Phase 2 Stream Geomorphic Assessment of Walloomsac River and Roaring Branch, Bennington County, Vermont FINAL REPORT

March 2007

Prepared for:

Town of Bennington, Vermont

and

Bennington County Conservation District

Prepared by:

Gomez and Sullivan Engineers, P.C.

and

Parish Geomorphic

Executive Summary

With the goal of developing a River Corridor Protection and Channel Management Plan for the Roaring Branch and Walloomsac River in Bennington, VT, a Phase 2 fluvial geomorphological assessment was conducted during the summer and fall of 2006. The focus of the Phase 2 assessment was the entire Roaring Branch (within Bennington and a portion of Woodford) and the mainstem Walloomsac River from its confluence with the Roaring Branch downstream to the Bennington town line. A total of 11.3 river miles on these two rivers were assessed using Vermont's Phase 2 protocols. The assessment allowed for an inventory of historic and current land and channel management activities and an evaluation of the related effects on the geomorphic condition of the river system.

The Roaring Branch is shaped through a glacially formed alluvial fan, and is composed of very coarse materials. Tributaries that form the Roaring Branch descend from the higher elevations of the Green Mountains and as the river approaches the center of Bennington, the valley slope decreases and sediment is deposited in the stream channel. The stream channel is very dynamic, comprised of multiple channels in many locations. Berms, largely composed of river bed material, were historically built up in the floodplains to protect developments and the stream banks have been rebuilt and armored in response to flood damages. These man made alterations have increased the energy within the system and have resulted in various adjustment processes occurring.

The multiple channel patterns and bed forms characteristic of the Roaring Branch change frequently in response to high flow events as "slugs" of sediment are transported erratically through the system. This study has found the Roaring Branch in Bennington to be extremely sensitive and hazardous to erosion despite repeated efforts to contain or control the flood channel. Extensive scour and bed degradation was observed along hardened banks regardless of whether the dominant channel process within the reach was one of aggradation or degradation.

The Walloomsac River, which has a total drainage area of 156 square miles, originates in the Town of Bennington at the confluence of South Stream and Barney Brook, and flows generally northwest 16.4 miles to the Hoosic River in New York State. The river flows through residential, commercial and industrial areas of Bennington. Downstream of its confluence with Roaring Branch, the river meanders through commercial, residential and agricultural areas. The Walloomsac River is more stable than Roaring Branch, however areas of historical berming, dredging and straightening are present, especially in the area just downstream of its confluence with the Roaring Branch. Bank protection structures and bridges within the study area are being exposed to channel adjustment hazards. Management of the Walloomsac River is particularly important as considerable opportunity exists for future development to encroach on the river corridor which will inevitably cause management conflicts.

Recovery for such dynamic river channels means defining a corridor in which the dynamic processes of successive aggradation and deposition can occur. The limits of the corridor will be defined during the development of the Fluvial Erosion Hazard Zone. In the case of the Roaring Branch, its recovery is restricted by development, encroachment, and bridge constrictions.

The results of the geomorphic assessment provide a picture of governing channel processes, existing constraints, and restoration opportunities and will aid in the development of the River Corridor Protection and Channel Management Plan. Preliminary potential restoration and management alternatives are listed within and will be presented to the Town for discussion. This will allow an opportunity for feedback and initiate action on the part of Town to move forward with implementation of a corridor protection plan.

Table of Contents

List of Tables and Figures

Title **Page Number**

Acronyms and Abbreviations

ANR	Agency of Natural Resources
BCCD	Bennington County Conservation District
CEM	Channel Evolution Model
DMS	Data Management System
FEH	Fluvial Erosion Hazard
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
ft.	feet
GIS	geographic information system
GPS	global positioning system
LIDAR	Light Detection and Ranging
NRCS	Natural Resource Conservation Service
QA	quality assurance
RGA	Rapid Geomorphic Assessment
RHA	Rapid Habitat Assessment
SGAT	Stream Geomorphic Assessment Tool
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
W/D	width/depth (ratio)
WPA	Works Progress Administration

1.0 Project Background

The Roaring Branch of the Walloomsac River is adjusting in an attempt to balance watershed inputs of water and sediment with its imposed boundary conditions. To address these conditions, a fluvial geomorphological assessment was conducted on the Roaring Branch and the Walloomsac River in the Town of Bennington and a portion of the Town of Woodford, Vermont during the summer and fall of 2006.

The data collected will allow for an assessment of historic and current land and channel management activities and the related effects to the geomorphic condition of these rivers. The results of the geomorphic assessment provide a picture of governing channel processes, identify additional data needs, and ultimately aid in the development of channel management and river corridor restoration plan for the river system within the study area.

Project partners include the Vermont Agency of Natural Resources (ANR) River Management Program, the Bennington County Conservation District (BCCD), and the Town of Bennington. A kick-off meeting was held in August 2006 to discuss the project approach and geographic scope. The geographic scope and goals of the Phase 2 assessment and the project were discussed, and it was understood that the complexity of the project site would necessitate additional information not usually collected during Phase 2 work (as outlined by the protocols) in order to develop the River Corridor Protection and Channel Management Plan. It was also understood that the additional data needs and the corresponding timeframes would be discussed as the project unfolded.

1.1 Goals and Objectives

The development of a River Corridor Protection and Channel Management Plan for Roaring Branch and Walloomsac River is the final goal of this project. The Phase 2 assessment was conducted to collect geomorphic data on the Roaring Branch and portions of the Walloomsac River, as part of the development of this plan.

The objectives of the Phase 2 assessment were to:

- Collect geomorphic and habitat data according to Vermont's rapid assessment protocols;
- Interpret the data to determine dominant channel processes, channel type, condition, and sensitivity;
- Identify where and how the river channels are responding to historical human modifications;
- Document potential areas of abandoned floodplain in the study area where reconnection with the river channel may allow for improved energy dissipation and sediment and flood flow attenuation.

1.2 Study Area

The Walloomsac River has a total drainage area of 156 square miles and originates in the Town of Bennington at the confluence of South Stream and Barney Brook. The Walloomsac flows generally northwest 16.4 miles to the Hoosic River in New York State (**Figure 1**). The river flows through residential, commercial and industrial areas of Bennington. Downstream of its confluence with Roaring Branch, the Walloomsac River meanders through residential and agricultural areas.

The drainage area of the Roaring Branch is approximately 41 square miles. The Roaring Branch originates in the Town of Woodford, and has a very deep boulder-strewn channel (FEMA 1986). The Roaring Branch flows west through Woodford Hollow along the face of a glacial delta (USACE 1975).

Evidence from historic topographical maps and aerial photographs indicates that the current location of the Roaring Branch below Route 9 to the confluence with the Walloomsac was altered between 1898 and 1942. According to the 1898 topographical map, the Roaring Branch confluences with the Walloomsac just east (and upstream) of the Town of Bennington. The 1942 aerial photographs show the channel at this time to be relocated north of Bennington center in its current location. It is not known whether the river was relocated by man or by natural adjustment, but it is important to note that the river has occupied it present location for fewer than 100 years. Since that time, the Roaring Branch and the Walloomsac have undergone a history of significant alteration and control in response to large flood events and severe erosion (See section 1.3 Flood History).

1.3 Flood History

Significant floods in the basin and the resulting damage, as well as the manipulation of the rivers in response to the flooding episodes are summarized in this section. Major floods on record that caused damage on the Walloomsac River and the Roaring Branch occurred in 1869, 1898, 1927, 1936, 1938, 1948, 1950, 1973, 1976 and more recently, 1987 (USACE 1975). The Roaring Branch drainage area is particularly susceptible to flooding because the natural valley is narrow, and development has encroached into the valley. In addition, the historic population trend has been towards the valley floors, as is the case with the Town of Bennington.

The major flood events have caused significant damage to the stream channel and surrounding area, the most damaging event occurred in November 1927 when Main Street in Bennington was flooded (FEMA 1986). In response to these flooding episodes, significant flood protection measures were implemented along the Walloomsac River and Roaring Branch including: floodplain filling, channel dredging and straightening, streambank armoring, and the creation of physical barriers such as berms and levees adjacent to the rivers.

To gain perspective on the severity and occurrence of the floods, the flow frequency characteristics of the Walloomsac River at the USGS gaging station in North Bennington (gage no. 01334000) are presented. **Table 1** shows magnitude and frequency of discharges at the gage for the period 1932-2000.

Table 1: The Peak Flow for Given Recurrence Intervals (cfs) at USGS Stream Gaging Station.

2-year	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**	**500-year**
3,310	4,870	5,980	7,480	8,660	9,890	13,000

Source: USGS 2002.

Although the 1927 flood was before the installation of the gauge, it is considered one of the worst floods in the state's history. A peak magnitude of 15,000 cfs in the Walloomsac River was estimated during this flood (USACE 1975). The flood in November 1927 was the result of a tropical storm over Vermont. In the late morning and afternoon of Nov. 3, 1927, all Vermont rainfall records were broken with over 7 inches of rain falling at Bennington in two days. The damage for this flood was massive and eventually resulted in changes to flood policy and the implementation of major flood control projects throughout in the state. Millions of dollars have been spent in Vermont as a direct result of flood damage, and about $60 million has been spent on flood-control projects statewide since 1990 (ANR Act 137 Report, 1999).

Since the gauge installation, the maximum flood peak on record of 8,450 cfs was recorded at the USGS gage on September 21, 1938. A hurricane known as the Great New England Hurricane of 1938 brought days of record rain and flooding to Vermont. After the 1938 flood, a 1,325-foot concrete floodwall was built on the west bank of the Roaring Branch, upstream and downstream of the Brooklyn Bridge. Earthen dikes (levees) were also built on both sides of the Roaring Branch from the Brooklyn Bridge downstream to the river's confluence with the Walloomsac River. The earthen levee was built primarily from material that had been deposited on the streambed during the flood - boulders, cobbles and gravel - with some riprap stabilization in a couple of areas near structures. This flood wall was originally built by the town as a Works Progress Administration (WPA) project in 1939. In addition, the channel was dredged and straightened, in possibly one of the largest channelization projects in Vermont's history, from what is now the area of the Route 7 Bridge to the area of the Route 9 Bridge.

Floodwaters in December 1948 (peak flow of 7,920 cfs) and August 1950 (peak flow of 7,800 cfs) seriously damaged a 725-foot-long section of the WPA-built floodwall and cluttered a section of the Roaring Branch channel with gravel and boulders. This debris reduced the streamflow capacity of the Roaring Branch and caused a potentially dangerous flooding situation.

The U.S. Army Corps of Engineers (USACE) reconstructed this section of floodwall from July 1951 to April 1952. This section of the WPA-built floodwall was later incorporated as part of the Bennington Local Protection Project. During this time, the Corps also excavated accumulated gravel and boulders from about 3,000 feet of the Roaring Branch channel (the second large scale dredging operation on this reach of river). This material was deposited at critical sections along the left bank to form earthen dikes. The intent of the snagging and clearing project was to improve the flow capacity of Roaring Branch, thereby reducing the threat of flooding.

The Bennington Local Protection Project, located along the left bank of Roaring Branch, begins about 1,000 feet upstream of the Brooklyn Bridge and ends on Park Street. The project was completed in November 1971 by the USACE to protect Bennington from damage caused by the floodwaters of Roaring Branch. The project, about one mile in length, is now operated and maintained by Bennington and consists of: 1) two sections of earthfill dike with stone slope protection, 2) three sections of concrete floodwall, 3) four drainage structures, and 4) a ponding and pumping area near Park Street.

The first dike section is about four feet high and begins about 1,000 feet upstream of the Brooklyn Bridge and extends downstream for 530 feet. The second section begins about 700 feet downstream of the Brooklyn Bridge and ties into high ground adjacent to Mount Anthony Union High School on Park Street. This dike is 3,180 feet long and averages six feet high (**Figure 2**).

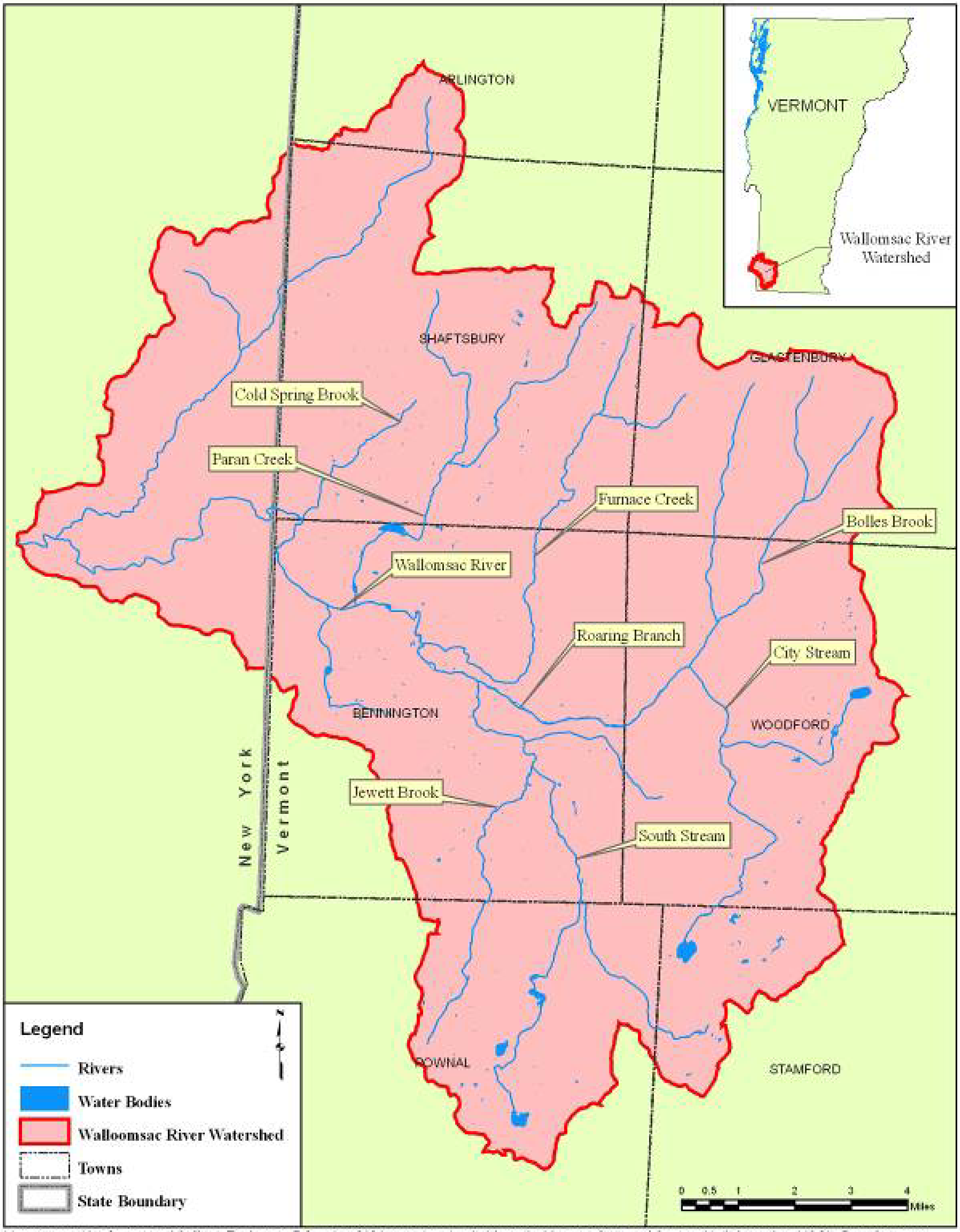
Two sections of concrete floodwall were added to the original 1,325- foot-long floodwall built in 1939 to form a concrete floodwall with stone slope protection totaling almost 1,500 feet. The first section of floodwall starts about 500 feet upstream of the Brooklyn Bridge and extends for 34 feet before tying into the second section of floodwall, which is the WPA floodwall. The third section of floodwall is located immediately downstream of the WPA floodwall and is 116 feet long. This floodwall is approximately 8-12 feet high.

A report in 1975 by the USACE states that the channel was recently cleaned of all vegetation and notes that abundant amounts of brush and trees have grown in the channel in the past. In 1975, it was also noted that open space on or near the floodplain is coming under increasing pressure for development. During August, 1976, heavy rains from Hurricane Belle caused flooding throughout Vermont. The peak flow recorded at the Walloomsac River was 6,510 cfs which undermined a 250-foot-long section of floodwall by dislodging the stone slope protection at its base and exposing its footing. The placement of additional stone slope protection to secure the floodwall was completed in June 1977.

During a one-week period beginning at the end of March 1987, a pair of intense rainstorms hit most of New England, causing major flooding in Vermont (USACE 1987). These two storms, augmented by snowmelt in the mountains, created two separate and significant flood peaks and resulted in widespread flooding and damage to the Roaring Branch. Rainfall totals in the Walloomsac basin were around 6 inches over the week. The flood peak was 7,350 cfs on April 5, 1987. The flood caused extensive erosion of the banks of the Roaring Branch; in response, the Natural Resources Conservation Service and the State of Vermont reconstructed and armored several thousand linear feet of Roaring Branch streambank from an area downstream of the Route 9 Bridge in Bennington downstream to the Route 7 Bridge. There was also extensive channel clearing and excavation of sediment deposits. Photographs of the stream repair work from this period are included in **Appendix B**.

Also present along the Walloomsac River, and the Roaring Branch in particular, are extensive areas of historical berming and dredging. The history of the berming and dredging is less well known. Our field visits verified a complex system of berms on both sides of the river that are often overlapping and spaced across the floodplain.

Figure 1: Walloomsac River Watershed.



Map prepared by Gomez and Sullivan Engineers, P.C. using GIS layers downloaded from the Vermont Center of Geographic Information (VCGI). Data Sources: Rivers & Water Bodies – USGS DLG; Walloomsac River Watershed - USGS HUC10 Basins; State & Town Boundaries - BNDHASH.

Figure 2: Historic Photograph of the Floodwall and Dike along Roaring Branch.

The Bennington Local Protection Project protects Bennington from damage caused by the floodwaters of Roaring Branch. The left photo shows a section of the 1,472-foot-long concrete floodwall (bottom arrow); the beginning of the 3,180-foot-long dike (middle arrow); and the end of the dike (top arrow). The Brooklyn Bridge spans Roaring Branch in the lower part of the photo.

Source: U.S. Army Corps of Engineers, New England District, 1995. Date of photo uncertain.

2.0 Methods

This study of the geomorphic characteristics of the Walloomsac and Roaring Branch rivers utilized methods presented in Vermont's Phase 2 Rapid Stream Assessment Field Protocols (ANR, 2006a). Prior to conducting the Phase 2 assessment (methods outlined in section 2.1), the data generated for the study area during the Phase 1 assessment was reviewed. Phase 1, the remote sensing phase of the geomorphic assessment, was conducted by BCCD. Phase 1 involved the collection of data from topographic maps, aerial photographs, existing studies, as well as from very limited field reconnaissance (windshield surveys).

Phase 1 methods included selecting study streams, dividing streams into reaches of homogeneous channel and valley geomorphic characteristics, evaluating geology, soils, land cover, reach hydrology, in-stream channel modifications and floodplain modifications on each reach. The evaluation of these parameters allowed for the assignment of a numeric impact rating for each reach, and provisional reference stream types were established based on valley land forms and their geology. Predictions of channel condition (departure from reference), adjustment process, and reach sensitivity were based on evaluations of watershed and river corridor land use and channel and floodplain modifications.

The Phase 1 assessment was conducted on the entire main-stems and tributaries of the Roaring Branch and Walloomsac River and included 43 reaches. Of these, 9 reaches were selected on the Roaring Branch and Walloomsac River mainstem for the Phase 2 assessment (**Figure 3**).

Survey data, topographic maps, aerial and ground photography, and hydraulic calculations from the Woodford Packers Site court case of 2001 was provided by the Vermont Agency of Natural Resources for review by the study team. The data and observations and determinations of channel condition and morphology presented in the case are consistent with our observations and interpretations of the river, and provide historical data for which to compare present day conditions.

2.1 Field Assessment

The focus of the Phase 2 assessment was the Roaring Branch and the mainstem Walloomsac River downstream of its confluence with the Roaring Branch. A total of 11.3 river miles on the Walloomsac River and Roaring Branch were assessed using Phase 2 protocols.

Phase 2 field efforts were conducted during September and October, 2006, and consisted of identifying bankfull features, collecting field measurements of the channel dimensions, impacts, shoreline and riparian condition, floodplain encroachment and modification, and determining substrate characterization. The measurements were collected to determine the stream reach type, condition and sensitivity.

Each reach was traversed by a field crew of two or three persons. Each crew had a complete set of orthophotos and topographic maps, as well as the Phase 1 reach summary reports for each reach. Reaches on the Roaring Branch were covered on foot and the floodplain and terrace areas on each side of the river were examined. The Walloomsac River was traversed using a canoe and also by wading on foot. A field sketch was completed for each river reach and representative photographs were collected.

Cross-sections were collected at representative locations within each reach. Along the Roaring Branch, two representative cross-sections were chosen from each reach. Channel dimensions were derived from the cross-sections to verify and update the stream type classifications and bedform types. The Phase 2 field work also included a Rapid Habitat Assessment (RHA) and Rapid Geomorphic Assessment (RGA) for each stream reach and segment.

Bridge assessments were also conducted, which entailed visiting each bridge crossing the Walloomsac River and Roaring Branch and collecting information in accordance with the methods outlined in the Bridge and Culvert Assessment of Vermont's Phase 2 Assessment Protocols.

At the time of this report, methods were being examined to accurately describe the profile of the channel and relief of the surrounding floodplain. The complex system of berms on the floodplain of the Roaring Branch has a significant impact on the ability of the channel to access its floodplain during flood events. Therefore, removal of berms poses one possible management strategy. Information such as channel invert elevation (profile), floodplain elevations, and the presence and magnitude of berms in the floodplain must be collected to complete a management plan for the river. The methods being considered include conducting a ground survey to identify the berms using high-resolution GPS, or performing LIDAR surveys (Light Detection and Ranging) of the area using aerial equipment.

2.2 Data Management

Standard field forms from Appendix A of the Phase 2 Handbook were used to record field data. For each reach and segment, these forms included rapid stream assessment field notes, cross-section worksheets, photo logs, and the RHA and RGA field forms. Field sketches were completed on forms prepared prior to field mobilization that included an outline of the river for each reach at a scale of approximately 1:2500.

The field teams collected GPS data on the instream features consistent with the protocols. The feature types collected with GPS are listed in **Table 2**. Data were collected in the field using a Trimble Model Pro-XH high-resolution GPS backpack unit. The GPS data collected in the field was differentially corrected in the office to improve accuracy and then reviewed with ArcGIS software. This data could not be directly imported in to the Stream Geomorphic Assessment Tool (SGAT). Rather the data was uploaded to Arcview 3 and the features collected in the field were re-created within the SGAT extension.

All of the field data forms were scanned and archived. Photographs were collated and archived to a compact disk. The field data and cross-section plots were imported in the Vermont on-line Data Management System (DMS).

2.3 Quality Assurance and Quality Control Procedures

In order to ensure the collection of accurate and consistent data, users of the Vermont ANR Stream Geomorphic Assessment protocols need to establish a quality assurance program for each phase of the assessment. The protocols outline three key components of quality assurance (QA): training, data review, and use of a data management system. Conducting a QA program at all levels of assessment ensures that data is accurate and complete.

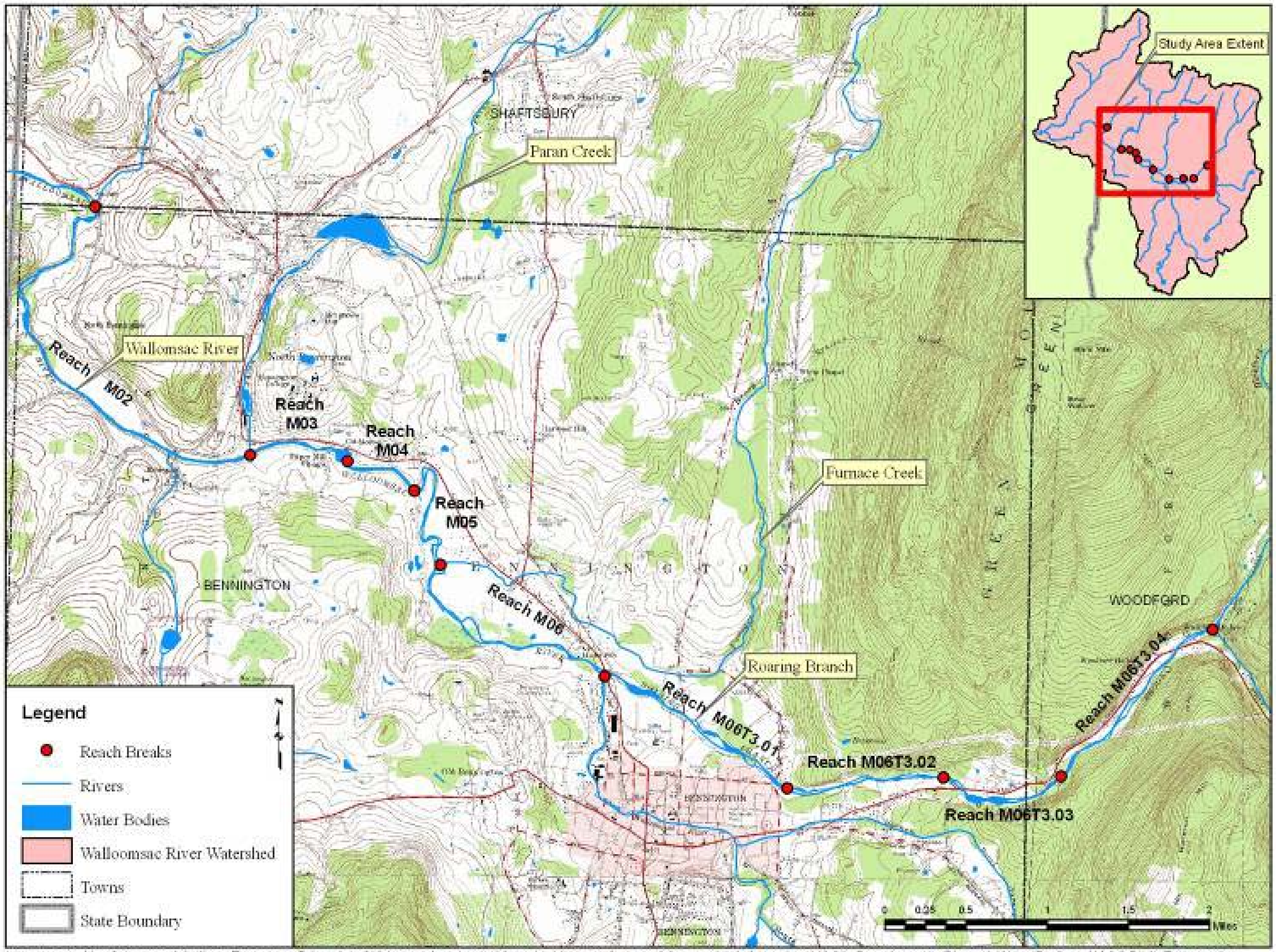
The trained Field Coordinator was on-site during the entire Phase 2 field assessment. The Phase 2 data was first reviewed and interpreted by field assessors and then presented to River Management Program staff for their review and discussion. As a result of the QA/QC review, field data sheets were adjusted at the direction of River Management Program staff which then resulted in several changes to the channel types, conditions and sensitivities as originally interpreted by the consultant. Data was entered into the DMS and the automatic QA process was performed.

Table 2: Stream Impacts Documented with GPS During the Phase 2 Assessment.

Impact	Sub-Impact
Point Features	
Alluvial Fan	N/A
Grade Control	Dam
	Ledge
	Waterfall
	Weir
Mass Failure	N/A
Dredging	Dredging
	Gravel Mining
	Commercial Mining
Debris Jams	N/A
Stormwater Inputs	N/A
Beaver Dams	N/A
Migration	Neck Cut-off
	Flood Chute
	Avulsion
	Braiding
Head Cuts and Steep Riffles	Head Cuts
	Steep Riffle
Stream Crossing	Stream Ford
	Animal Crossing
Flow Regulation & Water Withdrawals	Drinking
	Irrigation
	Snow Making
	Bypass
Gullies	N/A
Bridges and Culverts	N/A
Line Features	
Development	N/A
Encroachment	Berms
	Improved Paths
	Roads
	Railroads
Bank Armoring and Revetment	Rip-Rap
	Hard Bank
	Other
Erosion	N/A
Straightening	Straightening
	With Windrowing

Note: Bridges were marked as point features during that Phase 2 Assessment.

Figure 3: Walloomsac River and Roaring Branch - Phase 2 Reaches.



Map prepared by Gomez and Sullivan Engineers, P.C. using GIS layers downloaded from the Vermont Center of Geographic Information (VCGI). Data Sources: Rivers & Water Bodies - USGS DLG; Topography - USGS DRG; Walloomsac River Watershed - USGS HUC10 Basins; State & Town Boundaries - BNDHASH.

3.0 Geomorphic Context

3.1 Roaring Branch

The Roaring Branch begins in the Town of Woodford at the point where City Stream joins Bolles Brook. The Phase 2 study area included four reaches (M06T3.04 to M06T3.01) encompassing the entire length of the Roaring Branch (4.6 miles). The Roaring Branch, as it travels through Bennington, transitions from a single thread channel with a few flood chutes to a multiple thread anastomosing river that flows through reworked glaciofluvial outwash composed of very coarse sediment. The Roaring Branch (and the upstream reach of the Walloomsac) is currently reworking vast sediment deposits that were deposited in typical alluvial fan formation under previous climatic conditions, likely the end of the Pleistocene epoch period when the flow regime was influenced by glacial melt water. The surrounding geology of the Roaring Branch is predominantly till with some bedrock outcrops one of which constricts flow in Reach M06T3.04.

The lower reaches of the Roaring Branch are a multi-thread anastomosing channel. Anastomosing channels are generally characterized as multithread channels being separated by vegetated islands. While anastomosing channels generally require a large sediment supply they are less dynamic than braided channels which are usually multi-thread channels separated by unvegetated islands or bars. Braided channels can completely change their planform at a time scale of hours, days or weeks, with low discharges. Whereas anastomosing channels generally require larger events to mobilize sufficient sediment to alter the planform.

Evidence from historic topographical maps and aerial photographs indicates that the lower 8,200 feet (Reaches M06T3.01 and part of M06T3.02) of the Roaring Branch were relocated to the north of Bennington center between 1898 and 1942. According to the 1898 topographical map the confluence of the Roaring Branch and the Walloomsac was just east (and upstream) of the town center, and the point where the new channel and the historic channel diverged is located downstream of the substation and upstream of Brooklyn Bridge. The present day confluence is located northeast and downstream of the old downtown location. While the circumstances and the reasons for the relocation are unknown, this significant change in planform and slope has likely played a major role in the condition and response of the channel to flood events in the years since the relocation.

Over the past century, the Roaring Branch has experienced several severe floods which led to the anthropogenic manipulation of the river on multiple occasions. Major alteration to the channel include the first massive channelization and dredging project of the lower portion of Roaring Branch (reaches M06T3.01 and part of M06T3.02) following the 1938 flood, a second dredging effort in 1951 and 1952, and numerous channel maintenance (deforesting of vegetated islands and dredging) between 1952 and the 1990s. In addition, a history of berm construction along the Roaring Branch is evident. In the lower reaches in particular the berms constrict flows in what would otherwise be an unconstrained valley setting. While these serve to entrench the river and contain flood waters to a certain extent they also have the effect of increasing water depths and velocities and the erosive power of the river, which has proved to continually threaten and erode the berms themselves.

Large scale channel relocations, such as occurred between 1898 and 1942, typically take many years to stabilize, unless they are carefully planned and natural channel design concepts are incorporated. It is realistic to assume that an imbalance with regards to flow and sediment transport existed in the Roaring Branch system in the decades following the relocation. The nature of the surficial geology through which the Roaring Branch flows is such that there is a large quantity of sediment to be manipulated. Subsequent to the channel relocation, many factors have prohibited equilibrium conditions (i.e., a natural and stable reference condition) from ever establishing in the river including: the removal of sediment from the river by dredging and channelization works in the 1930s, 1950s and periodic maintenance through the 1990s; the imposition of control works such as floodwalls and berms; bridge constrictions; and encroachment from development. ***The dynamic nature of the lower reaches of the Roaring Branch is first and foremost a response to a historic shift in location within the valley and subsequent anthropogenic manipulation of sediment and artificial control on the natural planform of the river.***

As mentioned, the extent of historic manipulation of the Roaring Branch further complicates the definition of stream reference conditions, particularly in the lower reaches. There, the absence of a historic reference condition means one must predict the channel condition that was likely to form were it allowed to stabilize without anthropogenic manipulation and control, given the geology, flow regime, topography and natural controls. Although the historic condition (last 100 years) of the lower reaches of the Roaring Branch appear to be multi-thread, we believe the reference condition would be that of a single thread channel, with meso-scale bed forms of riffles and pools in the lower reaches and possibly steps and pools as seen in some parts of the upper reaches where the gradient is fairly high.

An option for management of a "modified" reference condition exists within the Vermont Phase 2 protocols for situations where watershed land use conversion, alone or in combination with channel, valley, floodplain and/or flow modifications, may prohibit the evolution of the channel back to the natural reference stream type. In this case, management towards an equilibrium state that is different than the natural reference stream type that historically existed may be more consistent with river corridor conservation goals (ANR 2006a). In the case of the Roaring Branch, the overall management implications are the same: the Roaring Branch must be managed as a stream type that is different than the historic condition.

The equilibrium of flow and sediment transport of these reaches remains unbalanced to the present day. This imbalance continues to cause the river to shift its planform and create multiple channels under larger flood events (anastomosing condition) in attempts to regain equilibrium between flow and sediment load. This process should be expected to continue, and any further dredging, channelization, or encroachment into the river corridor, without due consideration of natural process and adjustment, will exacerbate the rate of change and the potential for further damage.

Since the USGS gage has been in place, there have been significant floods in the basin, however, none approaching the 100-year magnitude. Since flood events of lesser magnitude have caused damage to the Town, damage to flood control works, and loss of life, it is important to implement a River Corridor Protection and Channel Management Plan to attenuate the possible impacts of higher magnitude floods which are likely to occur in the future.

3.2 Walloomsac River

The Phase 2 assessment was conducted on five reaches on the Walloomsac River, totaling 6.7 river miles. Reach M06 begins where the Roaring Branch joins the Walloomsac River in Bennington. The assessment continued on the mainstem reaches downstream near the Bennington town line where Reach M02 ends (**Figure 3**). The Walloomsac River through these reaches is a single thread channel with a few islands and flood chutes. There are several flow obstructions such as dams and weirs and several bridges also cross the river. The upstream reach of the Walloomsac flows through glacial outwash like the Roaring Branch. At the transition from Reach M06 to M05 the surficial geology becomes recent alluvium. At the transition from Reach M03 to M02 there is also an injection of glacial outwash where

Paran Creek joins the Walloomsac. The geology of the surrounding area is primarily till with bedrock outcrops.

Since the valley has been inhabited, the Walloomsac has been impacted by human disturbances. Some berms have been constructed along the upper reaches and several dams, weirs, and bridges have also been constructed which have constricted flow and altered the valley. In particular, Reach M06 has experienced severe encroachment and incision from bridge constrictions, berms and bank hardening. The most significant impact downstream of M06 is a 16-foot high dam at the downstream end of Reach M04 which creates a backwater for the entire reach (~2400 feet).

Reference stream types for the Walloomsac were fairly easy to determine as the river has endured far less anthropogenic manipulation than the Roaring Branch. The stream type departure analysis was complicated in Reach M04 due to the backwater effect of the dam as this has rendered the reach largely inactive in terms of sediment transport. The reference condition of the Walloomsac was largely a single thread channel although there were several islands and flood chutes that had developed.

Sediment size decreases downstream to Reach M04 where sediment was primarily sand due to the backwater. Reach M03 was found to be composed primarily of gravel much like reach M05. Reach M02 however was composed of primarily of cobbles. While this may appear to be unusual, it was likely caused by the glacial outwash deposits at the head of Reach M02 which were likely coarser than the alluvial deposits of Reach M03. This phenomenon has been documented in rivers in mountain systems on both coasts of Canada (Rice 1998, Davey and Lapointe 2007). Rice (1998) has described this increase of sediment size by a point source of sediment and subsequent downstream fining as a sedimentary link.

Although the majority of the Walloomsac corridor has not been severely encroached upon to date, it remains important to adopt a River Corridor Protection and Channel Management Plan to ensure that conditions do not worsen. There is evidence to suggest that more sediment is being conveyed downstream as compared to historical levels, and there is a definite sediment transport discontinuity within the system at the confluence area of the Roaring Branch and the Walloomsac. As noted above, since the USGS gaging station was installed (~73 years of record) there has not been a 100-year flood. A flood of this magnitude has the potential for causing significant damage to infrastructure. A management plan would delineate a protective corridor and identify other means that would mitigate damage to infrastructure from high flow events.

4.0 Reach Descriptions

Phase 1 results reported the stream reference types for each assessed reach (**Table 3**). A narrative description of each reach and segment evaluated during the Phase 2 assessment is presented below. Note that left and right banks are always identified facing downstream. Field data and associated Phase 2 stream types are summarized in **Table 4**. Note that the Phase 2 cross-section data are presented in Appendix A. The photographs collected for each reach are assembled in Appendix C. The Bridge and Culvert Assessment photographs are contained in Appendix D. The field data, cross-section plots, and spatially referenced stream features are also accessible on-line through the DMS.

Table 3: Phase 1 Reference Stream Types.

Reach ID Number	Channel Length (ft.)	Channel Slope (ft.)	Valley Width (ft.)	Confinement Type	Sinuosity	Stream Type	Bed material	Bed feature Type
M06T3.04	7250	2.14	467	Broad	1.03	C	Cobble	Step-Pool
M06T3.03	4479	2.46	966	Very Broad	1.11	C	Cobble	Step-Pool
M06T3.02	5336	2.53	951	Very Broad	1.01	C	Cobble	Step-Pool
M06T3.01	7469	1.87	771	Very Broad	1.07	C	Cobble	Step-Pool
M06	8131	0.58	1788	Very Broad	1.18	C	Cobble	Riffle-Pool
M05	5760	0.26	1769	Very Broad	1.67	C	Gravel	Riffle-Pool
M04	2662	0.38	803	Broad	1.08	C	N/A	Riffle-Pool
M03	3748	0.27	596	Broad	1.07	C	Gravel	Riffle-Pool
M02	15061	0.17	887	Broad	1.04	C	Cobble	Riffle-Pool

Note: Reference Stream Types modified after QA/QC of Phase 2 data by ANR.

4.1 Detail Descriptions

Roaring Branch

M06T3.04

This reach was the upstream limit of the current Phase 2 study area. The reach starts at the confluence of City Stream and Bolles Brook in Woodford and flows southwest, parallel to State Route 9. The Roaring Branch crosses under Route 9 approximately 1,000 feet downstream of the start of the reach. Upstream of the Route 9 Bridge there is a side channel on river right beyond the berms along the right bank. The left bank area is confined by fill for the road and also Woodford Town Offices are located here. At the bridge, the river bends sharply and travels parallel and south of Route 9. Between the river and Route 9 on river right, there are substantial areas of residential development. The channel downstream of Route 9 in this reach appears to have been channelized and is fairly straight and consists of a single thread. Berms are located along river right and old channels on the floodplain along river left. River left is also confined by a steep valley wall, but movement of the channel in this area was evident. Also present are areas of bank erosion where the channel is attempting to widen (**Figure 4**). Side bars along the channel consist of large cobble and boulders. Man-made grade controls in the form of boulder/cobble weirs created for swimming areas are present in the reach. The channel is also confined in places by lateral bedrock controls (**Figure 5**).

A Rapid Stream Assessment was completed for this reach, which included a Rapid Geomorphic Assessment (RGA) and Rapid Habitat Assessment (RHA). Additionally, two representative cross-sections were established in this reach to better understand the ongoing processes of the river. The first cross-section for this reach is shown in **Figure A1**. Note the berming near to the bank, as well as in the old floodplain on the right. The building up of the left floodplain to accommodate Route 9 limits flood conveyance and sediment storage on the left bank. The planform of this reach is characterized as Step-Pool. An additional cross-section was established at an area of residential development on river right in order to examine potential areas of floodplain connection within this reach (**Figure A2**). The area represented by this cross-section has an accessible floodplain on the right (albeit developed residentially) under flood flows (two times maximum bankfull height).

The RGA score of 0.54 indicates that the channel is considered to be in fair condition and appears to be undergoing planimetric adjustment. The channel here has also been dredged several times (USACE 1975). In addition to the historic channel dredging, some berms have been constructed to protect the road. Given the extent of anthropogenic alterations to this reach, a stream condition of "fair" is appropriate. The RHA score of 0.67 indicates that the channel is considered to contain good riverine habitat. Despite the many disturbances this reach has experienced, the reach still seems to have retained good habitat characteristics.

The Phase 1 assessment determined this reach to be of type C3. Refinement during the Phase 2 assessment determined the reach type to be type C3b due the entrenchment ratio, the width/depth ratio and the slope greater than 0.02 (**Table 4**). Although there doesn't appear to be a significant stream type departure, the river is undergoing adjustments in response to anthropogenic manipulation of the reach. This channel is under major adjustment and was determined to be highly sensitive as it is responding to anthropogenic influences. The channel through this reach appears to be in Stage IIc of the D-stage Channel Evolution Model (CEM) as steeper gradients have been imposed through channelization and the channel is widening and migrating laterally to regain equilibrium.

M06T3.03

The Roaring Branch continues to flow parallel and to the south of Route 9 in this reach. The right bank floodplain was again constrained by the presence of Route 9. Steep riffles in aggradational areas are present throughout the reach. Old flood chutes and channels were also found on the left bank river floodplain area. Berms located on the floodplain concentrate flood flows and limit the sediment storage and attenuation function within this reach. The river eventually crosses back under Route 9 in Bennington. Just upstream of this bridge, there are remnants of an old bridge in the channel which may have contributed to the massive depositional area upstream of the current bridge (**Figure 6**). Mid-channel bars, vegetated islands and steep riffles were prevalent upstream of the Route 9 Bridge.

The reach extends for approximately 700 feet downstream of Route 9 Bridge where channel braiding and depositional features continue. Downstream of the bridge, berming and armoring of the right bank and floodplain is extensive. This stream reach was classified as a D3b with a step-pool morphology. The classification generally applies to the upper half of the reach, where the cross-sectional data were collected. The downstream portion of the reach begins to transition into a more multi-channel anastomosing system.

Major adjustment processes include widening, as evidenced by the creation of new channels and island formations. The representative cross-section for this reach is shown in **Figure A3**. The berming and old channels on the left floodplain are evident. The same pattern is observed at cross-section number 2 in this reach (**Figure A4**). A significant load of sediment is working through the reach as is evident from the site conditions, as many large bar features were observed. In addition to the bar features, several steepened riffles were noted which is an indication of the migration of coarse sediments (**Figure 7**).

The RGA score of 0.33 indicates that the channel is in poor condition. This channel has also been dredged several times over the past century (USACE 1975). The channel appears to have experienced historic degradation as it no longer has access to the surrounding floodplain. There are berms along this reach that constrict flow which are mainly restricted to the lower end of the reach where they serve as protection for the road. The RHA score of 0.70 indicated that the reach exhibited good habitat characteristics. The channel was determined to be a D3b channel in the Phase 2 assessment. Reference condition was determined to be type C3b indicating that there is a stream type departure due to channel degradation and the influence of the berms on channel form. The D3b type of channel is considered to have an extreme sensitivity. The channel is currently experiencing both vertical and lateral adjustments although it largely remains a step-pool system, particularly in the upstream portion of the reach. The downstream portion of the reach, where there are more channel constrictions, appears to have a more anastomosing planform. This portion of the reach appears to be more sensitive than the upstream portion and has experienced a more significant stream type departure. The channel appears to be at Stage IId of the D-Stage channel evolution model due to the historic degradation that has occurred and the ongoing planimetric adjustments.

M06T3.02

Reach M06T3.02 of the Roaring Branch begins at the confluence of an intermittent stream entering from the north and downstream of Route 9 Bridge, and ends approximately 500 feet upstream of Brooklyn Bridge. Extensive berming on both banks and floodplain areas continues throughout this reach, which flows in a westerly direction. The channel breaks away from Route 9, and the left bank and floodplain is bermed to protect the developments along Route 9. This reach contains the former Woodford Packers site, which has been filled extensively. A cross-section was established in this area. Berms and old channels are present on river right at this cross-section (**Figure A5**).

Both banks have been re-built and rip-rapped in areas to repair damage caused during a flood in 1987 (see photographs in **Appendix B**). This reach features more extensive channel braiding than upstream. Areas of sediment deposition and degradation are evident (**Figure 8**). There is sediment stored in many large bar features observed throughout the reach (**Figure 9**). Large headcuts are present and seem to be undermining areas of riprap along the banks. Bifurcated and anastomosing channel areas are common to this reach where the bed and water surface elevations are markedly different between channels, up to six feet in areas (cross-section number 2 in **Figure A6**).

A new highway (Route 279) is proposed that will cross over the river to the east of the substation. The design calls for no further encroachment into the floodplain (i.e., abutment to stay parallel with the extent of the substation encroachment). To the east of the proposed highway are several mobile homes that are located in the floodplain of the existing river and set across historic flood chutes of the river. These homes were affected by the 1987 flooding.

The RGA score of 0.28 for this reach is generally indicative of a channel in poor condition and accounts for the extent of the impacts of the many berms and dredging projects on the channel condition and stability. The berms have served to greatly constrict the valley and floodplain available to the stream and are often discontinuous. Some of these berms may be spoil piles remaining from channel dredging activities. The channel condition appears to be poor due to the historic dredging that has occurred and the many berms and levees present along the banks. The RHA score of 0.68 indicated that there are good habitat conditions present through the reach. The reach was also determined to be extremely sensitive due to field observations and channel type.

Phase 1 analyses determined the channel type to be D. However, while this may be the historic channel type, for reasons detailed in Section 3.1, the channel setting indicates that a type C channel is the modified reference condition. Phase 2 analyses determined the steam type is D3b with a multi-thread channel form, particularly in the downstream section of this reach. This would indicate that there is a significant stream type departure from a stable condition (acknowledging that the reference condition has not been permitted to manifest for this portion of river in well over a hundred years). The channel appears to be in Stage IId of the D-stage channel evolution model as it is currently an anastomosing channel. It is apparent that the river is undergoing large adjustments in response to the historic dredging and berming, leading to an extremely unstable channel.

M06T3.01

Reach M06T3.01 begins upstream of the Brooklyn Bridge and ends at the confluence with the Walloomsac River. The reach flows through a more developed area of Bennington and features five bridges within the reach. Extensive berming is present on both sides of the river. The USACE constructed a local protection project throughout the reach that consists of a flood wall on the left side of the river upstream and downstream of the Brooklyn Bridge and an engineered levee, also on the left side of the river (refer to **Figure 2**). The right floodplain contains a network of berms consisting of dredged material from the river, which are intended to protect the residential and other development on the river right. An extensive levee project was also completed by the Natural Resource Conservation Service (NRCS) after the 1987 floods on the right bank between the Brooklyn Bridge and Park Street (personal communication, B. Cahoon, ANR).

The channel constrictions at the bridges (Brooklyn, Park Street and Route 7) are causing large amounts of sediment deposition throughout the reach (**Figure 10**). These areas of deposition are currently being degraded as evidenced by headcutting through the coarse alluvial material. This cycle of deposition and degradation is expected to continue, and is re-set during larger flood events that re-deposit significant amounts of cobble and boulders in these regions. The channel also contains substantial amounts of large woody debris and bank erosion, and the reshaping of island formations within the channel is apparent (**Figure 11**).

Open fields behind the Veterans Home on the left bank of the river appear to provide good floodplain connection with the channel in the lower part of this reach as shown from the cross-section data collected (**Figure A7**). Downstream of the Route 7 Bridge, the channel narrows due to development and two more bridges (railroad and Benmont Ave.) before joining the Walloomsac River.

Similar channel features, as observed upstream, are present throughout this reach (i.e., areas of sediment deposition and degradation). Large head cuts are present and are undermining areas of riprap along the banks, especially upstream of the Park Street Bridge. Bifurcated and anastomosing channel areas are common to this reach where the bed and water surface elevations are markedly different, up to six feet or more in areas, between channels (see **Figure A8**). The high berms on both banks of the river in this location are also of note.

The RGA score of 0.26 is indicative of a channel in poor condition and as with upstream, the extent of the impacts of the many berms and dredging projects on the channel condition and stability is apparent. Channel sensitivity was likewise determined to be extreme. An RHA score of 0.69 indicated that the habitat characteristics of the reach were in good condition. Based on the Phase 2 assessment, the channel was determined to be a multi-channel system of type D3. The historic channel type is a D type channel; however, given the channel setting of the reach the modified reference condition should be a type C channel, for reasons similar to the upstream Reach M06T3.02. A significant stream type departure is apparent as the current condition of the reach is an anastomosing D type channel. The reach has also been highly confined by the many berms thus further altering the valley form from being unconfined to being narrowly confined.

<u>Walloomsac River</u>

M06b

Reach M06 begins where the Roaring Branch enters the Walloomsac River. Reach M06 was classified as a braided D3 type channel in the Phase 1 assessment. This reach was split into two segments as part of the Phase 2 assessment; the upstream segment being M06b and the downstream segment being M06a. Segmentation was deemed appropriate given the stark difference in channel grade. In addition, the upstream segment transitions from CEM Stage III to Stage IV, and the downstream segment is predominantly in Stage IV. Further segmentation of the M06b was discussed. Similar to the reaches of the Roaring Branch, further segmentation would impose smaller scale and highly dynamic processes into definitive reach breaks that might look very different at another point in time. For this reason, no further segmentation for the purposes of the Phase 2 report was undertaken. However, as design work is undertaken to develop conceptual management options within this reach, further delineation of channel process and reach breaks may be appropriate.

From its confluence with the Roaring Branch, the Walloomsac River flows northwesterly through a commercial and residential area. There is a channel spanning weir, pedestrian bridge, and a bedrock grade control just downstream of the pedestrian bridge. Here the adjacent land use on the left side of the river is dominated by a golf course. There are areas of erosion and hard bank protection on both banks through this segment. In-channel features include two large transverse bars (**Figure 12**). Aggradational material is generally small cobble. Berms are present on the right bank and terrace and areas of the left bank appear to be built up with non-native fill material along the golf course, which is actively eroding (**Figure 13**).

The cross-section completed in the downstream end of Segment M06b is shown in **Figure A9**. In this location the river has access to the golf course on the left side of the river during high flows. Conversations with the golf course personnel indicated that areas of the course were routinely flooded.

This segment is in a geomorphically transitional area. It is in this part of the reach that an appreciable amount of coarse sediments leaving the Roaring Branch are being deposited. Several large bar features were observed during the field assessment and were typically composed of coarse material, albeit finer than the reach immediately upstream (M06T3.01).

The RGA score of 0.41 indicates that the channel is in fair condition. The dominant processes observed in this reach were channel aggradation, widening, and planimetric adjustment. The RHA also yielded a score of 0.68 and was found to be in good condition with good habitat characteristics throughout the reach. The Phase 1 assessment determined the stream type to be D; however, the Phase 2 field measurements and observations determined this reach to be transitioning from a type F to a type C3. Based on the location of the channel in the valley, the channel slope, the general condition of the channel and lack of multi-thread channel observed in the field, it was determined that a D type channel may not be the reference condition. Based on the conditions observed in the field, this reach appears to have a reference condition of type C3. The channel appears to be in both Stage III and Stage IV of the channel evolution model which is consistent with the aggradation, channel widening, and planimetric adjustment observed in the RGA. Based on the coarse sediment size and the fair condition of the reach, the sensitivity was determined to be high to very high. Areas of significant bank erosion were observed indicating the channel is experiencing a degree of migration and is accommodating the deposition of sediment within the bar features. The channel does appear to be active, particularly in the upstream portion of the reach where there is more entrenchment, more channel constrictions, and the Roaring Branch deposits an abundance of coarse sediments.

M06a

Downstream of the golf course, Reach M06 was segmented due to a pronounced change in gradient. Furthermore, the dominant bed substrate in segment M06a changes to gravel from the cobbles in the upstream segment. Areas of bank protection and erosion were also prominent throughout this segment, the downstream end of which is at the confluence with Furnace Brook. This segment was only slightly entrenched and was in a broad valley.

Adjacent land use on the right bank is dominated by Morse Industrial Park, and on the left bank there is a mix of forested and residential areas. The cross-section, shown in **Figure A10**, shows the right bank is built up to protect the industrial area, while there is good floodplain connectivity on the left bank in the forested area. This segment of Reach M06 is characterized by a variety of significant bar features. In the downstream portion of the reach, several debris jams are present.

A rapid stream assessment was completed for this segment which included an RGA, an RHA, and a representative cross-section. The RGA score of 0.65 indicates that the channel is in borderline good condition. The dominant process observed in this segment was widening and planimetric adjustment. The RHA score was 0.76 which is considered to be a reach that contains good habitat characteristics. The Phase 1 assessment determined that the segment was a multiple channel system with a D channel type. However, the field data collected did not support this classification. Based on the location of the channel in the valley, the channel slope, the general condition of the channel, and lack of multi-thread channel observed in the field, a reference stream type of C4 should be used. The bars within this segment are much finer in nature than the upstream reach, which is expected due to the reduced gradient of the channel compared to upstream (**Figure 14**). Several woody debris jams were also observed which contribute to some of the channel adjustments that were noted. This reach contains several large bars or islands and has been subject to a variety of bank stabilization works, indicating that this reach has likely adjusted to accommodate the deposition that has occurred. This segment was determined to be in Stage IV of channel evolution due largely to the extent of lateral migration and planimetric adjustments that are ongoing in this segment. Due to the smaller nature of the substrate in this reach and the variety of bank stabilization measures observed, this segment was determined to have a high sensitivity.

M05

Reach M05 begins upstream at the confluence with Furnace Brook on the north edge of Morse Industrial Park and meanders along Silk Road, ending just downstream of the Silk Road covered bridge. At the upstream extent of the reach, the river is widening and eroding into its right bank. This reach is largely isolated from its floodplain at bankfull flow levels.

The left bank is bermed and built up further to protect the residential properties along Silk Road. The downstream portions of the reach features a tortuous meander bend, the banks on both sides are built up and the river is constrained by road development. The field assessment on the lower portion of this reach was somewhat limited due to restricted access per landowner request.

There was a significant avulsion that occurred recently in the vicinity of the Route 279 Bridge (**Figure 15**). It is not known if the bridge construction influenced this occurrence but the presence of an extreme amount of woody debris in the area indicates the possibility that a debris jam may have caused or contributed to the cut-off (**Figure 16**). Throughout the reach several smaller side bars were observed and the deposits appeared to diminish in a downstream direction. The RGA yielded a score of 0.58 which is considered to be a fair channel condition. However, it is unclear as to the nature of the recent channel avulsion beneath the bridge which contributed in large part to the low RGA score attributed to this reach. The RHA assessment yielded a score of 0.68 indicating good habitat conditions in the reach. A representative cross section was also established for this reach and is shown in **Figure A11**.

Phase 1 stream type was determined to be type E. This appears to be due to the high sinuosity of the reach. However, the process in Phase 1 does not include the width/depth analysis. Phase 2 analysis of the data indicated that the stream type was C4. This classification is largely due to the width/depth ratio that was determined to be ~26. Channel length lost to the avulsion was estimated and the sinuosity was re-calculated based on that estimation. Change in sinuosity due to the avulsion was from 1.88 to 1.67, still well over 1.5 sinuosity threshold for type E streams. Due to the unknown cause of the avulsion and the reasonably good condition of the channel, a stream type departure does not appear to have occurred. The channel does not appear to have reacted greatly to the avulsion either by rapidly aggrading and degrading to adjust slope or by large changes in planform. The sensitivity rating for this reach is therefore very high. The recent changes in planform indicate that the channel is in Stage IV of the channel evolution model.

M04

Reach M04 begins downstream of the Silk Road Bridge and flows westerly parallel to Route 67A, and ends at the Paper Mill Dam. The entire reach is impounded by the Paper Mill Dam and the substrate is composed predominantly of sand and fine material (**Figure 17**). Adjacent land use consists of agriculture on the left corridor and residential on the right. There are dense shrubs on most of the banks along the reach. Bank conditions along this reach indicate that canoes/boats are launched for recreational purposes. Upstream of the Paper Mill Dam, the channel splits to form a large island with the Paper Mill Dam to the east and a dam founded on bedrock under Murphy Road to the west. There is also evidence of recreational use immediately upstream of the dam on this island.

The dams at the downstream end of this reach create a backwater throughout the reach that has created a large area of sediment deposition. This backwater has led to a very stable channel as there is little gradient through this reach. The RGA score reflects the stability of the reach by classifying it as being in good condition. The dominant process observed was aggradation, which is expected in backwater zones. The RHA assessment determined the reach to be of fair habitat quality (0.49) largely due to the backwater nature of the reach. The representative cross-section for this reach is shown in **Figure A12**. The CEM Stage is I as this is a very stable channel with only the deposition of fine sediment occurring and minor toe scour of some banks due to wind and wave action. The Phase 1 assessment determined the reference condition to be of channel type C. However, due to the impounded nature of the channel, the channel type was not evaluated in Phase 2 and a stream departure analysis was not completed.

M03

Reach M03 flows parallel to Route 67A from the Paper Mill Dam to the confluence with Paran Creek. The right bank is confined by a road and there are a few houses along the river in the upper portion of the reach. The land use on river left is largely agricultural; the left bank is high and the river is entrenched. Immediately downstream of the dam and island, there is a short section of multi-thread channel. During the Phase 2 assessment, a discharge of sewage like effluent was noted coming from the north, entering the river through a pipe. The discharge was grey and had a foul odor. It was raining lightly at the time of the observation. The proceeding day it was no longer raining and the discharge was not observed.

The upper portion of this reach is typically sediment starved due to the influence of the Paper Mill Dam. Immediately below the dam the substrate is quite coarse. Rock revetments have been installed on several banks within the vicinity of the dam (**Figure 18**) likely in response to erosion caused by the channel as the river attempts to regain sediment trapped in the backwater of Reach M04. The RGA score of 0.49 indicates that the stream is in fair condition. The dominant channel process appears to be degradation. This was demonstrated through the representative cross-section (**Figure A13**) as well as the high incision ratio observed. The RHA yielded a score of 0.67 indicating good habitat characteristics for this reach. Although the channel setting indicates that the reference condition was a C4 type channel, recent degradation has made it an entrenched type F4 channel indicating a stream type departure. This reach is therefore rated as having an extreme sensitivity. The large amount of degradation observed in this reach is likely in response to the sediment deficit resulting from the upstream dam. The CEM Stage was determined to be III although the upstream limits of the reach are likely closer to Stage II due to the degradational nature of the channel below the dam.

M02

Reach M02 begins at the confluence with Paran Creek and flows northwesterly to the downstream reach point at the confluence with Cold Spring Brook off Harrington Road. Present within the reach is a weir associated with the USGS gaging station and the outfall for Bennington's wastewater treatment plant effluent. The upstream portion of the reach follows River Road and land use along the remainder of the reach is mostly agricultural, with a few residential areas. Reach M02 was the longest reach studied in this assessment and is relatively stable and un-impacted and has several bedrock outcrops in the channel. This reach appeared to have a close balance of erosion and deposition typical of most stable alluvial streams. Bar features within the reach were generally comprised of gravels with some cobble (**Figure 19**). Although the reach was a single-thread channel, there was a small section in the downstream part of the reach with several small islands and bar features.

The RGA score of 0.58 indicated a fair stream condition. Although, the channel appeared to have experienced historic degradation, it is now widening and is in Stage III of the channel evolution model. This is evidenced both by the RGA results and also by the form of the representative cross-section (**Figure A14**). The RHA assessment yielded a score of 0.65 indicating the good habitat characteristics available in this reach. The Phase 1 assessment determined the reference channel type to be type C3 based on channel settings. The Phase 2 assessment determined the channel to be of type F3 due to an entrenchment of 1.5 and a channel slope of 0.17%. Although the channel is now considered to be in fair condition, historically there had been a stream type departure from a C type to channel to the current F3 type channel, resulting in an extreme sensitivity rating.

Table 4: Stream Type for Phase 2 Reaches, Based on Field Measurements.

Reach Number	Bankfull Width (ft.)	Floodprone Width (ft.)	Max. Depth (ft.)	Low Bank Ht. (ft.)	Entrenchment Ratio	W/D ratio	Sinuosity	Channel Slope (%)	Incision Ratio	Stream Type	Bed material	Bed feature Type
Roaring Branch												
M06T3.04	75	350	5.1	6.5	4.7	25.3	1.03	2.14	1.3	C3b	Cobble	Step-Pool
M06T3.03	70	90	4.5	10.5	1.3	24.4	1.11	2.46	2.3	D3b	Cobble	Anastomosing
M06T3.02	91	141	4.0	6.6	1.5	30.1	1.01	2.53	1.6	D3b	Cobble	Anastomosing
M06T3.01	219	419	4.0	5.0	1.9	115	1.07	1.87	1.3	D3	Cobble	Anastomosing
Walloomsac River												
M06b	85	295	4.0	4.4	3.5	29.8	1.18	0.58	1.1	C3	Cobble	Riffle-Pool
M06a	122	500	5.7	5.7	4.1	35.1	1.18	0.58	1.0	C4	Gravel	Riffle-Pool
M05	93	358	5.0	6.6	3.8	26.3	1.67	0.26	1.3	C4	Gravel	Riffle-Pool
M04	120	400	6.6	8	3.3	24.0	1.08	0.38	1.2	N/A	Sand	Impounded
M03	88	98	4.0	9.9	1.1	30.4	1.07	0.27	3.2	F4	Gravel	Riffle-Pool
M02	91	140	4.0	5.9	1.5	33.5	1.04	0.17	2.0	F3	Cobble	Riffle-Pool

4.2 Summary of Reaches

4.2.1 Reach Condition

Stream condition was assessed for each reach or segment using Rapid Geomorphic Assessment protocols outlined in the Vermont Phase 2 Handbook. Each reach/segment on Roaring Branch and the Walloomsac River were assigned an RGA score based on the geomorphic processes occurring within the study areas. This can be a subjective process as each individuals interpretation of the landscape is often different, particularly with such a wide range of values to choose from. However, this procedure does provide valuable insight into the ongoing channel processes and general state of the system. When characterizing a reach's condition, it is relevant to be aware of the physical controls that govern the reach and the possible modifying factors. Habitat characteristics are evaluated using the Rapid Habitat Assessment which evaluates each reach for their habitat potential based on the ecological and physical parameters available. This is also a fairly subjective process as there are many parameters that can be interpreted in many ways. **Table 5** shows a summary of Reach Conditions for each reach.

Roaring Branch

Roaring Branch was in poorer condition than the Walloomsac largely because of the extent of anthropogenic alterations to the river. The river has been modified dramatically and frequently (dredging, extensive berms and levees) thereby inhibiting an establishment of equilibrium which is reflected in the poor RGA scores. In terms of habitat, the Roaring Branch generally exhibited good habitat conditions, largely due to its unembedded, large sediment size and its good variability of water depths and velocities.

Walloomsac River

From a geomorphic perspective, the Walloomsac River is more stable than Roaring Branch. It has also been significantly less altered over the past century with alterations limited to weirs, bridges, and one dam causing a backwater. RGA and RHA scores generally indicated that the channel was in good condition, both from a geomorphic and an ecological point of view. Although the Walloomsac is less dynamic than the Roaring Branch, it remains important to allow the channel to evolve naturally without artificially constraining it with berms as has been done upstream.

Table 5: Summary of Reach Conditions for the Roaring Branch and Walloomsac River.

Reach ID	RGA Score	RGA Condition	RHA Score	RHA Condition
M06T3.04	0.54	Fair	0.67	Good
M06T3.03	0.33	Poor	0.70	Good
M06T3.02	0.28	Poor	0.68	Good
M06T3.01	0.26	Poor	0.69	Good
M06b	0.41	Fair	0.76	Good
M06a	0.65	Good	0.68	Good
M05	0.58	Fair	0.68	Good
M04	0.65	Good	0.49	Fair
M03	0.49	Fair	0.67	Good
M02	0.58	Fair	0.65	Good

4.2.2 Stream Type Departure and Sensitivity

Roaring Branch

The Roaring Branch is an anastomosing river system seeking to return to a reference or stable condition through an inactive alluvial fan. The fan material is post-glacial and that the hydrology and sediment sources of the Roaring Branch are no longer sufficient to activate or form the fan. The reference condition for the Roaring Branch is a single thread (C-Type) channel. The anastomosing condition (D-Type) is not the reference condition, but a stage in the recovery of a highly manipulated system (D-Stage Evolution Model). Anastomosing rivers are transitional states between meandering and braided rivers, and are typically a response to decrease sediment supply over time, and can occur in steeper channels with large substrate sizes. The Roaring Branch seems more stable in terms of the time scales and flood magnitudes required to drastically change the planform than would be expected of a braided system (Knighton 1998).

Given the frequent and significant alterations of the Roaring Branch through dredging, channelization, and the construction of berms and levees, the stream reference type indicated in **Table 6.a** is the type that would exist if the Roaring Branch were to be left untouched and allowed to move to an equilibrium state The present channel type reflects the results of the Rapid Geomorphic Assessment and field observations.

Although all four reaches of the Roaring Branch have been altered and are very dynamic channels, the downstream portions are the most active and have undergone the most dramatic stream type departure. This river seems to be undergoing the D-stage Channel Evolution Model. In D-stage channel evolution, the more dominant, active adjustment processes is typically aggradation, widening, and planform change. The process may start with limited vertical adjustment and goes right into aggradation and a lateral adjustment processes (ANR 2006a). Although the upper reach is actively adjusting, it has not undergone a complete stream type departure. The downstream reaches have not only been dredged but they have been re-aligned to pass to the north of Bennington instead of through it. These reaches appear to have been dredged on several occasions since their realignment thereby inhibiting their attainment of an equilibrium state. Channel evolution stage was determined based on reach characteristics and transect information. This, in conjunction with stream type departure and general channel condition, was used to determine the stream sensitivity rating for each reach.

Table 6.a: Summary of Stream Type Departure and Sensitivity Analysis for Roaring Branch.

Reach ID	Reference Type	Present Type	Channel Adjustment Process	Channel Evolution Stage	Stream Sensitivity
M06T3.04	C3	C3b	Planimetric	**IIc	High
M06T3.03	C3b	D3b	Degradation	**IId	Extreme
M06T3.02	C3b	D3b	Aggradation/degradation	**IId	Extreme
M06T3.01	C3	D3	Aggradation/degradation	**IId	Extreme

*** D-Stage Channel Evolution Model*

Walloomsac River

Throughout the historic period of record, the Walloomsac River has also been modified by humans, but to a lesser extent than Roaring Branch. Modifications have been largely limited to weirs, dams, bridges, bank revetments, and some berms in the upstream reach. Two reference types are shown in **Table 6.b.** The first is the Phase 1 reference type and the second is the reference type that was refined in Phase 2 following field investigations and interpretation of the data. Three of the Phase 1 channel types were modified during the Phase 2 assessment. The reference type of the entire Walloomsac River was determined to be a C type channel; however the present channel types varied along the river. A present day stream type was not determined for Reach M04 due to the backwater nature of the reach caused by the downstream dam. Major stream type departures were found to have occurred on the two downstream reaches (M02 and M03) where there was evidence of historic degradation and current planimetric adjustment. Channel evolution stages were determined for five reaches based on the Rapid Stream Assessment and transect information. The Walloomsac reaches were found to be in either Stage III or IV of the F-stage evolution model and were therefore primarily exhibiting signs of channel planform changes. The difference between F and D-stage channel evolution processes is the degree of channel incision (ANR 2006a). Stream sensitivity analysis relied on both stream type departure analysis and the channel evolution stage.

Table 6.b: Summary of Stream Type Departure and Sensitivity Analysis for the Walloomsac River.

Reach ID	Reference Type	Present Type	Channel Adjustment Process	Channel Evolution Stage	Stream Sensitivity
M06b	C3	F3/C3	Widening/planimetric	III/IV	High
M06a	C4	C4	Planimetric	IV	High
M05	C4	C4	Planimetric	IV	Very High
M04	C4	N/A	Aggradation	N/A	High
M03	C4	F4	Degradation	III	Extreme
M02	C3	F3	Widening	III	Extreme

Note: Upper portions of Segment M06B is highly entrenched, F-Type stream with Very High sensitivity.

4.2.3 Fluvial Erosion Hazard Mapping

Using the stream sensitivity ratings based on the geomorphic stream type and RGA score, a fluvial erosion hazard rating has been proposed for each stream segment in **Table 7**. Fluvial erosion hazard (FEH) types are derived from six stream sensitivity ratings using two letter descriptors (VL=Very Low; LW=Low; MD=Moderate; HI=High; VH=Very High; and EX=Extreme). The stream sensitivity rating provides a basis for fluvial erosion hazard classification because major vertical or lateral channel adjustments are known to result in extensive erosion of adjacent lands causing damage to private property and public infrastructure (ANR 2005).

Fluvial erosion hazard corridors are developed using calculated belt widths and channel widths, definition of valley walls and meander centerlines, and other field data documenting any unique characteristics associated with stream reach sensitivity. These data are then used in the FEH module of the SGAT program to draw a first draft of the FEH corridor based on belt width guidelines established for each hazard type.

Regional Planning Commissions, with technical assistance from the River Management Program, will support municipalities in generating fluvial erosion hazard maps and advise local boards in the development of flood hazard mitigation strategies for consideration and adoption by the town (ANR 2005). The FEH map will be developed to accommodate the anticipated flow and sediment attenuation needs of the river corridor and will take into consideration developments and infrastructure existing within the river corridor that may be at risk. Ultimately, with technical assistance from the River Management Program and BCCD, the fluvial erosion hazard maps will be presented for consideration and adoption by the town and may be used to advise existing and future land use investments and infrastructure development.

Table 7: Proposed FEH Ratings.

Stream Segment	Sensitivity	Existing Stream Type	Natural Valley Type	Departure from Equilibrium	FEH Rating	
M06T3.04	High	C3b	Broad	Major Adjustment	HI	6
M06T3.03	Extreme	D3b	Very Broad	Major Adjustment	EX	10
M06T3.02	Extreme	D3b	Very Broad	Stream Type Departure	EX	10
M06T3.01	Extreme	D3	Very Broad	Stream Type Departure	EX	10
M06b	Very High	F3/C3	Very Broad	Major Adjustment	VH	8
M06a	High	C4	Very Broad	Major Adjustment	HI	7
M05	Very High	C4	Very Broad	Major Adjustment	VH	7
M04*	High	C5	Broad	Reference	HI	7
M03	Extreme	F4	Broad	Stream Type Departure	EX	9
M02	Extreme	F3	Broad	Stream Type Departure	EX	8

*For Reach M04, which is impounded, the reference stream type was used (C) for the sensitivity rating.

Figure 4: Roaring Branch - Reach M06T3.04, Erosion on Right Bank.

Figure 5: Roaring Branch - Reach M06T3.04, Bedrock Wall on Left Bank.

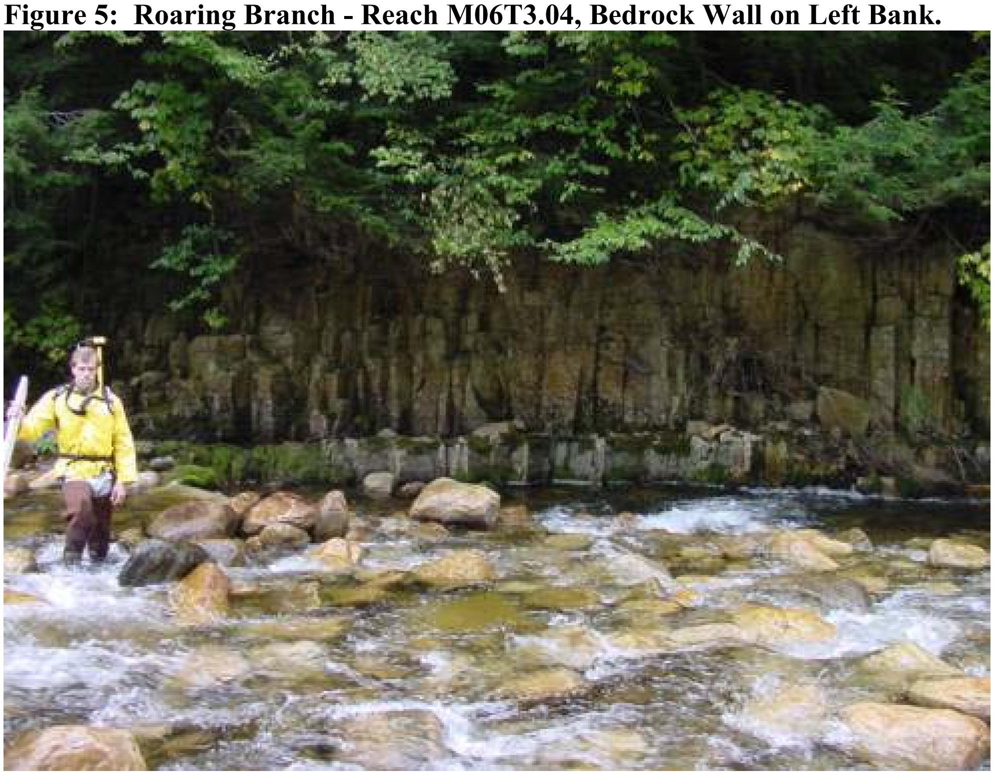


Figure 6: Roaring Branch - Reach M06T3.03, Upstream View of Old Bridge Remains.

Figure 7: Roaring Branch - Reach M06T3.03, Steep Riffle.

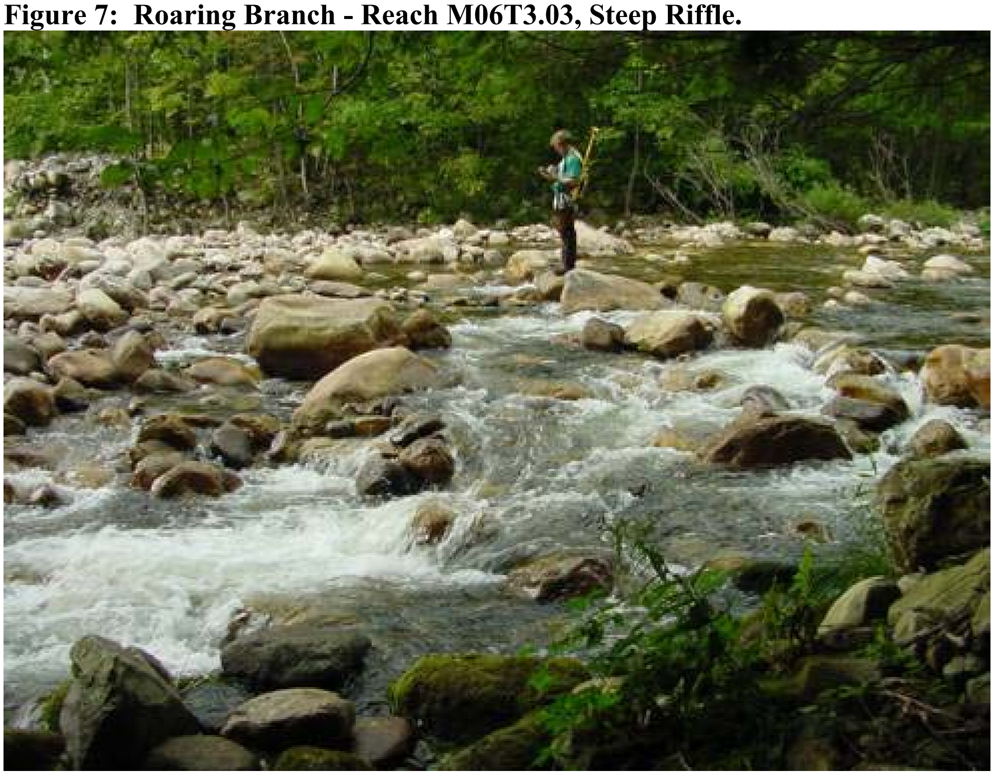


Figure 8: Roaring Branch - Reach M06T3.02, Headcut through Coarse Deposition.

Figure 9: Roaring Branch - Reach M06T3.02, Large Side Bar near Protected Bank.

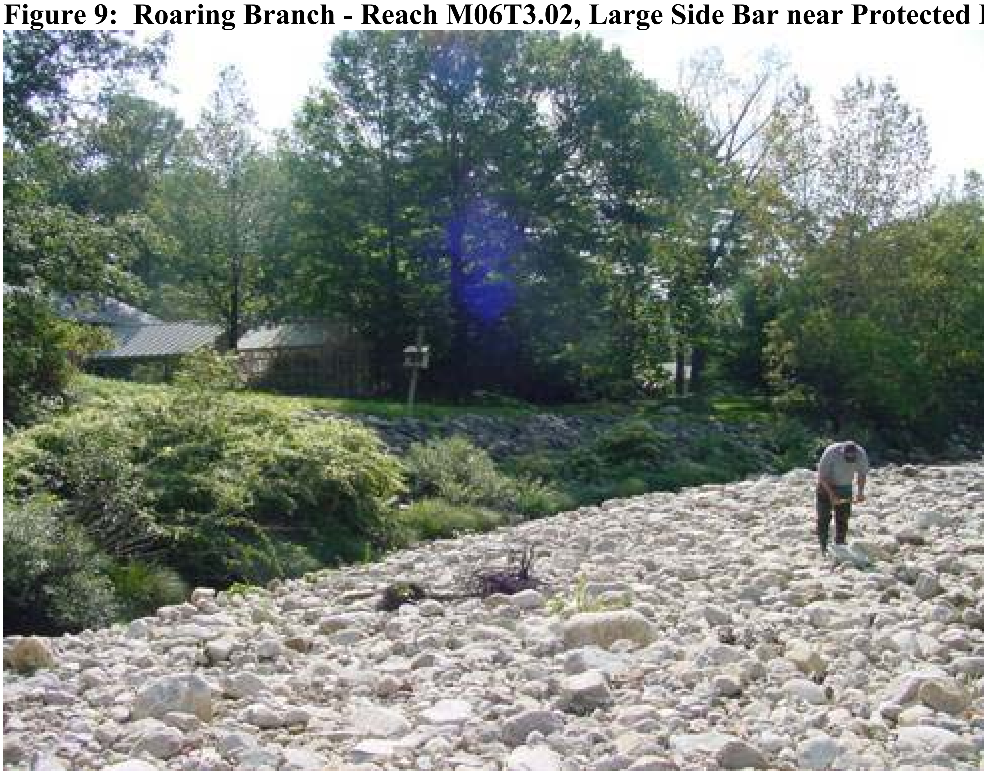


Figure 10: Roaring Branch - Reach M06T3.01, Deposition Upstream of Park Street Bridge.

Figure 11: Roaring Branch - Reach M06T3.01, Mixed Deposition Around Island.

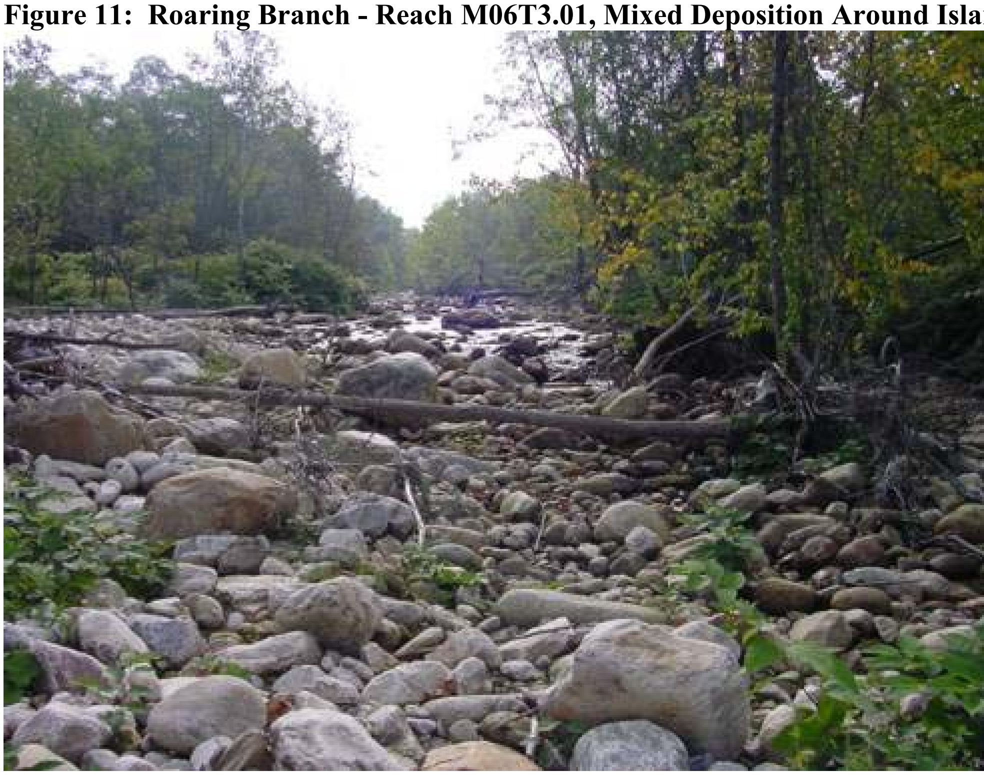


Figure 12: Walloomsac River - Segment M06b, Steep Transverse Bar.

Figure 13: Walloomsac River - Segment M06b, Erosion on Left Bank.

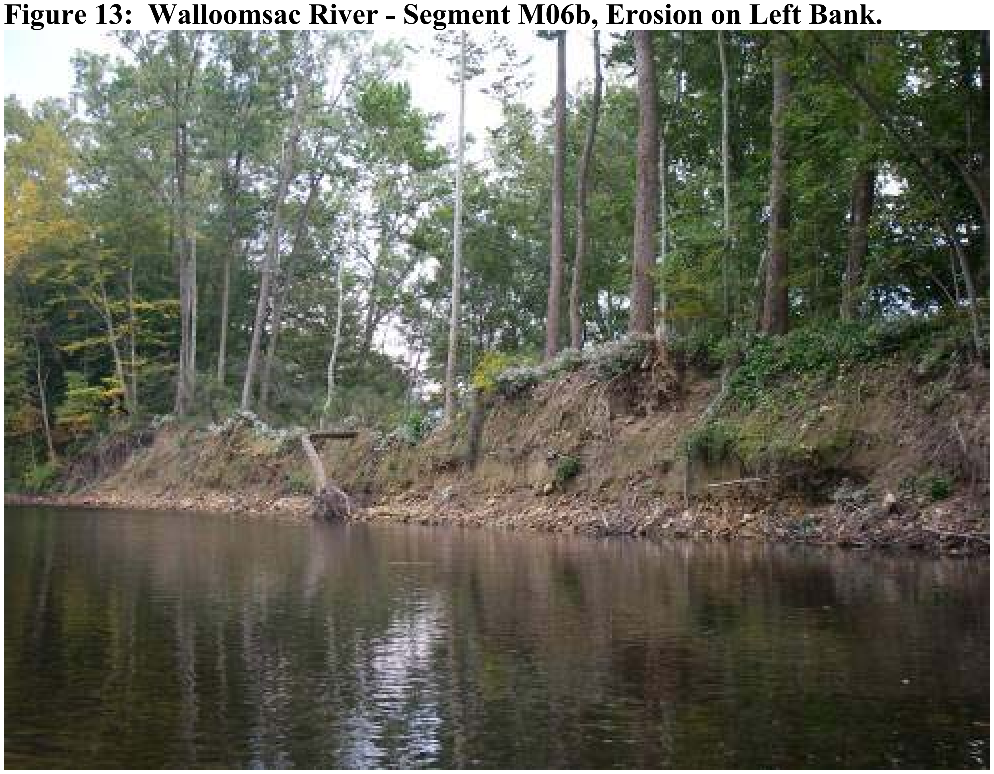


Figure 14: Walloomsac River - Segment M06a, Upstream View of Side Bar.

Figure 15: Walloomsac River - Reach M05, Orthophoto Showing Old Channel.

Figure 16: Walloomsac River - Reach M05, Woody Debris and Bar near Route 279 Bridge.

Figure 17: Walloomsac River - Reach M04, Upstream View of Impoundment.

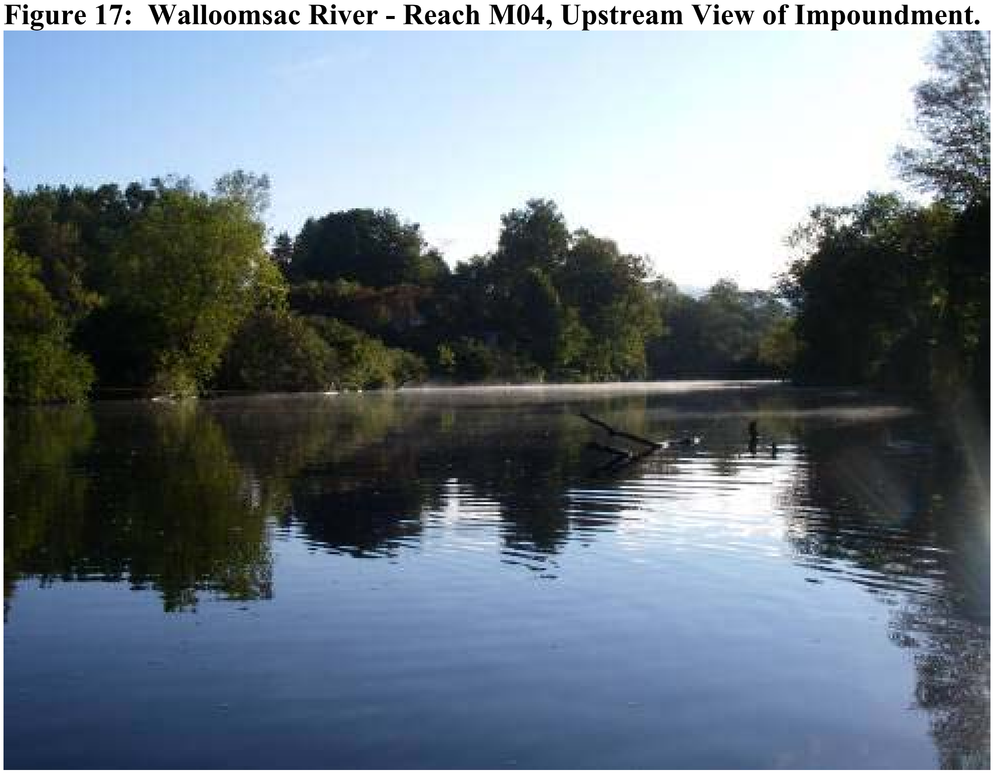


Figure 18: Walloomsac River - Reach M03, Left Bank Revetment, Upstream View.

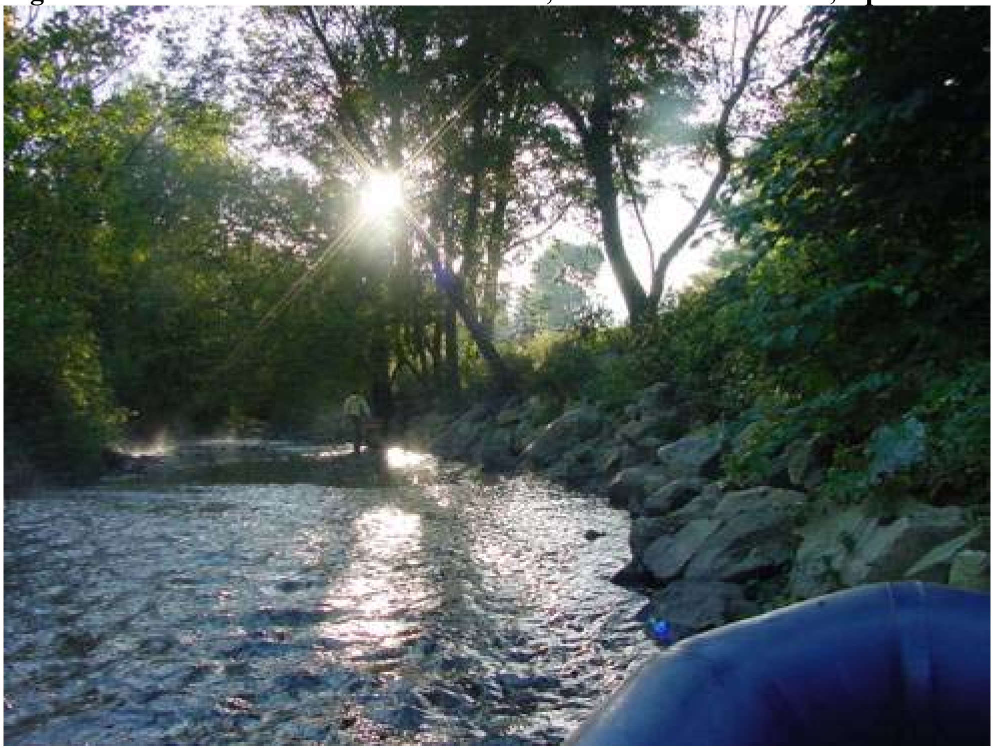
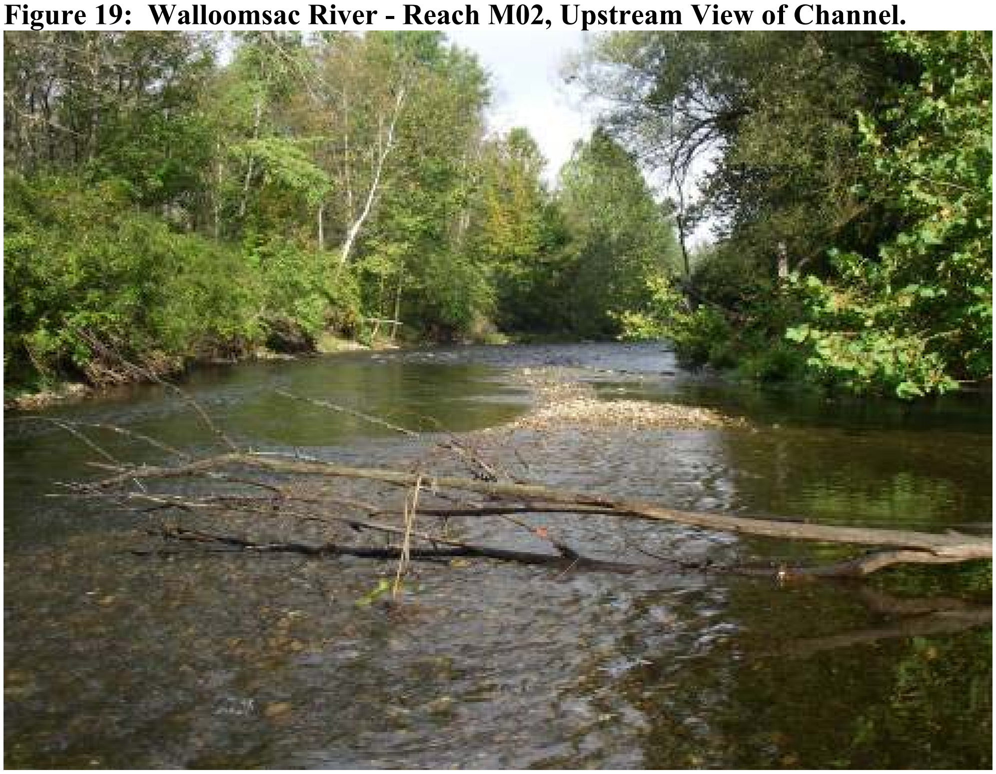


Figure 19: Walloomsac River - Reach M02, Upstream View of Channel.



5.0 Management Alternatives

The project team has identified a list of plausible restoration and management alternatives for the Town of Bennington. Management alternatives presented in this Phase 2 report should be considered introductory and may change as the River Corridor Protection and Channel Management Plan is developed. The selection of specific sites and best management option for each site will be completed as part of the management plan and is beyond the scope of the Phase 2 Report. The purpose here is to generate discussion about which alternatives best meet the goals for the project and provide the highest likelihood of successful implementation. The eventual management strategies may include implementing several of the management alternatives at a single site. The development of the River Corridor Protection and Channel Management Plan will involve additional discussions with Vermont ANR, the Town of Bennington, BCCD and the Regional Planning Commission.

Each Management Alternative is classified as a Passive Geomorphic Approach, an Active Geomorphic Approach, a Channelization Approach or a No Action Approach (ANR 2006b and Fischenich 2003). Each approach is summarized below. A matrix describing each management alternative highlighting how each would meet project goals and objectives is provided in **Table 8**.

- **Passive Geomorphic Approach –** Passive approaches involve restoration management alternatives that remove constraints on a river's ability to establish geomorphic stability over time. Approaches can include enhancing ecological function of corridors and establishing protected land within the river's corridor.
- **Active Geomorphic Approach –** Active approaches restore a geomorphically stable state through the construction of channel bed, banks and/or floodplains using process driven and natural channel design concepts.
- **Channelization Approach –** Channelization approaches seek to maintain rivers through dredging and bank armoring applications where the dimension, pattern and profile are not consistent with the condition.
- **No Action Approach –** The No Action approach takes no action whatsoever to address or remedy management conflicts. Erosion of bed and banks are allowed to continue and no effort is made to improve corridor ecological condition and function.

Additional discussion regarding the Roaring Branch is warranted given the extreme challenges the river has presented for the Town. It is hypothesized that the river is in a state that is greatly departed from a stable condition and will therefore remain dynamic and pose a threat of further erosion and damage to property during flood events. Historic manipulation of in-stream sediments and artificial constraints on natural planform adjustment are the primary reason for the instability. As part of any successful management plan, these artificial constraints imposed on the channel will need to be alleviated or mitigated and all dredging and other channel manipulation activities should be either halted or designed with channel responses and evolution processes in mind. Channel manipulations have only served to worsen channel conditions in the past. Although some berms may be necessary in the lower reaches to contain the channel, the river will require a reasonable floodplain allowing it to adjust itself naturally where possible. The river management corridor necessary for the Roaring Branch should be based on a single thread channel which is one of the reference conditions this channel would reach were it allowed to fully adjust itself without anthropogenic interference. The need to establish and protect a river corridor is accentuated by the current stream departure on the Roaring Branch. A sustainable and stable corridor width for a B or C-type channel is typically wider than for the historic D-type condition.

Table 8: Management Alternatives Matrix.

Management Alternative	Description	Objectives / Goals
Passive Geomorphic Approach		
Corridor conservation	Protecting undeveloped land from future development within the riparian corridor. The limits of the corridor will be defined during the development of the Fluvial Erosion Hazard (FEH) zone. Through this process, the potential avenues for FEH Corridor protection implementation (e.g., ordinance, zoning, overlay districts, etc.) will be examined.	Allows for unrestrained natural adjustment of the river. Protects floodplain areas required for flow dispersement and sediment storage and attenuation. Decreases erosive forces within the channel. Allows for the revegetation and protection of a wooded corridor which increases erosion protection and ecological function of corridor.
Land acquisition	Purchasing private land within the corridor and selectively removing encroachments such as infrastructure and bank protection.	Returns to state of unrestrained natural adjustment of river. Creates floodplain areas for flow dispersement and sediment storage and attenuation. Decreases erosive forces within the channel. Allows for the revegetation and protection of a wooded corridor which increases erosion protection and ecological function of corridor.
Berm removal	Throughout the system, berms are confining flood flows, reducing sediment storage capacity both on the floodplain and within the channel, and increasing erosion and transport. A better understanding of the configuration of the berms on the floodplain will lead to management alternatives which may include complete berm removal or removal of berms in critical areas.	Allows for unrestrained natural adjustment of river where berms currently constrain flows. Creates floodplain areas required for flow dispersement and sediment storage and attenuation. Decreases erosive forces within the channel.
Offset berm construction	Floodplain storage and corridor width can be increased in many areas by removing berms in close proximity of the river. Berms offset further from the channel on the limits of the corridor may need to be constructed to protect development and property.	Returns to state of unrestrained natural adjustment of river. Creates floodplain areas for flow dispersement and sediment storage and attenuation. Decreases erosive forces within the channel. Allows for the revegetation and protection of a wooded corridor which increases erosion protection and ecological function of corridor.
Infrastructure alteration	If bridges or other infrastructure or bank alterations are shown to have severe impacts to channel instability, recommendations as to the alteration of the structure may be made.	Allows for natural geomorphic process to occur without interruption caused by severe constrictions of flow. Eliminates areas of sediment and flow impoundment upstream of bridges and degradation and erosion at the bridge.
Active Geomorphic Approach		
Chute activation	Actively train flood flows into abandoned chutes to increase sediment storage capacity.	Reactivate abandoned chutes to encourage natural channel adjustment to occur. Activates floodplain areas required for flow dispersement and sediment storage and attenuation. Decreases erosive forces within the main channel.
Channel construction/relocation	Restoration and channel bed, bank and floodplain construction techniques to alter planform and shape of river. However, unlike past engineering works, this design should involve the implementation of riffle-pool or step-pool sequences as appropriate given slopes and valley conditions.	Actively create geomorphically stable natural channels that are free to adjust naturally and unrestrained. Creates floodplain areas required for flow dispersement and sediment storage and attenuation. Decreases erosive forces within the channel. Actively revegetate and maintain a wooded corridor which increases erosion protection and ecological function of corridor.
Grade control	In-stream restoration techniques to prevent further bed degradation or to encourage sediment accumulation within the channel itself.	Protects critical bed elevations such as in the vicinity of bridges. Prevents large head cuts from migrating upstream. Would allow for the selective adjustment of bed elevations to increase in channel sediment storage and minimize detrimental effects of grade changes.
Channelization Approach		
Active sediment management	Dredging in-channel sediments to improve flood capacity or reduce sediment loads to downstream reaches.	Does not meet project goals of reducing erosive forces and limiting damage from floods. This particular management activity has continually set back the clock on the rivers ability to stabilize. Should be considered only if damage to or failure of infrastructure is imminent due to sediment accumulation.
No Action Approach		
No Action	Do not address current conflicts with river management.	Does not meet project goals of reducing erosive forces and limiting damage from floods.

6.0 Conclusions and Preliminary Recommendations

The Phase 2 assessment is a prerequisite step in the overall project goal of developing a River Corridor Protection and Channel Management Plan for the Town of Bennington. The Phase 2 work to date has accomplished several necessary goals, including:

- Familiarizing the project team with the region, the rivers, and the history of floods and management of the river;
- Identifying an overall geomorphic context and dominant channel processes and geomorphic units (reaches);
- Determining channel form, type, condition and sensitivity for each reach;
- Presenting introductory Channel Management Alternatives for further discussion and refinement in the River Corridor Protection and Channel Management Plan; and
- Identifying data gaps required to further and adequately understand channel condition, rates of change, reach sensitivity, and management options.

Based on the work completed thus far, it is reasonable to conclude that the Roaring Branch is actively adjusting and continues to present a great risk to the Town of Bennington. The history of channel relocation, manipulation and control has prevented a less dynamic and stable system from developing. The river system contains a large sediment supply and the presence of the numerous berms has only resulted in constraining stream energy, which in turn has lead to accelerated rates of change in channel form. Berms, bridges and public and private property within the system are exposed to on-going channel adjustment hazards. A management plan that includes both passive and active geomorphic approaches will be necessary to mitigate future damage from flood events and continued channel adjustment.

There are also existing and potential future management conflicts on the Walloomsac River, which provides contrasting form and processes to the Roaring Branch. There is evidence to suggest that more sediment is being conveyed downstream as compared to historical levels, and there is a definite sediment transport discontinuity at the confluence area with the Roaring Branch. This in turn increases the risks to the Town, as channel migration, aggradation, erosion, and widening are likely to continue to occur in Reaches M06a and M06b. The middle and lower reaches of the Walloomsac offer great opportunity to be proactive, rather than reactive in management strategies. Relatively stable and natural conditions exist and can be protected with passive geomorphic management approaches.

The risk presented by the current state of the rivers in the Town of Bennington to property and the environment is great. This risk is evident and demonstrated by the history of disasters and management conflicts. Current development and growth within the Town and predicted climatic changes such as global warming are likely to increase the risk and challenges for the Town. A River Corridor Protection and Channel Management Plan is the next essential step to implementing reactive measures to address the legacy of mismanagement and proactive measures to protect process-essential real-estate within the boundaries of the Town of Bennington.

7.0 References

Davey, C., and Lapointe, M. 2007. Sedimentary links and the spatial organization of Atlantic salmon (*Salmo salar*) spawning habitat in a Canadian Shield river. Geomorphology. 83 (1-2): 82-96.

Federal Emergency Management Agency. 1986. Flood Insurance Study, Town of Bennington, Bennington County, Vermont. Washington, D.C., June 17, 1986.

Fischenich, J. C. 2003. Technical Considerations for Evaluating Riverine/Riparian Restoration Projects ERDC/EL TR-WRAP-03-XX, April 2003, U.S. Army Engineer Research and Development Center Environmental Laboratory, Vicksburg, MS.

Knighton, D. 1998. Fluvial Forms and Processes: A new perspective. Oxford University Press: New York.

Rice, S. 1998. Which tributaries disrupt downstream fining along gravel-bed rivers? Geomorphology. 22: 39-56.

U.S. Army Corps of Engineers, New York District. 1975. Flood Plain Information, Walloomsac River – South Stream – Roaring Branch, Town of Bennington, VT. New York, March, 1975.

U.S. Army Corps of Engineers, New England District. 1987. Post Flood Report March/April 1987. Waltham, MA. April, 1987.

U.S. Army Corps of Engineers, New England District. 1995. Water Resources Development, Vermont (NEDEP-360-1-37). Waltham, MA. November, 1995.

U.S. Geological Survey. 2002. Flow-Frequency Characteristics of Vermont Streams. Water-Resources Investigations Report 02-4238. Pembroke, NH.

Vermont Agency of Natural Resources. 2005. Vermont Fluvial Erosion Hazard Mitigation Program. DEC River Management Program. May 16, 2005

Vermont Agency of Natural Resources. 2006a. Vermont Stream Geomorphic Assessment, Phase 2 Handbook, Rapid Stream Assessment Field Protocols. March, 2006.

Vermont Agency of Natural Resources. 2006b. Alternatives for River Corridor Management. Vermont DEC River Management Program Position Paper. November 20, 2006.