

# Cold River Corridor Plan Rutland County, Vermont

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## Executive Summary

The Cold River watershed is drained by steep slopes of the Green Mountains in the Towns of Shrewsbury, Mendon, and Clarendon. The combination of the mountainous setting and underlying geology makes the Cold River very powerful and dynamic during major flood events. During Tropical Storm Irene in late August of 2011, approximately 6-7 inches of rain fell in the headwaters of the watershed. This amount of rainfall, combined with its intensity, caused the Cold River to rise very quickly and carry a tremendous amount of bedload sediment to the lower reaches along Cold River Road and on down to the alluvial fan below US Route 7 situated in the Otter Creek valley in Clarendon. As was evident during this extreme flood event, the road corridors and settlement patterns along the Cold River are especially susceptible to fluvial erosion. Many areas of roadways, bridges, and some residences sustained severe damage during this flood event.

In an effort to understand the root causes of river instability and plan for channel instability and fluvial erosion hazards in the Cold River corridor, the stakeholders in the watershed have sought to develop a database of Stream Geomorphic Assessment (SGA) data for most stream reaches of significant size in the watershed. This effort began in early 2007 with a remote, desktop review of the reaches in the watershed, and continued later that year with detailed field measurements (i.e., Phase 2 SGA). The collection of this data allows for a much more comprehensive erosion hazard planning approach, in contrast to the conventional approach of multiple “spot fixes” with limited knowledge of the river system. In early 2012, The Rutland Natural Resources Conservation District (RNRCD) received a grant from the Vermont Agency of Natural Resources (Ecosystem Restoration Program) to develop a River Corridor Management Plan for the Cold River watershed. Fitzgerald Environmental Associates, LLC (FEA) was hired by RNRCD in spring of 2012 to develop the plan. The objectives of the planning study are described below.

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

The Cold River is dynamic and highly erosive during flood events because of ongoing adjustments to its dimensions, patterns, and profiles. These adjustments are in response to impacts from historical sedimentation in the valleys from early European settlement and deforestation that caused hillslope erosion, as well as modern day impacts from channel straightening, dredging, berming, and corridor encroachment associated with adjacent railroads, agriculture, and other land uses. Recent extreme flood events such as Tropical Storm Irene have also triggered channel incision and redevelopment of floodplain access in some reaches. Ongoing vertical and lateral channel migration is likely in the future for many reaches in the watershed. Given these predictions for future channel adjustments, the following watershed-scale and site-specific management observations and approaches are summarized from the corridor plan:

- The stressor identification analysis revealed limited watershed-scale impacts from recent land use changes (i.e., development). For example, the overall watershed land cover is 92% forest with very minimal development (<1%) and agricultural lands (3.6%). Most of the agricultural land use is concentrated in the lower watershed along the fertile soils in the Otter Creek valley.

- Corridor encroachments, berming, and historical channel straightening have significantly impacted the many reaches of Cold River. Six (6) river segments along the Cold River 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.
- Site level approaches to restoration of dynamic equilibrium conditions were evaluated in detail at the reach scale. This effort resulted in the identification of 29 restoration project areas, including 14 projects that do not require significant further study (i.e., passive approaches such as buffer plantings and corridor protection), and 15 projects requiring further feasibility study or engineering design (i.e., active restoration approaches such as bridge replacements). A map of the potential project areas is included in Appendix A. Five project areas that were identified by the Cold River steering committee as high-priority were evaluated in further detail. Project summaries are included in Appendix B.
- We recommend the continued use/enforcement of the adopted Fluvial Erosion Hazard (FEH) zone ordinance in the Town of Shrewsbury, with consideration of appropriate stream setbacks in areas where the FEH zone is not mapped (e.g., smaller tributaries draining to Cold River). In Clarendon, where an FEH ordinance has not been adopted, the Town is encouraged to consider the adoption of FEH zoning to protect public safety during future flood events, and improve aquatic habitat and water quality in the river over the long-term.
- The management of accumulating sediment in the lower reaches of the Cold River between US Route 7 and Middle Road has been identified as a key concern in the Town of Clarendon due to ongoing conflicts at road crossings and adjacent properties. This area, which is characterized as an alluvial fan, will continue to aggrade (i.e., accumulate) sediment transported from upstream reaches. Due to the extreme amount of bedload sediment mobilized during Tropical Storm Irene, sediment aggradation will continue to be severe in this area over the next decade. A long-term management plan which includes berm removal, floodplain restoration, and the periodic maintenance of channel sediments in a way that sustains aquatic habitat is needed for this area. One project packet included in Appendix B (project #26), outlines strategies for re-connecting historic floodplains and reducing property damage in future flood events.
- We recommend that the Town of Shrewsbury carefully consider those areas of river corridor in the town identified for added protection (i.e., conservation easements) above and beyond the FEH restrictions to protect upstream floodplains and mitigate downstream effects of fluvial erosion hazards in Shrewsbury and Clarendon. Refer to projects 8 and 9 in Table 5.3.
- There is a strong need to address high-priority areas of channel and floodplain restoration to mitigate the effects of dredging/berming that occurred following TS Irene. These areas, which include projects 11, 24, 25, and 28 (see Appendix B for detailed project descriptions), have elevated risks of future flood damage for both adjacent lands and downstream areas.

## **1.0 Project Background**

### **1.1 Introduction**

The Cold River drains steep terrain on the western slopes of the Green Mountains in the Towns of Shrewsbury, Mendon, and Clarendon. Due to its mountainous setting and underlying geology, the Cold River is very powerful and dynamic during major flood events. This was especially evident during Tropical Storm Irene in late August of 2011, when an estimated 6-7 inches of rain fell in the headwaters of the watershed. This amount of rainfall, combined with its intensity, caused the Cold River to rise very quickly and carry a tremendous amount of bedload sediment to the lower reaches along Cold River Road and on down to the Otter Creek valley in Clarendon. The road corridors and settlement patterns along the Cold River are especially susceptible to fluvial erosion. Many areas of roadways, bridges, and some residences sustained severe damage during this flood event.

In response to Tropical Storm Irene, and in an effort to understand and plan for stream channel instability and fluvial erosion hazards in the Cold River watershed, the stakeholders in the watershed have sought to develop a database of Stream Geomorphic Assessment (SGA) data for most stream reaches of significant size in the watershed. This effort began in early 2007 with a remote, desktop review of the reaches in the watershed, and continued later that year with detailed field measurements (i.e., Phase 2 SGA) in the fall. This data allows for a much more comprehensive erosion hazard planning approach, in contrast to the conventional approach of multiple “spot fixes” with limited knowledge of the river system.

In early 2012, RNRCD received a grant from the Vermont Agency of Natural Resources (Ecosystem Restoration Program) to develop a River Corridor Management Plan for the Cold River watershed. Fitzgerald Environmental Associates, LLC (FEA) was hired by the Rutland Natural Resources Conservation District (RNRCD) in spring of 2012 to develop the plan. The goals of the planning study are described below.

### **1.2 Study Goals**

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

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

The Rutland Regional Planning Commission (RRPC) retained Round River Design, LLC. to complete Phase 2 Stream Geomorphic Assessments (SGA) following the RMP protocols on approximately 12.7 miles of the Cold River in the fall of 2007. Using this background data as a basis for planning, the goal of the River Corridor Planning effort for these watersheds is to provide:

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

### 1.3 Project Partners

The planning team for the ongoing SGA and River Corridor Planning work in the Cold River watershed includes the following groups:

- Rutland Conservation District
- Vermont Department of Environmental Conservation
- Rutland Regional Planning Commission
- Town of Shrewsbury
- Town of Clarendon

## 2.0 Background Watershed Information

### 2.1 Geographic Setting and Land Use History

The Cold River watershed is located in Rutland County, Vermont, and has an area of approximately 37mi<sup>2</sup> (Figure 2.1). The Cold River flows westerly and joins the Otter Creek which then drains northerly into Lake Champlain. It is one of the major watersheds comprising the Upper Otter Creek Watershed. The watershed drains from forested headwaters in the Green Mountains covering portions of five towns: Clarendon, Mendon, Shrewsbury, Killington, and Rutland Town. The watershed includes Johnsons Pond, and several other smaller ponds and wetlands. It joins the Otter Creek at approximately 520 feet above sea level near the town boundary of Clarendon and Rutland Town (RRD, 2007).

Land cover data based on imagery from 2006 (NOAA, 2008) are summarized in Table 2.1. The Cold River is drained by a rural watershed, with forests representing the dominant land cover type (92.4%). Agricultural lands cover 3.6% of the watershed and are concentrated in the subwatersheds for reaches M01, M02, M03, M06, M07, and M10. Developed lands cover 0.6% of the watershed and follow a similar distribution, concentrated in M01, M03, and M10. Developed and agricultural land cover is minimal outside of the Phase 2 assessment area. Wetland cover is relatively high in several subwatersheds, especially near the headwaters in reach M10.

<b>Land Cover/Land Use Type</b>	<b>Phase 2 Subwatersheds</b>	<b>Cold River Watershed (total)</b>
Agriculture	8.2%	3.6%
Development	1.4%	0.6%
Forest	84.7%	92.4%
Open Water	0.2%	0.1%
Scrub/Shrub	1.7%	1.3%
Wetland	3.7%	2.1%
Area (Mi <sup>2</sup> )	14.1	36.7

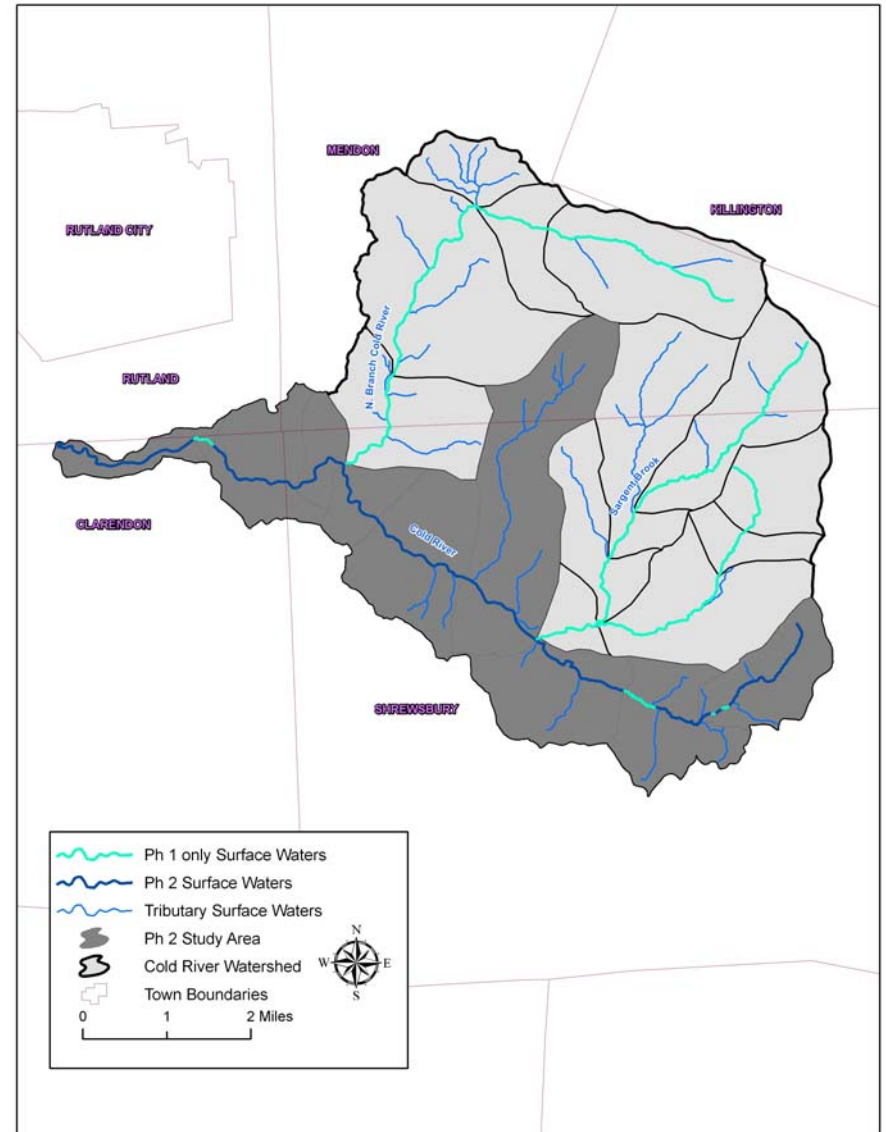
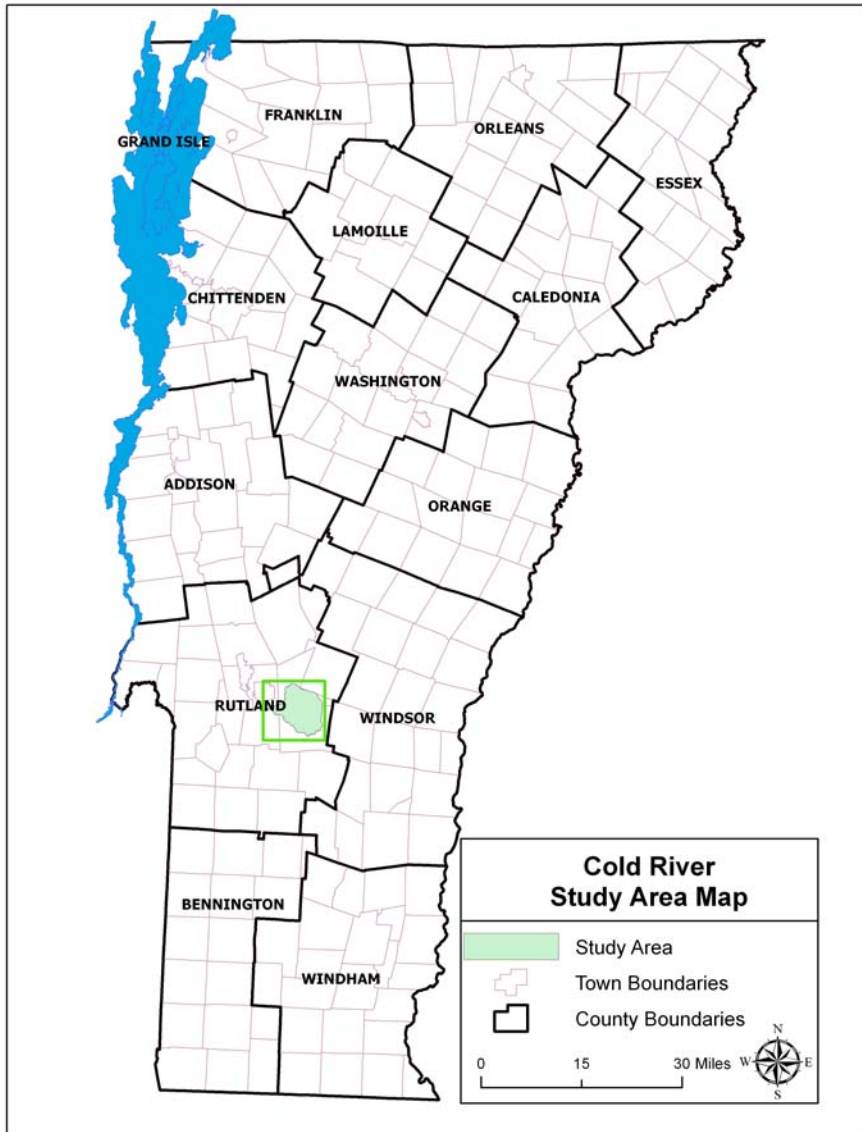


Figure 2.1 Cold River watershed location maps

### *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 Cold 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 for agriculture, likely left over 80% of the watershed devoid of trees at one time or another (Albers, 2000). This landscape change had a tremendous impact on waterways like the Cold 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 Cold River watershed is covered by forest. Only 3.6% of the watershed is occupied by agricultural land uses today.

## **2.2 Geologic Setting**

In a broad geologic context the Cold River watershed spans two larger biophysical regions. The lower reaches are within the "Vermont Valley" (VV) – a continuation of the Champlain Valley that lies in between the Green Mountains and the Taconic Mountains. The upper reaches of the watershed lie in the "Southern Green Mountain" (SM) biophysical region, a huge anticlinorium comprised of three anticlines that have been compressed and uplifted and trend in a North-South direction (Stewart, 1972; Thompson and Sorenson, 2000). The upper watershed lies in a bedrock setting that is composed primarily of metamorphosed schists and gneisses. The lower reaches are characterized by mostly Cambrian carbonate rock and limestone/marble most similar to the Champlain Valley. The VV was heavily scoured by the Pleistocene ice sheet which also left significant glacial and surficial deposits (Thompson and Sorenson, 2000; Vermont Geological Survey, 1952).

The underlying bedrock of the watershed influences the topography and energy gradients of the streams while the rock characteristics can influence the erodibility (and therefore channel stability) as well as the chemical water quality properties of a stream. Frequent bedrock exposures in the headwaters of the Cold River corridor influence the channel position and longitudinal profile of the river. These exposures tend to lock the channel in place in areas and make them more resistant to erosion; however bedrock grade controls are less common in the lower reaches of the Cold River and therefore the channel is more prone to vertical adjustments. Soils maps delineated by the Natural Resource Conservation Service were used to identify surficial geology materials (RRD, 2007). Ice-contact, glacial till, and alluvial deposits are the dominant surficial geologic materials in the watershed (Figure 2.2).

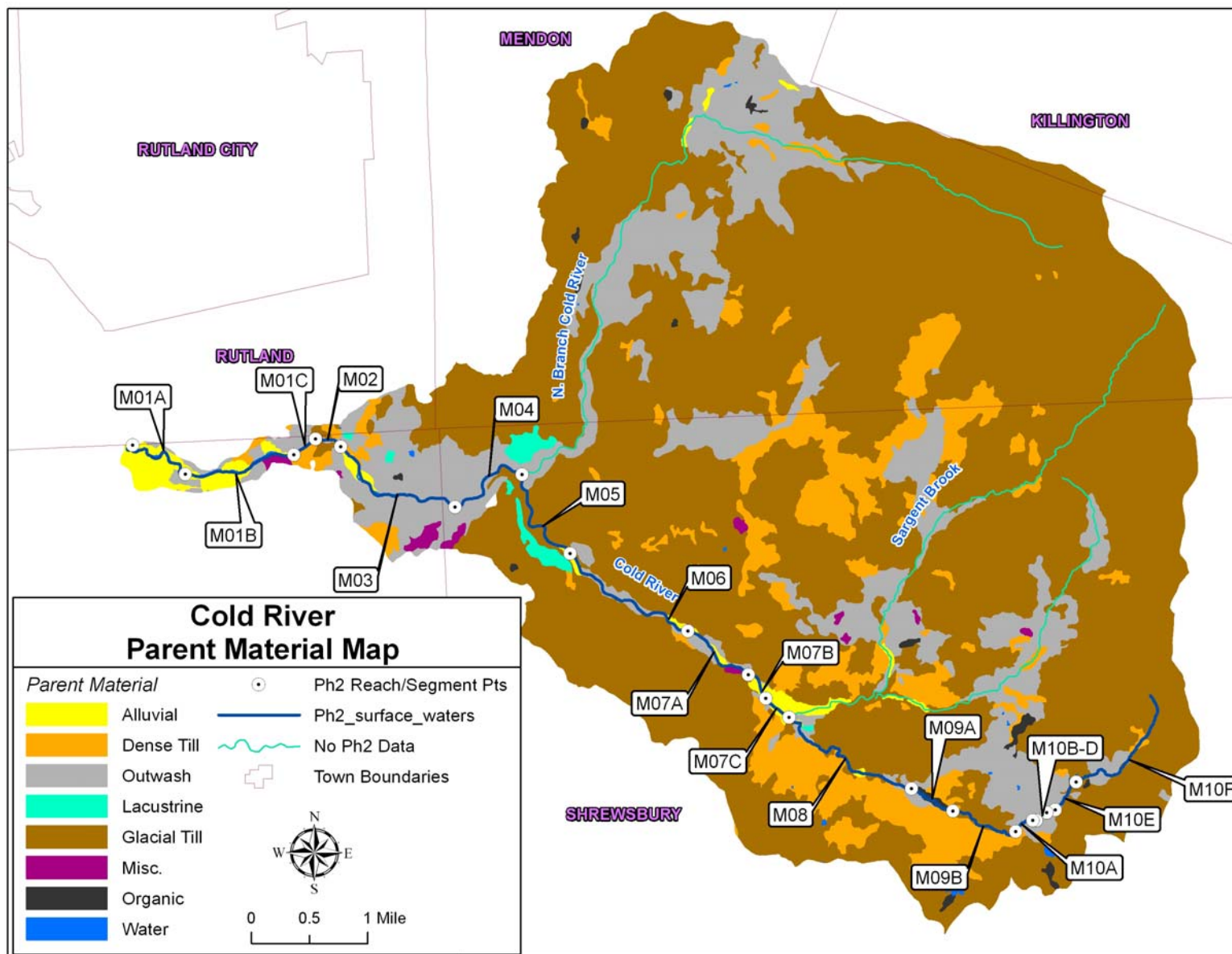


Figure 2.2 Parent surficial materials in the Cold River watershed

### 2.3 Geomorphic Setting

Table 2.2 provides a summary of the reference reach data for the ten (10) Phase 2 reaches assessed in the watershed. The Cold River reaches are found in a varied setting with narrow to very broad valleys, B and C-type stream types, and bedrock, riffle-pool, or plane bed bedform.

**Table 2.2** Reference reach characteristics for the Cold River

Reach ID	Watershed Area (Mi <sup>2</sup> )	Channel Length (Mi)	Channel Width (ft)	Channel Slope`	Sinuosity	Valley Type*	Reference Stream Type†	Bedform‡
M01	36.7	2.0	63.9	1.02	1.08	VB	C	Riffle-Pool
M02	36.2	0.3	63.5	2.96	1.11	NC	B	Bedrock
M03	36.1	1.3	63.5	2.33	1.09	NW	C	Riffle-Pool
M04	34.7	0.8	62.4	2.76	1.08	NW	B	Plane Bed
M05	23.1	1.0	52.2	2.89	1.05	SC	B	Plane Bed
M06	22.4	1.4	51.5	1.96	1.10	BD	C	Riffle-Pool
M07	20.3	1.2	49.2	1.69	1.03	VB	C	Riffle-Pool
M08	4.7	1.5	25.8	2.68	1.21	NW	C	Plane Bed
M09	2.9	1.2	21.0	0.48	1.19	VB	C	Riffle-Pool
M10	1.4	2.0	15.1	5.12	2.40	VB	C	Riffle-Pool

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

‡ per Montgomery and Buffington, 1997

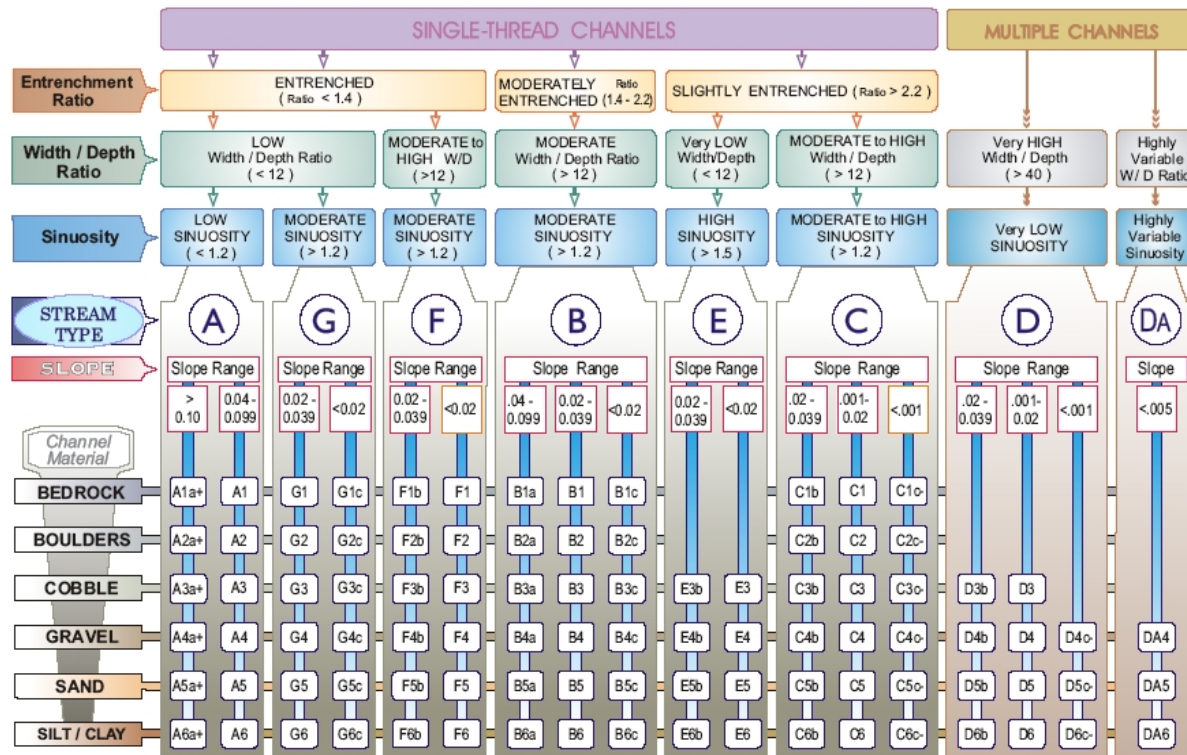
The river reaches assessed in this study are found in varied topographic terrain. Variation in topography and valley slope influences the channel morphologies that would be expected under reference (i.e., undisturbed) conditions. A Phase 1 SGA study was previously carried out by RRPC in 2007, and included summary data of the topographic characteristics that influence valley and channel morphology, including watershed area, channel/valley slopes, predicted channel widths, and sinuosity. Following the Phase 2 SGA work completed as the basis for this study, reference reach characteristics for some of the reaches were refined based on improved knowledge of the reach and valley setting. The reach characteristics were used to classify natural channels using two classification systems developed by Rosgen (1994) and Montgomery and Buffington (1997).

Several parameters including entrenchment, channel dimensions, sinuosity, and slope are factored into stream classifications. The reference stream type classification was determined in the Phase 1 SGA and corroborated in the Phase 2 SGA for potential stream type departures. Out of the 10 assessed reaches, there are three (3) B type streams and seven (7) C type streams. There are 6 riffle-pool, 3 plane-bed, and 1 bedrock type reaches. The sinuosity is generally low in the Cold River watershed, but valley confinement types range significantly between the reaches. Channel slope along the main stem of the Cold River is low to moderate (1 to 2.9%) except for the low gradient reach M09 (0.5%) and the steeper headwaters in M10 (5.1%).

The Rosgen system (Figure 2.3) uses measurements of channel and floodplain dimensions to make predictions about river processes. This classification system is used widely by federal and state agencies as a way of communicating about river form and function in the context of restoration management. The Montgomery and Buffington classification system is based on a river's "bedform", whereby the shape of the bed and its features (e.g., riffle and pools) are used to understand the

dominant hydraulic and sediment processes of the river. This system is also used widely in Vermont and other states as part of geomorphic assessment methods.

### The Key to the Rosgen Classification of Natural Rivers



KEY to the ROSGEN CLASSIFICATION of NATURAL RIVERS. As a function of the "continuum of physical variables" within stream reaches, values of *Entrenchment* and *Sinuosity* ratios can vary by +/- 0.2 units; while values for *Width / Depth* ratios can vary by +/- 2.0 units.

**Figure 2.3** The Rosgen (1994) classification of streams based on channel morphology. Key parameters for classification include 1) the entrenchment ratio (floodprone width / bankfull channel width), 2) width to depth ratio (bankfull width / mean channel depth), and 3) channel sinuosity (channel length / straight-line valley length). Entrenched channels are typically dominated by sediment transport processes, whereas slightly entrenched channels (C and E types) have sediment transport and depositional processes.

### 2.4 Hydrology, Flood History and Channel Management

No stream gage records exist for the Cold River watershed. However, hydrologic data for the watershed was derived using the Streamstats program, developed for the state of Vermont by the United States Geological Survey (USGS). Based on the Streamstats summary basin characterization, the Cold River has a drainage area of 36.7mi<sup>2</sup> and the bankfull discharge (two year flow frequency) is approximately 1240 cfs at the mouth.

#### USGS Gaging Data and Flooding History

The USGS operates a real-time flow monitoring gage on the Otter Creek in Rutland, VT (gage #04282000) that reveals some flood history for the basin. Based on the gage's historical data, there have been flows above 10,000 cfs in the years 1947, 1949, 1973, 1987, and 2011. These flows approximate the 25-year flood and suggest that similar flood flows would have occurred in the Cold River watershed during those years.

### *Tropical Storm Irene*

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



**Figure 2.4** Irene damage on the CCC Road in Shrewsbury  
(The Mountain Times, [www.mountaintimes.info](http://www.mountaintimes.info))



**Figure 2.5** US 7 bridge over the Cold River  
(Nick Johnson, [www.gmoutlook.com](http://www.gmoutlook.com))

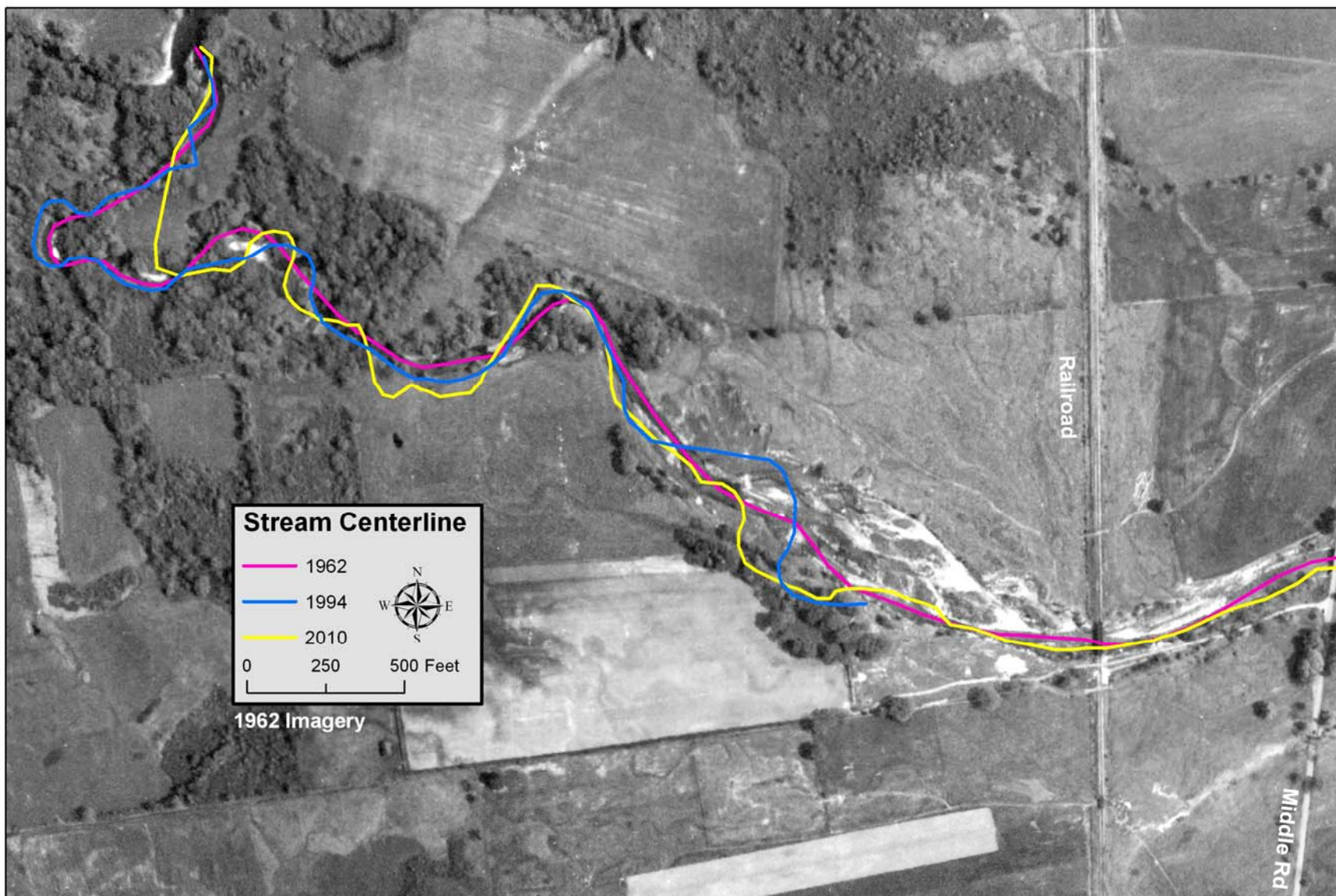
In the Cold River watershed, damage resulting from Tropical Storm Irene was severe. There were several areas of extreme damage along adjacent roadways, including the destruction of the US 7 bridge in Clarendon (Figure 2.5). Other areas of severe damage included the CVPS power line crossing of Cold River Road, and multiple areas of road washouts along the upper section of Cold River Road. Below in Table 2.3 is a summary of areas that saw the most severe damage or channel adjustments during Tropical Storm Irene.

**Table 2.3** Severe Damage Areas in Watershed from Tropical Storm Irene

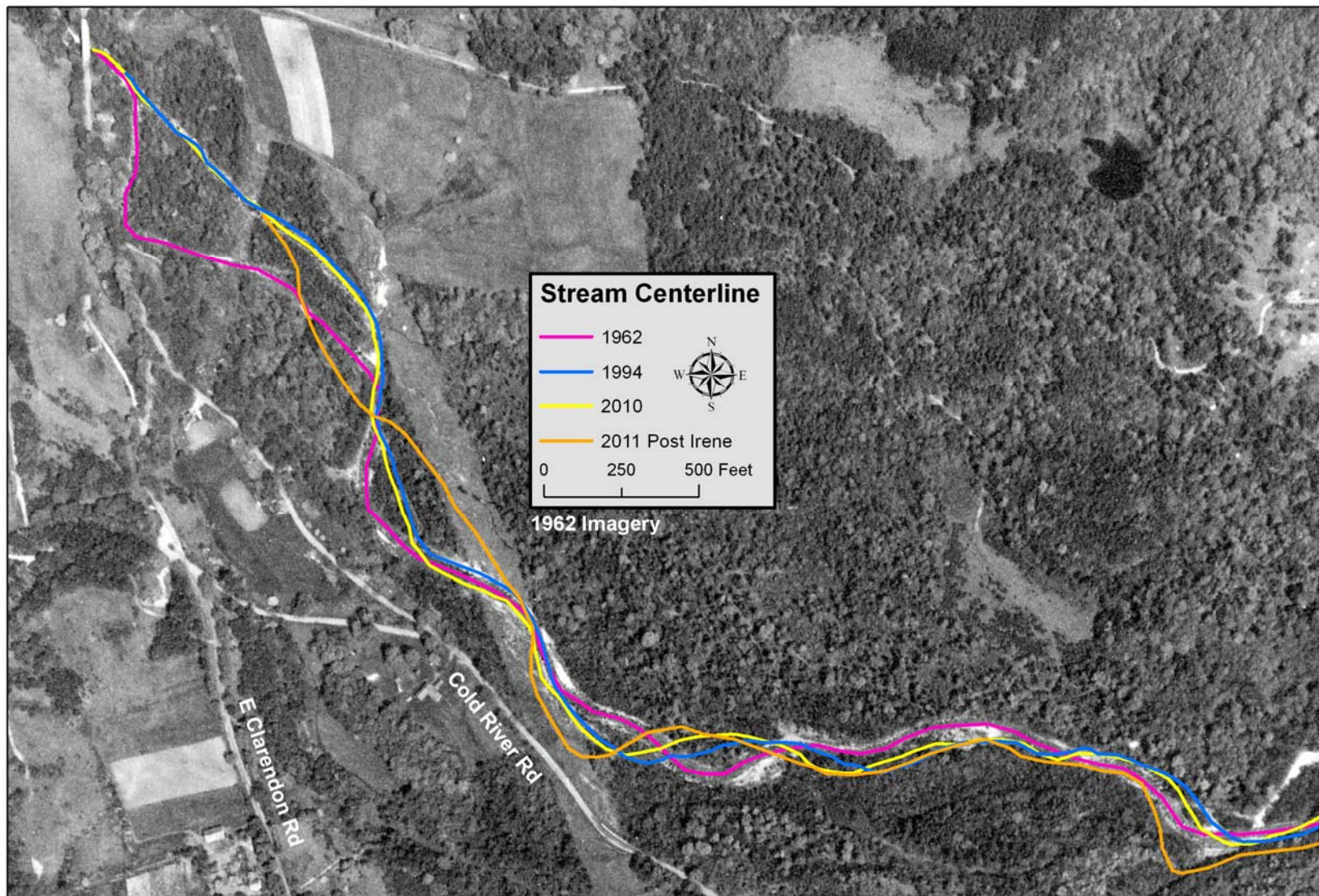
Road or Area	Reach/Segment	Damages and Repairs
CCC Road, Shrewsbury	M10-E	Overbank flooding and erosion downstream of private driveway bridge to house (500ft north of Old Plymouth Rd).
Old Plymouth Road, Shrewsbury	M10-E	Undersized culvert destroyed. To be replaced by bridge under design for Town by OCE.
Eastham Road, Shrewsbury	M10-E	Damage to inlet end of 6ft CMP culvert and erosion along embankment (200ft south of Northam Rd intersection).
Mountain School Road, Shrewsbury	M10-E	Erosion at outlet end of culvert and partial embankment failure (150ft south of Northam Rd intersection).
Cold River Road - Wilmouth Hill Rd Intersection, Shrewsbury	M07-C	Overbank flows from Sargent Brook caused erosion and fine sediment deposition in fields to north. Bank failure along north and south banks upstream of bridge. Road embankment failure on south bank downstream of bridge.
Cold River Road, Shrewsbury	M07-A	Road embankment erosion/failure on south bank (0.5 and 0.7 miles west of Wilmouth Hill Road).
Cold River Road, Shrewsbury	M06	Road embankment erosion/failure on south bank; Culvert failure and erosion on south side of road (1 mile east of Wallace Road).
Upper Cold River Road, Shrewsbury	M05	Road embankment erosion/failure on south bank leading down to covered bridge resulted in road closing.
Cold River Road, Clarendon	M03	Embankment erosion/failure on south bank and damaged homes; Damage to utility poles; Severe channel adjustments and erosion (near North Shrewsbury Road intersection).
US 7 Bridge, Clarendon	M01-B	Bridge/road failure due to severe erosion along the north bank causing closure of US 7.
Middle Road, Clarendon	M01-B	Severe overbank flooding and fine sediment deposition south of Middle Road bridge; Embankment failure on south bank.
West of Middle Road, Clarendon	M01-A	Severe overbank flooding and fine sediment deposition in farm fields west of railroad crossing.

*Flood Recovery and Channel Management*

Common flood recovery efforts in the 1960's and 70's in Vermont involved dredging and deepening river channels to create more hydraulic capacity, armoring embankments even where it resulted in severe river encroachment, and re-channelizing rivers to their pre-flood location. These activities often resulted in greater vulnerability due to the loss of floodplain access, particularly in communities found downstream of long stretches of channel manipulation. In reviewing historical aerial photographs of the Cold River watershed, we can see evidence of these management practices and also track how the river channels have changed since then. The images below include channel centerlines mapped from different years of aerial photography, including the 1962 photographs used as the background image (Figures 2.6 and 2.7).



**Figure 2.6** Stream centerlines for lower Cold River (Segment M01-A) illustrate the changes in channel planform that have occurred since the 1960's



**Figure 2.7** Stream centerlines for the Cold River (Reach M03) illustrate changes in channel planform since the 1960's and the extreme channel migration that occurred during Tropical Storm Irene (orange line)

## 2.5 Ecological Setting

Cold River watershed is located in the Vermont Valley (VV) and the Southern Green Mountain (SM) Biophysical Regions (Thompson and Sorenson, 2000). Reaches M01 through M04 lie in the VV region. The VV region is a narrow break between the Taconic Mountains and the Green Mountains and is distinct from the neighboring mountainous regions, and most similar to the Champlain Valley. The flat landscape and fertile soils present in the VV region led to agricultural and transportation uses. Natural forests along the valley floors were likely biologically rich and abundant. Gravel terraces are predominantly covered by white pine/hemlock forests. The VV region is important for animal migration both along the valley and between the large mountain ranges. Elevations range from 160' at the mouth of Cold River to 2080' at the top of Bald Mountain.

Reaches M05-M10 are located in the Southern Green Mountain Biophysical Region. Climate in this region is cool and wet due to the higher elevations and steep terrain. Wetlands are common on the plateaus of the SM region as evident in subwatersheds for reach M10E and M10F. Human settlement was much lower in this region; however most of the natural forests were cut by the early 1900's. Northern hardwoods and hemlock forests are the dominant natural forest types. Elevations range from 900' to 2480'.

VTDEC has collected benthic macroinvertebrate samples at river mile 6.8 on the Cold River (Segment M07-B, and at river miles 1.5 and 4.5 on Sargent Brook in Shrewsbury (Table 2.4). This sampling occurred between 1993 and 1999 and the results generally reflect healthy macroinvertebrate populations in these reaches.

Date Sampled	DEC ID	Location	River Mile	SGA Reach	Mean Density	Mean Species Richness	Mean EPT* Richness	Community Assessment
10/6/1993	55410000068	Cold River	6.8	M07-B	960	44	24.5	Good
10/1/1993	554105000014	Sargent Brook	1.4	T2.02	862	45.5	22	Good
10/6/1997	554105000045	Sargent Brook	4.5	T2.04	365	29.5	23	Very good
10/23/1998	554105000045	Sargent Brook	4.5	T2.04	828	25.8	19.2	Very good
10/15/1999	554105000045	Sargent Brook	4.5	T2.04	450	27	19.5	Very good

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

## 3.0 Methods

The Vermont River Management Program (RMP) has invested many years of effort into developing a state-of-the-art system of Stream Geomorphic Assessment (SGA) protocols. The SGA protocols are intended to be used by resource managers, community watershed groups, municipalities and others to identify how changes to land use affect hydro-geomorphic processes at the landscape and reach scale, and how these changes alter the physical structure and biotic habitat of streams in Vermont. The SGA protocols have become a key tool in the prioritization of restoration projects that will 1) reduce

sediment and nutrient loading to downstream receiving waters such as Lake Champlain and the Connecticut River, 2) reduce the risk of property damage from flooding and erosion, and 3) enhance the quality of in-stream biotic habitat. The protocols are based on defensible scientific principles and have been tested widely in many watersheds throughout the state.

### **3.1 Phase 1 and 2 SGA Methods**

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

Phase 1 data were collected in 2007 by RRPC on 21 reaches on the Cold River and its tributaries, and were summarized in the VTDEC Database Management System (DMS). A total of 10 reaches were identified for Phase 2 assessment conducted by Round River Design in the fall of 2007. A total of 16 segments on the Cold River were assessed for Phase 2 data, and data were entered into the Data Management System (DMS). All major human impacts and natural features noted during the Phase 2 surveys were indexed in a GIS using the Feature Indexing Tool (FIT; VTDEC, 2009).

### **3.2 Phase 2 Quality Assurance/Quality Control**

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

### **3.3 Bridge and Culvert Assessments**

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

### **3.4 Stressor and Departure Analysis**

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

- River science and societal benefits of managing streams in a sustainable manner toward equilibrium conditions
- Methods for assessing and mapping stream geomorphic conditions, and identifying and prioritizing river corridor protection and restoration projects

- Methods for examining project feasibility and negotiating management alternatives with stakeholders
- Information on current programs available to Vermont landowners, towns, and other interested parties to implement river corridor protection and restoration projects

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

#### *3.4.1 Stressor Analysis*

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

Stressor, departure and sensitivity maps have been prepared to depict the effects of significant physical processes occurring within the Cold 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.

#### *3.4.2 Departure Analysis*

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

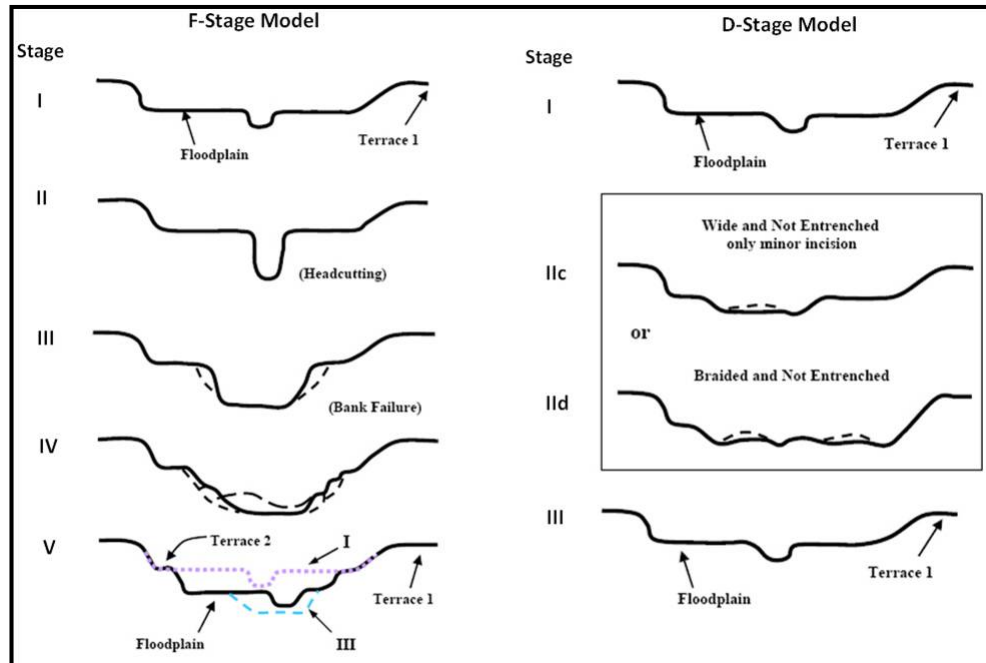
Analysis of a watershed's sediment regime is a useful approach for summarizing the reach and watershed-scale stressors affecting the equilibrium conditions of river channels. Sediment regime mapping provides a context for understanding the sediment transport and channel evolution processes (Schumm, 1977) which govern changes in geometry and planform for river channels in a state of disequilibrium. The VTANR River Corridor Planning Guide (VTANR, 2010) outlines a methodology for understanding the reference and altered sediment regimes of reaches according to data collected during the Phase 2 field assessments. The sediment regime types used in this analysis are summarized below in Table 3.1.

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

Sediment Regime	Narrative Description
<b>Transport</b>	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.
<b>Confined Source and Transport</b>	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.
<b>Unconfined Source and Transport</b>	Sand, gravel, or cobble plane bed streams; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to entrenchment or incision and associated bed form changes; these streams are not a significant sediment supply due to boundary resistance such as bank armoring, but may begin to experience erosion and erosion and supply both coarse and fine sediment when bank failure lead to channel widening; storage of coarse or fine sediment is negligible due to high transport capacity derived from the deep incision and little or no floodplain access. Look for straightened, incised or entrenched streams in unconfined valleys, which may have been bermed and extensively armored and are in Stage II or early Stage III of channel evolution.
<b>Fine Source and Transport &amp; Coarse Deposition</b>	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.
<b>Coarse Equilibrium (in = out) &amp; Fine Deposition</b>	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.
<b>Deposition</b>	Silt, sand, gravel, or cobble streams with variable and braided bed forms; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to changes in slope and/or depth resulting in the predominance of transient depositional features; storage of fine and coarse sediment frequently exceeds transport**. Floodplains are accessed during high frequency (annual) floods. Look for unconfined streams, which are not incised or entrenched, have become significantly over-widened, and if high rates of bank erosion are present, it is offset by the vertical growth of unvegetated bars. These regimes may be located at zones of naturally high deposition (e.g., active alluvial fans, deltas, or upstream of bedrock controls), or may exist due to impoundment and other backwater conditions above weirs dams and other constrictions.

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

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



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

### 3.4.3 Sensitivity Analysis

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

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

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

### 3.5 Project Identification

Site-specific projects were identified using methods outlined by VTANR in Chapter 6 Preliminary Project Identification and Prioritization (VTANR, 2010). This planning guide is intended to aid in the development of projects that protect and restore river equilibrium conditions. The projects identified

for the study reaches can be classified under one of the following categories: Active Geomorphic Restoration, Passive Geomorphic Restoration, and Conservation.

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

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

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

## 4.0 Results

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

### 4.1 Phase 2 SGA Results

A complete summary of the individual Rapid Habitat Assessment (RHA) and Rapid Geomorphic Assessment (RGA) scores are shown below (Table 4.1). Additional, segment-specific data summaries are provided in Appendix A for each reach assessed for Phase 2 data.

Phase 2 Segment ID	RHA Condition	RHA Score	RGA Score	RGA Condition	Stream Sensitivity
M01-A	Fair	0.48	0.55	Fair	Very High
M01-B	Fair	0.41	0.40	Fair	Very High
M01-C	Good	0.65	0.59	Fair	High
M03	Fair	0.58	0.43	Fair	High
M04	Good	0.75	0.50	Fair	High
M05	Good	0.72	0.46	Fair	Extreme
M06	Fair	0.57	0.46	Fair	High
M07-A	Fair	0.48	0.50	Fair	Extreme
M07-B	Fair	0.62	0.63	Fair	Very High
M07-C	Fair	0.42	0.55	Fair	Extreme
M08	Good	0.65	0.60	Fair	High
M09-B	Good	0.65	0.63	Fair	Very High
M10-A	Fair	0.62	0.63	Fair	High

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

Phase 2 Segment ID	RHA Condition	RHA Score	RGA Score	RGA Condition	Stream Sensitivity
M10-C	Good	0.66	0.76	Good	High
M10-E	Fair	0.48	0.56	Fair	High
M10-F	Good	0.82	0.78	Good	High

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

## 4.2 River Corridor Planning

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

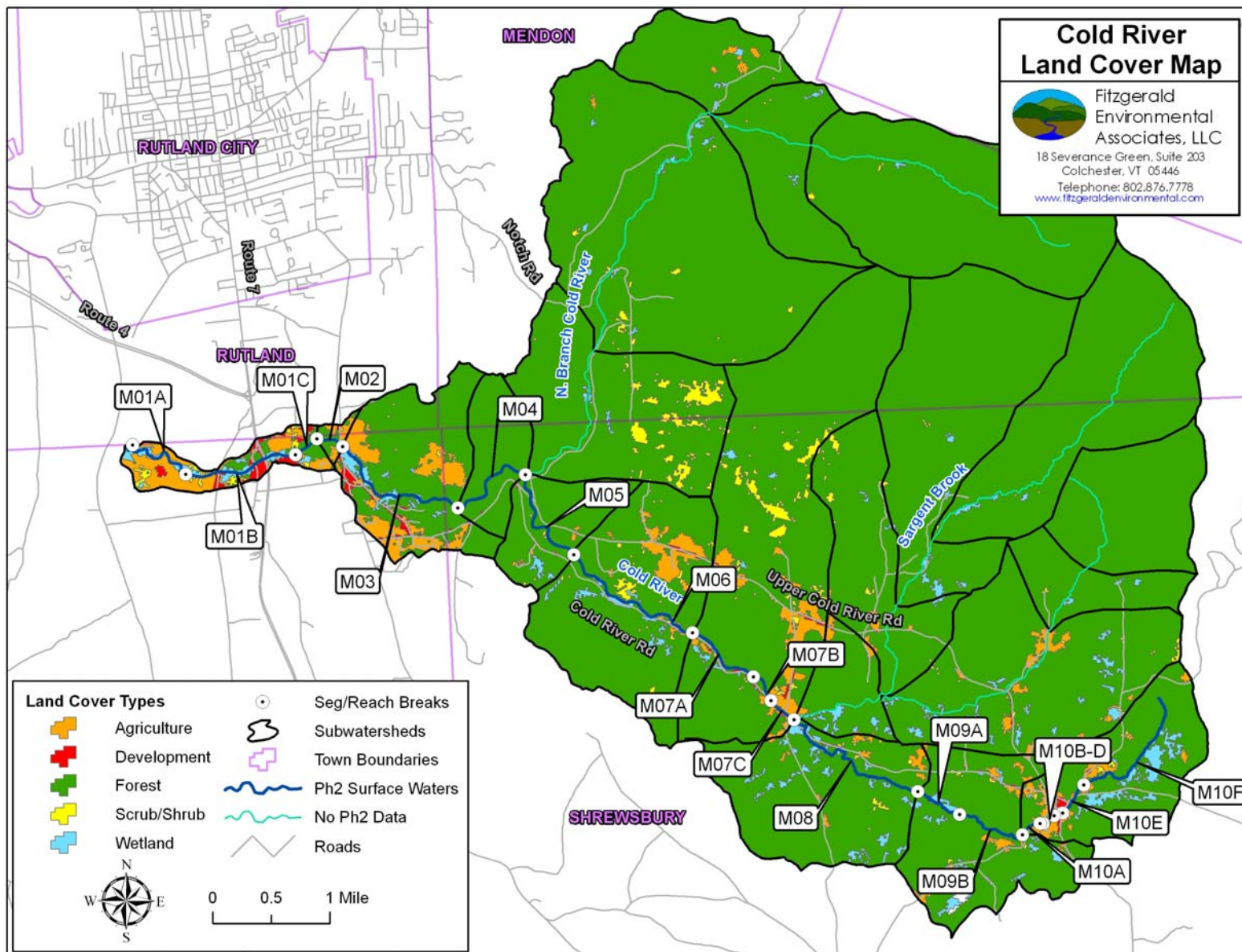
### 4.2.1 Stressor Maps

#### Land Use

The Cold River watershed contains a mixture of land cover types (Table 4.2; NOAA, 2008) typical of rural Vermont watersheds. The upslope subwatersheds and highlands are predominately forested, while the river corridors and valley bottoms have a greater percentage of agricultural and developed land (Figure 4.1). Lands classified as scrub/shrub are typically found in areas of transition from old field to forest or in telephone/utility line right-of-ways. Developed lands (including road corridors) occupy only 0.6% of the watershed, with more area occupied by wetlands (2.1%). Agricultural lands are most concentrated in the lower reaches with additional agricultural areas in the middle and upper reaches. Developed lands closely follow major roads throughout the watershed.

**Table 4.2** Land use/Land cover data for the Cold River watershed and tributaries

Land Cover/Land Use Type	Phase 2 Subwatersheds	Cold River Watershed (total)
Agriculture	8.2%	3.6%
Development	1.4%	0.6%
Forest	84.7%	92.4%
Open Water	0.2%	0.1%
Scrub/Shrub	1.7%	1.3%
Wetland	3.7%	2.1%
Branch Area (Mi <sup>2</sup> )	14.1	36.7



### **Hydrologic Regime Stressors**

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

The hydrologic regime may be defined as the timing, volume, and duration of flow events throughout the year and over time. The hydrologic regime may be influenced by climate, soils, geology, groundwater, watershed land cover, connectivity of the stream, riparian, and floodplain network, and valley and stream morphology. The hydrologic regime, as addressed in this section, is characterized by the input and manipulation of water at the watershed scale and should not be confused with channel and floodplain “hydraulics,” which describes how the energy of flowing water affects reach-scale physical forms and is affected by reach-scale physical modifications (e.g., bridges modify channel and floodplain hydraulics).

When the hydrologic regime has been significantly altered, stream channels will respond by undergoing a series of channel adjustments. Where hydrologic modifications are persistent, the impacted stream will adjust morphologically (e.g., enlarging when stormwater peaks are consistently higher) and often result in significant changes in sediment loading and channel adjustments in downstream reaches. The current day stressors to the hydrologic regime have been mapped using the variables extracted from the Phase 2 field dataset (e.g., stormwater outfalls), watershed-scale loss of wetlands, and density of the road network within each subwatershed. Wetland loss was mapped as the area where hydric soils (NRCS mapping) and National Wetland Inventory (NWI) areas intersected with urban or agricultural land uses in the watershed, with the remaining areas assumed to be intact wetland. This approach allows for the interpretation of loss of hydrologic attenuation of surface runoff at the reach and watershed scale. Stormwater outfall locations mapped during the Phase 2 assessments are included to depict areas of increased stormflows (Figure 4.2).

Areas of impact to the hydrologic regime include:

- Moderate road density in subwatersheds draining to reaches M02 and M05 (3.3 and 3.4Mi/Mi<sup>2</sup> respectively)
- Localized corridor wetland loss in M01, M02, M03, M06, and M07 due mainly to conversion to agricultural lands
- Stormwater inputs from developed areas in M01, M03, M06, M07, and M08

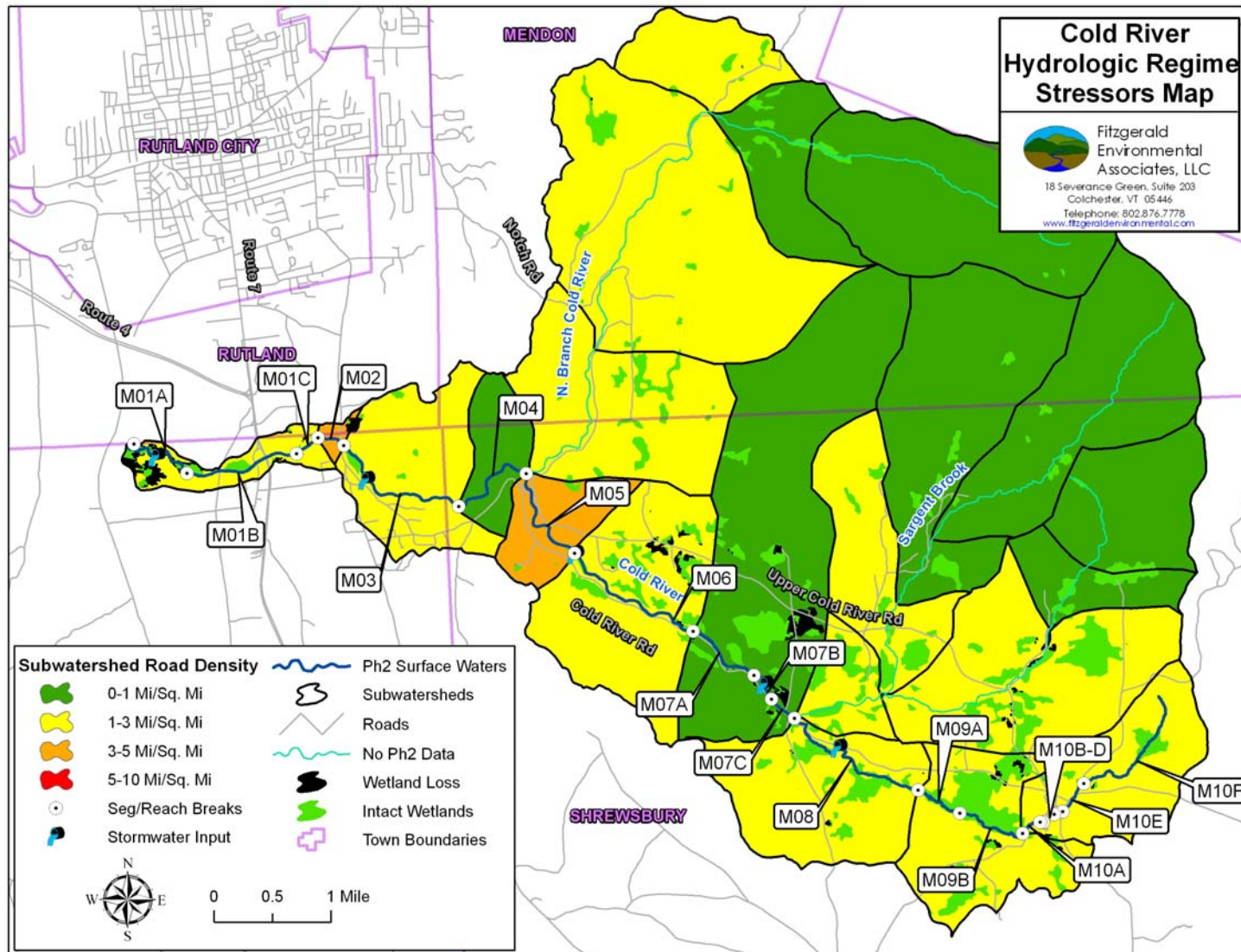


Figure 4.2 Hydrologic regime stressors for the Cold River watershed

### **Sediment Load Indicators**

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

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

The current day stressors to the sediment regime have been mapped using the variables extracted from the Phase 2 field dataset, and the percent of agriculture (cropland and bare land) within each subwatershed. Four classes of percent agriculture were mapped to depict the relative impact of sediment delivery from agricultural lands at the reach and watershed-scales. In addition, depositional and migration features mapped during the Phase 2 assessments are included to depict areas of increased vertical and lateral channel adjustments due to sediment aggradation. Mass failures, gullies and bank erosion depict where sediment delivery from the channel boundaries is occurring (Figure 4.3).

Areas impacted by high sediment load stressors include:

- Very high agricultural land use for subwatersheds draining to reaches M01, M02, and M03 (44%, 42%, 21% respectively)
- High bank erosion in segments M01-A, M03, M05, and M06
- High density of depositional features in reaches M07-C and M09-B
- High density of migration features in segments M03, M04, M05, M08, and M10-F

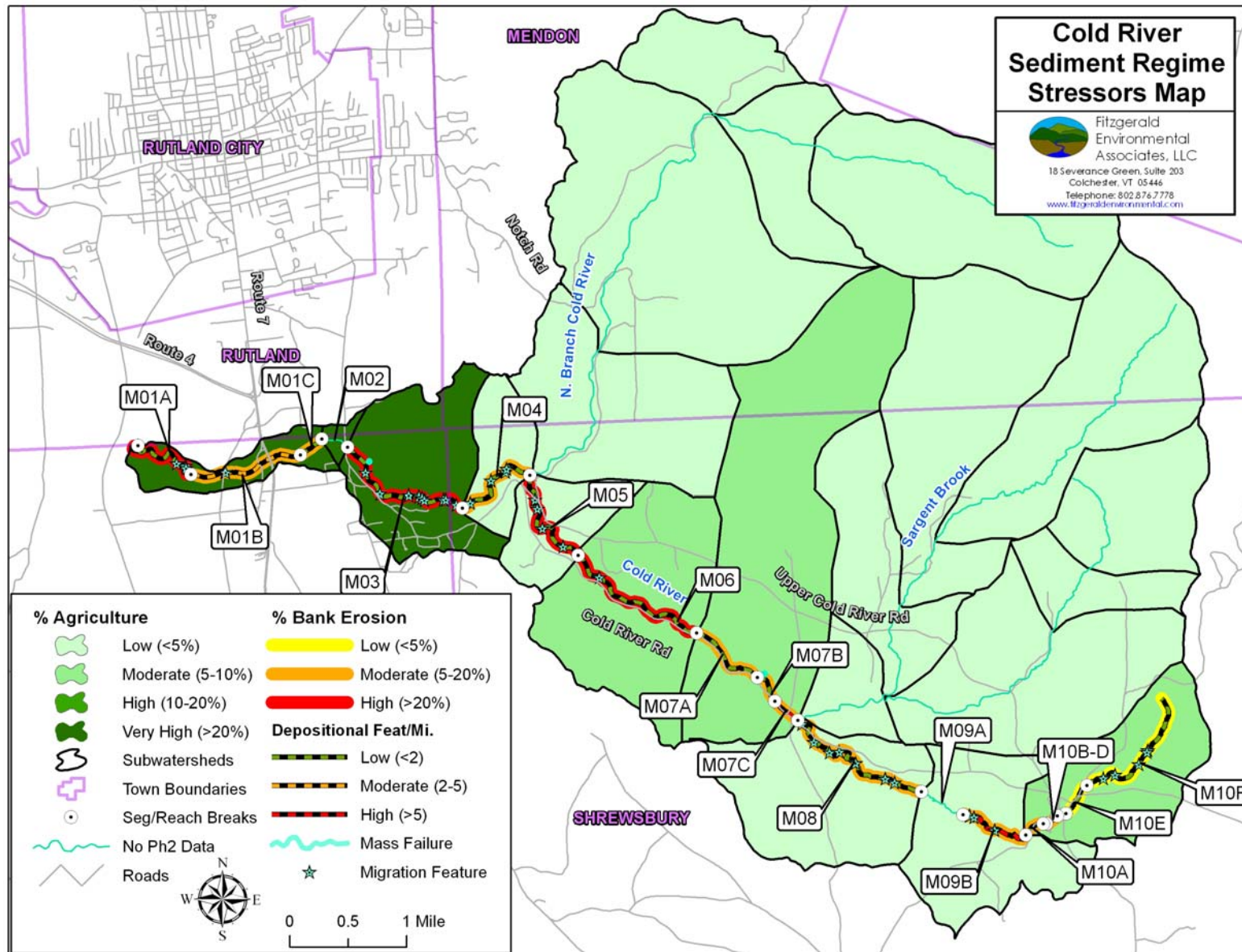
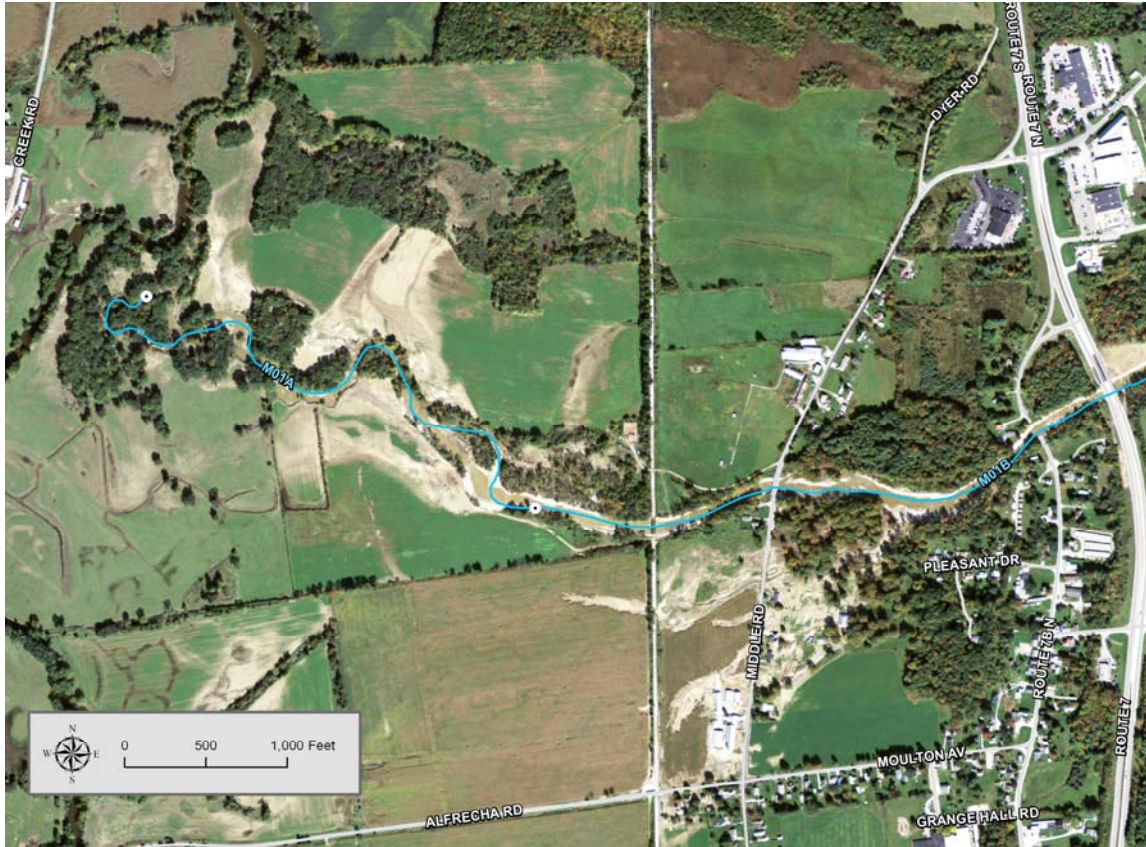


Figure 4.3 Sediment regime stressors for the Cold River watershed



**Figure 4.4** Post-Irene sediment deposition in floodplain near Middle Road, Clarendon



**Figure 4.5** Mass failure (40' H x 330' L) located on the right (north) bank upstream of road embankment failure on Cold River Road in Shrewsbury (Segment M07-B)

### **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 Cold River study area have been mapped using the variables extracted from the Phase 2 field dataset (Figure 4.6). Areas of channel straightening mapped during the Phase 1 and 2 assessments are included to depict areas of increased channel slope. Corridor encroachment data highlights where roads and development have reduced the floodplain area, typically resulting in increased stream power and channel deepening. Additional data showing the location of natural channel features (e.g., ledges and waterfalls) depict areas that have a natural resistance to vertical channel change.

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

#### *Increases in Slope and Depth*

- Extreme channel straightening in segments: M01-B, M01-C, M07-A, M07-B, M07-C, M10-A, M10-C, M10-E
- High straightening in segments: M03 and M06
- Extensive corridor encroachments from adjacent roadways and embankments in segments: M01-B, M06, M07-A, M07-B, M07-C, M10-A, M10-C, and M10-E.
- Dredging in segments M01-B, M06, M07-A, M07-C, and M08.

#### *Controls on Slope and Depth*

- Some dense areas of grade controls on segments M02, M03, M10-A, and M10-D
- An on-stream dam is located in segment M10-B

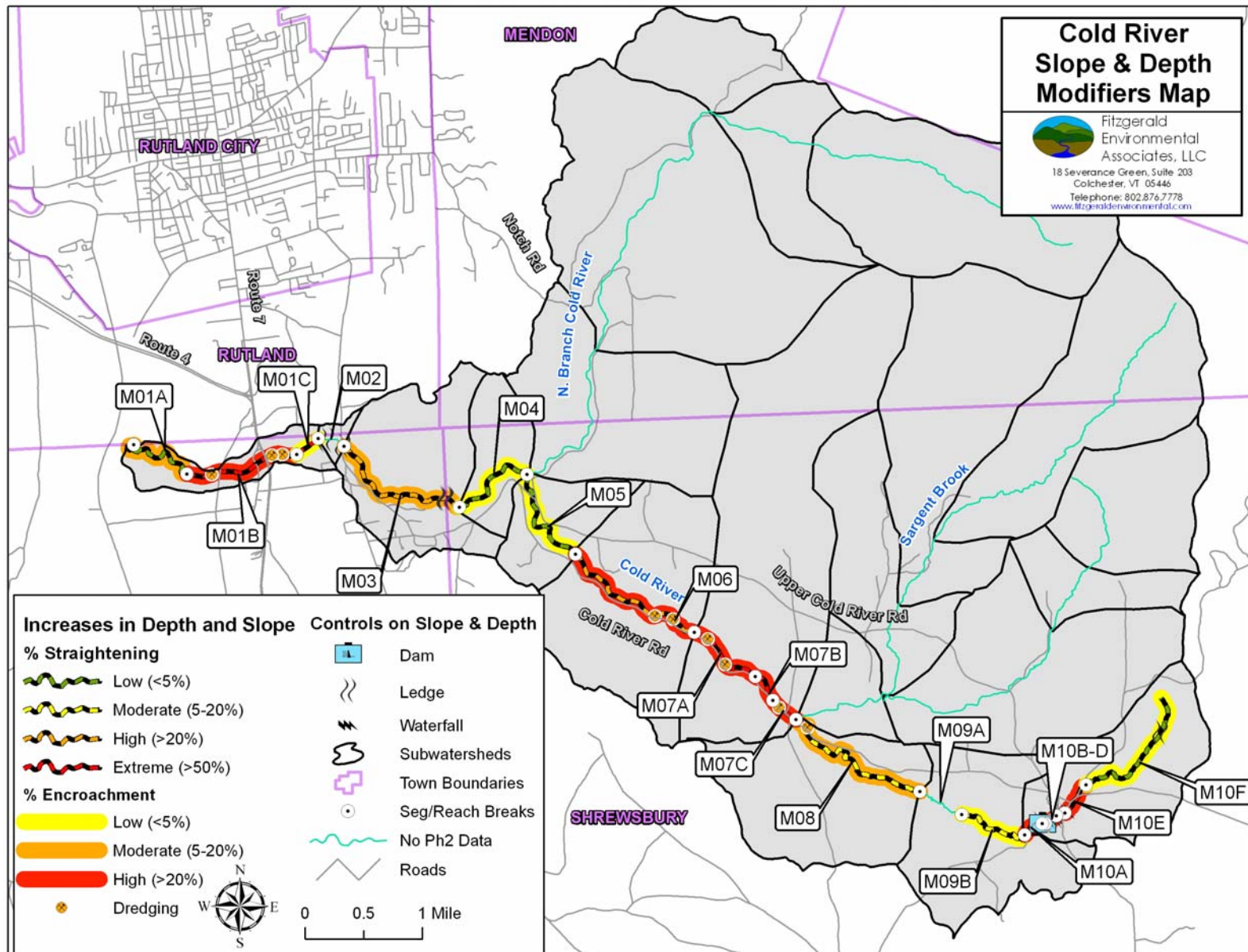
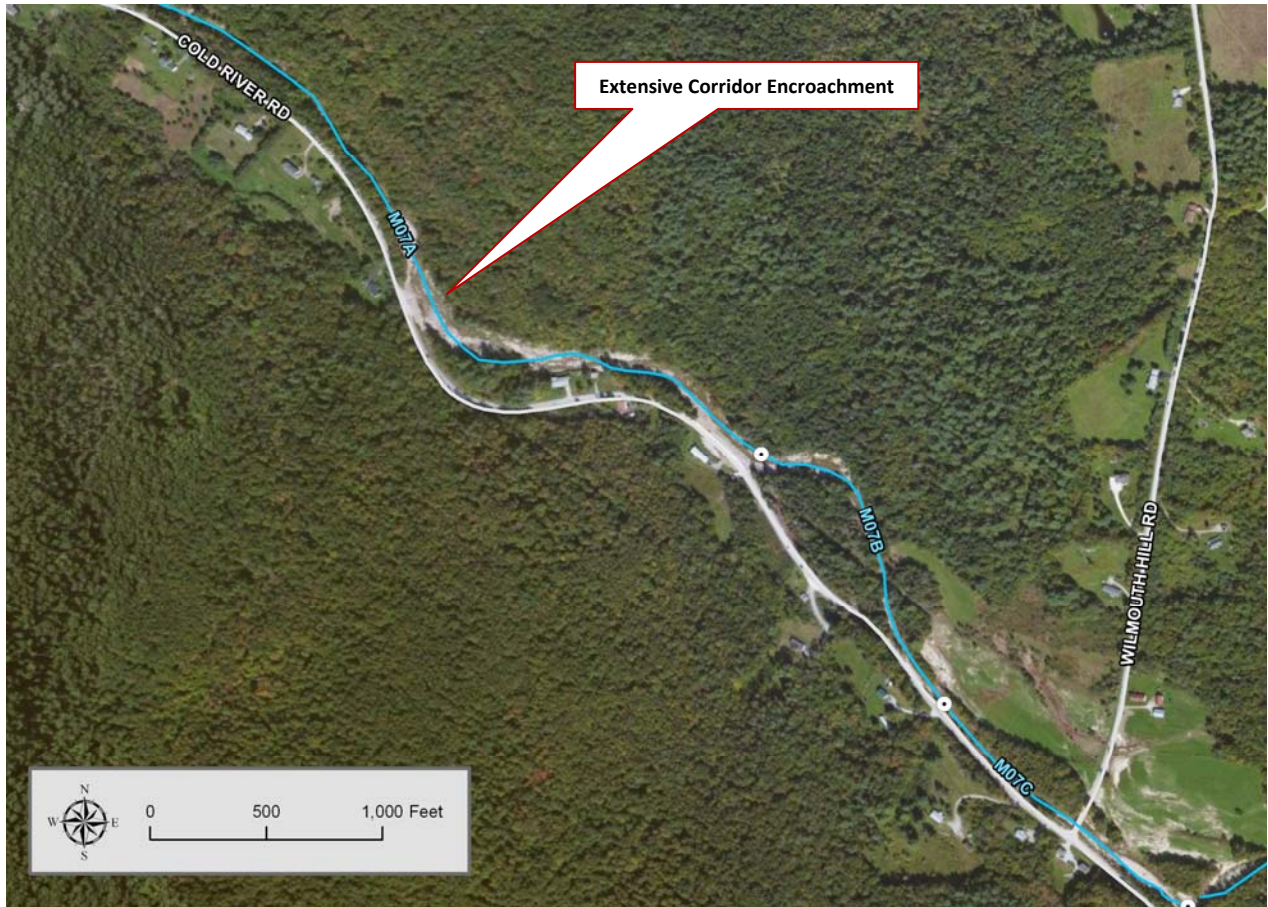


Figure 4.6 Slope and depth modifiers for the Cold River watershed



**Figure 4.7** Corridor encroachments from Cold River Road along the south side of the channel in reach M07, Shrewsbury



**Figure 4.8** Impoundment behind dam in Segment M10-B

### **Modifications to Channel Boundary and Riparian Conditions**

The boundary conditions of a river encompass the bed and bank substrate, and the vegetation and root material found along the riverbank. Human alterations to the river boundary conditions are often made to increase the resistance of the banks and bed to reduce lateral and vertical adjustments. However, extensive removal of riparian vegetation in the absence of bank hardening can cause a decrease in boundary resistance, and lead to increased lateral migration (Figure 4.9). Other natural and human-installed features within the channel, such as bedrock ledges and dams, affect boundary resistance in an upstream and downstream direction by controlling vertical adjustment processes.

Alterations to the channel boundary conditions and riparian areas in the Cold River study area have been mapped using the variables extracted from the Phase 2 field dataset (Figure 4.9). Relative bank armoring (e.g., rip-rap) highlights areas of increased resistance to lateral migration, whereas relative bank erosion highlights reaches where significant lateral adjustments are found. Additional data showing the location of natural channel features (e.g., ledges and waterfalls) depict areas that have a natural resistance to channel change.

Areas influencing riparian zone and boundary conditions include:

#### *Increased Boundary Resistance*

- Some dense areas of natural grade control on segments M02, M03, M10-A, and M10-D
- An on-stream dam is located on Segment M10-B
- High bank armoring on segments M07-A, M07-B, M07-C, M10-C, and M10-E

#### *Decreased Boundary Resistance*

- High bank erosion in segments M01-A, M03, M05, M06, and M10-A
- Dredging in segments M01-B, M06, M07-A, M07-C, and M08.
- High density of riparian buffer width impacts in segments M01-A, M06, M07-C, and M10-E.

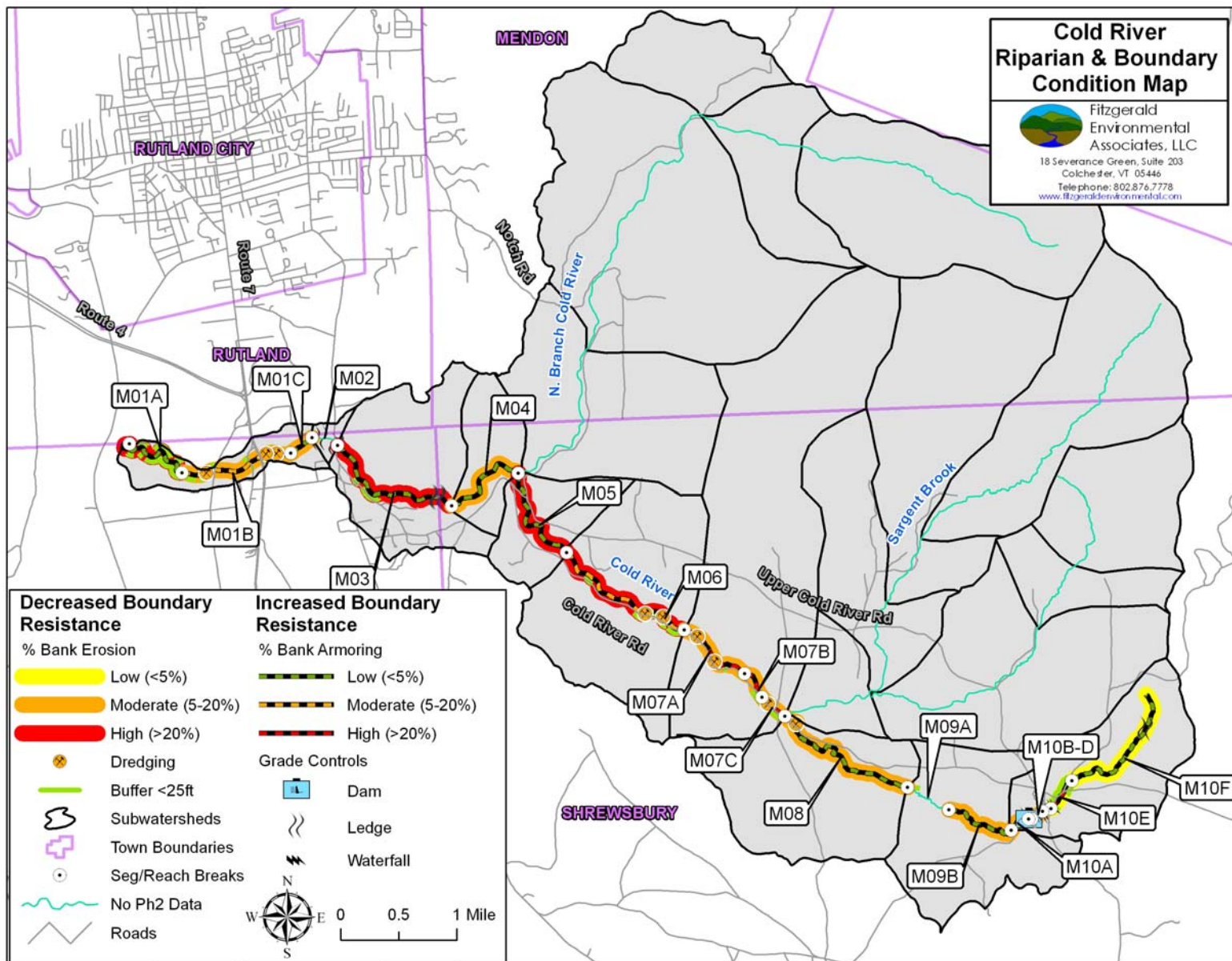


Figure 4.9 Riparian and boundary condition stressors for the Cold River watershed

#### 4.2.2 Departure Analysis

The reference and existing sediment regime types have been mapped using data from the Phase 1 and 2 assessments (Figures 4.10 and 4.11). Several segments in the Cold River watershed have undergone a departure in both sediment regime and stream type due to channel incision and/or widening as a result of: 1) historical land uses, 2) encroachments or development in the river corridor, or 3) extensive straightening and bank armoring. Stream type departures (per Rosgen, 1994) are summarized below (Table 4.3) to better describe the reaches where physical changes in channel morphology have accompanied sediment regime changes.

**Table 4.3** Summary of Stream Type Departures from Reference Conditions

Phase 2 Segment ID	Stream Type Departure	Dominant Adjustment Type
M03	C to B	Historic Incision and Widening
M05	B to F	Historic Incision and Widening
M07-A	C to F	Straightening and Encroachment
M07-C	C to F	Straightening and Encroachment
M10-A	C to B	Encroachment and Incision
M10-E	C to B	Straightening and Encroachment

**Reach M03:** Historic incision has caused a disconnect between the river and its floodplain. This incision has created a B3 plane-bed stream with major widening and planform adjustments occurring as the stream works to redevelop a floodplain bench. Continued channel adjustment should be expected.

**Reach M05:** The river is developing a new floodplain as it recovers from historic incision. Planform adjustments, flood chutes, and bar formation is occurring as the river attempts to return to B3 dimensions.

**Segment M07-A:** A residential area has encroached the river and incision has led to entrenchment. Berming, dredging, and bank armoring have been implemented in an attempt to lock the channel in its present location.

**Segment M07-C:** This segment has been highly altered due to channel straightening and streambank armoring, primarily along Cold River Road and nearby residences.

**Segment M10-A:** The river is highly incised through this segment. Incision is due to encroachment from Northam Road and an altered sediment balance due to an on-stream pond upstream. Widening is minimized due to bank armoring.

**Segment M10-E:** This segment flows through the residential area of Upper Shrewsbury and the river is highly impacted by straightening and armoring. Despite a high degree of channel incision, widening and planform adjustments have been limited due to armoring.

In addition to stream type departures, several reaches/segments of the Cold River have undergone departures in sediment regimes in the absence of stream type departures. These departures are summarized below in Table 4.4.

<b>Table 4.4</b> Summary of Sediment Regime Departures			
Phase 2 Segment ID	Reference Sediment Regime	Existing Sediment Regime	Cause of Departure
M01-A	Coarse Equilibrium & Fine Deposition	Fine Source & Transport; Coarse Dep.	Historical channel incision; active aggradation/planform adjustments
M01-B	Coarse Equilibrium & Fine Deposition	Unconfined Source & Transport	Historical channel incision; active aggradation/planform adjustments
M01-C	Transport	Confined Source & Transport	Active channel incision
M03	Coarse Equilibrium & Fine Deposition	Confined Source & Transport	Active channel incision and widening
M04	Transport	Confined Source & Transport	Active channel incision and widening
M05	Transport	Confined Source & Transport	Active channel incision and widening
M06	Coarse Equilibrium & Fine Deposition	Fine Source & Transport; Coarse Dep.	Historical channel incision; channel widening and planform adjustments
M07-A	Coarse Equilibrium & Fine Deposition	Confined Source & Transport	Active channel incision and widening
M07-B	Coarse Equilibrium & Fine Deposition	Fine Source & Transport; Coarse Dep.	Historical channel incision; minor channel widening and planform adjustments
M07-C	Coarse Equilibrium & Fine Deposition	Confined Source & Transport	Active channel incision
M08	Coarse Equilibrium & Fine Deposition	Unconfined Source & Transport	Active channel incision and widening
M10-A	Coarse Equilibrium & Fine Deposition	Unconfined Source & Transport	Active channel incision and widening
M10-E	Coarse Equilibrium & Fine Deposition	Unconfined Source & Transport	Active channel incision

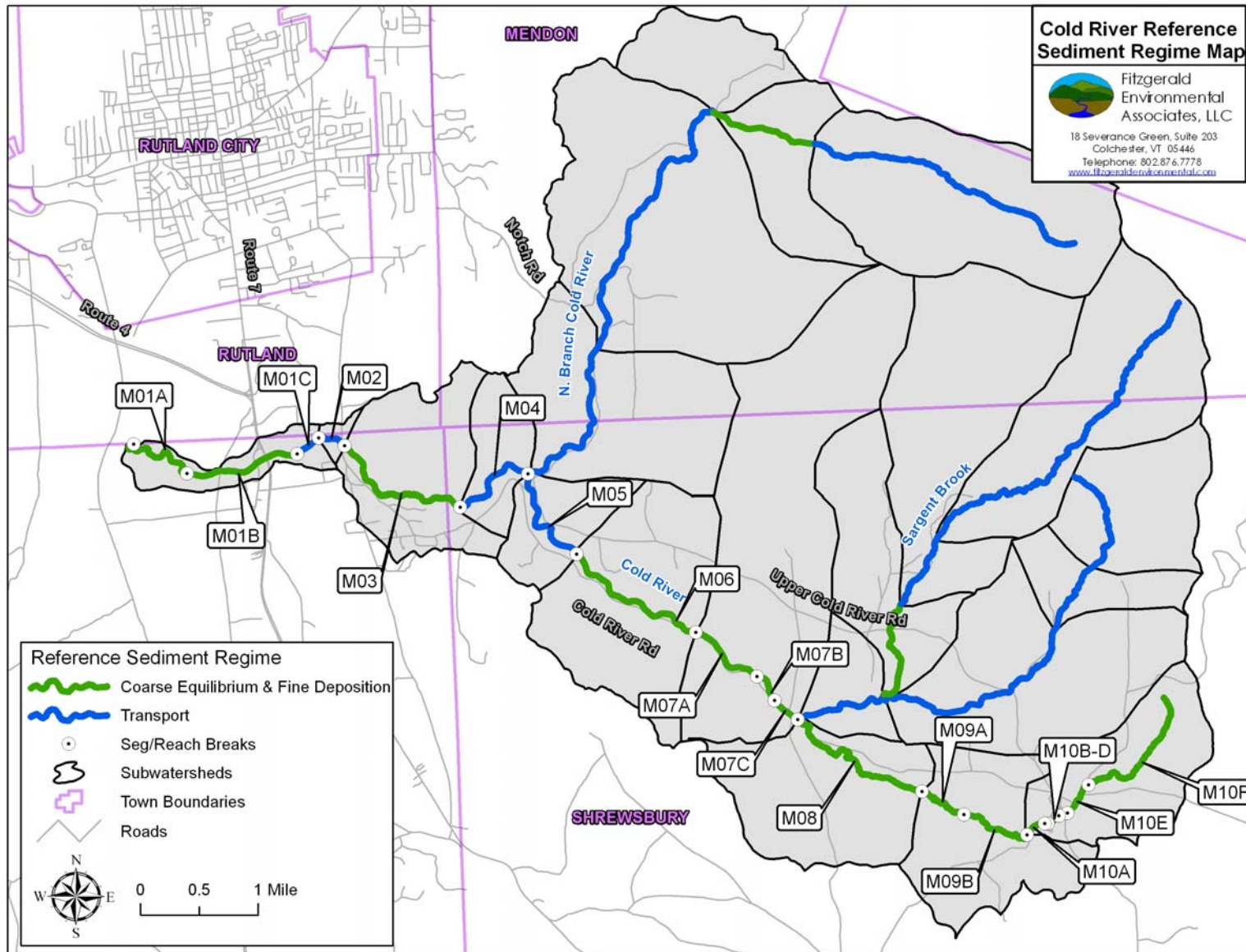


Figure 4.10 Reference sediment regime map for the Cold River watershed

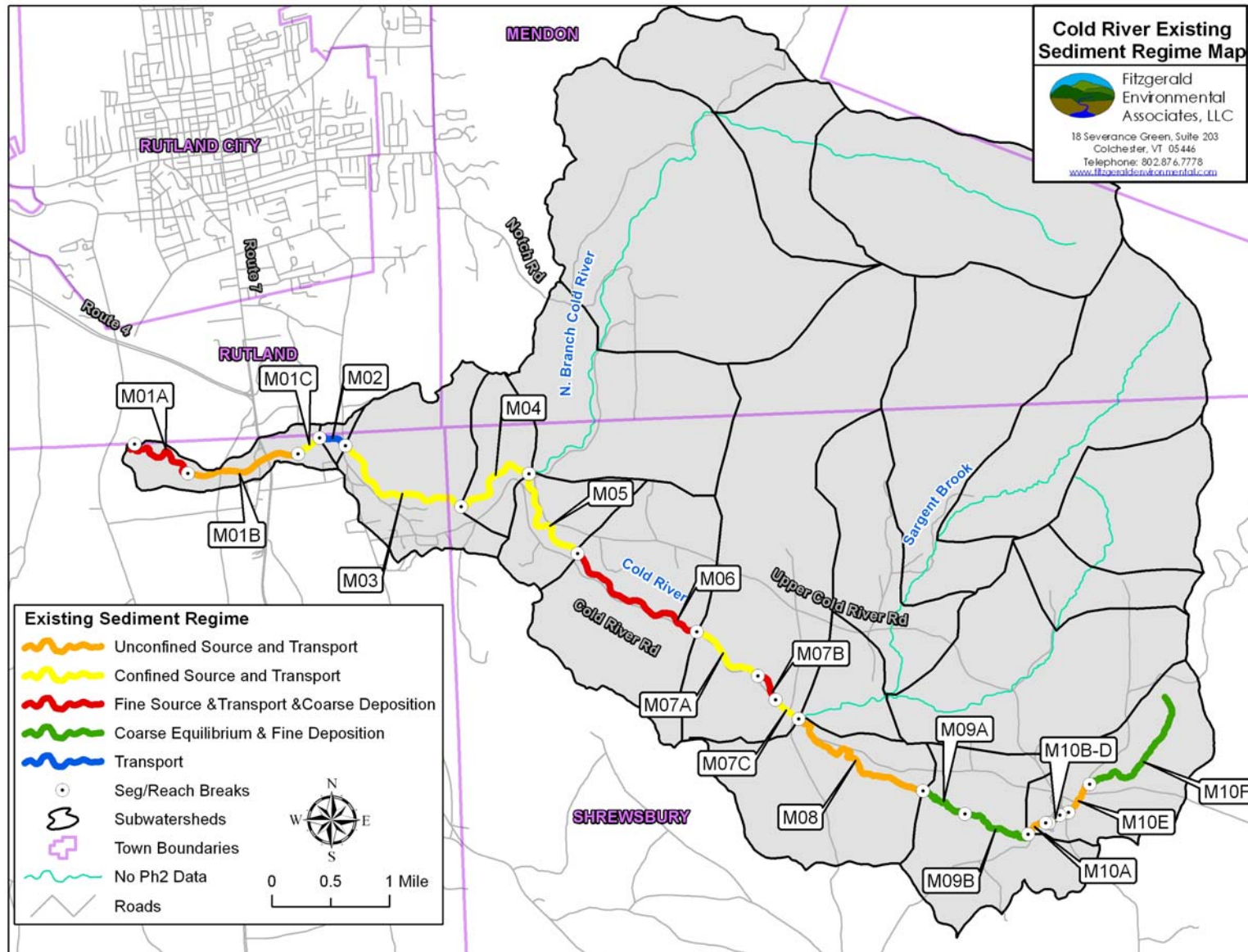


Figure 4.11 Existing sediment regime map for the Cold River watershed

#### 4.2.3 Sensitivity Analysis

The methods outlined in the VTANR Corridor Planning Guide have been used to describe the stream sensitivities of the segments in the Cold 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 4.12). Three (3) segments have heightened sensitivities of “Extreme” and four (4) 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) and channel degradation resulting from historical channel straightening, corridor encroachments, and incision.

Segment M01-A is highly dynamic with a high degree of channel adjustment and bank erosion. Segment M01-B has a high degree of straightening and windrowing in an attempt to stop channel adjustments. Channel constricting structures are increasing instability. Historic incision in reach M05 may have lead to a stream type departure from G to F and the stream is currently adjusting planform to recreate B3 dimensions. Segment M07-A has departed from a C to an F type stream due to entrenchment. Berming, dredging, and bank armoring were all carried out on this segment to restrict migration along a residential area. M07-B is somewhat incised and floodplain access is limited due to berming. M07-C is affected by encroachment, straightening, and armoring along Cold River Road leading to a departure from C to F type. Segment M09-B is widening due to aggradation of sand and gravel from an unknown source (RRD, 2007).

**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
M01-A	Very High	Straightening, Erosion
M01-B	Very High	Straightening, Dredging, Incision
M05	Extreme	Widening
M07-A	Extreme	Encroachment, Berming, Dredging, Armoring
M07-B	Very High	Incision, Berming
M07-C	Extreme	Straightening, Armoring, Encroachment, Widening
M09-B	Very High	Straightening, Aggradation

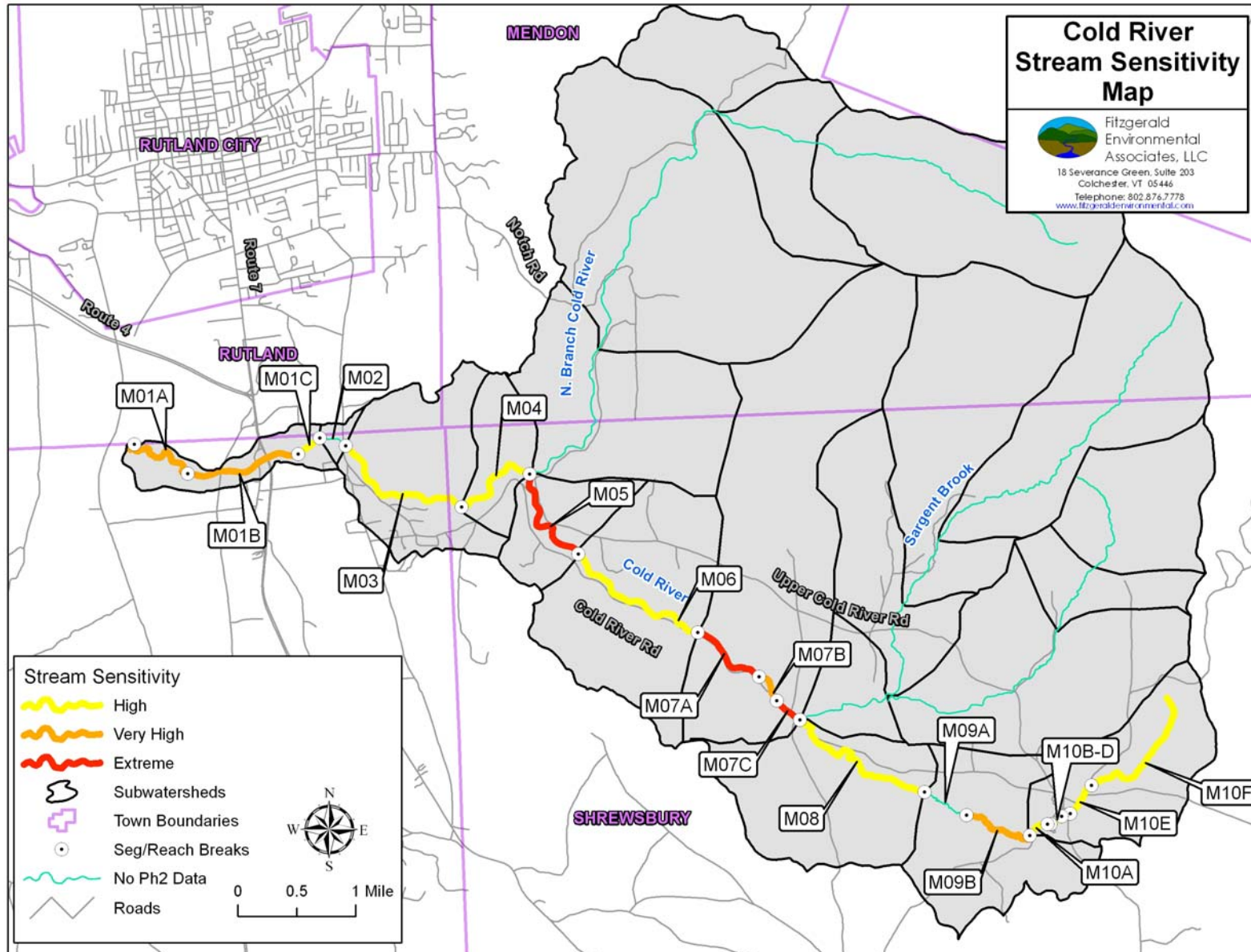


Figure 4.12 Stream Sensitivity map for the Cold River watershed

## 5.0 Preliminary Project Identification

### 5.1 Watershed Level Opportunities

#### 5.1.1 Stormwater Runoff

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

The Cold River watershed generally 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. 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.

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 (Figure 4.13). 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.

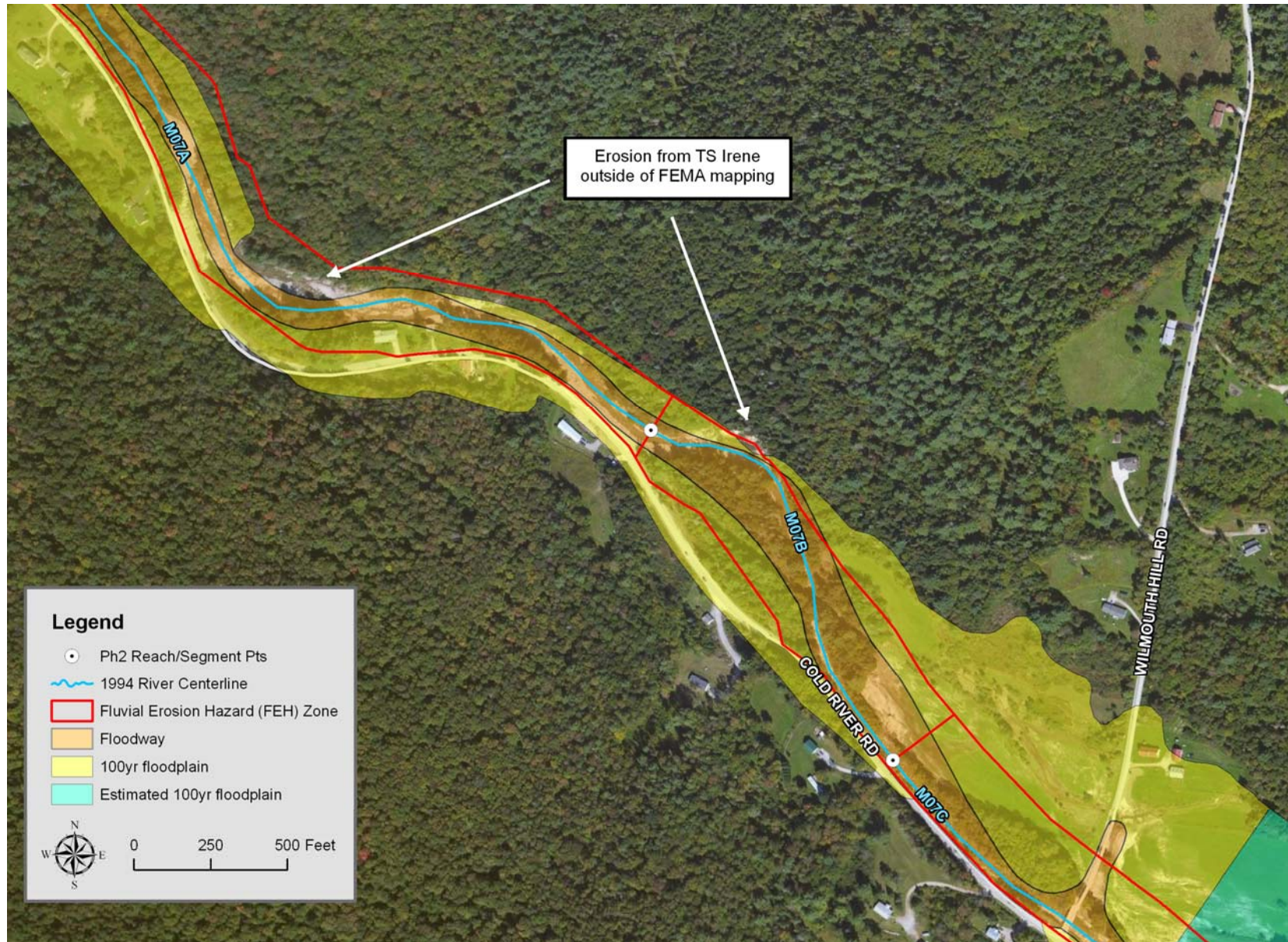


Figure 4.13 Map of Reach M07 comparing FEH zone with FEMA floodplain mapping. Aerial photography flown post-Irene.

### 5.1.3 Stream Crossings

Throughout Vermont, undersized and poorly aligned river crossings critically interrupt floodflows, sediment and woody debris movement downstream, and fish and wildlife migration. These conditions result in 1) channel instability and/or damage to infrastructure and personal property, 2) increased flooding, and 3) decreased fish and wildlife population health. Some culverts and bridges in the Cold River study area are currently undersized and causing various problems such as upstream deposition, excessive erosion and downstream bed degradation (Tables 5.1 and 5.2). As such structures come up for replacement, resizing them to accommodate expected discharge and sediment loads and placing them in proper alignment with stream channels is highly recommended.

Reach/Seg ID	Channel Width (ft)	Structure Width (ft)	Percent of Bankfull Channel Width	Location/Comments
M10-E	15.1	6.5	43%	Old Plymouth Rd
M09-B	21	18	86%	Private-logging
M08	25.8	15	58%	Private-logging
M08	25.8	30	116%	Cold River Rd
M07-C	49.2	60	122%	Wilmouth Hill Rd
M05	52.2	90	172%	Upper Cold River Rd
M02	63.5	65	102%	Cold River Rd
M01-C	63.9	125	196%	Railroad
M01-B	63.9	100	156%	Route 7
M01-B	63.9	84	131%	Middle Rd
M01-B	63.9	70	110%	Railroad

Reach	Location	Percent Bankfull Width	Geomorphic Compatibility	Aquatic Organism Passage*(AOP)	AOP Retrofit Potential
M10-E	Eastham Rd	36%	Partially Compatible	Reduced AOP	MLL
M10-A	Mt School Rd	79%	Partially Compatible	No AOP Including salmonids	LLL
M10-A	Northam Rd	43%	Partially Compatible	Reduced AOP	MLL
<p>* Notes on AOP Retrofit Potential:                      H: High probability the existing culvert can be retrofitted                      M: Medium probability the existing culvert can be retrofitted                      L: Low probability the existing culvert can be retrofitted</p> <p>Position 1 (left): For strong swimmers                      Position 2 (Center): For moderate swimmers                      Position 3 (right): For weak swimmers</p>					

## 5.2 Site-Level Project Opportunities

The site-level projects developed for the Cold River watershed are provided below in Table 5.3. The project strategy, technical feasibility, and priority for each project are listed by project number and reach/segment. A total of 29 projects were identified to promote the restoration or protection of channel stability and aquatic habitat. The table summarizes key information for each project, including the site stressors and constraints, project strategy, priorities for hazard mitigation and ecological benefit, relative costs, and potential partners.

Table 5.3 includes a ranking of project priority, using our best professional judgment (and input from the steering committee), 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 in the table. 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 A. The 29 projects are further broken down by category as follows: fifteen (15) active geomorphic restoration projects; fourteen (14) passive geomorphic restoration projects, including two (2) conservation projects.

**Table 5.3** Site-Level Project Identification for the Cold River

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
<b>#1: Constricted channel, North Shrewsbury</b>  Segment M10-E  43.53087 N 72.82515 W	<b>Active Restoration</b>  <i>Bridge Retrofit/ Replacement</i>	Where the Upper Cold River enters the Village of North Shrewsbury it passes a narrow footbridge before entering ~400' of straightened and armored channel.	Consider opportunities for expanding the channel width in this section including widening bridge abutments and/or sloping back the left bank to prevent debris snagging and erosion as occurred during TS Irene.	Moderate	Low	Reduction of flood hazard and possibility of road damage and property loss.	Moderate. Needs further investigation.	VTANR; Town of Shrewsbury
<b>#2: North Shrewsbury Riparian Corridor</b>  Segment M10-E  43.52893 N 72.8268 W	<b>Passive Restoration</b>  <i>Buffer Plantings</i>	Streamside vegetation cleared from just upstream of the Old Plymouth Rd. crossing downstream through private property to near Eastham Rd. culvert. Banks eroded and were re-armored with rock and cobbles following TS Irene.	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(s) to assess interest and cooperation	Low	Moderate	Improved biotic habitat within reach; Potentially reduced property loss from erosion	Low to moderate costs for buffer planting	Rutland-NRCD; NRCS (Tress for Streams); Landowner
<b>#3: Eastham Road Culvert</b>  Segment M10-E  43.52776 N 72.82793 W	<b>Active Restoration</b>  <i>Culvert Retrofit/ Replacement</i>	Phase 2 assessment noted Eastham Rd. culvert as being 36% of bankfull width. Culvert and road appeared to have been partially damaged by Irene. Reduced aquatic organism passage.	Examine flood hazard reduction potential of replacing/retrofitting Eastham Road culvert.	Moderate	Moderate	Reduced likelihood of future culvert washout. Improved aquatic organism passage.	Moderate to high costs for culvert replacement.	Town of Shrewsbury, VTRANS

**Table 5.3 Site-Level Project Identification for the Cold River**

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
<b>#4: Mountain School Road In-stream Pond</b>  Segment M10-B  43.52632 N 72.83188 W	<b>Active Restoration</b>  <i>Dam Removal</i>	The in-stream pond creates discontinuity in sediment transport (creating scour downstream) and may be a flood hazard if the dam ever breaches. Biologically the dam is a barrier to aquatic organism passage and the pond may increase water temperature in the Cold River. Road accesses school and Town Road Dept. Road was likely overtopped during Irene due to inadequate outlet.	Remove dam and restore historic Cold River channel. Replace culvert under Mountain School Rd. to ensure aquatic organism passage and reduce flood hazard potential.	Moderate	Moderate	Re-connection of sediment transport from headwaters downstream. Improve habitat connectivity. Reduced flood hazard to Mountain School Rd (which provides access to a school and the town work center).	High construction and permitting costs for pond and structure removal	VTANR; Town of Shrewsbury; Landowner
<b>#5: Mountain School Road Culvert Outlet</b>  Segment M10-A  43.52632 N 72.83188 W	<b>Active Restoration</b>  <i>Culvert Retrofit/ Replacement</i>	Large fallen tree at outlet of culvert has the potential to create further scour and eventual collapse the road embankment.	Coordinate with Town or private contractor to remove or at least cut and redistribute pieces of the tree so as to prevent future flood hazard to the Mountain School Road embankment and culvert.	High	High	Reduced infrastructure loss from erosion	Relatively low costs for labor and removal costs.	Town of Shrewsbury
<b>#6: Northam Road Culvert</b>  Segment M10-A  43.5259 N 72.83375 W	<b>Active Restoration</b>  <i>Culvert Retrofit/ Replacement</i>	Phase 2 assessment noted Northam Rd. culvert as being 43% of bankfull width. Visual indicators of damage to roadway from Irene.	Examine flood hazard reduction potential of replacing/retrofitting Northam Road culvert.	Moderate	Low	Reduced likelihood of future road washout.	Moderate to high costs for culvert replacement.	Town of Shrewsbury, VTRANS

**Table 5.3 Site-Level Project Identification for the Cold River**

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
<p><b>#7: Riparian Corridor Downstream of Northam Rd. Culvert.</b></p> <p>Segment M09-B</p> <p>43.52438 N 72.83575 W</p>	<p><b>Passive Restoration</b></p> <p><i>Buffer Plantings</i></p>	<p>Streamside vegetation historically cleared in a field west of Northam Rd. (downstream from Northam Rd. culvert). Some bank erosion observed during Phase 2. An ATV ford existed during the Phase 2 Assessment in 2007.</p>	<p>Plant stream buffer with native woody vegetation in areas lacking canopy cover and/or further protect existing saplings through fencing or other means to encourage their growth. Use a setback of 15ft with larger tree stock to avoid loss from channel migration; Plant smaller, more vigorous stock along near bank. Coordinate with landowner(s) to assess interest and cooperation</p>	Low	Moderate	Improved biotic habitat within reach; Potentially reduced property loss from erosion	Low to moderate costs for buffer enhancement plantings	Rutland-NRCD; NRCS (Tress for Streams); Landowner
<p><b>#8: North Shrewsbury Riparian Forest</b></p> <p>Segment M09-B</p> <p>43.52541 N 72.84048 W</p>	<p><b>Passive Restoration</b></p> <p><i>Conservation</i></p>	<p>Excellent conservation reach given sediment and water attenuation capacity and minimal existing development. Downstream of channelized reaches in North Shrewsbury Village.</p>	<p>Protect stream corridor from future development. Maintain, update, and enforce Town of Shrewsbury Flood Hazard Area Regulations.</p>	Moderate	Low	Downstream benefits through the maintenance of water and sediment attenuation in this riparian and wetland area.	Potentially low – wetlands constraints may already make development unlikely	Rutland NRCD; VRC, VLT
<p><b>#9: North Shrewsbury Wetlands complex</b></p> <p>Segment M09-A</p> <p>43.52808 N 72.84857 W</p>	<p><b>Passive Restoration</b></p> <p><i>Conservation</i></p>	<p>Downstream of channelized reaches in North Shrewsbury Village. High priority conservation reach given sediment and flood water attenuation capacity. Johnson’s Pond outlet flows into this wetland.</p>	<p>Protect wetland complex from future development. Examine current protection under Shrewsbury Zoning and NWI status. Update and enhance protection as necessary.</p>	Moderate	Low	Downstream benefits through the maintenance of water and sediment attenuation in this riparian and wetland area.	Potentially low – wetlands constraints may already make development unlikely	Rutland NRCD; VRC, VLT

**Table 5.3 Site-Level Project Identification for the Cold River**

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
<p><b>#10: Upstream Sargent's Confluence</b></p> <p>Reach M08</p> <p>43.53288 N 72.86348 W</p>	<p><b>Passive Restoration</b></p> <p><i>Corridor Protection</i></p>	Largely forested reach with good floodplain access. Lower ~1000 just above confluence with Sargent's Brook has some encroachments and berming.	Long-term stream corridor protection to avoid conflict with river migration and development. Maintain, update, and enforce Town of Shrewsbury Flood Hazard Area Regulations.	Low	Low	Reduce future conflict; ensure long-term protection of river corridor.	Low for FEH only protection.	VTANR, Town of Shrewsbury, FEMA, RRPC, VRC, VLT
<p><b>#11: Sargent Brook Confluence</b></p> <p>Segment M07-C</p> <p>43.53898 N 72.87445 W</p>	<p><b>Passive Restoration</b></p> <p><i>Corridor Protection/ Buffer Restoration</i></p>	Cold River historically straightened and armored along Cold River Road resulting in incision. Sargents Brook bermed above confluence to prevent overbank flooding onto farm fields. Wilmouth Hill bridge and road run perpendicular to the flow putting them at risk of washout.	Farm at confluence of Sargent Brook and Cold River experienced significant overbank flooding during Irene. Consider possible corridor easement in conjunction with buffer plantings.	High	High	Important sediment and floodwater attenuation area where Sargents Brook meets the Cold River.	Potentially moderate to high costs for easements due to private ownership; low cost for buffer plantings.	Rutland-NRCD NRCS (CREP); VRC, VLT
<p><b>#12: Sargent Brook Confluence</b></p> <p>Segment M07-C</p> <p>43.53943 N 72.87336 W</p>	<p><b>Active Restoration</b></p> <p><i>Berm Removal/Culvert Replacement</i></p>	Cold River historically straightened and armored along Cold River Road resulting in incision. Sargents Brook bermed above confluence to prevent overbank flooding onto farm fields. Wilmouth Hill bridge and road run perpendicular to the flow putting them at risk of washout.	Removal of berm on the right bank of Sargents Brook near the confluence with the Cold River to allow overbank flooding in the adjacent hay field. Investigate culverts on Wilmouth Hill Road to ensure adequate sizing for flood water passage.	High	Low	Important sediment and floodwater attenuation area where Sargents Brook meets the Cold River.	Low cost of berm removal. Moderate to high costs for culvert upgrades to Wilmouth Hill Road.	Rutland-NRCD; VTDEC; Town of Shrewsbury

**Table 5.3 Site-Level Project Identification for the Cold River**

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
<p><b>#13: Wilmouth Hill Rd. Bridge</b></p> <p>Segment M07-C</p> <p>43.53971 N 72.87576 W</p>	<p><b>Active Restoration</b></p> <p><i>Bridge Retrofit/ Replacement</i></p>	<p>Bridge is 24ft wide and is a constriction to the floodprone width and created significant backwater during TS Irene resulting in flooding and erosion along both banks upstream.</p>	<p>If structure comes up for replacement, it should be resized according to the VTDEC RMP recommendations..</p>	Moderate	Low	<p>Reduced risk of debris catchment during large flood which could cause flooding and erosion.</p>	<p>Potentially high costs for structure redesign and replacement.</p>	<p>Town of Shrewsbury, VTANR, VTRANS</p>
<p><b>#14: Floodplain forest downstream of Wilmouth Hill Rd. Bridge</b></p> <p>Segment M07-B</p> <p>43.54328 N 72.87914 W</p>	<p><b>Passive Restoration</b></p> <p><i>Corridor Protection</i></p>	<p>Forested floodplain on left bank at inside of bend has numerous recent and historic flood chutes.</p>	<p>Investigate corridor easement in relation to FEH to ensure that this floodplain forest remains intact. Maintain, update, and enforce Town of Shrewsbury Flood Hazard Area Regulations.</p>	Moderate	Low	<p>Important sediment and floodwater attenuation reach due to channelization in upstream reaches.</p>	<p>Potentially moderate to high costs for easements due to private ownership; Needs further landowner investigation.</p>	<p>Town of Shrewsbury, VTANR</p>
<p><b>#15: Cold River Rd. Embankment</b></p> <p>Segment M07-A</p> <p>43.54473 N 72.88171 W</p>	<p><b>Active Restoration</b></p> <p><i>Bank Stabilization &amp; Channel Restoration</i></p>	<p>Post-Irene armoring of left bank to protect Cold River Rd. resulted in a channel constriction (~38' width). Embankment material does not seem sufficient for long-term protection.</p>	<p>Conduct alternatives analysis for the redesign of the embankment and removal of channel constriction.</p>	High	Low	<p>Reduce possibility of future embankment failure.</p>	<p>Potentially moderate to high costs for design and construction.</p>	<p>Town of Shrewsbury, VTANR, VTRANS</p>
<p><b>#16: Threatened Structure</b></p> <p>Segment M07-A</p> <p>43.54532 N 72.88398 W</p>	<p><b>Passive Restoration</b></p> <p><i>Corridor Protection/ Bank Stabilization</i></p>	<p>Cold River shifted ~30' to the south threatening structure(s) on left bank.</p>	<p>Conduct alternatives analysis for the protection of property on the south bank.</p>	High	Low	<p>Reduce flood hazard to property.</p>	<p>High costs for private land protection.</p>	<p>FEMA; Landowner</p>

**Table 5.3** Site-Level Project Identification for the Cold River

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
<b>#17: Cold River Rd. Embankment</b>  Segment M07-A  43.54589 N 72.88551 W	<b>Active Restoration</b>  <i>Bank Stabilization &amp; Channel Restoration</i>	Post-Irene armoring of left bank to protect Cold River Rd. consisted of undersized materials and dredged materials.	Conduct alternatives analysis for the redesign of the embankment. Remove or redistribute spoils.	High	Low	Reduce possibility of future embankment failure.	Potentially moderate to high costs for design and construction.	Town of Shrewsbury, VTANR, VTRANS
<b>#18: Threatened Structures</b>  Segment M06  43.55152 N 72.89495W	<b>Passive Restoration</b>  <i>Corridor Protection/ Bank Stabilization</i>	Several structures lie in the corridor of the Cold River.	Conduct alternatives analysis for the protection of these properties.	High	Low	Reduce flood hazard properties.	High costs for private land protection.	FEMA; Landowner
<b>#19: Dredged Materials Berm</b>  Reach M06  43.5517 N 72.89805 W	<b>Active Restoration</b>  <i>Berm Removal</i>	Floodplain access at inside of meander bend has been reduced by the placement of material dredged from the channel. The low berm may be difficult to remove due to vegetation.	Remove low berm on inside of meander in order to encourage overbank flooding and relieve pressure on Cold River Rd. embankment.	Moderate	Low	Reduce channel constriction that may threaten upstream structures; reduce erosive forces on Cold River Rd. embankment.	Low to moderate; Needs further investigation.	VTANR
<b>#20: Cold River Rd. Embankment</b>  Reach M06  43.55176 N 72.89922 W	<b>Active Restoration</b>  <i>Bank Stabilization &amp; Channel Restoration</i>	Post-Irene armoring of left bank to protect Cold River Rd. consisted of undersized materials and dredged materials. Head-cut exists downstream. Embankment armoring needs to be properly keyed to prevent future undermining.	Conduct alternatives analysis for the redesign of the embankment. Remove or redistribute spoils.	High	Low	Reduce possibility of future embankment failure.	Potentially moderate to high costs for design and construction.	Town of Shrewsbury, VTANR, VTRANS

**Table 5.3 Site-Level Project Identification for the Cold River**

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
<b>#21: Cold River Rd. Culverts</b>  Reach M06  43.5527 N 72.90136 W	<b>Active Restoration</b>  <i>Culvert Retrofit/ Replacement</i>	Over-road flooding during Irene led to the replacement of 2 possibly undersized culverts under Cold River Rd. that return overbank flows to the main channel.	Analyze drainage networks to ensure that culverts are sized properly for the tributary and overbank flows that they were installed to pass.	Moderate	Low	Prevent Cold River Rd. from being washed out during major storm event. Ensure tributary culvert does not plug with sediment from normal flows.	Moderate	Town of Shrewsbury, VTANR, VTRANS
<b>#22: Covered Bridge Reach Protection</b>  Reach M05  43.56303 N 72.91839 W	<b>Passive Restoration</b>  <i>Corridor Protection</i>	Area of high stream power in a semi-confined valley that exhibits infrequent overbank flows into flood chutes. Several new large mass failures occurred during Irene. Reach is almost entirely forested.	Long-term stream corridor protection to avoid conflict with river migration and development. Maintain, update, and enforce Town of Shrewsbury Flood Hazard Area Regulations. Consider an analysis of further hill-slope hazards where mass-failures may occur.	Low	Low	Reduce future conflict, ensure long-term protection of river corridor for downstream landowners.	Low for FEH only protection. High for stabilization of mass failures and covered bridge protection.	VTANR, Town of Shrewsbury, VT Geologic Survey, VRC, VLT, FEMA
<b>#23: Forest Below North Branch Confluence</b>  Reach M04  43.56629 N 72.92773 W	<b>Passive Restoration</b>  <i>Corridor Protection</i>	Area of high stream power that exhibits overbank flows into numerous flood chutes. Reach is almost entirely forested.	Long-term stream corridor protection to avoid conflict with river migration and development. Maintain, update, and enforce Town of Shrewsbury Flood Hazard Area Regulations.	Moderate	Low	Reduce future conflict, ensure long-term protection of river corridor.	Low for FEH only protection.	VTANR, Town of Shrewsbury, VRC, VLT

**Table 5.3 Site-Level Project Identification for the Cold River**

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
<p><b>#24: High-energy Non-cohesive Floodplain</b></p> <p>Reach M03</p> <p>43.56654 N 72.94485 W</p>	<p><b>Passive Restoration</b></p> <p><i>Corridor Protection</i></p>	<p>Area of high stream power that exhibits infrequent overbank flows into numerous flood chutes. Much of the upper reach is forested while the lower half has seen encroachment by residences, roads, and power lines.</p>	<p>Long-term stream corridor protection to avoid conflict with river migration and development. Conduct analysis of property ownership, zoning, and other existing protections. Update FEMA-maps, adopt local FEH zoning, and/or acquire easements.</p>	<p><b>High</b></p>	<p>Low</p>	<p>Reduce long-term conflict between this dynamic stream reach and surrounding infrastructure. Protect downstream reaches through floodwater and sediment attenuation.</p>	<p>Moderate to high costs for easements due to private ownership; Needs further investigation</p>	<p>VTANR, Town of Clarendon, FEMA, Central Vermont Public Service</p>
<p><b>#25: Restoration of Post-Irene Channel Straightening</b></p> <p>Reach M03</p> <p>43.56995 N 72.94775 W</p>	<p><b>Active Restoration</b></p> <p><i>Channel Restoration</i></p>	<p>Lower half of reach displayed significant lateral migration, overbank flooding into flood-chutes, and deposition. Large portions of channel were dredged and straightened and bermed following Irene. CVPS powerlines and a few private structures in vicinity of project reach.</p>	<p>Alternatives analysis of for the restoration of the channel to provide for future overbank flood and sediment attenuation, habitat improvement, and long-term dynamic equilibrium in this reach.</p>	<p><b>High</b></p>	<p>Low</p>	<p>Reduce long-term conflict between this dynamic stream reach and surrounding infrastructure. Protect downstream reaches through floodwater and sediment attenuation.</p>	<p>Moderate to high costs for channel reconstruction; Needs further investigation</p>	<p>VTANR, Town of Clarendon, FEMA, Central Vermont Public Service</p>
<p><b>#26: North Clarendon FEH</b></p> <p>Reach M01</p> <p>43.56898 N 72.96921 W</p>	<p><b>Passive Restoration</b></p> <p><i>Corridor Protection</i></p>	<p>The Village of North Clarendon and surrounding settlement lies in the vicinity of a dynamic stream segment. Existing buildings and infrastructure lie within stream corridor. Historic and recent channel straightening and berming exist along much of reach along with several bridge crossings.</p>	<p>Long-term stream corridor protection to avoid conflict with river migration and development. Update FEMA-maps and adopt local FEH zoning.</p>	<p><b>High</b></p>	<p>Low</p>	<p>Reduce long-term conflict between this dynamic stream reach and the infrastructure of North Clarendon.</p>	<p>Moderate to high costs for easements due to private ownership; low cost for FEH. Needs further investigation</p>	<p>VTANR, Town of Clarendon, FEMA, RRPC</p>

**Table 5.3 Site-Level Project Identification for the Cold River**

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
<b>#27: Route 7 Protection</b>  Reach M01-B  43.57077 N 72.96439 W	<b>Active Restoration</b>  <i>Bridge Retrofit</i>	Overbank flooding (exacerbated by bridge constriction?) during Irene eroded the Rt. 7 roadway approach to the bridge cutting off access to this major north-south highway. Several residences exist on the downstream side of this structure.	Alternatives analysis to examine increasing the capacity of the bridge to permit floodwater and sediment transport during major events.	High	Low	Reduced channel constriction, reduce possibility of Rt. 7 damage.	Moderate to high.	VTANR, VTRANS, FEMA, ACOE
<b>#28: Lower Cold River Berm Removal/Relocation</b>  Segment M01-B  43.56877N 72.97352 W	<b>Active Restoration</b>  <i>Berm Removal/Relocation</i>	Historic channel straightening and berming has increased stream power through this segment. Numerous berms (largely consisting of dredged material) have been pushed up on both banks. Removal or relocation will need to account for multiple bridges, farm roads, and houses that line in this segment.	Conduct a comprehensive inventory and feasibility analysis of the removal/relocation of berms in order to reconnect floodplain while still protecting infrastructure. Include consideration of adding additional openings through the railroad and Middle Road crossings to allow for water passage.	High	Low	Reduce long-term conflict between this dynamic stream reach and the infrastructure of North Clarendon.	Low to moderate costs for berm removal. Moderate to high costs for easements that may need to be acquired.	VTANR, Town of Clarendon, FEMA, VRC, VLT
<b>#29: Otter Creek Confluence Buffer Restoration</b>  Segment M01-A  43.57068 N 72.98033 W	<b>Passive Restoration</b>  <i>Buffer Plantings</i>	The lowest reach of the Cold River has a very low sediment transport capacity due to its low slope. The stream type is characterized by lateral migration and overbank flooding. Current agricultural use of both the north and south banks.	Plant stream buffer with native woody vegetation in areas lacking canopy cover. Use a setback of 15ft with larger tree stock to avoid loss from channel migration; Plant smaller, more vigorous stock along near bank. Coordinate with landowner to assess interest and cooperation	Low	High	Improved biotic habitat within reach; Potentially reduced property loss from erosion	Low to moderate costs for buffer restoration. CREP easement possible.	Rutland-NRCD; NRCS (CREP & WRP), USFWS

### 5.3 Restoration Project Prioritization

The corridor planning partners reviewed and commented on the list of preliminary projects during a steering committee meeting on October 15, 2012. Five (5) project “bundles” from the initial list of 29 total projects were chosen for further development. Project summaries are included in Appendix B 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
- A list of current and potential technical partners and funding
- Preliminary cost estimates for the selected alternative
- A review of regulatory requirements

The five project bundles chosen for further investigation were:

1. Projects 11 and 12: Cold River Reach M07-C at Sargent Brook confluence near Wilmouth Hill Road intersection with Cold River Road.
  - *Active and Passive Restoration: Floodplain Restoration and Corridor Protection*
2. Projects 15, 17, and 20: Cold River Reaches M06 and M07-A along Cold River Road.
  - *Active Restoration: Bank Stabilization and Channel Restoration*
3. Projects 24 and 25: Cold River Reach M03 along Cold River Road near VELCO line.
  - *Active and Passive Restoration: Channel and Floodplain Restoration, Corridor Protection*
4. Project 26: Cold River Reach M01 in between US Route 7 and Middle Road
  - *Active and Passive Restoration: Channel and Floodplain Restoration, Corridor Protection*
5. Fluvial Erosion Hazard (FEH) Analysis for the Town of Clarendon to compare FEH overlay with FEMA-mapped floodplain.

## 6.0 Conclusions & Recommendations

The Cold River is a powerful and dynamic river flowing through glacial outwash sediments in its valley. These sediments are mobilized during extreme flood events such as Tropical Storm and transported down through the river corridor, with areas of extreme sedimentation occurring in the alluvial fan where the Cold River meets the Otter Creek valley and floodplain. While flood damages resulting from inundation occurred in some areas in 2011 during Irene, fluvial erosion has been the principal mode of damage to roadways, homes, and farm fields in the Towns of Shrewsbury and Clarendon during flood events.

Within certain areas of the Cold River corridor, ongoing vertical and lateral channel migration is likely in the future. Given these predictions for future channel adjustments, the following watershed-scale and site-specific management observations and approaches are recommended:

- The management of accumulating sediment in the lower reaches of the Cold River between US Route 7 and Middle Road has been identified as a key concern in the Town of Clarendon due to ongoing conflicts at road crossings and adjacent properties. This area, which is characterized as an alluvial fan, will continue to aggrade (i.e., accumulate) sediment transported from upstream reaches. Due to the extreme amount of bedload sediment mobilized during Tropical Storm Irene, sediment aggradation will continue to be severe in this area over the next decade. A long-term management plan which includes berm removal, floodplain restoration, and the periodic maintenance of channel sediments in a way that sustains aquatic habitat is needed for this area.
- Continued use/enforcement of the adopted Fluvial Erosion Hazard (FEH) zone ordinance in the Town of Shrewsbury, with consideration of appropriate stream setbacks in areas where the FEH zone is not mapped (e.g., smaller tributaries draining to Cold River). In Clarendon, where an FEH ordinance has not been adopted, the Town is encouraged to consider the adoption of FEH zoning to protect public safety during future flood events, and improve aquatic habitat and water quality in the river over the long-term.
- Address high-priority areas of channel and floodplain restoration to mitigate the effects of dredging/berming that occurred following TS Irene. These areas, which include projects 11, 24, 25, and 28 (see Appendix B for detailed project descriptions), have elevated risks of future flood damage for both adjacent lands and downstream areas.
- The Town of Shrewsbury carefully consider those areas of river corridor in the town identified for added protection (i.e., conservation easements) above and beyond the FEH restrictions to protect upstream floodplains and mitigate downstream effects of fluvial erosion hazards in Shrewsbury and Clarendon (projects 8 and 9 in Table 5.3).

## 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](http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_geoassesspro.htm)

**Acre** -- A measure of area equal to 43,560 ft<sup>2</sup> (4,046.87 m<sup>2</sup>). 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 made 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** -- soil 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.