Bear Creek Environmental

Phase 1 and 2 Stream Geomorphic Assessments
Roaring Brook Watershed
Killington, Vermont

Final Report
January 26, 2006

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ACKNOWLEDGEMENTS

Bear Creek Environmental (BCE) would like to thank several individuals for assisting with the Phase 1 and 2 Geomorphic Assessments of the Roaring Brook Watershed. We thank Shannon Hill of the Vermont Agency of Natural Resources for assisting with field data collection and for providing technical expertise. Steve Schild of the Rutland Regional Planning Commission offered GIS support. We would like to acknowledge Shannon Hill, Jennifer Callahan, and Jim Pease for providing review comments on the draft report. The BCE project team is also grateful to the riparian landowners within the Roaring Brook watershed for granting us access to our study reaches.

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EXECUTIVE SUMMARY

Phase I and Phase 2 Stream Geomorphic Assessments within the Roaring Brook watershed were completed by Bear Creek Environmental during summer 2005. These stream geomorphic assessments provide information about the physical condition of streams within the Roaring Brook watershed and the factors that influence the stability of these systems. The project was funded through the Vermont Clean and Clear Program. The Stormwater Section of the Vermont Department of Environmental Conservation (DEC) sponsored the project, and the VDEC River Management Program provided technical expertise and shared quality control/quality assurance responsibilities with Bear Creek Environmental. The study included Roaring Brook, the East Branch of Roaring Brook, the West Branch of Roaring Brook, Rams Head Creek, and one unnamed tributary. Roaring Brook's watershed was divided into 15 reaches based on confinement, slope, soils, and tributary influence. The Phase 2 study focused on stream reaches on the main stem of the Roaring Brook from the confluence with the Ottauquechee River, upstream to Killington Resort.

The study followed the Phase 1and 2 assessment protocol developed by the DEC River Management Program. Information from the study came from the DEC, the Vermont Mapping Program, the Vermont Center for Geographic Information, the Town of Killington, and field data collected by Bear Creek Environmental. The Phase 1 study used a combination of remote sensing (i.e. mapping) and windshield surveys to understand the stream's response to natural and human disturbances that have influenced the Roaring Brook watershed. 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 to collect habitat quality data for the study reaches.

The focus of the Phase 1 study is to evaluate parameters that may cause channel adjustment such as floodplain modifications, channel modifications, and land use. Of the four impact categories measured during the Phase 1 Assessment, floodplain modification was the category identified as having the greatest potential for causing channel adjustment in the Roaring Brook

watershed. Forty percent of the reaches resulted in an impact rating of high for berms and roads and for corridor development. Land use was also identified as an important factor with River corridor land cover/land use receiving an impact rating of high for about half of the stream reaches. In-stream channel modification was also identified as having the potential to cause channel adjustment in the Roaring Brook watershed. Bridges and culverts, bank armoring and channel straightening received high impact scores. The meander migration, meander width ratio, and meander wavelength indicate that some reaches are in adjustment. Meander width ratios measured on Roaring Brook indicate the river has become straighter and steeper, possibly resulting in degradation and loss of access to its floodplain.

The Phase 2 assessment focused on data collection relating to the stream channel, the riparian corridor, and aquatic habitat. This information can be used in watershed planning, for the establishment of erosion hazard zones, and for the identification of watershed improvement projects. The Phase 2 assessment consists of field notes that are collected through a reach, and the completion of a Rapid Geomorphic Assessment (RGA) and Rapid Habitat Assessment (RHA).

The Phase 2 Rapid Geomorphic Assessment (RGA) is important for understanding the geomorphic stability of a reach. The RGA includes an evaluation of reach condition (departure from reference condition), channel adjustment process, and the reach sensitivity. The reach condition describes the degree of departure of the channel from its reference stream type. Reference streams have no significant channel or floodplain modifications. Reach condition ratings correspond to degrees of expected adjustment. The channel adjustment process is a change in the form of the channel due to natural causes or human impacts. Reach sensitivity describes how sensitive a stream reach is to changes within the watershed, and is dependent upon the existing stream type and the condition of the reach.

Seven of the segments assessed for the Phase 2 study resulted in a geomorphic condition of fair, indicating they are undergoing major adjustment processes. Two segments resulted in a geomorphic condition of good, reflecting minor adjustment is occurring. The Phase 2 Rapid Geomorphic Assessment (RGA) was used to evaluate the stage of channel evolution. Most of the Phase 2 reaches were found to be in fair condition, had undergone historical channel widening or down cutting, and were currently undergoing major to minor channel adjustments. Additionally, much of the Roaring Brook watershed appears to be undergoing a second evolutionary process associated with the build up of sediment that is being washed into the stream channel from gravel parking lots, roads, and development. This is especially evident in the upper reaches of the Roaring Brook watershed, where significant wash off from the Killington Access Road was noted to be filling in pools.

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. In general, the Rapid Habitat Assessment (RHA) rating was similar to the RGA. Four of nine segments resulted in a rating of fair for the RHA. Five segments resulted in a rating of good.

Three of the eight Roaring Brook mainstem reaches have stream types that are very susceptible to shifts in both lateral and vertical stability caused by direct channel disturbance and changes in the flow and sediment regimes of the contributing watershed. Rates of lateral adjustment are influenced by the presence and condition of riparian vegetation. For this reason, the acquisition of easements, streamside plantings, and buffer protection should be a high priority for restoration planning and design work.

In summary, the Phase 1 and 2 Geomorphic Assessments provided evidence that the mainstem of Roaring Brook has been significantly altered by floodplain encroachment, channel straightening, and the disturbance of the riparian vegetation. In addition, stormwater from Killington and its associated development have altered both the hydrology and sediment regime of the upper watershed. Recommendations for improvements within the Roaring Brook watershed are provided at the end of this report.

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SECTION 1: PROJECT OVERVIEW AND BACKGROUND

1.1 PROJECT OVERVIEW

Bear Creek Environmental was retained by the Vermont Department of Environmental Conservation (VDEC) to conduct Phase 1 and 2 Stream Geomorphic Assessments within the Roaring Brook watershed. Roaring Brook is located in the upper reaches of the Ottauquechee River watershed (Figure 1). The Phase 1 assessment was conducted on Roaring Brook, the East Branch of Roaring Brook, the West Branch of Roaring Brook, Rams Head Creek, and one other major tributary (Figure 2). The Phase 2 assessment was conducted on the entire main stem of Roaring Brook from the confluence with the Ottauquechee River, upstream to Killington Resort.

Roaring Brook from river mile 1.4 upstream 0.2 miles is listed on the 2004 State of Vermont 303(d) list of impaired waters. On the East Branch of Roaring Brook, there is an impaired segment from river mile 0.1 to river mile 0.6 (Figure 3). Both of these streams have stormwater runoff, land development, and erosion listed as water quality problems within these segments. Impaired uses include aesthetics and aquatic life support. The main objectives of the study were to provide an overview of the general physical characteristics of the watershed, assess the impact of parameters such as land use, channel modification, floodplain modification, erosion and debris/ice-jam potential on each reach, and determine which reaches may be in channel adjustment.

Data and information for the Roaring Brook watershed was obtained from the VDEC and the Vermont Center for Geographic Information (VCGI). Windshield surveys of the watershed were conducted in June 2005. Mary Nealon, Michael Blazewicz and Alyssa Borowske of Bear Creek Environmental visited the majority of the reaches to conduct Phase 2 surveys during the months of June and July 2005. Shannon Hill, scientist with the River Management Program of ANR, joined BCE scientists during the Phase 2 assessment of reaches T6.07 and T6.08.

1.2 BACKGROUND INFORMATION

1.2.1 Description of Study Area

Roaring Brook is a tributary to the Ottauquechee River near Sherburne Center, Vermont and has a watershed size of 5.61 square miles (Figure 1). The Ottauquechee River is within the Connecticut River Basin. The Phase 1 assessment included stream reaches on Roaring Brook, East Branch of Roaring Brook, West Branch of Roaring Brook, Rams Head Creek, and one unnamed tributary
(Figure 2).

The Roaring Brook watershed is located within the Green Mountains of Vermont. The watershed lies just south of Sherburne Pass, which was historically reshaped by ice (Van Diver, 1987). The geologic formation where the Roaring Brook watershed is located is known as the Precambrian massif (Van Diver, 1987). The dominant soil types in the Roaring Brook watershed are glacial till and ice-contact deposits.

With the exception of a few reaches, Roaring Brook flows through a steep gradient valley. Most reaches within the watershed have a slope of approximately 10% and in the upper reaches slopes are much greater. There are only a few reaches where slopes are less than 5%.

The Roaring Brook watershed is dominated by forested land. However, all subwatersheds except one contain agricultural fields or urban land as a sub-dominant land use. Orthophotos from the 1970s show that Roaring Brook was dominated by

forest land. According to town officials, most of the subdivisions currently in Killington were historically agricultural land. The Killington ski area was developed in 1958 and subsequent development around it was mostly constructed in the late 1960s to the mid 1970s. New development within the watershed continues today.

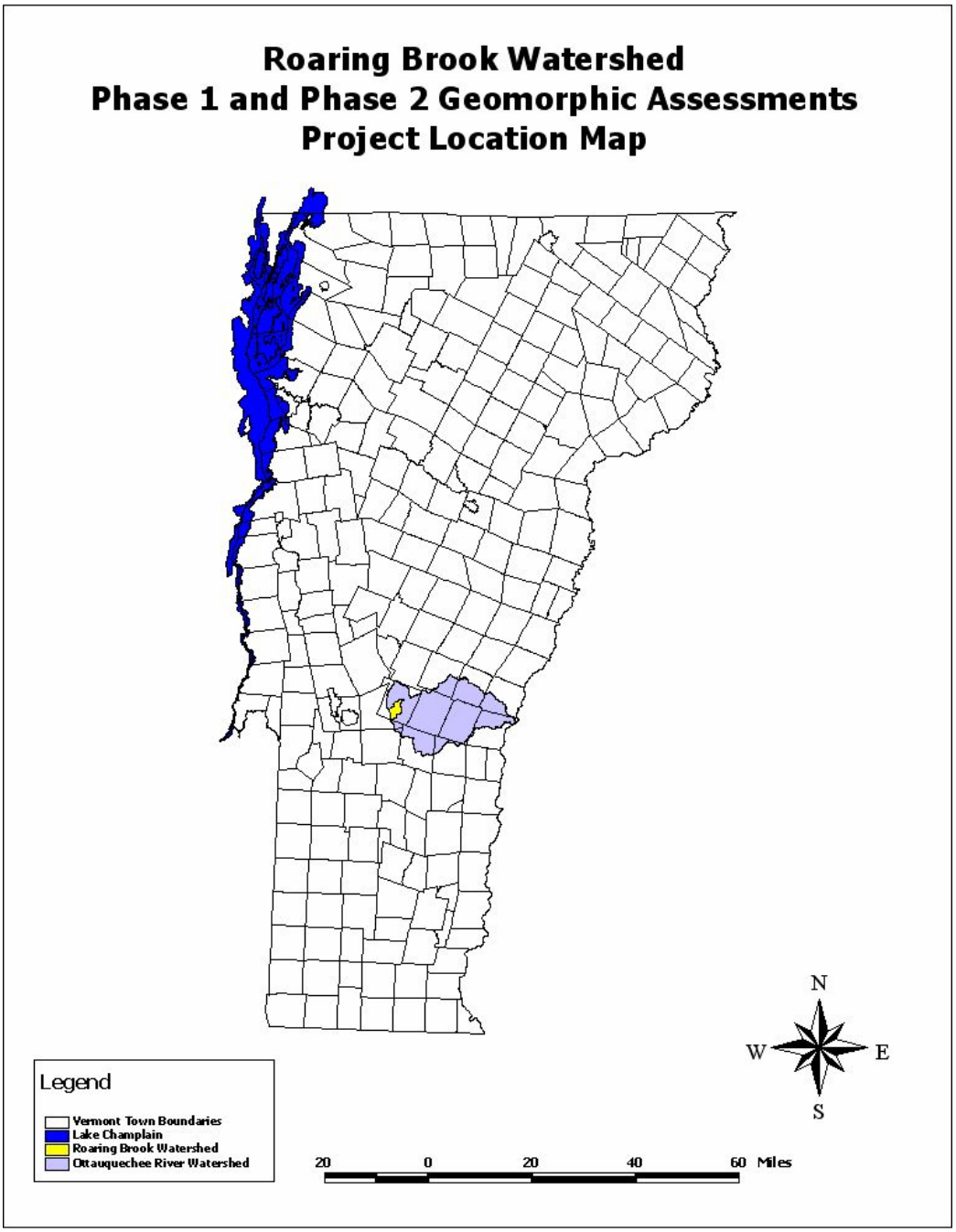

Figure 1. Project Location Map for the Phase 1 and 2 Assessment

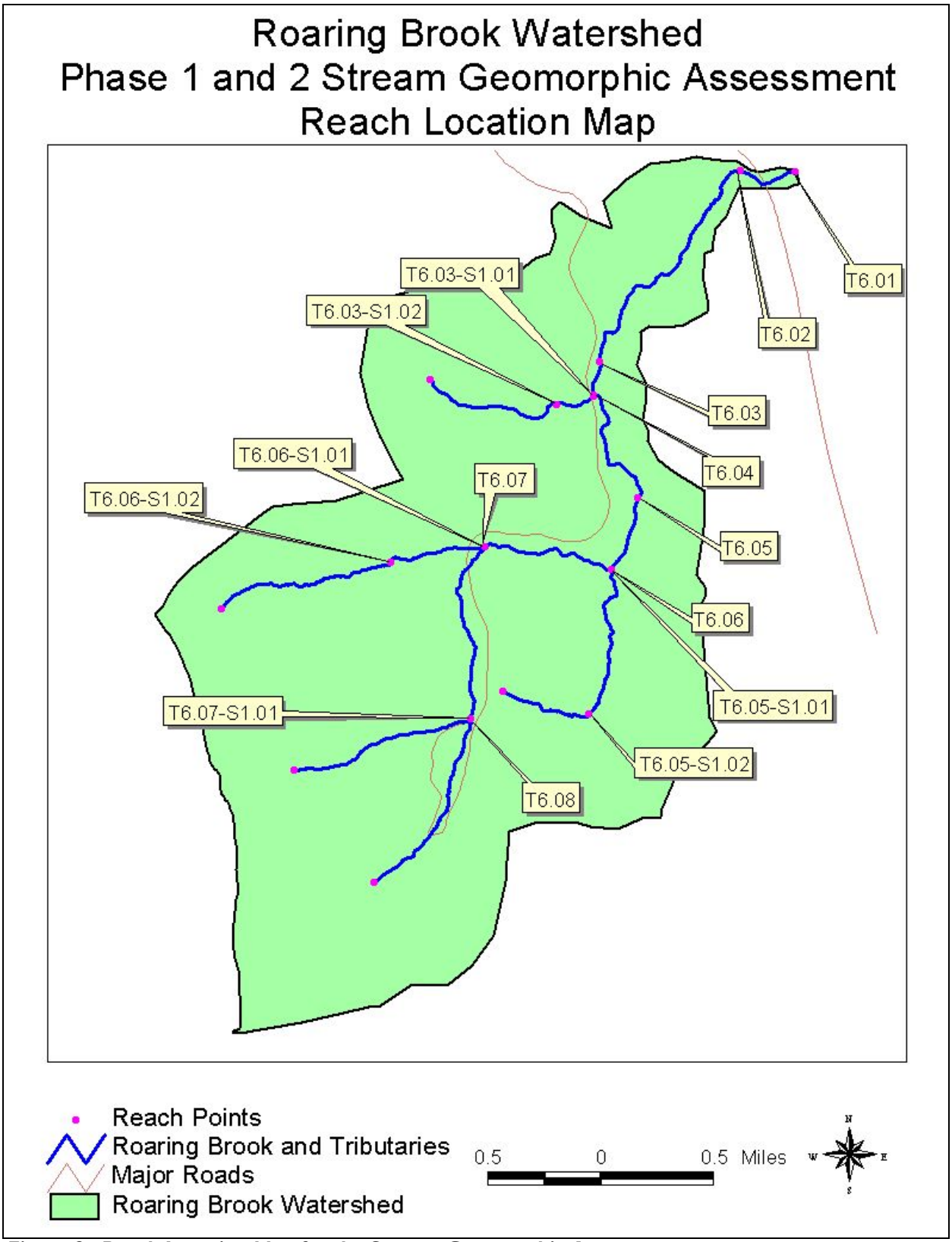

Figure 2. Reach Location Map for the Stream Geomorphic Assessment

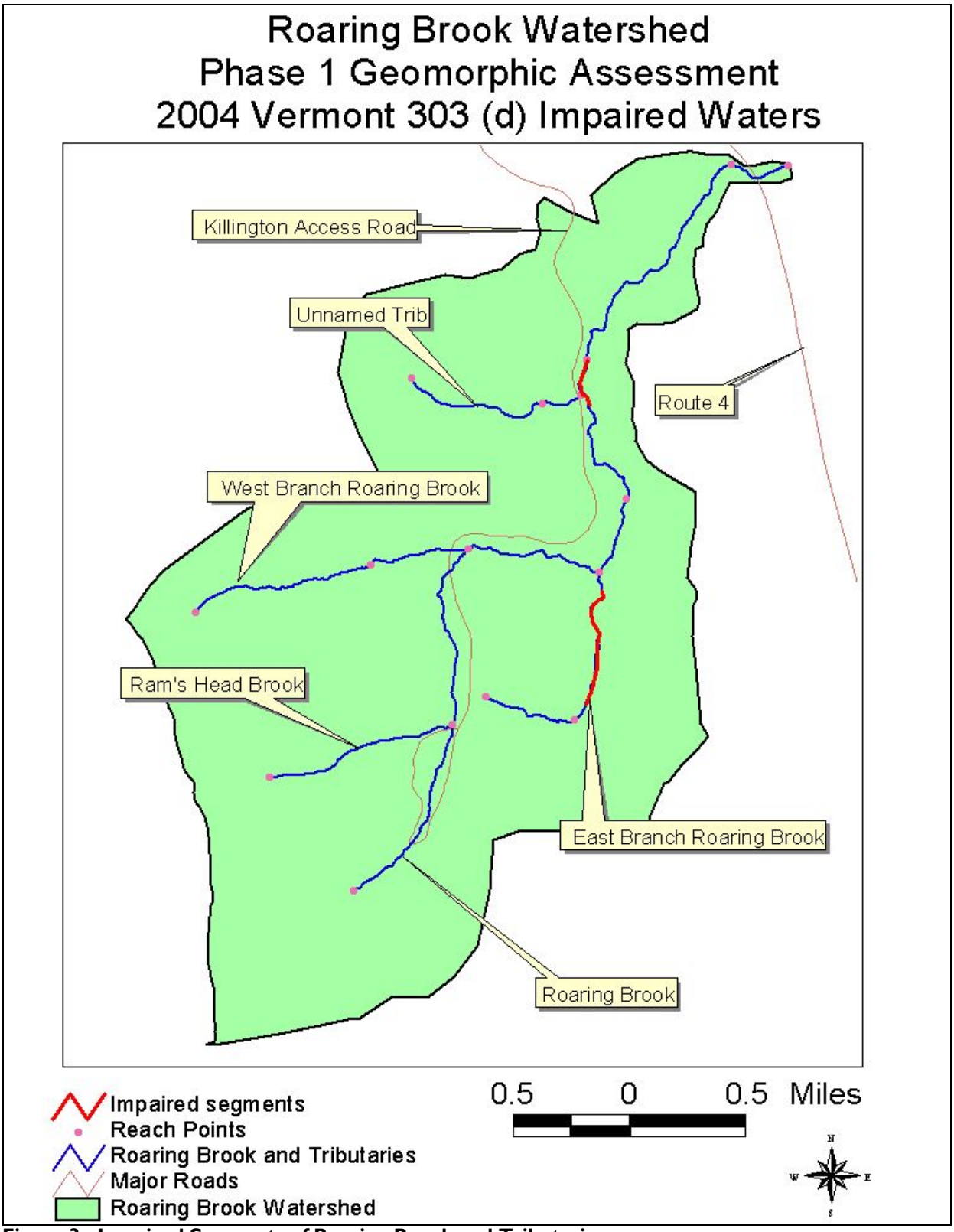

Figure 3. Impaired Segments of Roaring Brook and Tributaries

1.2.2 Flood History

The Killington town clerk was contacted for information regarding the flood history and channel management of the Roaring Brook watershed. According to the town clerk, there are no known problem areas for flooding in the town. They believe that the 1927 flood came through the area, but did not know of any damage as a result of it. There also are no records of channel management practices for the Roaring Brook watershed.

Since there are no USGS stream gages within the Roaring Brook watershed, data from another river was used to better understand the hydrologic history of Roaring Brook. Long term data from the U.S. Department of the Interior, U.S. Geological Survey (USGS) gage on the Ottauquechee River in West Bridgewater, VT (gage #01150900) was obtained. The Ottauquechee River gage was selected because it is located near the confluence of Roaring Brook and the Ottauquechee River. Although the drainage area at the Ottauquechee River gage is much larger (23.4 sq. miles) than the Roaring Brook watershed, it does provide some useful information about when large flood events occurred. The peak flows for the period of record (1985 through the present) are presented below in Figure 4. The peak flows for 2000 and 2002 were close to a 10 year recurrence interval. The peak flow for 1996 was between the ten year and 25 year recurrence interval.

To get a longer period of record for the area, the USGS gage on the Ottauquechee River in North Hartland, VT (gage #01151500) was also obtained. The drainage area at this gage is 221 square miles. The gage provides a continuous record of flow from 1927 through the present. The USGS indicates that the data from the North Hartland gage is affected by regulation or diversion. The long term record (see Figure 5) shows peak discharges for 1948 and 1953 were at the 10 year recurrence interval. The peak flows for 1934, 1949, and 1952 were between a ten year and 25 year recurrence interval. 1936 was approximately a 50 year recurrence interval, while water year 1928 exceeded the 50 year recurrence interval.

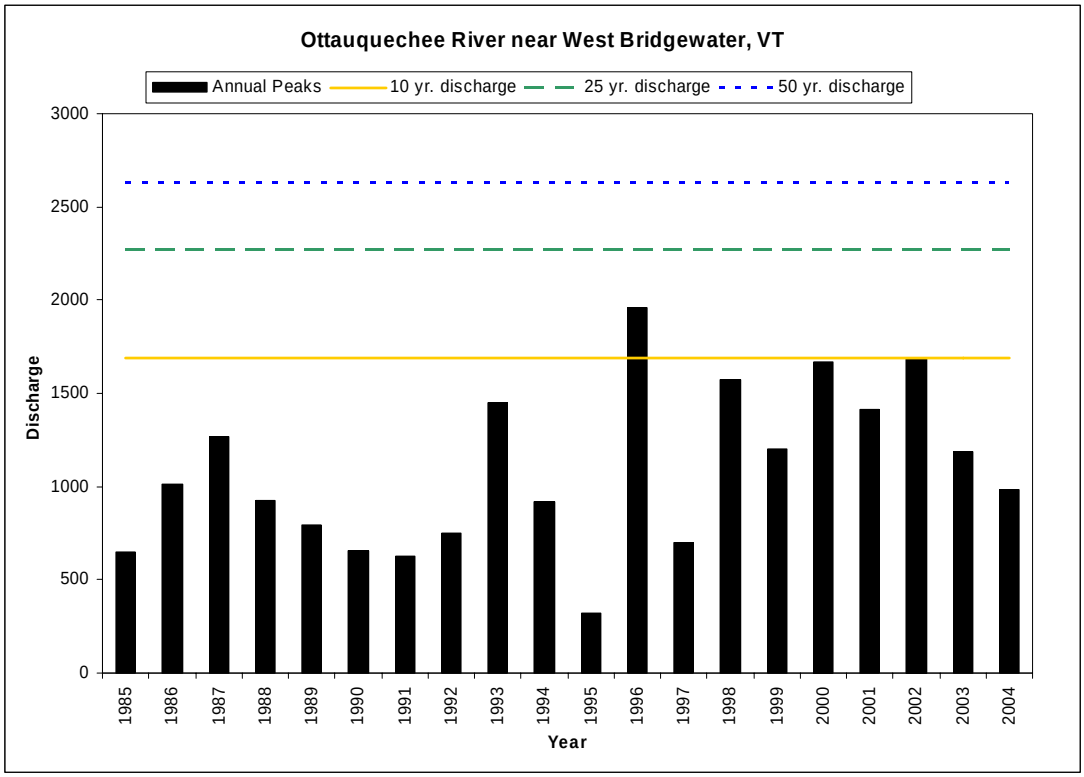

Figure 4. Annual Peak Discharge for Ottauquechee River near West Bridgewater, VT.

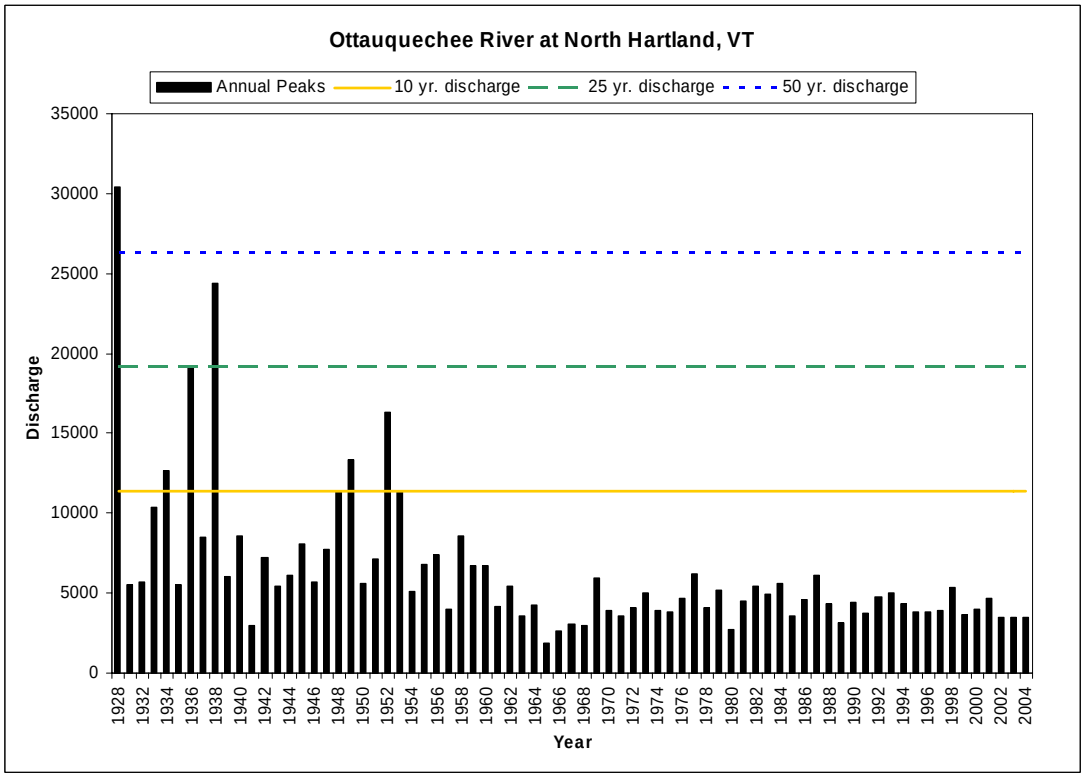

Figure 5. Annual Peak Discharge for Ottauquechee River at North Hartland, VT.

SECTION 2: PHASE 1 STREAM GEOMORPHIC ASSESSMENT

2.1 PHASE 1 METHODOLOGY

The Phase I assessment followed procedures specified in the Vermont Stream Geomorphic Assessment Handbook Phase 1 (Vermont Agency of Natural Resources 2005a), and used version 3.02 of the Stream Geomorphic Assessment Tool (SGAT) GIS extension. All assessment data were recorded on the Agency of Natural Resources (ANR) Phase I data sheets, and were entered into the DMS.

2.1.1 Phase 1 Parameters

During the Phase 1 Assessment, data was collected for each parameter in Table 1. The parameters were then rated according to the following menu options (NS – not significant, low impact, high impact or No info –no information). A zero was scored for options NS and No info, a one for low impact and a two for high impact.

Table 1. Parameters Included in Impact Scores

Step #	Parameter
4.1	Watershed Land Cover/ Land Use
4.2	Corridor Land Cover/ Land Use
4.3	Riparian Buffer Width
5.1	Flow Regulations and Water Withdrawals
5.2	Bridges and Culverts
5.3	Bank Armoring and Revetments
5.4	Channel Modifications
5.5	Dredging and Gravel Mining History
6.1	Berms and Roads
6.2	River Corridor Development
6.3	Depositional Features
6.4	Meander Migration / Channel Avulsion
6.5	Meander Width Ratio
6.6	Wavelength Ratio
7.2	Bank Erosion – Relative Magnitude
7.3	Ice and Debris Jam Potential

The reach indexing tool (RIT) was used to document steps 5.3, 5.4, and 6.1. This tool is an extension of ArcView and utilizes the Vermont Hydrography Dataset (VHD) (VCGI, 2003) to automate measuring the length of stream segments. The impacts were entered into an attribute table, which was uploaded to the DMS.

2.1.2 Phase 1 QA Review

To assure a high level of confidence in the Phase 1 and 2 SGA data, strict QA/QC procedures were followed by BCE. These procedures involved a thorough in-house review of all data as well as automated and manual QC checks with the DEC River Management Program. The three base shapefiles (valley walls, meander centerlines, and subwatershed) were submitted to Shannon Hill for QA review prior to running the SGAT extension. After Step 2 of the Phase 1 Assessment was completed, Bear Creek Environmental conducted its own manual QA review of the reference stream types. Then the SGAT project and resultant shapefiles were sent to the River Management Program for another QA review, which included a manual QA review of reference stream types. In early June 2005, Phase 1 ArcView shapefiles were submitted to Shannon Hill for a QA review following the completion of Step 7 of the Phase 1 assessment.

BCE conducted its own in-house QA review after all the Phase 2 data were entered into the DMS and the Phase 1 data were updated. Lengths of armoring, berms, and erosion on field forms were checked against DMS values as well as calculated lengths in GIS shapefiles. Then the Phase 2 GIS shapefiles were submitted to the ANR for a third QA review. Some minor revisions were made by Bear Creek Environmental to the DMS following this review. These changes include updating the meander migration, belt width, and average wavelength parameters.

2.2 PHASE I RESULTS

2.2.1 Reach Locations

The Roaring Brook watershed was divided into 15 reaches for the Phase I Assessment. Page 1 of Appendix A provides the reach locations including reach description, town where the reach is located, and latitude and longitude generated from SGAT. Figure 2 shows the location of study reaches used in the Phase I Assessment. Each point represents the downstream end of the reach.

2.2.2 Reference Stream Types

Reference stream types are defined as stream channel forms and processes that would exist in the absence of human-related changes to the channel, floodplain, and/or watershed. Stream and valley characteristics including valley confinement, and slope determined through remote sensing were used to determine the reference stream type. The reference reach characteristics were later refined during the windshield survey and Phase 2 assessment. Reference reach typing was based on both the Rosgen (1996) and the Montgomery and Buffington (1996) classification systems.

Page 2 of Appendix A provides a complete listing of reference stream types for each reach within the project area. The reference stream types are shown in Figure 6. The majority of the stream reaches fall within the "B" stream type (see Table 2). The step-pool type streams in this category accounted for approximately 30 percent of the length of assessed reaches, while the one plane bed section accounted for 5 percent of the study area by length. In reference condition, these streams are narrowly confined to narrow, have moderate to steep slopes, and have cobble as bed material.

Five reaches were categorized as "A" type streams by reference. The cascade comprises approximately 9 percent of the study area, by length, and the step-pool comprises 29 percent of the study area. These streams by reference are narrowly confined, have very steep slopes, and boulder or cobble as the dominant bed material.

Four of the 15 reaches (approximately 13 percent of the study area by stream length) fall within the "C" stream type and were noted to be riffle-pool systems. Reference "C" streams are unconfined, have moderate to gentle slopes, and have cobble or gravel as bed material.

One reach, T2.02, was designated as an "F" type stream with a step-pool bed form. The reach comprises approximately 13 percent of the study area by length. This stream reach is narrowly confined, with a very steep slope and is dominated by cobbles as bed material.

Table 2. Reference Stream Type

Stream Type	Confinement	Channel Slope	Bed Material	Percentage by Channel Length of Assessed Reaches
A/ Cascade	Narrowly confined	Very steep	Boulder	9
A/Step-Pool	Narrowly confined	Very steep	Cobble	29
F/Riffle-pool	Narrowly confined	Very steep	Cobble	14
B/Step-pool	Narrowly confined to Semi confined	Steep	Cobble	30
B/ Plane Bed	Narrow	Moderate to steep	Cobble	5
C/Riffle-pool	Broad or Very Broad	Moderate to gentle	Cobble-Gravel	13

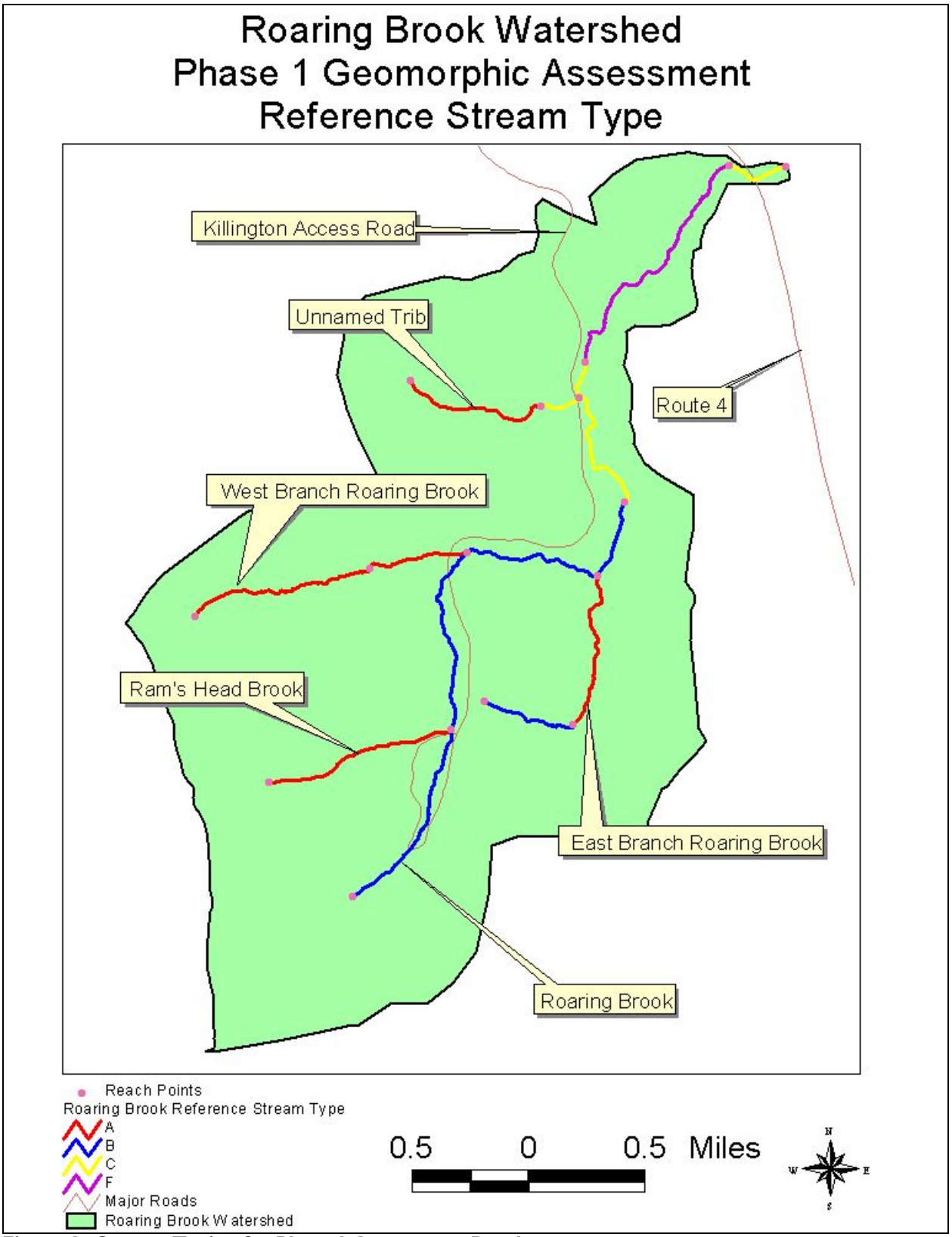

Figure 6. Stream Typing for Phase I Assessment Reaches

2.2.3 Basin Geology and Soils

The characteristics of the Roaring Brook watershed were determined using a combination of soils data, review of topographic maps, and information acquired during the windshield survey. Page 3 of Appendix A, provides a summary of the basin characteristics, such as alluvial fans, grade control structures, geologic materials, valley side slopes, and soil characteristics.

There were no alluvial fans identified within the study reaches. Grade control structures such as ledge and dams were noted during the windshield survey. Channel spanning ledge was noted in six of the 15 reaches (T6.01, T6.02, T6.05, T.06, and T6.07 and T6.08). Ledge acts as a grade control by keeping the base elevation of a river from being lowered, and prevents the river from incising in that location. Only one dam, Snowshed Pond, is located within the study area. Snowshed Pond is located at the upper end of reach T6.05-S1.02. One reach, T6.07, had multiple grade controls which included ledge and a weir used for snowmaking water withdrawals. The steepness of the valley side slopes was determined using a combination of a topographic map and the soils layer. The valley side slope steepness was variable, but overall steep to extremely steep side slopes dominated the watershed.

The dominant surficial geology of the Roaring Brook watershed consists of glacial till and ice-contact deposits (see page 4 of Appendix A). With one exception, the reaches characterized as "C" channels within the Roaring Brook watershed have ice-contact deposits as the dominant geologic material. As shown on page 5 of Appendix A, these soils are rarely flooded and have severe to very severe erodibility. T6.03, a "C" type stream, had a dominant soil type that is frequently flooded and moderate erodibility. The rest of the reaches have till as the dominant geologic materials. These soils are rarely flooded and have very severe erodibility.

2.2.4 Land Cover – Reach Hydrology

The land use within a watershed plays an important role in the hydrology of the receiving waters. The percentage of urban and cropland development within the

watershed are factors which change a watershed's response to precipitation. The most common effects of urban and cropland development is increasing peak discharges and runoff by reducing infiltration and travel time (United States Department of Agriculture 1986). The land use/land cover within the stream corridor itself is also an important parameter to evaluate. This land use/land cover plays an important role in the sediment deposition and erosion which occurs during annual flood events (Vermont Agency of Natural Resources 2004).

As outlined in the Phase I handbook, impact ratings were assigned for watershed land cover/land use and stream corridor land cover/land use as follow:

High – 10% or more is crop and/or urban
Low – Between 2 and 10 % is crop and/or urban
NS – Not Significant – Less than 2 % is crop and/or urban

The land cover/land use information is provided on pages 6 through 8 of Appendix A. Eleven of the reaches resulted in a watershed /land use impact rating of low and the rest were not significant. The dominant land cover/land use within the river corridor was forested land for all but three reaches. These three reaches had urban land as their dominant land use. Seven of the fifteen reaches resulted in a high impact rating for corridor land cover/use.

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. As summarized on page 9 of Appendix A, one of the stream reaches, T6.03, had over 75 percent of the reach with little or no buffer on both banks. This stream reach, which lacks a high quality riparian buffer, is at a significantly higher risk of experiencing high rates of lateral erosion. Two more reaches (T6.05 and T6.05-S1.02) had 50 percent of their reach with little or no buffer. One stream reach, T6.04, had a buffer on the left side of the stream between 26 and 50 feet that comprised 65 percent of the reach.

2.2.5 Historic Channel Modifications

Channel modifications may impact a stream reach by affecting the hydraulics and the sediment regime. Historic channel modifications were assessed in this Phase I study by evaluating flow regulations, bridges and culverts impacts, bank armoring, windrowing, straightening, and dredging. The percentage by length of reach impacted by one or more of these channel modifications was estimated and is summarized in Report Number 5 (see Appendix A pages 10 and 11).

Flow Regulations

Two reaches within the Roaring Brook watershed were rated as high impact for flow regulation. T6.07, located on the main stem has a weir in the channel that has affected sediment depositional patterns in the channel. The upper reach on the East Branch of Roaring Brook has an onstream impoundment, which is disrupting natural sediment transport within the reach.

Bridges and Culverts

As part of the Phase 1 Stream Geomorphic Assessment, the number of bridges and culverts within the study reach were counted by identifying stream crossings on the topographic map and orthophotos. These stream crossings were confirmed during the windshield survey. The percentage of the reach impacted by stream crossing structures was estimated during the windshield survey and from orthophotos. Impact ratings for bridge and culverts were evaluated by determining the percentage of the reach length that is channelized, has split flow, or makes a sharp "S" bend upstream or downstream of bridges or culverts. The impact from bridge and culverts on stream dimension, pattern or profile was high for three reaches, T6.01, T6.03, and T6.03-S1.01. The remaining reaches appeared to be low or not significant.

Bank Armoring

The amount of bank armoring within a watershed is often indicative of the occurrence of channel processes, which result in bank erosion. Bank armoring, also called

revetments, can be made of a variety of material including wooden cribs, gabions, logs, and rock riprap. The most common type of revetment in Vermont is rock riprap. The following criterion was used to provide an impact rating for human placed bank armoring.

H	High – Greater than 30% of the reach length is armored
L	Low – Between 10 and 30% of the reach length is armored
NS	Not Significant – Less than 10% of the reach length is armored
No Info	Bank armoring has not been evaluated for the entire reach and impact at the reach level is unknown

Rock riprap and log revetments were the only types of revetments noted within the study area. Bank armoring was noted in seven of the 15 reaches. Of these reaches, armoring received an impact rating of high for two of the reaches (T6.01 and T6.03) and low or not significant for the remaining reaches.

Channel Modifications (Windrowing and Straightening)

During the windshield survey evidence of historic channelization projects were recorded. The total reach length (in feet) and the percentage of the reach length directly impacted by the channel modification were noted. Categories considered as part of the Step 5.4 (channel Modifications) included the following menu options:

- Straightening – Manual straightening of a channel without windrowing.
- With Windrowing – pushing gravel up from the stream bed onto the top of either bank as part of the straightening of the river.
- None – No known channel straightening.
- Not evaluated – All data sources have not been evaluated.

Channel straightening was identified by reviewing orthophotos and through field confirmation during the windshield and Phase 2 survey. Portions of stream reaches that have been historically channelized or straightened are shown below in Figure 7. Five reaches were given an impact rating of high due to channel straightening while five other

reaches had an impact rating of low. Reach T6.01 was also identified as being straightened with windrowing.

Dredging History

Since the Roaring Brook watershed is so small (<10 square miles), there are no records at the Vermont Agency of Natural Resources regarding the dredging and gravel mining history of the Roaring Brook watershed. However, when some reaches were straightened, some dredging probably occurred as well.

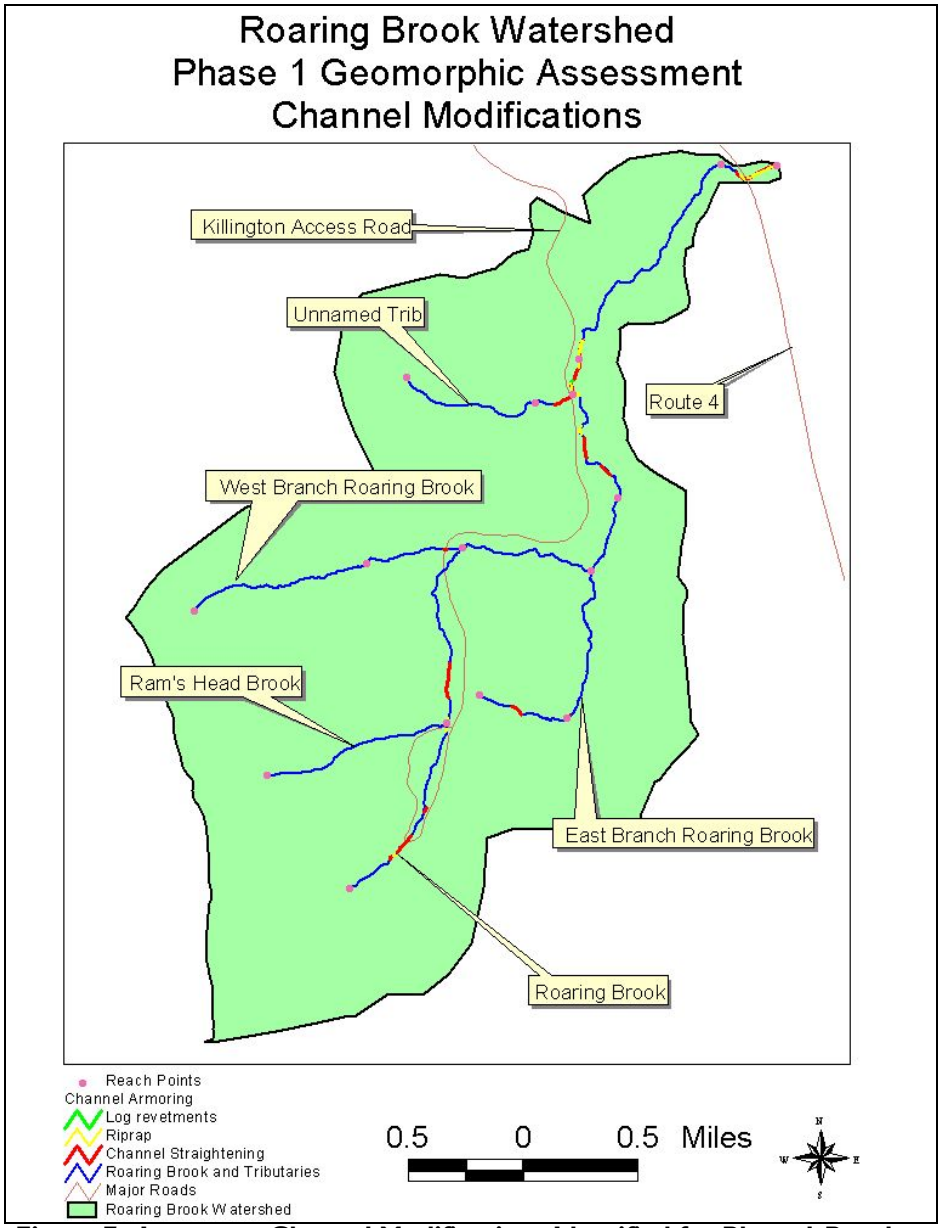

Figure 7. In-stream Channel Modifications Identified for Phase 1 Reaches

2.2.6 Floodplain Modifications

In this step of the Phase I assessment, careful attention is paid to infrastructure and other development which restricts access to the floodplain, resulting in vertical or lateral confinement of flood flows. The parameters included in this step are: Berms and Roads, River Corridor Development, Depositional Features, Meander Migration/Channel Avulsion, Meander Width Ratio, and Wavelength Ratio. Some of the primary factors, which may influence floodplain function for Roaring Brook, are discussed below: Report 6, which is included on pages 12 and 13 of Appendix A, contains the Phase 1 information for Floodplain and Planform changes.

Berms and Roads

An estimate of the percentage of the river corridor length along which berms, roads, railroad, or improved paths run parallel to the stream was estimated using information from maps, orthophotos, and the windshield survey. Reaches where berms, roads, railroads or improved paths were located along 20 percent or more of the river corridor were given impacted ratings of high. The following reaches on the main stem of Roaring Brook received an impact rating of high for berms and roads: T6.01, T6.03, T6.04, T6.07, and T6.08. One reach on the unnamed tributary, T6.03-S1.01, also had an impact rating of high for berms and roads. The remaining reaches, except for those on Rams Head Creek and the West Branch of Roaring Brook, had an impact rating of low.

River Corridor Development

The river corridor development parameter looks at whether developments within the river corridor are effectively decreasing the belt width. The percentage of the reach length with houses, fill, parking lots or other development within the river corridor was tabulated using maps, orthophotos, and knowledge from the windshield survey. Six of the 15 reaches (T6.01, T6.03, T6.03-S1.01, T6.04, T6.05-S1.02, and T6.07) had an impact rating of high for river corridor development.

Depositional Features

The 1990s orthophotos series (1:5000) as well as results from the windshield survey were used to evaluate depositional features within the Roaring Brook watershed. The presence of bars (mid channel or point bars) and deltas were noted in each of the study reaches. The ANR has included depositional features as a component of the Phase I analysis because these features are indicative of an increased sediment load and a high likelihood that the streambed is actively aggrading and/or undergoing lateral migration. An unvegetated bar indicates the bar has recently formed or is in the process of growing.

Six of the 15 reaches (T6.02, T6.04, T6.06, T6.07, T6.08, and T6.03-S1.01) had multiple depositional features present. Most of these reaches were on the main stem. In all cases the impact was rated as low or not significant.

Meander Migration

Orthophotos were used to evaluate areas where Roaring Brook and its tributaries have migrated, bifurcated, or avulsed[1]. Current orthophotos from 1994 and historic orthophotos from 1976 were over layered to compare the location of the river channel over time. The current and the historic orthophotos span a range of approximately 20 years. In addition to the orthophoto analysis, Phase 2 field surveys helped to verify channel avulsions and islands on the main stem of Roaring Brook. One reach on the main stem of Roaring Brook, T6.08, received an impact rating of high for meander migration, while eight reaches received an impact rating of low. Avulsions, often associated with debris jams, appeared to be the primary mechanism for lateral migration of the Roaring Brook. T6.05-S1.02, which flows through a wetland, appeared to have migrated by eroding its outer bank on meander bends.

[1] An avulsion is a change in planform resulting form a meander cut-off.

Meander Width and Wavelength

The 1990 series (1:5000) orthophotos in conjunction with topographic maps were used to determine the meander belt width and the meander wavelength for streams typed in Step 2.10 as C or E riffle-pool or ripple dune reference stream types (i.e. unconfined systems). The topographic maps were used to determine the valley direction, while the most current orthophoto series was used to provide the accurate location of channel meanders.

The meander belt width is the horizontal distance between to opposite, outside banks on fully developed meanders. The meander width ratio is calculated by dividing the average belt width for the reach by the bankfull width. The ANR Phase 1 protocol considers unconfined, gravel dominated streams with moderate to gentle gradients, which are in regime, to have belt widths in the range of 5 to 8 times the channel width. Half of the unconfined reaches (2 out of 4) fell outside of the range expected for channels which are in regime. Two of the study reaches (T6.03 and T6.03-S1.01) were rated as high impact for meander width ratio, and the other two reaches, which are on Roaring Brook, received an impact rating of not significant.

The reaches with the high impact ratings had meander width ratios less than 5. These low values may indicate the stream has become straighter and steeper, possibly resulting in degradation and loss of access to its floodplain. Field observations confirm that in several locations the Roaring Brook has been straightened, has incised, and/or has lost access to its floodplain.

The meander wavelength consists of two bend ways. The wavelength ratio is calculated by dividing the average wavelength by the bankfull channel width. Leopold 1994 and Williams 1985 (cited in Vermont Agency of Natural Resources, 2005a) have shown unconfined, gravel dominated streams in shallow-sloped valleys to have wavelengths in the range of 10 to 12 times the channel width. Three of the reaches resulted in a high impact rating for meander wavelength while one reach received an impact rating of low.

For two of these reaches (T6.03 and T6.03-S1.01), the wavelength ratio was one, suggesting the stream is currently straightened and will likely aggrade and become more sinuous.

2.2.7 Bed and Bank Windshield Survey

The dominant bed form, dominant bank material, bank erosion/bank height, and debris/ ice jam potential were recorded during the windshield survey, and these results are summarized in on pages 14 and 15 of Appendix A. The dominant bed form and dominant bank material were previously discussed under Section 4.2, Stream Typing. The amount of bank erosion observed along a reach and the bank height were evaluated in conjunction with each other to provide a bank erosion impact rating. Bank erosion was rated as low or not significant for all of the reaches. The locations of bank erosion are illustrated in Figure 8.

Debris/Ice Jam Potential

Undersized culverts or bridges with spans less than the average channel width were the primary factors identified as potential for ice and debris jams. These structures, which are likely to cause constrictions during high flow events may result in lateral erosion or channel avulsions or may even endanger infrastructure. Two reaches received an impact rating of high for debris/ice-jam potential. Five reaches received an impact rating of low for debris/ice jam potential.

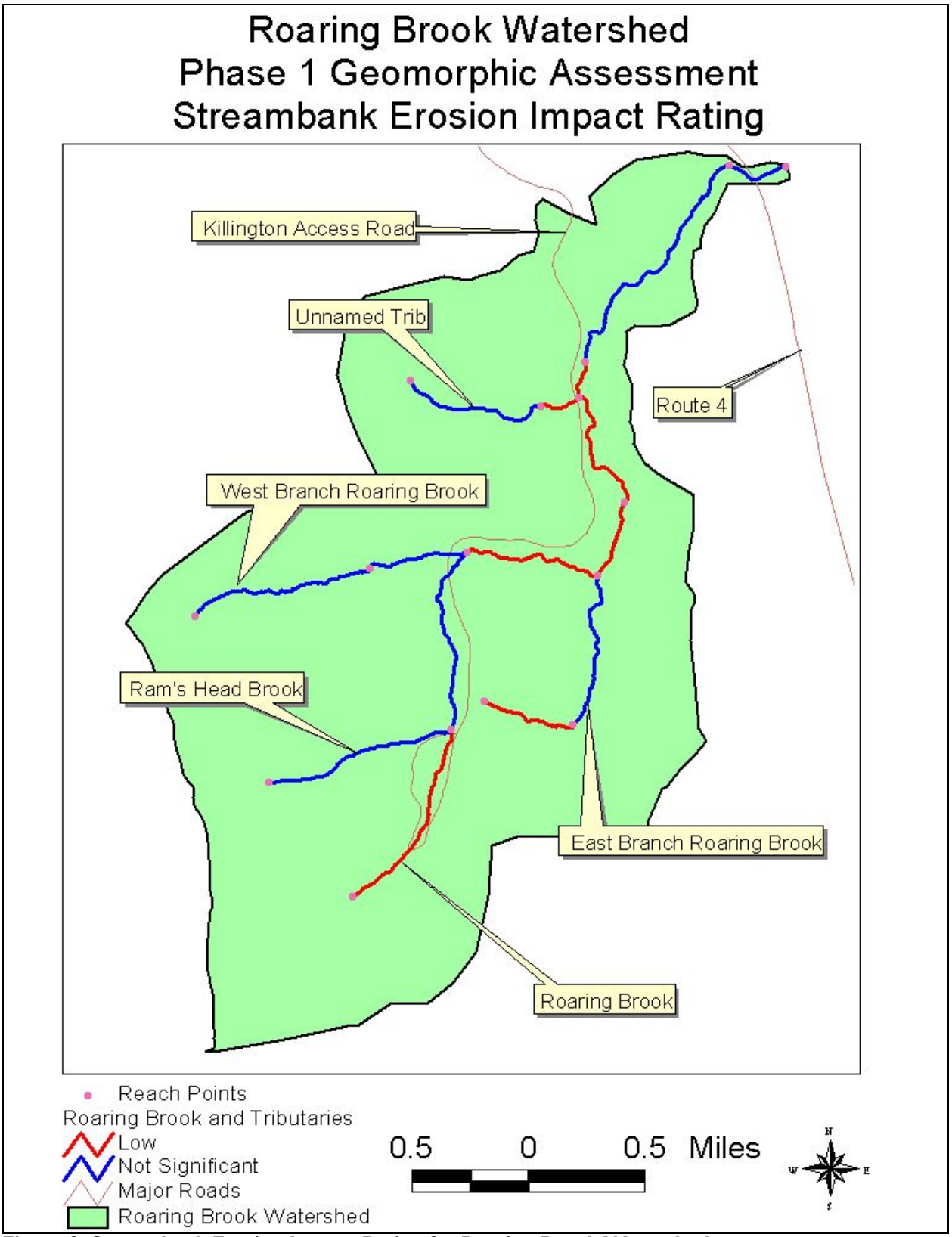

Figure 8: Streambank Erosion Impact Rating for Roaring Brook Watershed

2.3 PHASE I DATA ANALYSIS

2.3.1 Phase I Impact Scores

The Phase I evaluates parameters that may cause channel adjustment. These parameters are grouped into four major categories: land use, in-stream modifications, floodplain modifications, and bed and bank windshield survey. For each parameter, the maximum impact score for the entire watershed is 30 (15 reaches times impact score of 2). As shown below in Figure 9, the corridor land use parameters in the land use category received a high impact rating for the watershed. The parameters berms and roads, river corridor development and channel modifications also resulted in high scores.

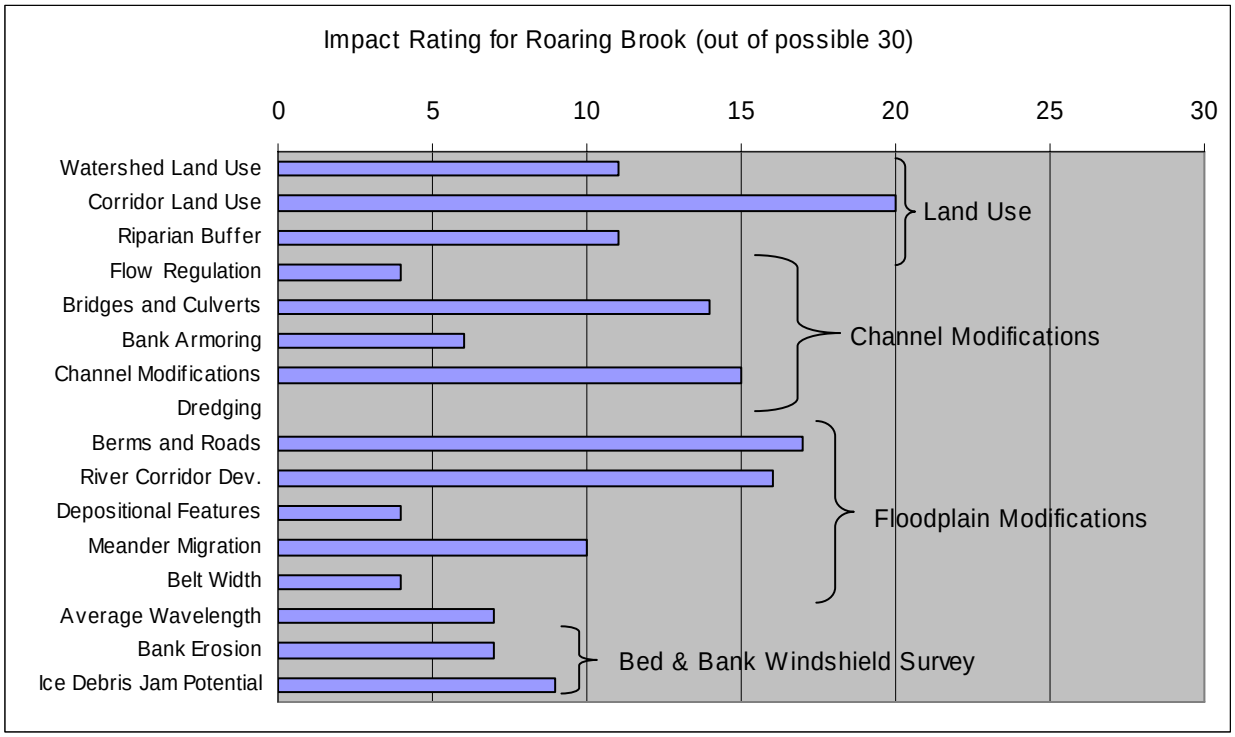

Figure 9: Impact Rating for Roaring Brook Watershed by Parameter and Category

The total impact scores for the Phase I assessment are provided on page 16 of Appendix A and the reach conditions are mapped below in Figure 10. The adjustment process and reach condition are summarized on page 17 of Appendix A.

Only one reach (T6.03) resulted in a reach condition of poor. This reach has undergone significant channel and floodplain modifications which may have resulted in a change in planform, profile, and dimension such that the stream is no longer in balance with the flow and sediment regime of its watershed.

Streams in fair condition are fully in adjustment and are experiencing major and rapid changes due to recent floodplain and channel modifications, land cover changes, and/or loss of riparian buffer. The majority of the unconfined stream reaches were in the fair category, while only one of the confined stream reaches (T6.08), located in the headwaters at the Killington ski resort was rated in fair condition by the Phase 1 DMS.

The streams in the good category have experienced some degree of human-induced change to their watershed, floodplain and/or channel and appeared to be undergoing only minor adjustments. None of the Phase 1 reaches resulted in a reach condition of good.

A reference reach has no significant channel or floodplain modifications and has a forested buffer, adjacent to the channel. In other words, these reaches are close to the natural condition. Streams in reference condition were found in the headwaters and were all A, B or F type streams (i.e. confined). None of the unconfined stream channels scored as a reference reach.

Figure 11 shows that the Phase 1 reach condition is generally related to proximity of roads or development. For the most part, the reaches rated as reference by the DMS were confined streams that require narrower belt widths. The reaches rated as fair or poor were typically unconfined streams located in the more highly developed areas of the watershed.

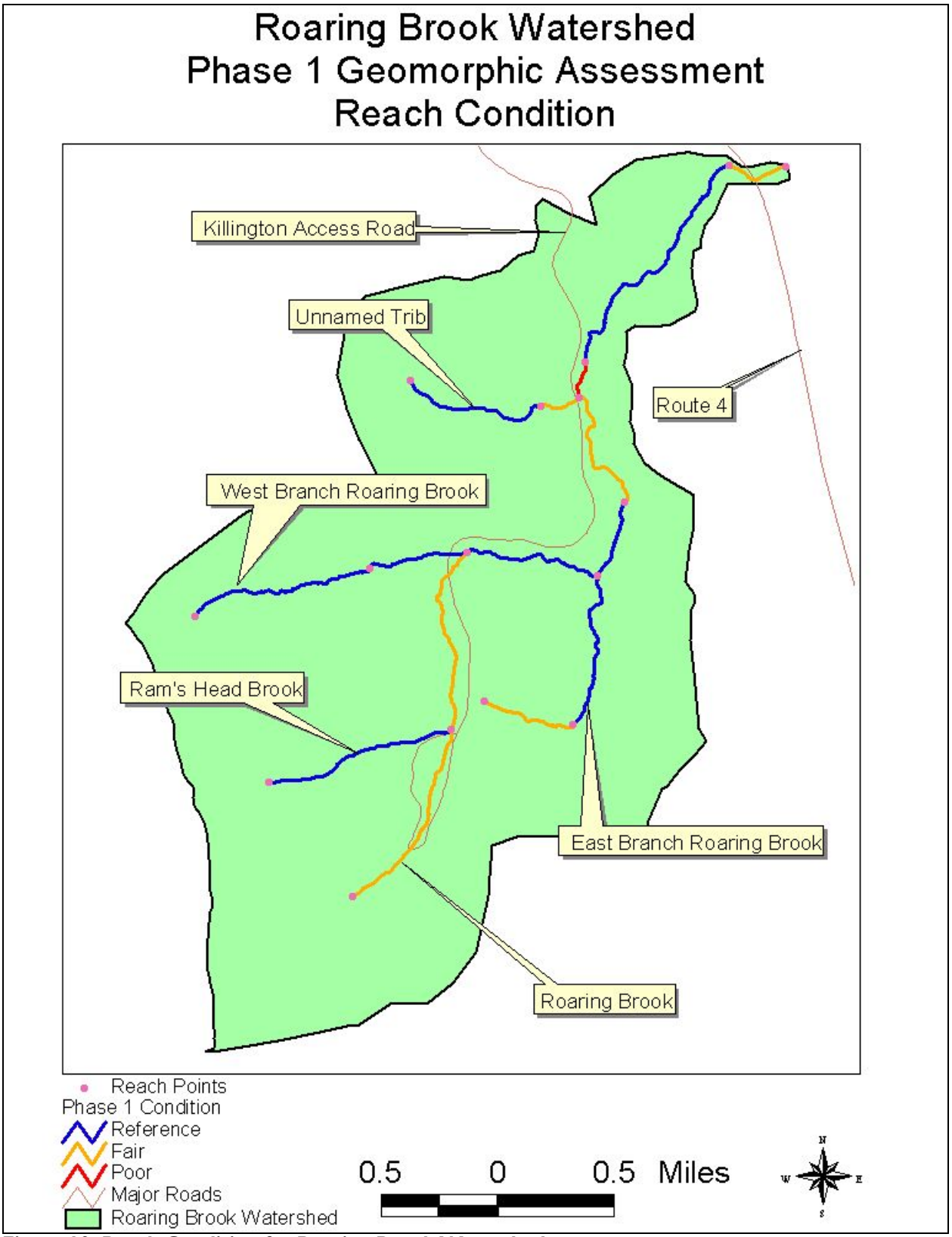

Figure 10: Reach Condition for Roaring Brook Watershed

Table 3: Reach Condition for Unconfined Streams

Reach Number	Confinement	Total Impact Score	Watershed Size (square miles)	Reach Condition (from Phase I Database)
T6.01	BD[2]	17	5.61	Fair
T6.03	VB[3]	21	4.92	Poor
T6.03-S1.01	VB	18	0.63	Fair
T6.04	VB	14	4.25	Fair
T6.05-S1.02	NW[4]	11	0.38	Fair
T6.07	NW	15	1.97	Fair

Table 4: Reach Condition for Confined Streams

Reach Number	Confinement	Total Impact Score	Watershed Size (square miles)	Reach Condition (from Phase I Database)
T6.02	NC[5]	7	5.58	Reference
T6.03-S1.02	NC	5	0.58	Reference
T6.05	SC[6]	10	3.95	Reference
T6.05-S1.01	NC	7	0.75	Reference
T6.06	SC	9	2.96	Reference
T6.06-S1.01	NC	3	0.73	Reference
T6.06-S1.02	NC	1	0.56	Reference
T6.07-S1.01	NC	4	0.35	Reference
T6.08	SC	13	1.11	Fair

[2] Broad
[3] Very Broad
[4] Narrow
[5] Narrowly confined
[6] Semi-confined

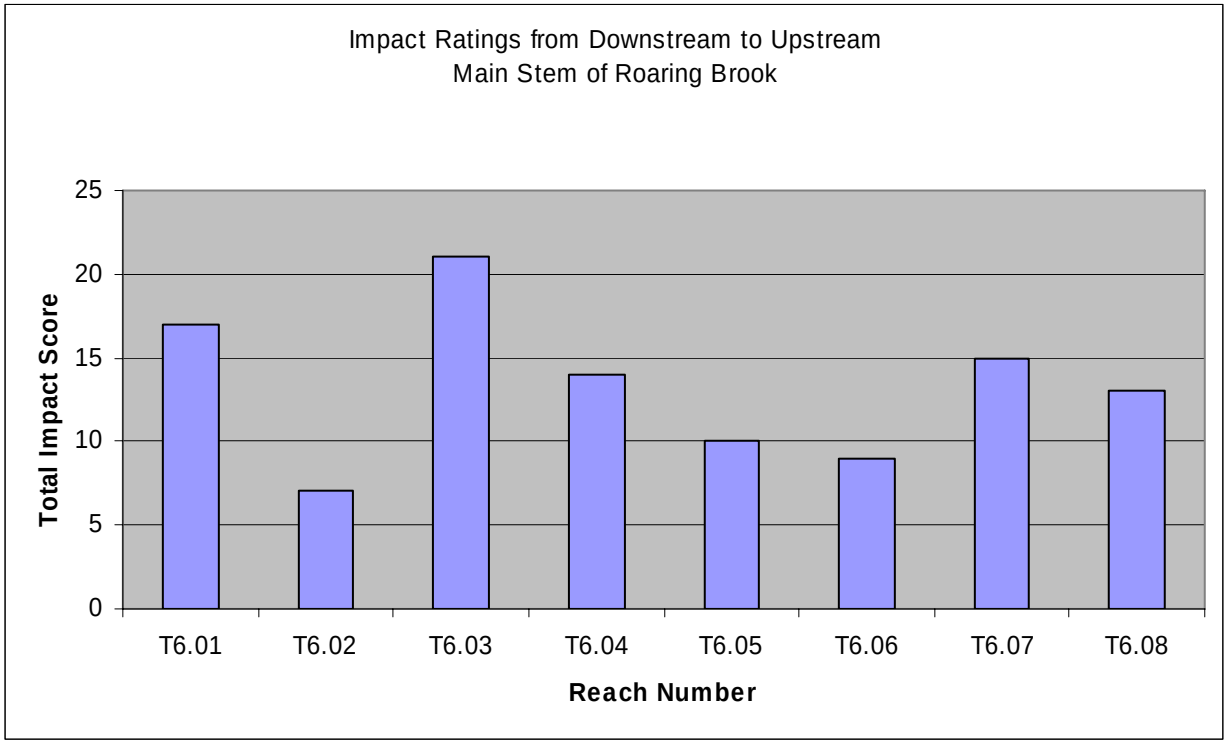

Figure 11: Impact Ratings from downstream to upstream on the main stem of Roaring Brook

2.3.2 Phase 1 Adjustment Processes

Page 17 of Appendix A, provides a summary of the primary adjustment processes that were predicted based on the Phase 1 Stream Geomorphic Assessment. The Phase 1 data suggest that most of the stream reaches are experiencing more than one type of channel adjustment process. Based on the Phase 1 data, degradation and planform adjustment were identified as the primary adjustment factors in the Roaring Brook watershed.

2.3.3 Phase 1 Reach Sensitivity

The stream sensitivity is automated in the DMS based on the existing stream type and condition of each reach. Highly sensitive reaches are more likely to be in adjustment, and are very sensitive to land use changes within the watershed. Seven of the 15 reaches resulted in a high sensitivity, while seven reaches had moderate sensitivity. One only reach, T6.06-S1.02, a high gradient stream with boulder substrate resulted in a sensitivity of very low.

SECTION 3: PHASE 2 STREAM GEOMORPHIC ASSESSMENT

3.1 PHASE 2 METHODOLOGY

The Phase 2 assessment followed procedures specified in the Vermont Stream Geomorphic Assessment Handbook Phase 2 (Vermont Agency of Natural Resources 2005b). 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.

3.1.1 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 2005b). 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.

3.1.2 Phase 2 QA/QC Review

The DMS and the ArcView Shapefiles for the Roaring Brook Phase 2 study were submitted to Shannon Hill of the ANR for a quality assurance (QA/QC) review in October 2005. The Phase 1 DMS and ArcView shapefiles were updated by Michael Blazewicz and Pamela DeAndrea based on the Phase 2 field assessment work during the

Phase 2 QA/QC process in late September 2005. Mary Nealon and Michael Blazewicz provided QA/QC to critical components of the RGA data in October of 2005.

3.2 PHASE 2 RESULTS

The results of the Phase 2 study are summarized below by reach number, and reports from the Phase 2 database are included on pages 1 through 18 of Appendix B.

3.2.1 Reach T6.01

Reach T6.01 was segmented by BCE scientist due to a change in the Roaring Brook's slope, bedform, presence of grade control, and a change in the amount of historic channel modification.

Segment T6.01-A

Segment T6.01-A is the first reach in Roaring Brook. It begins at the confluence with the Ottauquechee River and continues upstream to a bridge crossing with VT Route 100. This reach drains the entire Roaring Brook watershed, an area of 5.6 square miles. The historic land use in segment T6.01-A has reverted back to forest and the reach currently has a healthy riparian buffer and a closed channel canopy. This segment is a "C" channel with a plane bed form. It has been significantly influenced by historic channel straightening and dredging and berming (windrowing) which occurred many years ago. The incision ratio of this reach, 1.35, indicated historic channel degradation. As shown below in Figure 12, the incision, along with the large berms and boulders that armor both banks, has eliminated floodplain access for most of this reach. Widening and planform adjustment also appears to have been limited by the bank armor. The straightness of the reach creates effective transport of sediments. Minor aggradation is occurring throughout much of the reach until the confluence of the Ottauquechee River, (Figure 13) where a large depositional feature exists.

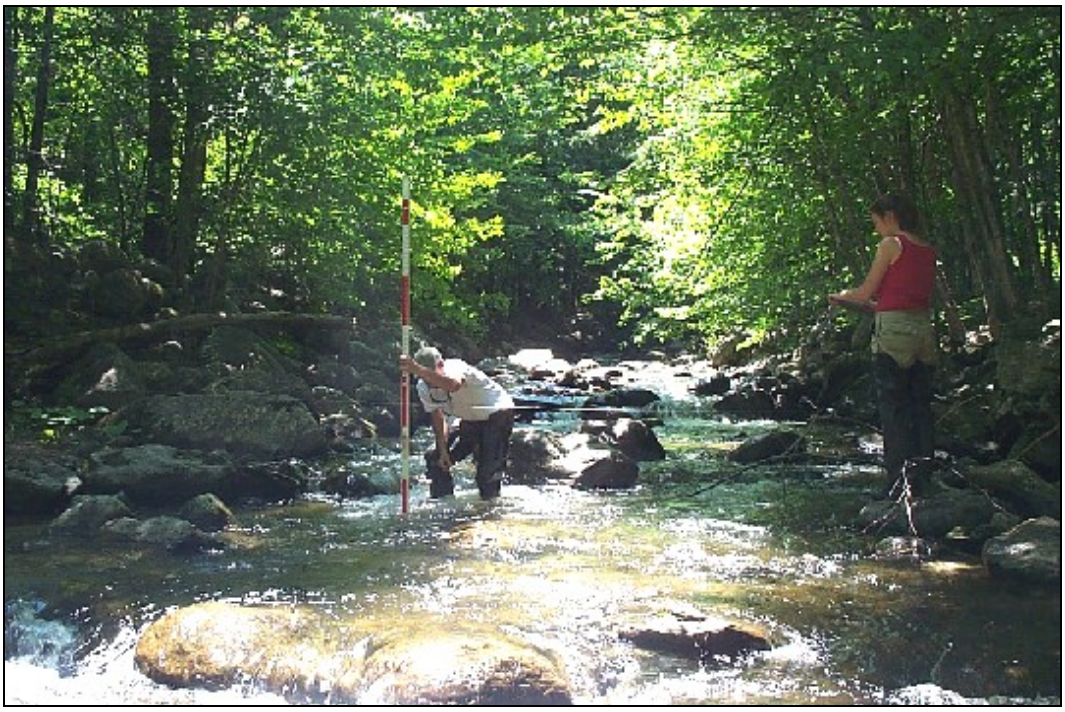

Figure 12: T6.01-A was historically straightened and has become a plane bed stream. Note the high rock berm on the left side of the photograph that was used by a past landowner to prevent the river from accessing its floodplain.

Figure 13: Large depositional feature (delta) at the confluence of Roaring Brook and the Ottauquechee River.

Segment T6.01-B

Segment T6.01-B is also a "C" type channel, however with bedrock grade control at the downstream end and a more natural planform, this segment has retained its bedform as a step-pool system. Despite grade control at the lower end of this reach, there appears to have been some incision that has occurred The incision ratio measured was 1.61. Minor aggradation and widening was also found to be occurring within this reach. Riparian conditions along the stream were generally excellent, with a closed riparian canopy (see Figure 14) except near the bridge crossing of VT Route 4.

Figure 14: Segment T6.01-B has a step-pool bedform and good riparian conditions.

3.2.2 Reach T6.02

Reach T6.02 is a very long reach (6321 feet) through a steep valley. The channel slope through this reach ranges from 5-8%. Although the reach has multiple islands associated with debris jams (and thus rated lowest in planform adjustment), the reach was found to

be overall in good geomorphic condition. T6.02 does not appear to be undergoing any major channel evolution process.

Riparian conditions along almost the entire reach were excellent. Although there was some noticeable deposition of fine sediments, the reach scored well in the rapid habitat assessment due to its many deep pools, abundant large woody debris, and healthy riparian corridor (Figure 15).

The exception to these conditions is found at the very upstream end of this reach, where, for 425 feet, the stream runs between two parking lots, has rip-rapped banks, and no riparian buffer.

Figure 15: T6.02 is a naturally wide, highly entrenched channel with excellent riparian conditions.

3.2.3 Reach T6.03

Reach T6.03 is a short reach (840 feet) that begins behind the Pickle Barrel restaurant where the valley wall of the Roaring Brook opens up and the stream becomes less

entrenched. This reach is the first reach that has been greatly affected by commercial development in the stream corridor and appears to have been historically straightened in some areas. Twenty-five to fifty percent of the banks have been armored with rock rip-rap and log revetments. The riparian buffer of both banks, which averages between 25 and 50 feet, has been significantly disturbed by human activities. Three stormwater outfalls empty into this reach. The combination of these human encroachments, historic channel straightening, and other effects have caused some major degradation to occur. An incision ratio of 1.6 was measured in the field. It appears that the stream is currently undergoing minor aggradation (fine particles made up 32% of the pebble count) and widening in response to these impacts (Figure 16).

Figure 16: Active aggradation and widening of Reach T6.03.

3.2.4 Reach T6.04

Reach T6.04 begins just above a culvert on Roaring Brook Road and continues upstream for 3206 feet until a change in confinement occurs near the lower portion of the

Killington golf course. This reach has also has been impacted by historic channel straightening and floodplain encroachment. The current incision ratio was measured to be 1.8, indicating major historic degradation. There was some evidence of current widening as the river attempts to rebuild a new lower floodplain bench. However, it remains wide and shallow, and is a slightly entrenched "C" type channel with a weak riffle pool bedform (Figure 17). T6.04 is actively responding to sediment which is being stored in the form of point and side bars. One active flood chute and an island were noted along the reach indicating that the reach is also undergoing minor planform adjustment. This planform adjustment, however, is limited by the Killington Access Road and the Killington Golf Course which have encroached on the historic floodplain of this reach, effectively changing the valley width by cutting off access to westward channel planform migration. The current riparian corridor is dominated by commercial buildings on the left bank and residential buildings along the right valley wall. The left bank would benefit from riparian buffer restoration as it is dominated by only a 5-25 foot wide buffer. Three stormwater outfalls empty into this reach.

Figure 17: Typical cross-section along reach T6.04 with weak riffle-pool bedform. The brook has historically incised and is showing some evidence of channel widening.

3.2.5 Reach T6.05

Reach T6.05 begins at the lower end of the Killington Golf Course and continues upstream to the culvert at Ravine Road. Reach T6.05 has no major adjustment process occurring (see Figure 18). None the less, the cumulative evidence of minor degradation, aggradation, planform adjustment and widening showed that this reach is being affected by upstream activities and is only in fair geomorphic condition.

Figure 18: Reach T6.05 has no major adjustment processes occurring. It was likely cobble dominated by reference but is currently dominated by coarse and fine gravels.

Reach M6.05 had a relatively low incision ratio of 1.2 and was found to have remained, or have evolved back to a "B" channel. It retains a weak step-pool bedform that has high amounts of sand and fine gravel (37%) for a stream with a 3.7% slope. The major riparian land use in this reach is the Killington Golf Course which dominates the left corridor.

3.2.6 Reach T6.06

Roaring Brook reach T6.06 begins at a tributary above Ravine Road and continues upstream for 3284 feet to the intersection of another tributary below the Killington Access Road. Riparian conditions within the reach varied. Buffer width ranged from over 100 feet to zero feet depending on the proximity to the golf course, or development on the Killington Access Road. A large waterfall at the upstream end and bedrock within the mid-segment are providing grade control to the reach.

Historic degradation, floodplain encroachment, and the introduction of sediments not formed from within the stream channel (allochthonous), have affected this reach greatly. It was found to be a weak step-pool channel that is being impacted by large amounts of sediment (41% of substrate count). There were multiple mid-channel and side bars through the reach. The reach appears to be actively aggrading and widening as it looks to regain access to its floodplain and transport and store the abundant allochthonous sediments that are within the channel (Figure 19).

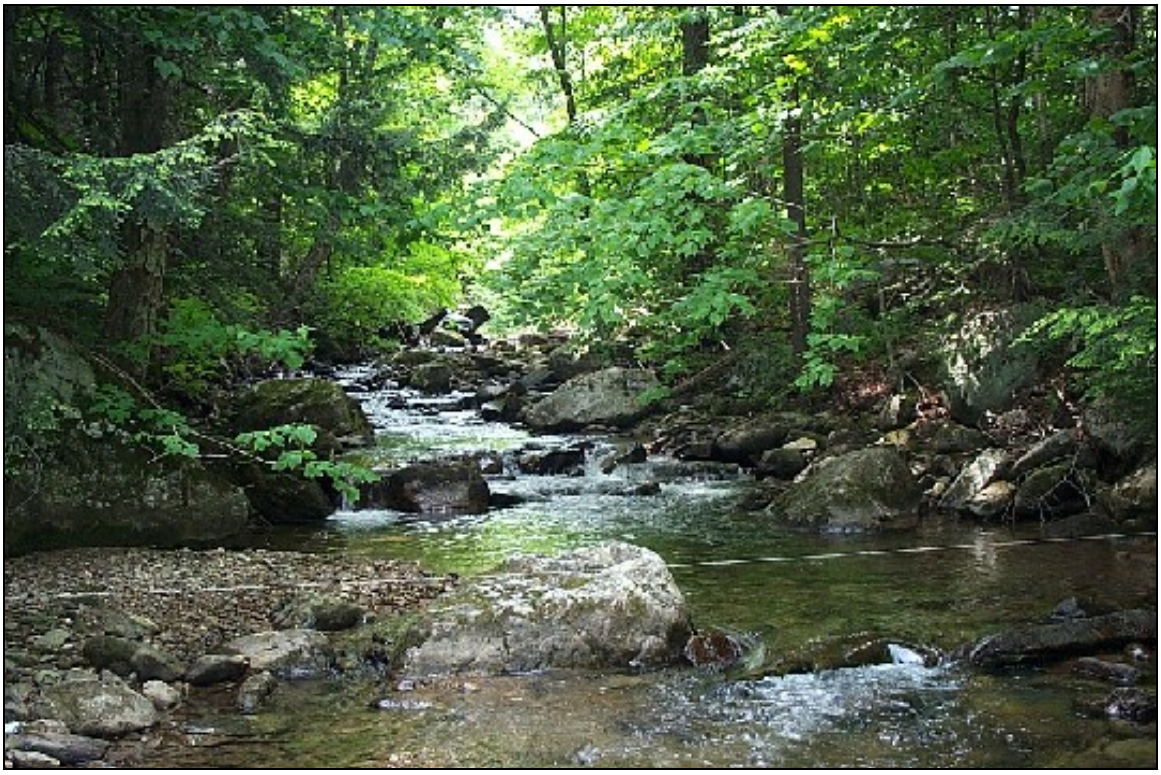

Figure 19: Typical cross-section along reach T6.06. Deposits of gravel (left side of photo), are common throughout this reach.

3.2.7 Reach T6.07

Roaring Brook reach T6.07 begins below the Killington Access Road and continues upstream to the confluence with a tributary above the Ram's Head parking lot. Reach T6.07 was found to be in extreme adjustment due to aggradation, and was also undergoing major widening and minor planform adjustments. An incision ratio of 1.35 indicates that the stream may have historically degraded. Currently 40% of the bottom substrates are comprised of sand and fine gravels (Figure 20), creating fair habitat. It was moderately entrenched "B" type channel that has multiple, mid, point, side, and diagonal bars as a result of increased allochthonous sediment in the channel (Figure 21). In general, there is a healthy riparian corridor along the reach, except at its upper end where a major parking lot for Killington Ski Area (Ram's Head) encroaches on the river corridor. The parking lot is bermed along the brook and stormwater is channeled down slope into a stormwater retention basin that then drains into the stream. This is one of two stormwater outfalls observed on this reach that is causing sedimentation of Roaring Brook.

Figure 20: Major sediment buildup at a debris jam along T6.07.

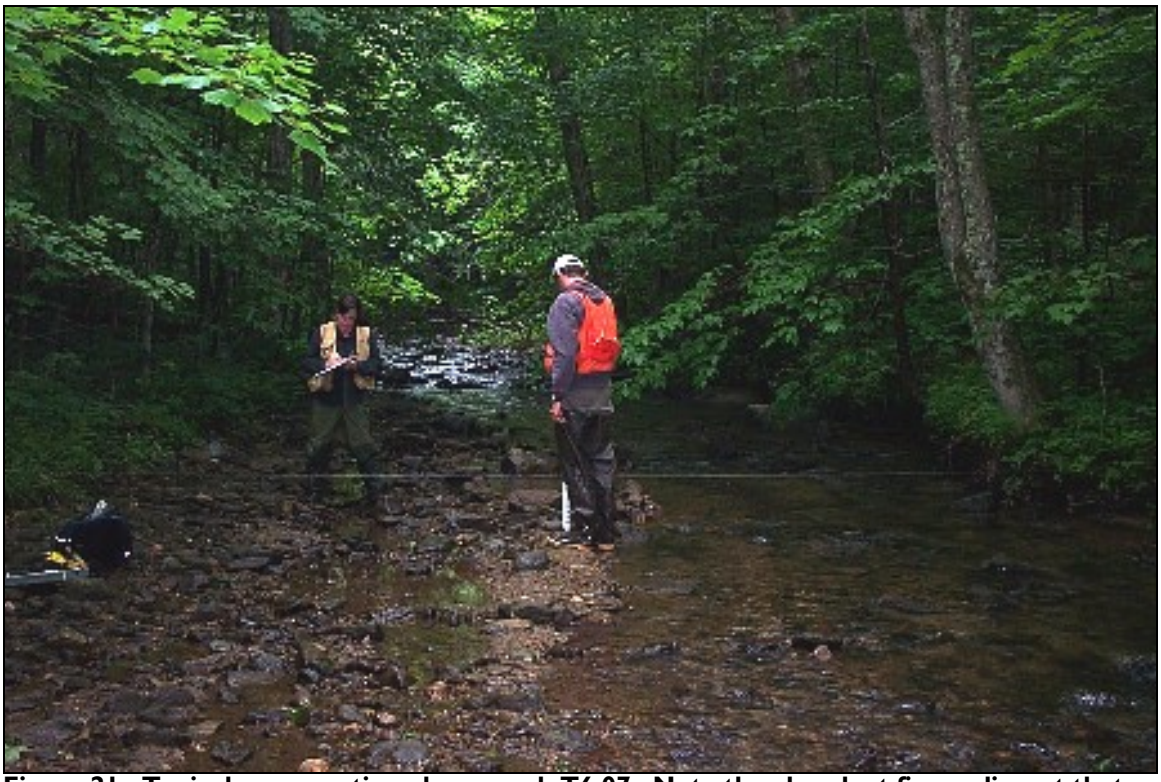

Figure 21: Typical cross-section along reach T6.07. Note the abundant fine sediment that has filled in much of the stream bottom. Habitat in this reach was rated as fair due to excessive sediment and lack of deep pools.

3.2.8 Reach T6.08

Reach T6.08 is the highest reach assessed in the Roaring Brook. It begins above the Ram's Head parking lot at elevation 2250 feet and continues under the Killington base lodge upstream to elevation 2640 feet. T6.08 drains a watershed area of only 1.1 square miles. Like most reaches surveyed on the Roaring Brook, T6.08 is slightly incised with an incision ratio of 1.31 (see Figure 22). As shown in Figure 23, the channel is actively adjusting through major aggradation and widening. This step-pool system has one mid channel bar and several side bars indicating abundant sediment in the channel. Habitat within reach T6.08 has been greatly impacted by stormwater runoff. Seven stormwater outfalls drain into this reach bringing allochthonous sediment into the system. Wash off from the Killington Access Road was noted to be a significant contributor of sediment to the upper Roaring Brook watershed. Large gullies, draining road runoff, were noted along Reach T6.08, and pools were filled in with road materials.

Figure 22: Typical cross-section along reach T6.08.

Figure 23: Abundant road gravels and sediment are entering the Roaring Brook system at Reach T6.08.

3.3 GEOMORPHIC CONDITION SUMMARY

Understanding the response to changes in the sediment regime, hydrology, and the channel area and planform of the Roaring Brook is highly useful for informing restoration efforts.

3.3.1 Channel Management History

Natural and anthropogenic impacts alter the delicate equilibrium of sediment and discharge in natural stream systems and set in motion a series of morphological responses (e.g. incision, widening, aggradation, and/or planform change) as the channel tries to reestablish equilibrium. Small to moderate changes in slope, discharge or sediment supply can alter sediment transport capacity and channel geometry; while large changes can transform stream types of entire reaches (Ryan 2001). Human-induced practices that have contributed to stream instability within the Roaring Brook watershed include:

- Channelization
- Berming
- Alteration of woody riparian vegetation
- Flood plain encroachments
- Urbanization (increase stormwater runoff)
- Poor road maintenance practice and infrastructure installation (Figure 24)
- Loss of wetlands

These anthropogenic practices have altered the delicate balance between water and sediment discharges. Channel morphologic responses to these practices contribute to channel bed degradation 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 24: Undersized culverts, like this one on reach T6.08, disrupt the sediment transport capacity of the steam and often lead to both upstream and downstream destabilization.

3.3.2 Reach Condition

The reach condition is determined using the RGA protocol, and is based on the degree of departure of the channel from its reference stream type (Vermont Agency of Natural Resources 2005b). The reference stream type for each of the Phase 2 reaches was previously identified in Figure 6. Of the 9 segments where Phase 2 RGA's were conducted on Roaring Brook, seven segments rated in the fair category and only two segments rated in the good category (Table 5). There does not appear to be any correlation between location in the watershed and condition of the reach. Instead, stream condition in the Roaring Brook seems more related to corridor land use (Figure 25).

Table 5. Phase 2 Reach Condition for Roaring Brook

Segment Number	Existing Stream Type	RGA Score	Reach Condition
T6.01-A	C3b	0.55	Fair
T6.01-B	C3b	0.61	Fair
T6.02	F3b	0.65	Good
T6.03	C4b	0.58	Fair
T6.04	C4	0.65	Good
T6.05	B4	0.64	Fair
T6.06	B4a	0.53	Fair
T6.07	B4a	0.40	Fair
T6.08	B4a	0.53	Fair

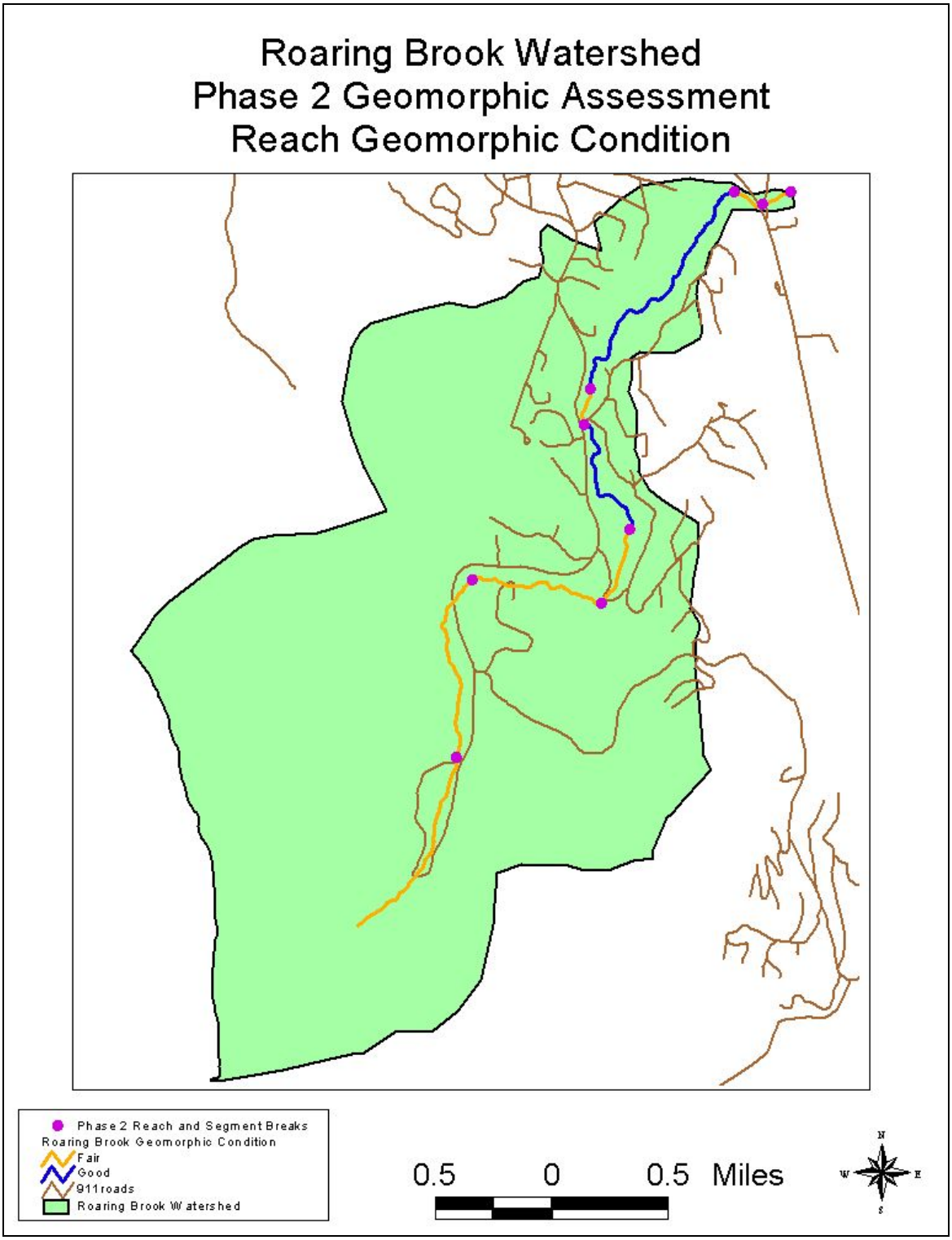

Figure 25: Phase 2 Geomorphic Condition in the Roaring Brook Watershed.

3.3.3 Channel Evolution

The reach condition ratings of Roaring Brook indicate that many of the reaches are actively in a process of minor or major geomorphic adjustment. The most common adjustment processes seem to be historic degradation, active aggradation, planform change, and widening.

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 streamflows are contained in a channel as a result of degradation or floodplain encroachment, or when sediments overwhelm the stream channel and the energy is concentrated into both banks.

The quantity of sediment and sediment size 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 through incision, aggradation, widening, or planform change. According to ANR's F-stage channel evolution model (Appendix C) the 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.

In many areas of the Roaring Brook, this channel evolution process is occurring in response to changes in its sediment, slope, and/or discharge associated with the human influences on the watershed. Table 6 refers to the channel evolution of each study reach.

Table 6. Stream Type and Channel Evolution Stage

Segment Number	Entrenchment Ratio	Width to Depth Ratio	Reference Stream Type	Existing Stream Type	Channel Evolution Stage	Major Adjustment Process
T6.01-A	5.1	16	C	C3b	III	**Aggradation** Widening Planform
T6.01-B	4.1	13	C	C3b	III	Aggradation Widening
T6.02	1.1	30	F	F3a	I	Planform
T6.03	4.9	16	C	C4b	III	Aggradation Widening
T6.04	9.8	15	C	C4	III	Widening Planform
T6.05	2.2	19	B	B4	III	Aggradation Widening Planform
T6.06	1.8	16	B	B4a	III	**Aggradation Widening** Planform
T6.07	2.2	25	B	B4a	III	**Aggradation Widening**
T6.08	2.1	19	B	B4a	III	**Aggradation Widening**

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

Much of the Roaring Brook watershed has retained its natural character, however, many segments have been impaired by floodplain encroachments, undersized structures, and changes in hydrology and sediment associated with stormwater. In terms of the channel evolution model, the Roaring Brook main stem generally appears to be in stage III of the "F" channel evolution model as summarized on page 19 of Appendix B. The channel has undergone historic degradation and widening. All of the cross sections on study reaches were found to be incised. The incision ratio through most of the Roaring Brook ranged

form 1.2 to 1.8. The incision ratio 31.8 for Reach T6.02 is naturally high due to its "F" stream type). The width to depth ratio, particularly in the upper watershed indicated the channel was over wide. These findings are in agreement with the Center for Watershed Protection et al. (1999) study that found Roaring Brook to be in a transitional phase with most of the stress manifesting as channel widening.

Additionally, much of the Roaring Brook watershed appears to be undergoing a second evolutionary process (D-stage channel evolution) associated with excess allochthonous sediment that is being washed into the stream channel from gravel parking lots, roads, and development. This is especially evident in reaches 6.06, 6.07 an 6.08 where aggradation is a major channel adjustment process (Table 6).

3.3.4 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 (Vermont Agency of Natural Resources 2005b).

Figure 26 is a map presenting the existing stream types found in the Roaring Brook watershed. The stream sensitivity of these reaches, generalized according to stream type and geomorphic condition per the ANR protocol, is depicted in Table 7 and in Figure 27. Reach T6.02 and T6.03 were rated as having very high sensitivity, while the remaining Phase 2 segments were high sensitivity.

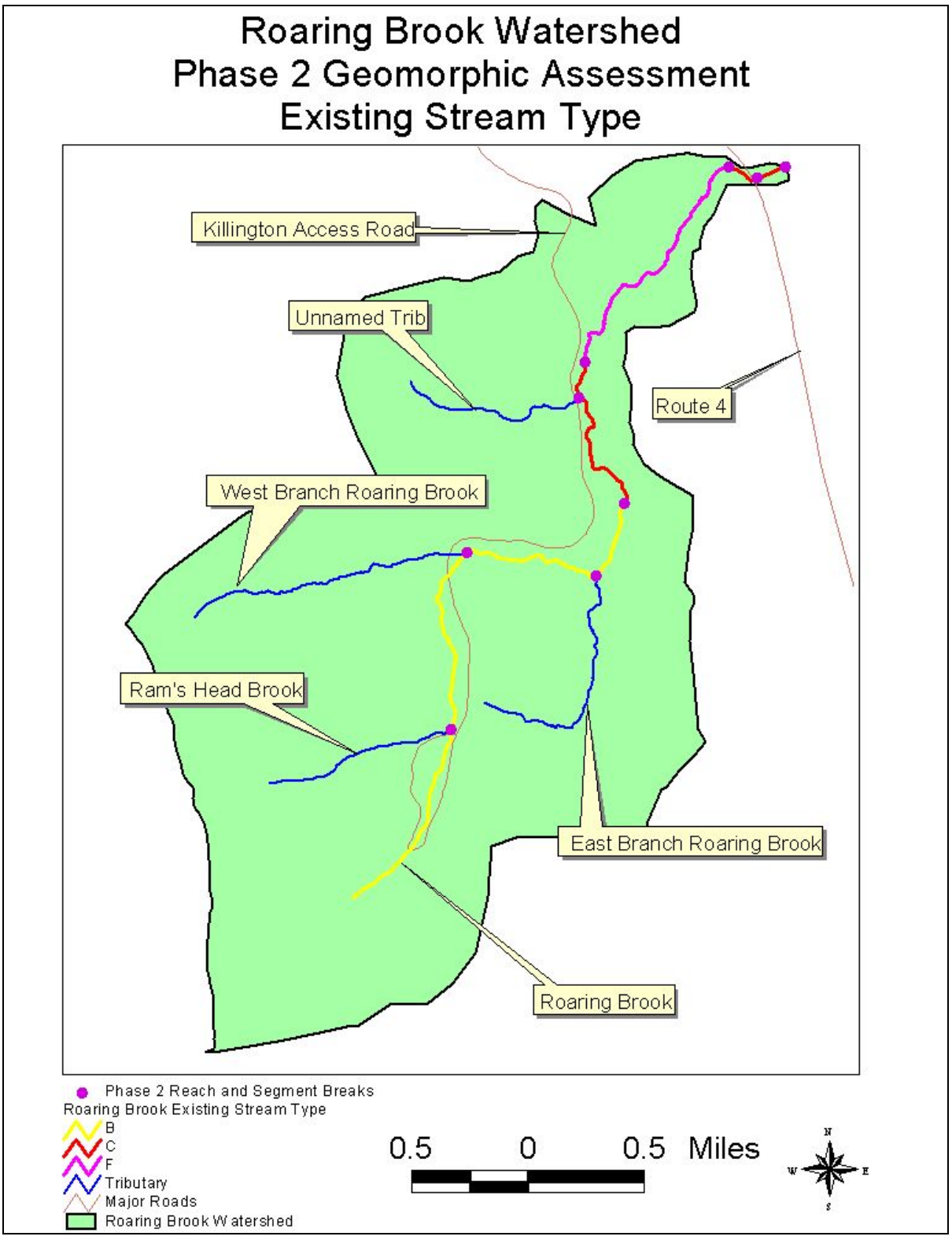

Figure 26: Phase 2 Stream Types in the Roaring Brook Watershed.

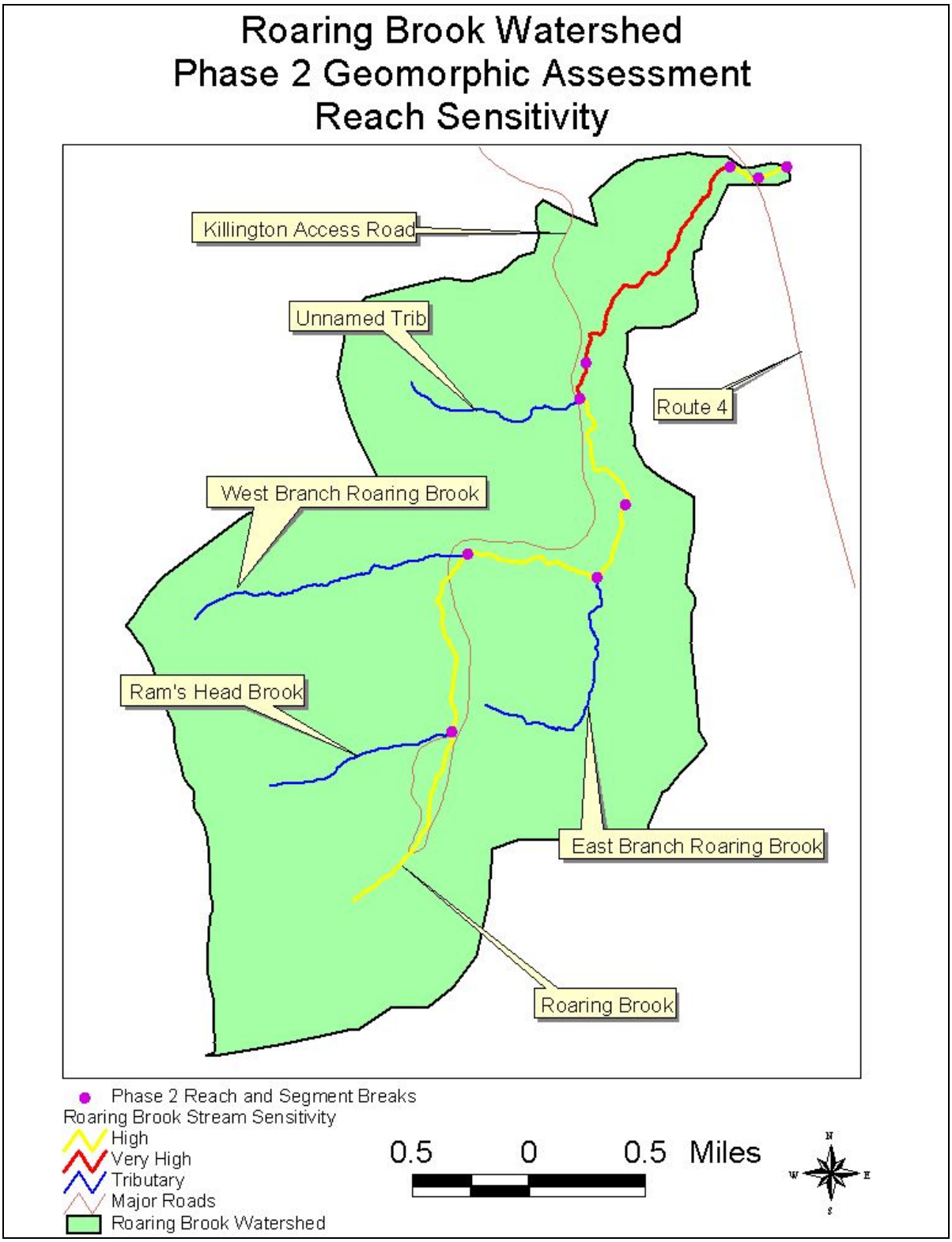

Figure 27: Phase 2 Stream Sensitivity in the Roaring Brook Watershed

Table 7. Stream Sensitivity for Phase 2 Reaches				
Segment Number	**Existing Stream Type**	**Stream Type Departure**	**Geomorphic Condition**	**Sensitivity**
T6.01-A	C3b	No	Fair	High
T6.01-B	C3b	No	Fair	High
T6.02	F3a	No	Good	Very High
T6.03	C4b	No	Fair	Very High
T6.04	C4	No	Good	High
T6.05	B4	No	Fair	High
T6.06	B3	No	Fair	High
T6.07	B4	No	Fair	High
T6.08	B4	No	Fair	High

3.4 PHASE 2 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.

The results of the Rapid Habitat Assessment (RHA) are provided on page 20 of Appendix B. Table 8 below shows a comparison of the habitat condition based on the RHA and the geomorphic condition based on the Rapid Geomorphic Assessment (RGA). For four of the nine segments, both the RHA and the RGA resulted in ratings of fair. Two segments shared an RHA and RGA rating of good. Three segments, T6.01-A, T6.01-B and T6.06 both had good RHA results despite fair RGA ratings (Figure 28). In general the study reaches lacked strong bedform features (several were plane bed) 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 much of the study area (Figure 26). Many reaches had significant intrusion into their river corridor and lacked adequate riparian buffers. Overall, the RHA score was similar to the RGA score, implying that the ecological health of the Roaring Brook is intricately tied to the geomorphic condition of the stream.

Table 8. Comparison of RHA and RGA for Phase 2 Reaches

Segment Number	RGA Score	RHA Score	Rating RGA	Rating RHA
M6.01-A	0.55	0.65	Fair	Good
M6.01-B	0.61	0.81	Fair	Good
M6.02	0.65	0.72	Good	Good
M6.03	0.58	0.51	Fair	Fair
M6.04	0.65	0.68	Good	Good
M6.05	0.64	0.62	Fair	Fair
M6.06	0.53	0.69	Fair	Good
M6.07	0.40	0.47	Fair	Fair
M6.08	0.53	0.60	Fair	Fair

Figure 26: Reach T6.07 rated "fair" for habitat. The reach lacked in-stream woody habitat, riparian vegetation, a riffle-pool system due to historic straightening, and was heavily embedded with fine particles of sand.

Figure 27: Reach T6.02 rated "good" for habitat. The reach had an abundance of in-stream woody habitat, excellent riparian vegetation and riparian buffer, a diversity of substrates, and a diversity of velocity and depth patterns including many deep pools.

SECTION 4: OUTREACH AND EDUCATION

Prior to the start of the Roaring Brook watershed assessment, Bear Creek Environmental met with John Cole of Killington Resort as well as Jennifer Callahan, DEC Stormwater, and Shannon Hill, ANR River Management, to generate a discussion of the project, listen to Killington's concerns and input, and to provide Killington with an introduction to the Geomorphic Assessment protocol.

SECTION 5: RECOMMENDATIONS

Based on the 2005 Phase 1 and 2 Assessments of the Roaring Brook watershed, Bear Creek Environmental recommends the following:

1. Implement stormwater and sediment control efforts whenever possible. Sedimentation of Roaring Brook, particularly form gravel parking lots and drainage swales along the Killington Access Road, could be reduced through better road maintenance and stormwater treatment and retention.

2. The Town of Killington should consider adopting a zone ordinance to limit further floodplain encroachment and to protect riparian buffers.

3. The reference stream type for much of the main stem of the Roaring Brook within the Killington town line appears to be "C". C type stream 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.

4. 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 DEC 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. At the lowest end of the Phase 2 study area, this equates to a meander belt width of 144 feet (or approximately 72 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.

5. Conduct a bridge and culvert survey following ANR protocols to gather specific information about undersized structures in the Roaring Brook watershed. Replace undersized structures when opportunities and/or funding become available.

6. Carefully consider the stream type, evolution stage, and sensitivity before conducting any active geomorphic restoration projects in the main channel of Roaring Brook.

SECTION 6: REFERENCES

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