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Phase 2 Stream Geomorphic Assessment
Winooski River Watershed
Main Stem in Village and Tributaries
Town of Cabot
Washington County, Vermont

Final Report
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EXECUTIVE SUMMARY

A Phase 2 Stream Geomorphic Assessment of several targeted reaches was conducted within the Upper Winooski River watershed by Bear Creek Environmental in the autumn of 2005. The project was funded through FEMA Map Modernization Management Support (MMMS) to support the development of fluvial erosion hazard maps. The Vermont River Management Program provided technical expertise and shared quality control/quality assurance responsibilities with Bear Creek Environmental. The study included one reach on the main stem of the Upper Winooski River and six tributary reaches. The seven targeted reaches were divided into sixteen segments based on confinement, stream type, land use and other important factors.

The study followed the Phase 2 assessment protocol developed by the ANR River Management Program. Information from the study came from the ANR, the Vermont Mapping Program, the Vermont Center for Geographic Information, the Town of Cabot, and field data collected by Bear Creek Environmental. The Phase 2 Rapid Stream Assessment included field observations and measurements that are used to verify the Phase 1 stream geomorphic data, to provide field evidence of channel adjustment processes, and rate the health and condition of the riparian corridor and aquatic habitat.

The Phase 2 Rapid Geomorphic Assessment (RGA) is important for understanding the geomorphic stability of a reach. Phase 2 assessments were conducted on seven reaches targeted (15 segments) in this study. Six segments resulted in a geomorphic condition of good, having evidence of only minor adjustment. Eight of the segments assessed for the Phase 2 study resulted in a geomorphic condition of fair, showing signs of major adjustment. One segment, on the tributary that flows adjacent to the Cabot Recreation field, resulted in a geomorphic condition of poor; this segment was observed as undergoing extreme geomorphic adjustment.

Many of the tributaries and the main stem of the Winooski River in Cabot are experiencing high rates of bank erosion. The bank erosion has been accelerated due to land use activities and channel and floodplain modifications. Significant channel straightening, bank armoring, berming, and floodplain encroachment have occurred within this river system both on the mainstem and on the lower ends of the tributaries. These impacts have resulted in the loss of natural energy dissipation of the river system via meandering and flooding the fields along the river. Over time, the river has down cut into the streambed resulting in loss of floodplain access and increased energy within the channel. The increased energy within the channel has lead to severe bank erosion and subsequent channel widening.

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1.0 INTRODUCTION

A Phase 1 stream geomorphic assessment of the Upper Winooski River watershed was completed during early summer 2004 by Bear Creek Environmental (BCE) and the Cabot Conservation Committee. The results of the Phase 1 assessment are provided in a report issued by Bear Creek Environmental (2004a). Phase 2 Assessments were completed of the main stem of the Upper Winooski River from the Cabot/Marshfield Town lines to above the Village of Cabot during August 2004 (Bear Creek Environmental 2004b).

BCE was retained by the State of Vermont, Agency of Natural Resources, to assess additional Phase 2 reaches in Cabot during fall 2005. This second phase of Phase 2 funding was used to gain information about the geomorphic condition of the Upper Winooski River and tributaries in preparation for the production of fluvial erosion hazard (FEH) maps. Gary Gulka, of the Cabot Conservation Committee acquired landowner permission to assess these additional Phase 2 reaches. Mary Nealon of BCE was the Field Task Leader for the project.

The Winooski River Watershed has a watershed size of 24.5 square miles just above the confluence of Molly Falls Brook in Marshfield, just south of the Cabot/Marshfield Town lines (Figure 1). The Phase 2 study focused on one reach on the main stem of the Winooski River within the Village of Cabot as well as two major tributaries (Tributaries T2 and T3). A reach

location map is included below for reference (Figure 2).

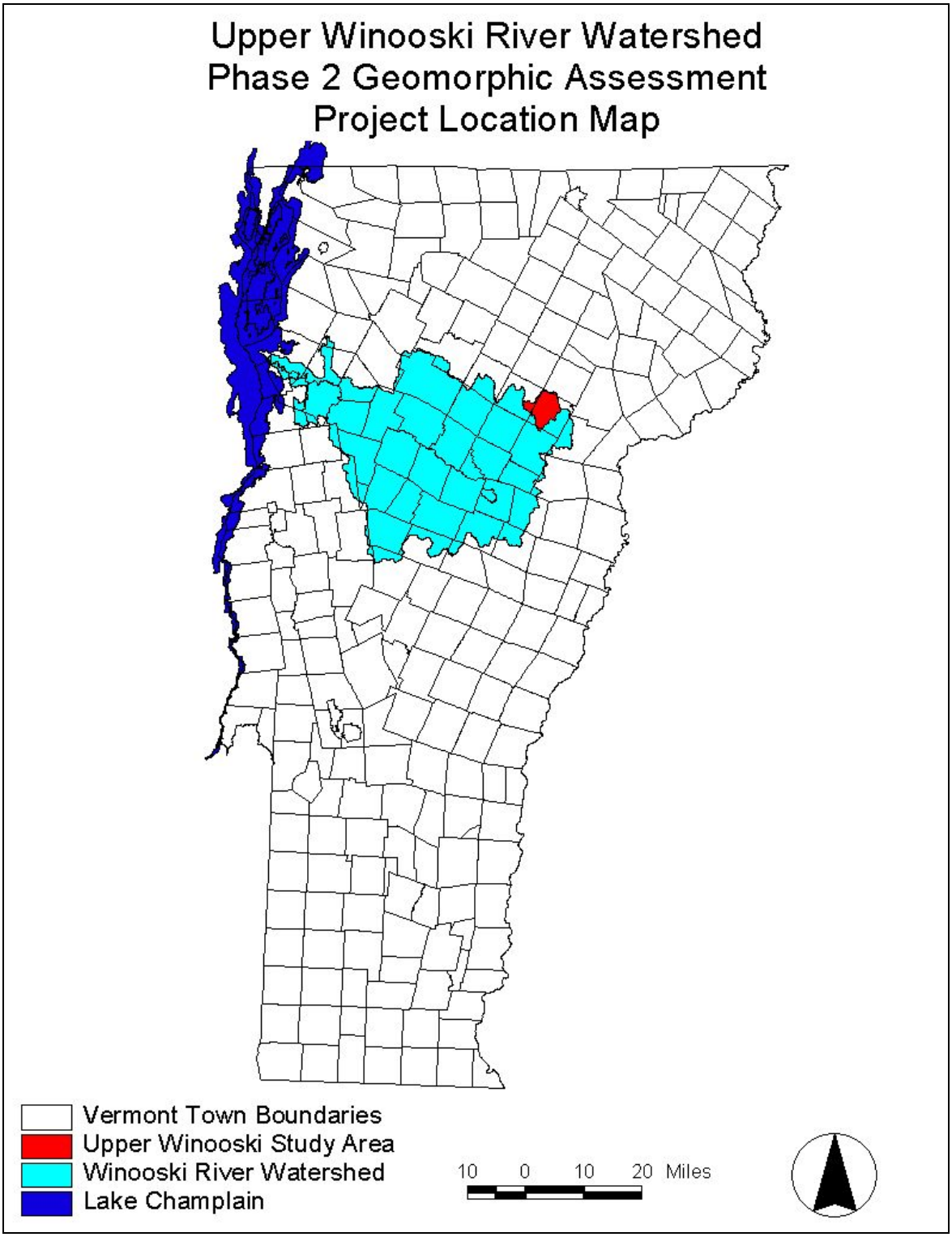

Figure 1. Project Location Map

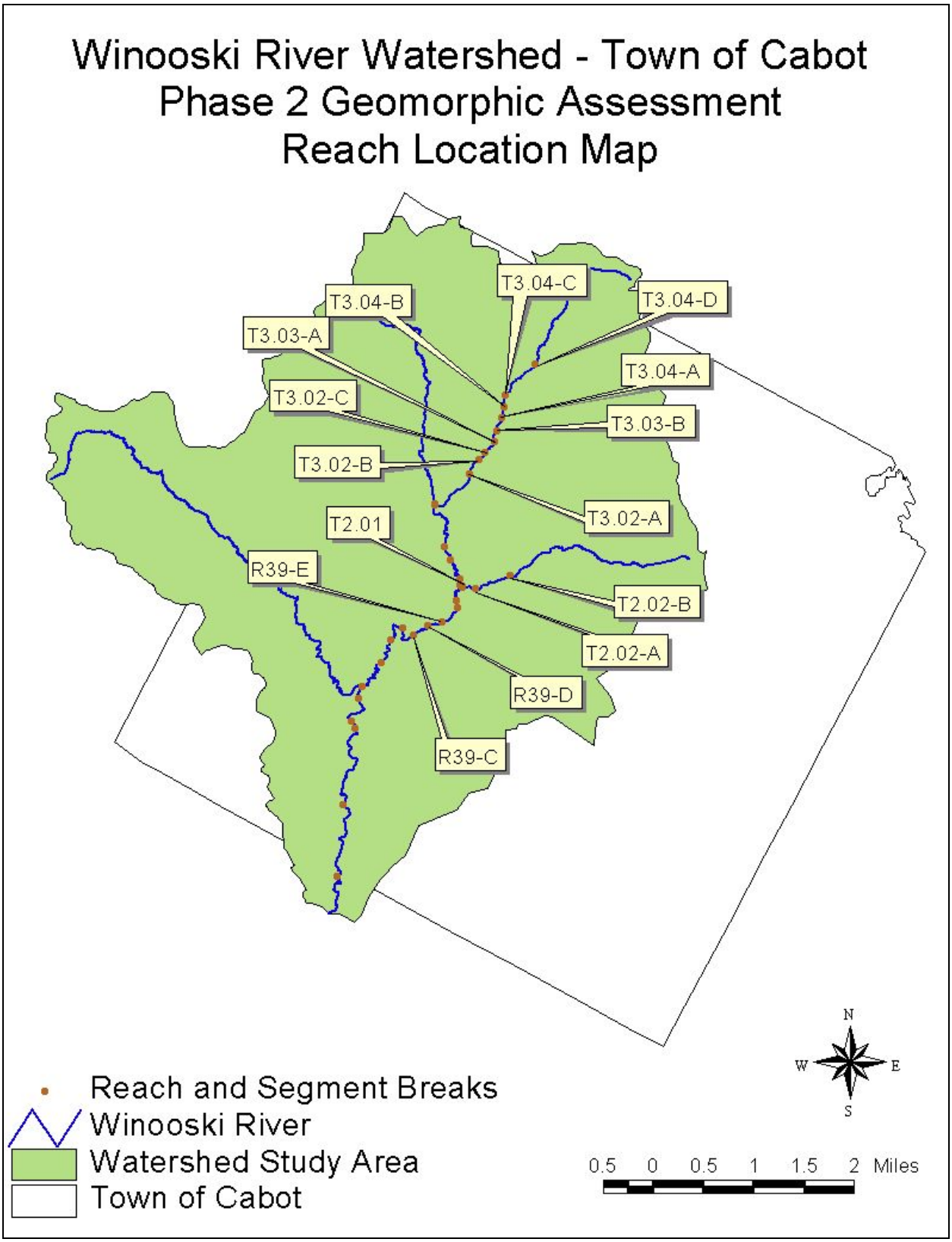

Figure 2. Reach Location Map

2.0 PHASE 2 METHODOLOGY

The Phase 2 assessment followed procedures specified in the Vermont Stream Geomorphic Assessment Handbook Phase 2 (Vermont Agency of Natural Resources 2005). All assessment data were recorded on the Agency of Natural Resources Phase 2 data sheets, and were entered in to the ANR Stream Geomorphic Assessment data management system (DMS). The Phase 1 database was updated using the field data from the Phase 2 assessment.

2.1 Phase 2 Field Protocols

The ANR's Phase 2 stream geomorphic assessment protocol includes seven categories of investigation. These categories are as follows:

1. Valley and River Corridor
2. Stream Channel
3. Riparian Banks, Buffers and Corridor
4. Flow Modifiers
5. Channel, Bed and Planform Changes
6. Rapid Habitat Assessment (RHA)
7. Rapid Geomorphic Assessment (RGA)

The parameters and protocols used for undertaking each of the above steps are outlined in the Phase 2 Handbook (Vermont Agency of Natural Resources 2005). The entire length of each Phase 2 reach was walked to determine segment breaks. Bank erosion, grade control structures, bank revetments, debris jams, depositional features, stormwater inputs, flood chutes and other important features were mapped within all segments.

2.2 Phase 2 QA/QC Review

The Phase 1 DMS and ArcView shapefiles were updated by Michael Blazewicz and Pamela DeAndrea based on the Phase 2 field assessment work during December 2005. Mary Nealon and Michael Blazewicz provided QA/QC to critical components of the RGA data in February of 2006. The DMS and the ArcView shapefiles for the Upper Winooski Phase 2 study were submitted to Ty Mack and Kari Dolan of the ANR for a quality assurance (QA/QC) review in February 2006. A response to QA comments received from the ANR was provided by BCE on March 22, 2006.

3.0 PHASE 2 RESULTS

Phase 2 assessments of seven reaches were performed by BCE during October and November 2005. One segment T3.03-B was heavily influenced by beaver dams, and therefore, in accordance with ANR protocols, was not fully assessed. In total, the seven assessed reaches were broken into fourteen segments following the Phase 2 protocol (ANR 2005). The Phase 2 Reach Summary Reports from the ANR Data Management System for each segment are provided on pages 1 through 32 of Appendix A.

3.1 Reach R39

Winooski River reach R39, which flows through the Village of Cabot, was only partially completed during the 2004 assessment. In 2005, at the time of this study, BCE scientists completed the geomorphic assessment of this reach. Due to changes in channel confinement the remaining portion of this reach was broken into three segments.

Segment R39-C

Winooski River segment R39-C begins slightly downstream of Cabot Creamery Cooperative, Inc. (below Cabot Village) and continues upstream for 900 feet. The reach flows through a naturally narrowly confined valley over a portion of broken ledge. The hillsides on both side of the stream are extremely steep. The reach was classified as a "B" stream type dominated by boulder sized substrates (Figure 3). The bedform of the reach was classified as plane bed. Overall this reach was assessed as being in good geomorphic condition.

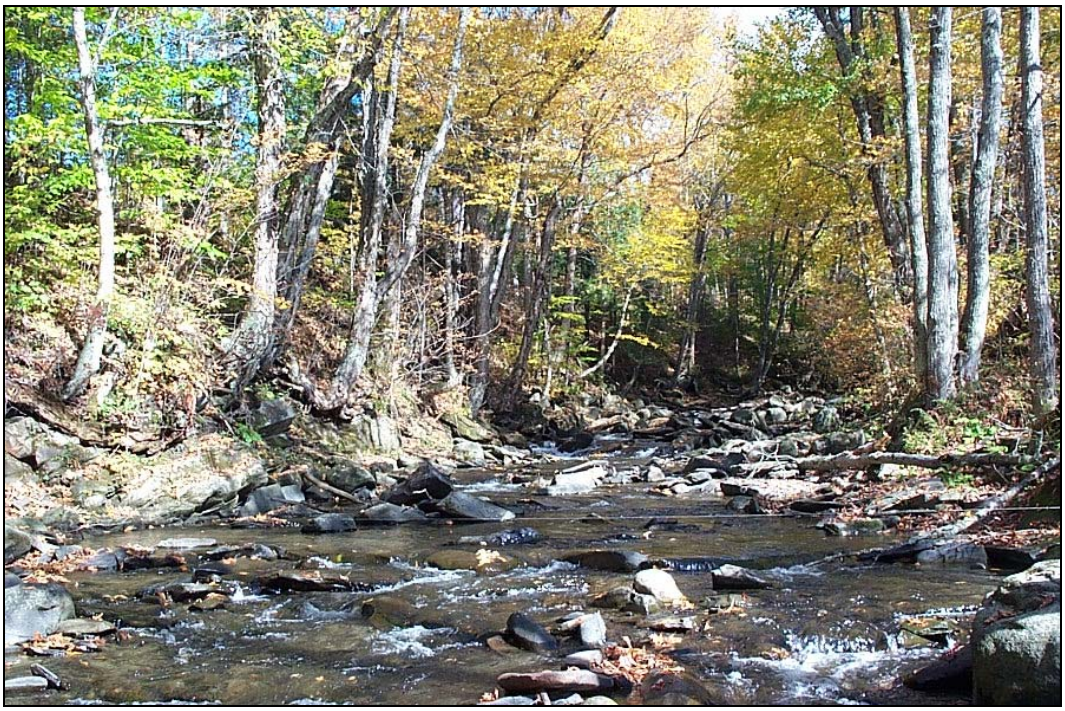

Figure 3: R39-C is a B channel dominated by boulder sized substrates.

Segment R39-D

Winooski River segment R39-D begins across from Cabot Creamery and flows for 850 feet upstream to just below the Elm Street Bridge. The reach was believed to have been a "C" channel by reference; however, the segment has historically incised becoming a Bc. This incision has led to loss of a riffle-pool bedform. The stream has been actively adjusting through this reach through channel widening and planform adjustment. These adjustment processes have created a new smaller floodplain bench at the new bankfull level, however, the reach remains entrenched (Figure 4).

The stream corridor of this reach has been impacted by development. There are several stormwater outfalls into this reach. The right buffer averages between 5 and 25 feet, indicating disturbance.

Figure 4: R39-D is a C channel by reference that has undergone historic incision. The stream is actively widening and undergoing planform adjustment as it works to build a new floodplain bench.

Segment R39-E

Segment R39-E begins just downstream of the Elm Street Bridge and continues upstream to the end of the reach, just north of the hardware store in Cabot Village. Here the valley walls of the Winooski River naturally narrow to a semi-confined valley. The reference stream type for this segment is a "B" channel dominated by cobbles. Floodplain encroachment, channel straightening, and streambank armoring, however, have combined to cause historic channel degradation within this reach and a change to a narrowly confined stream. The left streambank had 100% development within its corridor and less than five feet of riparian vegetation width (Figure 5). BCE scientists classified the reach as an F type channel with a plane bed form.

Figure 5: R39-E has undergone historic incision that may be associated with floodplain encroachment, straightening and armoring.

3.2 Reach T2.01

Upper Winooski River watershed tributary T2 was broken into three reaches during the Phase 1 Assessment. Reach T2.01 begins at the confluence with the Winooski River just north of Cabot Village. The reach runs for 700 feet adjacent to the town recreation field. Extensive channel management has influenced this reach. Both the right and left banks have been armored with rock rip-rap and walls for over three-quarters of the reach. Additionally, a berm runs along the top of the left bank for 100 feet. Although the reach spills out into a broad valley, channel straightening has reduced the sinuosity of this reach to very low. Riparian buffer conditions on both banks have been highly altered, particularly on the right bank where woody vegetation has been removed completely. Raising of the elevation of the recreation field back in the late 1990s has contributed to loss of floodplain access for this small tributary.

By reference, this reach should be a "C" type channel with a riffle-pool bedform. The combined channel management activities, however, have led to a stream type departure.

BCE scientists found evidence of historic channel incision (the incision ratio was measured to be 2.1). This incision was followed by widening as the stream attempted to redevelop a new floodplain at a lower elevation. Widening, characterized by severe bank erosion, has been managed by extensive armoring of the banks. The resulting response and management has led to an "F" type channel with a plane bed form (Figure 6).

Figure 6: T2.01 has been straightened. Incision and widening have created an "F" type channel that is no longer a riffle-pool system.

3.3 Reach T2.02

Winooski River tributary reach T2.02 was broken into two segments by BCE scientists during the Phase 2 Assessment. The break was made to capture a change in existing stream type.

Segment T2.02-A

Segment T2.02-A begins above the Main Street bridge and continues upstream for several thousand feet. At the downstream end of the reach, the stream winds past the

Cabot Town sand and gravel storage yard. Sand piles from the storage yard have removed access to the floodplain as well as allowing fine sediments to actively enter the stream system (Figure 7). Upstream of the town's sand yard the segment flows through a forested valley until reaching a bedrock waterfall that marks the end of the segment.

Extreme historic degradation has occurred in this segment. BCE scientists measured the incision ratio to be 2.8. As a result of floodplain loss, the stream has widened and undergone major planform adjustments (Figure 8). BCE scientists recorded that nearly half of the total length of each bank has been eroded by channel adjustment processes. In addition to this excess sediment, several mass failures were observed within this reach. By reference, this stream flows through a broad valley and is a "C" type channel with a plane bed form by reference. The major channel adjustments, however, have caused a stream type departure to a "B" channel. Widening and planform adjustment is likely to continue to occur where boundary conditions allow as the stream works to develop a wide floodplain and evolve back into a "C" type channel.

Figure 7: The Cabot Town sand and gravel storage yard has filled in the floodplain of segment T2.02-A as well as contributed fine sediment to the stream system.

Figure 8: Segment T2.02-A has historically incised, widened, and rebuilt a small floodplain.

Segment T2.02-B

Tributary segment T2.02-B begins at a bedrock waterfall and continues upslope for 4500 feet until reaching the confluence of a major tributary several hundred feet upstream from Menard Road. The segment flows through a forested valley with well forested buffers on both banks. Despite grade control at the downstream end of this reach, this reach has also undergone extreme incision. The incision ratio was measured to be 2.1. Although the river is a "C" channel by reference flowing through a very broad valley, active incision has led to major widening and planform adjustment as the stream attempts to redevelop a new floodplain at a lower elevation (Figure9). Widening is evident in that nearly half of both streambanks were eroded and many trees had fallen into the channel. Planform adjustment was evident through multiple channel avulsions, flood chutes, and the undercutting of outside banks which has led to multiple mass failures.

The combination of these channel adjustments has led to a predominately "F" type stream channel. This reach will likely continue to undergo major planform adjustment and widening as a new floodplain is developed.

Figure 9: Typical cross-section along segment T2.02-B with weak riffle-pool bedform. The brook has shown extreme degradation, widening, and planform adjustment.

3.4 Reach T3.01

Upper Winooski River tributary T3 was broken into five reaches during the Phase 1 Assessment. Reach T3.01 begins south of Houston Hill Road at the confluence with the Winooski River and continues upstream under South Walden Road approximately 2800 feet. The dominant land use within the river corridor is hay field. Some road and a few residences are also located within the corridor. This segment flows through a very broad valley and is an "E" type channel by reference. Historic channel straightening through this reach has been extensive. Channel armoring has occurred on over a quarter of each bank. As a result, the reach is somewhat incised (incision ratio of 1.55) and has lost the meander geometry that would otherwise develop a well defined riffle-pool bedform. Instead, it is a weak-riffle pool "E" type channel that has only marginal

(less than 5 feet wide) riparian buffer and has likely lost much of its former floodplain access (Figure 10). In response, the channel was observed to be in the process of major widening and undergoing minor planform adjustment as it works to redevelop a low floodplain bench and regain its former sinuosity.

Figure 10: Segment T3.01 is an "E" type channel that has incised due to historic straightening and armoring.

3.5 Reach T3.02

Upper Winooski tributary reach T3.02 begins approximately 2800 feet above the confluence of the main stem. Here, the slope increases and the valley width becomes narrower. The reach continues upstream to where a major tributary enters the brook. Here also, the channel slope decreases, the road backs away from the stream, and the entrenchment changes. BCE scientists segmented this reach into three segments based on an observed change in entrenchment, therefore resulting in different reference stream types.

Segment T3.02-A

T3.02-A is just under 1000 feet in length. It is a highly impacted segment due to South Walden Road, which runs along the entire right corridor. In addition, portions of the

stream have been manually straightened. Four hundred feet of windrowing was observed on the right bank. One quarter of each bank has been impacted by rip-rap and channel armoring. The major adjustment process found was historic degradation which has led to an incision ratio of 1.5. Minor widening and planform adjustment is currently occurring within the segment. Despite these historic impacts and adjustment, the channel remains a "C" type stream which has a weak riffle-pool bedform (Figure 11).

Figure 11: Despite historic incision associated with straightening and floodplain encroachment, segment T3.02-A has retained some floodplain access and remains a "C" type channel.

Segment T3.02-B

Segment T3.02-B is a short segment of only 500 feet. It begins where bedrock ledges begin to dominate the stream bottom and the valley walls of the stream narrow. This narrowing of the valley wall has lowered the entrenchment of the stream creating a "B" type channel by reference. Due to the extremely stable boundary condition of the streambanks (mostly bedrock) and streambed (21% bedrock), this segment has remained a "B" type stream channel. Minor widening and planform adjustment was

observed within this reach, however, geomorphic condition appears good despite some impacts to the riparian buffer (Figure 12).

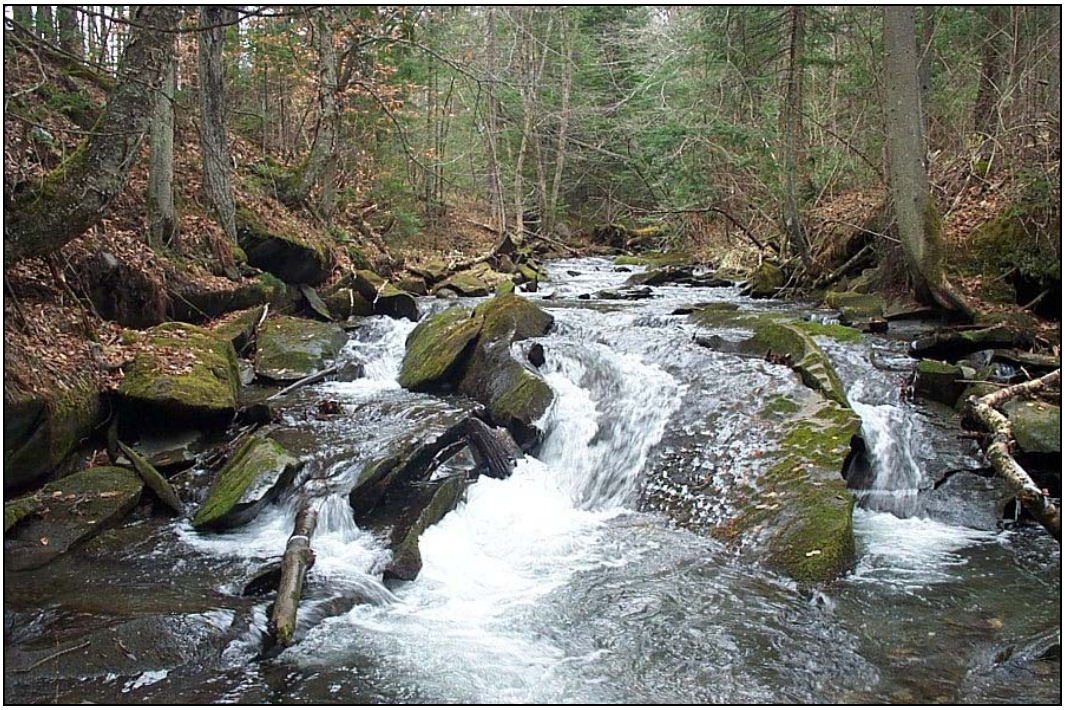

Figure 12: Segment T3.02-B is a "B" type channel in good geomorphic condition.

Segment T3.02-C

Segment T3.02-C is another short segment. It begins above the bedrock grade control of T3.02-B and continues upstream for 800 feet until a tributary enters the brook and reach T3.03 begins. This segment flows through a fairly well forested riparian buffer comprised of mixed trees. There is only minor floodplain encroachment within the reach from S. Walden Road. In general, the stream appears to have retained its natural sinuosity through this reach and its reference "C" type riffle-pool system. Minor degradation (incision ratio was measured to be 1.2) may have initiated some minor widening and planform adjustment through the reach; however, overall it is in good geomorphic condition (Figure 13).

Figure 13: Segment T3.02-C is undergoing some minor widening and planform adjustment, however, is in good geomorphic condition as a "C" type riffle-pool stream.

3.6 Reach T3.03

Upper Winooski tributary reach T3.03 captures a very broad valley with a low slope that occurs between steeper reaches on Tributary 3. BCE scientists segmented this reach into two segments due to the impact of beaver dams in the upper portion of this reach.

Segment T3.03-A

Segment T3.03-A flows through a very broad valley for 800 feet. The left corridor is dominated by hay fields, while shrubs and saplings dominate the right. Over half of the right river corridor has been encroached upon by South Walden Road. Extensive historic channel straightening has occurred within this segment. This straightening has likely led to channel incision (measured ratio was 1.25). Removal of riparian vegetation, combined with channel adjustment following incision has caused over half of the

streambanks of this reach to show sign of active erosion. In response, over one third of each bank has been rip-rapped with rock armor, further destabilizing the channel. The reach is currently undergoing extreme planform adjustment and widening (Figure 14). At the time of the study the reach has remained an "E" type channel with a riffle-pool bedform.

Figure 14: Segment T3.03-A is undergoing extreme planform adjustment and widening.

Segment T3.03-B

Segment T3.03-B was only partially assessed due to six beaver dams which have altered nearly all of the 650 feet of the 850 total feet of this segment at the time of this study (Figure 15). In general this reach was bordered by a healthy riparian buffer and would be considered an "E" type stream by reference.

Figure 15: Water and sediment flow through segment T3.03-B was altered by six beaver dams at the time of the study.

3.7 Reach T3.04

Upper Winooski tributary reach T3.04 encompasses a variety of stream types. BCE scientists segmented this reach into four segments due to changes in observed stream type and condition.

Segment T3.04-A

Segment T3.04-A is a 750 foot segment that has been extensively historically straightened. The segment corridor is dominated by shrub and saplings on the left side (where the buffer width is over 100 feet wide) and residential development on the right (where the buffer width is less than 5 feet wide) (Figure 16). Rock armoring of the channel exists on 360 feet of the right bank. While this segment has remained an "E" type channel, historic straightening has caused the reference riffle-pool bedform to be replaced with a plane bed system. In addition, this straightening has likely led to bed degradation (the incision ratio was measured to be 1.7). This major historic incision is being followed by minor aggradation, widening, and planform adjustment.

Figure 16: Segment T3.04-A has been straightened and incised. The right buffer has been significantly impacted.

Segment T3.04-B

Segment T3.04-B is another relatively short segment of 775 feet in length. Although South Walden Road has impacted 500 feet of the right streambank, in general, this reach has retained high quality riparian vegetation and good planform geometry. This reference floodplain, dominated by alder (*Alnus*) and willow (*Salix*) species, maintains a good boundary condition to slow adjustment of this "E" type channel (Figure 17). Although there is evidence of historic channel degradation, BCE scientists found only minor planform adjustment and widening occurring. On the stream right, a new low floodplain bench has already been developed along much of the reach.

Of the impacts that have occurred to this reach, perhaps the most profound are the two channel constrictions, a four foot diameter culvert (Figure 18) and an old foot bridge, that are disrupting sediment transport in the reach.

Figure 17: Segment T3.04-B has a healthy riparian buffer of native shrubs that help to maintain the "E" type channel.

Figure 18: An undersized culvert on segment T3.04-B is disrupting sediment transport and flow through this reach.

Segment T3.04-C

Segment T3.04-C is a segment of nearly 2500 feet that begins where the valley wall confines and the slope of the tributary increases. The segment flows through forested land of mixed trees over several bedrock ledges that provide grade control to the reach. The stream is a naturally semi-confined "B" type system with a step-pool form (Figure 19). While there has been some evidence of channel straightening along 500 feet of the segment, the reach appears to be mostly unaffected by it. Again good grade controls and a forested buffer are keeping the segment relatively stable. Some minor planform adjustment was noted by BCE scientists; however, this was typically associated with large woody debris recruitment as the stream adjusted around a fallen tree. Overall this reach was in good geomorphic condition.

Figure 19: Segment T3.04-C is a "B" type channel with a healthy riparian buffer.

Segment T3.04-D

T3.04-D is a short segment of only 700 feet in length. At the start of this segment, the slope of the channel decreases and the valley width broadens to a narrow valley. In this narrow valley, the stream becomes a less entrenched "C" type channel with a riffle-pool

bedform (Figure 20). This segment flows through an undisturbed forested buffer. Only very minor degradation was observed in this reach, which is in overall good geomorphic condition.

Figure 20: Segment T3.04-D is in good geomorphic condition.

4.0 GEOMORPHIC CONDITION

Understanding the response to changes in the sediment regime, hydrology, and the channel area and planform of the Upper Winooski River is highly useful for informing restoration efforts. Such responses are influenced by past channel management, the current condition, channel evolution processes that are occurring within the reach, and the sensitivity of the stream to these changes.

4.1 Channel and Floodplain Management History

Natural and anthropogenic impacts may alter the delicate equilibrium of sediment and discharge in natural stream systems and set in motion a series of morphological responses (aggradation, degradation, and widening and/or planform adjustment) as the channel tries to reestablish a dynamic equilibrium. Small to moderate changes in slope, discharge, and/or sediment supply can alter the size of transported sediment as well as

the geometry of the channel; while large changes can transform reach level channel types (Ryan 2001). Human-induced practices that have contributed to stream instability within the Upper Winooski River watershed include:

- Forest clearing
- Channelization and bank armoring
- Removal of woody riparian vegetation
- Floodplain encroachments
- Urbanization
- Poor road maintenance and installation of infrastructure
- Loss of wetlands

These anthropogenic practices have altered the delicate balance between water and sediment discharges within the watershed. Channel morphologic responses to these practices contribute to channel bed degradation (Figure 21) and/or aggradation that further create unstable channels. These morphologic changes tend to migrate both upstream and downstream contributing to system-wide instability. (Ryan 2001)

Figure 21: Undersized culverts disrupt the sediment transport capacity of the stream and may lead to both upstream and downstream destabilization. Improperly sized structures, such as this one on T2.02-B, can create scour below.

4.2 Reach Condition

The reach condition is determined using the Rapid Geomorphic Assessment protocol, and is based on the degree of departure of the channel from its reference stream type (VANR 2005). Of the 15 assessed segments, none were found to be in reference geomorphic condition. Six segments (R39-C, T3.02-B, T3.02-C, T3.04-B, T3.04-C and T3.04-D) were found to be in good geomorphic condition, exhibiting only minor adjustment processes. Eight segments were in only in fair condition, currently undergoing major adjustments through degradation, aggradation, widening, and/or a change in their planform. Only one segment, T2.02-B, was found to be in poor geomorphic condition. This reach was undergoing extreme geomorphic adjustment. Table 1 and Figure 22 illustrate the geomorphic condition of the streams within the study area. There does not appear to be any correlation between location in the watershed and condition of the reach. Instead, stream condition in the Upper Winooski seems more related to corridor land use, floodplain encroachment, the reference stream type and its inherent sensitivity to stressors in the watershed (Figure 23).

Table 1. Phase 2 Geomorphic Condition - Upper Winooski River and Tribs

Segment Number	Existing Stream Type	RGA Score	Reach Condition
R39-C	B2	0.76	Good
R39-D	B4c	0.53	Fair
R39-E	F3b	0.55	Fair
T2.01	F3b	0.55	Fair
T2.02-A	B4	0.44	Fair
T2.02-B	F4b	0.20	Poor
T3.01	E4	0.48	Fair
T3.02-A	C4	0.63	Fair
T3.02-B	B4	0.78	Good
T3.02-C	C4	0.65	Good
T3.03-A	E4	0.50	Fair
T3.04-A	E4	0.58	Fair

Table 1. Phase 2 Geomorphic Condition - Upper Winooski River and Tribs			
Segment Number	**Existing Stream Type**	**RGA Score**	**Reach Condition**
T3.04-B	E4	0.65	Good
T3.04-C	B4	0.78	Good
T3.04-D	C4b	0.80	Good

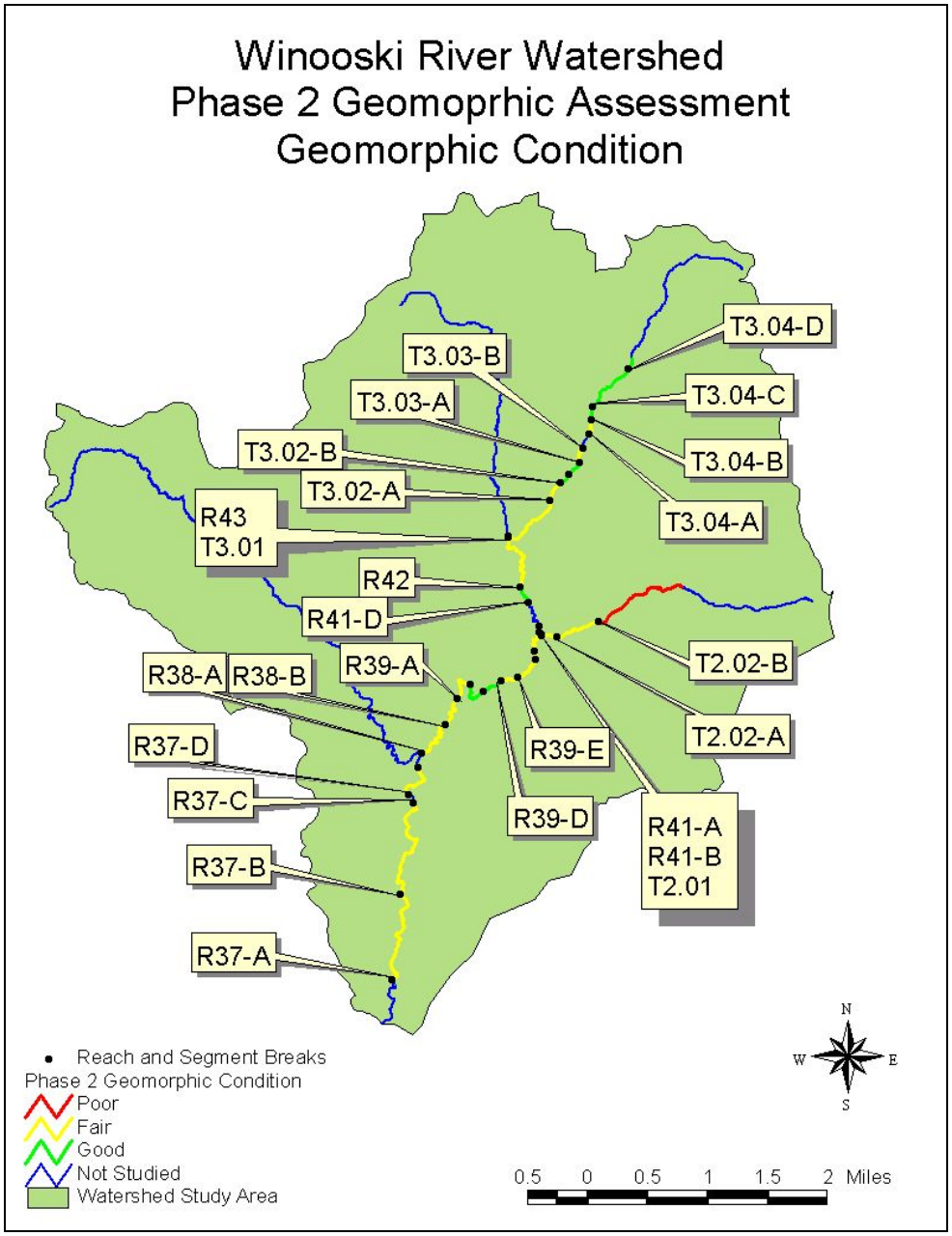

Figure 22: Phase 2 Geomorphic Condition of the Upper Winooski Watershed

4.3 Channel Evolution

The reach condition ratings of Upper Winooski River indicate that many of the reaches are actively, or have historically, undergone a process of minor or major geomorphic adjustment.

The most common adjustment processes in the Upper Winooski River are widening and planform adjustment as a result of historic degradation within the channel. Degradation is the term used to describe the process whereby the stream bed lowers in elevation through erosion, or scour, of bed material. Aggradation is a term used to describe the raising of the bed elevation through an accumulation of sediment. The planform is the channel shape as seen from the air. Planform change can be the result of a straightened course imposed on the river through different channel management activities, or a channel response to other adjustment processes such as aggradation and widening. Channel widening occurs when stream flows are contained in a channel as a result of degradation or floodplain encroachment, or when sediments overwhelm the stream channel and the erosive energy is concentrated into both banks.

The quantity and size of sediment that is being transported by a stream is proportional to the slope of the stream and the amount of water the stream is discharging. A change in any one of these variables will result in a corresponding change in the other variables to achieve equilibrium. A large change in one of these variables will be followed by channel evolution as the stream works to regain equilibrium. Typical stages of channel evolution include:

- A pre-disturbance period
- Incision – Channel degradation and headcutting
- Aggradation and channel widening
- The gradual formation of a stable channel with access to its flood plain at a lower base of elevation.

Most of the reaches studied in the Upper Winooski River watershed are undergoing a channel evolution process in response to large scale changes in its sediment, slope,

and/or discharge associated with the human influences on the watershed. Table 2 refers to the channel evolution of each study reach and the primary adjustment processes that are occurring.

Table 2. Stream Type and Channel Evolution Stage

Segment Number	Entrenchment Ratio	Width to Depth Ratio	Reference Stream Type	Existing Stream Type	Channel Evolution Stage	Major Active Adjustment Process
R39-C	1.5	16.5	B2	B2	V	None
R39-D	2.2	19.7	C4	B4c	IV	**Aggradation** Widening
R39-E	1.3	14.1	B3	F3b	II	Aggradation Widening Planform
T2.01	1.3	18.7	C3	F3b	III	Widening Planform
T2.02-A	1.5	26.8	C4	B4	III	**Widening Planform** Aggradation
T2.02-B	1.1	21.7	C4	F4b	II	**Degradation Widening Planform Aggradation**
T3.01	13.8	6.9	E4b	E4	III	**Widening Planform** Aggradation
T3.02-A	4.8	13.7	C4	C4	III	Widening Planform
T3.02-B	1.9	17.1	B4	B4	I	Widening Planform
T3.02-C	6.6	13.3	C4	C4	III	Degradation Widening Planform
T3.03-A	13.5	6.7	E4	E4	III	**Widening Planform**
T3.04-A	22.4	10.6	E4	E4	III	Aggradation Widening Planform
T3.04-B	11.2	9.9	E4	E4	III	Aggradation Widening Planform
T3.04-C	2.1	15.4	B4	B4	I	Planform
T3.04-D	5.3	13.5	C4b	C4b	I	Degradation

Red Bold lettering – denotes extreme adjustment process
Bold Black lettering – denotes major adjustment process
Black lettering (no bold) – denotes minor adjustment process

In terms of the ANR channel evolution model, the Upper Winooski River and the lower reaches of its tributaries are predominately between stages II and III of the "F-stage" channel evolution model (see Appendix B). In many reaches the channel has undergone historic degradation. Many of the cross sections on study reaches were found to be incised. The incision ratio ranged form 1.1 to 2.9. Five of the assessed segments were found to have a bankfull elevation that was at least one mean bankfull depth lower than the top of the low bank indicating a high level of bed degradation. Where the system is actively adjusting to this lower bed elevation, it is moving laterally and widening in order to create a new floodplain at a lower elevation. This widening and planform adjustment is leading to another adjustment process, aggradation. Aggradation in the Upper Winooski River study area seems to be a combination of autochthonous sediment that is created as the stream widens and erodes its banks to reestablish a new floodplain as well as from allochthonous sources such as gravel roads and land clearing. Unvegetated mid channel bars, point bars in "E" type channels, side bars and bank erosion confirm the channel is undergoing extensive lateral migration.

4.4 Stream Sensitivity

Sensitivity refers to the likelihood that a stream will respond to a watershed or local disturbance or stressor, such as; floodplain encroachment, channel straightening or armoring, changes in sediment or flow inputs, and/or disturbance of riparian vegetation. Assigning a sensitivity rating to a stream is done with the assumption that some streams, due to their setting and location within the watershed, are more likely to be in an episodic, rapid, and/or measurable state of change or adjustment. A stream's inherent sensitivity may be heightened when human activities alter the setting characteristics that influence a stream's natural adjustment rate including: boundary conditions; sediment and flow regimes; and the degree of confinement within the valley. Streams that are currently in adjustment, especially those undergoing degradation or aggradation, may become acutely sensitive (ANR 2004).

Figure 23 is a map presenting the existing stream types found in the Upper Winooski River watershed. The stream sensitivity of these reaches, generalized according to stream type as per the ANR protocol, is depicted in Table 4 and in Figure 24.

Table 4. Stream Sensitivity for Phase 2 Reaches

Segment Number	Existing Stream Type	Stream Type Departure	Geomorphic Condition	Sensitivity
R39-C	B2	No	Good	Very Low
R39-D	B4c	Yes	Fair	Very High
R39-E	F3b	Yes	Fair	Extreme
T2.01	F3b	Yes	Fair	Extreme
T2.02-A	B4	Yes	Fair	Very High
T2.02-B	F4b	Yes	Poor	Extreme
T3.01	E4	No	Fair	Very High
T3.02-A	C4	No	Fair	Very High
T3.02-B	B4	No	Good	Moderate
T3.02-C	C4	No	Good	High
T3.03-A	E4	No	Fair	Very High
T3.04-A	E4	No	Fair	Very High
T3.04-B	E4	No	Good	High
T3.04-C	B4	No	Good	Moderate
T3.04-D	C4b	No	Good	High

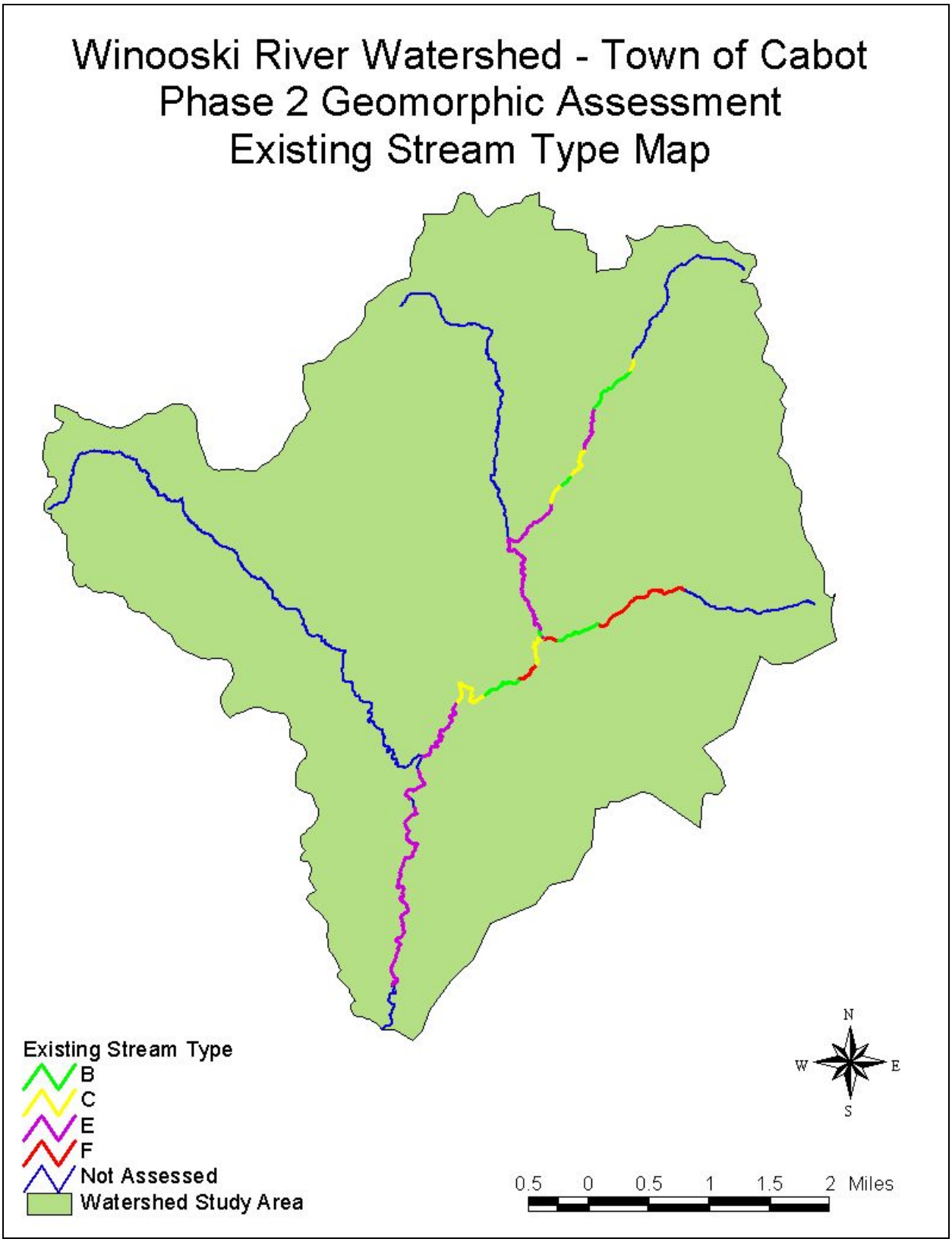

Figure 23: Phase 2 Existing Stream Type Map

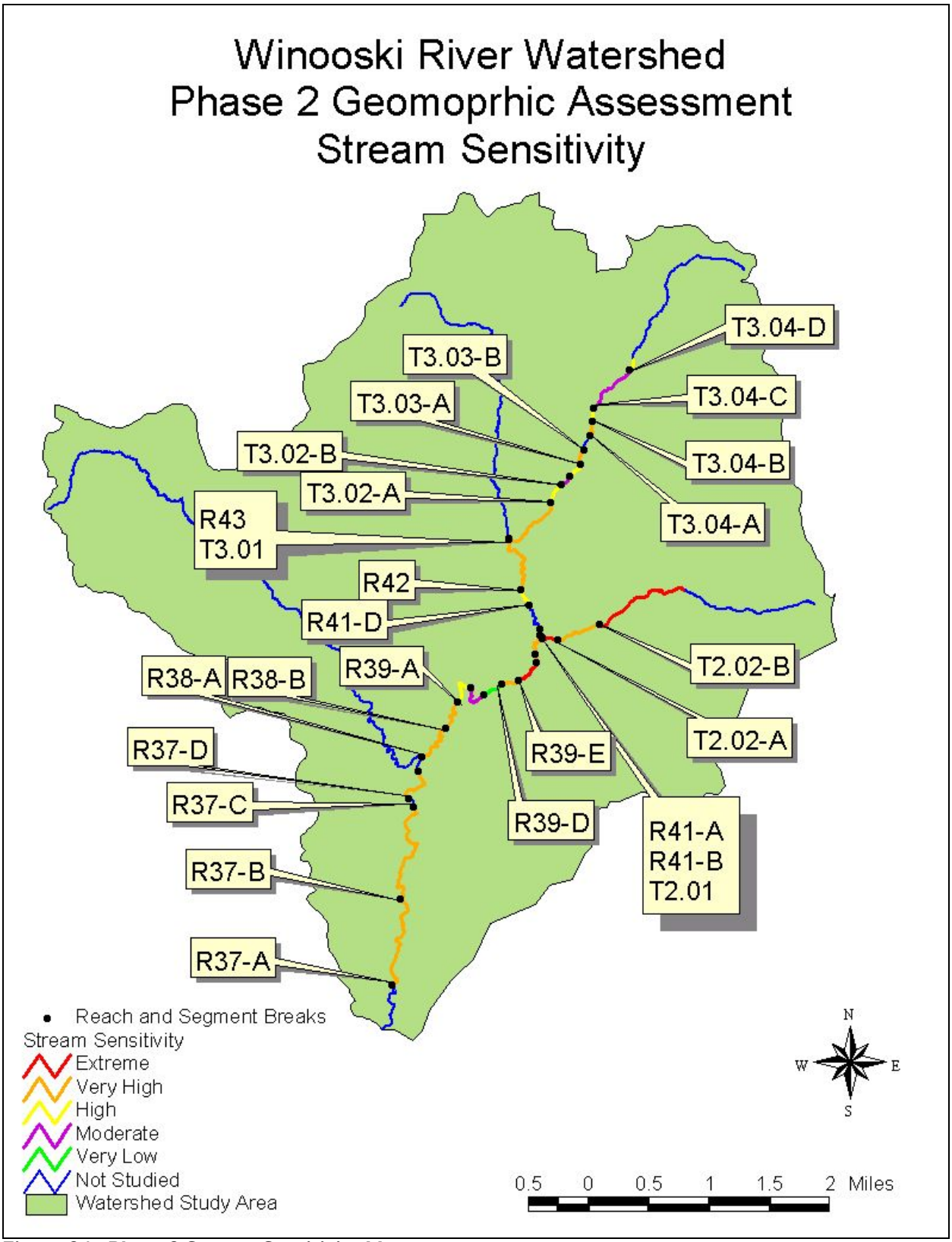

Figure 24: Phase 2 Stream Sensitivity Map

5.0 HABITAT EVALUATION

The Rapid Habitat Assessment (RHA) is used to evaluate the physical components of a stream (the channel bed, banks, and riparian vegetation) and how the physical condition of the stream affects aquatic life. The results can be used to compare physical habitat condition between sites, streams, or watersheds, and also serve as a management tool in watershed planning or similar land-use planning.

Table 5 below shows a comparison of the habitat condition based on the Rapid Habitat Assessment (RHA) and the geomorphic condition based on the Rapid Geomorphic Assessment (RGA). For seven of the fifteen segments, both the RHA and the RGA resulted in ratings of fair. As shown in Figure 25, Segment T2.02-B had a rating of poor for geomorphic condition, but a rating of fair for habitat. Five segments resulted in a good rating for both geomorphic condition and habitat condition (Figure 26). In general the study reaches lacked a strong riffle-pool bedform (many were plane bed or had pools that were filled with fine sediments) and the diversity of habitat features that this brings. Additionally, sediment contributions of sand and fine gravel from the watershed, as well as localized contributions from banks that were eroding as the river adjusts, have created an embedded river bottom along reach 39 in the Village of Cabot and Tributary 3. Segments R39-D, R39-E, and T2.01, and T3.01 lacked adequate riparian buffers. Overall, the RHA score was similar to the RGA score, implying that the ecological health of the Upper Winooski River is intricately tied to the geomorphic condition of the stream.

Table 5. Comparison of RHA and RGA for Phase 2 Reaches

Segment Number	Score RGA	Score RHA	Rating RGA	Rating RHA
R39-C	0.76	0.56	Good	Fair
R39-D	0.53	0.48	Fair	Fair
R39-E	0.55	0.40	Fair	Fair
T2.01	0.55	0.36	Fair	Fair
T2.02-A	0.44	0.61	Fair	Fair

Table 5. Comparison of RHA and RGA for Phase 2 Reaches

Segment Number	Score RGA	Score RHA	Rating RGA	Rating RHA
T2.02-B	0.20	0.55	Poor	Fair
T3.01	0.48	0.51	Fair	Fair
T3.02-A	0.63	0.65	Fair	Good
T3.02-B	0.78	0.77	Good	Good
T3.02-C	0.65	0.69	Good	Good
T3.03-A	0.50	0.51	Fair	Fair
T3.04-A	0.58	0.50	Fair	Fair
T3.04-B	0.65	0.72	Good	Good
T3.04-C	0.78	0.72	Good	Good
T3.04-D	0.80	0.79	Good	Good

Figure 25: Reach T2.02-B rated "fair" for habitat, but poor for geomorphic condition. The reach had a high percentage of unstable banks and substrate embeddedness was rated as only fair.

Figure 26: Reach T3.02-B rated "good" for habitat. The reach had in-stream woody habitat, excellent riparian vegetation and riparian buffer, a diversity of substrates, and a diversity of flows including several deep pools.

6.0 RECOMMENDATIONS

Based on the 2005 Phase 2 Assessment of the Upper Winooski River watershed, Bear Creek Environmental recommends the following:

1. Develop and implement a river corridor protection plan. The implementation of a river corridor protection plan goes a long way towards toward reducing fluvial erosion hazards and minimizing land use conflicts. As a starting point, fluvial geomorphic relationships can be used to determine the width of a river corridor which is needed to accommodate the meander geometry under equilibrium conditions. As discussed in the Defining River Corridors Fact Sheet, prepared by the Vermont ANR River Management Programs, rivers with gentle gradients and narrow to broad valleys require a meander belt width of 6 times the channel width to accommodate the meanders. On the lower end of Tributary 3 (reach T3.01), this equates to a meander belt width of 126 feet (or approximately 63 feet on each side of the meander center line). The River Corridor Plan would also provide some structure for identifying river restoration and corridor protection project types and effective approaches.

2. The reference stream type for much of the main stem of the Upper Winooski River is a "C" or "E". These slightly entrenched, meandering channels are highly dependent upon vegetation for stability. For this reason, the establishment and protection of vegetated

buffers should be high priority in restoration planning and design work. Riparian buffers provide many benefits. Some of these benefits are protecting and enhancing water quality, providing fish and wildlife habitat, providing streamside shading, and providing root structure to prevent bank erosion.

3. Floodplain access is the most effective means at controlling streambank erosion and for streams to attenuate excess sediment. Encroachment in the Upper Winooski watershed has led to loss of habitat and geomorphic instability. Reconnecting floodplains and floodplain wetlands would provide critical stormwater retention, sediment reduction, and overall stream system health.

4. Relocate the town garage and sand storage pile. Consider designing a stream restoration project to provide floodplain access and improve stream bank stability at this location.

5. Conduct a bridge and culvert survey of private and public structures to gather specific information about structure impacts in the Upper Winooski watershed. Replace undersized structures when opportunities and/or funding become available.

7.0 REFERENCES

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