line	Encroachment	Berm Improved Path Road Railroad
5.3	3.1	Line	Bank Armoring or Revetment	Rip-Rap Hard Bank Other
7.2	3.1	Line	Erosion	NA
5.4	5.5	Line	Straightening	Straightening With Windrowing

Phase 3: Phase 3 surveys involve the collection of detailed, reach-scale survey data to verify or build upon Phase 2 data. These surveys are typically carried out prior to project development for an "active" channel management approach (e.g., floodplain restoration), or for long-term monitoring purposes.

2.2 Quality Assurance

The VTDEC Quality Assurance (QA) protocols outlined in the SGA protocols (VTDEC, 2009) were followed in order to ensure a complete and accurate dataset. FEA and VTDEC shared responsibility for QA for the

SGAT shapefiles and the finalized Phase 2 dataset. The DMS database for all Phase 2 assessed reaches in the watershed was finalized in June, 2014.

2.3 Bridge and Culvert Assessments

FEA conducted bridge surveys on all private and public bridges 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 (VTDEC, 2009) were followed. Latitude and Longitude of each structure was recorded in the field with a GPS unit or digitized based on aerial imagery. The assessment included various photographs documenting the condition of each structure.

2.4 Stressor and Departure Analysis

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

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

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

2.4.1 Stressor Analysis

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

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

2.4.2 Departure Analysis

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

Analysis of a watershed's sediment regime is a useful approach for summarizing the reach and watershed-scale stressors affecting the equilibrium conditions of river channels. Sediment regime mapping provides a context for understanding the sediment transport and channel evolution processes (Schumm, 1977) which govern changes in geometry and planform for river channels in a state of disequilibrium. The VTANR River Corridor Planning Guide (VTANR, 2010) outlines a methodology for understanding the reference and altered sediment regimes of reaches according to data collected during the Phase 2 field assessments. The sediment regime types used in this analysis are summarized below in Table 2.2.

Table 2.2: Sediment regime types for corridor planning (VTANR, 2010).

Sediment Regime	Narrative Description
Transport	Steeper bedrock and boulder/cobble cascade and step-pool stream types; typically in more confined valleys, do not supply appreciable quantities of sediments to downstream reaches on an annual basis; little or no mass wasting; storage of fine sediment is negligible due to high transport capacity derived from both the high gradient and/natural entrenchment of the channel.
Confined Source and Transport	Cobble step pool and steep plane bed streams; confining valley walls, comprised of erodible tills, glacial lacustrine, glacial fluvial, or alluvial materials; mass wasting and landslides common and may be triggered by valley rejuvenation processes; storage of coarse or fine sediment is limited due to high transport capacity derived from both the gradient and entrenchment of the channel. Look for streams in narrow valleys where dams, culverts, encroachment (roads, houses, etc.), and subsequent channel management may trigger incision, rejuvenation, and mass wasting processes.
Unconfined Source and Transport	Sand, gravel, or cobble plane bed streams; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to entrenchment or incision and associated bed form changes; these streams are not a significant sediment supply due to boundary resistance such as bank armoring, but may begin to experience erosion and supply both coarse and fine sediment when bank failure lead to channel widening; storage of coarse or fine sediment is negligible due to high transport capacity derived from the deep incision and little or no floodplain access. Look for straightened, incised or entrenched streams in unconfined valleys, which may have been bermed and extensively armored and are in Stage II or early Stage III of channel evolution.
Fine Source and Transport & Coarse Deposition	Sand, gravel, or cobble streams with variable bed forms; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to vertical profile and associated bed form changes; these streams supply both coarse and fine sediments due to little or no boundary resistance; storage of fine sediment is lost or severely limited as a result of channel incision and little or no floodplain access; an increase in coarse sediment storage occurs due to a high coarse sediment load coupled with the lower transport capacity that results from a lower gradient and/or channel depth. Look for historically straightened, incised, or entrenched streams in unconfined valleys, having little or no boundary resistance, increased bank erosion, and large unvegetated bars. These streams are typically in late Stage III and Stage IV of channel evolution.

Table 2.2: Sediment regime types for corridor planning (VTANR, 2010).

Sediment Regime	Narrative Description
Coarse Equilibrium (in = out) & Fine Deposition	Sand, gravel, or cobble streams with equilibrium bedforms; at least one side of the channel is unconfined by valley walls; these streams transport and deposit coarse sediment in equilibrium (stream power—produce as a result of channel gradient and hydraulic radius—is balanced by the sediment load, sediment size, and channel boundary resistance); and store a relatively large volume of fine sediment due to the access of high frequency (annual) floods to the floodplain. Look for unconfined streams, which are not incised or entrenched, have boundary resistance (woody buffers), minimal bank erosion, and vegetated bars. These streams are Stage I, late IV, and Stage V.
Deposition	Silt, sand, gravel, or cobble streams with variable and braided bed forms; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to changes in slope and/or depth resulting in the predominance of transient depositional features; storage of fine and coarse sediment frequently exceeds transport**. Floodplains are accessed during high frequency (annual) floods. Look for unconfined streams, which are not incised or entrenched, have become significantly over-widened, and if high rates of bank erosion are present, it is offset by the vertical growth of unvegetated bars. These regimes may be located at zones of naturally high deposition (e.g., active alluvial fans, deltas, or upstream of bedrock controls), or may exist due to impoundment and other backwater conditions above weirs dams and other constrictions.

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

Channel evolution models (CEM) also provide a basis for understanding the temporal scale of channel adjustments and departure in the context of SGA Phase 2 results. Both the "D" stage and "F" stage CEMs (VTDEC, 2009) are helpful for explaining the channel adjustment processes underway in the Green River watershed. The "F" stage CEM is used to understand the process that occurs when a stream degrades (incises) its bed. The more dominant adjustment process for the "D" stage channel evolution is aggradation, widening and planform change. D-stage CEM typically occurs where grade controls prevent severe channel incision and abandonment of the adjacent floodplain. The common stages of both CEMs are depicted in Figure 2.1 below.

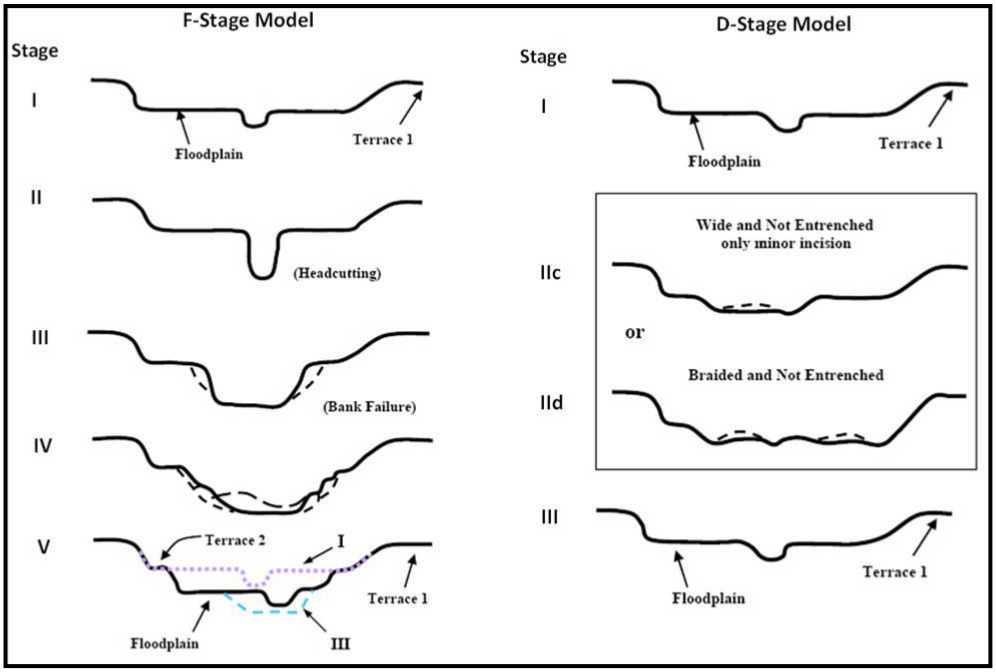


Figure 2.1: Typical channel evolution models for F-stage and D-stage (VTDEC, 2009).

2.4.3 Sensitivity Analysis

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

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

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

2.5 Project Identification

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

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

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

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

3.0 Phase 1 Data Analysis and Results

3.1 Phase 1 Reaches

Phase 1 reaches were selected based on the original intent of including the Green River mainstem and Hinesburg Brook, as both sustained major erosion damage during TSI. However, reaches were delineated for a total of five tributaries in the watershed (Figure 3.1), including: T1 Roaring Brook, T2 Deer Pond Brook, T3 Hinesburg Brook, T4 Pond Brook, and T5 Harrisville Brook. Phase 1 assessments were limited to the reaches selected in consultation with the steering committee, including Green River mainstem M01 through M17, and Hinesburg Brook T3.01 through T3.03. Detailed information about each reach location is found in the reach reports in Appendix A.

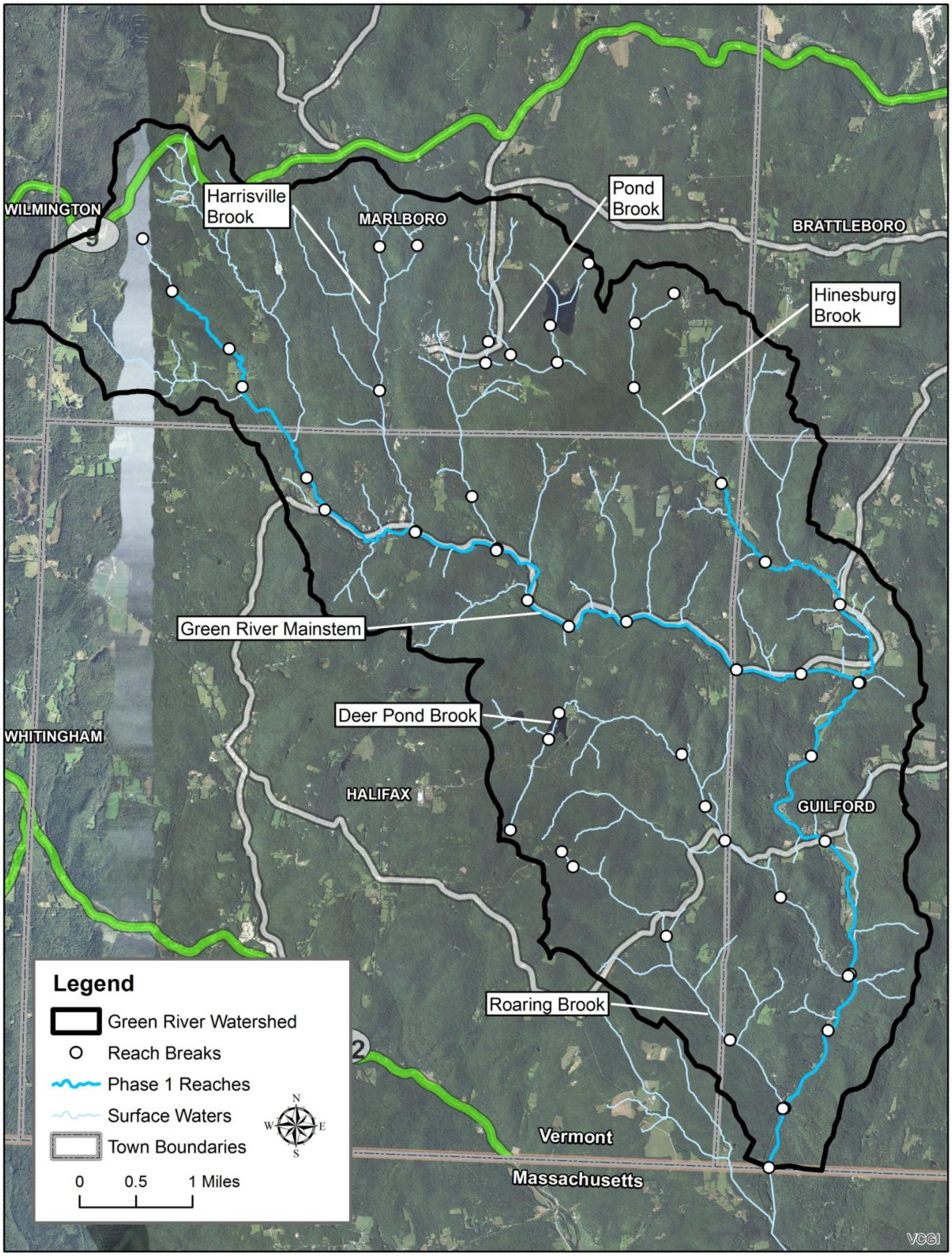


Figure 3.1: Green River Phase 1 reach breaks and assessed reaches.

3.2 Phase 1 Impacts Summary

Based on the Phase 1 impact scores, the DMS developed predictions for channel adjustment processes (VTDEC, 2009). These predictions are based on the dominant impacts recorded for each reach, and are categorized based on the impacts typically associated with the following four channel adjustment processes: 1) Degradation (e.g., channel incision); 2) Aggradation (e.g., increased sediment deposition); 3) Channel widening (e.g., increased bank erosion); 4) Planform Changes (e.g., irregular meander patterns) (Table 3.1 and Figure 3.2). In the Green River watershed, river corridor and floodplain encroachments were the most pervasive impacts (Figure 3.3), with 15 out of 20 reaches having a "high" impact. Using the channel adjustment process ratings, a provisional geomorphic rating is developed for each reach based on the methods outlined in the SGA Phase 1 protocols (VTDEC, 2009). Table 3.2 outlines the four possible geomorphic ratings based on the SGA methods, and Figure 3.4 presents the provisional geomorphic condition for all study reaches.

Table 3.1: Final impact score parameters for phase 1 dataset.

Phase 1 Step	Phase 1 Parameter	Impact Category
4.1	Local Watershed Land Cover/Land Use	Land Use
4.2	Corridor Watershed Land Cover/Land Use	
4.3	Riparian Buffer Width	
5.1	Flow Regulations	Channel Modifications
5.2	Bridges and Culverts	
5.3	Bank Armoring	
5.4	Channel Straightening	
5.5	Dredging and Gravel Mining	
6.1	River Corridor Encroachments	Floodplain Modifications and Planform Changes
6.2	River Corridor Development	
6.3	Depositional Features	
6.4	Meander Migration	
6.5	Meander Belt Width Departure	
6.6	Meander Wavelength Departure	
7.2	Bank Erosion	Bed and Bank Conditions
7.3	Debris and Ice Jam Potential	

Table 3.2: SGA reach condition ratings.

SGA Rating	Predicted Conditions and Processes
Reference	In Equilibrium – no apparent or significant channel, floodplain, or land cover modifications; channel geometry is likely to be in balance with the flow and sediment produced in its watershed.
Good	In Equilibrium but may be in transition into or out of the range of natural variability – minor erosion or lateral adjustment but adequate floodplain function; any adjustment from historic modifications nearly complete.
Fair	In Adjustment – moderate loss of floodplain function; or moderate to major planform adjustments that could lead to channel avulsions.
Poor	In Adjustment and Stream Type Departure - may have changed to a new stream type or central tendency of fluvial processes – significant channel and floodplain modifications may have altered the channel geometry such that the stream is not in balance with the flow and sediment produced in its watershed.

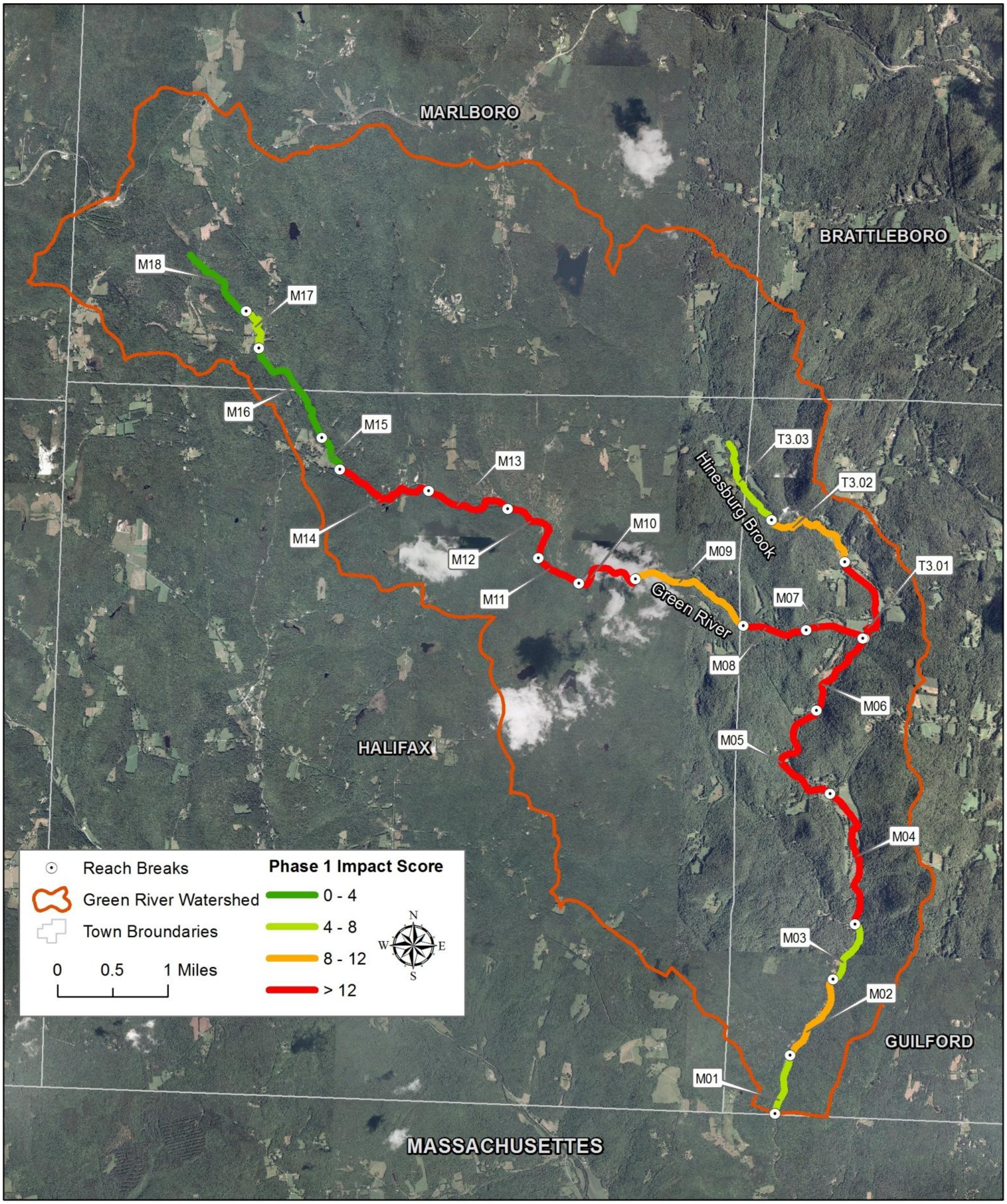


Figure 3.2: Phase 1 impact scores for the Green River watershed.

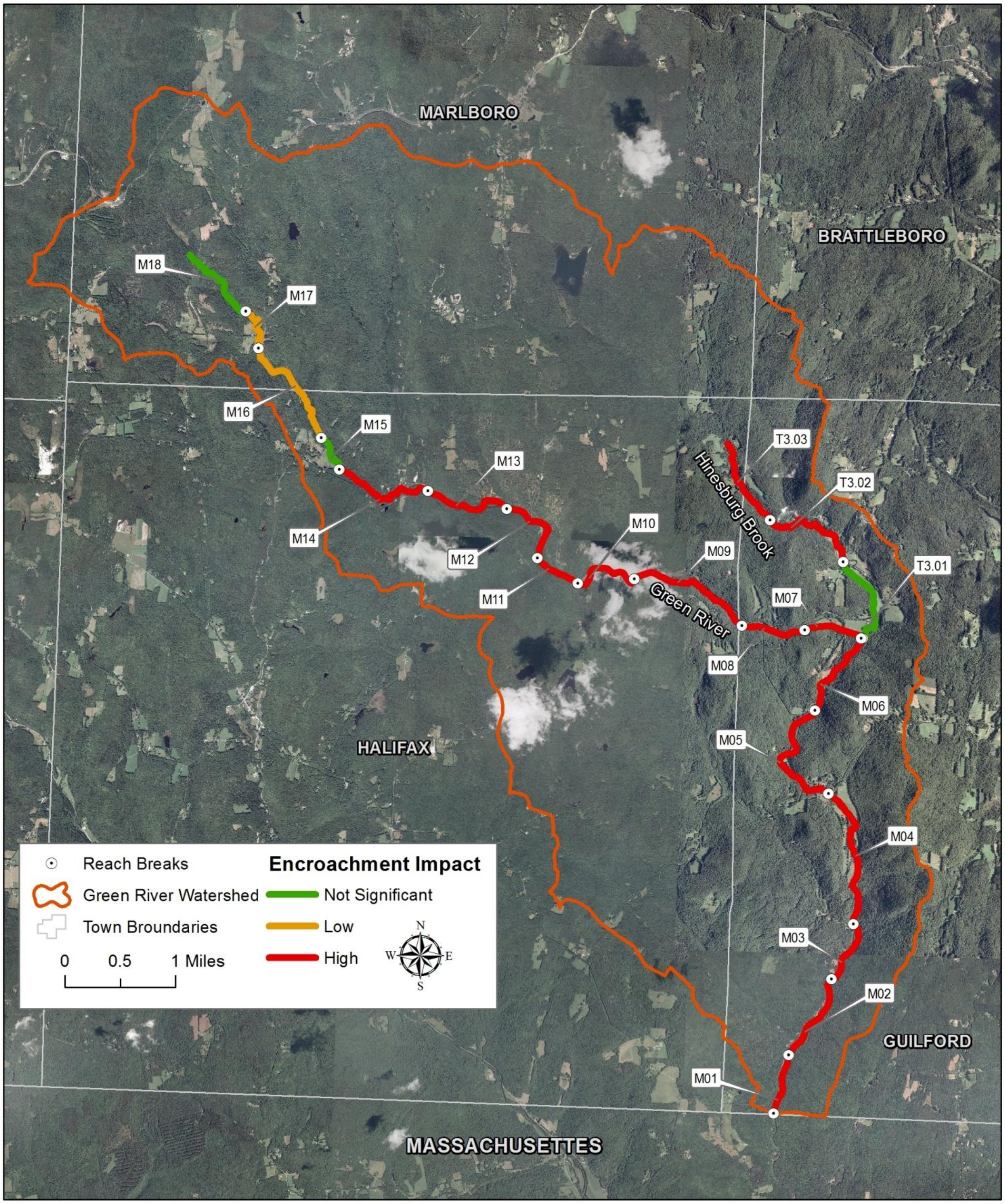


Figure 3.3: Phase 1 encroachment impacts for the Green River watershed.

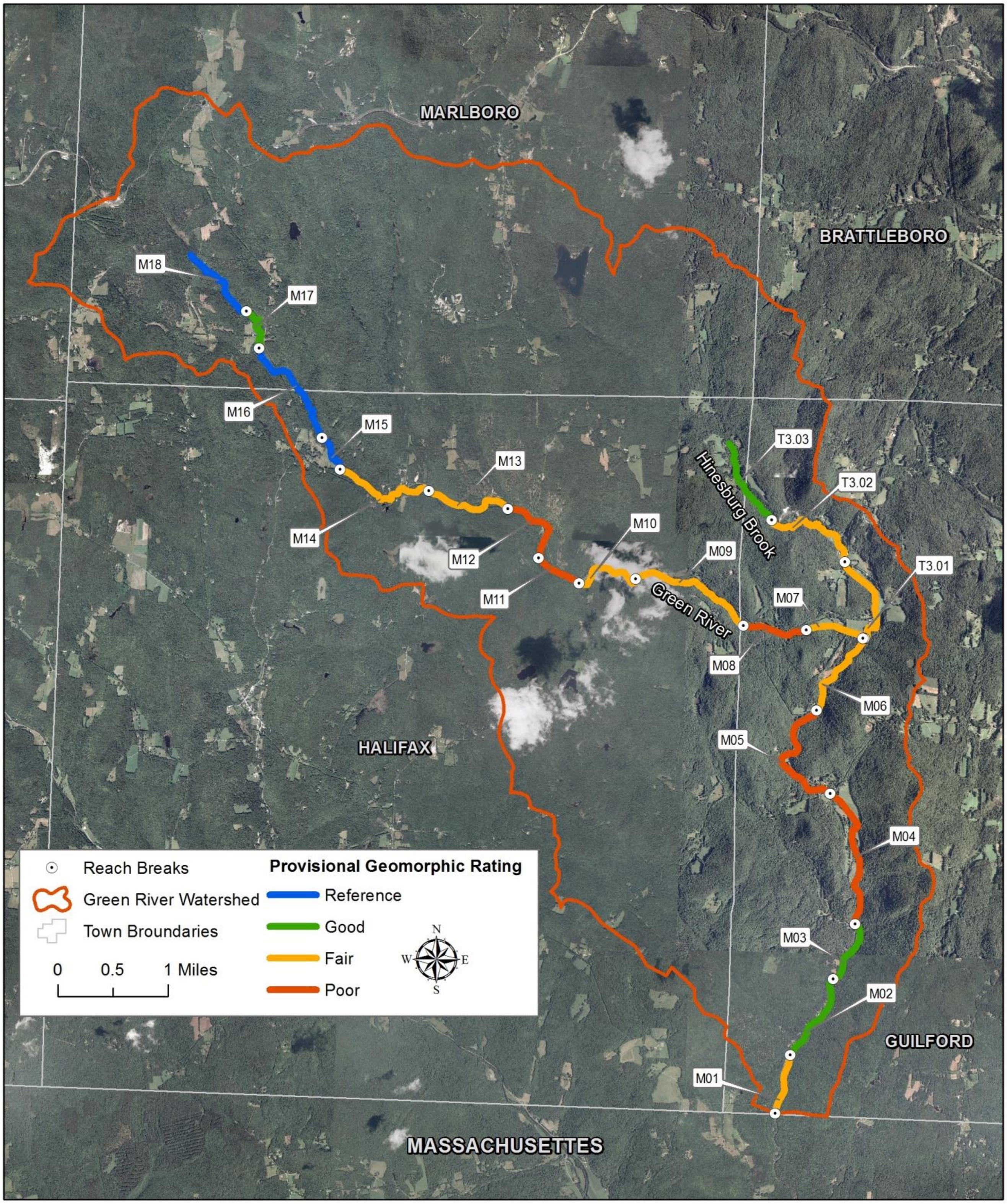


Figure 3.4: Provisional geomorphic ratings for the Green River watershed.

3.3 Phase 2 Reach Prioritization

The scope of work under the VTANR ERP grant included a minimum of 8 river miles for Phase 2, with a focus on the Green River mainstem. Using the Phase 1 Impact Ratings as the primary basis for reach selection, a list of priority reaches was developed for the Phase 2 surveys. This list was reviewed by the steering committee, and 10 reaches (8.6 river miles) were selected along the mainstem for Phase 2, including reaches M04 through M13. Table 3.3 summarizes the selected reaches based on watershed location, channel length, and preliminary reference stream type.

Table 3.3: Phase 1 Impact Ratings and Selected Phase 2 Reaches in **Bold**.

Surface Water	Reach ID	Channel Length (Mi)	Reference Stream Type†	Bedform‡	Impact Score (Geo Condition)
Green River	M01	0.56	B4c	Riffle-Pool	8 (Fair)
	M02	0.85	B4c	Riffle-Pool	10 (Good)
	M03	0.62	B4c	Riffle-Pool	7 (Good)
	M04	**1.37**	**C4**	**Riffle-Pool**	**22 (Poor)**
	M05	**1.28**	**C3**	**Riffle-Pool**	**19 (Poor)**
	M06	**0.86**	**C4**	**Riffle-Pool**	**16 (Fair)**
	M07	**0.90**	**C4**	**Riffle-Pool**	**17 (Fair)**
	M08	**0.99**	**C4**	**Riffle-Pool**	**22 (Poor)**
	M09	**0.86**	**B3**	**Riffle-Pool**	**10 (Fair)**
	M10	**0.55**	**C3**	**Riffle-Pool**	**17 (Fair)**
	M11	**0.61**	**B3c**	**Riffle-Pool**	**13 (Poor)**
	M12	**1.19**	**C3b**	**Riffle-Pool**	**19 (Poor)**
	M13	**0.70**	**B3**	**Riffle-Pool**	**16 (Fair)**
	M14	0.44	C4	Riffle-Pool	13 (Fair)
	M15	0.73	C4	Riffle-Pool	4 (Reference)
	M16	0.84	B3	Step-Pool	3 (Reference)
	M17	1.03	C4	Riffle-Pool	6 (Good)
	M18	0.38	A2	Step-Pool	2 (Reference)
Hinesburg Brook	T3.01	1.11	C3b	Riffle-Pool	13 (Fair)
	T3.02	0.51	B3	Step-Pool	11 (Fair)
	T3.03	0.83	B3a	Step-Pool	8 (Good)

† per Rosgen, 1994; ‡ per Montgomery and Buffington, 1997

As described above, a number of reaches were excluded from the Phase 2 surveys due to budget limitations. These included the lowermost mainstem reaches (M01 to M03), the uppermost mainstem reaches (M14 to M18), and all of Hinesburg Brook (T3.01 to T3.03). Phase 1 data were populated in the DMS for each reach, and below is a brief summary of each area and a justification for exclusion from the Phase 2 study.

Lower Green River (M01 to M03)

Beginning at the VT-MA border, the first three reaches of the Green River are characterized by channel slopes of less than 1 percent, and a confined valley setting. River Road follows and encroaches on the river throughout this section (Figure 3.5). There are several homes found along Green River Road, but they are all situated on the west side of the road and are elevated above the floodplain. Although the road sustained significant damage during TSI, mapping of fluvial erosion hazards along residential development would not have been as valuable as in other areas of the watershed. Given the confined valley and the long-term maintenance of the road, mapping of the river corridor can be achieved without the collection of detailed Phase 2 SGA data. As such, these reaches were excluded from the Phase 2 reaches per advice from VTDEC.

Figure 3.5: Looking downstream near the state line along Reach M01 with encroachment from River Road.

Upper Green River (M14 to M18)
Upstream of the confluence of Harrisville Brook with the Green River (M13-M14 reach break), the main stem varies considerably. There appeared to be less flooding and erosion damage in these reaches from TSI. Major flood damage from reach M13 and downstream appeared to coincide with heavy runoff entering the main stem from the northerly drainages including Harrisville Brook and Pond Brook. Severe damage also occurred along US Route 9 in Marlboro due to flooding in the upper Whetstone Brook watershed; this area corresponds to the same steep, mountainous areas draining to the Green River watershed.

Three reaches in the upper watershed (M14, M15, and M17) had “C-type” channel and floodplain morphology, with some impacts noted due to road encroachments (Figure 3.6). Two reaches are characterized by steeper channels in confined valley settings (M16 and M18). Several bedrock grade controls were noted in the upper reaches along Butterfield Road (Figure 3.6). In general, the reaches were in good condition in this section of the watershed.

Figure 3.6: Road encroachment along M14 (left) and bedrock grade controls in upper M16 (right).

Hinesburg Brook (T1.01 to T1.03)

Hinesburg Brook (T1) sustained severe flooding and erosion damage during TSI. During our windshield surveys we noted several areas of large gravel deposits that were dredged and windrowed during flood recovery (Figure 3.7). These activities appear to have left the channel further confined, reducing the potential for floodwater storage in future floods and therefore making downstream areas more vulnerable to future flood damage. Since Phase 2 data were not collected on Hinesburg Brook, we cannot make site-specific recommendations at this time. However, given the level of damage observed, general recommendations to improve flood resiliency would follow those made for the Green River (see section 5 of report). For example, areas with intact and accessible floodplain should be targeted for restricting development or other activities that would alter the floodplain. Future Phase 2 data collection is recommended on Hinesburg Brook to better understand channel stability and habitat.

Figure 3.7: Berming and windrowing of TSI flood sediments in T3.01 (left) and T3.02 (right).

4.0 Phase 2 Results and River Corridor Planning

Phase 2 assessments were conducted on 10 reaches in May of 2014. Four (4) reaches were segmented in the field for a total of 15 Phase 2 reaches and segments covering 8.6 miles of stream channel (Figure

4.1). The following section includes a summary sheet for each assessed reach or segment and a summary of the watershed and reach-scale stressors on channel stability.

4.1 Phase 2 Segment Summary Sheets

One page summaries for each Phase 2 segment/reach are presented in this section. The impact summary section assigns Not Significant, **Low**, or **High** levels of impact based on data collected during the Phase 2 assessments. Impact levels were assigned based on the longitudinal effect (<5% - Not Significant, 5-20% - Low, and >20% - High), and the overall impact of discrete features on the reach/segment (constrictions, stormwater inputs, steep riffles, etc.). Potential impacts for bridges were summarized with the following abbreviations:

- **AOP**: Aquatic organism passage
- **D**: Deposition upstream and/or downstream
- **E**: Bank erosion upstream and/or downstream
- **I**: Ice/Debris jamming
- **R/R**: Failing bank armor upstream and/or downstream
- **S**: Scour upstream and/or downstream

Habitat assessment rankings for large woody debris and pool counts are defined in Table 4.1.

Table 4.1: LWD and Pool Ranking for RHA.

Rank	LWD		Pool	
	Diameter (ft)	Length (relative to wbkf)	Depth (ft)	Length/Width (relative to wbkf)
1	0.5≤D<1.0	<0.5	1.0≤D<2.0	<0.5
2	0.5≤D<1.0	≥0.5	1.0≤D<2.0	≥0.5
3	1.0≤D<2.0	<0.5	2.0≤D<3.0	<0.5
4	1.0≤D<2.0	≥0.5	2.0≤D<3.0	≥0.5
5	D≥2.0	<0.5	D≥3.0	<0.5
6	D≥2.0	≥0.5	D≥3.0	≥0.5
7	--	--	D≥3.0	≥1.0

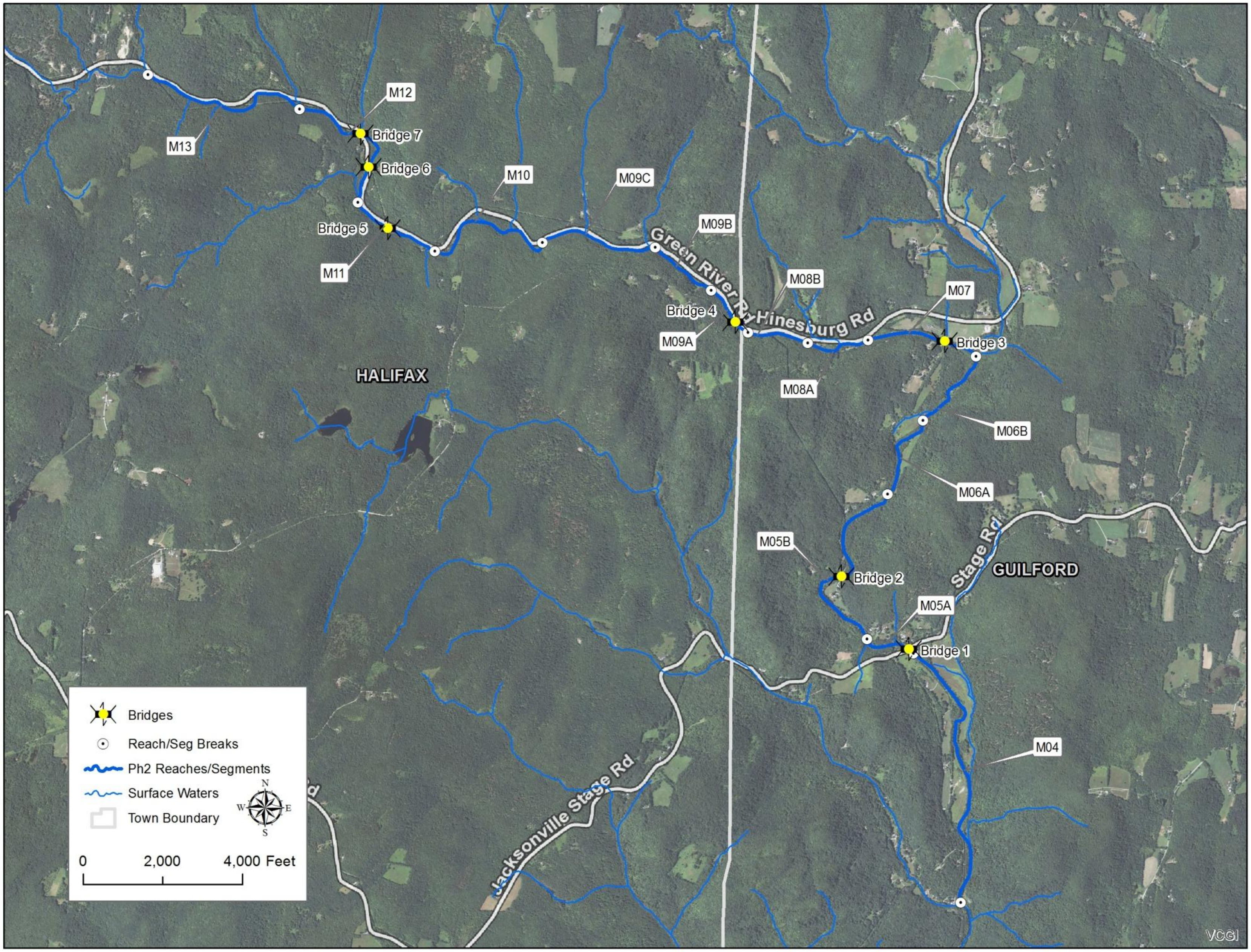


Figure 4.1: Green River Phase 2 Reach, Segment, and Bridge Location Map.

Stream: Green River **Reach:** M04 **Town:** Guilford **Date Assessed:**05/14/14

Channel Length (ft): 7,210 **Channel Slope (%):** 0.87 **Sinuosity:** 1.04 **Watershed Area (mi^2):** 26.13

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	C	C

Ph2 Cross-Section Data

Curve Width (ft)	55.1
Bankfull Width (ft)	69
Max Depth (ft)	3.1
Width/Depth Ratio	27.8
Entrenchment Ratio	7.7
Incision Ratio	1.7

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
None in reach.			

\# of Other Constrictions: 0
\# of Grade Controls: 4

Rapid Habitat Assessment

Rank	LWD	Pools
1	4	4
2	11	2
3	5	5
4	5	0
5	0	2
6	0	2
7	-	0
#/mile	18	10

Number of Debris Jams: 2

Step 6/7 Summary

RHA Score/Condition	57/Fair
Habitat Type Departure	None
RGA Score / Condition	50/Fair
Dominant Adjustment	Planform
CEM Model Stage	F / IV
Stream Type Departure	None
Stream Sensitivity	Very High

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- #1 - Road embankment repair to protect road and increase bankfull width (wbkf)
- #2 - Utility pole in active flood chute
- #3 - Corridor protection and buffer plantings in valuable right floodplain
- #4 - Road embankment repair to protect road
- #5 - Buffer plantings on VLT land

Reach Highlights: Though the reach is highly incised (1.7), a large floodplain meadow is present throughout the reach and is accessible during larger events. Huge debris and sediment deposition were observed across the floodplain from TSI. The channel widened during recent episodic flooding and is currently building of bars and gradually forming meanders indicating planform adjustment, resulting in a stage IV CEM designation. The upper portion of the reach has high encroachment from River Rd on the right bank, but still maintains an accessible floodplain on the opposite bank.

Ample flood storage, which was accessed during TSI leaving debris deposits along far tree line of field

Typical over widened channel demonstrated by bank scouring

Stream: Green River **Reach:** M05A **Town:** Guilford **Date Assessed**:05/14/14

Channel Length (ft): 1,376 **Channel Slope (%):** N/A **Sinuosity:** 1.06 **Watershed Area (mi^2):** 24.73

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Broad
Bedform	Riffle-Pool	Plane Bed
Median Substrate	Cobble	Gravel
Stream Type	C	B_c

Ph2 Cross-Section Data

Curve Width (ft)	53.7
Bankfull Width (ft)	
Max Depth (ft)	
Width/Depth Ratio	
Entrenchment Ratio	
Incision Ratio	

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Stage Rd	160%	

\# of Other Constrictions: 0
\# of Grade Controls:1

Rapid Habitat Assessment

Rank	LWD	Pools
1	2	0
2	1	0
3	0	1
4	2	1
5	0	0
6	0	1
7	-	0
#/mile	19	11

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	NA/Poor
Habitat Type Departure	Plane Bed
RGA Score / Condition	NA/Fair
Dominant Adjustment	
CEM Model Stage	
Stream Type Departure	
Stream Sensitivity	

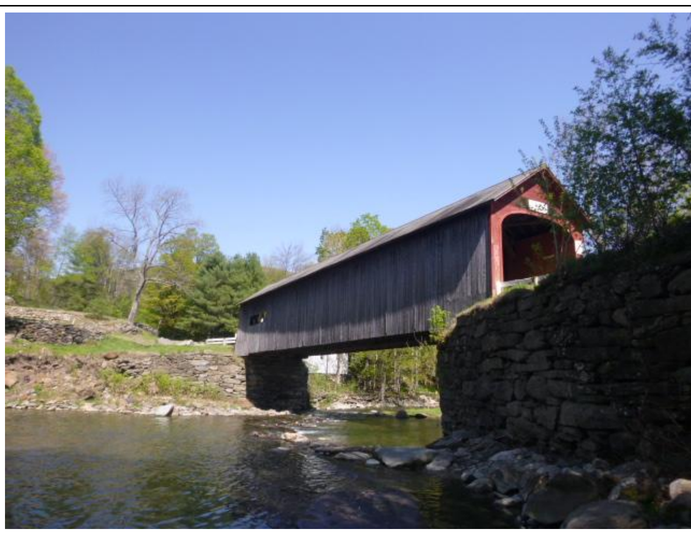
Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	**Dredging**

Potential Projects in Reach

- #6 - Timber crib dam sediment management and/or long term planning for dam removal.

Reach Highlights: This reach was segmented out and only partially assessed due to extreme sedimentation and ponding above the timber crib dam. The 13 foot tall dam has completely filled in with sand and gravel burying the natural stream bottom for approximately 1,100 feet to the start of M05-B. The dam is built on a bedrock grade control which continues downstream to the stacked stone abutments for the historic Green River covered bridge. A fish ladder was constructed around the dam, however the sediment deposits above the dam limit fish movement at low flows.



Historic Green River covered bridge

Sediment filling channel above dam

Stream: Green River **Reach:** M05B **Town:** Guilford **Date Assessed**:05/14/14

Channel Length (ft): 5,382 **Channel Slope (%):** 0.82 **Sinuosity:** 1.12 **Watershed Area (mi^2):** 24.73

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	53.7
Bankfull Width (ft)	63
Max Depth (ft)	3.1
Width/Depth Ratio	28.3
Entrenchment Ratio	1.3
Incision Ratio	2.1

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	G River Rd	140%	D, E

\# of Other Constrictions: 0
\# of Grade Controls:1

Rapid Habitat Assessment

Rank	LWD	Pools
1	4	2
2	11	5
3	2	3
4	1	2
5	0	0
6	0	2
7	-	0
#/mile	18	14

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	61/Fair
Habitat Type Departure	None
RGA Score / Condition	43/Fair
Dominant Adjustment	Degradation
CEM Model Stage	F / II
Stream Type Departure	C → F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- #7 - Berm removal to restore access to left floodplain
- #8 - Move utility pole and assess bank stability

Reach Highlights: This reach was heavily encroached by Green River Rd causing the channel to degrade (CEM stage II) greatly reducing floodplain access, resulting in major incision (2.1) and entrenchment (1.3) and a stream type departure of C to F. Following TSI, some of the existing floodplain was further disconnected by berms created from sediment deposits removed from adjacent fields. Lower banks were scoured back in recent floods resulting in a widened channel. There are indications of aggradation and planform adjustment, though significant aggradation would have to occur in order for floodplain access to be restored for smaller storm events.

Berm on left bank from TSI sediment deposits removed from floodplain

Road encroachment observed through most of reach resulting in degradation of the channel bed and erosion

Stream: Green River **Reach:** M06A **Town:** Guilford **Date Assessed**:05/15/14

Channel Length (ft): 2,284 **Channel Slope (%):** 0.90 **Sinuosity:** 1.05 **Watershed Area (mi^2):** 23.86

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Very Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Cobble
Stream Type	C	B_c

Ph2 Cross-Section Data

Curve Width (ft)	52.9
Bankfull Width (ft)	63
Max Depth (ft)	3.1
Width/Depth Ratio	30.7
Entrenchment Ratio	2.0
Incision Ratio	1.5

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
None in reach.			

\# of Other Constrictions: 0
\# of Grade Controls:0

Rapid Habitat Assessment

Rank	LWD	Pools
1	4	2
2	7	3
3	0	1
4	6	1
5	0	0
6	0	1
7	-	0
#/mile	39	18

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	58/Fair
Habitat Type Departure	None
RGA Score / Condition	51/Fair
Dominant Adjustment	Degradation
CEM Model Stage	F / II
Stream Type Departure	C → B_c
Stream Sensitivity	Very High

Impact Summary

Bank Erosion	**Stormwater**
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- #9 - Remove recent cobble berm to increase access to large left floodplain. Berm is actively eroding and may have breached/eroded in a recent high water event, allowing for sufficient floodplain access
- #10 - Buffer plantings on both floodplains to stabilize banks and improve stream habitat

Reach Highlights: This segment is moderately incised (1.5) due to road encroachment and straightening along Green River Rd and being pinned between a recent berm and a tall armored bank upstream of the road encroachment. The new berm was constructed post-TSI partially blocking access to a large left floodplain. The bed indicated some widening and planform adjustment, but was still degrading overall (CEM stage II) as represented in the C to B stream type departure.

Berm greatly reduces access to a large left bank floodplain and straightens the channel

Bank armoring along road Green River Rd. at a sharp bend in the river

Stream: Green River **Reach:** M06B **Town:** Guilford **Date Assessed**:05/15/14

Channel Length (ft): 2,246 **Channel Slope (%):** 1.08 **Sinuosity:** 1.05 **Watershed Area (mi^2):** 23.86

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Very Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	C	C

Ph2 Cross-Section Data

Curve Width (ft)	52.9
Bankfull Width (ft)	77
Max Depth (ft)	2.6
Width/Depth Ratio	47.2
Entrenchment Ratio	2.6
Incision Ratio	1.3

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
None in reach.			

\# of Other Constrictions: 0
\# of Grade Controls:2

Rapid Habitat Assessment

Rank	LWD	Pools
1	3	2
2	5	4
3	1	0
4	1	0
5	0	0
6	0	1
7	-	0
#/mile	23	16

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	56/Fair
Habitat Type Departure	None
RGA Score / Condition	40/Fair
Dominant Adjustment	Planform
CEM Model Stage	F /IV
Stream Type Departure	None
Stream Sensitivity	Very High

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- #11 - Conservation to protect valuable floodplain throughout reach

Reach Highlights: This segment significantly widened (46%) during TSI. The increased bank scour and intermittent erosion indicate that the channel is still adjusting planform (CEM stage IV) and aggrading within the widened channel. A huge cobble/gravel bar was observed in the middle of the segment, where the channel avulsed to the opposite side of the valley. Low incision (1.3) indicates that floodplain remains available in this C-type channel.

Channel migration resulting in large depositional features

Channel has recently widened and still has accessible floodplain

Stream: Green River **Reach:** M07 **Town:** Guilford **Date Assessed**:05/15/14

Channel Length (ft): 2,878 **Channel Slope (%):** 1.44 **Sinuosity:** 1.00 **Watershed Area (mi^2):** 18.14

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	46.9
Bankfull Width (ft)	74
Max Depth (ft)	2.2
Width/Depth Ratio	52.8
Entrenchment Ratio	1.1
Incision Ratio	2.2

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	G. River Rd.	196%	D

# of Other Constrictions: 0
# of Grade Controls:1

Rapid Habitat Assessment

Rank	LWD	Pools
1	8	3
2	10	7
3	4	4
4	6	0
5	0	0
6	0	2
7	-	0
#/mile	51	29

Number of Debris Jams: 2

Step 6/7 Summary

RHA Score/Condition	59/Fair
Habitat Type Departure	None
RGA Score / Condition	34/Poor
Dominant Adjustment	Widening
CEM Model Stage	F /III
Stream Type Departure	C → F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- #12 - Remove berm along left bank to restore access to floodplain

Reach Highlights: This reach has been significantly impacted from straightening and berming. Recent berming was observed in areas of dredging following TSI. In the upper reach a tall historic berm pinned the river against the valley wall. These berms greatly reduced floodplain access and reduced the entrenchment ratio (1.1) resulting in a stream type departure from C to F. The channel was scoured and widened during TSI (CEM stage III) and had a relatively featureless bed. Large woody debris piles were observed well outside the channel indicating mechanical removal following TSI.

Large woody debris removed from channel following TSI

A historic berm creates a human elevated floodplain by eliminating access to the adjacent field

Stream: Green River **Reach:** M08A **Town:** Guilford **Date Assessed:**05/27/14

Channel Length (ft): 1,654 **Channel Slope (%):** 1.50 **Sinuosity:** 1.02 **Watershed Area (mi^2):** 17.9

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	46.6
Bankfull Width (ft)	69
Max Depth (ft)	2.8
Width/Depth Ratio	45.9
Entrenchment Ratio	1.1
Incision Ratio	2.3

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
None in reach.			

\# of Other Constrictions: 0
\# of Grade Controls:0

Rapid Habitat Assessment

Rank	LWD	Pools
1	4	3
2	6	1
3	1	3
4	0	0
5	0	0
6	0	0
7	-	0
#/mile	35	22

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	54/Fair
Habitat Type Departure	None
RGA Score / Condition	28/Poor
Dominant Adjustment	Degradation
CEM Model Stage	F /II
Stream Type Departure	C → F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	**Head Cut**
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- #13 - Remove abandoned house and associated materials from left floodplain, stabilize eroding banks on island where septic system was located, protect highly active corridor from future development

Reach Highlights: A major avulsion occurred during TSI in the middle of this segment. The encroached and undersized historic channel plugged with debris and cobbles/boulders at a sharp bend and a new channel carved to bedrock along the right valley wall creating a large island with a now abandoned house on it. Huge cobble and gravel deposits formed throughout the widened channel. The segment is given a CEM stage of II because the bed is still actively degrading with a large head cut as it works through the recently deposited material. This segment is highly unstable and is continuously adjusting within the newly formed channel. The degradation of the channel has resulted in extreme incision (2.3) and loss of floodplain access causing a stream type departure from C to F.

Recently abandoned historic channel

Overwidened new channel cutting down through TSI deposits

Stream: Green River **Reach:** M08B **Town:** Guilford **Date Assessed:**05/27/14

Channel Length (ft): 1,555 **Channel Slope (%):** 1.81 **Sinuosity:** 1.02 **Watershed Area (mi²):** 17.9

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Semi-Confined
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Cobble
Stream Type	C	B_c

Ph2 Cross-Section Data

Curve Width (ft)	46.6
Bankfull Width (ft)	45
Max Depth (ft)	2.1
Width/Depth Ratio	26.8
Entrenchment Ratio	1.6
Incision Ratio	1.9

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
None in reach.			

# of Other Constrictions: 0
# of Grade Controls:0

Rapid Habitat Assessment

Rank	LWD	Pools
1	1	2
2	2	0
3	0	1
4	2	0
5	0	0
6	0	0
7	-	0
#/mile	16	10

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	58/Fair
Habitat Type Departure	None
RGA Score / Condition	49/Fair
Dominant Adjustment	Degradation
CEM Model Stage	F /II
Stream Type Departure	C →B
Stream Sensitivity	High

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- #14 - Add topsoil and plant upper armor slope along Green River Road

Reach Highlights: This segment is highly encroached and armored along Hinesburg Rd with development throughout. The extensive armoring pinned the channel against the right valley wall leading to large mass failures and incision as the bed degrades (CEM stage II). Somewhat accessible floodplain benches remain throughout the segment causing the stream type departure from C to B.

Narrow and somewhat accessible floodplain benches consistent throughout reach

Large mass failure at upper reach break

Stream: Green River **Reach:** M09A **Town:** Halifax **Date Assessed:**05/15/14

Channel Length (ft): 1,436 **Channel Slope (%):** 1.77 **Sinuosity:** 1.01 **Watershed Area (mi^2):** 17.28

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Semi-Confined	Semi-Confined
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	B	F

Ph2 Cross-Section Data

Curve Width (ft)	45.9
Bankfull Width (ft)	36
Max Depth (ft)	2.4
Width/Depth Ratio	19.7
Entrenchment Ratio	1.5
Incision Ratio	1.6

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Deer Park	109%	None

\# of Other Constrictions: 1
\# of Grade Controls:0

Rapid Habitat Assessment

Rank	LWD	Pools
1	2	1
2	1	1
3	2	0
4	1	0
5	0	0
6	0	1
7	-	0
#/mile	22	11

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	46/Fair
Habitat Type Departure	None
RGA Score / Condition	47/Fair
Dominant Adjustment	Degradation
CEM Model Stage	F /II
Stream Type Departure	B → F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	Deposition
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- None

Reach Highlights: This segment is heavily armored and encroached on the left bank by Green River Rd. The right bank is naturally armored due to stony soils. The new Deer Park Rd Bridge does not represent a channel constriction at the abutments, however riprap along the base of walls constricts the channel to 32ft. Most of the reach is constricted by the road embankment to an average Wbkf =35ft. A large mass failure was observed at the bottom of the reach where the stream moves away from the road and has a chance to widen/adjust planform. Incision was moderate to high (1.6), but due to the nearly continuous armor and confinement the stream is stuck in CEM stage II. Entrenchment ratio is 1.5 but stream type departure from B to F best represents impacts to channel/valley morphology on this reach.

This reach was heavily armored along Green River Rd

Road encroachment contributed to mass failures and bank erosion on opposite bank

Stream: Green River **Reach:** M09B **Town:** Halifax **Date Assessed**:05/15/14

Channel Length (ft): 1,819 **Channel Slope (%):** 4.50 **Sinuosity:** 1.01 **Watershed Area (mi^2):** 17.28

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Semi-Confined	Narrowly-Confined
Bedform	Step-Pool	Step-Pool
Median Substrate	Boulder	Boulder
Stream Type	A	A

Ph2 Cross-Section Data

Curve Width (ft)	45.9
Bankfull Width (ft)	60
Max Depth (ft)	2.3
Width/Depth Ratio	41.9
Entrenchment Ratio	1.2
Incision Ratio	1.0

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
None in reach.			

\# of Other Constrictions: 0
\# of Grade Controls:0

Rapid Habitat Assessment

Rank	LWD	Pools
1	9	4
2	14	1
3	0	13
4	13	3
5	1	2
6	1	1
7	-	0
#/mile	110	69

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	68/Good
Habitat Type Departure	None
RGA Score / Condition	80/Good
Dominant Adjustment	Stable
CEM Model Stage	F /I
Stream Type Departure	None
Stream Sensitivity	Very Low

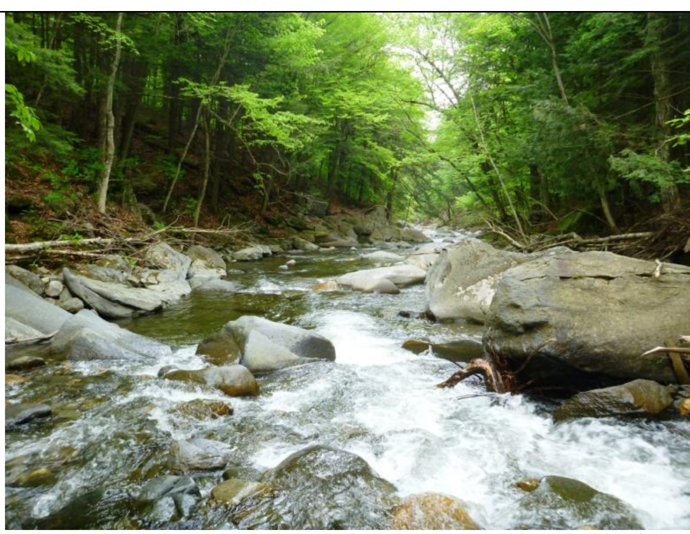
Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- None

Reach Highlights: This segment was in near reference condition as an A2 step-pool. The channel was stable, resulting in a CEM stage I designation. Some increased gravel deposition was observed in pools as flood sediments work through the segment. A large mass failure occurred on the right bank at the bottom of the segment and is likely a contributing sediment source for lower reaches.



Well defined step pool sequence through boulders

Debris blocking flood chute forcing flow against the far right bank resulting in a mass failure

Stream: Green River **Reach:** M09C **Town:** Halifax **Date Assessed:**05/15/14

Channel Length (ft): 3,038 **Channel Slope (%):** 2.06 **Sinuosity:** 1.01 **Watershed Area (mi^2):** 17.28

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Semi-Confined	Semi-Confined
Bedform	Riffle-Pool	Plane Bed
Median Substrate	Cobble	Cobble
Stream Type	C_b	B

Ph2 Cross-Section Data

Curve Width (ft)	45.9
Bankfull Width (ft)	46
Max Depth (ft)	2.8
Width/Depth Ratio	25.6
Entrenchment Ratio	1.5
Incision Ratio	2.3

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
None in reach.			

\# of Other Constrictions: 0
\# of Grade Controls:2

Rapid Habitat Assessment

Rank	LWD	Pools
1	14	1
2	10	1
3	0	5
4	2	3
5	0	1
6	0	0
7	-	0
#/mile	45	19

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	53/Fair
Habitat Type Departure	RP → PB
RGA Score / Condition	41/Fair
Dominant Adjustment	Degradation
CEM Model Stage	F /II
Stream Type Departure	C → B
Stream Sensitivity	High

Impact Summary

Bank Erosion	**Stormwater**
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- #15 - Add topsoil and plant upper armor slope along two sections of Green River Road

Reach Highlights: This segment is deeply incised (2.3) and entrenched (1.5) leading to a stream type departure from C to B. Floodplain storage was limited throughout the reach to small raised benches. Green River Rd shares the narrow valley throughout and the river is typically pushed up against the right valley wall, exacerbating bank erosion and mass failures. The river has very little room to widen or adjust planform and is therefore likely stuck in CEM stage II.


Bank armoring and road encroachment resulting in heavy bank scour and erosion on opposite bank


Limited floodplain storage on raised bench, which was consistent throughout the reach

Stream: Green River **Reach:** M10 **Town:** Halifax **Date Assessed**:05/15/14

Channel Length (ft): 3,703 **Channel Slope (%):** 1.72 **Sinuosity:** 1.13 **Watershed Area (mi^2):** 15.96

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	44.3
Bankfull Width (ft)	68
Max Depth (ft)	2.2
Width/Depth Ratio	41
Entrenchment Ratio	1.3
Incision Ratio	2.2

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
None in reach.			

\# of Other Constrictions: 0
\# of Grade Controls:0

Rapid Habitat Assessment

Rank	LWD	Pools
1	7	0
2	10	0
3	2	1
4	4	1
5	0	0
6	0	1
7	-	2
#/mile	32	7

Number of Debris Jams: 2

Step 6/7 Summary

RHA Score/Condition	63/Fair
Habitat Type Departure	None
RGA Score / Condition	38/Fair
Dominant Adjustment	Widening
CEM Model Stage	F /III
Stream Type Departure	C → F
Stream Sensitivity	Extreme

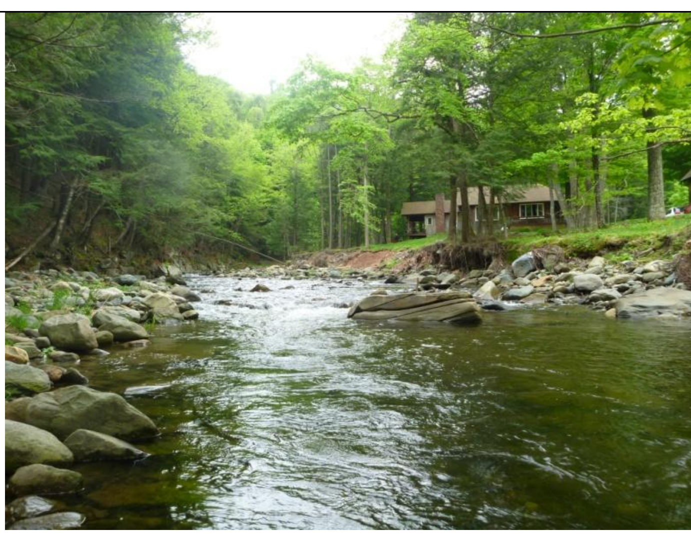
Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- #16 - Buffer plantings along low floodplain bench between the river and Green River Road
- #17 - Buffer planting and bank stabilization along Dawn till Dusk farm property

Reach Highlights: This reach widened during TSI by scouring away the lower banks (CEM stage III). This resulted in extreme incision (2.2) and loss of historic floodplain access creating a stream type departure from C to F. Some planform adjustments were observed, but most banks were well forested or armored, limiting future adjustments. Evidence of a major debris jam during TSI was observed, which likely caused a large flood chute mid-reach.


Bedrock forces flow against property causing bank erosion as channel widens


Bank scour observed through most of reach indicating recent widening

Stream: Green River **Reach:** M11 **Town:** Halifax **Date Assessed**:05/14/14

Channel Length (ft): 2,334 **Channel Slope (%):** 1.90 **Sinuosity:** 1.03 **Watershed Area (mi^2):** 14.91

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	B_c	B_c

Ph2 Cross-Section Data

Curve Width (ft)	43
Bankfull Width (ft)	54
Max Depth (ft)	2.5
Width/Depth Ratio	31.8
Entrenchment Ratio	1.3
Incision Ratio	1.6

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Foot Bridge	74%	None

\# of Other Constrictions: 0
\# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	3	1
2	15	0
3	3	3
4	0	0
5	0	1
6	0	0
7	-	0
#/mile	47	11

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	50/Fair
Habitat Type Departure	None
RGA Score / Condition	45/Fair
Dominant Adjustment	Degradation
CEM Model Stage	F /II
Stream Type Departure	None
Stream Sensitivity	High

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	Deposition
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- #18 - Reconfigure bridge abutment armoring to reduce channel constriction and vulnerability of erosion
- #19 - Add topsoil and plant upper armor slope along two sections of Green River Road

Reach Highlights: Reference channel morphology includes C and B_c, with B_c dominant. This reach widened during TSI as lower banks were scoured away. The channel is now moderately incised (1.6) and entrenched (1.3) and has accessible floodplain benches, causing no stream type departure. Minor planform adjustments are occurring but much of the reach is encroached and armored along Green River Road. This armoring and encroachment limit the amount of stream adjustment and likely slow the progress out of stage II. Erosion was common opposite encroachment and armoring.

Bank armoring around foot bridge causes channel constriction

Bank erosion observed through much of the reach as a result of road encroachment and armoring

Stream: Green River **Reach:** M12 **Town:** Halifax **Date Assessed:**05/14/14

Channel Length (ft): 3,870 **Channel Slope (%):** 1.96 **Sinuosity:** 1.07 **Watershed Area (mi^2):** 14.41

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	Cb	F

Ph2 Cross-Section Data

Curve Width (ft)	42.4
Bankfull Width (ft)	59
Max Depth (ft)	3.0
Width/Depth Ratio	30.7
Entrenchment Ratio	1.3
Incision Ratio	2.2

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	G. River Rd.	189%	None
B	G. River Rd.	165%	D
	Bedrock	59%	None

# of Other Constrictions: 0
# of Grade Controls: 1

Rapid Habitat Assessment

Rank	LWD	Pools
1	3	0
2	9	0
3	5	7
4	7	0
5	0	1
6	0	2
7	-	0
#/mile	32	13

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	56/Fair
Habitat Type Departure	None
RGA Score / Condition	46/Fair
Dominant Adjustment	Degradation
CEM Model Stage	F /II
Stream Type Departure	C → F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- #20 - Add topsoil and plant upper armor slope along two sections of Green River Road
- #21 - Remove historic berm and/or road armoring to restore access to a floodplain along the left bank
- #22 - Corridor protection for a small accessible left floodplain between river and Green River Road

Reach Highlights: This reach widened during TSI as lower banks were scoured away. The channel is now deeply incised (2.2) and entrenched (1.3). Minor planform adjustments are occurring but much of the reach is encroached, bermed, or armored along Green River Road. A historic berm cuts off access to some of the only available floodplain in the upper reach. Deep incision cuts off floodplain access on both banks in the lower reach. The limited flood plain access and extreme incision and entrenchment were the driving forces behind the C to F stream type departure. The erosion and heavy scour on both banks in the lower reach appears to be primarily from TSI.


Bank armoring and road encroachment causes the channel to degrade as well as erode banks


Bank armoring and berm that cuts off floodplain access

Stream: Green River **Reach:** M13 **Town:** Halifax **Date Assessed:**05/14/14

Channel Length (ft): 4,453 **Channel Slope (%):** 2.10 **Sinuosity:** 1.06 **Watershed Area (mi^2):** 9.48

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Semi-Confined
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	B	B

Ph2 Cross-Section Data

Curve Width (ft)	35.2
Bankfull Width (ft)	26
Max Depth (ft)	3.0
Width/Depth Ratio	12.8
Entrenchment Ratio	1.5
Incision Ratio	1.4

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
	Bank Armor	84%	None

\# of Other Constrictions: 0
\# of Grade Controls: 2

Rapid Habitat Assessment

Rank	LWD	Pools
1	6	7
2	20	0
3	1	2
4	11	0
5	0	0
6	0	0
7	-	0
#/mile	45	10

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	57/Fair
Habitat Type Departure	None
RGA Score / Condition	52/Fair
Dominant Adjustment	Degradation
CEM Model Stage	F /II
Stream Type Departure	None
Stream Sensitivity	High

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- #23 - Add topsoil and plant upper armor slope along two sections of Green River Road

Reach Highlights: Green River Rd shares the narrow valley throughout the reach, increasing confinement and entrenchment (1.5). The encroachment from Green River Rd exaggerated the incision and entrenchment along this reach, but did not justify a stream type departure. During TSI, the road was damaged and subsequently armored for approximately half of the reach. The stream is pushed against the right valley wall in several areas leading to large mass failures. Tight constriction from the armored embankment is increasing incision in other areas where the valley wall has not failed. Overall this reach has limited opportunity to widen or adjust planform and is likely stuck in CEM stage II for a long time given the extensive bank armoring.

Reach is heavily impacted by bank armoring and road encroachment

Mass failures result from armoring and encroachment as the bed degrades

4.2 Phase 2 Results Summary

RHA and RGA scores for all Phase 2 reaches/segments are summarized in Table 4.2. Detailed summaries of geomorphic data for each segment are provided in Appendix B. Habitat assessment summary data is provided in Appendix C.

Table 4.2: Summary RHA and RGA data for all Phase 2 Reaches and Segments

Reach/Segment	RHA Score	RHA Condition	RGA Score	RGA Condition
M04	57%	Fair	50%	Fair
M05A	*	Poor	*	Fair
M05B	61%	Fair	43%	Fair
M06A	58%	Fair	51%	Fair
M06B	56%	Fair	40%	Fair
M07	59%	Fair	34%	Poor
M08A	54%	Fair	28%	Poor
M08B	58%	Fair	49%	Fair
M09A	46%	Fair	48%	Fair
M09B	68%	Good	80%	Good
M09C	53%	Fair	41%	Fair
M10	63%	Fair	38%	Fair
M11	50%	Fair	45%	Fair
M12	56%	Fair	46%	Fair
M13	57%	Fair	53%	Fair

*RHA and RGA assigned based on administrative judgment, full assessments not conducted on M05A

4.3 River Corridor Planning

The following sections summarize the stressor identification and departure maps. 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. These data, when combined with other watershed-scale data developed in this study, allows for the assessment of physical departure from reference conditions, and serves to validate watershed-scale patterns and stream conditions observed in the field. The mapping of physical stressors and natural or human constraints allowed for 1) a process-based approach to understanding stream conditions at different scales, and 2) an evaluation of the connectivity of stressors along the channel network. The maps were referenced during the project identification process summarized in Section 5.0.

4.3.1 Stressor Maps

Modifications to Riparian and Boundary Condition

The boundary conditions of a river encompass the bed and bank substrate, and the vegetation and root material found along the riverbank. Human alterations to the river boundary conditions are often made to increase the resistance of the banks and bed to reduce lateral and vertical adjustments. However, extensive removal of riparian vegetation in the absence of bank hardening can cause a decrease in boundary resistance, and lead to increased lateral migration. 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 Green River study area have been mapped using the variables extracted from the Phase 2 field dataset (Figure 4.6). Bank armoring (e.g., rip-rap) highlights areas of increased resistance to lateral migration, whereas bank erosion highlights reaches where significant lateral adjustments are found. Additional data showing the location of natural and man-made channel features (e.g., ledges and dam) depict areas that have a resistance to channel change.

Areas influencing riparian zone and boundary conditions include:

Increased Boundary Resistance

- Some dense areas of natural grade control on segments: M04, M09C, M12, and M13
- An on-stream dam is located on segment M05A (Figure 4.2)
- Extensive bank armoring on segments: M09A (Figure 4.3), M11, and M13

Decreased Boundary Resistance

- High bank erosion in segments: M08A, M11, and M12 (Figure 4.4)
- Large mass failures in segments: M08B (Figure 4.5), M10, M12, and M13
- Dredging in segments: M04, M05A, M05B, M07, and M10
- High density of riparian buffer width impacts in segments M04, M05B, M07, M08A, M09A, M09C, and M13

Figure 4.2: Historic timber crib dam on segment M05A.

Figure 4.3: Extensive bank armoring on segment M09A.

Figure 4.4: Bank erosion on reach M11.

Figure 4.5: Large mass failure on segment M08B.

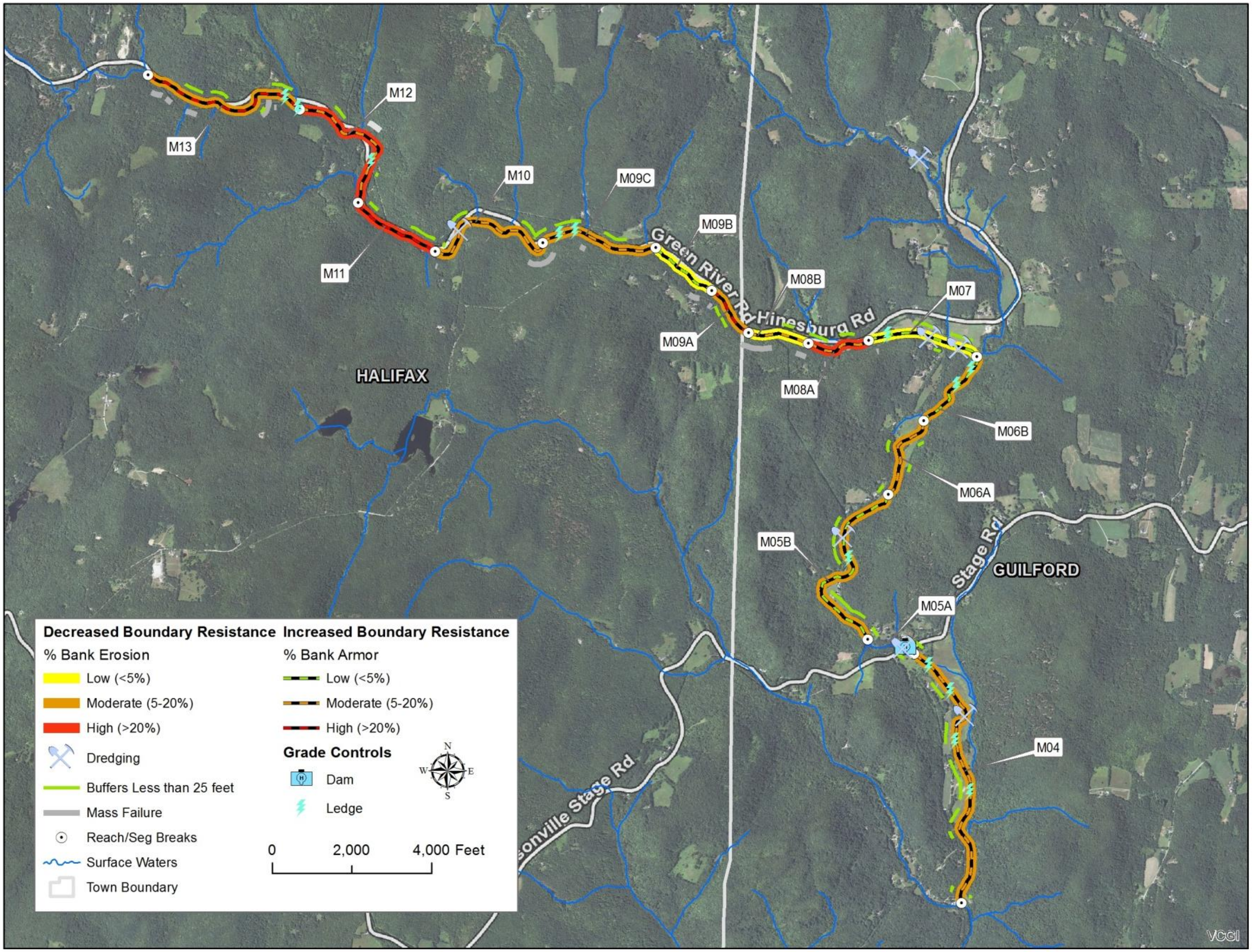


Figure 4.6: Riparian and boundary condition modifiers for the Green River watershed.

Channel Slope and Depth Modifiers

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

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

Alterations to channel slope and depth in the Green River study area have been mapped using the variables extracted from the Phase 2 field dataset (Figure 4.11). 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, development, and berms have reduced the floodplain area, typically resulting in increased stream power and channel deepening. Additional data shows the location of natural channel features (ledges) and a man-made dam, which depict areas that have a resistance to vertical channel change.

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

Increases in Slope and Depth

- Extreme channel straightening in segment : M08B (Figure 4.7)
- High straightening in segments: M04, M06A, M07, and M12
- Extreme corridor encroachments in segments: M08, M09A, M09C, M11, M12, and M13 (Figure 4.8)
- High corridor encroachments in segments: M04, M05B, M06A, and M10 (Figure 4.9)
- Dredging in segments: M04, M05A, M05B, M07, and M10

Controls on Slope and Depth

- Segments with numerous or large natural grade controls: M04, M09C, M12, and M13 (Figure 4.10)
- Segments with man-made grade control (dam): M05A

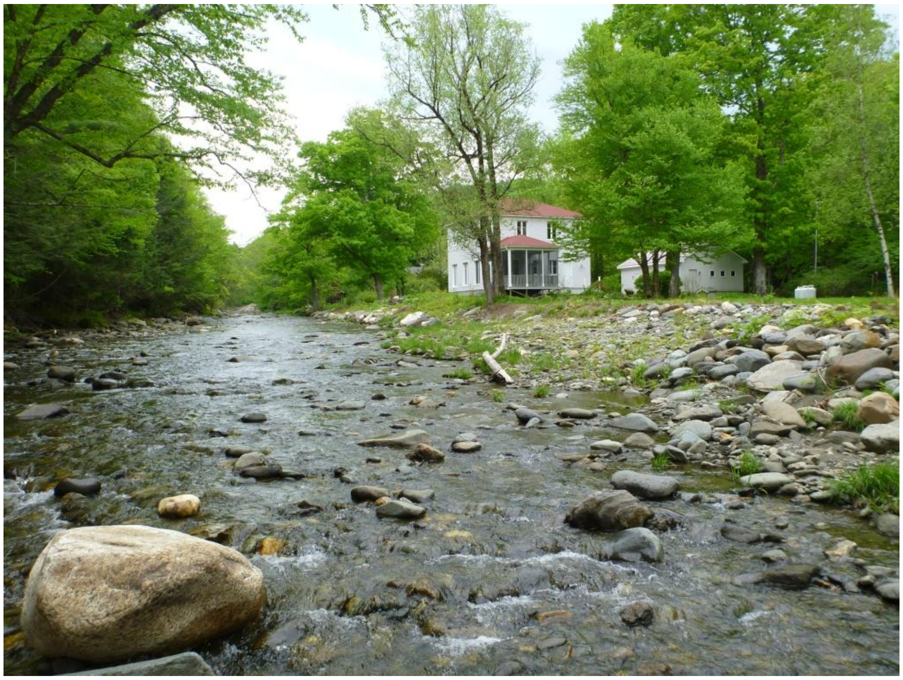


Figure 4.7: Historic straightening on segment M08B.

Figure 4.8: Road encroachment on reach M12.

Figure 4.9: Recently constructed cobble berm on segment M06A

Figure 4.10: Bedrock gorge with grade control in reach M12.

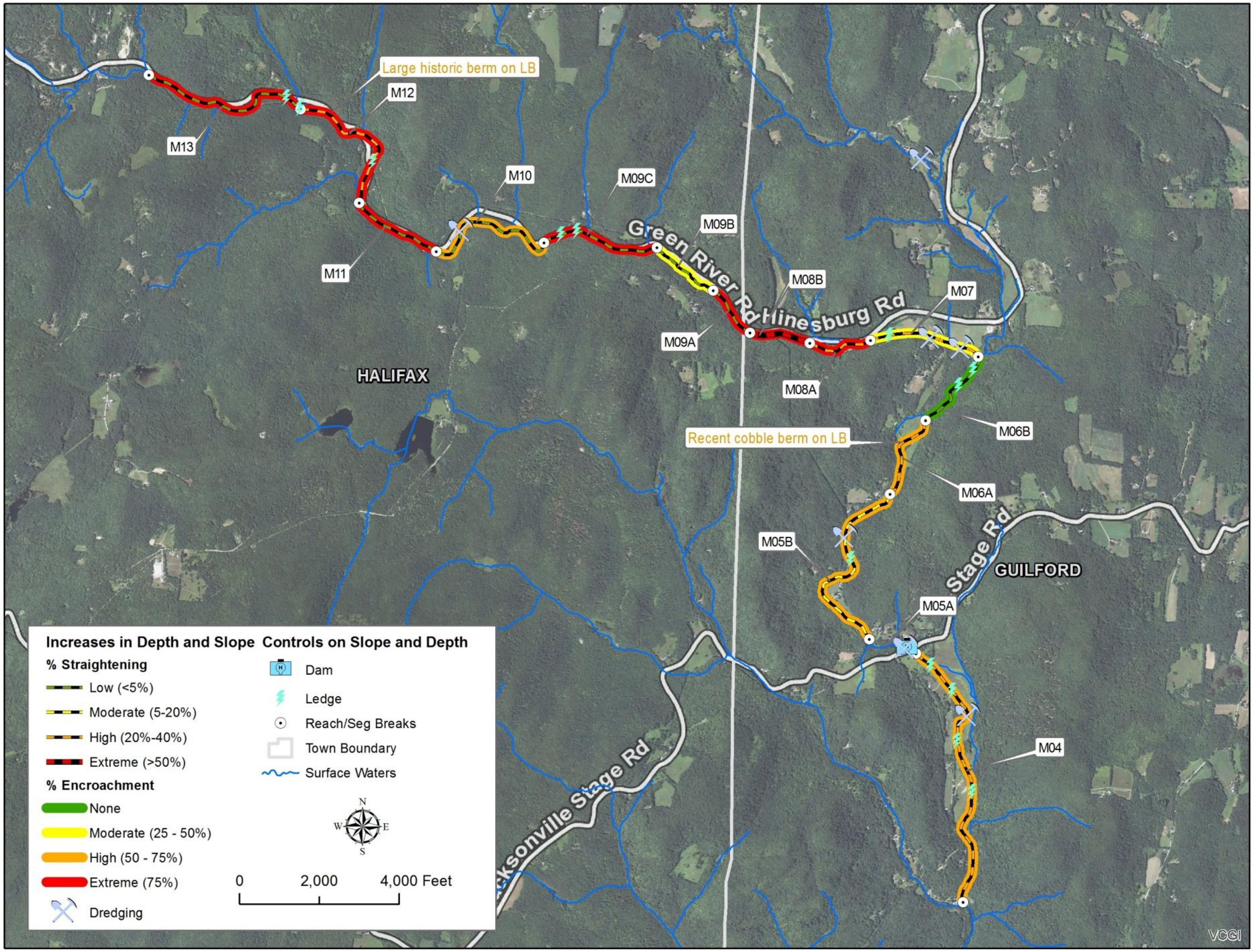


Figure 4.11: Controls on slope and depth for the Green River Watershed.

4.3.2 Departure Analysis

The reference and existing sediment regime types have been mapped using data from the Phase 1 and 2 assessments (Figures 4.12 and 4.13). Several segments in the Green River study area have undergone a departure in both sediment regime and stream type due to channel incision and/or widening as a result of: 1) historical land uses, 2) encroachments or development in the river corridor, or 3) extensive straightening and bank armoring. Many of the channel adjustments caused by these historic stressors were exacerbated by the extreme flood of 2011, leading to further stream type departures. Segment M09B was the only Phase 2 study segment that was assessed as stable and did not contain a stream type departure and/or a sediment regime departure.

Stream type departures (per Rosgen, 1994) are summarized below (Table 4.3) to better describe the reaches where physical changes in channel morphology have accompanied sediment regime changes.

Table 4.3: Summary of stream type departures from reference conditions.

Phase 2 Segment ID	Stream Type Departure	Dominant Adjustment Type
M05B	C to F	Recent/Historic Incision and Corridor Encroachment
M06A	C to B	Recent/Historic Incision and Corridor Encroachment
M07	C to F	Recent Widening and Recent/Historic Corridor Encroachment
M08A	C to F	Recent Avulsion and Active Incision
M08B	C to B	Recent/Historic Incision and Corridor Encroachment
M09A	B to F	Recent/Historic Incision and Corridor Encroachment
M09C	C to B	Recent/Historic Incision and Corridor Encroachment
M10	C to F	Recent Widening and Recent/Historic Corridor Encroachment
M12	C to F	Recent Widening and Incision and Historic Corridor Encroachment

In addition to the above-described morphological stream type departures, several reaches/segments of the Green River have undergone departures in sediment regimes in the absence of stream type departures. All sediment regime departures are summarized below in Table 4.4. An additional map summarizing dominant channel adjustment processes is included in Figure 4.14.

Table 4.4: Summary of Sediment Regime Departures.

Phase 2 Segment ID	Reference Sediment Regime	Existing Sediment Regime	Cause of Departure
M04	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent incision and active widening
M05A	Coarse Equilibrium and Fine Deposition	Deposition	Large historic impoundment
M05B	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Major incision from historic encroachment and recent flooding
M06A	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Moderate incision from historic and recent encroachment
M06B	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Major recent deposition and active widening
M07	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Historic and active widening, deposition
M08A	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Recent avulsion and widening, active incision
M08B	Transport	Confined Source and Transport	Incision from armoring and encroachment
M09A	Transport	Confined Source and Transport	Incision from armoring and encroachment
M09C	Transport	Confined Source and Transport	Incision from armoring and encroachment
M10	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Recent widening and historic incision
M11	Transport	Confined Source and Transport	Incision from armoring and encroachment
M12	Coarse Equilibrium and Fine Deposition	Confined Source and Transport	Incision from armoring and encroachment
M13	Transport	Confined Source and Transport	Incision from armoring and encroachment

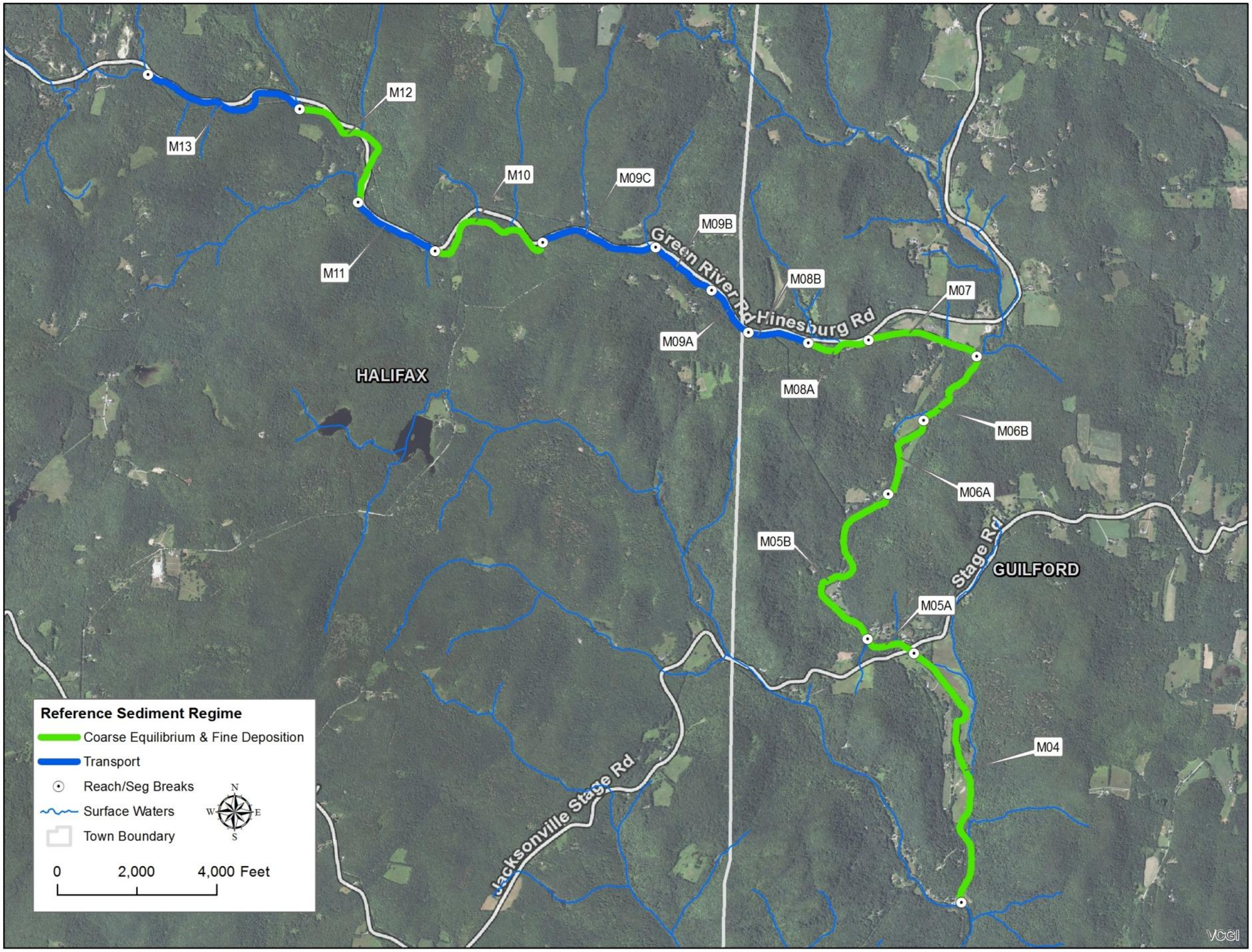


Figure 4.12: Reference Sediment Regime for the Green River watershed.

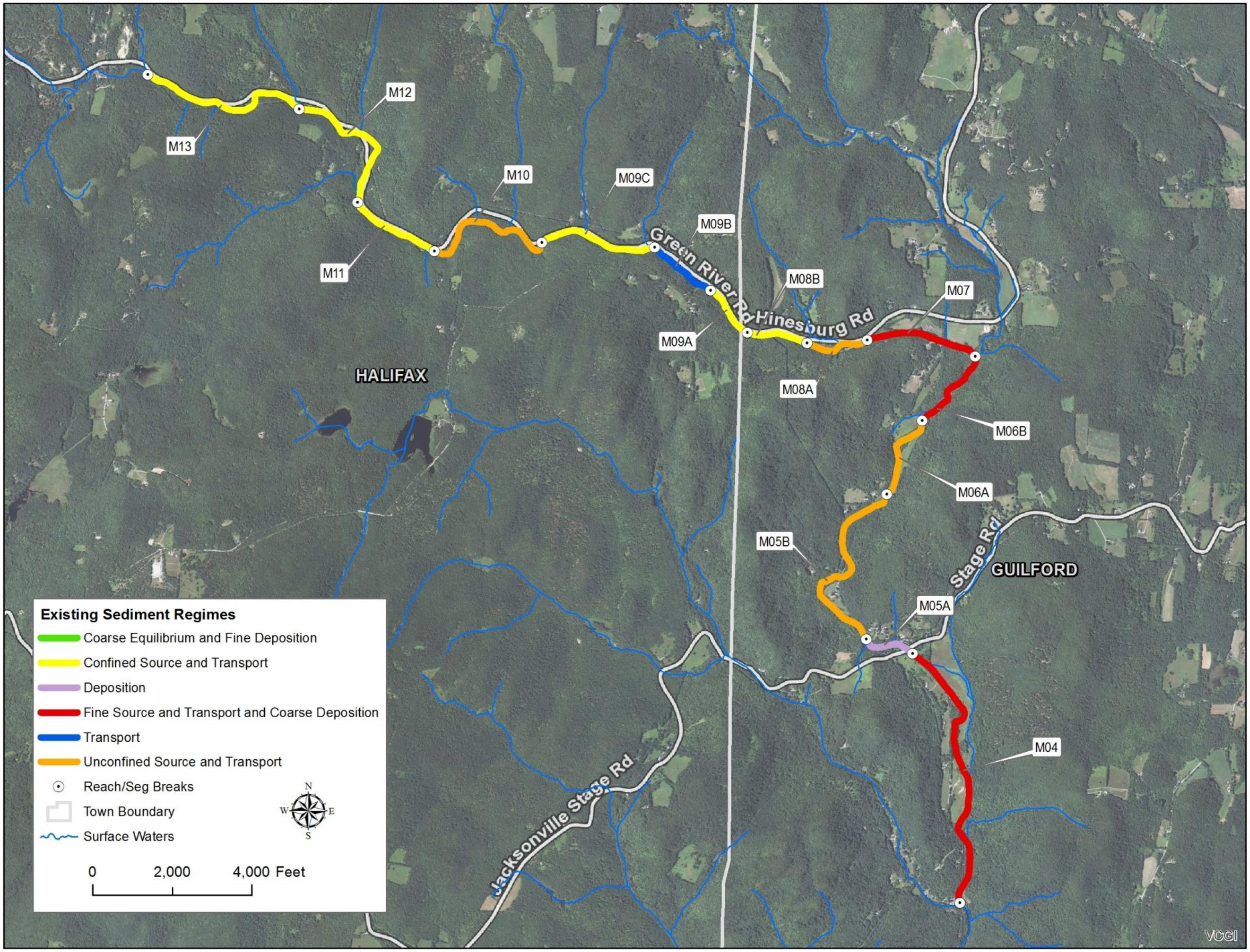


Figure 4.13: Existing Sediment Regime for the Green River watershed.

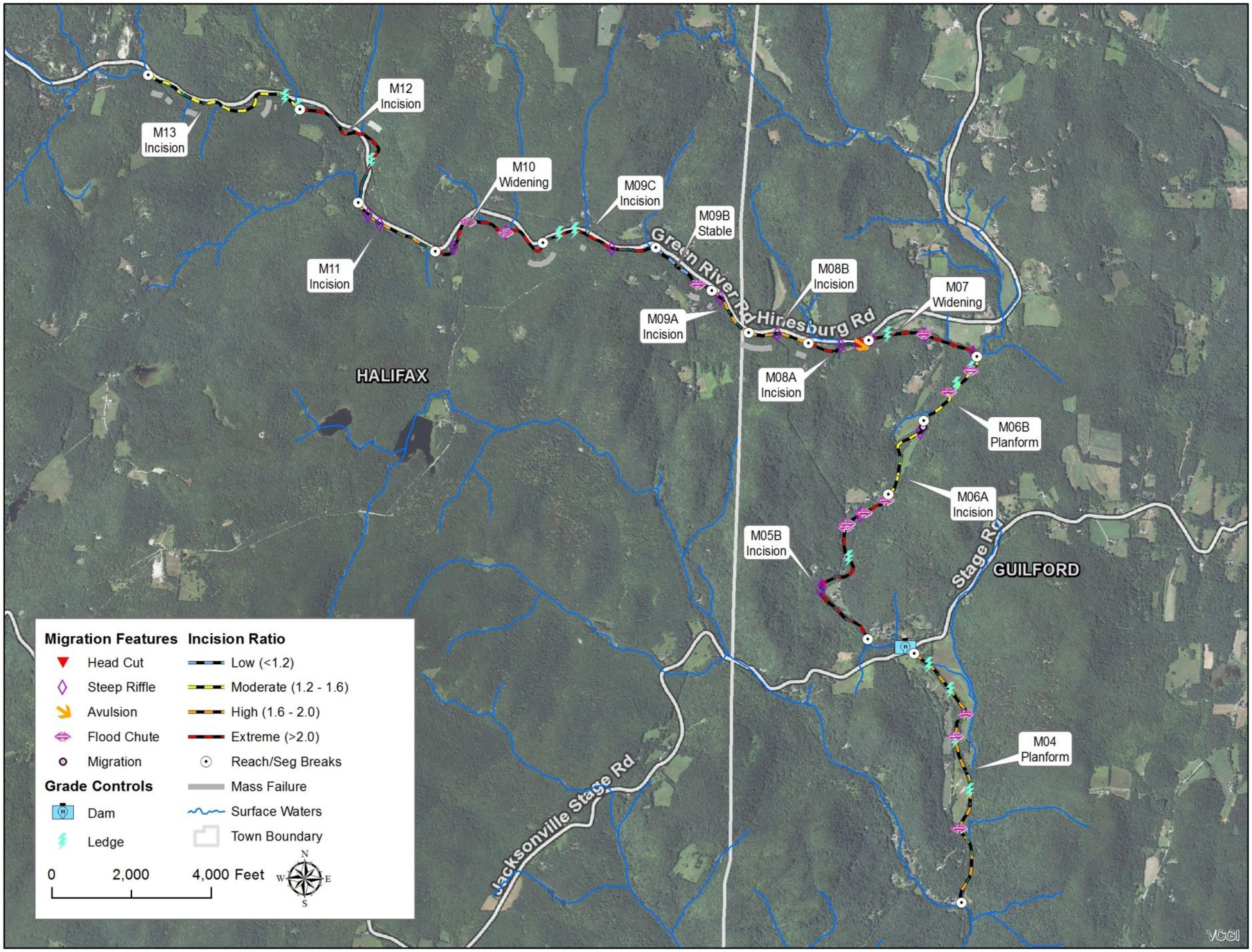


Figure 4.14: Channel Adjustment Process Map for the Green River watershed.

4.3.3 Sensitivity Analysis

The methods outlined in the VTANR Corridor Planning Guide have been used to describe the stream sensitivities of the segments in the Green River study area. Using the stream geometry and substrate data in conjunction with overall geomorphic stability (RGA score) as determined during the Phase 2 surveys, stream sensitivity ratings have been assigned to each segment (Figure 4.15). Six segments have heightened sensitivities of “Extreme” and three segments have heightened sensitivities of “Very High” due to human impacts. The increased stream sensitivity ratings are most often because of stream type departures (STD) (Table 4.5).

Incision due to encroachment, armoring, or straightening was the most common scenario for "Extreme" sensitivity in the study area. Areas of major deposition coupled with encroachment also led to "Extreme" sensitivity on some segments. "Very High" sensitivity segments were typically due to incision, however some of the reaches were impacted by major deposition from recent floods leading to widening and aggradation.

Table 4.5: Very High and Extreme sensitivity segments and descriptions of the specific impacts and adjustments.

Phase 2 Segment ID	Stream Sensitivity	Description of Impacts
M04	Very High	Widening, Incision
M05B	Extreme	STD, Incision, Encroachment, Armoring
M06A	Very High	STD, Incision, Encroachment
M06B	Very High	Widening, Deposition
M07	Extreme	STD, Historic Straightening and Berming, Widening
M08A	Extreme	STD, Avulsion, Incision, Deposition
M09A	Extreme	STD, Encroachment, Armoring, Constriction, Incision
M10	Extreme	STD, Widening, Armoring, Encroachment
M12	Extreme	STD, Incision, Widening, Encroachment

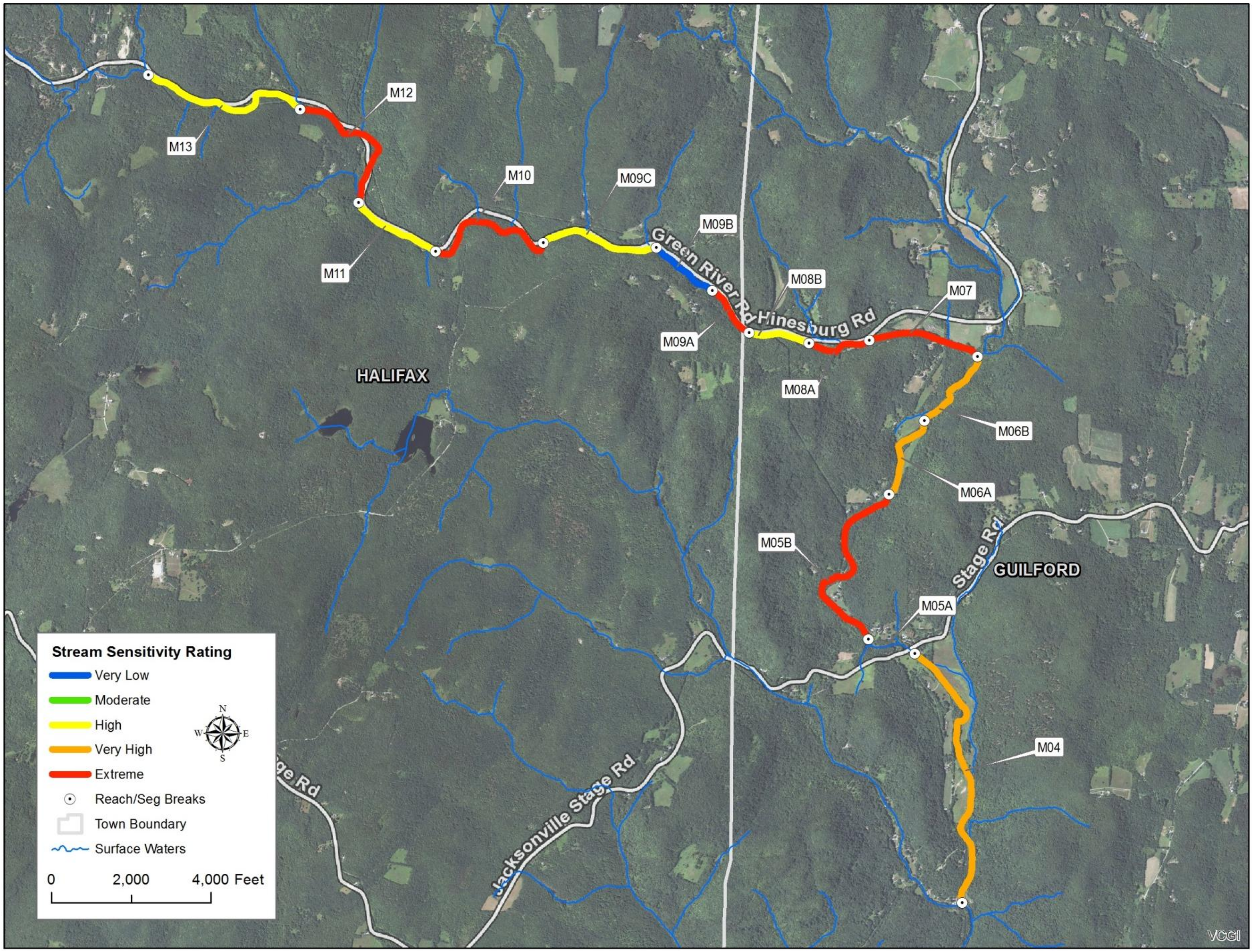


Figure 4.15: Stream Sensitivity Ratings for the Green River study area.

5.0 Preliminary Project Identification

5.1 Watershed Level Opportunities

5.1.1 Stormwater Runoff

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

The Green River watershed has limited stormwater impacts because of the largely forested watersheds and low road densities. In the future, if development pressures heighten concerns about impacts from stormwater runoff, the towns in the watershed could consider enacting local standards and guidelines for stormwater treatment or mitigation. Alternatively, concerns about stormwater management can be raised during local development review as necessary. Local planning efforts are important to control and monitor stormwater and development impacts on natural resources. By planning proactively, towns can reduce long-term costs and risks associated with stormwater runoff. Options that the towns could consider at the local level include:

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

5.1.2 Fluvial Erosion Hazard Zones

Many Vermont communities found along rivers large and small 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 in Vermont is fluvial erosion. Fluvial erosion hazards have been increased and exacerbated by historical channel management practices in Vermont such as channel straightening, berming, and floodplain encroachment. This is especially true in the Green River watershed, where significant damage to roadways and residences occurred during TSI in 2011.

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

5.1.3 Stream Crossings

Throughout Vermont, undersized and poorly aligned river crossings interrupt floodflows, sediment and woody debris movement downstream, and fish and wildlife migration. These conditions result in 1) channel instability and/or damage to infrastructure and personal property, 2) increased flooding, and 3) decreased fish and wildlife population health. The study area on the Green River did not contain any culverts and only one bridge was undersized (Table 5.1). Debris jams formed during TSI on some of the larger bridges - particularly those with piers - exacerbating area flooding and infrastructure damage (Figure 5.1). As such structures come up for replacement, resizing them to accommodate expected discharge and sediment loads and placing them in proper alignment with the stream channel is highly recommended.

Figure 5.1: Green River Road crossing on M05 (left) which was overtopped severly damaging the road and an adjacent house during TSI (right).

Table 5.1: Summary of Bridge Data in the Green River Watershed.

Map ID #	SGA Reach/ Segment	Town	SGAID	Road	Material	Curve Channel Width (ft)	Structure Length (ft)	Structure Height (ft)	Structure Width (ft)	% Bankfull Width
1	M05	Guilford	100000000013071	STAGE RD	Timber	53.7	22	17.0	86.0	160
2	M05	Guilford	700000000013073	GREEN RIVER RD	Concrete	53.7	25	15.0	75.0	140
3	M07	Guilford	100000000113071	GREEN RIVER RD	Concrete	46.9	46	8.0	92.0	196
4	M09	Halifax	100000000213071	DEER PARK RD	Concrete	45.9	21	13.0	50.0	109
5	M11	Halifax	700000000013083	Private Rd	Timber	43.0	6	11.5	32.0*	74*
6	M12	Halifax	100000000013081	GREEN RIVER RD	Steel	42.4	26	14.5	80.0	189
7	M12	Halifax	100000000113081	GREEN RIVER RD	Steel	42.4	26	16.0	70.0	165

* actual width between concrete abutments is 60 feet, but effective width is 32 feet due to constriction from Type IV rip-rap.

5.2 Site-Level Project Opportunities

The site-level projects developed for the Green River are provided below in Table 5.2. The project strategy, technical feasibility, and priority for each project are listed by project number and reach/segment. A total of 23 projects were identified to promote the restoration or protection of channel stability and aquatic habitat. The table summarizes key information for each project, including the site stressors and constraints, project strategy, priorities for hazard mitigation and ecological benefit, relative costs, and potential partners.

Table 5.2 includes a ranking of project priority, using our best professional judgment (and input from VTDEC, WRC, and other local stakeholders), of hazard mitigation and ecological benefits. Many river corridor restoration projects help mitigate flood and erosion hazards **and** improve the ecological conditions of the reach and watershed as a whole (e.g., improved habitat, protection of water quality, etc.). However, some project types provide a greater benefit to one over the other. While it is difficult to place a specific value on each project, rankings of “low,” “medium,” and “high” are intended to provide a means to compare the types of benefits each project provides relative to the others. A summary of what is meant by these two priority types is provided below.

> *Hazard Mitigation Priority:* refers to the potential for the project to mitigate flood and erosion hazards for the river corridor in the reach and in downstream areas. For example, replacing an undersized culvert with an appropriately sized structure could reduce flood/erosion hazards around the structure and downstream.
>
> *Ecological Benefits Priority:* refers to the potential for the project to improve aquatic habitat conditions and water quality in the reach and watershed. For example, a riparian buffer planting will improve habitat by increasing shading along the river and reducing long-term bank erosion.

The project locations for the study area are included on the maps provided in Appendix D. The 23 projects are further broken down by category as follows: Eleven (11) active geomorphic restoration projects and twelve (12) passive geomorphic restoration projects, including one conservation project.

Table 5.2: Site-Level Project Identification for the Green River Watershed.

Project #, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
#1 **River Road** Reach M04 42.7630 N 72.6625 W	**Active Restoration** Road Embankment	Existing road embankment consists of large, rounded material and is constricting the bankfull channel to 40'. Some rock armor is unstable. Left floodplain is accessible upstream with some avulsion risk.	Develop design to repair/replace rip-rap. Potentially install a stacked stone wall to increase bankfull channel width to ~50' and reduce road vulnerability.	Moderate	Low	Increase channel width and capacity; protect critical road embankment from future flood washouts.	Stacked stone wall costs are approximately $500/lf. Length is approx 150lf. Costs could exceed $75,000.	Town of Guilford
#2 **Utility Line** Reach M04 42.7634 N 72.6622 W	**Active Restoration** Utility Repairs	The utility providing service to houses on the east side of the river is located in an active flood chute with moderate channel avulsion potential. Utility pole may have been abandoned but pole and old cables are still vulnerable to erosion.	Move at least one utility pole out of active river area. If pole is no longer in use, remove pole and abandoned cables to avoid debris snagging in future floods.	Moderate	Low	Reduce risk of utility line damage and loss of residential service?	Moderate	Green Mountain Power; Landowner
#3 **Riparian Corridor** Reach M04 42.7642 N 72.6686 W	**Passive Restoration** Corridor Protection and Buffer Plantings	Large hayfield on right floodplain (approx. 6 acres) is moderately accessible and provides very important floodwater storage during larger events. Buffer width is very narrow throughout and channel may start to migrate in to field due to lack of resistance.	Plant stream buffer with native woody vegetation in areas lacking canopy cover to reduce streambank erosion and improve water quality and habitat. Coordinate with landowner to assess interest, cooperation, and potential for maintaining forested buffer and conserving land in permanent easement.	**High**	Moderate	Very important floodwater and sediment storage zone during large floods. Dampens floodwave on lower reaches along River Road where floodplain access is minimal.	Low to Moderate dependent on size of area to be conserved. Low costs for buffer planting.	NRCS CREP; VTANR ERP; WCNRCD Trees for Streams

Table 5.2: Site-Level Project Identification for the Green River Watershed.

Project #, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
#4 **River Road** Reach M04 42.7698 N 72.6628 W	**Active Restoration** Road Embankment	Approximately 500' of bank armoring is failing in some places with the channel thalweg (i.e., deepest part of flow) pushed against the embankment. Bankfull width is adequate at 60ft. A few of the existing trees stabilizing the road bed are falling over.	Alternatives analysis to repair portions of the embankment or potentially replace the entire embankment with larger material and a stacked wall.	**High**	Moderate	Protect road from major washout, reduce sediment inputs to stream, increase shading and habitat.	Stacked stone wall costs are approximately $500/lf. Length is approx 400lf. Costs could exceed $150,000.	Town of Guilford
#5 **VLT Property** Reach M04 42.7704 N 72.6616 W	**Passive Restoration** Buffer Plantings	The left floodplain is under conservation management through the Vermont Land Trust. The floodplain is low and very accessible. Major TSI deposits were observed. Recent buffer planting site was damaged and needs to be replanted in some locations. The channel is actively adjusting planform and will likely continue to migrate into the left floodplain.	Plant stream buffer with native woody vegetation throughout to reduce streambank erosion and improve water quality and habitat. Land is under conservation management but work with VLT to allow for channel migration through property over long-term.	Moderate	Moderate	Slow erosion with continued channel migration, increase shading and inputs of woody debris.	Low costs for materials and labor for infill buffer plantings.	Vermont Land Trust; WCNRCD Trees for Streams
#6 **Timber Crib Dam** Segment M05A 42.7757 N 72.6675 W	**Active Restoration** Dam Maintenance	The Green River timber crib dam is an important historic feature on the river. However, the dam is currently filled in with sediment, and is likely increasing water temperature and streambed scour downstream. The fish ladder is impassable at lower flows due to upstream sedimentation.	Evaluate the following as part of long term planning for the dam: 1) sediment maintenance plan to periodically remove coarse sediment and restore fish passage; 2) in the event of dam failure or future removal, understand the fate of the sediment behind dam and whether it should be removed or allowed to naturally transport downstream based on the condition of downstream reaches.	Moderate	**High**	Restore natural flow and sediment transport. Improve channel stability downstream. Improve fish passage, decrease sediment loading, decrease water temperatures.	High costs for sediment maintenance. High costs for dam removal in future if dam failure occurs.	Green River Village Preservation Trust; Private Landowners

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Project #, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
#7 **Green River Rd** Segment M05B 42.7776 N 72.6728 W	**Active Restoration** Berm Removal & Buffer Plantings	Recently windrowed cobbles are restricting access to a floodplain (approx. 1 acre) in lawn/hayfield on the left bank. There is minimal additional accessible floodplain available in reach.	Remove cobble berm to restore floodplain access on left bank. Buffer plantings to stabilize bank and improve shading.	**High**	Low	Increase sediment and floodwater attenuation in reach. Improved near bank habitat and shading.	Low cost of berm removal and buffer plantings.	WCNRCD Trees for Streams; Private landowner
#8 **Utility Line along Green River Rd** Reach M05B 42.7634 N 72.6622 W	**Active Restoration** Utility Repairs	The river is actively migrating through the right bank and has eroded past a utility pole which is currently in the stream. Utility pole may have been abandoned but pole and old cables are still vulnerable to erosion.	Move utility pole and assess bank for stability and erosion risk for Green River Road. If pole is no longer in use, remove pole and abandoned cables to avoid debris snagging in future floods.	Moderate	Low	Reduce risk of utility line damage and loss of residential service.	Moderate	Green Mountain Power; Landowner
#9 **Floodplain** Reach M06A 42.7904 N 72.6663 W	**Active Restoration** Berm Removal	A new berm from TSI material severely restricts floodplain access on the left bank. The left floodplain (approx. 5 acres) is low and was heavily accessed during TSI. A tall bank with remnants of historic armoring and possibly a historic berm exists on the right bank. The floodplain is elevated.	The berm is actively failing and sufficient floodplain access may already be available following recent high flows. The berm should not be repaired and need for additional berm removal should be assessed. Work with landowner on the right floodplain to allow the bank and historic armoring/berm to continue failing, access to right floodplain may eventually be restored. Protect with River Corridor Easement.	**High**	Moderate	Provide valuable sediment and stormflow attenuation in reach to take pressure off downstream areas. Floodplain access on this property dampens floodwave on Green River village where floodplain access is minimal.	Low to moderate cost of berm removal. Recent flooding may have eroded/breached the berm enough to allow for sufficient floodplain access with no further action.	WCNRCD; VTANR; Private Landowner
#10 **Floodplain** Reach M06A 42.7904 N 72.6663 W	**Passive Restoration** Corridor Protection and Buffer Plantings	Buffer vegetation is variable on both banks in the upper half of the segment. The right bank is eroding upstream of the historic berm. The left bank has no woody vegetation behind the new cobble berm.	Potentially coupled with project #9. Work with landowners to remove the left berm, allow for channel migration on both banks, and plant native woody vegetation along both banks. Protect with River Corridor Easement.	**High**	Moderate	Reduce erosion rates as channel adjusts planform, increase shading and inputs of woody debris.	Low to Moderate dependent on size of area to be conserved. Low costs for buffer planting.	NRCS CREP; VTANR ERP; WCNRCD Trees for Streams; Private Landowner

Table 5.2: Site-Level Project Identification for the Green River Watershed.

Project #, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
#11 **Harris Dr.** Reach M06B 42.7940 N 72.6598 W	**Passive Restoration** Conservation	Segment is very active with recent channel avulsions and major sediment deposition. Existing forested floodplains on one or both banks are accessible during moderate storm events. A logging road exists along the left valley wall in the upper segment.	Prevent stream corridor from future development of logging, and monitor recently logging road for erosion/runoff. Protect with River Corridor Easement.	Moderate	Low	Downstream benefits through the maintenance of water and sediment attenuation in this riparian area.	Low to Moderate costs depending on conservation or easement approach and size of parcel.	VLT; Private Landowner
#12 **Green River Rd** Reach M07 42.7970 N 72.6650 W	**Active Restoration** Berm Removal	A historic and newly constructed berm along the left bank restrict access to an elevated floodplain (approx. 1 acre). As a result, floodplain access is minimal in this reach.	Work with landowner to potentially remove berm to restore access to floodplain during large events. Ensure that increased floodplain access does not increase inundation risk to house in floodplain.	**High**	Moderate	Provide sediment and stormflow attenuation during large storms.	Low to moderate cost of berm removal.	WCNRCD; VTANR; Private Landowner
#13 **Abandoned House - Hinesburg Road / Harris Drive** Reach M08A 42.7962 N 72.6729 W	**Active and Passive Restoration** Corridor Protection, House/Debris Removal, Bank Stabilization	A large channel avulsion occurred during TSI and the channel is currently pushed against the right valley wall and actively adjusting width and depth. A house was completely cut off and is abandoned on the new right floodplain. The former channel is an active flood chute and could potentially be re-accessed as the primary channel.	Explore buyout of property through town: remove house and debris, explore potential to stabilize eroding banks on new channel (i.e., on island where septic system used to be), plant native woody vegetation, assess access and stability of former channel, protect corridor from future development.	**High**	Moderate	Remove debris which could enter stream in future floods. Reduce sediment and nutrient inputs from eroding lawn and leach field. Reduce potential damage to Hinesburg Road if channel re-accessed former location. Protect highly active corridor from future development.	Low costs for more detailed hydraulic and alternatives analysis. Potentially moderate to high costs for restoration and demolition work.	Landowner; Town of Guilford; FEMA

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Project #, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
#14 **Green River Rd** Reach M08B 42.7971 N 72.6786 W	**Passive Restoration** Buffer Planting	A tall armored slope was constructed from coarse river bed material after TSI. Upper armored slope is not revegetating rapidly due to lack of topsoil.	Add topsoil/grubbings (free of invasive species) to upper slope and seed with conservation mix. Plant smaller stock saplings to encourage long term woody vegetation along banks and shading of channel.	Low	Moderate	Increase shading and woody debris inputs to stream.	Low costs for materials and labor for infill buffer plantings.	Town of Guilford; WCNRCD Trees for Streams
#15 **Green River Rd** Reach M09C Multiple Sites	**Passive Restoration** Buffer Planting	Two bank armoring sites from TSI lack vegetation on upper slope.	Add topsoil/grubbings (free of invasive species) to upper slope and seed with conservation mix. Plant smaller stock saplings to encourage long term woody vegetation along banks and shading of channel.	Low	Moderate	Increase shading and woody debris inputs to stream.	Low costs for materials and labor for buffer plantings.	Town of Halifax; WCNRCD Trees for Streams
#16 **Green River Rd** Reach M10 Multiple Sites	**Passive Restoration** Buffer Planting	A low floodplain bench was constructed during post-TSI removal of a major debris jam in the upper reach. Seeded with grass, no woody vegetation. An additional bank armor sites from TSI in lower reach lacks vegetation on upper slope.	Plant woody vegetation on floodplain bench. Add topsoil/grubbings (free of invasive species) to upper slope and seed with conservation mix. Plant smaller stock saplings to encourage long term woody vegetation along banks and shading of channel.	Low	Moderate	Increase shading and woody debris inputs to stream.	Low costs for materials and labor for buffer plantings.	Town of Halifax; WCNRCD Trees for Streams
# 17 **Dawn till Dusk Farm** Reach M10 42.8029 N 72.7099 W	**Passive Restoration** Buffer Planting	Landowner is concerned with bank erosion on property. Channel incised considerably during TSI and is causing some erosion on left bank. No structures are at risk.	Work with landowner to plant woody buffer vegetation and advise on bank stabilization options.	Low	Low	Reduce erosion and sediment inputs, increase shading and woody debris inputs to channel.	Low costs for materials and labor for buffer plantings.	WCNRCD Trees for Streams

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Project #, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
#18 Private Footbridge Reach M11 42.8044 N 72.7159 W	**Active Restoration** Bridge Abutment Configuration	Existing private footbridge has a 60' span, but sloping rock abutments create a significant channel constriction to 32'. Armor slope and structure vulnerable to failure in future floods.	Work with landowner to reconfigure rock abutments to increase bankfull width and reduce vulnerability at structure.	Moderate	Low	Improve flow and sediment/debris transport through bridge, reduce risk of debris plugging during storm events.	Moderate costs to reconfigure lower armor slopes.	Landowner
#19 Green River Rd Reach M11 Multiple Sites	**Passive Restoration** Buffer Planting	Two bank armoring sites from TSI lack vegetation on upper slope.	Add topsoil/grubbings (free of invasive species)to upper slope and seed with conservation mix. Plant smaller stock saplings to encourage long term woody vegetation along banks and shading of channel.	Low	Moderate	Increase shading and woody debris inputs to stream.	Low costs for materials and labor for buffer plantings.	Town of Halifax; WCNRCD Trees for Streams
#20 Green River Rd Reach M12 Multiple Sites	**Passive Restoration** Buffer Planting	Two bank armoring sites from TSI lack vegetation on upper slope.	Add topsoil/grubbings (free of invasive species) to upper slope and seed with conservation mix. Plant smaller stock saplings to encourage long term woody vegetation along banks and shading of channel.	Low	Moderate	Increase shading and woody debris inputs to stream.	Low costs for materials and labor for buffer plantings.	Town of Halifax; WCNRCD Trees for Streams
#21 Green River Rd Reach M12 42.8113 N 72.7204 W	**Active Restoration** Berm Removal and Road Embankment Armoring	A tall historic berm blocks access to the left floodplain (approx. 1 acre). The channel cut through the berm on the upstream end during TSI, but road repairs filled in this access point with rip-rap. Floodplain storage is low throughout reach.	Alternatives analysis to remove berm, or restore access to floodplain at the upstream access point, and move rock rip-rap along road to protect embankment.	**High**	Low	Provide valuable floodplain storage for attenuation of sediment and stormflow before stream enters long stretch with minimal storage. Reduce risk of debris catching on downstream bridge which experienced major damage and overbanks flows during TSI.	Limited costs to remove portion of recently placed rip-rap at upstream end. High costs and impacts to remove historic berm.	Town of Halifax; Landowner

Table 5.2: Site-Level Project Identification for the Green River Watershed.

Project #, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
#22 **Floodplain along Green River Rd** Reach M12 42.8126 N 72.7230 W	**Passive Restoration** Corridor Protection	A short stretch (500 ft) of intact and accessible floodplain on the left bank in between the river and road was accessed during TSI. Floodplain stores significant sediment and floodwaters during floods.	Prevent stream corridor from future development. Protect with River Corridor Easement.	Moderate	Low	Provide valuable floodplain storage for attenuation of sediment and stormflow along Green River Road where minimal storage is available. Reduce risk of debris catching on downstream structures which experienced major damage during TSI.	Low to Moderate costs depending on conservation or easement approach and size of parcel.	VTANR; VLT; Landowner
#23 **Green River Rd** Reach M13 Multiple Sites	**Passive Restoration** Buffer Planting	Two bank armoring sites from TSI lack vegetation on upper slope. Total length of armor slope approx 600 feet.	Add topsoil/grubbings to upper slope and seed with conservation mix. Plant smaller stock saplings to encourage long term woody vegetation along banks and shading of channel.	Low	Moderate	Increase shading and woody debris inputs to stream.	Low to Moderate costs for materials and labor for buffer plantings.	Town of Halifax; WCNRCD Trees for Streams

5.3 Restoration Project Prioritization

The corridor planning partners reviewed and commented on the list of preliminary projects during a watershed tour in August, 2014, and via email. Five (5) project "bundles" from the initial list of 23 total projects were chosen for further development. Project summaries are included in this appendix for the five highest priority project bundles. Each summary includes:

- A description of the site location and river reach
- A brief technical summary of the stressors on channel stability and aquatic habitat
- A description of channel and floodplain restoration alternatives
- Preliminary cost estimates for restoration alternative
- A list of current and potential technical partners and funding
- A review of regulatory requirements

The five project bundles chosen for further investigation were:

1. Project 3: Reach M04 - Large hayfield between the right bank and River Road.
    - *Passive Restoration: Corridor Protection and Buffer Plantings*
2. Project 7: Segment M05-B - Recent cobble berm along left bank upstream of timber crib dam.
    - *Active Restoration: Berm Removal and Buffer Plantings*
3. Projects 9 and 10: Segment M06-A - Recent cobble berm along left bank and a large floodplain hayfield.
    - *Passive Restoration: Corridor Protection, and Buffer Plantings*
4. Project 13: Segment M08-A - Abandoned house off of Harris Drive
    - *Active and Passive Restoration: Corridor Protection, House/Debris Removal, Bank Stabilization*
5. Project 21: Segment M12 - Historic and recently constructed left bank berm
    - *Active Restoration and Passive Restoration: Berm Removal and Corridor Protection*

6.0 Conclusions and Recommendations

The steep terrain draining the Green River watershed coupled with road networks and properties sharing the narrow river valleys create fluvial erosion hazards throughout the Towns of Guilford and Halifax. While flood damages in Vermont and Massachusetts resulting from inundation occurred in 2011 during Tropical Storm Irene, fluvial erosion has been the principal mode of damage to roadways, homes, and properties along the Green River. The Green River watershed received over 7 inches of rainfall during Tropical Storm Irene and the subsequent flooding produced some of the worst damage in Vermont. Severe damage to roads and bridges slowed recovery efforts and severed access to dozens of homes. As a result of impacts from this flood, and the increasing severity of rainfall and flood events in the last decade, the Towns of Guilford and Halifax are wise to take a long-term corridor planning approach to better understand, plan for, and mitigate fluvial erosion hazards within the watershed.

The Green River channel is still adjusting its width, depth, and planform to the following historical and ongoing impacts: 1) aggradation of sediment in the valleys due to European settlement and deforestation that occurred during the 1700's and 1800's; 2) channel straightening, dredging, and corridor encroachment associated with adjacent roads, agriculture, and other land uses; 3) significant floods in recent years such as those in October of 2005 and Tropical Storm Irene in August of 2011.

The Guilford-Halifax town line represents a distinct transition in channel slope, valley width, sediment transport capacity, and the types and degree of current and historic impacts. The lower reaches in Guilford are characterized by wider valleys, lateral erosion and deposition processes, and planform adjustments. These reaches are dynamic and highly erosive during flood events due to ongoing adjustments to their dimensions, patterns, and profiles. The lateral adjustments in the lower reaches are likely in response to impacts from historical sedimentation, as well as modern day impacts from channel straightening, dredging, berming, and corridor encroachment. Tropical Storm Irene triggered channel incision, mass wasting of valley slopes, major inputs of sediment and woody debris to the channel, and redevelopment of floodplain access in some areas through aggradation. Ongoing vertical and lateral channel migration is likely in the future for many of the lower reaches in Guilford.

These changes are less likely in the upper reaches (Halifax) due to extensive armoring and encroachment along Green River Road. The steeper and more confined reaches in Halifax transport large volumes of sediment and have little opportunity to spill on to floodplains and dissipate energy. As a result, these reaches convey large volumes of water and sediment downstream. These high energy reaches caused catastrophic damage to roads and bridges during Tropical Storm Irene in locations where embankment armoring failed or at bridges that were undersized or obstructed by debris.

A summary of key flood resiliency themes and recommendations are included below at the watershed-scale and town-scale:

<u>Green River Watershed</u>

- The Green River watershed is an extremely flashy watershed due to its steep headwaters and soils with poor infiltration. The National Flood Insurance Program (NFIP) study for the Green River does not cover the entire river corridor and is not a detailed study; therefore inundation hazards appear to be underestimated in many locations. Given the hydrologic characteristics of the watershed, it is recommended that both Halifax and Guilford consider flood hazard ordinances that prevent encroachment in the 100-year floodplain.

- Fluvial Erosion Hazard (FEH) zones should be considered in Guilford and Halifax to better map flood and erosion risks for both the safety and protection of their citizens, and the infrastructure controlled by the municipality.
- Floodplains that are accessible by the river during most flood events are limited in the watershed. Therefore, efforts to protect the high-priority floodplains identified in this plan will pay dividends in the long-term with respect protection of downstream property infrastructure.
- Given the severe bank and valley erosion initiated by Tropical Storm Irene in the upper river reaches in Halifax, towns and residents will need to plan for ongoing sedimentation in the lower, wider valleys (i.e., downstream of Green River village).
- Berms constructed following Tropical Storm Irene, such as those identified in this plan, should be removed to restore floodplain access where possible.

Guilford

- The larger floodplain protection projects identified in this plan are key to the long-term stability of properties and infrastructure downstream such as Green River village and Green River Road.
- Due to upstream channel instability caused by Tropical Storm Irene, ongoing sediment maintenance costs for the Green River Dam are likely to remain high for the foreseeable future. This timber crib dam that will someday reach the end of its life, at which point the community will be faced with a decision to remove or replace the structure. In light of the ongoing maintenance costs and requirements, we encourage the community to engage in discussions about the fate of the dam well before this day.

Halifax

- Limited floodplain protection opportunities exist in Halifax, and therefore those few opportunities identified in this plan are very important for the protection of nearby infrastructure and downstream areas.
- Extensive roadway reconstruction following Tropical Storm Irene left the river prone to bed erosion and bank instability on the opposite bank. While there may not be a feasible way to address these issues, there are opportunities to further “naturalize” the banks along the road through the redevelopment of vegetated slopes overlying the riprap armor.
- The ongoing bed and bank erosion along the heavily armored stretches of Green River Road should be monitoring closely in the near term, and especially following subsequent floods. If the river bed continues to incise (i.e., cut down), the embankments could be at risk of failure. Channel bed armoring may be required in some areas to prevent these failures.

7.0 References

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8.0 Glossary of Terms

Adapted from:

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

And

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

Acre -- A measure of area equal to 43,560 ft^2 (4,046.87 m^2). One square mile equals 640 acres.

Adjustment process --or type of change, that is underway due to natural causes or human activity that has or will result in a change to the valley, floodplain, and/or channel condition (e.g., vertical, lateral, or channel plan form adjustment processes)

Aggradation -- A progressive buildup or raising of the channel bed and floodplain due to sediment deposition. The geologic process by which streambeds are raised in elevation and floodplains are formed. Aggradation indicates that stream discharge and/or bed-load characteristics are changing. Opposite of degradation.

Algae -- Microscopic plants that grow in sunlit water containing phosphates, nitrates, and other nutrients. Algae, like all aquatic plants, add oxygen to the water and are important in the fish food chain.

Alluvial -- Deposited by running water.

Alluvium -- A general term for detrital deposits make by streams on riverbeds, floodplains, and alluvial fans; esp. a deposit of silt or silty clay laid down during time of flood. The term applies to stream deposits of recent time. It does not include subaqueous sediments of seas or lakes.

Anadromous -- Pertaining to fish that spend a part of their life cycle in the sea and return to freshwater streams to spawn.

Aquatic ecosystem -- Any body of water, such as a stream, lake, or estuary, and all organisms and nonliving components within it, functioning as a natural system.

Armoring -- A natural process where an erosion-resistant layer of relatively large particles is established on the surface of the streambed through removal of finer particles by stream flow. A properly armored streambed generally resists movement of bed material at discharges up to approximately 3/4 bank-full depth. Augmentation (of stream flow) – Increasing flow under normal conditions, by releasing storage water from reservoirs.

Avulsion -- A change in channel course that occurs when a stream suddenly breaks through its banks, typically bisecting an overextended meander arc.

Backwater -- (1) A small, generally shallow body of water attached to the main channel, with little or no current of its own, or (2) A condition in subcritical flow where the water surface elevation is raised by downstream flow impediments.

Backwater pool -- A pool that formed as a result of an obstruction like a large tree, weir, dam, or boulder.

Bank stability -- The ability of a streambank to counteract erosion or gravity forces.

Bankfull channel depth -- The maximum depth of a channel within a riffle segment when flowing at a bank-full discharge.

Bankfull channel width -- The top surface width of a stream channel when flowing at a bank-full discharge.

Bankfull discharge -- The stream discharge corresponding to the water stage that overtops the natural banks. This flow occurs, on average, about once every 1 to 2 years and given its frequency and magnitude is responsible for the shaping of most stream or river channels.

Bankfull width -- The width of a river or stream channel between the highest banks on either side of a stream.

Bar -- An accumulation of alluvium (usually gravel or sand) caused by a decrease in sediment transport capacity on the inside of meander bends or in the center of an overwide channel.

Barrier -- A physical block or impediment to the movement or migration of fish, such as a waterfall (natural barrier) or a dam (man-made barrier).

Base flow -- The sustained portion of stream discharge that is drawn from natural storage sources, and not affected by human activity or regulation.

Bed load -- Sediment moving on or near the streambed and transported by jumping, rolling, or sliding on the bed layer of a stream. See also suspended load.

Bed material -- The sediment mixture that a streambed is composed of.

Bed material load -- That portion of the total sediment load with sediments of a size found in the streambed.

Bed roughness -- A measure of the irregularity of the streambed as it contributes to flow resistance. Commonly expressed as a Manning "n" value.

Bed slope -- The inclination of the channel bottom, measured as the elevation drop per unit length of channel.

Bedform -- Individual patterns which streams follow that characterize the condition of the stream bed into several categories. (*See*: braided, dune-ripple, plane bed, riffle-pool, step-pool, and cascade)

Benthic invertebrates -- Aquatic animals without backbones that dwell on or in the bottom sediments of fresh or salt water. Examples: clams, crayfish, and a wide variety of worms.

Berms -- mounds of dirt, earth, gravel, or other fill built parallel to the stream banks designed to keep flood flows from entering the adjacent floodplain.

Biota -- All living organisms of a region, as in a stream or other body of water.

Boulder -- A large substrate particle that is larger than cobble, between 10 and 160 inches in diameter.

Boundary resistance -- The ability a stream bank has to withstand the erosional forces of the flowing water at varying intensities. Under natural conditions boundary resistance is increased due to stream bank vegetation (roots), cohesive clays, large boulder substrate, etc.

Braided -- A stream channel characterized by flow within several channels, which successively meet and divide. Braiding often occurs when sediment loading is too large to be carried by a single channel.

Braiding (of river channels) -- Successive division and rejoining of riverflow with accompanying islands.

Buffer strip -- A barrier of permanent vegetation, either forest or other vegetation, between waterways and land uses such as agriculture or urban development, designed to intercept and filter out pollution before it reaches the surface water resource.

Canopy -- A layer of foliage in a forest stand. This most often refers to the uppermost layer of foliage, but it can be used to describe lower layers in a multistoried stand. Leaves, branches and vegetation that are above ground and/or water that provide shade and cover for fish and wildlife.

Cascade -- A short, steep drop in streambed elevation often marked by boulders and agitated white water.

Catchment -- (1) The catching or collecting of water, especially rainfall. (2) A reservoir or other basin for catching water. (3) The water thus caught. (4) A watershed.

Channel -- An area that contains continuously or periodically flowing water that is confined by banks and a streambed.

Channelization -- The process of changing (usually straightening) the natural path of a waterway.

Channel evolution model (CEM) -- A series of stages used to describe the erosional or depositional processes that occur within a stream or river in order to regain a dynamic equilibrium following a disturbance.

Clay -- Substrate particles that are smaller than silt and generally less than 0.0001 inches in diameter.

Coarse gravel -- Substrate that is smaller than cobble, but larger than fine gravel. The diameter of this stream-bottom particulate is between 0.63 and 2.5 inches.

Cobble -- Substrate particles that are smaller than boulders and larger than gravels, and are generally between 2.5 and 10 inches in diameter.

Confinement -- *see* Valley confinement

Confluence -- (1) The act of flowing together; the meeting or junction of two or more streams; also, the place where these streams meet. (2) The stream or body of water formed by the junction of two or more streams; a combined flood.

Conifer -- A tree belonging to the order Gymnospermae, comprising a wide range of trees that are mostly evergreens. Conifers bear cones (hence, coniferous) and have needle-shaped or scalelike leaves.

Conservation -- The process or means of achieving recovery of viable populations.

Contiguous habitat -- Habitat suitable to support the life needs of a species that is distributed continuously or nearly continuously across the landscape.

Cover -- “cover” is the general term used to describe any structure that provides refuge for fish, reptiles or amphibians. These animals seek cover to hide from predators, to avoid warm water temperatures, and to rest, by avoiding higher velocity water. These animals come in all sizes, so even cobbles on the stream bottom that are not sedimented in with fine sands and silt can serve as cover for small fish and salamanders. Larger fish and reptiles often use large boulders, undercut banks, submerged logs, and snags for cover.

Critical shear stress -- The minimum amount of shear stress exerted by stream currents required to initiate soil particle motion. Because gravity also contributes to streambank particle movement but not on streambeds, critical shear stress along streambanks is less than for streambeds.]

Cross-section -- A series of measurements, relative to bankfull, that are taken across a stream channel that are representative of the geomorphic condition and stream type of the reach.

Crown -- The upper part of a tree or other woody plant that carries the main system of branches and the foliage.

Crown cover -- The degree to which the crowns of trees are nearing general contact with one another.

Cubic feet per second (cfs) -- A unit used to measure water flow. One cubic foot per second is equal to 449 gallons per minute.

Culvert -- A buried pipe that allows flows to pass under a road.

Debris flow -- A rapidly moving mass of rock fragments, soil, and mud, with more than half of the particles being larger than sand size.

Deciduous -- Trees and plants that shed their leaves at the end of the growing season.

Degradation -- (1) A progressive lowering of the channel bed due to scour. Degradation is an indicator that the stream's discharge and/or sediment load is changing. The opposite of aggradation. (2) A decrease in value for a designated use.

Detritus -- is organic material, such as leaves, twigs, and other dead plant matter, that collects on the stream bottom. It may occur in clumps, such as leaf packs at the bottom of a pool, or as single pieces, such as a fallen tree branch.

Dike -- (1) (Engineering) An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of lowlands; a levee. (2) A low wall that can act as a barrier to prevent a spill from spreading. (3) (Geology) A tabular body of igneous (formed by volcanic action) rock that cuts across the structure of adjacent rocks or cuts massive rocks.

Dissolved oxygen (DO) -- The amount of free (not chemically combined) oxygen dissolved in water, wastewater, or other liquid, usually expressed in milligrams per liter, parts per million, or percent of saturation.

Ditch -- A long narrow trench or furrow dug in the ground, as for irrigation, drainage, or a boundary line.

Drainage area -- The total surface area upstream of a point on a stream that drains toward that point. Not to be confused with watershed. The drainage area may include one or more watersheds.

Drainage basin -- The total area of land from which water drains into a specific river.

Dredging -- Removing material (usually sediments) from wetlands or waterways, usually to make them deeper or wider.

Dune-ripple -- A bedform associated with low-gradient, sand-bed channels; the low gradient nature of the channel causes the sand to form a sequence of dunes and small ripples; significant sediment transport typically occurs at most stream stages.

Ecology -- The study of the interrelationships of living organisms to one another and to their surroundings.

Ecosystem -- Recognizable, relatively homogeneous units, including the organisms they contain, their environment, and all the interactions among them.

Embankment -- An artificial deposit of material that is raised above the natural surface of the land and used to contain, divert, or store water, support roads or railways, or for other similar purposes.

Embeddedness -- is a measure of the amount of surface area of cobbles, boulders, snags and other stream bottom structures that is covered with sand and silt. An embedded streambed may be packed hard with sand and silt such that rocks in the stream bottom are difficult or impossible to pick up. The spaces between the rocks are filled with fine sediments, leaving little room for fish, amphibians, and bugs to use the structures for cover, resting, spawning, and feeding. A streambed that is not embedded has loose rocks that are easily removed from the stream bottom, and may even "roll" on one another when you walk on them.

Entrenchment ratio --The width of the flood-prone area divided by the bankfull width.

Epifaunal – "epi" means surface, and "fauna" means animals. Thus, "epifaunal substrate" is structures in the stream (on the stream bed) that provide surfaces on which animals can live. In this case, the animals are aquatic invertebrates (such as aquatic insects and other "bugs"). These bugs live on or under cobbles, boulders, logs, and snags, and the many cracks and crevices found in these structures. In general, older decaying logs are better suited for bugs to live on/in than newly fallen "green" logs and trees.

Ephemeral streams -- Streams that flow only in direct response to precipitation and whose channel is at all times above the water table.

Equilibrium Condition -- The state of a river reach in which the upstream input of energy (flow of water) and materials (sediment and debris) is equal to its output to downstream reaches. Natural river reaches without human impacts tend towards a "stable" state where predictable channel forms are maintained over the long term under varying flow conditions.

Erosion -- Wearing away of rock or soil by the gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical, chemical, or biological forces.

Eutrophic -- Usually refers to a nutrient-enriched, highly productive body of water.

Eutrophication -- The process of enrichment of water bodies by nutrients.

Fine gravel -- Is substrate which is larger than sand, but smaller than coarse gravel. It is between 0.08 and 0.63 inches in diameter.

Flash flood -- A sudden flood of great volume, usually caused by a heavy rain. Also, a flood that crests in a short length of time and is often characterized by high velocity flows.

Floodplain -- Land built of fine particulate organic matter and small substrate that is regularly covered with water as a result of the flooding of a nearby stream.

Floodplain (100-year) -- The area adjacent to a stream that is on average inundated once a century.

Floodplain Function – Flood water access of floodplain which effects the velocity, depth, and slope (stream power) of the flood flow thereby influencing the sediment transport characteristics of the flood (i.e., loss of floodplain access and function may lead to higher stream power and erosion during flood).

Flow -- The amount of water passing a particular point in a stream or river, usually expressed in cubic feet per second (cfs).

Fluvial -- Migrating between main rivers and tributaries. Of or pertaining to streams or rivers.

Fluvial Geomorphology—The study of how rivers and their landforms interact over time through different climatic conditions.

Ford -- A shallow place in a body of water, such as a river, where one can cross by walking or riding on an animal or in a vehicle.

Fry -- A recently hatched fish.

Gabion -- A wire basket or cage that is filled with gravel or cobble and generally used to stabilize streambanks.

Gaging station -- A particular site in a stream, lake, reservoir, etc., where hydrologic data are obtained.

Gallons per minute (gpm) -- A unit used to measure water flow.

Geographic information system (GIS) -- A computer system capable of storing and manipulating spatial data.

Geomorphology -- A branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and the buildup of erosional debris.

Glide -- A section of stream that has little or no turbulence.

Grade control -- A fixed feature on the streambed that controls the bed elevation at that point, effectively fixing the bed elevation from potential incision; typically bedrock, dams. or culverts.

Gradient -- Vertical drop per unit of horizontal distance.

Grass/forb -- Herbaceous vegetation.

Gravel -- An unconsolidated natural accumulation of rounded rock fragments, mostly of particles larger than sand (diameter greater than 2 mm), such as boulders, cobbles, pebbles, granules, or any combination of these.

Groundwater -- Subsurface water and underground streams that can be collected with wells, or that flow naturally to the earth's surface through springs.

Groundwater basin -- A groundwater reservoir, defined by an overlying land surface and the underlying aquifers that contain water stored in the reservoir. In some cases, the boundaries of successively deeper aquifers may differ and make it difficult to define the limits of the basin.

Groundwater recharge -- Increases in groundwater storage by natural conditions or by human activity. See also artificial recharge.

Groundwater Table -- The upper surface of the zone of saturation, except where the surface is formed by an impermeable body.

Habitat -- The local environment in which organisms normally live and grow.

Habitat diversity -- The number of different types of habitat within a given area.

Habitat fragmentation -- The breaking up of habitat into discrete islands through modification or conversion of habitat by management activities.

Headcut -- A sharp change in slope, almost vertical, where the streambed is being eroded from downstream to upstream.

Headwater -- Referring to the source of a stream or river.

High gradient streams -- typically appear as steep cascading streams, step/pool streams, or streams that exhibit riffle/pool sequences. Most of the streams in Vermont are high gradient streams.

Hydraulic gradient -- The slope of the water surface. See also streambed gradient.

Hydraulic radius -- The cross-sectional area of a stream divided by the wetted perimeter.

Hydric -- oil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper horizon.

Hydrograph -- A curve showing stream discharge over time.

Hydrologic balance -- An accounting of all water inflow to, water outflow from, and changes in water storage within a hydrologic unit over a specified period of time. Hydrologic region -- A study area, consisting of one or more planning subareas, that has a common hydrologic character.

Hydrologic unit Code (HUC) -- A distinct watershed or river basin defined by an 8-digit code.

Hydrology -- The scientific study of the water of the earth, its occurrence, circulation and distribution, its chemical and physical properties, and its interaction with its environment, including its relationship to living things.

Hyporheic zone -- The area under the stream channel and floodplain where groundwater and the surface waters of the stream are exchanged freely.

Impoundment -- An area where the natural flow of the river has been disrupted by the presence of human-made or natural structure (e.g. weir or beaver dam). The impoundment backwater extends upstream causing sediment to be deposited on the stream bottom.

Improved paths – Paths that are maintained and typically involve paved, gravel or macadam surfaces.

Incised river -- A river that erodes its channel by the process of degradation to a lower base level than existed previously or is consistent with the current hydrology.

Incision ratio -- The low bank height divided by the bankfull maximum depth.

Infiltration (soil) -- The movement of water through the soil surface into the soil.

Inflow -- Water that flows into a stream, lake,

Instream cover -- The layers of vegetation, like trees, shrubs, and overhanging vegetation, that are in the stream or immediately adjacent to the wetted channel.

Instream flows -- (1) Portion of a flood flow that is contained by the channel. (2) A minimum flow requirement to maintain ecological health in a stream.

Instream use -- Use of water that does not require diversion from its natural watercourse. For example, the use of water for navigation, recreation, fish and wildlife, aesthetics, and scenic enjoyment.

Intermittent stream -- Any nonpermanent flowing drainage feature having a definable channel and evidence of scour or deposition. This includes what are sometimes referred to as ephemeral streams if they meet these two criteria.

Irrigation diversion -- Generally, a ditch or channel that deflects water from a stream channel for irrigation purposes.

Islands -- mid-channel bars that are above the average water level and have established woody vegetation.

Kame – a deposit of stratified glacial drift in isolated mounds or steep-sided hills.

Lake -- An inland body of standing water deeper than a pond, an expanded part of a river, a reservoir behind a dam

Landslide -- A movement of earth mass down a steep slope.

Large woody debris (LWD) -- Pieces of wood at least 6 ft. long and 1 ft. in diameter (at the large end) contained, at least partially, within the bankfull area of a channel.

Levee -- An embankment constructed to prevent a river from overflowing (flooding).

Limiting factor -- A requirement such as food, cover, or another physical, chemical, or biological factor that is in shortest supply with respect to all resources necessary to sustain life and thus "limits" the size or retards production of a population.

Low gradient -- streams typically appear slow moving and winding, and have poorly defined riffles and pools.

Macroinvertebrate -- Invertebrates visible to the naked eye, such as insect larvae and crayfish.

Macrophytes -- Aquatic plants that are large enough to be seen with the naked eye.

Main Stem -- The principal channel of a drainage system into which other smaller streams or rivers flow.

Mass movement -- The downslope movement of earth caused by gravity. Includes but is not limited to landslides, rock falls, debris avalanches, and creep. It does not however, include surface erosion by running water. It may be caused by natural erosional processes, or by natural disturbances (e.g., earthquakes or fire events) or human disturbances (e.g., mining or road construction).

Mean annual discharge -- Daily mean discharge averaged over a period of years. Mean annual discharge generally fills a channel to about one-third of its bank-full depth.

Mean velocity -- The average cross-sectional velocity of water in a stream channel. Surface values typically are much higher than bottom velocities. May be approximated in the field by multiplying the surface velocity, as determined with a float, times 0.8.

Meander -- The winding of a stream channel, usually in an erodible alluvial valley. A series of sine-generated curves characterized by curved flow and alternating banks and shoals.

Meander amplitude -- The distance between points of maximum curvature of successive meanders of opposite phase in a direction normal to the general course of the meander belt, measured between center lines of channels.

Meander belt width -- the distance between lines drawn tangential to the extreme limits of fully developed meanders. Not to be confused with meander amplitude.

Meander length -- The lineal distance down valley between two corresponding points of successive meanders of the same phase.

Mid-channel Bars – bars located in the channel away from the banks, generally found in areas where the channel runs straight. Mid-channel bars caused by recent channel instability are unvegetated.

Milligrams per liter (mg/l) -- The weight in milligrams of any substance dissolved in 1 liter of liquid; nearly the same as parts per million by weight.

Moraine – a mass of till either carried by an active glacier or deposited on the land after a glacier recedes.

Natural flow -- The flow past a specified point on a natural stream that is unaffected by stream diversion, storage, import, export, return flow, or change in use caused by modifications in land use.

Neck cutoff -- A channel migration feature where the land that separates a meander bend is cut off by the lateral migration of the channel. This process may be part of the equilibrium regime or associated with channel instability.

Outfall -- The mouth or outlet of a river, stream, lake, drain or sewer.

Outwash – water-transported material carried away from the ablation zone of a melting glacier.

Oxbow -- An abandoned meander in a river or stream, caused by cutoff. Used to describe the U-shaped bend in the river or the land within such a bend of a river.

Peat -- Partially decomposed plants and other organic material that build up in poorly drained wetland habitats.

Perched groundwater -- Groundwater supported by a zone of material of low permeability located above an underlying main body of groundwater with which it is not hydrostatically connected.

Perennial streams -- Streams that flow continuously.

Permeability -- The capability of soil or other geologic formations to transmit water.

pH -- The negative logarithm of the molar concentration of the hydrogen ion, or, more simply acidity.

Planform -- The channel shape as if observed from the air. Changes in planform often involve shifts in large amount of sediment, bank erosion, or the migration of the channel. A channel straightened for agricultural purposes has a highly impacted planform.

Point bar -- The convex side of a meander bend that is built up due to sediment deposition.

Pond -- A body of water smaller than a lake, often artificially formed.

Pool -- A reach of stream that is characterized by deep, low-velocity water and a smooth surface.

Potential plant height -- the height to which a plant, shrub or tree would grow if undisturbed.

Probability of exceedance -- The probability that a random flood will exceed a specified magnitude in a given period of time.

Railroads – Used or unused railroad infrastructure.

Rapids -- A reach of stream that is characterized by small falls and turbulent, high-velocity water.

Reach -- A section of stream having relatively uniform physical attributes, such as valley confinement, valley slope, sinuosity, dominant bed material, and bed form, as determined in the Phase 1 assessment.

Rearing habitat -- Areas in rivers or streams where juvenile fish find food and shelter to live and grow.

Reference stream type --Uses preliminary observations to determine the natural channel form and process that would be present in the absence of anthropogenic impacts to the channel and the surrounding watershed.

Refuge area -- An area within a stream that provides protection to aquatic species during very low and/or high flows.

Regime theory -- A theory of channel formation that applies to streams that make a part of their boundaries from their transported sediment load and a portion of their transported sediment load from their boundaries. Channels are considered in regime or equilibrium when bank erosion and bank formation are equal.

Restoration -- The return of an ecosystem to a close approximation of its condition prior to disturbance.

Riffle -- A reach of stream that is characterized by shallow, fast-moving water broken by the presence of rocks and boulders.

Riffle-pool ratio -- The ratio of surface area or length of pools to the surface area or length of riffles in a given stream reach; frequently expressed as the relative percentage of each category. Used to describe fish habitat rearing quality.

Riffle-step ratio-- ratio of the distance between riffles to the stream width.

Riparian area -- An area of land and vegetation adjacent to a stream that has a direct effect on the stream. This includes woodlands, vegetation, and floodplains. Riparian buffer is the width of naturally vegetated land adjacent to the stream between the top of the bank (or top of slope, depending on site characteristics) and the edge of other land uses. A buffer is largely undisturbed and consists of the trees, shrubs, groundcover plants, duff layer, and naturally uneven ground surface. The buffer serves to protect the water body from the impacts of adjacent land uses. Riparian corridor includes lands defined by the lateral extent of a stream's meanders necessary to maintain a stable stream dimension, pattern, profile, and sediment regime. For instance, in stable pool-riffle streams, riparian corridors may be as wide as 10-12 times the channel's bankfull width. In addition the riparian corridor typically corresponds to the land area surrounding and including the stream that supports (or could support if unimpacted) a distinct ecosystem, generally with abundant and diverse plant and animal communities (as compared with upland communities).

Riparian habitat -- The aquatic and terrestrial habitat adjacent to streams, lakes, estuaries, or other waterways.

Riparian -- Located on the banks of a stream or other body of water.

Riparian vegetation -- The plants that grow adjacent to a wetland area such as a river, stream, reservoir, pond, spring, marsh, bog, meadow, etc., and that rely upon the hydrology of the associated water body.

Ripple -- (1) A specific undulated bed form found in sand bed streams. (2) Undulations or waves on the surface of flowing water.

Riprap -- Rock or other material with a specific mixture of sizes referred to as a "gradation," used to stabilize streambanks or riverbanks from erosion or to create habitat features in a stream.

River channels --Large natural or artificial open streams that continuously or periodically contain moving water, or which form a connection between two bodies of water.

River miles --Generally, miles from the mouth of a river to a specific destination or, for upstream tributaries, from the confluence with the main river to a specific destination.

River reach -- Any defined length of a river.

River stage -- The elevation of the water surface at a specified station above some arbitrary zero datum (level).

Riverine -- Relating to, formed by, or resembling a river including tributaries, streams, brooks, etc.

Riverine habitat -- The aquatic habitat within streams and rivers.

Roads -- Transportation infrastructure. Includes private, town, state roads, and roads that are dirt, gravel, or paved.

Rock -- A naturally formed mass of minerals.

Rootwad -- The mass of roots associated with a tree adjacent to or in a stream that provides refuge for fish and other aquatic life.

Run (in stream or river) -- A reach of stream characterized by fast-flowing, low-turbulence water.

Runoff -- Water that flows over the ground and reaches a stream as a result of rainfall or snowmelt.

Sand -- Small substrate particles, generally from 0.002 to 0.08 in diameter. Sand is larger than silt and smaller than gravel.

Scour -- The erosive action of running water in streams, which excavates and carries away material from the bed and banks. Scour may occur in both earth and solid rock material and can be classed as general, contraction, or local scour.

Sediment -- Soil or mineral material transported by water or wind and deposited in streams or other bodies of water.

Sedimentation -- (1) The combined processes of soil erosion, entrainment, transport, deposition, and consolidation. (2) Deposition of sediment.

Seepage -- The gradual movement of a fluid into, through, or from a porous medium. Segment: A relatively homogenous section of stream contained within a reach that has the same reference stream characteristics but is distinct from other segments in the reach in one or more of the following parameters: degree of floodplain encroachment, presence/absence of grade controls, bankfull channel dimensions (W/D ratio, entrenchment), channel sinuosity and slope, riparian buffer and corridor conditions, abundance of springs/seeps/adjacent wetlands/stormwater inputs, and degree of channel alterations.

Sensitivity -- of the valley, floodplain, and/or channel condition to change due to natural causes and/or anticipated human activity.

Shoals -- unvegetated deposits of gravels and cobbles adjacent to the banks that have a height less than the average water level. In channels that are over-widened, the stream does not have the power to transport these larger sediments, and thus they are deposited throughout the channel as shoals.

Silt -- Substrate particles smaller than sand and larger than clay; between 0.0001 and 0.002 inches in diameter.

Siltation -- The deposition or accumulation of fine soil particles.

Sinuosity -- The ratio of channel length to direct down-valley distance. Also may be expressed as the ratio of down-valley slope to channel slope.

Slope -- The ratio of the change in elevation over distance.

Slope stability -- The resistance of a natural or artificial slope or other inclined surface to failure by mass movement.

Snag -- Any standing dead, partially dead, or defective (cull) tree at least 10 in. in diameter at breast height and at least 6 ft tall. Snags are important riparian habitat features.

Spawning -- The depositing and fertilizing of eggs (or roe) by fish and other aquatic life.

Spillway -- A channel for reservoir overflow.

Stable channel -- A stream channel with the right balance of slope, planform, and cross section to transport both the water and sediment load without net long-term bed or bank sediment deposition or erosion throughout the stream segment.

Stone -- Rock or rock fragments used for construction.

Straightening -- the removal of meander bends, often done in towns and along roadways, railroads, and agricultural fields.

Stream -- A general term for a body of water flowing by gravity; natural watercourse containing water at least part of the year. In hydrology, the term is generally applied to the water flowing in a natural narrow channel as distinct from a canal. Stream banks are features that define the channel sides and contain stream flow within the channel; this is the portion of the channel bank that is between the toe of the bank slope and the bankfull elevation. The banks are distinct from the streambed, which is normally wetted and provides a substrate that supports aquatic organisms. The top of bank is the point where an abrupt change in slope is evident, and where the stream is generally able to overflow the banks and enter the adjacent floodplain during flows at or exceeding the average annual high water.

Stream channel -- A long narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.

Stream condition -- Given the land use, channel and floodplain modifications documented at the assessment sites, the current degree of change in the channel and floodplain from the reference condition for parameters such as dimension, pattern, profile, sediment regime, and vegetation.

Stream gradient -- A general slope or rate of change in vertical elevation per unit of horizontal distance of the bed, water surface, or energy grade of a stream.

Stream morphology -- The form and structure of streams.

Stream order -- A hydrologic system of stream classification. Each small unbranched tributary is a first-order stream. Two first-order streams join to make a second-order stream. A third-order stream has only first-and second-order tributaries, and so forth.

Stream reach -- An individual segment of stream that has beginning and ending points defined by identifiable features such as where a tributary confluence changes the channel character or order.

Stream type -- Gives the overall physical characteristics of the channel and helps predict the reference or stable condition of the reach.

Stream type departure -- When the current stream type differs from the reference stream type as a response to anthropogenic or severe natural disturbances. These departures are often characterized by large-scale incision, deposition, or changes in planform.

Streambank armoring – The installation of concrete walls, gabions, stone riprap, and other large erosion resistant material along stream banks.

Streambank erosion -- The removal of soil from streambanks by flowing water.

Streambank stabilization -- The lining of streambanks with riprap, matting, etc., or other measures intended to control erosion.

Streambed -- (1) The unvegetated portion of a channel boundary below the baseflow level. (2) The channel through which a natural stream of water runs or used to run, as a dry streambed.

Streamflow -- The rate at which water passes a given point in a stream or river, usually expressed in cubic feet per second (cfs).

Step (in a river system) --A step is a steep, step-like feature in a high gradient stream (> 2%). Steps are composed of large boulders lines across the stream. Steps are important for providing grade-control, and for dissipating energy. As fast-shallow water flows over the steps it takes various flow paths thus dissipating energy during high flow events.

Substrate -- (1) The composition of a streambed, including either mineral or organic materials. (2) Material that forms an attachment medium for organisms.

Surface erosion -- The detachment and transport of soil particles by wind, water, or gravity. Or a group of processes whereby soil materials are removed by running water, waves and currents, moving ice, or wind.

Surface water -- All waters whose surface is naturally exposed to the atmosphere, for example, rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc., and all springs, wells, or other collectors directly influenced by surface water.

Suspended sediment -- Sediment suspended in a fluid by the upward components of turbulent currents, moving ice, or wind.

Suspended sediment load -- That portion of a stream's total sediment load that is transported within the body of water and has very little contact with the streambed.

Tailwater -- (1) The area immediately downstream of a spillway. (2) Applied irrigation water that runs off the end of a field.

Thalweg -- (1) The lowest thread along the axial part of a valley or stream channel. (2) A subsurface, groundwater stream percolating beneath and in the general direction of a surface stream course or valley. (3) The middle, chief, or deepest part of a navigable channel or waterway.

Tractive Force --The drag on a streambed or bank caused by passing water, which tends to pull soil particles along with the streamflow.

Transpiration -- An essential physiological process in which plant tissues give off water vapor to the atmosphere.

Tributary -- A stream that flows into another stream, river, or lake.

Turbidity -- A measure of the content of suspended matter that interferes with the passage of light through the water or in which visual depth is restricted. Suspended sediments are only one component of turbidity.

Urban runoff -- Storm water from city streets and gutters that usually carries a great deal of litter and organic and bacterial wastes into the sewer systems and receiving waters.

Valley confinement -- Referring to the ratio of valley width to channel width. Unconfined channels (confinement of 4 or greater) flow through broader valleys and typically have higher sinuosity and area for floodplain. Confined channels (confinement of less than 4) typically flow through narrower valleys.

Valley wall -- The side slope of a valley, which begins where the topography transitions from the gentle-sloped valley floor. The distance between valley walls is used to calculate the valley confinement.

Variable-stage stream -- Stream flows perennially but water level rises and falls significantly with storm and runoff events.

Velocity -- In this concept, the speed of water flowing in a watercourse, such as a river.

Washout -- (1) Erosion of a relatively soft surface, such as a roadbed, by a sudden gush of water, as from a downpour or floods. (2) A channel produced by such erosion.

Water quality -- A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Waterfall -- A sudden, nearly vertical drop in a stream, as it flows over rock.

Watershed -- An area of land whose total surface drainage flows to a single point in a stream.

Watershed management -- The analysis, protection, development, operation, or maintenance of the land, vegetation, and water resources of a drainage basin for the conservation of all its resources for the benefit of its residents.

Watershed project -- A comprehensive program of structural and nonstructural measures to preserve or restore a watershed to good hydrologic condition. These measures may include detention reservoirs, dikes, channels, contour trenches, terraces, furrows, gully plugs, revegetation, and possibly other practices to reduce flood peaks and sediment production.

Watershed restoration -- Improving current conditions of watersheds to restore degraded habitat and provide long-term protection to aquatic and riparian resources.

Weir -- A structure to control water levels in a stream. Depending upon the configuration, weirs can provide a specific "rating" for discharge as a function of the upstream water level.

Wetland -- Areas adjacent to, or within the stream, with sufficient surface/groundwater influence to have present hydric soils and aquatic vegetation (e.g. cattails, sedges, rushes, willows or alders).

Width/depth ratio -- The ratio of channel bankfull width to the average bankfull depth. An indicator of channel widening or aggradation, and used for stream type classification.