River Corridor Plan for the White River and Tributaries in Sharon, Vermont

March 15, 2010

Prepared by:

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

Fitzgerald Environmental Associates, LLC.

Applied Watershed Science & Ecology

Prepared under contract to:

Two Rivers-Ottauquechee Regional Commission
3117 Rose Hill, The King Farm
Woodstock, VT 05091

TWO RIVERS-OTTAUQUECHEE REGIONAL COMMISSION
serving 30 towns in Vermont
3117 Rose Hill, The King Farm
Woodstock, VT 05091
www.trorc.org
802.457.3188
fax: 802.457.4728

List of Figures and Tables

Executive Summary

The White River drains a 712 square mile watershed spanning 30 towns in 5 counties. Tributary to the Connecticut River, the White River is one of the dominant landscape features in eastern Vermont. Numerous towns are found within its alluvial valley and along its steep banks, including the Town of Sharon. Within Sharon, four major tributaries drain to the river, including Quation Brook, Fay Brook, Broad Brook, and Elmers Brook. The river and its tributaries provide abundant recreational opportunities in the form of fishing and boating, natural beauty and aesthetics, and significant historical and cultural value.

In 2009, the Town of Sharon White River Task Force and the Two Rivers-Ottauquechee Regional Commission (TRORC) sought to collect geomorphic and habitat data for the White River and its tributaries within Sharon. The town is interested in including a fluvial erosion hazard (FEH) overlay district within their Flood Hazard bylaw. The Vermont Department of Environmental Conservation (VTDEC), with funding from the Clean and Clear Program, provided the project partners with funding to carry out Phase 2 Stream Geomorphic Assessments (SGA) within the town limits. Fitzgerald Environmental Associates, LLC was retained by TRORC in spring of 2009 to complete the field work and develop a summary report of the study findings. The following is a summary of Phase 2 SGA findings and the stressor and project identification effort:

- A total of 15 river reaches (23.5 river miles) were assessed using the VTDEC Phase 2 SGA Protocols. Due to the varied topographic terrain and valley setting, especially in the tributaries, the reaches were further subdivided into 30 segments for field data collection. Two segments, one on Quation Brook and one on Fay Brook, were not assessed due to lack of property access.

- White River main stem reaches are found in a semi-confined valley in Sharon. Despite low channel slopes, the confined valley setting limits the development of a meandering planform, and channel sinuosity is generally low. Channel morphologies are typical of B and C-type classification (Rosgen, 1994), with plane bed bedforms. With one exception (Segment R04-B), geomorphic stability and aquatic habitat conditions were found to be "fair". All White River reaches are in stage III of the channel evolution model (CEM).

- Quation and Fay Brooks, which enter the White River from the north, have a high degree of variability in channel gradient and valley setting. Both tributaries previously had 4 reaches defined (8 total) during the Phase 1 SGA study between 2001 and 2003. A total of 8 segments were assessed on Quation Brook, with 13 segments assessed on Fay Brook. A variety of stream channel forms (B, C, and E) are present on each brook due to the varying slope, valley confinement, and encroachment impacts from adjacent roads. Geomorphic stability and aquatic habitat conditions varied from "poor" on one Quation Brook segment due to road impacts, to "good" on numerous reaches that are relatively free of road encroachment. Most segments along Quation and Fay Brooks are in a state of adjustment, with a majority classified in stages II or III of the CEM.

- Elmers and Broad Brooks, which enter the White River from the south, also have variability in valley and channel morphology; however less variability was noted than in Quation and Fay Brooks. Two reaches on Elmers Brook and one reach on Broad Brook were included for assessment, with a total of 5 segments assessed during the Phase 2 field work. Geomorphic stability and aquatic habitat conditions were generally better than Fay and Quation Brooks; 3 out of 5 segments had "good" geomorphic stability, and one segment on Elmers Brook had "reference" habitat conditions.

- The stressor identification analysis revealed that historical alterations to the hydrologic and sediment regimes, in combination with channel straightening and encroachments, have resulted in many river miles departing from expected erosion and depositional processes. This departure results in a conversion of river segments to effective transporters of sediment to downstream areas, with a subsequent loss of storage of sediment and floodwaters within these reaches. The supply of sediment to the channel network is further exacerbated by excess stormwater runoff (and failure of side slopes) along the tributary reaches, especially in Quation and Fay Brooks where major roadways parallel and encroach upon the stream corridors.

- A total of 61 structures were assessed using the VTDEC methods during the Phase 2 field effort, including 29 culverts and 32 bridges. The results of a structure analysis indicate that only 8 percent of the assessed bridges and culverts are adequately sized to accommodate stream equilibrium conditions. None of the 29 assessed culverts have widths equal to or greater than bankfull channel width. The VTDEC Geomorphic Compatibility and Aquatic Organism Passage Screening Tools were used to prioritize structures for replacement or retrofit. Ten (10) culverts and 2 bridges have been identified as high priority to address compatibility problems with channel stability and aquatic organism passage.

- Watershed-level approaches to restoration of dynamic equilibrium conditions were evaluated, including mitigation of stormwater runoff, implementation of FEH zones, and the above-described analysis of structure data. FEH zones are recommended for the Town of Sharon to encourage long-term channel stability, reduce flood recovery and infrastructure maintenance costs, and increase public safety. Options exist for stormwater management regulations at the local level that would help avoid future runoff problems.

- Site level approaches to restoration of dynamic equilibrium conditions were evaluated in detail at the reach scale using a step-wise procedure developed by VTANR. This resulted in the identification of 27 unique projects for the Sharon study area, including 14 projects that do not require significant further study (i.e., passive approaches such as buffer plantings and corridor protection), and 13 projects requiring further feasibility study or engineering design (i.e., active restoration approaches such as culvert replacements).

1.0 Project Background

1.1 Introduction and Study Goals

In 2009, the Town of Sharon White River Task Force and the Two Rivers-Ottauquechee Regional Commission (TRORC) identified the White River and its tributaries with the Town of Sharon for assessment of fluvial geomorphic and aquatic habitat conditions. The Town of Sharon is interested in incorporating the science of fluvial geomorphology into their Town Plan and flood hazard bylaws. This could include the implementation of a fluvial erosion hazard (FEH) overlay district, and/or other site-specific management actions based on field collected data. Vermont Department of Environmental Conservation (VTDEC) provided TRORC with funding from the Clean and Clear Program to carry out Phase 2 Stream Geomorphic Assessments (SGA) of the White River and four of its major tributaries in Sharon.

Watershed restoration projects are most successful when carried out within a context for understanding how reach and watershed-scale stressors cause channel instability. The VTANR River Corridor Planning Guide provides sound, scientifically-defensible methods for identifying stressors on channel stability and restoration projects that will address them appropriately (VTDEC, 2007). The overall goal of the VTDEC River Management Program (RMP) is to "manage toward, protect, and restore the fluvial geomorphic equilibrium condition of Vermont rivers by resolving conflicts between human investments and river dynamics in the most economically and ecologically sustainable manner," (VTANR, 2007) achieved through:

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

The goal of the White River Phase 2 SGA study is to provide 1) a basis for understanding the overall causes of channel instability and habitat degradation, 2) the data needed to develop FEH zones within the Town of Sharon, and 3) a list of preliminary corridor restoration projects that can be further developed in the future.

1.2 Project Partners

The planning team for the White River Phase 2 SGA work included:

- Town of Sharon White River Task Force
- Two Rivers-Ottauquechee Regional Commission (TRORC)
- Vermont Department of Environmental Conservation (VTDEC)

The Town of Sharon White River Task Force functions as an advisory group to the Sharon Selectboard. The Task Force is comprised of one Selectman, one Planning Commissioner, one Conservation Commissioner, a representative from the White River Partnership, and one interested Sharon resident who also works for the VTDEC RMP.

Fitzgerald Environmental Associates, LLC (FEA) was retained by TRORC in spring of 2009 to carry out the Phase 2 SGA effort during the 2009 field season, and develop a summary report of the study findings. This summary report includes input from the Project Partners following a public presentation in March, 2010.

1.3 Previous Studies

Numerous studies of the White River watershed have been completed over the last 10 years. These include SGA studies and river corridor plans carried out in conjunction with RMP, fisheries studies from the Vermont Fish and Wildlife Department (VFWD), and summaries of implemented in-channel restoration efforts. Below is a brief summary of selected previous studies that are pertinent to the Sharon SGA work.

SGA and Corridor Planning

Three (3) river corridor plans (RCP) have been completed within the White River watershed following the RMP methods. All three RCPs were completed for subwatersheds in the upper (western) portion of the basin.

- A RCP was completed in 2007 for the Ayers Brook watershed within the towns of Brookfield, Braintree, and Randolph (BCE, 2007). The White River Partnership (WRP) sponsored the assessment and planning work. Ayers Brook, a tributary to the Third Branch of the White River, was studied due to its intensive channel management history and subsequent channel instability. Results indicated that channel incision and widening were common in the watershed due to historic channel management; FEH zones were recommended for the affected towns. The project resulted in three river corridor easements that covered a significant portion of the study area.
- A RCP was completed in 2007 for the Upper White River within the towns of Stockbridge, Pittsfield, Rochester, Hancock, and Granville (Redstart, 2007). The WRP initiated and sponsored the planning process. Extensive historical straightening was noted in all study reaches, and this has led to channel incision and loss of floodplain function. The study identified areas along the river corridor where long-term protection could allow for the redevelopment of healthy floodplain processes that would benefit the watershed conditions locally and in downstream areas.
- A RCP was completed in 2008 for the Tweed River within the towns of Stockbridge, Pittsfield, and Killington (Redstart, 2008). The WRP again initiated and sponsored the planning process. The Tweed River is found in the upper watershed and confluences with the White River main stem ("Upper White") in the town of Stockbridge. As in the other studies, extensive historical straightening was noted on many reaches of the Tweed River. The study recommended FEH zones as a tool for allowing the redevelopment of healthy floodplain processes that would reduce erosion risks and benefit aquatic habitat in the long-term.

Benthic Macroinvertebrate Sampling

VTDEC has conducted sampling of benthic macroinvertebrates at 34 unique locations throughout the White River watershed. Overall, the sampling results indicate that the bed substrate and water quality provide good to excellent conditions for these biota (Figure 1.1). Specifically within the Town of Sharon, macroinvertebrate samples were taken from the White River main stem four times since 1997 (Table 1.1). The sampling location was approximately ¼ mile upstream of the I-89 bridge crossing. The results indicate "good" to "very good" conditions exist for the expected biotic communities at this site.

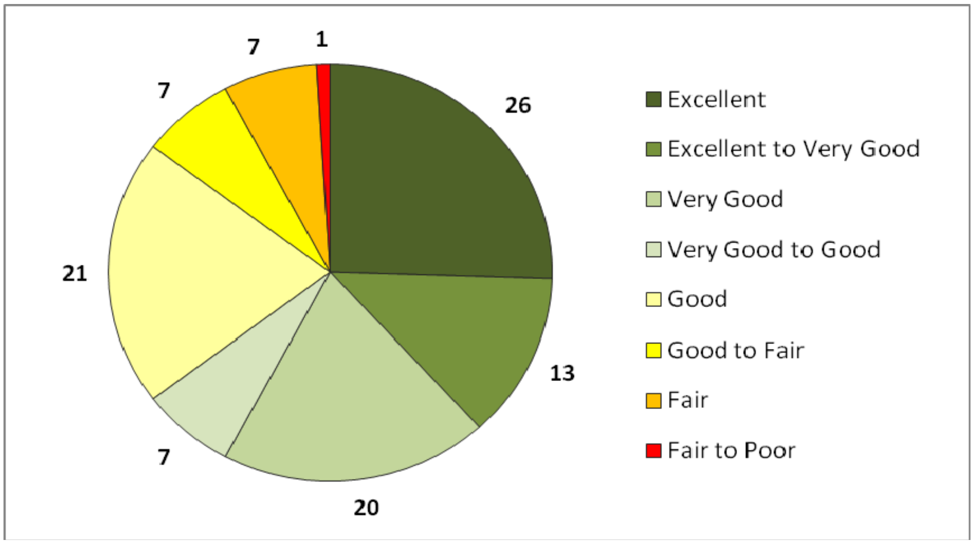

Figure 1.1 Summary of VTDEC benthic macroinvertebrate samples indicating habitat quality for 34 sites within the White River watershed. Data set encompasses 102 sampling events.

Table 1.1 VTDEC benthic macroinvertebrate sampling results for the White River in Sharon (VTDEC Site ID 130000000140)

Date Sampled	Mean Density	Mean Species Richness	Mean EPT* Richness	Community Assessment
10/9/1997	2724	38	21	Very Good to Good
10/6/1998	335	37	13	NA†
9/9/1999	1408	37	18	Good
9/13/2001	1324	30	16	Good

* EPT: Pollution sensitive families of Ephemeroptera, Plecoptera, and Trichoptera

† High flow event and scour prior to sampling precluded a background community assessment

Fisheries

The VFWD has conducted fisheries sampling on the White River and all the main tributaries in Sharon at various intervals. The White River main stem and Broad Brook have been sampled more frequently, while Fay, Quation, and Elmers Brooks have been sampled less frequently (Kirn, 2010). A brief summary of recent findings is included below.

- **White River** was sampled extensively within Sharon town limits in 2001 using angler creel methods (VFWD, 2001). The sampling indicated the habitat supports wild rainbow trout (*Oncorhynchus mykiss*), smallmouth bass (*Micropterus dolomieu*), and occasional brown trout (*Salmo trutta*). Nearly all of the trout observed during creel sampling (21 of 22) were stocked fish. Anglers caught an estimated 120 trout/mile in this section. Water temperatures reached or exceeded 80° F for 13 days from July through September. This section of the river is stocked annually with yearling rainbow trout.
- **Quation Brook** fisheries are limited by a passage barrier at the Route 14 (perched outlet) and I-89 culverts (600 feet in length). Upstream of this barrier wild brook trout (*Salvelinus fontinalis*) populations exist, however the habitat is heavily fragmented by numerous crossings of Route 132. Quation Brook was most recently sampled by VFWD in 2004 and 2006. No stocking occurs on Quation Brook.

- **Fay Brook** fisheries are also limited by a barrier at the Route 14 crossing at the confluence with the White River. Fish are able to pass this barrier during high flow stages on the White River in some years, and wild rainbow trout have been observed upstream to the large waterfall approximately 700 feet upstream of Route 14. Fay Brook was most recently sampled by VFWD in 1998 and 2003. The habitat upstream of the falls supports good brook trout populations; no stocking occurs upstream of the falls.
- **Elmers Brook** supports abundant wild brook trout and spawning rainbow trout populations downstream of the passage barrier at the railroad crossing. Rainbow trout are able to pass at the perched culvert beneath River Road during high spring flows on the White River. Elmers Brook was most recently sampled by VFWD in 2001 and 2004. Wild brook trout populations are also abundant upstream of the railroad crossing; no stocking occurs upstream of this point.
- **Broad Brook** has been sampled continuously at two stations for over 20 years. This tributary serves as a spawning stream for the White River's rainbow trout population. Rainbow and brook trout are present, as are brown trout in fewer numbers. Sampling at an upper station (elevation 820 feet) indicates that densities have often exceeded 1000 trout/mile during the last 10 years. The River Road culvert just upstream of the confluence with the White River was recently retrofitted to improve fish passage. No stocking occurs on Broad Brook.

2.0 Background Watershed Information

2.1 Geographic Setting and Land Use History

At its confluence with the Connecticut River in White River Junction, the White River drains a 712 square mile watershed spanning 30 towns in 5 counties. The study area encompassed by this SGA effort focused on main stem and tributary reaches within the Town of Sharon in Windsor County. In this study, the majority of one of the Fay Brook reaches (R7.S1.04) extends to the north into the Town of Strafford (Figure 2.1).

Sharon Village is found approximately 15 miles to the north and west of the Town of White River Junction. From the eastern end of the study area, the White River flows an additional 8 river miles in a southeasterly direction before meeting the Connecticut River.

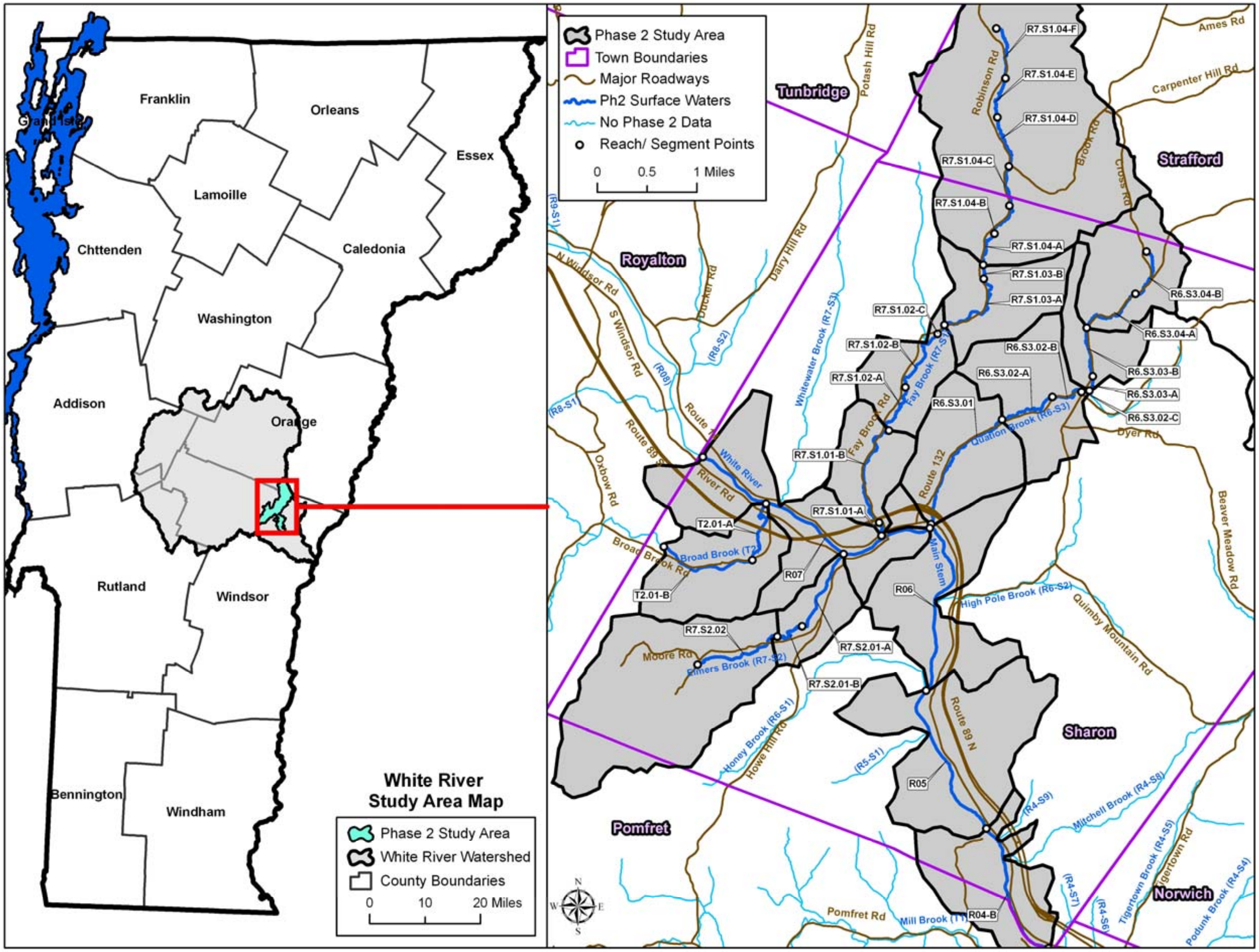

Figure 2.1 Study area location and Phase 2 segments for the White River and its tributaries in Sharon, VT

Prior to the forest clearing associated with European settlement, logging and farming the watershed would have been a mixture of deciduous forest on the valley floors, coniferous forest along the mountain spines, and a mixture of both along the slopes. Deforestation and grazing, largely from sheep farms, likely left over 80 percent of the watershed devoid of trees at one time or another (Albers, 1998). This landscape change had a tremendous impact on waterways like the White River. Exposed soils on steep slopes eroded and 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.

Logging has been a major factor in shaping the Vermont landscape as well as influencing the form and function of rivers and streams. The White River was used to transport logs down to the Connecticut River, where they continued down to the southern New England States for milling. Logs were dammed up behind the Sharon dam area before being released downstream (Figure 2.2). The image below is of one of the last large log drives down the White River. Thousands of logs fill the entire channel and piles cover the banks. The log flows would have had a tremendous impact on the bank and buffer conditions of the White River contributing huge amounts of sediment downstream along with the lumber.

Figure 2.2 One of the last log drives down the White River in Sharon, circa 1910 (UVM Landscape, 2010)

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, 1998). 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 85 percent of the White River watershed is covered by forest. With the increasing tourism sector in the state, and the need for hardwood lumber for homes, forestry has often replaced agriculture in the rural hill slopes of central Vermont.

Only 10 percent of the watershed is occupied by agricultural lands today, much of this along the river on the valley floors.

2.2 Geologic Setting

Due to its large area, the White River watershed spans four Biophysical regions of Vermont: Southern Green Mountains, Northern Green Mountains, Southern Vermont Piedmont, and Northern Vermont Piedmont (Thompson and Sorenson, 2000). Bedrock geology varies significantly across the watershed. Non-calcareous schists, phyllites, gneisses, and granofels dominate the upper watershed in the Southern and Northern Green Mountain and Biophysical regions. These rocks are of Precambrian and Cambrian origin, and are generally non-calcareous (i.e., contain low levels of Calcium). Carbonate and somewhat carbonate-rich rocks characterize the lower watershed, including the Sharon study area. These rocks were formed from the Cambrian through the Devonian age and are composed of limestones, dolomites, marbles, shales, slates, schists, and various other clastic metamorphosed rocks. Closer to the Connecticut River valley, other metamorphosed as well as mafic volcanic and clastic sedimentary rocks are found.

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

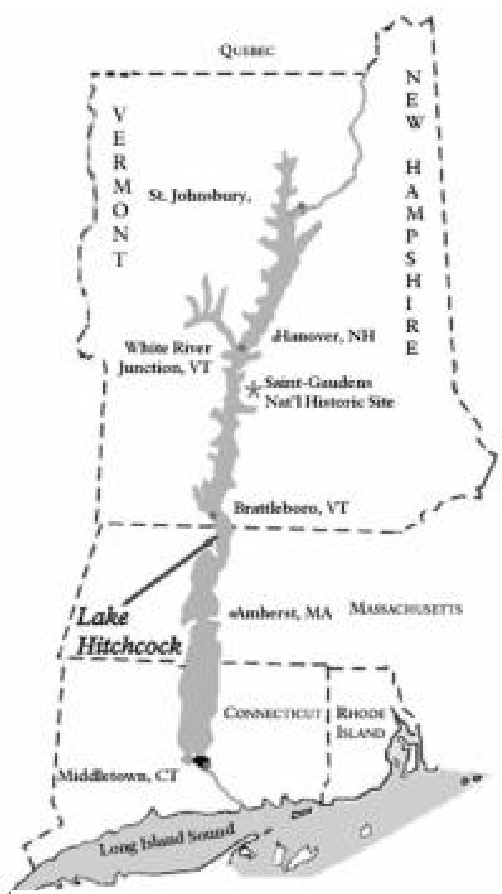

Figure 2.3 Maximum extent of Glacial Lake Hitchcock 14,000 years ago (NPS, 2010).

The presence of Glacial Lake Hitchcock had a significant effect on the surficial geology of the lower watershed (Figure 2.3; NPS, 2010). This lake occupied the Connecticut River Valley from central Connecticut north to St. Johnsbury during the retreat of the Laurentide ice sheet beginning approximately 18,000 years ago (Ridge and Larson, 1990). Silty-clay deposits found in the White River corridor downstream (east) of Sharon were caused by the presence of Glacial Lake Hitchcock (Figure 2.4). The great size of the lake, combined with the erosive forces of the glacier moving over bedrock surfaces allowed for the development of annual layering of fine sediments (e.g., varves) throughout the area affected by the lake. Varved clays are found at the confluence of a tributary with the White River in Hartford downstream (east) of the study area.

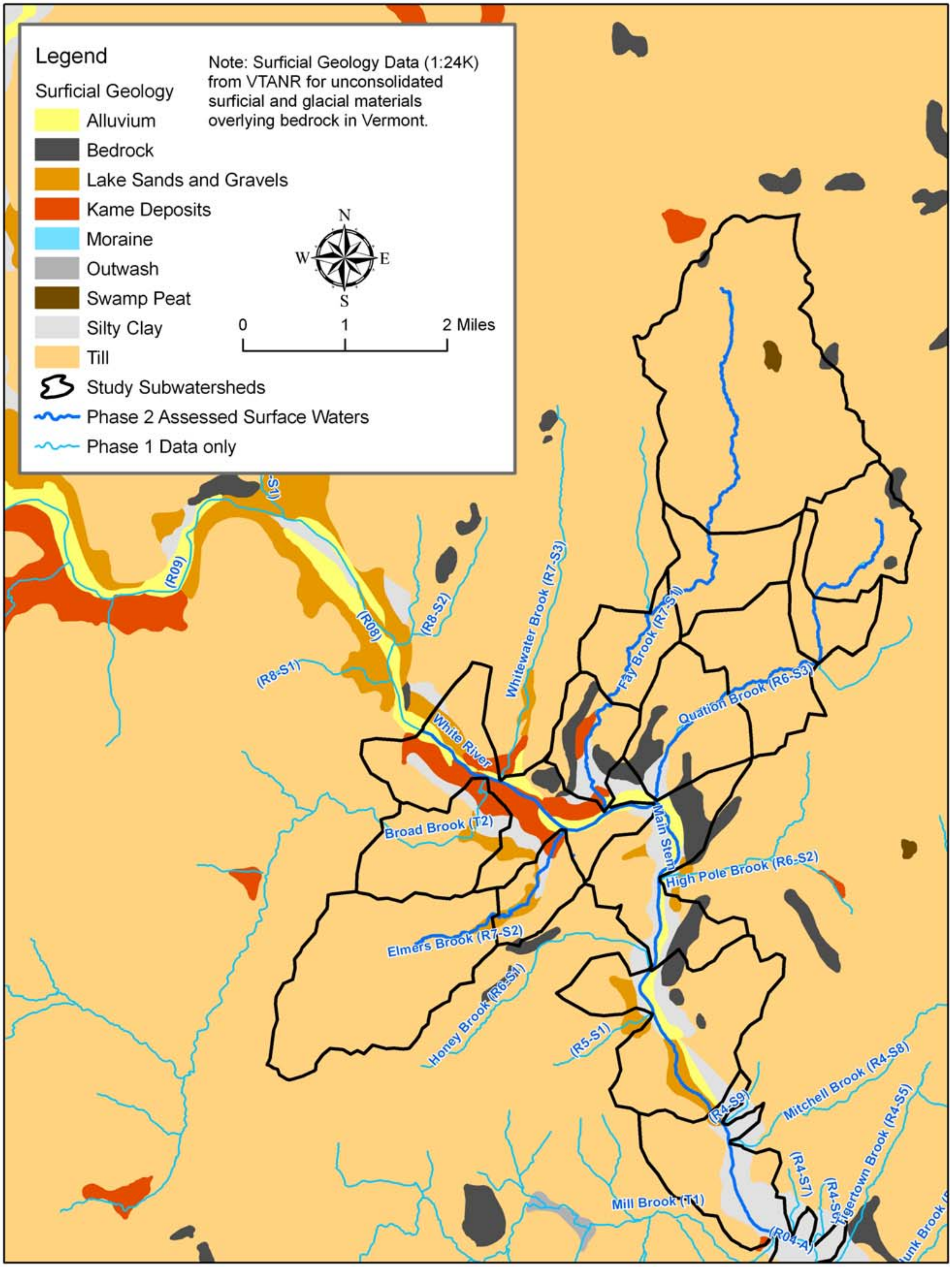

Figure 2.4 Surficial geology of the Phase 2 study area in Sharon, VT

2.3 Geomorphic Setting

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 VTDEC, 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 done in this study, reference reach characteristics for some of the reaches were refined based on improved knowledge of the reach and valley setting. The reach characteristics were used to classify natural channels using two classification systems developed by Rosgen (1994) and Montgomery and Buffington (1997).

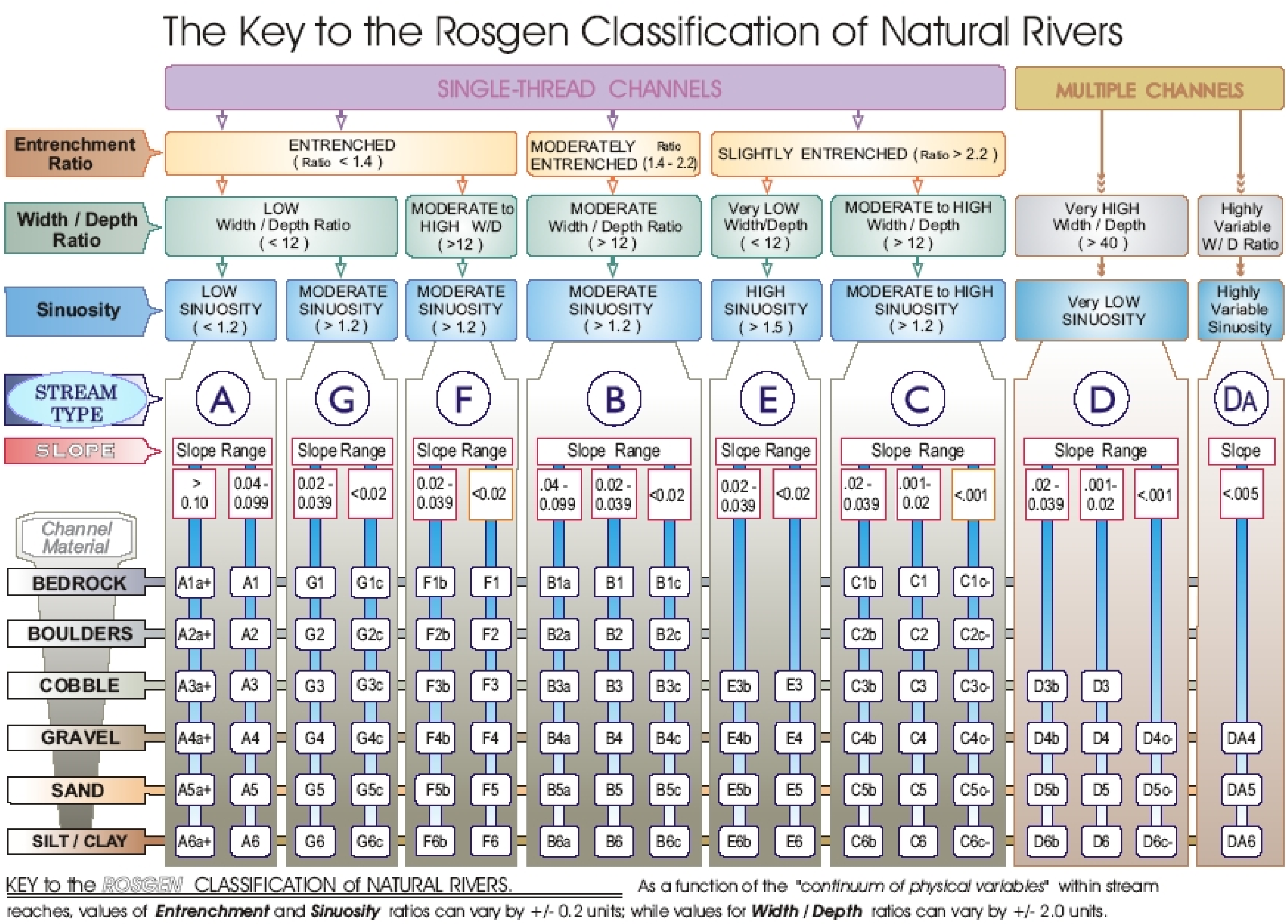

Figure 2.5 The Rosgen (1994) classification of streams based on channel morphology. Key parameters for classification include 1) the entrenchment ratio (floodprone width / bankfull channel width), 2) width to depth ratio (bankfull width / mean channel depth), and 3) channel sinuosity (channel length / 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.

The Rosgen system (Figure 2.5) 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.

Table 2.1 provides a summary of the reference reach data for the 15 reaches assessed in Sharon. White River main stem reaches are found in a semi-confined valley in Sharon. Despite low channel slopes, the confined valley setting limits the development of a meandering planform, and channel sinuosity is generally low. Channel morphologies are typical of B and C-type classification, with plane bed bedforms. Quation and Fay Brooks, which enter the White River from the north, have a high degree of variability in channel gradient and valley setting. During the Phase 2 assessments, the 8 study reaches were further divided into 20 segments to characterize the differences in morphology. Reference data found in Table 2.1 represent the best approximation of average channel form across the entire length of each reach. Elmers and Broad Brooks, which enter the White River from the south, also had a high degree of variability in channel gradient and valley setting. These reaches generally fall into B and C-type classification.

Table 2.1 Reference reach characteristics for the White River and tributaries in Sharon, VT

Surface Water	Reach ID	Watershed Area (sq. mi.)	Channel Length (mi.)	Channel Width (ft.)	Channel Slope (%)	Sinuosity	Valley Type*	Reference Stream Type†	Bedform‡
White River	R04	694.9	3.5	233.2	0.1	1.0	SC	B	Plane Bed
	R05	661.6	1.7	228.2	0.2	1.1	SC	B	Plane Bed
	R06	658.7	1.9	227.8	0.1	1.0	SC	C	Plane Bed
	R07	645.0	2.7	225.7	0.1	1.1	SC	B	Plane Bed
Quation Brook	R6-S3.01	5.8	1.5	28.5	6.7	1.1	SC	B	Step-Pool
	R6-S3.02	4.7	1.2	25.8	2.1	1.3	BD	C	Riffle-Pool
	R6-S3.03	1.6	0.7	9.0	1.7	1.0	VB	E	Riffle-Pool
	R6-S3.04	1.0	1.3	12.6	4.6	1.1	NW	B	Step-Pool
Fay Brook	R7-S1.01	8.3	1.4	33.3	3.9	1.1	SC	B	Step-Pool
	R7-S1.02	7.6	1.5	32.0	2.1	1.3	BD	C	Riffle-Pool
	R7-S1.03	5.6	1.1	28.0	2.1	1.2	SC	B	Step-Pool
	R7-S1.04	4.7	3.1	25.8	2.1	1.2	VB	C	Riffle-Pool
Elmers Brook	R7-S2.01	3.2	1.4	21.8	3.7	1.2	NW	B	Step-Pool
	R7-S2.02	2.6	1.0	18.5	2.9	1.2	BD	C	Riffle-Pool
Broad Brook	T2.01	17.0	1.8	45.6	1.9	1.2	BD	B	Plane Bed

* SC= Semi-confined; NW= Narrow; BD=Broad; VB=Very Broad
† per Rosgen, 1994
‡ per Montgomery and Buffington, 1997

2.4 Hydrology and Flood History

USGS Gaging Data

The United States Geological Survey (USGS) operates a real-time flow monitoring gage on the White River just upstream of the Quechee-West Hartford Bridge crossing in West Hartford, VT. The West

Hartford Gage is just downstream of the study area in Sharon. At the gage, the watershed drainage area is 690 square miles. Upslope, at the beginning of the study area the total watershed area is 672 square miles. The elevation in West Hartford is 374.5 feet above sea level and the gage is located at an area where bedrock spans the bottom of the channel. Boulder and cobble-sized particles are also found resting on the bedrock. This gage has been continuously monitoring the flows of the White River for the last 93 years. Flow frequency and magnitude data for this site was developed by Scott Olsen (2002) of the USGS as a part of a state-wide effort to characterize the flow-frequencies of Vermont's streams and rivers. Given the extensive flow record and the magnitude of storm events that occurred during that time period, recurrence intervals were developed for the White River for the 2, 5, 10, 25, 50, 100, and 500-year peak flow events (Table 2.2).

Table 2.2 Peak discharge for given recurrence intervals in the White River, VT

Recurrence Interval	Discharge Q (cfs)
2-Year	17,300
5-Year	25,300
10-Year	31,800
25-Year	41,600
50-Year	50,100
100-Year	59,800
500-Year	87,600

*Data obtained from Olsen, 2002

Flooding history

The annual peak discharges observed at the West Hartford Gage helps to explain what flow events shaped the main stem of the White River over the last century (Figure 2.6). Over the last 90 years there were a total of 9 major flow events that exceeded the 10-year peak flow discharge of 31,800 cfs. Five of these events were mostly the result of large snow packs melting at an above average rate creating a large spring flood. Other flood events were the result of excessive summer rain, or tropical storms. The second largest flood event observed over the period of record was the flood of 1938. This flood occurred in September and was the result of the rare Atlantic Hurricane that surged up the Atlantic, over Long Island, up through Connecticut, Rhode Island, New Hampshire and Vermont (Burns, 2005). The devastation of this event was widespread in and the hurricane is known as the "Great Hurricane of 1938." The peak discharge on the White River occurred on September 22, with a flow rate of 47,600 cfs. The gage height during the flood of 1938 was 19.26 feet. Out of all nine flood events that have occurred over the 10-Year recurrence interval on the White River, no event can rival in magnitude or damages the flood of 1927.

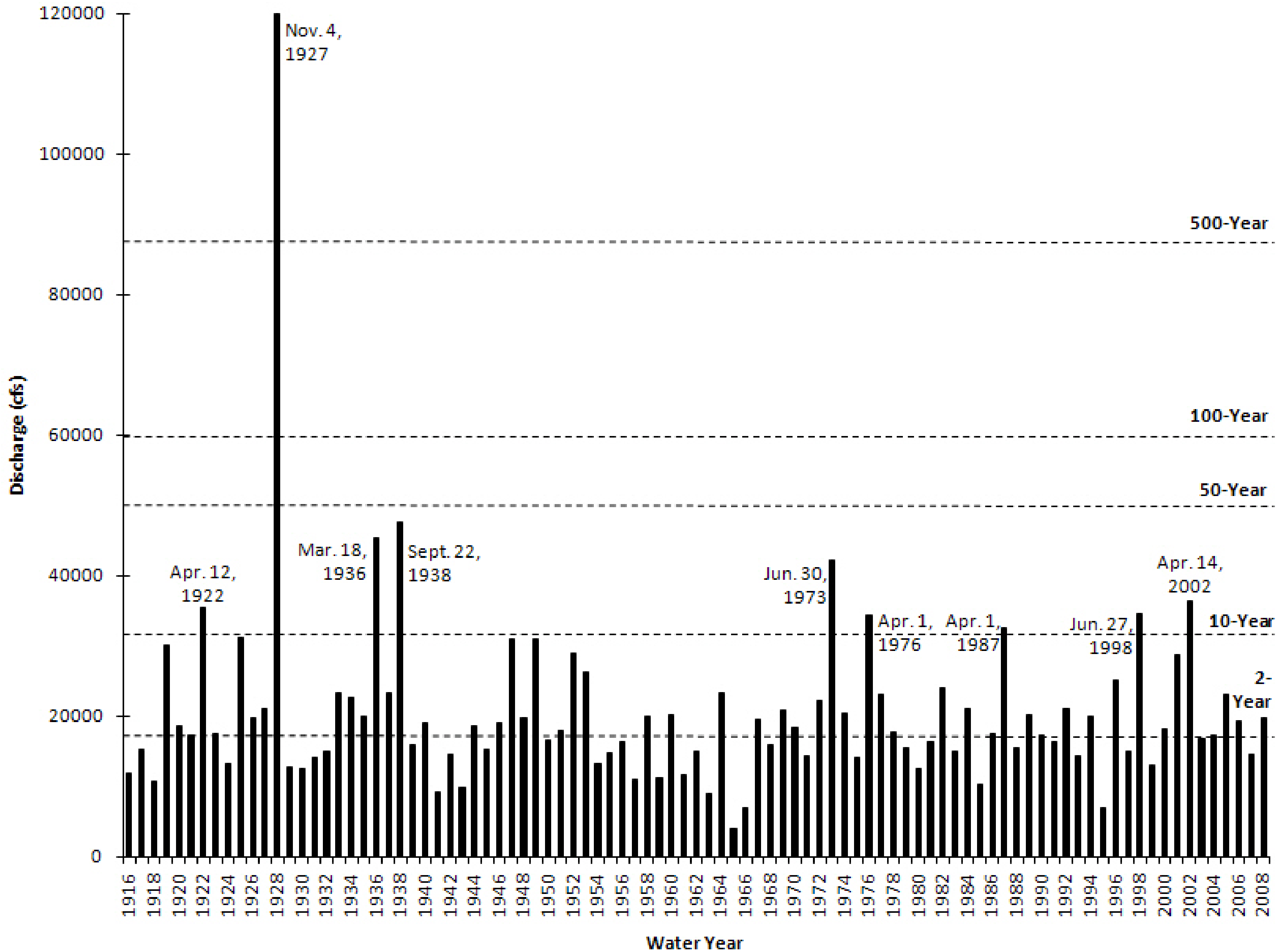

Figure 2.6 Annual peak discharges for USGS Gage # 01144000 on the White River in West Hartford, Vermont; Recurrence intervals from Olsen (2002)

The Flood of 1927

The flood of 1927 occurred in early November after leaf-fall. The rain storm was unprecedented in intensity and spatial extent (Figure 2.7). Almost the entire state received between 5 and 8 inches of rain over the course of a few days time. The volume of rainfall in combination with the time of year made the perfect conditions for severe devastation throughout the state. As observed in the peak discharge table, the flood of 1927 was the largest on record over the last 93-years, and according to the recurrence intervals the intensity observed at the West Hartford gage exceeds that of the 500-year flood event. The discharge of the flood is estimated to be approximately 120,000 cfs, which is 2.5-times greater than that of the flood of 1938. The stage height recorded for the flood of '27 was 29.3 feet, 10 feet higher than the second greatest flood event of the last century.

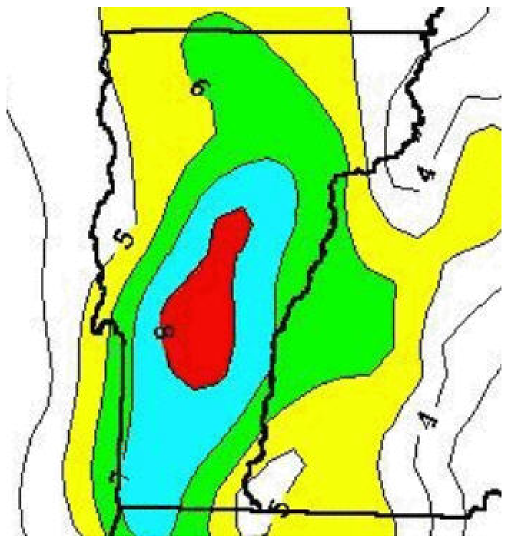

Figure 2.7 NWS Northeast River Forecast Center's predicted rainfall distribution during the 1927 flood in inches (NOAA, 2007)

The Winooski and White River valleys received the most intense rainfall leading up to the flood. Sharon, West Hartford, and downstream towns were among the areas hit hardest by the flood (Minsinger, 2003). Three dams were blown out by the rising waters on the main stem of the river, including the Sharon Dam. Railways and roadways along the White River were completely destroyed. There were no bridges left between Rochester and White River Junction following the flood (Minsinger, 2003). We hypothesize that the semi-confined valley setting in Sharon could have acted like a bottle neck of flood flows, causing even more damage due to greater stream velocity and power. Following the flood of 1927 many flights were flown to photograph and catalog the extent of damages from the flood (Figure 2.8). These images were obtained from the UVM Landscape Change program, which catalogs historic photos and reproduces the images setting today to compare Vermont's landscape over time (Figure 2.9). The photograph below shows the main stem reach R06 and some of R05. The Sharon dam, located in the center of the photograph was blown out during the flood and sent a large surge of water downstream. The Central Vermont Railroad Trestle also was washed out during the flood surge. Over 1,200 bridges were washed away state-wide and thousands of homes destroyed during the flood of 1927, making it the most devastating flood event in Vermont's history (Figure 2.10; NOAA, 2007).

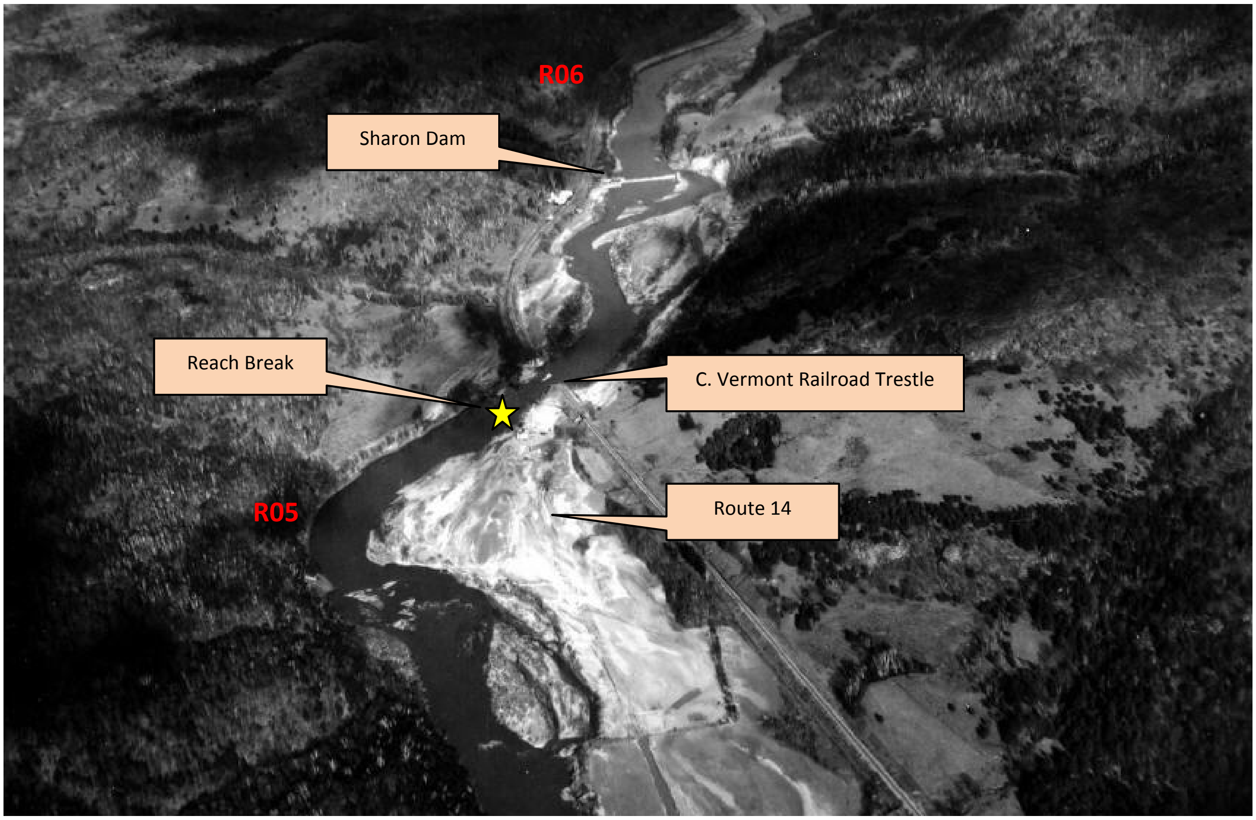

Figure 2.8 Historic aerial photo taken 11-08-1927 looking upstream toward Sharon (UVM Landscape, 2010)

Figure 2.9 Present day aerial photo taken 4-30-2004 looking upstream toward Sharon (UVM Landscape, 2010)

Figure 2.10 The abutments of the washed-out bridge in Sharon; the house was moved downstream (UVM Landscape, 2010)

2.5 Ecological Setting

As noted previously, White River watershed spans four Biophysical regions of Vermont: Southern Green Mountains, Northern Green Mountains, Southern Vermont Piedmont, and Northern Vermont Piedmont (Thompson and Sorenson, 2000).

Southern and Northern Green Mountains

The upper White River watershed is found within the Southern and Northern Green Mountain Biophysical regions. This region includes the highest peaks in the state along the spine of the Green Mountains. The Third Branch of the White River drains the eastern side of the Green Mountains in the towns of Granville, Hancock, and Rochester.

The Green Mountains have cold winters with short growing seasons. Along the highest peaks, boreal communities are found where winter conditions are harshest. The slopes grade into the Northern Hardwood forest type at elevations of around 2,500 feet. This forest type dominates much of the upper watershed, with the exception of floodplain forests along the White River corridor. The Green Mountains are home to many mammal species, including black bear, white-tailed deer, bobcat, fisher, beaver, and red squirrel.

Northern and Southern Piedmont

The lower White River watershed is found in the Northern and Southern Piedmont Biophysical regions of the state. The study area in Sharon is located in the Southern

Piedmont region. Gentle hills and valleys, the product of millions of years of erosion, characterize these regions. The forest communities found here reflect the slightly warmer temperatures than in the Green Mountains. The average annual temperature in White River Junction based on 30 years of record is 44.3° F, with average annual precipitation of 35.6 inches. Northern Hardwood forests dominate at many elevations: sugar maple, beech, white ash, and yellow birch are common throughout. Common mammals of the Southern Piedmont include white-tailed deer, eastern cottontail, porcupine, chipmunk, and gray squirrel.

As noted in Section 1.3, the White River and its tributaries provide aquatic habitat for numerous species of important recreational fishes. On the White River proper, rainbow trout, brown trout, and smallmouth bass are found within the Sharon limits. On the tributaries, wild brook trout populations are generally healthy, and Broad Brook in particular provides important spawning habitat for rainbow trout originating from the White River.

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

Phase 1 data were previously collected by VTDEC for the entire watershed between 2001 and 2003 and summarized in the VTDEC Database Management System (DMS). A total of 15 reaches were identified for further Phase 2 assessment in Sharon in 2009, including 4 reaches on the main stem and 11 tributary reaches. A total of 30 segments were assessed for Phase 2 data, and data were entered into the Data Management System (DMS). All major human impacts and natural features noted during the Phase 2 surveys were indexed in a GIS using the Feature Indexing Tool (FIT; VTDEC, 2007).

3.2 Phase 2 Quality Assurance

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

3.3 Bridge and Culvert Assessments

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

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

3.4 Stressor and Departure Analysis

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

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

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

3.4.1 Stressor Analysis

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

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

3.4.2 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 corridor, 2) the topography of the watershed, and 3) the regional climate.

Analysis of a watershed’s sediment regime is a useful approach for summarizing the reach and watershed-scale stressors affecting the equilibrium conditions of river channels. Sediment regime mapping provides a context for understanding the sediment transport and channel evolution processes (Schumm, 1977) which govern changes in geometry and planform for river channels in a state of disequilibrium. The VTANR River Corridor Planning Guide (VTANR, 2007) outlines a methodology for understanding the reference and altered sediment regimes of reaches according to data collected during the Phase 2 field assessments. The sediment regime types used in this analysis are summarized below in Table 3.1.

Table 3.1 Sediment Regime Types (VTANR, 2007)

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

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 White River watershed. The “F” stage CEM is used to understand the process that occurs when a stream degrades (incises) its bed. The more dominant adjustment process for the “D” stage channel evolution is aggradation, widening and planform change. D-stage CEM typically occurs where grade controls prevent severe channel incision and abandonment of the adjacent floodplain. The common stages of both CEMs are depicted in Figure 3.1 below.

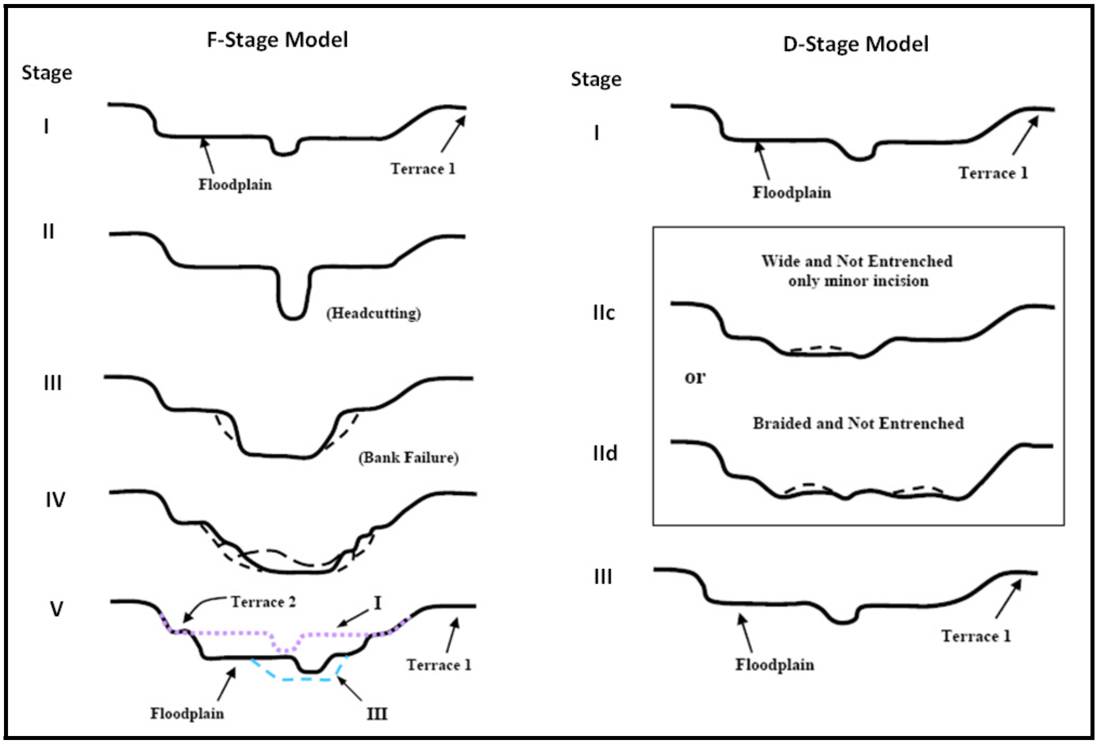

Figure 3.1 Typical channel evolution models for F-stage and D-stage (VTDEC, 2009)

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, 2007).

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

Stream sensitivity maps have been prepared for the White 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, 2007). 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 or reduction of human constructed constraints or the construction of meanders, floodplains or stable banks. Active 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. Active 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 stream 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 narratives describing the Phase 2 results and a summary of the watershed and reach-scale stressors on channel stability. Detailed summaries of geomorphic data for each segment, as well as a map of assessed segments, are provided in Appendix A. Habitat assessment summary data is provided in Appendix B.

4.1 Reach Narratives and Phase 2 Results

White River main stem Reaches (R04 – R07)

R04-A

Reach R04 was segmented because the downstream end of the study area, found at Sharon-Pomfret town line (and the confluence with Mill Brook, T1.01), was located in the middle of the reach. Segment A represents the part of the reach that was not assessed because it is found in the Town of Pomfret. Segment B is 1.5 miles in length and begins at the confluence with Mill Brook and extends to the reach break approximately 800 feet upstream of the confluence with a minor subtributary entering from the east. The segment is set in a semi-confined valley and has several prominent channel-spanning bedrock grade controls in the upper section (Figure 4.1). The segment channel slope is 0.15%. Overall the segment is well buffered to the west with the exception of a terrace in the lower segment that is in agricultural use. Route 14 is found within the eastern corridor for the entire segment. In most areas the road was built on the top of the steep slopes leading down to the naturally-armored river banks, and no evidence of human armoring or straightening was noted (however road encroachment was indexed for a majority of the segment).

Figure 4.1 Several bedrock grade controls in the upper segment

The segment has Bc channel morphology and plane bedform by reference. The cross-section was taken in the lower segment (Figure 4.2) where the only suitable riffle was found in the area where agriculture fields are found in the adjacent corridor. The substrate was predominately cobble (34%) and boulder (20%), with a median substrate size of 210 mm (cobble). The width-to-depth and entrenchment ratios of the channel are 41.5 and 1.4, respectively. Only minor incision was observed on this segment (IR = 1.1) where the channel appears to have redeveloped a new floodplain following significant channel change and widening caused by the 1927 flood. The floodplain along the right bank is composed of very thin soil deposits on bedrock that is grown over with dense willow (*Salix sp.*), alder (*Alnus sp.)*, and dogwood (*Cornus sp.)* species (WADs). The terrace beyond the right bank at the cross-section location is most likely a glacial terrace with an associated timescale greater than the last 200 years. Based on the parent material (some alluvial deposits from the river and a tributary entering from the west, but predominantly glacio-fluvial high on the terrace), this feature was likely formed when Glacial Lake Hitchcock occupied the Connecticut River basin and extended up into the White River valley. This terrace was only partially accessed during the 1927 flood, but not as extensively as the adjacent terrace in upstream reach R05.

Figure 4.2 Looking downstream at the cross section location

The dominant adjustment processes observed were widening (possible legacy adjustment from 1927 flood impacts). Due to the natural grade controls and the reformed floodplain, stage III of the D channel evolution model (CEM) was selected to characterize current channel morpholopgy in the context of historical adjustments. Overall, the channel was largely stable despite the high width-to-depth ratio (RGA score = “Good”’). Habitat in this segment is naturally limited due to the confined setting (e.g., limited meanders and pool formation) and inability of the channel to attenuate wood (RHA score = “Fair”). Woody debris and pool densities per mile were 24 and 8, respectfully.

R05

Reach R05 is 1.7 miles in length and begins at the reach break with R04 and extends upstream to the Central Vermont Railroad trestle crossing. R05 has a channel slope of 0.2%. The reach shares many characteristics with downstream segment R04B: it is set in a semi-confined valley; it has several prominent channel-spanning bedrock grade controls (Figure 4.3); it is well buffered to the west with the exception of a terrace in the lower reach where a sand pit is found within 200 feet of the channel. Route 14 and some residential development are found within the eastern corridor for the entire reach. According to the FEMA flood hazard mapping, the 100-year flood zone does not extend across Route 14 to the east, and overlaps with only a few residential properties along the east bank. However, aerial photos taken following the 1927 flood indicate that very large and infrequent flood events are capable causing flood and erosion damage within the valley limits to the east of Route 14. Several large bank failures on the west bank (approx. 100ft high x 600ft long; Figure 4.4) were noted during the field surveys. A town-owned gravel/sand pit is found along west bank within 200 feet of this failing slope, and could pose a significant erosion hazard in the future if the slope failure advances to the west.

Figure 4.3 One of several bedrock grade controls in the reach

Figure 4.4 Large mass failures along the west bank

The channel has F-type morphology due to a lower than expected entrenchment ratio. The reach likely had Bc type channel morphology and plane bedform by reference. The cross-section was taken mid-reach (Figure 4.5). There, the width-to-depth and entrenchment ratios of the channel are 31.7 and 1.2, respectively. An incision ratio of 2.0 is reported for this reach; however we do not think it is realistic that the channel bed has incised 10 feet from the floodplain as the incision ratio would indicate. Rather, there has likely been a lesser degree of bed incision that has reduced what limited access there was to the floodplain under natural conditions. The substrate was predominately cobble (48%); however an elevated level of sand in the bed (22%) was noted.

Figure 4.5 Looking upstream at the cross section location

The dominant adjustment processes observed were degradation and widening (RGA score = "Fair"); however ongoing bed incision is limited by natural grade controls. Bar formation within the reach has increased since the large flood events of the 1920's and 1970's, and the bars have grown in size considerably since the 1990's. Further channel widening is predicted in this reach according to the CEM. Adjustments in planform are also likely to occur along with widening, especially in areas downstream of grade controls where increased bed resistance is allowing bar features to increase in size. As in downstream segment R04B, habitat in this reach is naturally limited due to the confined setting (e.g., limited meanders and pool formation), and the RHA score was "Fair". R05 had the highest density of LWD (46 LWD/mile) of all the main stem reaches in the study, but pools were very limited (9 Pools/Mile) and no undercut banks were observed.

R06

Reach R06 is 1.9 miles in length and begins at the railroad trestle and extends upstream to the confluence with Quation Brook near Sharon village. R06 has a very low channel slope of 0.02%. As in the downstream reaches, R06 is well buffered to the west and Route 14 is found within the eastern corridor in the upper and lower sections of the reach. This reach is slightly less confined than upstream and downstream reaches, with a confinement ratio that borders on "semi-confined" and "narrow" valley classification. As such, there is greater width along the valley floor for the channel to meander and develop riffle-pool features (Figure 4.6) typical of rivers with similar valley geometry. The only grade control in this reach is associated with the failed Sharon Dam in the lower reach (Figure 4.7). This dam was built on a natural grade control, but because of the remnants of the concrete dam it is difficult to know whether or not the bedrock is channel spanning.

Figure 4.6 Deep pool along the left bank in the upper reach

Figure 4.7 Remnants of the Sharon Dam

This reach has some notable erosion features on both banks and two very prominent mid-channel bars. The current geomorphic state is still adjusting to historic incision following the 1927 flood and the failure of the Sharon Dam. Any sediment that aggraded behind the dam, prior to its failure, was transported out of the system and downstream. Now, the channel is re-aggrading sediment and some moderate bank erosion and widening is occurring. Bar enlargement and bank erosion is most severe in the lower reach near the railroad trestle (Figure 4.8). The substrate was predominately cobble (58%), with a median substrate size of 210 mm.

Figure 4.8 Bank erosion and failing rip-rap upstream of the railroad trestle

The dominant adjustment processes observed were aggradation and widening (RGA score = “Fair”). Bar formation and enlargement is occurring within the reach and causing channel widening (width-to-depth ratio = 40.2). Further channel widening and planform adjustments are predicted in this reach (currently CEM stage III). Habitat in this reach was limited due to the lack of meander and feature formation; the RHA score was “Fair”. R06 had a low density of LWD (23 LWD/Mile), pools were very limited (9 Pools/Mile) and no undercut banks were observed.

R07

Reach R07 is 2.7 miles in length and begins at the confluence with Quation Brook and extends upstream to a change in valley confinement. The reach has an overall channel slope of 0.09%. R07 has a greater degree of road encroachment, buffer impacts, and corridor development than downstream reaches. Route 14 encroaches on the left river corridor for nearly the entire reach, while Stationmasters Road and River Road encroach upon the southern (right) side of the river corridor in the lower and upper reach, respectively. Some areas of the buffer immediate the riverbanks have been cleared on the north bank in Sharon Village, diminishing slope stability, shading and habitat quality along the banks (Figure 4.9). The reach is set in a semi-confined valley and has several large channel-spanning bedrock grade controls along the entire reach length (Figure 4.10). ANR records indicate that gravel mining took place in the 1970’s just downstream of the confluence with Elmers Brook, however the relative impact (i.e., quantity of material removed) is unknown.

Figure 4.9 Felled mature trees on the north bank in Sharon

Figure 4.10 Bedrock grade control in upper reach

The cross-section was taken in one of the few suitable riffles in the lower reach immediately downstream of the River Road bridge. The width-to-depth and entrenchment ratios of the channel are 33.6 and 1.4, respectively. Moderate incision was observed at the cross-section (IR = 1.5) where the channel appears to have lost access to a small floodplain along the south bank. Because of the abundant grade controls the channel may have responded to the 1927 flood by incising moderately and then widening. Sediment from upslope is currently aggrading in the form of large bar features. Limited sinuosity given the valley morphology prohibits the formation of oscillating point bars; however numerous mid-channel features are present, including one very large bar near the upper reach break (Figure 4.11). Three flood chutes are associated with mid-channel deposition. The substrate was predominately cobble (42%); however a slightly elevated level of sand in the bed (12%) was noted.

Figure 4.11 Mid-channel deposition in the upper reach

Channel widening and aggradation were the dominant processes (RGA score = “Fair”’). Planform shifts would be expected in the future, especially where the valley is slightly less confined in the middle and upper reach (CEM stage III, F-model). As in downstream reaches, habitat in this reach is naturally limited by the valley confinement and the lack of meander and feature formation (RHA score = “Fair”). R07 had a moderate density of LWD for plane bed river types (36 LWD/Mile). Although the pool density was low (11 Pools/Mile), many high-quality pools greater than three feet in depth were noted around the bedrock outcrops and grade controls. Numerous large fish, presumably brown trout (*Salmo trutta)*, were seen holding in deep pools, especially near the confluence with Quation Brook (at the reach break with R06). Only one undercut bank were observed in the reach.

Quation Brook Reaches (R6.S3.01 – R6.S3.04)

R6.S3.01

Reach R6.S3.01 begins at the confluence with the main stem of the White River and it extends upstream 1.5 miles at an average slope of 6.7%. This reach is a B-type by reference with a subclass slope designation a. The valley is semi-confined with human-caused change in the valley width. The width-to-depth ratio and entrenchment ratio are both indicative of the stream type (WDR = 11.7; ER = 1.9). No incision was observed on this reach (IR = 1.0; Figure 4.12). Slope changes are common within this reach because of bedrock grade controls. This makes it possible for several different types of bedforms to be present: cascade, step-pool, and plane bed features were all observed, but step-pool features were dominant. The substrate was predominately cobble (37%) and boulder (38%) in R6.S3.01, with a median substrate size of 210 mm (cobble). The frequency of grade controls is higher in the lower reach, and the channel is vertically stable. Much of the reach is heavily encroached upon by Route 132, which limits the buffer width on the right side and impacts the valley width (Figure 4.13). In the upper reach the armoring and encroachment of the channel has caused some large mass failures to form. These features are contributing significant sediment to the upper reach and if slope failures persists problems with the roadway and channel flooding could result.

Figure 4.12 Cross-section location w/ no incision observed

Figure 4.13 Channel encroachment by Rt. 132 and armoring

R6.S3.01 has a unique stretch of channel upstream of the Odgen Road crossing. There, the valley remains narrow, but three smaller channels occupy the floodplain. These features have likely formed from flood chutes that have eroded down to carry a large portion of the channel's flow. This approximately 600-foot stretch was not segmented, because the valley wall and slope is similar to that up and downstream. Also, these natural floodplain features don't appear to be caused by significant instability, but rather natural processes seen in transport streams with higher slopes.

The Odgen road crossing is one of several features that inhibit the passage of aquatic species. Like the Odgen Road crossing, the Route 14 culvert is perched with a large plunge pool downstream. Other grade controls that exceed 10 feet in height also act as barriers to fish movement upstream. These features reduced the overall connectivity of the segment with the main stem of the White River. Woody debris was observed in fair quantities for the step-pools stream type (LWD = 118/Mile) and pools were common (Pools = 40/Mile). The connectivity issues in combination with the poor right bank and riparian area scores reduced the overall RHA condition (RHA score = “Fair”). Geomorphically, this reach is stabilized vertically by the bedrock grade controls. Changes in planform and the potential for flood levels to spill over the banks and follow the road reduced to score (RGA score = “Fair”) The D-Model of channel evolution was chosen to reflect the past adjustments in planform and the vertical stability because of bedrock controls (Stage = III).

R6.S3.02-A

Reach R6.S3.02 was segmented twice because of encroachments from Route 132, channel dimensions and stream type differences. R6.S3.02-A begins at the reach break with R6.S3.01 about 600 feet upstream of the first Route 132 crossing and extends upstream 0.7 miles at an average slope of 2.5%. The valley is narrow with minor human-caused change in the valley width towards the segment break with R6.S3.02-B. This segment is a C-type by reference with a subclass slope designation b. The width-to-depth ratio and entrenchment ratio are both indicative of the stream type (WDR = 18.2; ER = 2.8; Figure 4.14). Only minor incision was observed on this segment (IR = 1.2). The bedform is riffle-pool even with the high slope, because of large trees and several debris jams in the channel that have slowed the channel flow and created a meandering profile (Figure 4.15). The substrate is predominately cobble (33%) and gravel (39%), with a median substrate size of 40 mm (Gravel).

Figure 4.14 Cross-section location C-type geometry

Figure 4.15. Riffle-pool formation aided by debris jams

Minor scour and deposition features negatively impacted the habitat condition of the segment. Woody debris (LWD/Mile = 118) density was ‘reference’ and pools were common (Pools/Mile = 24). The stable banks and wide riparian areas in this segment positively influenced the habitat condition (RHA score = “Good”). The frequent debris jams and high woody debris density observed also made the segment geomorphically stable. No major adjustment processes were noted. The segment is in stage I of the F-type channel evolution model (RGA score = “Good”).

R6.S3.02-B

R6.S3.02-B begins at the segment break at the next Route 132 crossing and extends upstream 0.4 miles at an average slope of 2.8%. The valley is semi-confined with extensive human-caused change in the valley width. This segment exhibits B-type morphology with plane bedform. The width-to-depth and entrenchment ratios of the channel are 7.1 and 1.9, respectively. Reference conditions for this segment are likely similar to the downstream reach: C4-type, with riffle-pool bedform and narrow confinement. Incision was observed on this segment (IR = 2.0). The right floodplain of this segment is largely fill; placed there to provide an adequate base for Route 132 (Figure 4.16). The substrate was predominately cobble (48%) and Boulder (29%), with a median substrate size of 170 mm (Cobble). Much of the coarser substrate observed in the pebble count could be sourced from the extensive rip-rap was placed on both the left and right banks to prevent erosion (Figure 4.17).

Figure 4.16 Route 132 fill changing the right valley wall

Figure 4.17 Extensive rip-rapping on the left bank

Route 132 encroaches upon the channel throughout this segment and has significantly impacted both the geomorphic condition and the habitat. The bank and riparian buffer condition is significantly compromised by the rip-rap and the large volume of fill in the corridor. The habitat score is on the cusp of being “Poor” (RHA score = “Fair”). The ability for the channel to attenuate woody debris is diminished because there are fewer sources of mature trees (LWD/Mile = 74) and pools are minimal (Pools/Mile = 10). The high degree of human impacts on this segment have restricted all future planform shifts and widening and the channel is “stuck” in stage II of the CEM (RGA score= “Poor”). The straightening and encroachment also led to a stream type departure from C-type morphology to the current B-type making the transport of sediment downstream more likely.

R6.S3.02-C

R6.S3.02-C begins at the segment break just upstream of the Route 132 crossing near Beaver Meadow Road and extends upstream 0.1 miles to the reach break with R6.S3.03 at the Sunnybrook Trout Farm. The valley is very broad with no human-caused change in the valley width and average slope is approximately 0.9%. This segment exhibits E-type morphology with a width-to-depth and entrenchment ratio of 4.6 and 8.2, respectively. Recent incision was not observed on this segment (IR = 1.0), however evidence of a terrace in the floodplain was noted. The substrate was predominately sand (44%) and gravel (55%), with a median substrate size of 5 mm (Gravel). Bedform is predominately plane bed; however some nice dune-ripple features were observed where the channel was within an area densely covered with WAD species (Figure 4.18). A historic farm crossing remains in the lower segment. This structure is deteriorating and it acts as a constriction to the bankfull and floodprone flows, but a pool feature has scoured out underneath it (Figure 4.19).

Figure 4.18 Dune-ripple feature in area covered by dense WADs

Figure 4.19 Old farm-trail bridge that is deteriorating

The riparian buffer condition is reduced and much of the left corridor was recently used in hay production. Lots of smaller size class woody debris was observed (LWD/Mile = 262) and well-formed undercuts and pools were frequent (Pools/Mile = 159). However, the riparian condition and some connectivity issues in the downstream segment lowered the habitat (RHA score “Fair”). The channel appears to be recovering from historic channel straightening noted from aerial photographs taken in the 1970s. In cross section there appears to be an old terrace of a previously accessible floodplain, because of this feature stage IV of the CEM was chosen (RGA score = “Good”). The planform changes associated with straightening and historic degradation were the only significant adjustments observed.

R6.S3.03-A

R6.S3.03 was segmented because of lack of property access at the Sunnybrook Trout farm, which is surrounded by a large fence to prevent predator species from feeding on the fish (Figure 4.20). The segment is 0.2 miles in length and has a low slope of approximately 0.9%. R6.S3.03-A begins at the reach break at the Trout Farm and ends just downstream of the Route 132 crossing upstream. The valley is very broad with no human-caused change in the valley width. Administrative judgment was used to determine stream type: E-type, dune-bedform, and sand substrate.

Figure 4.20 The channel upstream of segment R6.S3.02-C within Sunnybrook Trout Farm

R6.S3.03-B

Segment R6.S3.03-B begins at the Route 132 crossing and extends up to a change in valley slope and confinement at the upstream reach break. The segment is approximately ½ mile in length, and is set in a very broad valley with a channel slope of approximately 1.7%. The valley width is slightly narrower than would be expected under reference conditions due to road encroachment from Route 132. The cross-section taken in the lower reach indicated E-type channel morphology with bed substrate dominated by sands (48%) and fine gravels (40%). The width-to-depth (WDR = 6.3) and entrenchment (ER = 10.7) ratios reflect the E-type morphology. Buffer conditions and historical impacts differed in the upper and lower segments. In the lower segment, the channel was bordered by dense shrub vegetation, mainly alders (*Alnus sp.*; Figure 4.21), and the planform was moderately sinuous. However, in the upper segment, there was evidence of historical straightening and the channel had a steeper slope with less sinuosity (Figure 4.22). Straightening was noted for approximately 900 feet, and impacts to the buffer and riparian corridor are greatest in middle and upper segment along the west bank.

Figure 4.21 Dense riparian vegetation in the lower segment

Figure 4.22 Straightening and plane bedform in upper segment

Habitat in this segment has been influenced by the impacts to the buffer vegetation, and the limited woody debris cover (LWD/Mile = 38). Although there was a high density of pools (Pools/Mile = 75), a majority of the pools were small. The RHA condition is "Fair." Although historical straightening was noted in the upper reach, no incision was noted in the cross-section. The geomorphic state of this segment is "Good" as no significant evidence of channel instability was observed (CEM stage I).

R6.S3.04-A

Reach R6.S3.04 was segmented because of channel dimensions and slope. R6.S3.04-A begins at the reach break just downstream of the culvert crossing at Highlake Road and ends upstream between a private driveway crossing that extends north off Route 132 and the second-to-last Route 132 Crossing. Valley type in R6.S3.04-A is semi-confined with minor human-caused changes due to road encroachment. The segment is 0.7 miles in length and has an average slope of 5.5%. The channel exhibits B-type channel morphology with a subclass slope rating of a. The substrate is predominately gravel (39%) and cobble (32%) with a median substrate size of 50 mm (Gravel) and step-pool bedform. Some sections of the segment had plane bedform where the slope lessened (Figure 4.23). The width-to-depth and entrenchment ratios are 10.6 and 2.3, respectfully.

Figure 4.23 Plane bed section of channel in upper segment

Two undersized culverts beneath Route 132 were noted, both with widths of 3 feet (23% of bankfull channel width). One of these culverts, found in the upper segment, had recently been armored at the inlet end due to past flood and erosion damage (Figure 4.24). These structures, due to their severe constriction of the channel, will continue to be problematic for channel stability and aquatic organism passage and have been prioritized for replacement in the project identification summary (see Section 5.2.3). Overall, with the exception of isolated instability around these crossings, the channel is stable with no major adjustment processes noted despite significant road encroachment on the corridor. No channel incision was noted in the cross-section, and only a minor increase in fine sediments may be attributable to stormwater runoff from Route 132 (RGA score = "Good"). Habitat was "Good" for the segment, with a high degree of wood inputs (LWD/mile = 161) and good pool formation (Pools/mile = 43). Moderate impacts to the buffer vegetation reduced the habitat condition slightly.

Figure 4.24 Armoring upstream of an undersized culvert (Rt. 132)

R6.S3.04-B

R6.S3.04-B is the final assessed segment of Quation Brook. This segment begins just downstream of the second-to-last crossing of Route 132 and extends up into the wetland area north of Cross Road. In total, the segment is 0.6 miles in length and has an average slope of approximately 2.8%. The valley setting of R6.S3.04-B is very broad, with no significant human-caused change to the valley width. The channel is E-type by reference, with a subclass slope of b. The width-to-depth (WDR = 10.4) and entrenchment (ER = 6.8) ratios reflect the E-type morphology observed in this segment (Figure 4.25). The bedform is riffle-pool and substrate is predominately gravel (58%) with a median substrate size of 50 mm (Gravel). The culvert at the Cross Road crossing is problematic (Figure 4.26). The culvert is undersized and partially collapsing, the upstream end of the structure is deteriorated and the road is eroding down into the channel. This structure has a high priority for replacement because of structural reasons and fish passage issues.


Figure 4.25 E-type channel with nice woody debris cover


Figure 4.26 Deteriorated outlet of the Cross Road culvert

Habitat in this segment has been negatively influenced largely by the high number of channel crossings as well as the limited availability of woody debris cover and scour and depositional features (LWD/Mile = 38; Pools/Mile = 14). The connectivity in this segment been compromised by the severely damaged Cross Road culvert, and several other system obstructions located downstream. The RHA condition is “Fair.” The geomorphic state of this segment is “Good” and the overall condition would improve if the Cross Road crossing was replaced. The channel is stable and in stage I of the CEM.

Fay Brook Reaches (R7.S1.01 – R7.S1.04)

R7.S1.01-A

Reach R7.S1.01 was segmented because of channel dimensions and confinement changes. R7.S1.01-A begins at the confluence with the main stem of the White River and it extends upstream 0.2 miles, ending just downstream of a large dam. This segment is C-type by reference with riffle-pool bedform (Figure 4.27). The valley is broad with minor human-caused change in channel confinement; the channel has an average slope of approximately 1.8%. The width-to-depth ratio and entrenchment ratios are 10.8 and 6.0, respectively. The WDR is low, but still within the confidence intervals of the Rosgen stream typing protocols. This segment has a high degree of incision, but no stream type departure (IR = 1.9). The substrate is predominately cobble (30%) and sand (25%) in R7.S1.01-A, with a median substrate size of 28 mm (Gravel). The bimodal distribution of sediment and excess sand is likely sourced from the banks, which were eroding through much of the segment. A length of the segment, mid-reach, approximately 150 feet long has been cleared of tree cover. There, the trees that were growing along the valley wall adjacent to the brook were felled into the channel (Figure 4.28). This area could become problematic in the future, both for bank and side slope stability.

Figure 4.27 Cross-section location looking upstream

Figure 4.28 Trees felled from valley wall adjacent to the channel

Large woody debris is abundant in this segment (LWD/Mile = 607), although some of the pieces were from the area where trees were cut down along the bank. Downstream where a large debris jam exists dozens of large limbs and trunk stock exists that provide habitat and sediment attenuation. Pools are also extensive (Pools/Mile = 117). However, the fair scores given to both banks and buffers and hydrologic characteristics lowered the over habitat condition (RHA score = “Fair”). The geomorphic state of the segment seems to be transitioning and is now in stage III of the CEM (RGA score = “Fair”). The channel has not yet widened, but degradation has ceased and bank erosion is prevalent. Widening and shifts in planform are likely to be the dominant adjustment processes in the future. Historic channel straightening is present and much of the channel is up against the valley wall.

R7.S1.01-B

Segment R7.S1.01-B begins downstream of the large dam at the series of grade controls and ends at the change in slope and confinement at the reach break upstream. The segment is 1.2 miles long and has an average channel slope of approximately 3.2%. The valley is semi-confined with human-caused changes to the valley width. By reference, given the slope and valley characteristics, the bedform would likely be step-pool. However, the changes in the valley width from the encroachments have caused the channel bedform to change to plane bed, while the B-type channel morphology remains (Figure 4.29). The width-to-depth ratio and entrenchment ratios are 11.8 and 2.0, respectively. A moderate degree of incision was observed (IR = 1.4). The substrate is predominately boulder (39%) and cobble (30%), with a median substrate size of 205 mm (Cobble). The dam located downstream of the high-spanning Interstate-89 crossing has a penstock indicative of power generation, but the current use of this structure is not known (Figure 4.30). The structure is aggrading sediment upstream in an area that was straightened under the Interstate.

Figure 4.29 Cross-section location looking downstream

Figure 4.30 Large dam upstream of the segment break

The departure from a step-pool system to a plane bed system reduced the large woody debris attenuation potential (LWD/Mile = 74). Encroachments, straightening, armoring and areas where vegetation has been reduced have contributed to reduced quality habitat and the total density of pools (Pools/Mile = 15; RHA score = “Fair”). Channel incision was present in areas that were not stabilized vertically by bedrock outcrops and the CEM stage reflects that incision (CEM stage = II). Geomorphic adjustments were predominately observed as areas degradation (incision) or as areas where the planform has historically been altered by channel encroachment (RGA score = “Fair”).

R7.S1.02-A

Reach R7.S1.02 was segmented three times because of channel dimensions and valley width. The first segment, R7.S1.02-A, is 0.6 miles in length with an average channel slope of approximately 1.4%. The segment begins at the change in confinement at the reach break and ends where the valley widens at the horse pasture on the east side of the channel. The valley is of narrow confinement and there is no human-caused change to the valley width. Segment R7.S1.02-A exhibits C-type morphology with riffle-pool bedform (Figure 4.31). The width-to-depth and entrenchment ratios are 12.9 and 2.6, respectively. The floodplain in this segment was accessible throughout, with no incision (IR = 1.0; Figure 4.32). Substrate in the segment is predominately cobble (46%) and gravel (31%), with a median substrate size of 87.5 mm (Cobble).

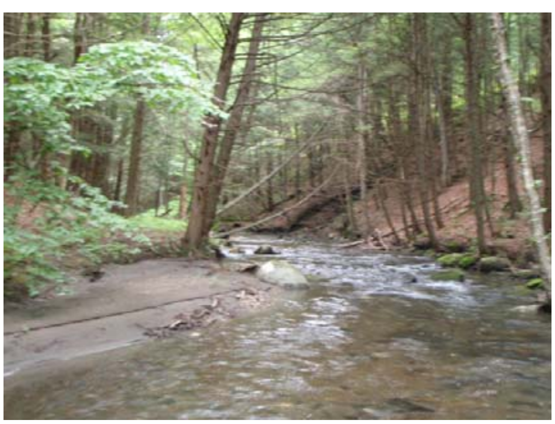

Figure 4.31 Well formed riffle-pool bedform

Figure 4.32 Accessible floodplain at the cross-section location

The majority of segment R7.S1.02-A has well-formed riffle-pool sequences, however, where the channel becomes slightly more confined by the valley the riffles become less defined, taking on a plane bedform. In the lower segment two stream crossings and two stream fords were observed; these features have had a minor impact on the riffle-pool formation in that stretch of the segment. Well-developed habitat features like undercut banks and refuge areas were most commonly found where the riffle pool sequences where well-formed. Woody debris density was reference (LWD/Mile = 155) and pools were abundant (Pools/Mile = 28). Some embeddedness was observed, which slightly influenced the bed substrate cover score and overall habitat condition (RHA score = "Good"). The lack of incision and occurrence of complete riffle formation were indicative of a stable segment (CEM stage = I; F-model). Only minor adjustments in channel planform in lower segment were observed (RGA score = "Good").

R7.S1.02-B

Segment R7.S1.02-B was segmented out because channel and valley dimensions differed from the downstream segment. The valley confinement is broad with no human-caused changes to the valley width. Segment R7.S1.02-B begins at the break near the horse pasture to the east and extends upstream 0.8 miles until the slope changes dramatically about 500 feet downstream of the Fay Brook Road Crossing. Segment R7.S1.02-B exhibits C-type channel morphology, with a subclass channel slope of b (2.3%). Width-to-depth and entrenchment ratios are 13.3 and 2.6, respectively. This segment has recently degraded and the floodplain is elevated slightly above the bed (IR = 1.3). Riffle-pool bed features have eroded with degradation and now plane bedform is dominant. Bed substrate is predominately gravel (27%) and cobble (34%) with a median particle size of 67.5 mm (Cobble). Where the segment begins at the horse pasture to the east, much of the buffer width is less than 25 feet on both sides of the channel. Two animal crossings were noted that provide access to the pasture area. Rip-rap was added at these locations to stabilize the banks up and downstream of the crossings (Figure 4.33). West of the channel upstream of the horse pasture area the corridor is used for hay production. This channel was likely straightened here to provide a more contiguous field area. The channel incision is most notable in the pasture and field area, yet the banks appear to be stable (Figure 4.34).

Figure 4.33 Stream animal crossing (rip-rap upstream)

Figure 4.34 Cross-section location in straightened area

The habitat condition has been influenced by the channel bedform departure from riffle-pool to plane bed (RHA score = "Fair"). The riffles have eroded when the stream incised and their spacing is 13 times that of the bankfull channel width. Pool density has reduced because of the incision scouring away bed features (Pools/Mile = 24), but large woody debris density remains reference (LWD/Mile = 142). The incision and planform change associated with channel straightening has been the main cause of a reduced geomorphic condition (RGA score = “Fair”) and the channel is in stage II of the CEM. Where the channel is experiencing some migration features, mid-segment, channel evolution stage might be transitioning into stage III of the CEM.

R7.S1.02-C

Segment R7.S1.02-C was segmented out because channel dimensions and slope differ from the downstream segment. The valley confinement is narrowly confined with significant human-caused changes to the valley width. The segment is 0.1 miles in length. It begins at the break in slope about 500 feet downstream of the Fay Brook Road Crossing and ends approximately 100 feet upstream of the crossing. Segment R7.S1.02-C exhibits G-type channel morphology, with an average channel slope of 3.9% (Figure 4.35). Width-to-depth and entrenchment ratios are 10.0 and 1.3, respectively. The channel has undergone significant historic degradation and now much of the segment is armored with rip-rap (IR = 2.4). By reference this segment should have step-pool bedform; however the degradation and subsequent armoring has caused plane bed morphology to dominate. Bed substrate is predominately boulder (33%) and cobble (32%) with a median particle size of 107.5 mm (Cobble). In addition to the armoring throughout the segment, much of the riparian buffer has a width which is less than 25 feet and development is common (Figure 4.36).

Figure 4.35 Cross-section location looking upstream

Figure 4.36 Low buffer width, rip-rap and corridor development

The reduced bank and buffer conditions, channel morphology, and hydrologic characteristics have led to a major departure in stream habitat condition (RHA score = “Fair”). The limited bank vegetation reduced the potential future sources of woody debris, but the current density is ‘good’ (LWD/Mile = 141). Pool formation has been reduced because of the bedform change from step-pool to plane bed (Pools/Mile = 33). The geomorphic condition of this reach has been compromised because of the channel degradation and impacts to the planform (RGA score = “Fair”). The segment is in stage II of the CEM because of the impacts to the channel planform through armoring. It is likely that the segment will remain in stage II of the CEM in the foreseeable future.

R7.S1.03-A

Reach R7.S1.03 was parsed into two segments because of changes in channel and valley dimensions. The valley wall in the first segment oscillates in and out from a semi-confined to a narrow setting, but the dominant width is that of a semi-confined setting. The cross-section location was chosen as a best representation of the overall channel dimensions with a valley width that is semi-confined. Segment R7.S1.03-A begins at the reach break just upstream of the Fay Brook Road crossing and extends upstream 0.9 miles ending where the valley wall broadens considerably. The channel has an average channel slope of approximately 2.8% and exhibits B-type morphology (Figure 4.37). The width-to-depth (WDR = 13.7) and entrenchment (ER = 2.2) ratios are indicative of the assigned stream type. Major incision was observed on this segment (IR = 1.6). By reference the bedform would most likely be step-pool, however, changes in channel processes associated with the encroachment of Fay Brook Road has led to a current bedform of plane bed. The substrate in this segment is predominately cobble (41%) and gravel (36%) with a median particle size of 65.0 mm (Cobble).

Figure 4.37 Segment R7.S1.03-A cross-section location looking upstream

Mid-segment, where the tributary enters from the east, the valley is semi-confined with extremely steep side slopes. Just upstream of this tributary two historic mill foundations that are failing seem to be trapping sediment upstream and downstream (Figure 4.38). This area also is predominately shrubby along the banks and the lack of tree cover could be attributed to past anthropogenic impacts. The habitat condition of this segment was influenced by the channel morphology and the stream habitat departure from step-pool to plane bed (RHA score = "Fair"). Woody debris density was good (LWD/Mile = 115) and pool density was fair (Pools/Mile = 35). Historic degradation and planform changes were dominant adjustment processes observed, most of which were associated with the encroachment of Fay Brook Road, or with the old mill foundations (RGA score = "Fair"). Some excess sediment from those structures is still working its way through the segment and the bar and migration features from the excess sediment has led to stage III of the CEM.

Figure 4.38 Historic mill structure that is influencing the sediment dynamics of the upper segment

R7.S1.03-B

Segment R7.S1.03-B is a short segment, 0.2 miles in length. R7.S1.03-B begins at the change in confinement from semi-confined to very broad and ends at the reach break with R7.S1.04-A, about 200 feet downstream of the driveway crossing off Fay Brook Road. There is no human caused change to the valley width in this reach and the average channel slope is approximately 1.6%. The channel exhibits C-type channel morphology with width-to-depth and entrenchment ratios of 15.6 and 2.9, respectfully (Figure 4.39). This segment has been largely straightened, and is incised as a result (IR = 1.8). Substrate is predominately gravel (69%) with a median particle size of 37.5 mm (Gravel). The bedform is riffle-pool; however, many of the riffles are sedimented, especially in the upper segment where the channel is not re-developing sinuosity (Figure 4.40)

Figure 4.39 Cross-section location looking upstream

Figure 4.40 Meander bed with riffle-pool sequence and point bar

The hay fields in the corridor and agricultural land use are responsible for decreasing the bank stability and reducing the riparian buffer width. Both right and left riparian areas have reduced canopy density and are now primarily grasses. The altered channel morphology also compromised habitat condition (RHA score = "Fair"). The substrate is gravely and only small areas of erosion were observed on the outside of meander bends. The WAD bank vegetation seemed to stabilize the channel boundaries with the floodplain. Woody debris density is very high in this segment, but the size-rank of the pieces was small (LWD/mile = 336). Pools were also abundant (Pools/Mile = 65). The geomorphic condition of this segment is "Fair." The instability in R7.S1.03-B is the result of past land use: adjustments in planform are occurring, particularly the redevelopment of sinuosity after historical straightening and incision. Currently sediment is aggrading, possibly from upstream bank erosion. Widening is likely to occur in the future as the segment is in early stage III of the CEM due to the aggradation and migration features.

R7.S1.04-A

The final reach of Fay brook is long (3.1 miles) and highly variable in form and setting. The reach was segmented four times to try to best represent the many unique settings observed. The first segment, R7.S1.04-A, begins at the reach break with R7.S1.03-B near the driveway crossing off Fay Brook Road approximately 1,600 feet due south of the intersection of Blake Hill Road and Fay Brook Road. R7.S1.04-A is 0.4 miles in length and has an average slope of approximately 1.4%. The valley setting is broad with human caused change to the valley width. The channel exhibits B-type morphology with a subclass slope of c and plane bedform (Figure 4.41). The width-to-depth and entrenchment ratios are 12.0 and 2.0, respectfully. Incision observed in straightened areas was far worse than it was in areas with no straightening (IR = 1.8). The current stream type is a departure from reference conditions of C-type with riffle-pool bedform, because much of the segment has been straightened and floodplain access has been reduced. Substrate in this segment is mostly gravel (32%) and cobble (36%) with a median particle size of 65.0 mm (cobble). In addition to the channel straightening, this segment has a high degree of development in the corridor as well as encroachments from Fay Brook Road and low buffer widths (Figure 4.42).

Figure 4.41 Cross-section location looking upstream

Figure 4.42. Low buffer width with development in the corridor

The habitat condition reflects the negative impacts to the bank and buffer conditions, channel morphology and scour and deposition features (RHA score = "Fair"). Woody debris is limited because of lack of the lack of trees on the near bank over much of the reach

(LWD/Mile = 87). Pools were scarce in this segment (Pools/Mile = 12). The stream type departure in this segment from C to B-type morphology has been driven by degradation caused by the past straightening of the channel (RGA score = "Fair"). Since no major aggradation was observed and the formation of bar features was limited the channel remains in stage II of the CEM.

R7.S1.04-B

Segment R7.S1.04-B begins at the change in confinement at the segment break and ends upstream where the channel is adjacent to the footing of Fay Brook Road. The segment is 0.4 miles in length and has an average channel slope of approximately 2.8%. The natural confinement is on the cusp between semi-confined and narrow; human caused changes in valley width have had only minor influences on the confinement setting for the whole segment. Approximately 68% of the valley walls along the road would be the same in phase 1, so the semi-confined setting is more appropriate. The existing valley setting of this segment is also semi-confined with some human caused change to the valley width in the upper and lower segment, where Fay Brook Road encroaches upon the channel. The stream type is C with a subclass slope of b, and the dominant bedform is plane bed. The width-to-depth and entrenchment ratios are 15.2 and 2.6, respectfully, and moderate incision was observed (IR = 1.4). The current bedform represents a departure from the reference bedform type of riffle-pool. The reference bedform and stream type are unusual given the confined setting of this segment, but the meandering profile in the confined valley appeared to be natural (Figure 4.43). Substrate in this segment was predominately cobble (48%) and gravel (26%) with a median particle size of 85.0 mm (Cobble). A driveway crossing located mid-segment is squashed by the road above it and in poor condition (Figure 4.44). Not only is the culvert perched, but also its capacity is undersized for bankfull flow events and sediment has aggraded upstream. Dredging pilings were observed upstream on both banks, indicating this problem is reoccurring. A large plunge-pool has formed downstream and the channel has widened and the perched outlet is problematic for aquatic organism passage.

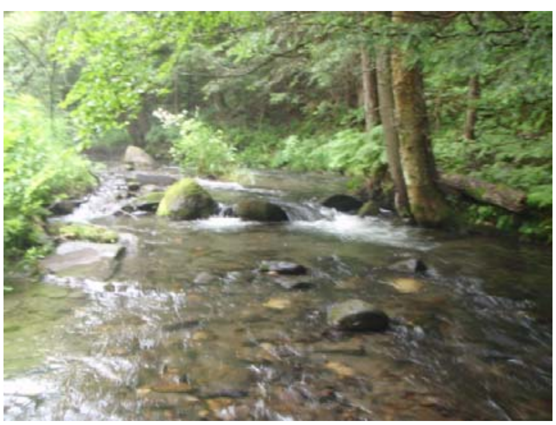

Figure 4.43 Cross-section location looking upstream

Figure 4.44 Squashed driveway crossing and dredging site

The connectivity issues of the culvert located mid-segment, as well as the decreased riparian area on both sides of the channel have contributed to the reduced habitat condition of this segment (RHA = "Fair"). Woody debris and pools were common (LWD/Mile = 124; Pool/Mile = 34). The channel shows some incision in the upper and lower segment. Also, planform shifts were noted as a result of the road encroachment. The overall geomorphic score is "Fair" and the channel is in stage II of the CEM.

R7.S1.04-C

R7.A1.04-C was segmented because of differences in valley width and channel dimensions. The segment begins just upstream of the large grade control where the channel is adjacent Fay Brook Road and extends upstream for 0.5 miles, ending just upstream of the Brook Road crossing. The channel has an average slope of approximately 1.2% and the valley setting is very broad with human caused change to the valley width. The channel exhibits E-type morphology with plane bedform. By reference the bedform would most likely be riffle-pool, however, much of the segment has been straightened and encroached upon, reducing the sinuosity and subsequently removing natural riffle-pool sequences. The substrate in R7.S1.04-C is almost entirely gravel (77%), with a median particle size is 10 mm.

Channel geometry is consistent with the stream type designation; the width-to-depth entrenchment ratios are 4.9 and 26.5, respectfully. The low bankfull width (and WDR) is common with E-type channels, especially when the near banks are dense with WAD and herbaceous cover (Figure 4.45). The dense WAD cover also helped stabilize the banks and no incision was observed in this segment (IR = 1.0). The upper end of this segment had a temporary grazing area for a large bull (Figure 4.46). Fencing livestock away from this section of the channel would improve long-term stability and overall health of this reach.

Figure 4.45 E-type channel with WAD and herbaceous cover

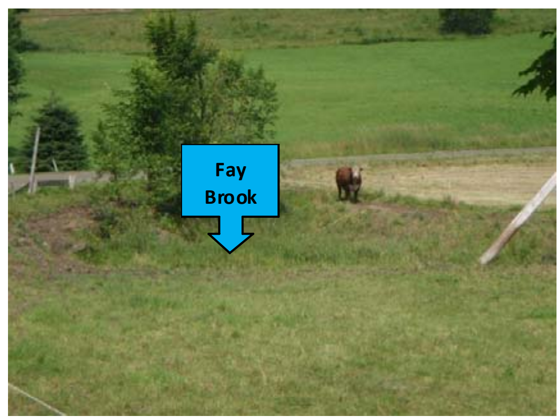

Figure 4.46 Large bull that grazes in and around the channel

The reduced riparian buffer area due to the agricultural corridor land use and issues resulting from channel straightening has lowered the overall habitat condition (RHA score = "Fair") Woody debris is predominately in the small size rank classes, but common (LWD/Mile = 85) as were pools (Pools/Mile = 32). The channel straightening has not seemed to trigger adjustment processes in the channel; its low slope and the vegetation cover of the segment prevented successive channel adjustments and incision (CEM stage = I). Erosion was observed only where herbaceous species were established on the banks. The overall geomorphic condition was "Good."

R7.S1.04-D

R7.S1.04-D begins near the intersection of Brook Road with Robinson Road and ends in the open pasture where cattle are grazed 0.6 miles upstream. This segment was broken out because of channel dimensions and lack of property access upstream. The confinement is narrow with human caused change in the valley width in the lower reach near the Round Farm complex where the channel has been straightened and encroached upon (Figure 4.47). R7.S1.04-D is a C-type channel with an average slope of approximately 1.8% (Figure 4.48). The channel geometry is consistent to the stream type with a width-to-depth ratio of 12.2 and an entrenchment ratio of 2.6. Slight degradation was observed in this segment, but the incision was not problematic to the stability of the channel (IR = 1.2). Bedform was predominately riffle-pool, however in the short straightened section the bedform was plane bed. Substrate was largely cobble (34%) and Gravel (35%) with a median particle size of 42.5 mm (Gravel).

Figure 4.47 Encroached/straightened area in lower segment

Figure 4.48 Well-formed C-type channel with riffle-pool bedform

The upstream and downstream ends of this segment have problems associated with anthropogenic impacts. The downstream end of the channel is encroached upon by Robinson Road, has low buffer width, and livestock grazing in the channel. The upstream end of segment has a much lower slope and a beaver dam was observed about 200 feet downstream of the segment break with R7.S1.04-E where cattle are grazing in the channel. These two areas only make up a small portion of the total segment length and the majority of the channel is well formed and stable as pictured above. The woody debris density is 'reference' (LWD/Mile = 113) and the pool density is 'good' (Pools/Mile = 21), improving the overall habitat condition (RHA score = "Good"). The geomorphic condition is largely stable (RGA score = "Good"). No one adjustment process seems to be negatively impacting the overall condition and the channel is in stage I of the CEM.

R7.S1.04-E

R7.S1.04-E was segmented because of lack of property access; the segment is fenced in and cattle were grazing at the time of assessment (Figure 4.49). The segment is 0.5 miles in length and has a low slope of approximately 0.9%. R7.S1.04-E begins at the segment break in the large field east of Robinson Road and ends about 100 feet downstream of the Robinson Road crossing. The valley is very broad with no human-caused change in the valley width.

Administrative judgment was used to determine stream type: E-type, dune-bedform, and sand substrate (Figure 4.50).

Figure 4.49 Cattle grazing in and around the channel

Figure 4.50 E-type channel upstream of segment R7.S1.04-D

R7.S1.04-F

The final segment of Fay Brook begins at the segment break and extends 0.6 miles upstream, ending at the Kratky Dam. The segment has an average slope of approximately 3.8% with most slope change occurring at grade controls. The valley is narrow with human-caused change in valley width in the lower segment where the channel parallels Robinson Road for about 600 feet. The channel exhibits C-type morphology with a subclass slope of b. The width-to-depth (WDR = 13.1) and entrenchment (ER = 2.7) ratios are both consistent with the stream type designation. Incision was not observed on this segment (IR = 1.0). Bedform was predominately riffle-pool, but in areas with many grade controls and elevation change step-pool bedform was also observed. Substrate was mostly cobble (27%) and gravel (42%) with a median substrate size of 10 mm (Gravel). The segment had two large waterfalls that were responsible for about 30 feet of elevation change (Figure 4.51). The Kratky Dam, which marks the end of reach R7.S1.04, was not included in the grade control listing of the reach, but the head of water above the outlet is approximately 20 feet (Figure 4.52). The dam was built for recreational purposes and acts as a large run-of-the river flow regulation.

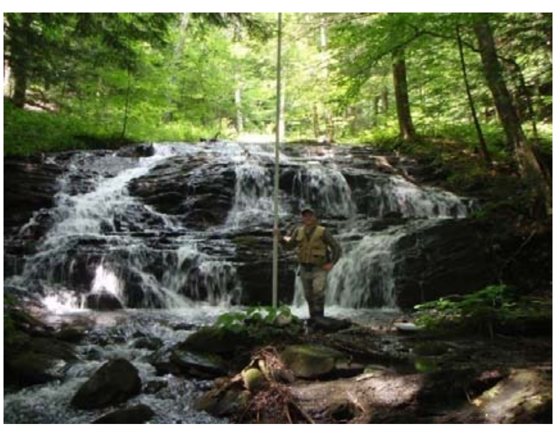

Figure 4.51 Waterfall: total height =18ft; height above water =17ft

Figure 4.52 Reservoir upstream of the Kratky Dam

The downstream end of this segment below the Robinson Road crossing is impacted by the road encroachment. This area is quite different than the upstream portion of the segment where the habitat is near-reference with abundant wood, pools, and undercuts. This area was not segmented out because of its length and its sensitivity would be similar to that of the entire segment. The overall score decreased slightly because of the influence of the road encroachment on the bank and buffer vegetation (RHA score = "Good"). The woody debris density is 'reference' (LWD/Mile = 198) and the pool density is 'good' (Pools/Mile = 35). Upstream of the second Robinson Road crossing the stream has an excellent meandering profile and a unique stream type where riffle-pool features occur between large cascades at bedrock ledges. The lower segment has some straightening, encroachment, and buffer less than 25 feet. These impacts lowered the geomorphic score slightly, because the upper segment is well buffered and in such stable condition (RGA score = "Good").

Elmers Brook Reaches (R7.S2.01 – R7.S2.02)

R7.S2.01-A

Elmers Brook reach R7.S2.01 was segmented because of channel dimensions and slope changes between the two segments. Segment R7.S2.01-A begins at the confluence with the main stem of the White River and extends upstream 0.9 miles ending where the confinement and slope changes at a farm crossing downstream of an auto salvage yard. The valley is semi-confined, with no human caused change in the valley width. R7.S2.01-A is a B-type channel with a slope of 4.3%. The width-to-depth and entrenchment ratios are 13.4 and 2.0, respectfully. No incision was observed on this segment (IR = 1.0). Given the steep slope the bedform is step-pool, however, upstream of the Central Vermont Railroad crossing the channel slope is lower and the bedform is riffle-pool. This section is only about 300 feet in length so no further segmentation was done. Substrate is predominately cobble (29%) and gravel (41%) with a median substrate size of 38.0 mm (Gravel).

This segment presents numerous restoration opportunities that have been summarized in Section 5 of this report. The culvert crossing of Route 14 is perched and replacing it or modifying it would greatly improve fish passage from the main stem up into the tributary (Figure 4.53). Also, the habitat downstream of the Sharon Meadows Road crossing is excellent and this area would be ideal for conservation (Figure 4.54).

Figure 4.53 A perched culvert at the Route 14 crossing

Figure 4.54 Potential conservation area

With the exception of a small area around the Central Vermont Railroad crossing, this segment has a diverse array of habitat features and many small brook trout were observed in the field. The habitat condition was negatively impacted by the connectivity score, which was lowered because of the perched culvert at Route 14 (RHA score “Good”). Woody debris was abundant (LWD/Mile = 235) and pools were common (Pools/Mile = 44). Some minor aggradation and planform shifts upstream of the railroad culvert slightly impacted the geomorphic condition, but the segment is largely stable (RGA score = “Good”). The well-buffered channel is in stage I of the CEM.

R7.S2.01-B

R7.S2.01-B is a highly sinuous segment that begins at the change in confinement at a farm crossing downstream of the auto salvage yard and ends at the reach break with R7.S2.02 downstream of the Moore Road culvert crossing. The segment is 0.5 miles in length and has an average slope of approximately 1.9%. The valley setting is broad with no human caused change to the valley width. The channel exhibits C-type morphology with riffle-pool bedform and high sinuosity (Figure 4.55). Channel geometry is consistent with the stream type designation and no incision was observed (WDR = 10.8; ER = 3.7; IR = 1.0). The width-depth ratio is on the cusp between E and C-type channels; however the cross-section was taken at a point where the channel was slightly narrower than the average width throughout. The substrate in R7.S2.01-B is mostly comprised of gravel-sized (47%) and cobble-sized (35%) particles and the median substrate size is 50.0 mm (Gravel).

Figure 4.55 Cross-section looking upstream; C-type morphology and riffle-pool bedform

This segment has excellent bank condition and, with the exception of one crossing by the auto salvage yard, has excellent riparian buffer condition as well. Well-formed riffle-pool sequences, the abundance of woody debris and pools (LWD/Mile = 172; Pools/Mile = 49) makes for excellent habitat throughout (RHA score = "Reference"). Several debris jams provided great habitat in the pools that formed below them (Figure 4.56). The geomorphic condition is stable (RGA score = "Good"). However, evidence of past terraces suggests that this reach has recently reestablished dynamic equilibrium following disturbance. Stage V of the channel evolution model best describes the state of this segment.

Figure 4.56 Debris jam with covered pool habitat feature downstream

R7.S2.02

Reach R7.S2.02 begins about 750 feet downstream of the crossing with Moore Road and ends where the channel splits into two equally-sized tributaries about 50 feet east of Maverick Farm Road. The reach is 1.0 mile in length and has an average channel slope of approximately 2.6%. The valley confinement is broad with no human caused change to the valley width. R7.S2.02 exhibits C-type morphology with a subclass slope of b. The width-to-depth and entrenchment ratios of the channel are 12.8 and 3.8, respectively. Channel degradation and straightening were observed on this reach with a moderate to high level of incision (IR = 1.6). The dominant bedform in R7.S2.02 was riffle-pool; however, some areas that were straightened had plane bed morphology. The reach had a substrate that was predominately cobble (51%) and gravel (38%) with a median particle size of 65.0 mm (Cobble).

The banks and buffers on the right side of the channel were usually well vegetated and wide, but the left buffer area had some areas that were less than 25 feet wide where the corridor was used for hay fields. The density of woody debris was 'reference' (LWD/Mile = 118) and the pool density was at the upper end of 'good' (Pools/Mile = 48). Debris jams and other snags that have fallen down into the channel made for good habitat throughout the reach (RHA score = "Good;" Figure 4.57). In the upper reach some dredging was noted (Figure 4.58). There, the channel was manipulated to create a series of swimming holes for the nearby landowners. Large piles of sediment about 3 feet high were observed on the banks on either sides of the channel downstream of the pools. The presence of dredging, straightening, and incision in this reach reduced the overall geomorphic condition (RGA score = "Fair"). Currently, the reach is in stage II of the CEM because limited widening has occurred.

Figure 4.57 Debris jam, with pool feature downstream

Figure 4.58 Area dredged to make a swimming hole

Broad Brook Reach (T2.01)

T2.01-A

Broad Brook is the second significantly sized tributary that drains into the White River. Reach T2.01 was segmented because of channel dimensions and valley width. The first segment, T2.01-A begins at the confluence with the main stem of the White River and ends just upstream of the Broad Brook Road bridge crossing. Valley dimensions in this segment are broad, with human caused changes to the valley width. The segment is 0.8 mile long and has an average channel slope of approximately 0.8%. T2.01-A exhibits C-type channel morphology with plane bedform (Figure 4.59). The current bedform represents a departure from reference bedform, which would be riffle-pool. Channel geometry is consistent with the stream typing (WDR = 15.9; ER = 2.5). Upstream of the Interstate-89 crossing the reach has been straightened and pushed up against the valley wall. There, a moderate degree of incision was observed (IR = 1.6). Substrate is dominated by cobble-sized particles (69%) with a median size of 130 mm (Cobble).

Figure 4.59 Cross-section location looking downstream

This segment has been largely impacted by the two culvert crossings, as well as historic channel straightening. The departure from a riffle-pool bedform setting to a plane bed has reduced the total density of pools (Pools/Mile = 14). Also, the poor riparian buffer condition on the right bank and the transport nature of the plane bed system reduced the channels potential to attenuate large woody debris (LWD/Mile = 45). The overall habitat condition was also impacted negatively by the channel morphology and geomorphic condition (RHA score = “Fair”). Geomorphically, this reach had several adjustment processes present. In the lower segment, between River Road and Interstate-89, the alignment of the culvert has caused the channel downstream to change its planform significantly (Figure 4.60). Since the culvert has a higher slope than the channel and the stream power is concentrated a large plunge pool has formed downstream that exceeds 8 feet of depth (Figure 4.61). The alignment of the culvert is toward the intersection of Broad Brook Road and River Road instead of toward the River Road Culvert. Over time it has slowly eroded the north side slope of the valley, and may pose a serious threat to the first house on Broad Brook Road in the future. This major migration feature and the bars associated with it are indicative of stage III of the CEM. The incision upstream also lowered the overall geomorphic score and makes this segment unstable (RGA score = “Fair”).

Figure 4.60. Channel migration observed over the last 34 years

Figure 4.61 Misaligned I-89 culvert with large plunge pool

T2.01-B

Segment T2.01-B begins just upstream of the first channel crossing of Broad Brook Road and ends approximately 1,000 feet upstream of the second Broad Brook Road Crossing. The segment is 1.0 mile in length and has an average channel slope of 2.7%. The valley in this segment is semi-confined with some human caused change to the valley width. T2.01-B exhibits B-type channel morphology with a reference bedform type of plane bed (Figure 4.62). Some minor widening of the channel was observed (WDR =22.8; Figure 4.63). The channel is entrenched (ER = 1.4) and no incision was observed (IR = 1.0). This reach had predominately cobble (43%) and boulder (30%) substrate with a median particle size of 140mm (Cobble).

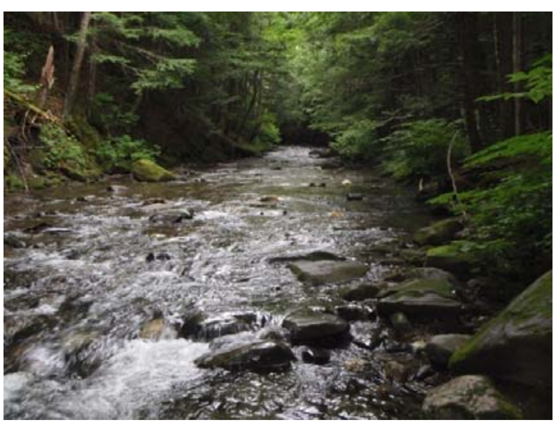

Figure 4.62 Typical plane bedform observed in T2.01-B

Figure 4.63 Widened channel in lower segment

Being plane bed by reference, this segment had moderate attenuation potential of woody debris and the density of wood was ‘reference’ (LWD/Mile = 68). Pools were predominately in the larger size classes and were often found at bedrock outcrops (Pools/Mile = 27). The banks and buffers were generally stable and adequately sized, except in the upper segment where the road encroached upon the left corridor and a hay field was in the right buffer upstream of the crossing (RHA score = "Good"). Overall, this plane bed channel is stable geomorphically (RGA score = "Good"). Only minor changes in planform associated with the road encroachment negatively impacted the condition. The channel has not undergone any recent channel evolution and is in stage I, (F-model).

Table 4.1 RHA and RGA scores for phase 2 assessed segments

Stream Name	Reach/ Segment ID	RHA Score	RHA Condition	RGA Score	RGA Condition
Lower White River	R04B	63%	Fair	73%	Good
	R05	57%	Fair	50%	Fair
	R06	61%	Fair	48%	Fair
	R07	58%	Fair	53%	Fair
Quation Brook	R6-S3.01	61%	Fair	58%	Fair
	R6-S3.02A	66%	Good	66%	Good
	R6-S3.02B	35%	Fair	34%	Poor
	R6-S3.02C	60%	Fair	66%	Good
	R6-S3.03A*	NA	NA	NA	Fair
	R6-S3.03B	56%	Fair	74%	Good
	R6-S3.04A	68%	Good	70%	Good
	R6-S3.04B	54%	Fair	68%	Good
Fay Brook	R7-S1.01A	61%	Fair	50%	Fair
	R7-S1.01B	44%	Fair	55%	Fair
	R7-S1.02A	69%	Good	66%	Good
	R7-S1.02B	56%	Fair	55%	Fair
	R7-S1.02C	39%	Fair	41%	Fair
	R7-S1.03A	51%	Fair	56%	Fair
	R7-S1.03B	59%	Fair	56%	Fair
	R7-S1.04A	50%	Fair	58%	Fair
	R7-S1.04B	58%	Fair	56%	Fair
	R7-S1.04C	56%	Fair	66%	Good
	R7-S1.04D	67%	Good	71%	Good
	R7-S1.04E*	NA	NA	NA	Fair
	R7-S1.04F	68%	Good	70%	Good
Elmers Brook	R7-S2.01A	68%	Good	66%	Good
	R7-S2.01B	86%	Reference	79%	Good
	R7-S2.02	66%	Good	64%	Fair
Broad Brook	T2.01A	58%	Fair	50%	Fair
	T2.01B	66%	Good	70%	Good

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

4.2 River Corridor Planning

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

4.2.1 Stressor Maps

Land Use

The White River watershed contains a mixture of land cover types (Table 4.2; NOAA, 2008), including significant amounts of forest cover throughout. The entire upslope watershed is currently 84% forested, with approximately 10% covered by agricultural lands. Lands classified as scrub/shrub are typically in transition from old field to forest, and cover 3.1% of the watershed. Developed lands (including road corridors) occupy only 1.6% of the watershed, with lesser amounts occupied by wetlands (1%) and open water (0.3%). Land use distribution is quite consistent across the individual tributary watersheds in Sharon. The relative area covered by agriculture varies slightly, with the highest percentages found in the Broad Brook watershed (14.2%) and the lowest percentages found in the Quation Brook watershed (7.6%). Developed lands represent less than 1% of each tributary watershed.

Table 4.2 2006 NOAA Land Cover data for the entire White River watershed and the assessed tributaries

Land Cover Type	Quation Brook (R6.S3)	Fay Brook (R7.S1)	Elmers Brook (R7.S2)	Broad Brook (T2)	Entire Watershed
Agriculture	7.6%	8.9%	12.1%	14.2%	9.7%
Development	1.0%	0.8%	0.1%	0.7%	1.6%
Forest	87.5%	87.2%	85.2%	80.7%	84.3%
Open Water	0.6%	0.3%	0.0%	0.0%	0.3%
Scrub/Shrub	2.3%	2.3%	2.2%	3.8%	3.1%
Wetland	1.0%	0.5%	0.3%	0.6%	1.0%

Hydrologic Regime Stressors

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

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

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

When the hydrologic regime has been significantly altered, stream channels will respond by undergoing a series of channel adjustments. Where hydrologic modifications are persistent, the impacted stream will adjust morphologically (e.g., enlarging when stormwater peaks are consistently higher) and often result in significant changes in sediment loading and channel adjustments in downstream reaches. The current day stressors to the hydrologic regime have been mapped using the variables extracted from the Phase 2 field dataset, watershed-scale loss of wetlands, and density of the road network within each subwatershed. Wetland loss was mapped as the area where hydric soils (NRCS mapping) and National Wetland Inventory (NWI) mapped areas intersected with urban or agricultural land uses in the watershed, with the remaining areas assumed to be intact wetland. This approach allows for the interpretation of loss of hydrologic attenuation of surface runoff at the reach and watershed scale. In addition, stormwater outfall locations mapped during the Phase 2 assessments are included to depict areas of increased stormflows. Flow regulating structures (e.g., dams) are also depicted on the maps. A summary of the local (reach-scale) and upslope impacts to the hydrologic regime for each segment based on the map in Appendix D is provided in Table 4.3 at the end of this section.

Sediment Load Indicators

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

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

The current day stressors to the sediment regime have been mapped using the variables extracted from the Phase 2 field dataset, and the percent of agriculture within each subwatershed. Four classes of percent agriculture were mapped to depict the relative impact of sediment delivery from agricultural lands at the reach and watershed scales. In addition, depositional and migration features mapped during the Phase 2 assessments are included to depict areas of increased vertical and lateral channel adjustments due to aggradation. Mass failures, gullies and bank erosion depict where sediment delivery from the channel boundaries is occurring. A summary of the local and upslope impacts to sediment loading for each reach based on the maps in Appendix D is provided in Table 4.3.

Channel Slope and Depth Modifiers

Many of Vermont's rivers and streams have been historically manipulated and straightened to maintain an unnaturally steep slope, 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, 2007).

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

Alterations to channel slope and depth in the Sharon study area have been mapped using the variables extracted from the Phase 2 field dataset (see maps in Appendix D). Areas of channel straightening mapped during the Phase 1 and 2 assessments are included to depict areas of increased channel slope. Corridor encroachment data highlights where roads and development have reduced the floodplain area, typically resulting in increased stream power and channel deepening. Additional data showing the location of natural channel features (e.g., ledges and waterfalls) depict areas that have a resistance to vertical channel change. The presence of beaver activity in each reach indicates where temporary controls on vertical adjustments may be found. A summary of the local impacts to channel depth and slope for each reach is provided in Table 4.3.

Modifications to Channel Boundary and Riparian Conditions

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

Alterations to the channel boundary conditions and riparian areas in the Sharon study area have been mapped using the variables extracted from the Phase 2 field dataset (see maps in Appendix D). Relative bank armoring (e.g., rip-rap) highlights areas of increased resistance to lateral migration, whereas relative bank erosion highlights reaches where significant lateral adjustments are found. Additional data showing the location of natural channel features (e.g., ledges and waterfalls) depict areas that have a resistance to channel change. A summary of the local impacts to channel boundary conditions, including impacts to riparian vegetation, is provided in Table 4.3.

4.2.2 Departure Analysis

The reference and existing sediment regime types have been mapped using data from the Phase 1 and 2 assessments (Figure 4.63). Many segments have undergone a departure in sediment regime type due to channel incision and/or widening as a result of: 1) historical land uses, 2) encroachments or development in the river corridor, or 3) extensive straightening and bank armoring. Reaches with departures are summarized below.

White River main stem: Reaches R05, R06, and R07 all have become greater sources of coarse sediments due to historical incision and ongoing channel widening.

Quation Brook: R6-S3.01 has become a greater source of coarse sediments from the channel boundaries due to road encroachment in the corridor and resulting mass failures. R6-S3.02B has departed from a fine depositional reach to a transport reach due to channel straightening and extensive armoring. R6-S3.03-A has departed from a fine depositional reach to an unconfined source and transport reach due to extensive channel straightening.

Fay Brook: R7-S1.01-A has departed from a fine depositional reach to an unconfined source and transport reach due to channel straightening and incision. Numerous segments in the middle and upper part of Fay Brook have undergone departures due to corridor encroachment or channel straightening, including R7-S1.02B, R7-S1.02C, R7-S1.03A, R7-S1.03B, R7-S1.04A, R7-S1.04B, and R7-S1.04E.

Elmers Brook: Reach R7-S2.02 has departed from a coarse equilibrium regime to a source and transport regime due to a high degree of channel straightening, with incision resulting.

Broad Brook: Segment T2.01-A has departed from a coarse equilibrium regime to a source and transport regime due to a high degree of channel straightening, with channel incision and migration resulting.

4.2.3 Sensitivity Analysis

The methods outlined in the Corridor Planning Guide have been used to describe the stream sensitivities of the segments in the Sharon 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 4.64). Additional, larger maps are provided in Appendix D to depict segment sensitivity ratings and channel evolution model and stage. Six reaches have heightened sensitivities of “very high” or “extreme” due to human impacts. These include:

- **White River Reach R05** has been assigned an “extreme” sensitivity rating due to channel incision and loss of floodplain access. The resulting departure in channel classification (B to F) indicates that future channel adjustments and erosion hazards could be severe.

- **Quation Brook Segment R6-S3.03-A** has been assigned a “very high” rating due to historical channel straightening. This reach would be expected to have a meandering planform under reference conditions, so future lateral adjustments are likely.
- **Fay Brook Segment R7-S1.01-A** has been assigned a “very high” rating due to historical channel straightening. This reach would be expected to have a meandering planform under reference conditions, so future lateral adjustments are likely.
- **Fay Brook Segment R7-S1.02-C** has been assigned a rating of “extreme” due to a severe incision and a departure in channel morphology (B to G). This departure indicates that future channel adjustments and erosion hazards could be severe.
- **Fay Brook Segment R7-S1.03-B** has been assigned a rating of “very high” due to a historical channel straightening and severe incision. This departure indicates that future channel adjustments and erosion hazards could be severe. Lateral channel adjustments are likely as this segment seeks to redevelop a meandering planform.
- **Fay Brook Segment R7-S1.04-E** has been assigned a rating of “very high” due to a historical channel straightening. This reach would be expected to have a meandering planform under reference conditions, so future lateral adjustments are likely.

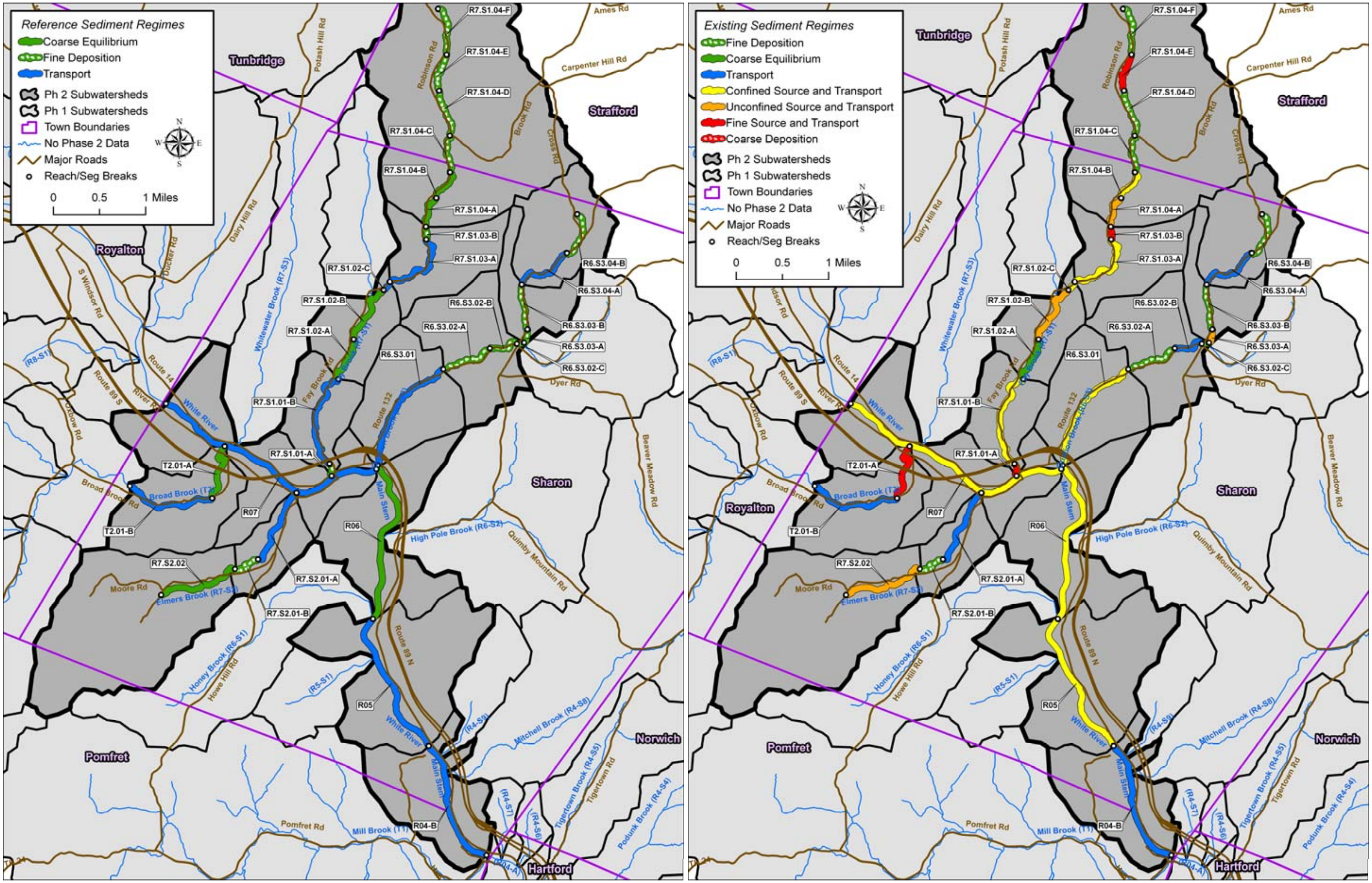

Figure 4.63 Reference and Existing Sediment Regime Types

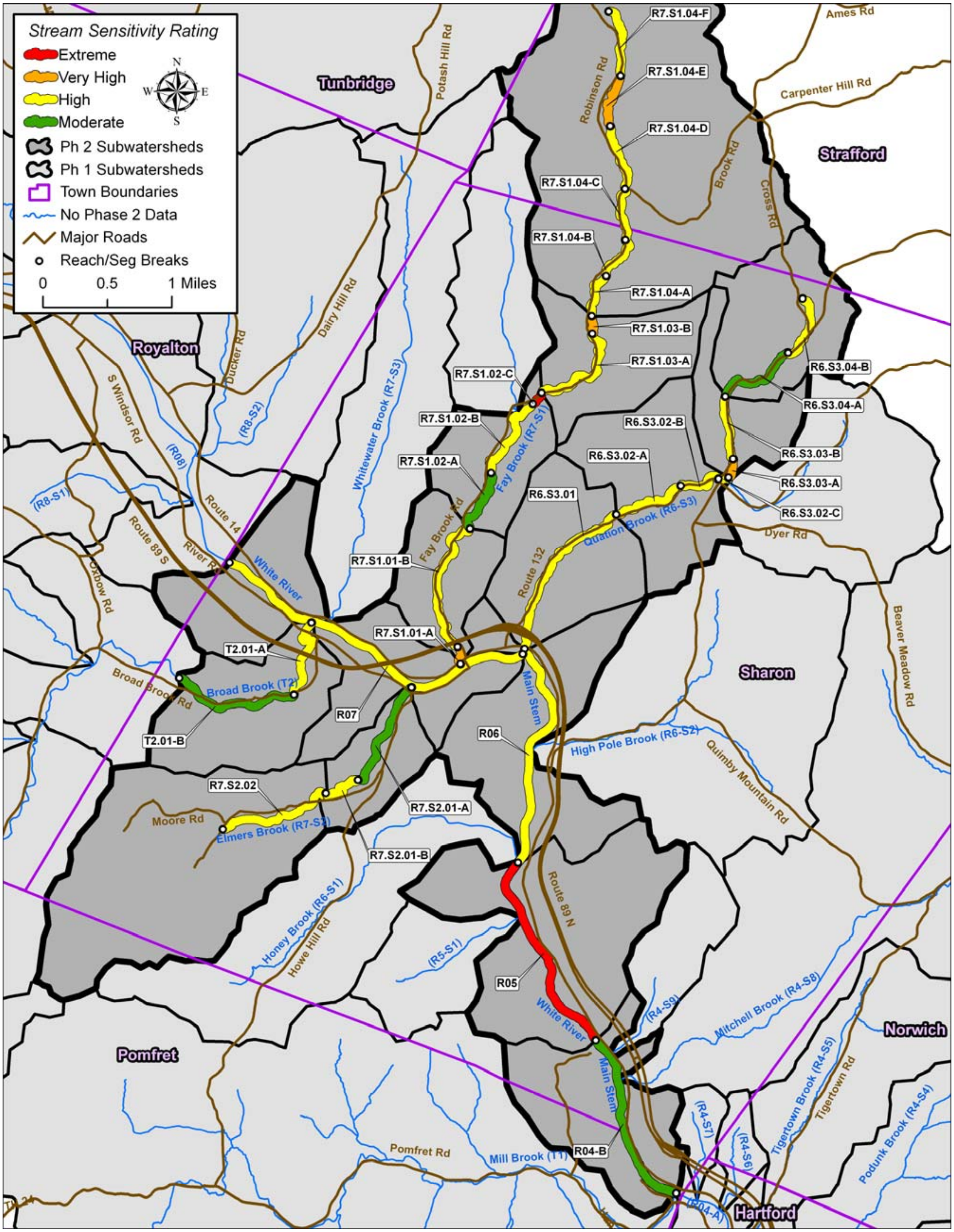

Figure 4.64 Stream sensitivity ratings

Table 4.3 Watershed and Reach-Scale Stressors Impacting Equilibrium Conditions

Stream Segment (CEM; RGA)*	Regime Stressors		Reach Scale Stressors	
	Hydrologic	Sediment	Stream Power	Boundary Resistance
White River R04-B (III; Good)	*Increase in Flows* • Moderate upslope corridor and reach development (5 - 10%) • Very high local road density (>5 Miles/Mile^2) • Low degree of wetland loss (0- 10%)	*Increased Load* • Moderate local agriculture land use (5 - 20%) • Moderate corridor agriculture land use (5 - 20%)	*Increase* • Moderate corridor development (5 - 20%) and high encroachment (20 - 50%) *Decrease* • High degree of widening	*Increase* • Segment largely bedrock controlled; some grade controls (3) *Decrease* • Moderate reduction in riparian vegetation; buffer < 25ft (5 - 20%)
White River R05 (III; Fair)	*Increase in Flows* • Moderate localized corridor and reach development (5 - 10%) • Moderate local road density (2 - 3 Miles/Mile^2)	*Increased Load* • Moderate bank erosion (5 - 20%) • Multiple mass failures in reach	*Increase* • High corridor development (20 - 50%) and high encroachment (20 - 50%) • F-type channel morphology *Decrease* • Moderate degree of widening	*Increase* • Some grade controls (3) *Decrease* • Moderate bank erosion (5 - 20%) • Multiple mass failures in reach
White River R06 (III; Fair)	*Increase in Flows* • Moderate localized reach development (5 - 10%) • High local road density (3 - 5 Miles/Mile^2)	*Increased Load* • High bank erosion (20 - 50%) • Moderate number of depositional features	*Increase* • Moderate corridor development (5 - 20%) and moderate encroachment (5 - 20%) *Decrease* • High degree of widening • Moderate number of depositional features	*Increase* • Grade control at Sharon Dam (Breached) location (1) *Decrease* • High bank erosion (20 - 50%)
White River R07 (III; Fair)	*Increase in Flows* • Moderate localized corridor and reach development (5 - 10%) • High local road density (3 - 5 Miles/Mile^2)	*Increased Load* • Moderate bank erosion (5 - 20%) • Moderate number of depositional features • Moderate corridor agriculture land use (5 - 20%)	*Increase* • Extreme corridor encroachment (>50%) *Decrease* • Moderate degree of widening • Moderate number of depositional features	*Increase* • Many grade controls in reach (6) • Moderate bank armoring (5 - 20%) *Decrease* • Moderate reduction in riparian vegetation; buffer < 25ft (5 - 20%) • Moderate bank erosion (5 - 20%)
Quation Brook R6.S3.01 (III; Fair)	*Increase in Flows* • Moderate localized corridor development (5 - 10%) • High upslope corridor development (10 - 20%) • Moderate local road density (2 - 3 Miles/Mile^2)	*Increased Load* • Moderate local agriculture land use (5 - 20%) • High number of depositional features • Multiple mass failures in reach	*Increase* • Moderate stormwater inputs per mile (4 - 10) • Moderate corridor development (5 - 20%) and high encroachment (20 - 50%) • High channel straightening (20 - 50%) *Decrease* • High number of depositional features	*Increase* • Many grade controls in reach (9) • Moderate bank armoring (5 - 20%) *Decrease* • Moderate reduction in riparian vegetation; buffer < 25ft (5 - 20%) • Multiple mass failures in reach
Quation Brook R6.S3.02-A (I; Good)	*Increase in Flows* • Moderate local road density (2 - 3 Miles/Mile^2)	*Increased Load* • Moderate local agriculture land use (5 - 20%) • High number of depositional features • Moderate corridor agriculture land use (5 - 20%)	*Increase* • Moderate corridor encroachment (5 - 20%) • High channel straightening (20 - 50%) *Decrease* • High number of depositional features	*Decrease* • Moderate reduction in riparian vegetation; buffer < 25ft (5 - 20%)

Table 4.3 Watershed and Reach-Scale Stressors Impacting Equilibrium Conditions

Stream Segment (CEM; RGA)*	Regime Stressors		Reach Scale Stressors	
	Hydrologic	**Sediment**	**Stream Power**	**Boundary Resistance**
Quation Brook R6.S3.02-B (II; Poor)	*Increase in Flows* • Moderate local road density (2 - 3 Miles/Mile^2)	*Increased Load* • Moderate local agriculture land use (5 - 20%) • Moderate number of depositional features • Moderate corridor agriculture land use (5 - 20%)	*Increase* • High corridor encroachment (20 - 50%) and moderate encroachment (5 - 20%) • Extreme channel straightening (>50%) *Decrease* • Moderate number of depositional features	*Increase* • Some grade controls in reach (2) • High bank armoring (20 - 50%) *Decrease* • Moderate reduction in riparian vegetation; buffer < 25ft (5 - 20%)
Quation Brook R6.S3.02-C (IV; Good)	*Increase in Flows* • Moderate local road density (2 - 3 Miles/Mile^2) • High upslope road density (2 - 3 Miles/Mile^2)	*Increased Load* • Moderate local agriculture land use (5 - 20%) • High upslope agriculture land use (20 - 50%) • Moderate corridor agriculture land use (5 - 20%)	*Increase* • High corridor development (20 - 50%) and moderate encroachment (5 - 20%) • High channel straightening (20 - 50%)	*Increase* • Moderate bank armoring (5 - 20%) *Decrease* • High reduction in riparian vegetation; buffer < 25ft (20 - 50%)
Quation Brook R6.S3.03-A (NA; Fair)	*Increase in Flows* • High local road density (3 - 5 Miles/Mile^2) • Moderate degree of wetland loss (10 - 20%)	*Increased Load* • High local agriculture land use (20 - 50%) • High corridor agriculture land use (20 - 50%)	*Increase* • Moderate corridor encroachment (5 - 20%) • Extreme channel straightening (>50%)	*Decrease* • High reduction in riparian vegetation; buffer < 25ft (20 - 50%)
Quation Brook R6.S3.03-B (I; Good)	*Increase in Flows* • High local road density (3 - 5 Miles/Mile^2) • Moderate degree of wetland loss (10 - 20%)	*Increased Load* • High local agriculture land use (20 - 50%) • High number of depositional features • High corridor agriculture land use (20 - 50%)	*Increase* • High corridor encroachment (20 - 50%) • High channel straightening (20 - 50%) *Decrease* • High number of depositional features	*No Significant Increase or Decrease in Reach Boundary Resistance*
Quation Brook R6.S3.04-A (I; Good)	*Increase in Flows* • High local road density (3 - 5 Miles/Mile^2) • Moderate degree of wetland loss (10 - 20%	*Increased Load* • Moderate local agriculture land use (5 - 20%) • High number of depositional features • Multiple mass failures in segment • Gully in segment	*Increase* • Moderate stormwater inputs per mile (4 - 10) • Moderate corridor development (5 - 20%) and high encroachment (20 - 50%) *Decrease* • High number of depositional features	*Increase* • Some grade controls in reach (3) • Moderate bank armoring (5 - 20%) *Decrease* • Moderate reduction in riparian vegetation; buffer < 25ft (5 - 20%) • Multiple mass failures in segment • Gully in segment
Quation Brook R6.S3.04-B (I; Good)	*Increase in Flows* • High local road density (3 - 5 Miles/Mile^2) • Moderate degree of wetland loss (10 - 20%)	*Increased Load* • Moderate local agriculture land use (5 - 20%) • Moderate number of depositional features	*Increase* • High corridor encroachment (20 - 50%) • Moderate channel straightening (5 - 20%) *Decrease* • Moderate number of depositional features	*No Significant Increase or Decrease in Reach Boundary Resistance*

Table 4.3 Watershed and Reach-Scale Stressors Impacting Equilibrium Conditions

Stream Segment (CEM; RGA)*	Regime Stressors		Reach Scale Stressors	
	Hydrologic	**Sediment**	**Stream Power**	**Boundary Resistance**
Fay Brook R7.S1.01-A (III; Fair)	*Increase in Flows* • High localized corridor development (10 - 20%) • Very high local road density (>5 Miles/Mile^2)	*Increased Load* • High bank erosion (20 - 50%) • Moderate local agriculture land use (5 - 20%) • High number of depositional features • Dam in upstream segment	*Increase* • High stormwater inputs per mile (11 - 15) • High corridor development (20 - 50%) and moderate encroachment (5 - 20%) • Extreme channel straightening (>50%) *Decrease* • High number of depositional features	*Decrease* • High bank erosion (20 - 50%)
Fay Brook R7.S1.01-B (II; Fair)	*Increase in Flows* • High localized corridor development (10 - 20%) • Very high local road density (>5 Miles/Mile^2)	*Increased Load* • High number of depositional features • Multiple mass failures in segment • Dam in lower part of segment	*Increase* • Moderate stormwater inputs per mile (4 - 10) • Moderate corridor development (5 - 20%) and high encroachment (20 - 50%) • Moderate channel straightening (5 - 20%) *Decrease* • High number of depositional features	*Increase* • Many grade controls in reach (12) • Moderate bank armoring (5 - 20%) *Decrease* • Moderate reduction in riparian vegetation; buffer < 25ft (5 - 20%) • Multiple mass failures in segment
Fay Brook R7.S1.02-A (I; Good)	*Increase in Flows* • Low degree of wetland loss (0- 10%)	*Increased Load* • Moderate bank erosion (5 - 20%) • Moderate corridor agriculture land use (5 - 20%) • Gully in segment	*No Significant Increase or Decrease in Reach Stream Power*	*Increase* • Many grade controls in reach (5) *Decrease* • Moderate reduction in riparian vegetation; buffer < 25ft (5 - 20%) • Moderate bank erosion (5 - 20%) • Gully in segment
Fay Brook R7.S1.02-B (II; Fair)	*Increase in Flows* Low degree of wetland loss (0- 10%)	*Increased Load* • Moderate bank erosion (5 - 20%) • High number of depositional features • Moderate corridor agriculture land use (5 - 20%)	*Increase* • High channel straightening (20 - 50%) *Decrease* • High number of depositional features	*Increase* • One grade control in reach • Moderate bank armoring (5 - 20%) *Decrease* • High reduction in riparian vegetation; buffer < 25ft (20 - 50%) • Moderate bank erosion (5 - 20%)
Fay Brook R7.S1.02-C (II; Fair)	*Increase in Flows* Low degree of wetland loss (0- 10%)	*Increased Load* • Moderate corridor agriculture land use (5 - 20%)	*Increase* • Extreme corridor development (>50%) and high encroachment (20 - 50%) • Extreme channel straightening (>50%)	*Increase* • Extreme bank armoring (> 50%) *Decrease* • Extreme reduction in riparian vegetation; buffer < 25ft (> 50%)

Table 4.3 Watershed and Reach-Scale Stressors Impacting Equilibrium Conditions

Stream Segment (CEM; RGA)*	Regime Stressors		Reach Scale Stressors	
	Hydrologic	Sediment	Stream Power	Boundary Resistance
Fay Brook R7.S1.03-A (III; Fair)	*Increase in Flows* • Moderate upslope corridor development (5 - 10%)	*Increased Load* • Moderate bank erosion (5 - 20%) • High upslope agriculture land use (20 - 50%) • High number of depositional features • Moderate corridor agriculture land use (5 - 20%) • Multiple mass failures in segment	*Increase* • Moderate stormwater inputs per mile (4 - 10) • Moderate corridor development (5 - 20%) and high encroachment (20 - 50%) • Moderate channel straightening (5 - 20%) *Decrease* • High number of depositional features	*Increase* • Some grade controls in reach (3) • Moderate bank armoring (5 - 20%) *Decrease* • Moderate reduction in riparian vegetation; buffer < 25ft (5 - 20%) • Moderate bank erosion (5 - 20%) • Multiple mass failures in segment
Fay Brook R7.S1.03-B (III; Fair)	*Increase in Flows* • Moderate upslope corridor development (5 - 10%)	*Increased Load* • Moderate bank erosion (5 - 20%) • High upslope agriculture land use (20 - 50%) • Moderate corridor agriculture land use (5 - 20%)	*Increase* • Extreme channel straightening (>50%)	*Decrease* • High reduction in riparian vegetation; buffer < 25ft (20 - 50%) • Moderate bank erosion (5 - 20%)
Fay Brook R7.S1.04-A (II; Fair)	*Increase in Flows* • Moderate localized corridor development (5 - 10%) • Moderate degree of wetland loss (10 - 20%)	*Increased Load* • Moderate bank erosion (5 - 20%) • High local agriculture land use (20 - 50%) • Moderate number of depositional features • High corridor agriculture land use (20 - 50%) *Decreased Load* • Dam upstream; Kratky Dam	*Increase* • High corridor development (20 - 50%) and high encroachment (20 - 50%) • Extreme channel straightening (>50%) *Decrease* • Moderate number of depositional features	*Decrease* • Moderate reduction in riparian vegetation; buffer < 25ft (5 - 20%) • Moderate bank erosion (5 - 20%)
Fay Brook R7.S1.04-B (II; Fair)	*Increase in Flows* • Moderate localized corridor development (5 - 10%) • Moderate degree of wetland loss (10 - 20%)	*Increased Load* • Moderate bank erosion (5 - 20%) • High local agriculture land use (20 - 50%) • High number of depositional features • High corridor agriculture land use (20 - 50%)	*Increase* • Moderate corridor development (5 - 20%) and high encroachment (20 - 50%) • Moderate channel straightening (5 - 20%) • Dredging noted upstream of culvert crossing *Decrease* • High number of depositional features	*Increase* • Some grade controls in reach (4) • Moderate bank armoring (5 - 20%) *Decrease* • High reduction in riparian vegetation; buffer < 25ft (20 - 50%) • Moderate bank erosion (5 - 20%)
Fay Brook R7.S1.04-C (I; Good)	*Increase in Flows* • Moderate localized corridor development (5 - 10%) • Moderate degree of wetland loss (10 - 20%)	*Increased Load* • High local agriculture land use (20 - 50%) • High corridor agriculture land use (20 - 50%)	*Increase* • High corridor encroachment (20 - 50%) • Extreme channel straightening (>50%)	*Increase* • One grade control in reach *Decrease* • High reduction in riparian vegetation; buffer < 25ft (20 - 50%)

Table 4.3 Watershed and Reach-Scale Stressors Impacting Equilibrium Conditions

Stream Segment (CEM; RGA)*	Regime Stressors		Reach Scale Stressors	
	Hydrologic	**Sediment**	**Stream Power**	**Boundary Resistance**
Fay Brook R7.S1.04-D (I; Good)	*Increase in Flows* • Moderate localized corridor development (5 - 10%) • Moderate degree of wetland loss (10 - 20%)	*Increased Load* • High local agriculture land use (20 - 50%) • High number of depositional features • High corridor agriculture land use (20 - 50%) • Multiple mass failures in segment	*Increase* • Moderate corridor development (5 - 20%) and moderate encroachment (5 - 20%) • Moderate channel straightening (5 - 20%) *Decrease* • Beaver activity • High number of depositional features	*Increase* • Some grade controls in reach (2) *Decrease* • Moderate reduction in riparian vegetation; buffer < 25ft (5 - 20%) • Multiple mass failures in segment
Fay Brook R7.S1.04-E (NA; Fair)	*Increase in Flows* • Moderate localized corridor development (5 - 10%) • Moderate degree of wetland loss (10 - 20%)	*Increased Load* • High local agriculture land use (20 - 50%) • High corridor agriculture land use (20 - 50%)	*Increase* • High channel straightening (20 - 50%)	*Decrease* • Extreme reduction in riparian vegetation; buffer < 25ft (> 50%)
Fay Brook R7.S1.04-F (I; Good)	*Increase in Flows* • Moderate localized corridor development (5 - 10%) • Moderate degree of wetland loss (10 - 20%)	*Increased Load* • High local agriculture land use (20 - 50%) • High number of depositional features • High corridor agriculture land use (20 - 50%) • One mass failures in segment	*Increase* • Moderate corridor encroachment (5 - 20%) • Moderate channel straightening (5 - 20%) *Decrease* • High number of depositional features	*Increase* • Many grade controls in reach (13) *Decrease* • Moderate reduction in riparian vegetation; buffer < 25ft (5 - 20%) • One mass failures in segment
Elmers Brook R7.S2.01-A (I; Good)	*Increase in Flows* • High local road density (3 - 5 Miles/Mile^2)	*Increased Load* • Moderate local agriculture land use (5 - 20%) • High upslope agriculture land use (20 - 50%) • High number of depositional features • Multiple mass failures in segment	*Decrease* • High number of depositional features	*Increase* • Some grade controls in reach (3) *Decrease* • Multiple mass failures in segment
Elmers Brook R7.S2.01-B (V; Good)	*Increase in Flows* • High local road density (3 - 5 Miles/Mile^2)	*Increased Load* • Moderate bank erosion (5 - 20%) • High upslope agriculture land use (20 - 50%) • High number of depositional features	*Decrease* • High number of depositional features	*Decrease* • Moderate reduction in riparian vegetation; buffer < 25ft (5 - 20%) • Moderate bank erosion (5 - 20%)
Elmers Brook R7.S2.02 (II; Fair)	*Increase in Flows* • Moderate local road density (2 - 3 Miles/Mile^2)	*Increased Load* • Moderate bank erosion (5 - 20%) • High local agriculture land use (20 - 50%) • High number of depositional features • Multiple mass failures in reach	*Increase* • Moderate corridor development (5 - 20%) • High channel straightening (20 - 50%) • Dredging noted in swimming holes in upper reach *Decrease* • High number of depositional features	*Decrease* • High reduction in riparian vegetation; buffer < 25ft (20 - 50%) • Moderate bank erosion (5 - 20%) • Multiple mass failures in reach

Table 4.3 Watershed and Reach-Scale Stressors Impacting Equilibrium Conditions

Stream Segment (CEM; RGA)*	Regime Stressors		Reach Scale Stressors	
	Hydrologic	Sediment	Stream Power	Boundary Resistance
Broad Brook T2.01-A (III; Fair)	*Increase in Flows* • Moderate localized corridor development (5 - 10%) • High local road density (3 - 5 Miles/Mile^2)	*Increased Load* • Moderate bank erosion (5 - 20%) • High local agriculture land use (20 - 50%) • Multiple mass failures in segment	*Increase* • Extreme channel straightening (>50%) *Decrease* • High number of depositional features	*Increase* • Moderate bank armoring (5 - 20%) *Decrease* • Moderate reduction in riparian vegetation; buffer < 25ft (5 - 20%) • Moderate bank erosion (5 - 20%) • Multiple mass failures in segment
Broad Brook T2.01-B (I; Good)	*Increase in Flows* • Moderate localized corridor development (5 - 10%) • High local road density (3 - 5 Miles/Mile^2)	*Increased Load* • Moderate bank erosion (5 - 20%) • High local agriculture land use (20 - 50%) • Moderate number of depositional features • Multiple mass failures in segment • Gully in segment	*Increase* • High corridor encroachment (20 - 50%) *Decrease* • Moderate degree of widening • Moderate number of depositional features	*Increase* • One grade control in reach *Decrease* • Moderate bank erosion (5 - 20%) • Multiple mass failures in segment • Gully in segment

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

5.0 Preliminary Project Identification

5.1 Watershed Level Opportunities

5.1.1 Stormwater Runoff

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

Stormwater outfalls into the tributaries were common and sometimes associated with gullies delivering sediment to the channel. On Fay and Quation Brooks, runoff entering the channel from the adjacent roads carries with it fine sediments left behind from sanding in winter, and from road edges. Segments R6-S3.02A and R6-S3.02A on Quation Brook both had elevated levels of sand in the bed substrate that was likely attributable to high stormwater outfall densities from Route 132. Similarly, segment R7-S1.04D on Fay Brook had a high degree of sand in the bed substrate, perhaps due to upslope stormwater outfalls from Robinson Road.

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

- Requiring stormwater controls for development projects which are not large enough in scale to fall under state regulatory permits (less than 1 acre impervious cover), but likely have a measurable impact on adjacent waterbodies.
- 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 large rivers have faced significant property losses and risks to public safety during past flood events. While inundation-related flood loss is a significant component of flood disasters, the predominant mode of damage during floods is associated with fluvial erosion. Fluvial erosion hazards have been increased and exacerbated by historical channel management practices in Vermont such as channel straightening, berming, and floodplain encroachment.

Towns can reduce flood recovery and infrastructure maintenance costs and increase public safety by limiting development in areas adjacent to rivers with a high potential for vertical and lateral adjustment. The Fluvial Erosion Hazard (FEH) zone can be thought of as the corridor a river or stream requires to redevelop or maintain equilibrium conditions over the long term. FEH zones also indicate which reaches that have a higher propensity for severe migration during flood events. These reaches, which are given elevated ratings of “very high” or “extreme”, are high priority reaches for protection, especially when there is little existing protection afforded by wetlands or conservation easements. Reaches or segments with elevated ratings have been summarized in Section 4.2.3 and include: White River Reach R05, Quation Brook Segment R6-S3.03-A, and Fay Brook Segments R7-S1.01-A, R7-S1.02-C, R7-S1.03-B, and R7-S1.04-E.

5.2.3 Stream Crossings

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

Detailed summary data and a structure location maps for all bridges and culverts in the study area is included in Appendix C. Assessments were completed on 61 structures in the study area. Tables 5.1 and 5.2, found below, summarize key data collected for all structures. Both tables include a relative priority ranking for replacement or retrofit based on a review of the following three criteria: structure width in relation to bankfull channel width; aquatic organism passage (AOP); geomorphic compatibility. Ten (10) culverts and 2 bridges have been assigned a “high” priority for replacement or retrofit. Additional information about the recommended actions to address high priority structures is provided in the site-specific project identification summary in Table 5.3.

Table 5.1 Culvert summary data for White River watershed in Sharon, VT

Stream Name	Map ID	Reach/ Segment ID	Road Name	% Bankfull Width*	Geomorphic Compatibility	Aquatic Organism Passage (AOP)	Priority for Replacement or Retrofit
Quation Brook	5	R6.S3.01	Route 14	**37%**	Partially Compatible	Reduced	**High**
	6	R6.S3.01	Interstate 89	**37%**	Partially Compatible	Reduced	Low
	9	R6.S3.01	Odgen Ln	**40%**	Mostly Incompatible	None	**High**
	10	R6.S3.01	Route 132	**31%**	Partially Compatible	Reduced	Moderate
	12	R6.S3.02-B	Route 132	**43%**	Mostly Compatible	Reduced	Moderate
	13	R6.S3.02-B	Route 132	**31%**	Mostly Compatible	None	Moderate
	14	R6.S3.02-B	Route 132	**39%**	Mostly Compatible	Reduced	Moderate
	17	R6.S3.03-A	Route 132	**44%**	Partially Compatible	Reduced	Moderate
	18	R6.S3.04-A	Highlake Rd	**48%**	Partially Compatible	None	Low†
	19	R6.S3.04-A	Route 132	**24%**	Mostly Incompatible	Reduced	**High**
	20	R6.S3.04-A	Route 132	56%	Mostly Compatible	Reduced	Low
	21	R6.S3.04-A	Route 132	**34%**	Mostly Compatible	Reduced	Moderate
	22	R6.S3.04-A	Route 132	**20%**	Partially Compatible	Reduced	**High**
	23	R6.S3.04-A	Driveway off Route 132	52%	Mostly Compatible	Reduced	Low
	24	R6.S3.04-B	Route 132	54%	Partially Compatible	None	Moderate
	25	R6.S3.04-B	Route 132	**32%**	Partially Compatible	None	Moderate
	26	R6.S3.04-B	Cross Rd	**22%**	Partially Compatible	Reduced	**High**
Fay Brook	27	R7.S1.01-A	Route 14	**24%**	Mostly Incompatible	None	**High**
	45	R7.S1.04-B	Driveway off Fay Brook Rd	**20%**	Partially Compatible	None	**High**
	46	R7.S1.04-C	Trail to Robinson Cemetery	**47%**	Mostly Compatible	Reduced	Moderate
	47	R7.S1.04-C	Brook Rd	73%	Mostly Compatible	Reduced	Low
	49	R7.S1.04-F	Robinson Rd	**34%**	Partially Compatible	Reduced	Moderate
	50	R7.S1.04-F	Robinson Rd	**25%**	Partially Compatible	Reduced	Moderate
	51	R7.S1.04-F	Ordway Rd	**30%**	Partially Compatible	None	Moderate
Elmers Brook	52	R7.S2.01-A	River Rd	**38%**	Partially Compatible	None	**High**
	53	R7.S2.01-A	Railroad Culvert	61%	Partially Compatible	Reduced	Moderate
	57	R7.S2.02	Moore Rd	**30%**	Mostly Incompatible	Reduced	**High**
Broad Brook	58	T2.01-A	River Rd	**38%**	Mostly Compatible	Reduced	Low
	59	T2.01-A	Interstate 89	**43%**	Partially Compatible	Reduced	**High**

* Shaded for bankfull width percentage less than 25% (red) and 50% (yellow)
† Recently installed box culvert, therefore low priority

Table 5.2 Bridge summary data for White River watershed in Sharon, VT

Stream Name	Map ID	Reach/ Segment ID	Road Name	Percent Bankfull Width*	Priority for Replacement or Retrofit
White River main stem	1	R06	Railroad Trestle	90%	Low
	2	R07	River Road	108%	Low
	3	R07	Interstate 89 SB	250%	Low
	4	R07	Interstate 89 NB	250%	Low
Quation Brook	7	R6.S3.01	Johnsons Way	100%	Low
	8	R6.S3.01	Driveway off Route 132	**34%**	Moderate
	11	R6.S3.02-A	Driveway off Route 132	52%	Moderate
	15	R6.S3.02-C	Farm Road Crossing	67%	Moderate
	16	R6.S3.03-A	Sunnybrook Trout Farm Crossing	**46%**	Moderate
Fay Brook	28	R7.S1.01-B	Interstate 89 SB	1107%	Low
	29	R7.S1.01-B	Interstate 89 NB	1107%	Low
	30	R7.S1.01-B	Private Driveway	75%	Low
	31	R7.S1.01-B	Fay Brook Road	**50%**	Moderate
	32	R7.S1.01-B	Fay Brook Road	**43%**	Moderate
	33	R7.S1.01-B	Fay Brook Road	**50%**	Moderate
	34	R7.S1.02-A	Farm Road Crossing	52%	Moderate
	35	R7.S1.02-A	Logging Access Road Bridge	**50%**	Moderate
	36	R7.S1.02-B	Farm Road Crossing	**35%**	Moderate
	37	R7.S1.02-B	Snow Mobile Bridge	90%	Low
	38	R7.S1.02-C	Trail Crossing	77%	Low
	39	R7.S1.02-C	Fay Brook Road	**32%**	Moderate
	40	R7.S1.03-A	Fay Brook Road	**29%**	**High**
	41	R7.S1.03-B	Farm Road Crossing	**47%**	Moderate
	42	R7.S1.04-A	Driveway off Fay Brook Road	94%	Low
	43	R7.S1.04-A	Driveway off Fay Brook Road	78%	Low
	44	R7.S1.04-B	Driveway off Fay Brook Road	**36%**	Moderate
	48	R7.S1.04-D	Robinson Road	**38%**	Moderate
Elmers Brook	54	R7.S2.01-A	Sharon Meadows Rd	80%	Low
	55	R7.S2.01-B	Farm Access Road	**35%**	**High**
	56	R7.S2.01-B	Driveway off Moore Road	56%	Moderate
Broad Brook	60	T2.01-A	Broad Brook Rd	71%	Moderate
	61	T2.01-B	Broad Brook Rd	53%	Moderate

* Shaded for bankfull width percentage less than 50%

5.2 Site-Level Project Opportunities

The site-level projects developed for the White River watershed in Sharon 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 26 projects were identified to promote the restoration or protection of channel stability and aquatic habitat. The table summarizes key information for each project, including the site stressors and constraints, project strategy, priority, relative costs, and potential partners.

The project locations and categories identified for the study area are included on a map in Appendix E. The 27 projects are further broken down by category as follows: 13 active geomorphic restoration projects; 14 passive geomorphic restoration projects.

Project #, (Map Label), Location, Reach/Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners
White River #1 (WR-1) Bank failure north of Kenyon Hill Rd White River Reach R05	Passive Restoration	Large bank failures on west bank (approx. 100ft high x 600ft long). Gravel/sand pit along bank is within 200 feet of failing slope. Further advance of slope failure could connect to excavation.	Ensure proper setback of gravel and sand excavations to avoid erosion hazards, soil loss, and impacts to downstream water quality and habitat.	High	Moderate	Potentially reduced property loss from erosion; Mitigation of significant soil erosion in event that slope failures advance.	Relatively low costs if land under Town ownership.	Town of Sharon
White River #2 (WR-2) Bank failure upstream & downstream of railroad trestle White River Reaches R05/R06	Passive Restoration	Large bank failures on both banks (approx. 10ft high x 800ft long) upstream of railroad trestle; erosion along west bank extends downstream. Rip-rip failing upstream.	Avoid further development of infrastructure along east bank south of trestle. May need to address failed rip-rap upstream in near future. Bioengineered alternatives for bank stabilization (e.g., log deflectors) could be explored.	Moderate	Moderate	Potentially reduced property loss from erosion; Mitigation of significant soil erosion	Moderate to high costs for bank stabilization; Low costs for corridor protection if FEH zoning implemented.	RailAmerica, Inc.; Town of Sharon
White River #3 (WR-3) East bank down-stream of sharp bend – south of Village White River Reach R06	Passive Restoration	Large bank failures on both banks immediately south of town village. Large mid-channel gravel bar is causing channel to widen. Residential and agricultural land use along east bank.	Avoid further development of infrastructure along east bank. Consider easements for corridor protection. Plant stream corridor with native woody vegetation.	High	Moderate	Improved biotic habitat within reach; Potentially reduced property loss from erosion	Low costs for corridor protection if FEH zoning implemented; Low to moderate costs for buffer planting	Town of Sharon; Private landowner; White River Partnership (WRP); VT River Conservancy (VRC); NRCS (CREP)
White River #4 (WR-4) Buffer Planting along Rt. 14 west of White Brook Road White River Reach R07	Passive Restoration	Approximately 500 feet of north bank lacks native woody vegetation and is overgrown with Japanese knotweed. Large mid-channel channel bar indicates potential for channel widening.	Control knotweed and plant stream buffer with native woody vegetation in areas lacking canopy cover.	Low	Moderate	Reduced thermal loading; Reduced fine sediment loading; Improved biotic habitat within reach	Low to moderate costs for buffer restoration	Town of Sharon; Private landowner; White River Partnership (WRP); VT River Conservancy (VRC)

Project #, (Map Label), Location, Reach/Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners
Quation Brook #1 (QB-1) Culvert beneath Route 14 at mouth of brook Quation Brook Reach R6.S3.01	Active Restoration	Box culvert beneath Route 14 is undersized and perched above downstream surface water level. Increased velocities and height above surface water is reducing aquatic organism passage (AOP).	Replace culvert with an open-bottomed arch or bridge to improve AOP; Alternatively, explore potential retrofit of downstream end of culvert to improve AOP.	Moderate	High	Improved AOP in tributary reach where quality habitat was observed upstream.	Moderate to high costs for design and installation of new structure; Retrofit would be less costly.	VTRANS; WRP; VFWD
Quation Brook #2 (QB-2) Culvert beneath Odgen Road, mid-reach Quation Brook Reach R6.S3.01	Active Restoration	Squash corrugated steel culvert underneath Odgen Road is undersized and perched above downstream surface water level. Increased velocities and free-fall outlet is leading to reduced AOP.	Explore the potential to retrofit culvert to improve passage from downstream reach to above. Replacement may not be necessary.	Moderate	High	Improved AOP in tributary reach where quality habitat was observed upstream.	Moderate to high costs for design and installation of new structure; Retrofit would be less costly.	VTRANS; WRP; VFWD
Quation Brook #3 (QB-3) Along Route 132 approx. 1 mile from Village Quation Brook Reach R6.S3.01	Active Restoration	Multiple slope failures along east bank in close proximity to Route 132. Stormwater outfalls and rip-rap on the west bank are contributing to increased stream power and erosion potential downstream.	Mitigate stormwater outfalls and failing rip-rap. Bioengineered alternatives for bank stabilization (e.g., log deflectors) could be explored.	Moderate	Moderate	Potentially reduced property and infrastructure loss; Mitigation of significant soil erosion in event that slope failures advance.	Moderate to high costs for outfall mitigation and bank stabilization.	Town of Sharon; VTRANS
Quation Brook #4 (QB-4) Downstream of driveway north of Route 132/ Raymond Rd Intersection Quation Brook Seg. R6.S3.02-A	Conservation	Area from driveway crossing north of Route 132/Raymond Rd intersection to 1,700 feet downstream at reach break has good habitat and sediment attenuation potential from upslope segment R6.S3.0-A.	Corridor protection (e.g., easements) will enable area to remain in “good” RHA condition and sediment that is transported from above segment will settle out in developing meanders.	Moderate	Moderate	Protected habitat and stable channel with intact floodplain; reduced net sediment flux out of the reach over long-term.	Potentially moderate to high costs for easements.	Private Landowner; Town of Sharon;

Project #, (Map Label), Location, Reach/Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners
Quation Brook #5 (QB-5) Between Beaver Meadows Rd. Crossing and Highlake Rd. Quation Brook Seg. R6.S3.03-A & B	Passive Restoration	Over 300 ft of channel upstream of Sunnybrook Trout Farm lack native woody vegetation in the buffer. Channel historically straightened upstream and downstream of Route 132 crossing.	Buffer plantings in Sunnybrook Trout Farm area and approx. 900 feet upstream of Route 132 crossing where the channel has also been historically straightened.	Low	Moderate	Reduced thermal loading; Reduced fine sediment loading; Improved biotic habitat within reach	Low to moderate costs for buffer restoration	WRP; VFWD; Land Owner
Quation Brook #6 (QB-6) Culvert beneath Route 132 Quation Brook Seg. R6.S3.04-A	Active Restoration	Culvert beneath Route 132 located 700ft west of Muir Rd intersection. Severely undersized and incompatible with geomorphic stability. Increased velocities and height above surface water is reducing aquatic organism passage (AOP).	Replace culvert with an open-bottomed arch or bridge to improve AOP; Also consider replacement with box culvert similar to recently installed structure to east on Route 132.	High	Moderate	Reduced risks of flooding and road damage during flood events. Improved AOP.	Moderate to high costs for design and installation of new structure.	VTRANS; Town of Sharon
Quation Brook #7 (QB-7) Culvert beneath Route 132 Quation Brook Seg. R6.S3.04-A	Active Restoration	Culvert beneath Route 132 located 300ft west of Cowslip Hill Road intersection. Severely undersized with recent erosion damage noted during 2009 field survey. Increased velocities and height above surface water is reducing aquatic organism passage (AOP).	Replace culvert with an open-bottomed arch or bridge to improve AOP; Also consider replacement with box culvert similar to recently installed structure to west on Route 132.	High	Moderate	Reduced risks of flooding and road damage during flood events. Improved AOP.	Moderate to high costs for design and installation of new structure.	VTRANS; Town of Sharon
Quation Brook #8 (QB-8) Culvert beneath Cross Road Quation Brook Seg. R6.S3.04-B	Active Restoration	Culvert beneath Cross Road located 150ft west of Route 132 intersection. Severely undersized with recent erosion damage noted during 2009 field survey. Failing rip-rap at outlet and culvert rusted and deteriorated.	Replace culvert with larger culvert equal to at least 75% of stable bankfull channel width (9ft).	High	Moderate	Reduced risks of flooding and road damage during flood events. Improved AOP.	Moderate costs for design and installation of new structure.	Town of Sharon

Project #, (Map Label), Location, Reach/Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners
Fay Brook #1 (FB-1) Culvert beneath Route 14 at mouth of brook Fay Brook Seg. R7.S1.01-A	Active Restoration	Box culvert beneath Route 14 is undersized and "perched" in low flow events above downstream surface water level. Increased velocities and height above surface water is reducing aquatic organism passage (AOP).	Replace culvert with an open-bottomed arch or bridge to improve AOP; Alternatively, explore potential retrofit of downstream end of culvert to improve AOP.	Moderate	High	Improved AOP in tributary reach where quality habitat was observed upstream and trout are known to spawn.	Very high costs for replace-ment. Moderate costs for retrofit of outlet for improved AOP.	VTRANS; WRP; VFWD
Fay Brook #2 (FB-2) Dam west of Fay Brook Road Fay Brook Seg. R7.S1.01-A	Active Restoration	Dam located about 100 feet downstream of the I-89 crossing of Fay Brook west of Fay Brook Road.	Removal of large dam, approximately 15' high. The current use of the structure is unknown; but known to have been used for hydroelectric generation in past.	Low	Unknown	Would allow for passage of fish upstream. Potentially increasing viable spawning habitat to Salmonids by several miles upstream.	Very high costs to design and permit structure removal. Needs further cost-benefit analysis.	WRP; VFWD; Town of Sharon; Private Landowner
Fay Brook #3 (FB-3) Horse pasture and hay field east of Fay Brook Road Fay Brook Segment R7.S1.02-B	Passive Restoration	Field located 2,500 feet south and 1,000 feet west of Fay Brook Road and Clifford Farm Road Intersection. Buffer lacks native woody vegetation.	Consider corridor protection (e.g., easements) and plant stream buffer with native woody vegetation in areas lacking canopy cover; Potential CREP project or "Trees for Streams"	Moderate	Moderate	Reduced fine sediment loading to channel and downstream areas; Reduced thermal loading; Improved biotic habitat within reach	Low to moderate costs for buffer planting; No cost to allow buffer to revegetate on its own.	Private Landowner; WRP; VFWD; VTDEC; NRCS (CREP or "Trees for Streams")
Fay Brook #4 (FB-4) Large yard east of Fay Brook Road Fay Brook Segment R7.S1.02-B	Passive Restoration	Field located 500 feet southwest of Fay Brook Road and Clifford Farm Road Intersection. Buffer lacks native woody vegetation.	Consider corridor protection (e.g., easements) and plant stream buffer with native woody vegetation in areas lacking canopy cover; Potential CREP project or "Trees for Streams"	Moderate	Moderate	Reduced fine sediment loading to channel and downstream areas; Reduced thermal loading; Improved biotic habitat within reach	Low to moderate costs for buffer planting; No cost to allow buffer to revegetate on its own.	Private Landowner; WRP; VFWD; VTDEC; NRCS (CREP or "Trees for Streams")

Project #, (Map Label), Location, Reach/Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners
Fay Brook #5 (FB-5) Bridge beneath Fay Brook Road Fay Brook Seg. R7.S1.03-A	Active Restoration	Bridge beneath Fay Brook Road 0.6 miles east of intersection with Clifford Farm Road. Severely undersized with deposition (steep riffle) upstream, and erosion up and downstream.	Replace bridge with larger structure equal to at least 75% of stable bankfull channel width (28 ft).	High	Moderate	Reduced risks of flooding and road damage during flood events.	Moderate costs for design and installation of new structure.	VTRANS; Town of Sharon
Fay Brook #6 (FB-6) Culvert beneath driveway off Fay Brook Road Fay Brook Segment R7.S1.04-B	Active Restoration	Culvert beneath driveway located off Fay Brook Road 1/3 mile east of intersection with Blake Hill Road. Severely undersized with recent erosion damage noted during 2009 field survey. Reduced aquatic organism passage (AOP).	Replace culvert with an open-bottomed arch, bridge, or box culvert to improve channel stability and AOP.	High	Moderate	Reduced risks of flooding and road damage during flood events. Improved AOP.	Moderate costs for design and installation of new structure.	Private Landowner; WRP; VFWD
Fay Brook #7 (FB-7) Along Fay Brook Road Fay Brook Segment R7.S1.04-C	Passive Restoration	Long sections of Fay Brook downstream of Brook Road and Robinson Road intersection lack native woody vegetation in the buffer; Some sections have cattle grazing up to stream edge.	Consider corridor protection (e.g., easements) and plant stream buffer with native woody vegetation in areas lacking canopy cover; Potential CREP project or "Trees for Streams"	Moderate	High	Reduced fine sediment loading to channel and downstream areas; Reduced thermal loading; Improved biotic habitat within reach	Low to moderate costs for buffer planting; No cost to allow buffer to revegetate on its own. Moderate to high costs for easements	Private Landowner; WRP; VFWD; VTDEC; NRCS (CREP or "Trees for Streams")
Fay Brook #8 (FB-8) Along Robinson Road Fay Brook Segment R7.S1.04-E	Passive Restoration	Long sections of Fay Brook east of Robinson Road lack native woody vegetation in the buffer; Entire area has cattle grazing up to stream edge.	Consider corridor protection (e.g., easements) and plant stream buffer with native woody vegetation in areas lacking canopy cover; Potential CREP project or "Trees for Streams"	Moderate	High	Reduced fine sediment loading to channel and downstream areas; Reduced thermal loading; Improved biotic habitat within reach	Low to moderate costs for buffer planting; No cost to allow buffer to revegetate on its own. Moderate to high costs for easements	Private Landowner; WRP; VFWD; VTDEC; NRCS (CREP or "Trees for Streams")

Project #, (Map Label), Location, Reach/Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners
Elmers Brook #1 (EB-1) River Road culvert Elmers Brook Seg. R7.S2.01-A	Active Restoration	Culvert beneath River Road is undersized and "perched" above downstream surface water level. Increased velocities and height above surface water is reducing aquatic organism passage (AOP).	Replace culvert with an open-bottomed arch or bridge to improve AOP. Alternatively, explore potential retrofit of downstream end of culvert to improve AOP.	Low	High	Improved AOP in tributary reach where high densities of brook trout were observed; excellent habitat exists upstream.	High costs for replacement. Moderate costs for retrofit of outlet for improved AOP.	VTRANS; WRP; VFWD
Elmers Brook #2 (EB-2) Farm access road bridge Elmers Brook Segment R7.S2.01-B	Active Restoration	Bridge serving farm access road is constricting channel and causing significant sediment aggradation upstream; Cascade over rip-rap below bridge is likely reducing or preventing AOP.	Remove or retrofit structure to improve channel stability upstream and AOP.	Moderate	High	Improved AOP in tributary reach where high densities of brook trout were observed; excellent habitat exists upstream.	Moderate costs to replace or remove structure.	Private Landowner; WRP; VFWD
Elmers Brook #3 (EB-3) North of Moore Road Elmers Brook Segment R7.S2.01-B	Conservation	Excellent aquatic habitat observed in Elmers Brook downstream of Moore Road crossing. High densities of woody debris and pools in the channel, and healthy riparian buffer.	Conserve stream corridor to protect high quality habitat.	Low	High	Approximately ½ mile of high quality habitat	Potentially moderate to high costs for easements on over 5 acres.	Private Landowner; WRP; VFWD; VTDEC; Town of Sharon
Elmers Brook #4 (EB-4) East of Maverick Farm Road Elmers Brook Segment R7.S2.02	Passive Restoration	310ft section of brook lacks native woody vegetation in the buffer; Lack of shade contributes to elevated temperatures. Banks could become unstable in future as channel adjusts toward equilibrium.	Plant stream buffer with native woody vegetation in areas lacking canopy cover; Potential CREP project or "Trees for Streams"	Moderate	Moderate	Reduced fine sediment loading to channel and downstream areas; Reduced thermal loading; Improved biotic habitat within reach	Low costs for buffer planting.	Private Landowner; WRP; VFWD; VTDEC; NRCS (CREP or "Trees for Streams")

Project #, (Map Label), Location, Reach/Segment	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners
Broad Brook #1 (BB-1) In between River Road and I-89 Broad Brook Segment T2.01-A	Passive Restoration	Active lateral channel migration downstream of I-89 culvert. Mass failure along un-vegetated right bank near house west of Broad Brook Rd. Stream corridor lacks good native woody buffer.	Avoid further development of infrastructure and vegetation removal along east bank. Consider easements for corridor protection. Plant entire stream corridor with native woody vegetation.	High	High	Reduced fine sediment loading to channel and downstream areas; Reduced property loss; Improved biotic habitat within reach.	Low costs for corridor protection if FEH zoning implemented; Low to moderate costs for buffer planting	Private Landowner; WRP; VFWD; VTDEC; NRCS (CREP)
Broad Brook #2 (BB-2) I-89 culvert Broad Brook Segment T2.01-A	Active Restoration	700 ft culvert beneath I-89 is undersized and lacks bed substrate throughout. Increased velocities and lack of substrate is reducing aquatic organism passage (AOP).	Retrofit culvert with baffles to create variability in flow depths and velocities, and encourage trapping of bed sediments to improve AOP.	Low	High	Improved AOP in tributary reach where quality habitat was observed and high trout densities exist.	Moderate costs to design and install baffles	VTRANS; WRP; VFWD
Broad Brook #3 (BB-3) In between I-89 and Broad Brook Road Broad Brook Segment T2.01-A	Passive Restoration	Incised channel due to historical straightening and armoring along east bank. Lateral channel migration predicted in future. Limited buffers exist on east bank.	Protect stream corridor along eastern bank. Consider easements for long-term protection. Plant buffer in areas with less than 25ft of buffer width. FEH zone would cover area of interest.	Moderate	Moderate	Reduced property loss over the long term; Improved biotic habitat within reach.	Low costs for corridor protection if FEH zoning implemented; Low to costs for buffer planting	Private Landowner; WRP; VFWD; VTDEC; NRCS (CREP)

6.0 Conclusions & Recommendations

The White River and its tributaries in Sharon have great diversity in form, function, and condition. Historical floods, defunct dams and various types of human land use in the river corridor have all left a lasting imprint on the morphology and stability of the main stem and tributary channels. In order to understand how to sustainably manage these channels over the long-term, a historical perspective of the causes of current day conditions is very important.

The White River main stem is still adjusting its width, depth, and planform to the following historical impacts: 1) aggradation of sediment in the valley due to settlement and deforestation that occurred during the 1700's and 1800's; 2) failure of the Sharon Dam and other in-channel structures used during log drives; 3) the unparalleled erosive forces of 1927 flood. Although the White River in Sharon is found in a confined valley and is vertically controlled by numerous bedrock outcrops, moderate lateral channel migration is likely in the future. Given the current state of the channel and predicted future adjustments, the following watershed-scale and site-specific management actions are recommended:

- Implementation of FEH zones for the entire Town of Sharon (main stem and tributaries)
- Protection of specific areas of river corridor (see "high priority" projects in Table 5.3) along the main stem that are more prone to lateral adjustments
- Areas of buffer plantings along the main stem to improve stream bank shading and cover for fishes

The tributaries draining the northern section of Sharon, Quation and Fay Brooks, have a high degree of natural variability in form due to natural changes in slope and valley morphology. The presence of natural bedrock outcrops along these channels limits severe incision in many areas that might otherwise occur due to the following historical impacts: 1) road encroachment on the corridor and channel straightening in areas with high agricultural land use; 2) removal of native woody vegetation along the banks and buffers; 3) undersized culverts and bridges that severely constrict channel forming flows and interrupt the transport of wood and sediment down the channel network. Given the Phase 2 assessment results and the potential restoration projects summarized in Section 5, the following site-specific management actions are recommended:

- Replacement or retrofit of 7 culverts and 1 bridge that are incompatible with geomorphic stability and/or disrupting aquatic organism passage
- Buffer plantings in sections of Fay Brook where agricultural land use in the corridor has severely degraded aquatic habitat. Two of these areas could also be considered for corridor easements for long-term protection

The tributaries draining the southern section of Sharon, Elmers and Broad Brooks, also have a high degree of natural variability in form due to changes in slope and valley morphology. Reaches along these brooks have been primarily impacted by: 1) channel straightening in areas with high agricultural land use; 2) undersized culverts and bridges that severely constrict channel forming flows and interrupt the transport of wood and sediment down the channel network. Given the Phase 2 assessment results and the potential restoration projects summarized in Section 5, the following site-specific management actions are recommended:

- Replacement or retrofit of 3 culverts and 1 bridge that are incompatible with geomorphic stability and/or disrupting aquatic organism passage
- Buffer plantings in one section of Broad Brook where agricultural land use in the corridor and severe channel migration has degraded aquatic habitat
- Conservation of one area of Elmers Brook (below Moore Road) that has excellent aquatic habitat

Finally, additional sampling locations for the VTDEC biological sampling program are recommended to capture a range of habitat conditions within the study area. The segment on Elmers Brook downstream of Moore Road (R7.S2.01-B) scored “reference” for aquatic habitat, and would be worthwhile to sample for both macroinvertebrates and fishes. As far as impacted tributaries, Quation Brook Segment R6.S3.02-B and Fay Brook Segment R7.S1.02-C represent the degraded end of the spectrum.

7.0 References

BCE (Bear Creek Environmental, LLC.), 2007, Ayers Brook River Corridor Management Plan, Prepared for The White River Partnership, June 22, 2007

Burns, C., 2005, The Great Hurricane, 1938. Atlantic Monthly Press, New York, NY

Dunne, T. and Leopold, L. B., 1978, Water in Environmental Planning, WH Freeman and Co., San Francisco, CA.

Fitzgerald, E. P., 2007, Linking urbanization to stream geomorphology and biotic integrity in the Lake Champlain Basin, Vermont [M.S. Thesis]: Burlington, Vermont, University of Vermont, 121 p.

Kirn, Rich, 2010, Personal communication with Evan Fitzgerald via email

Lane, E. W. 1955. The Importance of Fluvial Morphology in Hydraulic Engineering. In: Proceedings of American Society of Civil Engineers. p. 1-17

MMI (Milone & MacBroom, Inc.) 2008a, The Vermont Culvert Geomorphic Capability Screening Tool. South Burlington, Vermont.

MMI (Milone & MacBroom, Inc.), 2008b, The Vermont Culvert Aquatic Organism Passage Screening Tool, South Burlington, Vermont.

Minsinger, W. E., 2003, The 1927 Flood in Vermont and New England, November 3-7, 1927: A Historical and Pictorial Summary. Blue Hill Meteorological Observatory and Science Center, E. Milton, MA

Montgomery, D. R., & Buffington, J. M., 1997, Channel-reach morphology in mountain drainage basins, *Geological Society of America Bulletin*, 109(5), 596-611.

NOAA (National Oceanic and Atmospheric Administration), 2008, Land Cover Analysis Data for New England from 2006 – Coastal Change Analysis Program. Accessed May, 2008 and available at: http://www.csc.noaa.gov/crs/lca/ccap.html

NOAA (National Oceanic and Atmospheric Administration), 2007, The Flood of 1927. Accessed February, 2010 and available at: http://www.erh.noaa.gov/btv/events/27flood.shtml

NPS (National Park System), 2010, Glacial Lake Hitchcock map accessed February, 2010 at: www.nps.gov/saga/naturescience/glaciers.htm

Redstart (Redstart Consulting), 2007, Upper White River Corridor, Prepared for: The White River Partnership and VTDEC River Management Program, July 2, 2007

Redstart (Redstart Consulting), 2008, Tweed River Watershed Corridor, Prepared for: The White River Partnership and VTDEC River Management Program, April 18, 2008

Ridge, J.C. and Larsen, F.D., 1990, Re-evaluation of Antevs' New England varve chronology and new radiocarbon dates of sediments from Glacial Lake Hitchcock: Geological Society of America, v. 102, p. 889-899

Rosgen, D. L., 1994, A classification of natural rivers, *Catena*, 22(3), 169 - 199.

Schumm, S. A., 1977, The Fluvial System, John Wiley and Sons, New York.

Thompson, E.H., and E.R. Sorenson, 2000, Wetland, Woodland, Wildland: A Guide to the Natural Communities of Vermont, Vermont Department of Fish and Wildlife and The Nature Conservancy.

UVM (University of Vermont), 2010, Landscape Change Program –Historical Photographs, Accessed November, 2009 at: http://www.uvm.edu/landscape//

VFWD (Vermont Fish and Wildlife Department), 2001, White River Trout Evaluations, Study period from January 1. 2001 through December 31, 2001

VTANR, 2007, Vermont Agency of Natural Resources River Corridor Planning Guide, Draft dated July 11, 2007. Accessed in August, 2007 at: http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_restoration.htm

VTDEC (Vermont Department of Environmental Conservation), 2009, Stream Geomorphic Assessment Handbook - Phase 1 & 2 Protocols. Vermont Agency of Natural Resources Publication. Available at: http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_geoassesspro.htm.

VTDEC (Vermont Department of Environmental Conservation), 2008, Municipal Guide to Fluvial Erosion Hazard Mitigation. Vermont River Management Program Publication. Available at: http://www.anr.state.vt.us/dec/waterq/rivers/docs/rv_municipalguide.pdf

VTDEC (Vermont Department of Environmental Conservation), 2009, Stream Geomorphic Assessment Handbook – Appendix G. Bridge and Culvert Assessment Protocol.

8.0 Glossary of Terms

Adapted from:

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

And

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

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

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

Debris flow -- A rapidly moving mass of rock fragments, soil, and mud, with more than half of the particles being larger than sand size.
Deciduous -- Trees and plants that shed their leaves at the end of the growing season.
Degradation -- (1) A progressive lowering of the channel bed due to scour. Degradation is an indicator that the stream's discharge and/or sediment load is changing. The opposite of aggradation. (2) A decrease in value for a designated use.
Detritus -- is organic material, such as leaves, twigs, and other dead plant matter, that collects on the stream bottom. It may occur in clumps, such as leaf packs at the bottom of a pool, or as single pieces, such as a fallen tree branch.
Dike -- (1) (Engineering) An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of lowlands; a levee. (2) A low wall that can act as a barrier to prevent a spill from spreading. (3) (Geology) A tabular body of igneous (formed by volcanic action) rock that cuts across the structure of adjacent rocks or cuts massive rocks.
Dissolved oxygen (DO) -- The amount of free (not chemically combined) oxygen dissolved in water, wastewater, or other liquid, usually expressed in milligrams per liter, parts per million, or percent of saturation.
Ditch -- A long narrow trench or furrow dug in the ground, as for irrigation, drainage, or a boundary line.
Drainage area -- The total surface area upstream of a point on a stream that drains toward that point. Not to be confused with watershed. The drainage area may include one or more watersheds.
Drainage basin -- The total area of land from which water drains into a specific river.
Dredging -- Removing material (usually sediments) from wetlands or waterways, usually to make them deeper or wider.
Dune-ripple -- A bedform associated with low-gradient, sand-bed channels; the low gradient nature of the channel causes the sand to form a sequence of dunes and small ripples; significant sediment transport typically occurs at most stream stages.
Ecology -- The study of the interrelationships of living organisms to one another and to their surroundings.
Ecosystem -- Recognizable, relatively homogeneous units, including the organisms they contain, their environment, and all the interactions among them.
Embankment -- An artificial deposit of material that is raised above the natural surface of the land and used to contain, divert, or store water, support roads or railways, or for other similar purposes.
Embeddedness -- is a measure of the amount of surface area of cobbles, boulders, snags and other stream bottom structures that is covered with sand and silt. An embedded streambed may be packed hard with sand and silt such that rocks in the stream bottom are difficult or impossible to pick up. The spaces between the rocks are filled with fine sediments, leaving little room for fish, amphibians, and bugs to use the structures for cover, resting, spawning, and feeding. A streambed that is not embedded has loose rocks that are easily removed from the stream bottom, and may even "roll" on one another when you walk on them.
Entrenchment ratio --The width of the flood-prone area divided by the bankfull width.
Epifaunal – "epi" means surface, and "fauna" means animals. Thus, "epifaunal substrate" is structures in the stream (on the stream bed) that provide surfaces on which animals can live. In this case, the animals are aquatic invertebrates (such as aquatic insects and other "bugs"). These bugs live on or under cobbles, boulders, logs, and snags, and the many cracks and crevices found in these structures. In general, older decaying logs are better suited for bugs to live on/in than newly fallen "green" logs and trees.
Ephemeral streams -- Streams that flow only in direct response to precipitation and whose channel is at all times above the water table.
Equilibrium Condition -- The state of a river reach in which the upstream input of energy (flow of water) and materials (sediment and debris) is equal to its output to downstream reaches. Natural river reaches without human impacts tend towards a "stable" state where predictable channel forms are maintained over the long term under varying flow conditions.
Erosion -- Wearing away of rock or soil by the gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical, chemical, or biological forces.
Eutrophic -- Usually refers to a nutrient-enriched, highly productive body of water.
Eutrophication -- The process of enrichment of water bodies by nutrients.
Fine gravel -- Is substrate which is larger than sand, but smaller than coarse gravel. It is between 0.08 and 0.63 inches in diameter.
Flash flood -- A sudden flood of great volume, usually caused by a heavy rain. Also, a flood that crests in a short length of time and is often characterized by high velocity flows.
Floodplain -- Land built of fine particulate organic matter and small substrate that is regularly covered with water as a result of the flooding of a nearby stream.
Floodplain (100-year) -- The area adjacent to a stream that is on average inundated once a century.

Floodplain Function – Flood water access of floodplain which effects the velocity, depth, and slope (stream power) of the flood flow thereby influencing the sediment transport characteristics of the flood (i.e., loss of floodplain access and function may lead to higher stream power and erosion during flood).
Flow -- The amount of water passing a particular point in a stream or river, usually expressed in cubic feet per second (cfs).
Fluvial -- Migrating between main rivers and tributaries. Of or pertaining to streams or rivers.
Fluvial Geomorphology—The study of how rivers and their landforms interact over time through different climatic conditions.
Ford -- A shallow place in a body of water, such as a river, where one can cross by walking or riding on an animal or in a vehicle.
Fry -- A recently hatched fish.
Gabion -- A wire basket or cage that is filled with gravel or cobble and generally used to stabilize streambanks.
Gaging station -- A particular site in a stream, lake, reservoir, etc., where hydrologic data are obtained.
Gallons per minute (gpm) -- A unit used to measure water flow.
Geographic information system (GIS) -- A computer system capable of storing and manipulating spatial data.
Geomorphology -- A branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and the buildup of erosional debris.
Glide -- A section of stream that has little or no turbulence.
Grade control -- A fixed feature on the streambed that controls the bed elevation at that point, effectively fixing the bed elevation from potential incision; typically bedrock, dams. or culverts.
Gradient -- Vertical drop per unit of horizontal distance.
Grass/forb -- Herbaceous vegetation.
Gravel -- An unconsolidated natural accumulation of rounded rock fragments, mostly of particles larger than sand (diameter greater than 2 mm), such as boulders, cobbles, pebbles, granules, or any combination of these.
Groundwater -- Subsurface water and underground streams that can be collected with wells, or that flow naturally to the earth's surface through springs.
Groundwater basin -- A groundwater reservoir, defined by an overlying land surface and the underlying aquifers that contain water stored in the reservoir. In some cases, the boundaries of successively deeper aquifers may differ and make it difficult to define the limits of the basin.
Groundwater recharge -- Increases in groundwater storage by natural conditions or by human activity. See also artificial recharge.
Groundwater table -- The upper surface of the zone of saturation, except where the surface is formed by an impermeable body.
Habitat -- The local environment in which organisms normally live and grow.
Habitat diversity -- The number of different types of habitat within a given area.
Habitat fragmentation -- The breaking up of habitat into discrete islands through modification or conversion of habitat by management activities.
Headcut -- A sharp change in slope, almost vertical, where the streambed is being eroded from downstream to upstream.
Headwater -- Referring to the source of a stream or river.
High gradient streams -- typically appear as steep cascading streams, step/pool streams, or streams that exhibit riffle/pool sequences. Most of the streams in Vermont are high gradient streams.
Hydraulic gradient -- The slope of the water surface. See also streambed gradient.
Hydraulic radius -- The cross-sectional area of a stream divided by the wetted perimeter.
Hydric -- oil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper horizon.
Hydrograph -- A curve showing stream discharge over time.
Hydrologic balance -- An accounting of all water inflow to, water outflow from, and changes in water storage within a hydrologic unit over a specified period of time. Hydrologic region -- A study area, consisting of one or more planning subareas, that has a common hydrologic character.
Hydrologic unit Code (HUC) -- A distinct watershed or river basin defined by an 8-digit code.
Hydrology -- The scientific study of the water of the earth, its occurrence, circulation and distribution, its chemical and physical properties, and its interaction with its environment, including its relationship to living things.
Hyporheic zone -- The area under the stream channel and floodplain where groundwater and the surface waters of the stream are exchanged freely.

Impoundment -- An area where the natural flow of the river has been disrupted by the presence of human-made or natural structure (e.g. weir or beaver dam). The impoundment backwater extends upstream causing sediment to be deposited on the stream bottom.
Improved paths – Paths that are maintained and typically involve paved, gravel or macadam surfaces.
Incised river -- A river that erodes its channel by the process of degradation to a lower base level than existed previously or is consistent with the current hydrology.
Incision ratio -- The low bank height divided by the bankfull maximum depth.
Infiltration (soil) -- The movement of water through the soil surface into the soil.
Inflow -- Water that flows into a stream, lake,
Instream cover -- The layers of vegetation, like trees, shrubs, and overhanging vegetation, that are in the stream or immediately adjacent to the wetted channel.
Instream flows -- (1) Portion of a flood flow that is contained by the channel. (2) A minimum flow requirement to maintain ecological health in a stream.
Instream use -- Use of water that does not require diversion from its natural watercourse. For example, the use of water for navigation, recreation, fish and wildlife, aesthetics, and scenic enjoyment.
Intermittent stream -- Any nonpermanent flowing drainage feature having a definable channel and evidence of scour or deposition. This includes what are sometimes referred to as ephemeral streams if they meet these two criteria.
Irrigation diversion -- Generally, a ditch or channel that deflects water from a stream channel for irrigation purposes.
Islands -- mid-channel bars that are above the average water level and have established woody vegetation.
Kame – a deposit of stratified glacial drift in isolated mounds or steep-sided hills.
Lake -- An inland body of standing water deeper than a pond, an expanded part of a river, a reservoir behind a dam
Landslide -- A movement of earth mass down a steep slope.
Large woody debris (LWD) -- Pieces of wood at least 6 ft. long and 1 ft. in diameter (at the large end) contained, at least partially, within the bankfull area of a channel.
Levee -- An embankment constructed to prevent a river from overflowing (flooding).
Limiting factor -- A requirement such as food, cover, or another physical, chemical, or biological factor that is in shortest supply with respect to all resources necessary to sustain life and thus "limits" the size or retards production of a population.
Low gradient -- streams typically appear slow moving and winding, and have poorly defined riffles and pools.
Macroinvertebrate -- Invertebrates visible to the naked eye, such as insect larvae and crayfish.
Macrophytes -- Aquatic plants that are large enough to be seen with the naked eye.
Mainstem -- The principal channel of a drainage system into which other smaller streams or rivers flow.
Mass movement -- The downslope movement of earth caused by gravity. Includes but is not limited to landslides, rock falls, debris avalanches, and creep. It does not however, include surface erosion by running water. It may be caused by natural erosional processes, or by natural disturbances (e.g., earthquakes or fire events) or human disturbances (e.g., mining or road construction).
Mean annual discharge -- Daily mean discharge averaged over a period of years. Mean annual discharge generally fills a channel to about one-third of its bank-full depth.
Mean velocity -- The average cross-sectional velocity of water in a stream channel. Surface values typically are much higher than bottom velocities. May be approximated in the field by multiplying the surface velocity, as determined with a float, times 0.8.
Meander -- The winding of a stream channel, usually in an erodible alluvial valley. A series of sine-generated curves characterized by curved flow and alternating banks and shoals.
Meander amplitude -- The distance between points of maximum curvature of successive meanders of opposite phase in a direction normal to the general course of the meander belt, measured between center lines of channels.
Meander belt width -- the distance between lines drawn tangential to the extreme limits of fully developed meanders. Not to be confused with meander amplitude.
Meander length -- The lineal distance down valley between two corresponding points of successive meanders of the same phase.
Mid-channel Bars – bars located in the channel away from the banks, generally found in areas where the channel runs straight. Mid-channel bars caused by recent channel instability are unvegetated.
Milligrams per liter (mg/l) -- The weight in milligrams of any substance dissolved in 1 liter of liquid; nearly the same as parts per million by weight.
Moraine – a mass of till either carried by an active glacier or deposited on the land after a glacier recedes.
Natural flow -- The flow past a specified point on a natural stream that is unaffected by stream diversion, storage, import, export, return flow, or change in use caused by modifications in land use.
Neck cutoff -- A channel migration feature where the land that separates a meander bend is cut off by the lateral migration of the channel. This process may be part of the equilibrium regime or associated with channel instability.

Outfall -- The mouth or outlet of a river, stream, lake, drain or sewer.
Outwash – water-transported material carried away from the ablation zone of a melting glacier.
Oxbow -- An abandoned meander in a river or stream, caused by cutoff. Used to describe the U-shaped bend in the river or the land within such a bend of a river.
Peat -- Partially decomposed plants and other organic material that build up in poorly drained wetland habitats.
Perched groundwater -- Groundwater supported by a zone of material of low permeability located above an underlying main body of groundwater with which it is not hydrostatically connected.
Perennial streams -- Streams that flow continuously.
Permeability -- The capability of soil or other geologic formations to transmit water.
pH -- The negative logarithm of the molar concentration of the hydrogen ion, or, more simply acidity.
Planform -- The channel shape as if observed from the air. Changes in planform often involve shifts in large amount of sediment, bank erosion, or the migration of the channel. A channel straightened for agricultural purposes has a highly impacted planform.
Point bar -- The convex side of a meander bend that is built up due to sediment deposition.
Pond -- A body of water smaller than a lake, often artificially formed.
Pool -- A reach of stream that is characterized by deep, low-velocity water and a smooth surface.
Potential plant height -- the height to which a plant, shrub or tree would grow if undisturbed.
Probability of exceedence -- The probability that a random flood will exceed a specified magnitude in a given period of time.
Railroads – Used or unused railroad infrastructure.
Rapids -- A reach of stream that is characterized by small falls and turbulent, high-velocity water.
Reach -- A section of stream having relatively uniform physical attributes, such as valley confinement, valley slope, sinuosity, dominant bed material, and bed form, as determined in the Phase 1 assessment.
Rearing habitat -- Areas in rivers or streams where juvenile fish find food and shelter to live and grow.
Reference stream type --Uses preliminary observations to determine the natural channel form and process that would be present in the absence of anthropogenic impacts to the channel and the surrounding watershed.
Refuge area -- An area within a stream that provides protection to aquatic species during very low and/or high flows.
Regime theory -- A theory of channel formation that applies to streams that make a part of their boundaries from their transported sediment load and a portion of their transported sediment load from their boundaries. Channels are considered in regime or equilibrium when bank erosion and bank formation are equal.
Restoration -- The return of an ecosystem to a close approximation of its condition prior to disturbance.
Riffle -- A reach of stream that is characterized by shallow, fast-moving water broken by the presence of rocks and boulders.
Riffle-pool ratio -- The ratio of surface area or length of pools to the surface area or length of riffles in a given stream reach; frequently expressed as the relative percentage of each category. Used to describe fish habitat rearing quality.
Riffle-step ratio-- ratio of the distance between riffles to the stream width.
Riparian area -- An area of land and vegetation adjacent to a stream that has a direct effect on the stream. This includes woodlands, vegetation, and floodplains. Riparian buffer is the width of naturally vegetated land adjacent to the stream between the top of the bank (or top of slope, depending on site characteristics) and the edge of other land uses. A buffer is largely undisturbed and consists of the trees, shrubs, groundcover plants, duff layer, and naturally uneven ground surface. The buffer serves to protect the water body from the impacts of adjacent land uses. Riparian corridor includes lands defined by the lateral extent of a stream's meanders necessary to maintain a stable stream dimension, pattern, profile, and sediment regime. For instance, in stable pool-riffle streams, riparian corridors may be as wide as 10-12 times the channel's bankfull width. In addition the riparian corridor typically corresponds to the land area surrounding and including the stream that supports (or could support if unimpacted) a distinct ecosystem, generally with abundant and diverse plant and animal communities (as compared with upland communities).
Riparian habitat -- The aquatic and terrestrial habitat adjacent to streams, lakes, estuaries, or other waterways.
Riparian -- Located on the banks of a stream or other body of water.
Riparian vegetation -- The plants that grow adjacent to a wetland area such as a river, stream, reservoir, pond, spring, marsh, bog, meadow, etc., and that rely upon the hydrology of the associated water body.
Ripple -- (1) A specific undulated bed form found in sand bed streams. (2) Undulations or waves on the surface of flowing water.
Riprap -- Rock or other material with a specific mixture of sizes referred to as a "gradation," used to stabilize streambanks or riverbanks from erosion or to create habitat features in a stream.
River channels --Large natural or artificial open streams that continuously or periodically contain moving water, or which form a connection between two bodies of water.
River miles --Generally, miles from the mouth of a river to a specific destination or, for upstream tributaries, from the confluence with the main river to a specific destination.

River reach -- Any defined length of a river.
River stage -- The elevation of the water surface at a specified station above some arbitrary zero datum (level).
Riverine -- Relating to, formed by, or resembling a river including tributaries, streams, brooks, etc.
Riverine habitat -- The aquatic habitat within streams and rivers.
Roads -- Transportation infrastructure. Includes private, town, state roads, and roads that are dirt, gravel, or paved.
Rock -- A naturally formed mass of minerals.
Rootwad -- The mass of roots associated with a tree adjacent to or in a stream that provides refuge for fish and other aquatic life.
Run (in stream or river) -- A reach of stream characterized by fast-flowing, low-turbulence water.
Runoff -- Water that flows over the ground and reaches a stream as a result of rainfall or snowmelt.
Sand -- Small substrate particles, generally from 0.002 to 0.08 in diameter. Sand is larger than silt and smaller than gravel.
Scour -- The erosive action of running water in streams, which excavates and carries away material from the bed and banks. Scour may occur in both earth and solid rock material and can be classed as general, contraction, or local scour.
Sediment -- Soil or mineral material transported by water or wind and deposited in streams or other bodies of water.
Sedimentation -- (1) The combined processes of soil erosion, entrainment, transport, deposition, and consolidation. (2) Deposition of sediment.
Seepage -- The gradual movement of a fluid into, through, or from a porous medium. Segment: A relatively homogenous section of stream contained within a reach that has the same reference stream characteristics but is distinct from other segments in the reach in one or more of the following parameters: degree of floodplain encroachment, presence/absence of grade controls, bankfull channel dimensions (W/D ratio, entrenchment), channel sinuosity and slope, riparian buffer and corridor conditions, abundance of springs/seeps/adjacent wetlands/stormwater inputs, and degree of channel alterations.
Sensitivity -- of the valley, floodplain, and/or channel condition to change due to natural causes and/or anticipated human activity.
Shoals -- unvegetated deposits of gravels and cobbles adjacent to the banks that have a height less than the average water level. In channels that are over-widened, the stream does not have the power to transport these larger sediments, and thus they are deposited throughout the channel as shoals.
Silt -- Substrate particles smaller than sand and larger than clay; between 0.0001 and 0.002 inches in diameter.
Siltation -- The deposition or accumulation of fine soil particles.
Sinuosity -- The ratio of channel length to direct down-valley distance. Also may be expressed as the ratio of down-valley slope to channel slope.
Slope -- The ratio of the change in elevation over distance.
Slope stability -- The resistance of a natural or artificial slope or other inclined surface to failure by mass movement.
Snag -- Any standing dead, partially dead, or defective (cull) tree at least 10 in. in diameter at breast height and at least 6 ft tall. Snags are important riparian habitat features.
Spawning -- The depositing and fertilizing of eggs (or roe) by fish and other aquatic life.
Spillway -- A channel for reservoir overflow.
Stable channel -- A stream channel with the right balance of slope, planform, and cross section to transport both the water and sediment load without net long-term bed or bank sediment deposition or erosion throughout the stream segment.
Stone -- Rock or rock fragments used for construction.
Straightening -- the removal of meander bends, often done in towns and along roadways, railroads, and agricultural fields.
Stream -- A general term for a body of water flowing by gravity; natural watercourse containing water at least part of the year. In hydrology, the term is generally applied to the water flowing in a natural narrow channel as distinct from a canal. Stream banks are features that define the channel sides and contain stream flow within the channel; this is the portion of the channel bank that is between the toe of the bank slope and the bankfull elevation. The banks are distinct from the streambed, which is normally wetted and provides a substrate that supports aquatic organisms. The top of bank is the point where an abrupt change in slope is evident, and where the stream is generally able to overflow the banks and enter the adjacent floodplain during flows at or exceeding the average annual high water.
Stream channel -- A long narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.
Stream condition -- Given the land use, channel and floodplain modifications documented at the assessment sites, the current degree of change in the channel and floodplain from the reference condition for parameters such as dimension, pattern, profile, sediment regime, and vegetation.

Stream gradient -- A general slope or rate of change in vertical elevation per unit of horizontal distance of the bed, water surface, or energy grade of a stream.
Stream morphology -- The form and structure of streams.
Stream order -- A hydrologic system of stream classification. Each small unbranched tributary is a first-order stream. Two first-order streams join to make a second-order stream. A third-order stream has only first-and second-order tributaries, and so forth.
Stream reach -- An individual segment of stream that has beginning and ending points defined by identifiable features such as where a tributary confluence changes the channel character or order.
Stream type -- Gives the overall physical characteristics of the channel and helps predict the reference or stable condition of the reach.
Stream type departure -- When the current stream type differs from the reference stream type as a response to anthropogenic or severe natural disturbances. These departures are often characterized by large-scale incision, deposition, or changes in planform.
Streambank armoring – The installation of concrete walls, gabions, stone riprap, and other large erosion resistant material along stream banks.
Streambank erosion -- The removal of soil from streambanks by flowing water.
Streambank stabilization -- The lining of streambanks with riprap, matting, etc., or other measures intended to control erosion.
Streambed -- (1) The unvegetated portion of a channel boundary below the baseflow level. (2) The channel through which a natural stream of water runs or used to run, as a dry streambed.
Streamflow -- The rate at which water passes a given point in a stream or river, usually expressed in cubic feet per second (cfs).
Step (in a river system) --A step is a steep, step-like feature in a high gradient stream (> 2%). Steps are composed of large boulders lines across the stream. Steps are important for providing grade-control, and for dissipating energy. As fast-shallow water flows over the steps it takes various flow paths thus dissipating energy during high flow events.
Substrate -- (1) The composition of a streambed, including either mineral or organic materials. (2) Material that forms an attachment medium for organisms.
Surface erosion -- The detachment and transport of soil particles by wind, water, or gravity. Or a group of processes whereby soil materials are removed by running water, waves and currents, moving ice, or wind.
Surface water -- All waters whose surface is naturally exposed to the atmosphere, for example, rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc., and all springs, wells, or other collectors directly influenced by surface water.
Suspended sediment -- Sediment suspended in a fluid by the upward components of turbulent currents, moving ice, or wind.
Suspended sediment load -- That portion of a stream's total sediment load that is transported within the body of water and has very little contact with the streambed.
Tailwater -- (1) The area immediately downstream of a spillway. (2) Applied irrigation water that runs off the end of a field.
Thalweg -- (1) The lowest thread along the axial part of a valley or stream channel. (2) A subsurface, groundwater stream percolating beneath and in the general direction of a surface stream course or valley. (3) The middle, chief, or deepest part of a navigable channel or waterway.
Tractive Force --The drag on a streambed or bank caused by passing water, which tends to pull soil particles along with the streamflow.
Transpiration -- An essential physiological process in which plant tissues give off water vapor to the atmosphere.
Tributary -- A stream that flows into another stream, river, or lake.
Turbidity -- A measure of the content of suspended matter that interferes with the passage of light through the water or in which visual depth is restricted. Suspended sediments are only one component of turbidity.
Urban runoff -- Storm water from city streets and gutters that usually carries a great deal of litter and organic and bacterial wastes into the sewer systems and receiving waters.
Valley confinement -- Referring to the ratio of valley width to channel width. Unconfined channels (confinement of 4 or greater) flow through broader valleys and typically have higher sinuosity and area for floodplain. Confined channels (confinement of less than 4) typically flow through narrower valleys.
Valley wall -- The side slope of a valley, which begins where the topography transitions from the gentle-sloped valley floor. The distance between valley walls is used to calculate the valley confinement.
Variable-stage stream -- Stream flows perennially but water level rises and falls significantly with storm and runoff events.
Velocity -- In this concept, the speed of water flowing in a watercourse, such as a river.

Washout -- (1) Erosion of a relatively soft surface, such as a roadbed, by a sudden gush of water, as from a downpour or floods. (2) A channel produced by such erosion.
Water quality -- A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.
Waterfall -- A sudden, nearly vertical drop in a stream, as it flows over rock.
Watershed -- An area of land whose total surface drainage flows to a single point in a stream.
Watershed management -- The analysis, protection, development, operation, or maintenance of the land, vegetation, and water resources of a drainage basin for the conservation of all its resources for the benefit of its residents.
Watershed project -- A comprehensive program of structural and nonstructural measures to preserve or restore a watershed to good hydrologic condition. These measures may include detention reservoirs, dikes, channels, contour trenches, terraces, furrows, gully plugs, revegetation, and possibly other practices to reduce flood peaks and sediment production.
Watershed restoration -- Improving current conditions of watersheds to restore degraded habitat and provide long-term protection to aquatic and riparian resources.
Weir -- A structure to control water levels in a stream. Depending upon the configuration, weirs can provide a specific "rating" for discharge as a function of the upstream water level.
Wetland -- Areas adjacent to, or within the stream, with sufficient surface/groundwater influence to have present hydric soils and aquatic vegetation (e.g. cattails, sedges, rushes, willows or alders).
Width/depth ratio -- The ratio of channel bankfull width to the average bankfull depth. An indicator of channel widening or aggradation, and used for stream type classification.