



## **Bear Creek Environmental**

---

### **Phase 2 Stream Geomorphic Assessment West Branch Ompompanoosuc River Watershed Town of Strafford, Vermont**

Final Report  
February 6, 2006

---

297 East Bear Swamp Road  
Middlesex, Vermont 05602

**Phone:** (802) 223-5140

**Fax:** (802) 229-4410

**email:** [bearcrk@sover.net](mailto:bearcrk@sover.net)



Bear Creek **Environmental**

297 East Bear Swamp Road, Middlesex, Vermont 05602  
Phone: (802) 223-5140 / Fax: (802) 229-4410

**Phase 2 Stream Geomorphic Assessment  
West Branch Ompompanoosuc River Watershed  
Town of Strafford, Vermont**

Final Report  
February 6, 2006

Prepared by:

Michael Blazewicz  
Staff Scientist

And

Mary Nealon  
Principal/River Scientist

Prepared for:

Strafford Conservation Commission

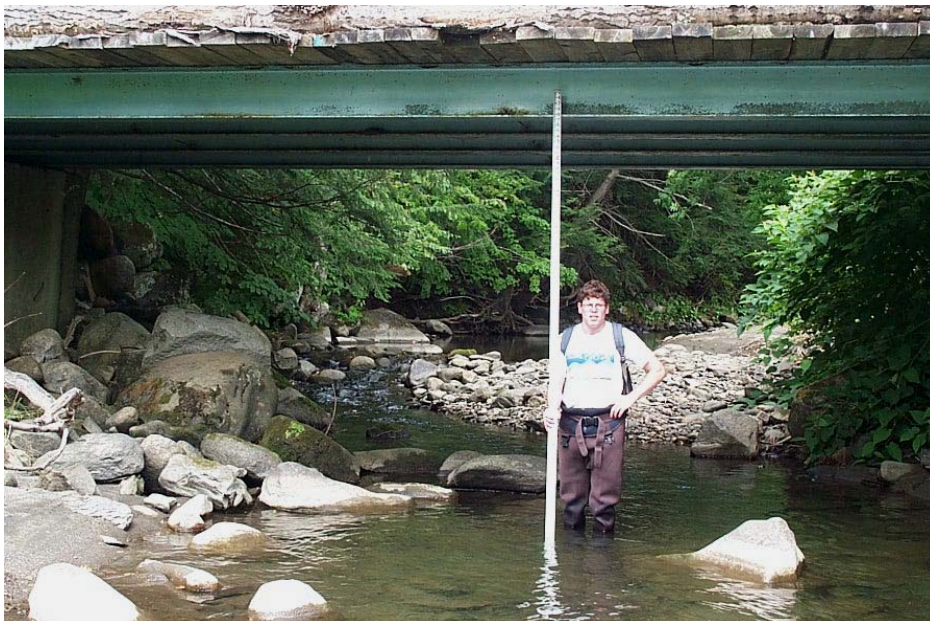


## Bear Creek **Environmental**

297 East Bear Swamp Road, Middlesex, Vermont 05602  
Phone: (802) 223-5140 / Fax: (802) 229-4410

### **ACKNOWLEDGEMENTS**

Bear Creek Environmental (BCE) would like to thank several individuals for assisting with the Phase 2 Geomorphic Assessment of the West Branch of the Ompompanoosuc River Watershed. We thank Ben Copans of the Vermont Agency of Natural Resources (ANR) for assisting with field data collection and Ty Mack of the ANR for providing technical expertise and QA review of the Phase 2 data. We would like to also acknowledge Ty Mack and Sally Mansur for providing review comments on the draft report. We appreciate Anne Peyton's assistance in contacting riparian landowners in order to receive their permission for us to access the study reaches. The BCE project team is grateful to those riparian landowners within the West Branch of the Ompompanoosuc River Watershed who granted us access to our study reaches and the many individuals in the community who were interested in talking to us about the river and sharing with us their knowledge and concerns.



# Phase 2 Stream Geomorphic Assessment West Branch Ompompanoosuc River Watershed Town of Strafford, Vermont

## TABLE OF CONTENTS

<b>EXECUTIVE SUMMARY .....</b>	<b>I</b>
<b>1.0 PROJECT OVERVIEW.....</b>	<b>1</b>
<b>2.0 BACKGROUND INFORMATION .....</b>	<b>2</b>
2.1 <b>DESCRIPTION OF STUDY AREA .....</b>	<b>2</b>
2.2 <b>REACH LOCATIONS.....</b>	<b>2</b>
2.3 <b>FLOOD HISTORY .....</b>	<b>8</b>
<b>3.0 PHASE 2 METHODOLOGY.....</b>	<b>9</b>
3.1 <b>FIELD PROTOCOLS .....</b>	<b>10</b>
3.2 <b>QA REVIEW.....</b>	<b>10</b>
<b>4.0 RESULTS.....</b>	<b>10</b>
<b>MAIN STEM .....</b>	<b>10</b>
4.1 <b>REACH M03 .....</b>	<b>11</b>
4.2 <b>REACH M04.....</b>	<b>13</b>
4.3 <b>REACH M05.....</b>	<b>15</b>
4.4 <b>REACH M06.....</b>	<b>16</b>
4.5 <b>REACH M07.....</b>	<b>19</b>
4.6 <b>REACH M08.....</b>	<b>21</b>
4.7 <b>REACH M09.....</b>	<b>22</b>
4.8 <b>REACH M10.....</b>	<b>25</b>
4.9 <b>REACH M11.....</b>	<b>28</b>
4.10 <b>REACH M12.....</b>	<b>30</b>
<b>TRIBUTARIES .....</b>	<b>31</b>
4.11 <b>REACH T2.01 .....</b>	<b>31</b>
4.12 <b>REACH T3.01 .....</b>	<b>33</b>
4.13 <b>REACH T4.01 .....</b>	<b>35</b>
4.14 <b>REACH T5.01 .....</b>	<b>37</b>
4.15 <b>REACH T6.01 .....</b>	<b>38</b>
4.16 <b>REACH T7.01 .....</b>	<b>39</b>
<b>5.0 GEOMORPHIC CONDITION.....</b>	<b>41</b>
5.1 <b>CHANNEL AND FLOODPLAIN MANAGEMENT HISTORY .....</b>	<b>41</b>
5.2 <b>REACH CONDITION.....</b>	<b>42</b>
5.3 <b>CHANNEL EVOLUTION .....</b>	<b>45</b>
5.4 <b>STREAM SENSITIVITY .....</b>	<b>48</b>
<b>6.0 HABITAT EVALUATION.....</b>	<b>52</b>
<b>7.0 OUTREACH AND EDUCATION.....</b>	<b>55</b>
<b>8.0 RECOMMENDATIONS.....</b>	<b>55</b>
<b>9.0 REFERENCES.....</b>	<b>56</b>



## Bear Creek **Environmental**

297 East Bear Swamp Road, Middlesex, Vermont 05602

Phone: (802) 223-5140 / Fax: (802) 229-4410

# **Phase 2 Stream Geomorphic Assessment West Branch Ompompanoosuc River Watershed Town of Strafford, Vermont**

## **EXECUTIVE SUMMARY**

The Strafford Conservation Commission retained Bear Creek Environmental to perform a Phase 2 Geomorphic Assessment of seventeen reaches on the West Branch Ompompanoosuc River (WBOR) Watershed in the Town of Strafford during summer and fall 2005. These stream geomorphic assessments provide information about the physical condition of streams within the WBOR watershed and the factors that influence the stability of these systems. The project was funded through a grant from the Upper Valley Community Foundation. The Vermont Department of Environmental Conservation (DEC) River Management Program provided technical expertise and shared quality control/quality assurance responsibilities with Bear Creek Environmental.

The study followed the Phase 2 assessment protocol developed by the DEC River Management Program. Information from the study came from the DEC, the Vermont Mapping Program, the Vermont Center for Geographic Information, the Town of Strafford, and field data collected by Bear Creek Environmental. The Phase 2 Rapid Stream Assessment included field observations and measurements that are used to verify the Phase 1 stream geomorphic data, to provide field evidence of channel adjustment processes, and rate the health and condition of the riparian corridor and aquatic habitat. The collection and synthesis of this information can be used in watershed planning, for the establishment of erosion hazard zones, and for the identification of watershed improvement projects.

The Rapid Habitat Assessment (RHA) is used to evaluate the physical components of a stream (the channel bed, banks, and riparian vegetation) and to understand how the physical condition of the stream affects aquatic life. The results can be used to compare physical habitat condition between sites, streams, or watersheds, and also serve as a management tool in watershed planning or similar land-use planning. Nineteen of twenty-one segments resulted in a rating of fair for the RHA. One segment resulted in a rating of poor. RHA results were found to be closely related to the geomorphic condition of the reach.

The Phase 2 Rapid Geomorphic Assessment (RGA) is important for understanding the geomorphic stability of a reach. The RGA includes an evaluation of reach condition (departure from reference condition), channel adjustment process, and the reach sensitivity. The reach condition describes the degree of departure of the channel from its reference stream type. The channel adjustment process is a change in the form of the channel due to natural causes or human impacts. Reach sensitivity describes how sensitive a stream reach is to changes within the watershed, and is dependent upon the existing stream type and the condition of the reach.

Phase 2 assessments were conducted on 16 of the 17 reaches included in the study. One reach, on a tributary on the northeast side of the watershed, could not be assessed due to unwillingness of the landowner to grant permission for access. The sixteen reaches were broken into 21 segments following the Phase 2 protocol (ANR 2005). Only one of the 21 reaches was found to be in reference geomorphic condition, having shown no signs of adjustment. Three segments were found to be in good geomorphic condition, having evidence of only minor adjustment. The remaining segments assessed for the Phase 2 study resulted in a geomorphic condition of fair. These reaches were observed as undergoing major geomorphic adjustment. None of the reaches were found to be in poor geomorphic condition. The Phase 2 Rapid Geomorphic Assessment (RGA) was used to evaluate the stage of channel evolution. Most of the segments assessed have undergone some channel incision (i.e. downcutting). Many of these incised reaches were in fair geomorphic condition and were currently undergoing major channel adjustments (e.g. channel widening, lateral migration, and aggradation).

Much of the main stem of the West Branch of the Ompompanoosuc River in Strafford is experiencing high rates of bank erosion. Bank erosion is most prevalent in the section of river between South Strafford Village and Alger Brook. The bank erosion has been accelerated due to land use activities and channel and floodplain modifications. Significant channel straightening, bank armoring, berming, and floodplain encroachment have occurred within this river system both on the mainstem and on the lower ends of the tributaries. These impacts have resulted in the loss of natural energy dissipation of the river system via meandering and flooding the fields along the river. Over time, the river has down cut into the streambed resulting in loss of floodplain access and increased energy within the channel. The increased energy within the channel has led to severe bank erosion and subsequent channel widening. Along much of the main stem, the river channel is currently migrating laterally to recreate a new floodplain at a lower elevation to dissipate the energy and to become more stable.

The disturbance and removal of the riparian vegetation in Strafford has decreased the resistance of the streambank to the erosive forces of the river. Rates of lateral adjustment are influenced by the presence and condition of riparian vegetation. For this reason, the acquisition of easements, streamside plantings, and buffer protection should be a high priority for restoration planning and design work. As the river works toward a more stable equilibrium, the Strafford Community has the opportunity to reestablish floodplain vegetation and protect the river from further encroachments. A river corridor plan is currently being developed by the Strafford Conservation Commission to make recommendations for river restoration and protection within the West Branch of the Ompompanoosuc River watershed.



## Bear Creek **Environmental**

297 East Bear Swamp Road, Middlesex, Vermont 05602  
Phone: (802) 223-5140 / Fax: (802) 229-4410

# **Phase 2 Stream Geomorphic Assessment West Branch Ompompanoosuc River Watershed Town of Strafford, Vermont**

## **I.0 PROJECT OVERVIEW**

The Strafford Conservation Commission (SCC) retained Bear Creek Environmental (BCE) to perform Phase 1 and 2 Stream Geomorphic Assessments of the West Branch Ompompanoosuc River (WBOR) Watershed. The funding for these projects was provided by the Upper Valley Community Foundation. A Phase 1 Stream Geomorphic Assessment of WBOR (Bear Creek Environmental, 2004) and Bridge and Culvert Assessments (Bear Creek Environmental, 2005) following the Vermont Agency of Natural Resources' (ANR) protocol were completed during 2004. Based on the Phase 1 Stream Geomorphic Assessment, BCE recommended that Phase 2 Assessments be conducted of 17 of the 40 Phase 1 reaches. These reaches included ten on the main stem and the seven most downstream reaches on each major tributary in the study area.

The fieldwork for the Phase 2 assessment was completed during August, September and October 2005. The Phase 2 Geomorphic Assessment was conducted to inform the community on the current and predicted adjustment processes of the WBOR. The Phase 2 information will be used to assist with river corridor planning and restoration within the Town of Strafford.

A glossary of stream geomorphic assessment terms is included in Appendix A of this report to assist the reader. These definitions, which were adapted from Fischenich (2000), are from Appendix Q of the Vermont Agency of Natural Resources' Stream Geomorphic Handbook (2004).

## **2.0 BACKGROUND INFORMATION**

### **2.1 Description of Study Area**

The WBOR has a watershed size of 40.2 square miles measured from a point just downstream of the Strafford/Thetford town lines. The WBOR within the Town of Strafford is a subwatershed of the Ompompanoosuc River (see Figure 1). The Ompompanoosuc River is within the Connecticut River Basin. There are seven major tributaries that are within the study area. With the exception of Old City Brook and Alger Brook, BCE scientists were unable to find definitive names for the tributaries that feed the WBOR in Strafford. For purposes of this report, the other five major tributaries were given the road name in the vicinity of the tributary. From South Strafford Village clockwise the stream names used in this report are: Downer Forest Brook, Route 132 Brook, Carpenter Hill Brook, Brook Road Tributary, Tunbridge Brook, Old City Brook, and Alger Brook (see Figure 2).

### **2.2 Reach Locations**

The Agency of Natural Resources staff and Pete Fellows of Two-Rivers Ottauquechee Regional Commission renumbered the reaches in the West Branch of the Ompompanoosuc in September 2005 to include the WBOR within the Town of Thetford. Two new main stem reaches and one tributary were added to the lowest part of the watershed. Therefore, reach M01 in the Strafford phase I report (Bear Creek Environmental 2004) has now become reach M03 and Tributary 1 is now Tributary 2, etc. Reach numbers in this and all future reports will reflect this update.

As described in the Phase I Final Report (Bear Creek Environmental 2004), the stream reaches M03 through M12 were recommended for inclusion in the Phase 2 study, as

were the lowest reaches of each major tributary in the Town of Strafford. The reach condition from the Phase I study for the proposed Phase 2 Assessment reaches ranged from reference to poor, as shown below in Table 1. Reaches were broken into segments in the field by BCE scientists based on ANR guidelines.

As shown in Figure 3, most of the reaches are Rosgen (1996) “E” or “C” channels by reference. E and C channels have wide valleys and moderate to gentle gradients. The difference between E and C channels is largely due to the shape of the channel. E channels have very low width to depth ratios and are highly sinuous by reference. This means that E channels are narrow and deep and have a long channel length relative to the valley length. C channels are typically wider and shallower and have moderate to high width to depth ratios and sinuosity. The lowest reach, M03, was found to be a “B” channel by reference. B channels have moderate to steep slopes and have narrower valleys than E or C channels.

## West Branch Ompompanoosuc River Watershed Town of Strafford, Vermont Phase 2 Geomorphic Assessment Project Location Map

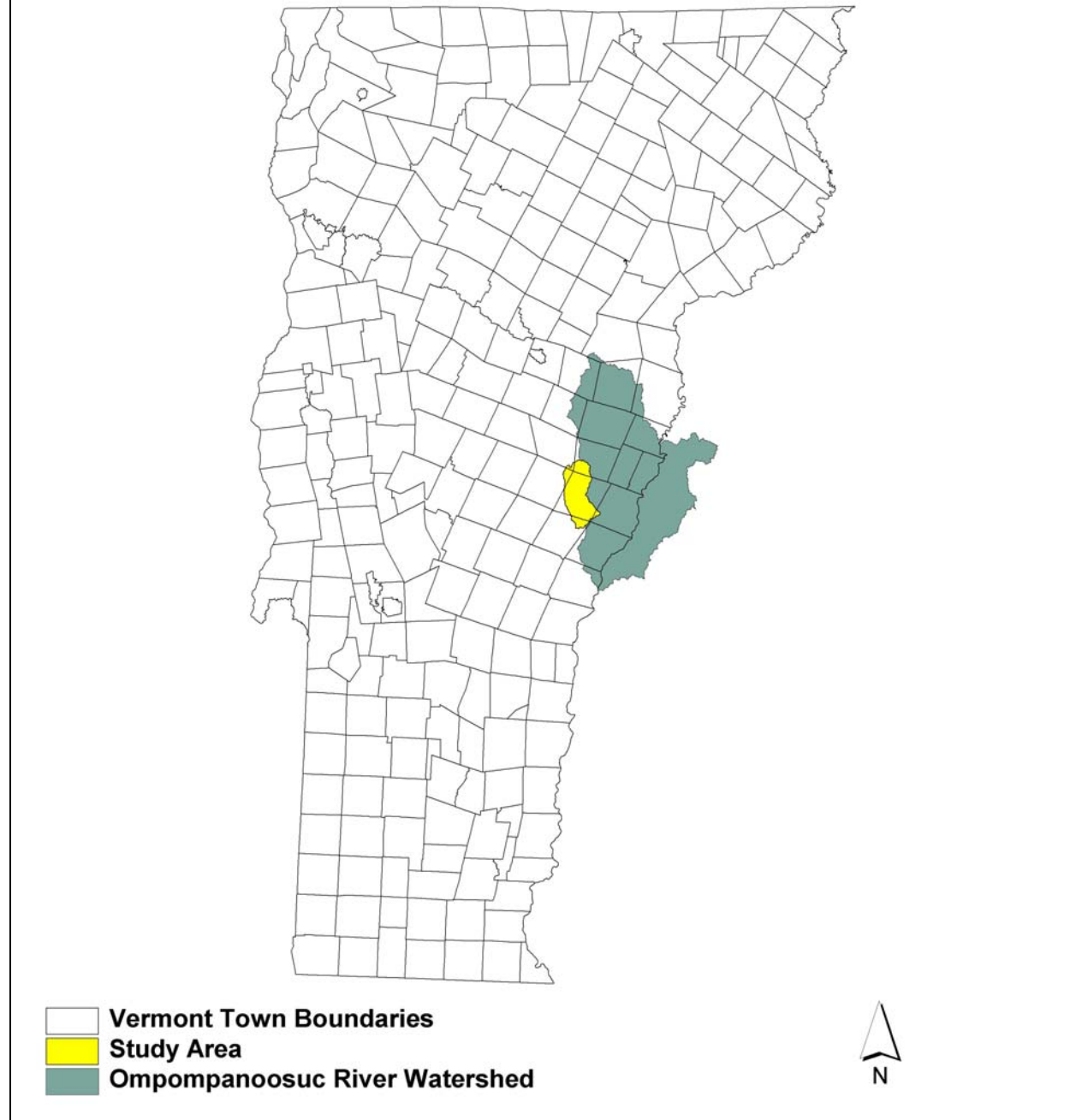


Figure 1. Project Location Map for the Phase 2 Assessment

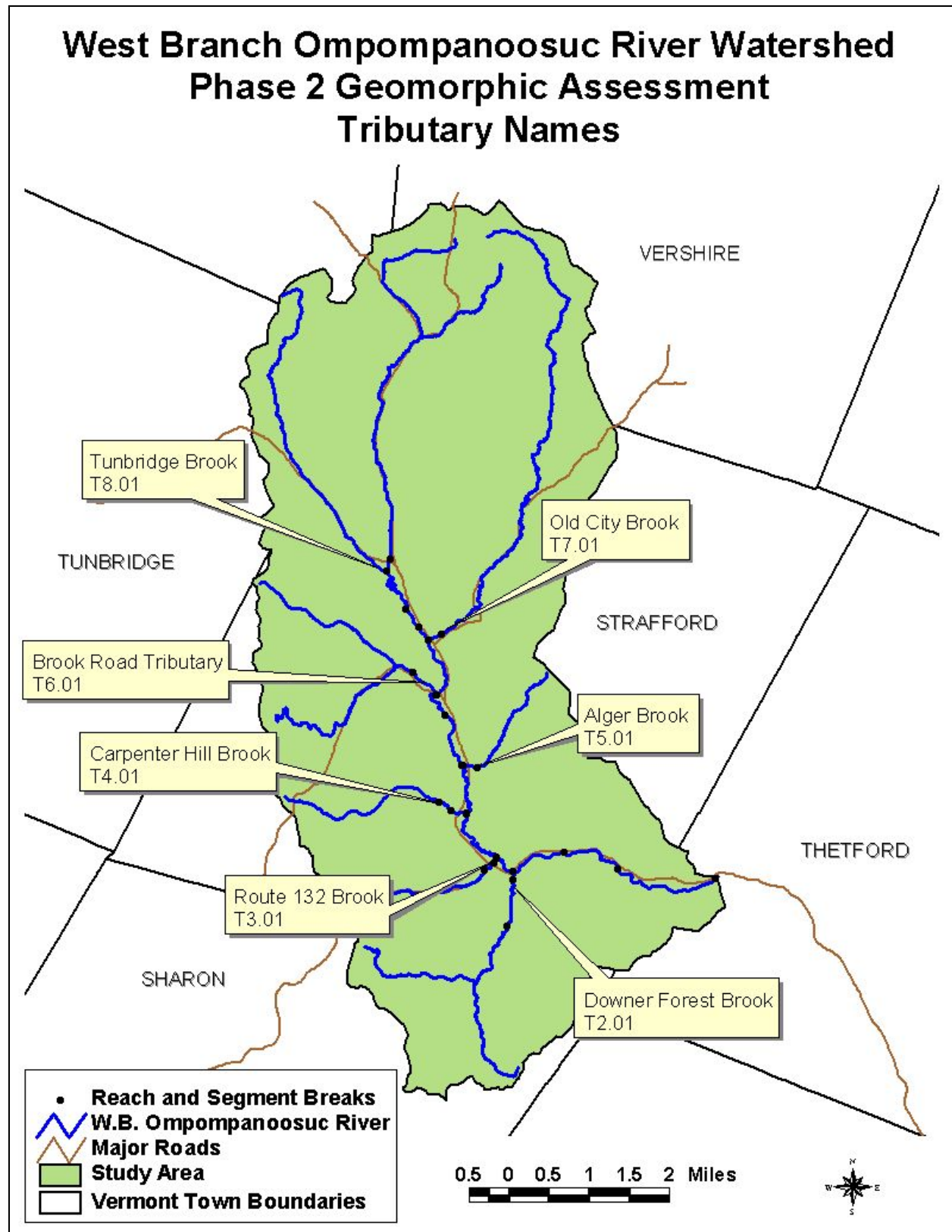


Figure 2. Major Tributaries within the West Branch Ompompanoosuc River Watershed in Strafford, VT

**Table I. Recommended Reaches for Phase 2 Assessment**

Reach No.	Channel Length (ft.)	Confinement Type	Channel Slope	Reference Stream Type	Bed Form	Phase I Reach Condition <sup>1</sup>
M03	7741	SC <sup>2</sup>	1.61	B3c	Plane bed	Reference
M04	4388	NW <sup>3</sup>	0.91	C4	Riffle-Pool	Fair
M05	4162	VB <sup>4</sup>	0.53	C4	Riffle-Pool	Poor
M06	1736	BD <sup>5</sup>	0.46	E5	Riffle-Pool	Poor
M07	5630	VB	0.09	E5	Riffle-Pool	Fair
M08	4220	VB	0.26	E4	Riffle-Pool	Poor
M09	6780	VB	0.25	E4	Riffle-Pool	Fair
M10	4563	VB	0.70	E4	Riffle-Pool	Fair
M11	7728	VB	0.40	E4	Riffle-Pool	Fair
M12	811	VB	2.34	C3b	Riffle-Pool	Good
T2.01	4166	NW	2.23	C4b	Riffle-Pool	Reference
T3.01	1518	BD	3.29	E4b	Riffle-Pool	Poor
T4.01	2323	VB	2.37	E4b	Riffle-Pool	Fair
T5.01	1026	VB	3.80	C4b	Riffle-Pool	Fair
T6.01	2173	VB	2.85	C4b	Riffle-Pool	Good
T7.01	937	VB	2.67	C3b	Riffle-Pool	Fair
T8.01	1505	VB	2.46	C4b	Riffle-Pool	Good

<sup>1</sup> Revised Phase 1 reach condition based on Phase 2 data

<sup>2</sup> Semi-confined

<sup>3</sup> Narrow

<sup>4</sup> Very broad

<sup>5</sup> Broad

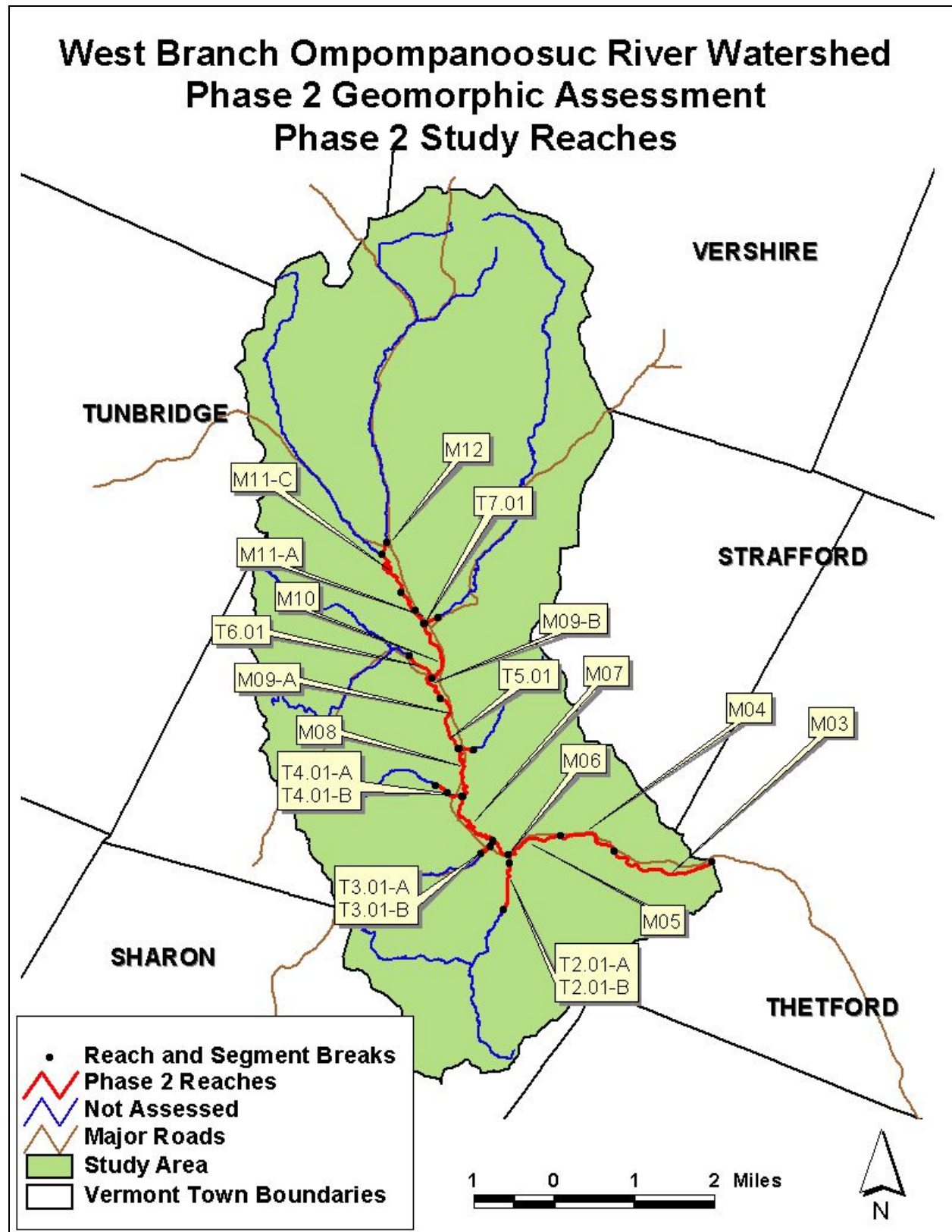


Figure 3: Reach Location Map

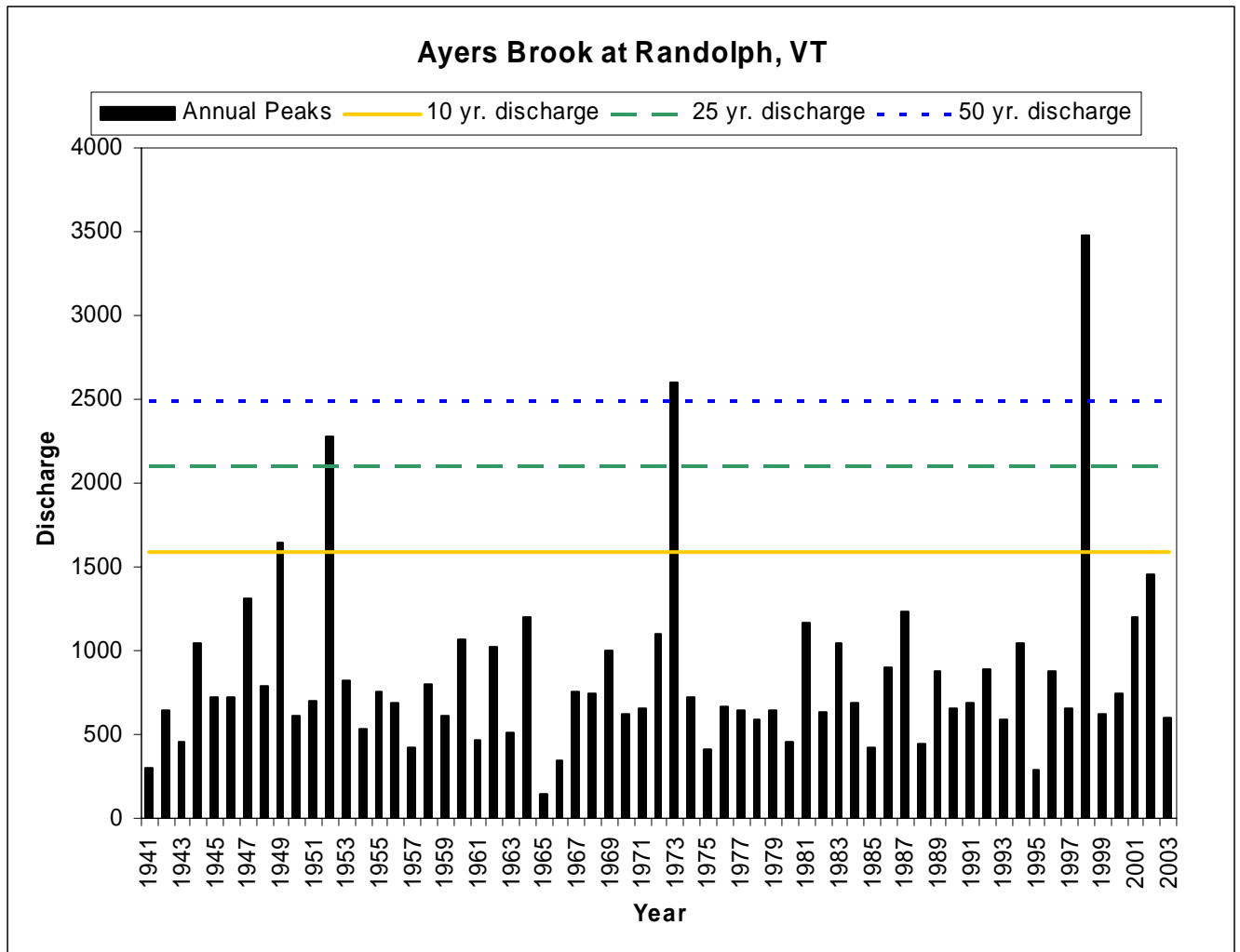
### **2.3 Flood History**

There are no USGS stream gauges within the West Branch of the Ompompanoosuc watershed. In order to better understand the flood history, long term data from the U.S. Department of the Interior, U.S. Geological Survey (USGS) gauge on Ayers Brook at Randolph, VT (gauge #01142500) was obtained. The Ayers Brook gauge was selected for a number of reasons. These reasons are as follows: 1. The Ayers Brook gauge is in close proximity to the WBOR watershed; 2. the stream flow of Ayers Brook is unregulated; and 3. the drainage area at the Ayers Brook gauge is 30.5 square miles, which is similar to the drainage area of the WBOR watershed at the Strafford/Thetford line. Sixty-four years of record are available for the Ayers Brook gauge at Randolph, VT. The gauge provides a continuous record of flow from 1940 through the present. Flow data from the gauge on the Ompompanoosuc River at Union Village, VT could not be used for the flood frequency analysis because peak discharge is influenced by flow regulation.

The long term record for Ayers Brook shows a 10 year discharge occurred in water year<sup>6</sup> 1949 and between a 25 and 50 year discharge occurred in 1952. During water years 1973 and 1998, the peak discharge exceeded the projected 50 year discharge. A graph of the flood frequency analysis is provided in Figure 4 below. The only anecdotal evidence of flood history available to BCE at the time of this report was from the Strafford selectboard. Selectboard members told the SCC that a bridge on Old City Falls Road washed out in 1973, thus supporting the peak discharge record at the Ayers Brook gauge (personal communication with Sally Mansur).

---

<sup>6</sup> A water year is a twelve month period from October 1 through September 30



**Figure 4: Flood frequency analysis for USGS 01142500 Ayers Brook at Randolph Vermont. Peak streamflow data from 1940 through 2003 were used in the analysis.**

### 3.0 PHASE 2 METHODOLOGY

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

### **3.1 Field Protocols**

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

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

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

### **3.2 QA Review**

The Phase I DMS and ArcView shapefiles were updated by Michael Blazewicz and Pamela DeAndrea based on the Phase 2 field assessment work during the Phase 2 QA/QC process in late September 2005. Mary Nealon and Michael Blazewicz provided QA/QC to critical components of the RGA data in October of 2005. The DMS and the ArcView Shapefiles for the WBOR Phase 2 study were submitted to the ANR for a QA review in October 2005.

## **4.0 RESULTS**

### **Main Stem**

Geomorphic and habitat assessments of sixteen of the seventeen Phase 2 reaches were performed by BCE during late summer and fall 2005. One reach, T8.01 on Tunbridge Brook, was not assessed due to unwillingness of the landowner to grant permission for access. The sixteen reaches were broken into 22 segments following the Phase 2 protocol (ANR 2005).

One segment, M1 I-B, was not assessed due to impoundments by beavers which disrupted the flow of sediment and transport within the segment.

The Phase 2 Reach Summary Reports from the ANR Data Management System for each segment are provided on pages 1 through 44 of Appendix B. Descriptions of the study reaches follow. Reaches M03 through M12 are main stem reaches that begin near the Strafford/Thetford town line and continue upstream towards Tunbridge. Following the main stem reaches are descriptions for each of the six major tributaries beginning at the downstream end of the study area at Reach T2.01 (Downer Forest Brook) and continuing upstream towards Old City Brook.

#### **4.1 Reach M03**

Reach M03 is the most downstream reach surveyed during this study. It drains a watershed area of 40.23 square miles. It begins at the confluence with the Abbot Brook (T1.01) and continues upstream to a change in valley width near Furnace Flats Road. This reach is a “B” type channel with a naturally occurring plane bed that is dominated by cobble substrates (Figure 5). “B” type channels with large substrates, such as this reach, tend to be more resilient to impacts within the watershed. This reach was found to be in good geomorphic condition.

Riparian habitat in this reach is generally mixed forest and exceeds 100 feet on each side. In-stream habitat, however, has been greatly affected in most of the reach from the Elizabeth Copper Mine site (See Figure 6). The tailings on the property are rich in metals and sulfides. As water passes over and through the tailings, sulfuric acid is produced and the metals within the tailings are dissolved and mobilized. This results in acid mine drainage. Acid mine drainage contributes an elevated load of metals to Copperas Brook and the WBOR (EPA).



**Figure 5. M03 is a plane bed system dominated by run habitat. The substrate was primarily large cobbles.**



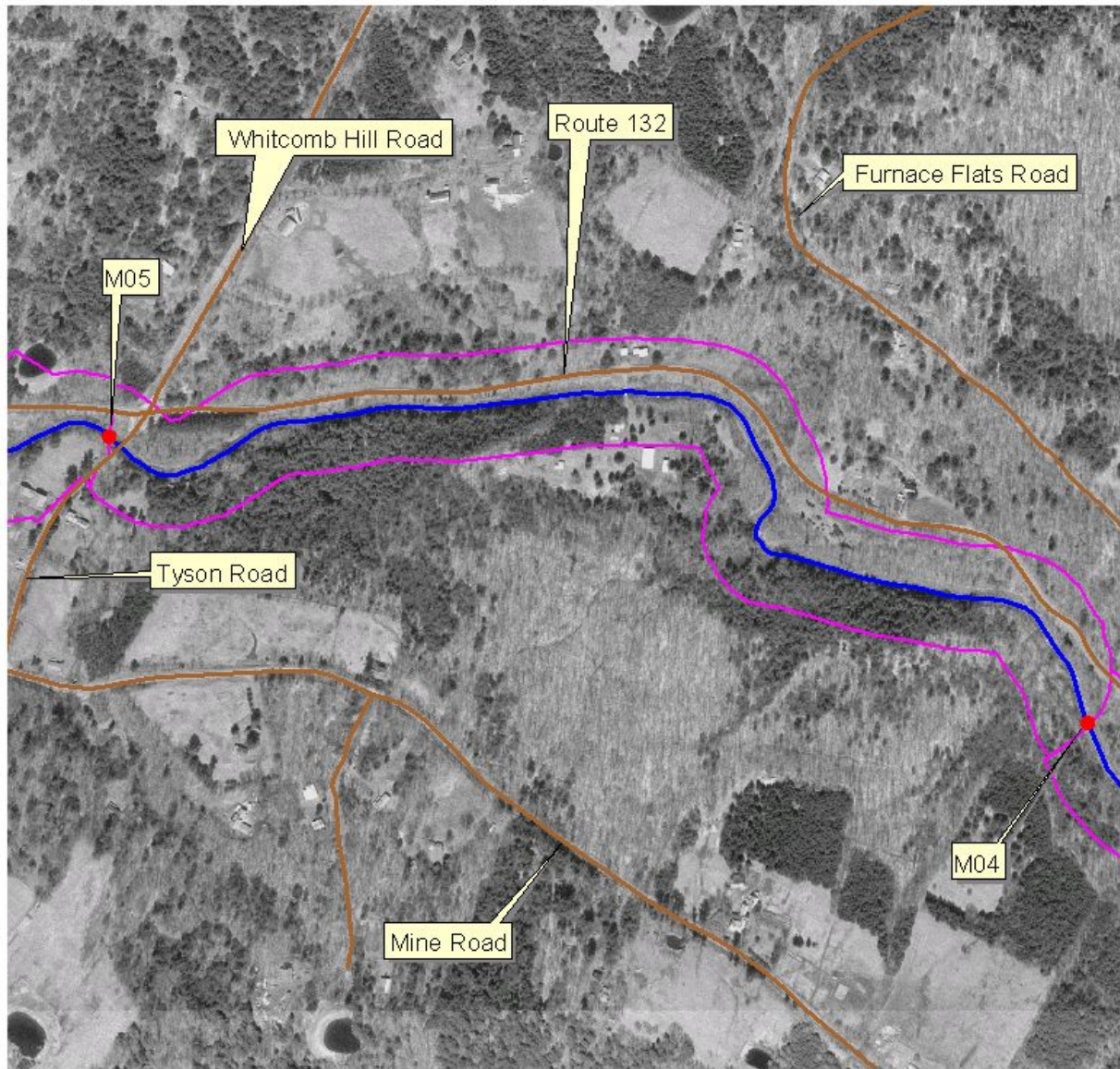
**Figure 6. The water quality of M03 has been drastically affected by the acid drainage from the Elizabeth Copper Mine. Here the clear waters of Abbot Brook converge with the West Branch of the Ompompanoosuc at the beginning of reach M03.**

## **4.2 Reach M04**

WBOR reach M04 begins just upstream from Furnace Flats Road and continues for 4388 feet upstream to just above where Tyson Road crosses the river. The confinement within reach M04 is narrow by reference, however, due to floodplain encroachment this reach has become semi-confined. Phase 1 valley wall mapping rated the valley width at 321 feet. Phase 2 Field verification mapped the Valley width at 173 feet, a change resulting from the encroachment of Route 132 (Figure 7). This reach has departed from its reference “C” type and has become a more entrenched “B” type channel. The bedform and habitat of the stream have been affected by this stream type departure. The bedform has likely changed from a riffle-pool to a plane bed with little depth cover for fish and aquatic organisms (Figure 7). Sediment storage was occurring in the form of mid channel, side, and diagonal bars, indicating the stream is aggrading and widening. Several flood chutes and islands are evidence that the channel is undergoing planform adjustment as it tries to reestablish a new floodplain at a lower elevation and return to a “C” channel. The incision ratio was calculated to be 1.7, suggesting the river has only fair access to the floodplain within this segment.

Erosion was moderate in this section and there were several mass failures where the stream has pushed against the valley wall (Figure 8). Although a few residences border this reach and Route 132 runs along much of the left corridor, the predominant land use in the river corridor is forest. The riparian buffer is generally in good condition, except where Route 132 encroaches into it. Figure 9 shows a large mass failure that has occurred downstream of the Tyson Road Bridge.

## West Branch Ompompanoosuc River Watershed Phase 2 Geomorphic Assessment Route 132 Encroachment along Reach M04



- Reach and Segment Breaks
- ▬ Roads
- ▭ River Corridor
- ▬ West Branch Ompompanoosuc River

200 0 200 400 600 800 Feet

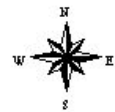


Figure 7. Route 132 Encroachment in the corridor of M04.



**Figure 8. M04 has undergone a stream type departure to a “B” channel and is dominated by run habitat.**



**Figure 9. Massive bank failure downstream of the Tyson Road Bridge.**

### **4.3 Reach M05**

Reach M05 begins just above the Tyson Road Bridge and continues upstream for 4162 feet to where Downer Forest Brook (T2.01) enters the main river channel. Reach M05 is a historically very broad valley by reference (measuring 698 feet in the Phase 1 study), however, due to floodplain encroachment, this reach has become broad (the Phase 2 valley width was measured at 350 feet). The floodplain encroachment includes the

Strafford Town sand storage yard, several hundred feet of improved paths, roads, and residential development. The town sand storage yard has impacted the river by adding additional sediment and debris into the channel through stormwater runoff (see Appendix C). This reach has departed from its reference “C” type and has become a more entrenched “B” type channel. The bedform and habitat of the stream have been affected by this stream type departure. A plane bed form, providing little depth cover for fish and aquatic organisms (Figure 10) has replaced a riffle-pool system. Sediment storage was occurring in the form of mid channel, point, and side bars, indicating the stream is aggrading and widening and redeveloping planform as it tries to reestablish a new floodplain at a lower elevation and return to a “C” channel.



**Figure 10. Reach M05 has undergone historic incision. It has widened and is working to expand its floodplain at a new elevation.**

#### **4.4 Reach M06**

Reach M06 begins at the confluence of Downer Forest Brook (T2.01) and continues upstream to Route 132 Brook (T3.01). It is a short reach of only 1736 feet and is flanked on its right side by South Strafford Village (Figure 11). Physical topography of the valley width was mapped to be 698 feet; however, encroachments from

development and Route 132 have reduced the valley width to 325 feet. By reference this reach is an “E” type channel. BCE scientists found evidence of floodplain encroachment, channel straightening and historic incision through this reach that have led to a stream type departure. In response to this incision, the stream has been very actively eroding its banks, has widened, and is undergoing planform adjustments as it works to create a new floodplain.

The result of this adjustment process is a weak riffle-pool bed structure that lacks habitat (Figure 12). Additionally, the riparian buffer, on the right bank has been heavily impacted by residential and commercial development. It now only averages about 5 feet wide. Landowners along this reach have reacted to the adjustment process of the river by heavily rip-rapping the right bank (1050 feet). Rock armoring of “E” type streambanks often causes further instability in the system. The left bank, perhaps in response to this armoring, as well as the localized channel adjustment, has 1300 feet of recorded streambank erosion.

It was also observed that there has been beaver activity within this reach. At the time of the Phase 2 assessment, the beaver presence did not appear to be affecting the geomorphic stability of the channel. Extra protection of riparian trees may be valuable within this reach in order to protect the existing buffer.



**Figure 11:** The lower end of Reach M06 flows in close proximity to several houses and commercial buildings in South Strafford Village.



**Figure 12.** M06 is an “E” channel that has historically incised and widened. It is currently a “C” channel that is redeveloping a new floodplain.

#### 4.5 Reach M07

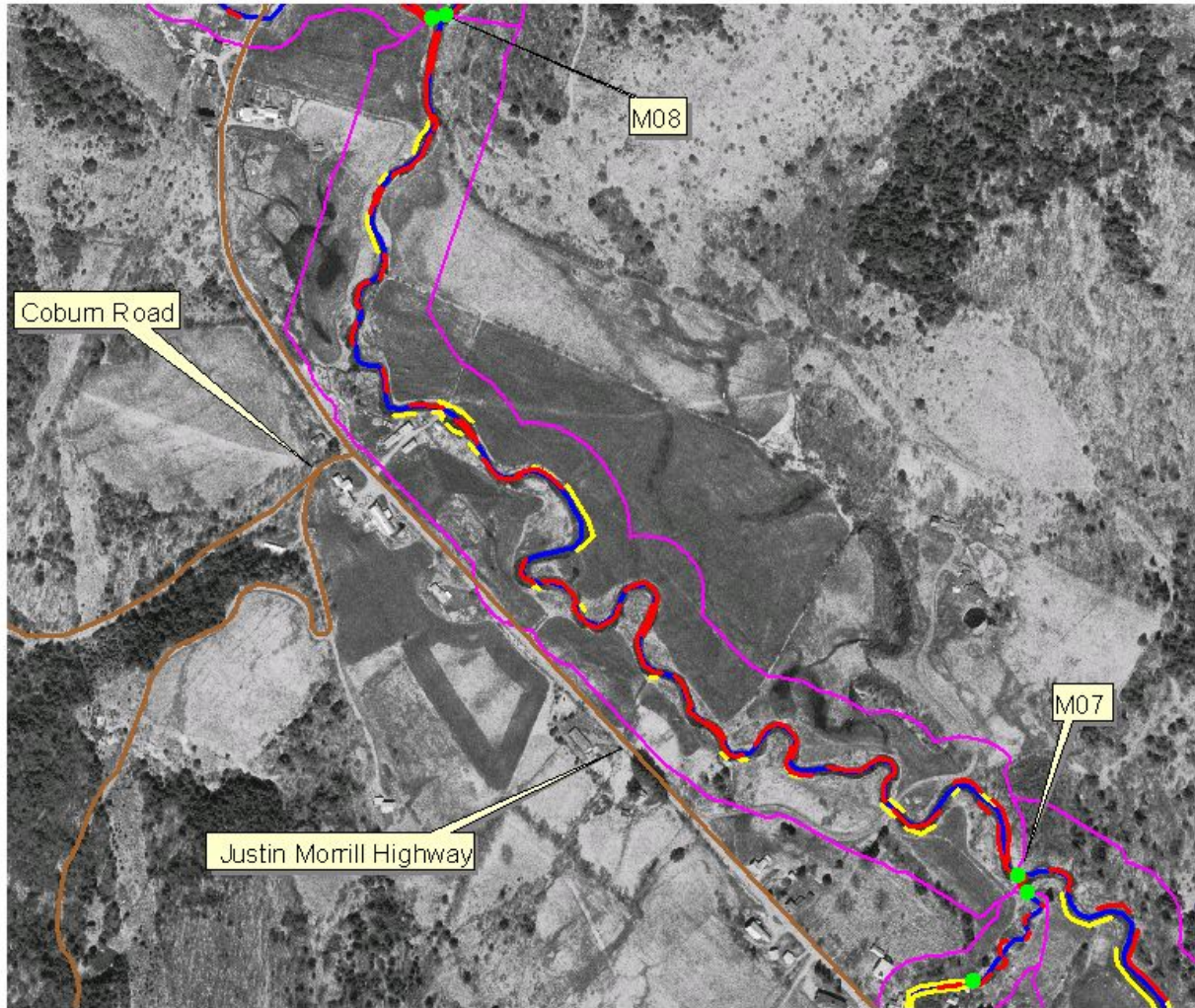
Reach M07 begins at the confluence of Route 132 Brook (T3.01) and continues upstream to Carpenter Hill Brook (T4.01). The reach is almost a mile long and is bordered on both sides by agricultural fields. The valley width here is very broad and the reference type is an “E” channel. BCE scientists found evidence of historic incision through this reach. In response to this incision, the stream has been very actively eroding its banks, has widened, and is undergoing planform adjustments as it works to create a new floodplain (Figure 13).



**Figure 13. M07 is an “E” channel by reference. Historic incision has caused major active adjustment as the stream works to redevelop a new floodplain.**

The result of this adjustment process is a “C” channel with a weak riffle-pool bed structure that lacks habitat. Additionally, the riparian buffer has been heavily impacted by agriculture. It now only averages between 5 and 25 feet wide. Landowners along this reach have attempted to armor the banks. Rock armoring of “E” type streambanks causes further instability in the system. The left and right banks, perhaps in response to this armoring, as well as the localized channel adjustment, each have 2400 feet of recorded streambank erosion (Figure 14).

## West Branch Ompompanoosuc River Watershed Phase 2 Geomorphic Assessment Bank Erosion and Armoring Along Reach M07



- Reach and Segment Breaks
-  Roads
-  Streambank Erosion
-  Bank Armoring
-  West Branch Ompompanoosuc River
-  River Corridor

200 0 200 400 600 800 Feet

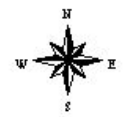


Figure 14. Heavy bank erosion and armoring along a very responsive reach M07.

#### **4.6 Reach M08**

Reach M08 begins at the mouth of Carpenter Hill Brook and ends at the confluence of Alger Brook (T5.01). The entire reach is approximately 4200 feet in length and is classified as an “E” type stream by reference. Historic channel incision, however, has caused channel instability. There are likely many factors that have led to channel incision and the fair geomorphic and habitat conditions found today through reach M08. The riparian buffer, critical to maintaining “E” type channels, has been reduced to less than five feet of width along most of the reach. Additionally, the Justin Morrill Memorial highway cuts right through the middle of the reach. Here, and in many other spots, the river has been straightened. Rock rip-rap, which often leads to further disturbance in “E” type channels, has been used along approximately 20% of each bank. Additionally 300 feet of the stream has effectively been denied access to its floodplain by a berm.

Reach M08 is now actively in a process of widening and planform adjustment as it rebuilds a new floodplain. Aggradation within the reach is likely attributed to autochthonous<sup>7</sup> sediment originating from eroding streambanks. Due to channel widening, the stream was found to have a high width to depth ratio and was therefore classified as a “C” type channel, a departure from its reference condition (Figure 15).

---

<sup>7</sup> Formed or originating in the place where found



**Figure 15. M08 is an “E” channel by reference. Historic incision has caused major active adjustment as the stream works to redevelop a new floodplain.**

#### **4.7 Reach M09**

West Branch of the Ompompanoosuc reach M09 was split into two segments by BCE scientists based on a change in sinuosity and bedform associated with historic channel straightening. M09-A, the downstream segment, has extensive channel straightening while M09-B, the upstream segment, has a more natural planform (see Figure 16).

##### Segment M09-A

Strafford reach M09-A begins at the confluence with Alger Brook and continues upstream for approximately 4050 feet to an area just south of the Upper Village. Here, aerial photographs and field verification displayed an obvious change in sinuosity and bedform due to the amount of historic channel straightening that had occurred. The lower end of this reach flows through predominately hay fields and has been extensively straightened. In most areas, the riparian buffer has been reduced to less than 25 feet of width. Despite the large change in planform and alterations within the riparian corridor, the stream has retained its reference “E” channel. It has, however, lost its riffle-pool bedform, which is often maintained by scouring on the outside bends of meanders. In

this extensively straightened reach, the stream has few meanders, and is predominately a plane bed stream (Figure 17).

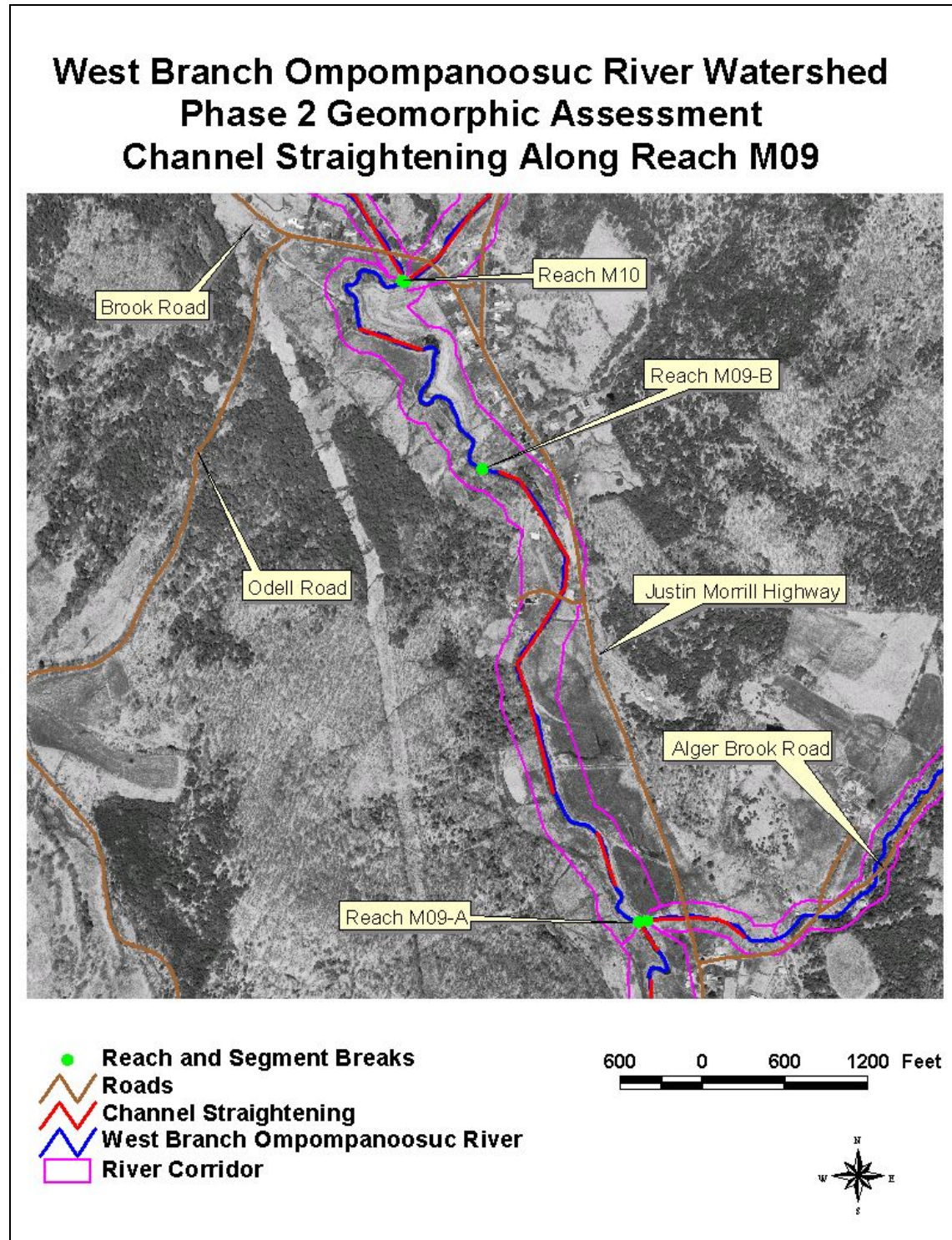


Figure 16: Extensive channel straightening on the lower end of reach M09.



**Figure 17. M09-A is an “E” channel that has been historically straightened. The result has been a conversion to a plane bed system and the loss of pool habitat.**

#### Segment M09-B

Segment B of Reach M09 begins where the reach has natural planform geometry and continues upstream for approximately 2730 feet to the next reach break at the mouth of T6.01 near the Brook Road Bridge in the Upper Village. This segment is an “E” type channel that has been actively adjusting for many years. In some areas, such as depicted in Figure 18, the stream has become over-wide and is a “C” type channel that may rebuild its floodplain and narrow back to an “E” channel.

The dominant corridor land use within this segment is also hay and crop fields. The fields have impacted the riparian buffer of this reach significantly, despite landowner attempts to restore portions of the buffer. In most locations, the riparian buffer is less than five feet wide from the top of the bank. BCE scientists also noted a 500 foot berm along the left bank.

Unlike many of the reaches in the main stem of the WBOR, this reach does not appear to have been greatly affected by (or at least currently reacting to) channel incision.

Much of this segment has already rebuilt a new floodplain. Instead, the channel is responding to excess sediment that is being transported through straightened reaches upstream. Currently the channel width is beginning to narrow through aggradation and the development of bar features. Planform adjustment continues, however, the stream is maintaining a riffle-pool bedform.



**Figure 18. M09-B is an “E” channel – although in some areas, it is rebuilding a floodplain and has “C” type characteristics.**

#### **4.8 Reach M10**

WBOR Reach M10 begins below the Brook Road Bridge in the Upper Village and continues upstream to the mouth of Old City Brook. The reach is just over 4500 feet long and appears to have been extensively straightened for much of that length. This intensive change in planform has caused Reach M10 to depart from its reference “E” channel type. Channel straightening likely led to increased stream power and eventually degradation into the stream bed (the incision ratio of this reach was measured to be 1.91). Bed degradation is currently being followed by channel widening, aggradation, and

planform adjustment. These adjustments and the loss of planform have resulted in a “C” channel with a weak riffle-pool bedform (Figure 19).

Additional impact to Reach M10 has occurred through development within the river corridor (Figure 20). The Justin Morrill Highway is within the river corridor in over 75% of this reach and has likely reduced the river’s ability to flood and meander. Additionally, rip-rap, which often destabilizes “E” type channels, is found along over 1000 feet of the right bank (and over 300 feet on the left bank). The riparian buffer is also impacted, especially on the left bank, which averages less than five feet wide.



**Figure 19. M10 has been historically straightened. It is over-wide and incised and is a “C” channel with poor habitat features.**

## West Branch Ompompanoosuc River Watershed Phase 2 Geomorphic Assessment Channel Impacts Along Reach M10

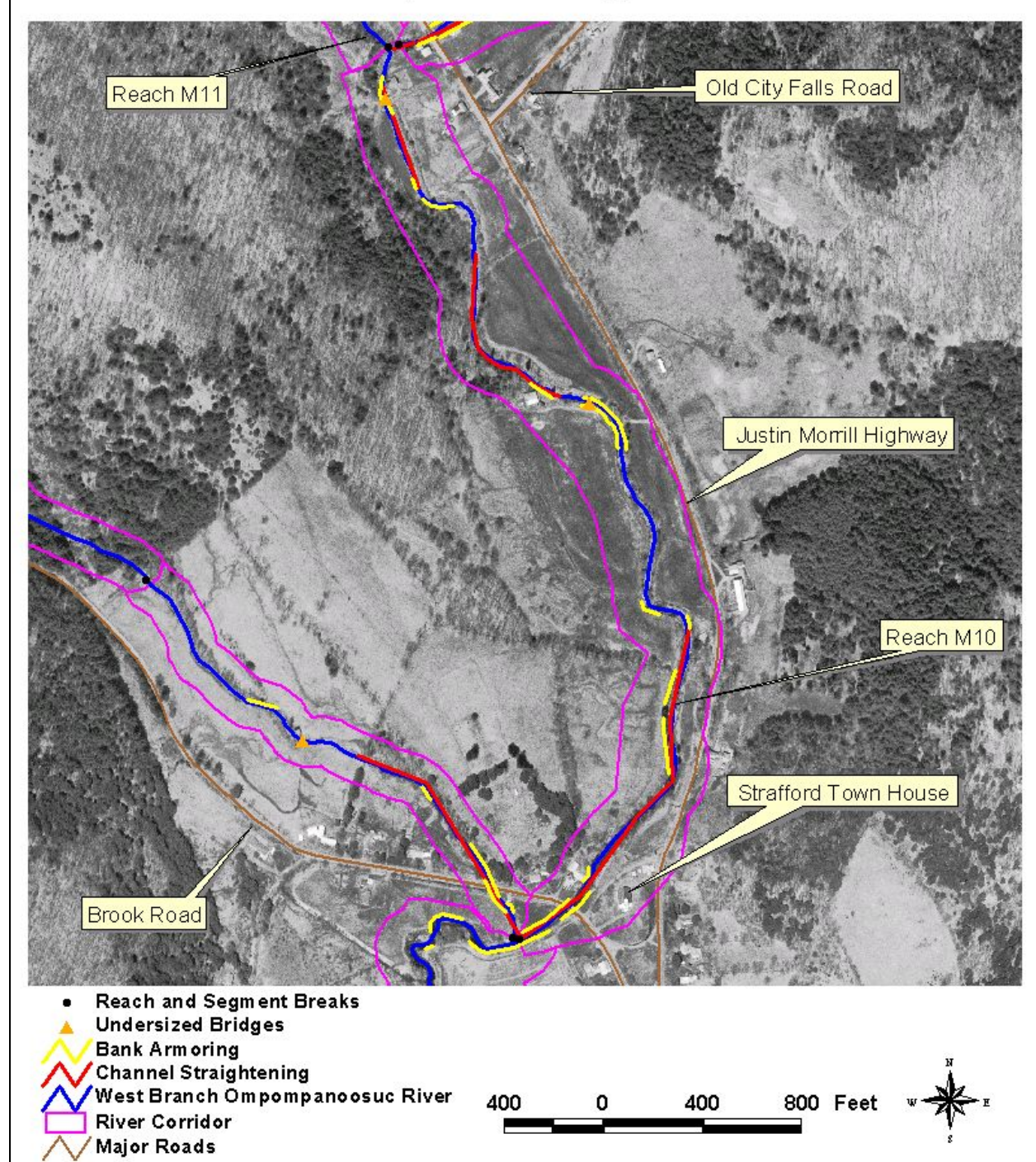


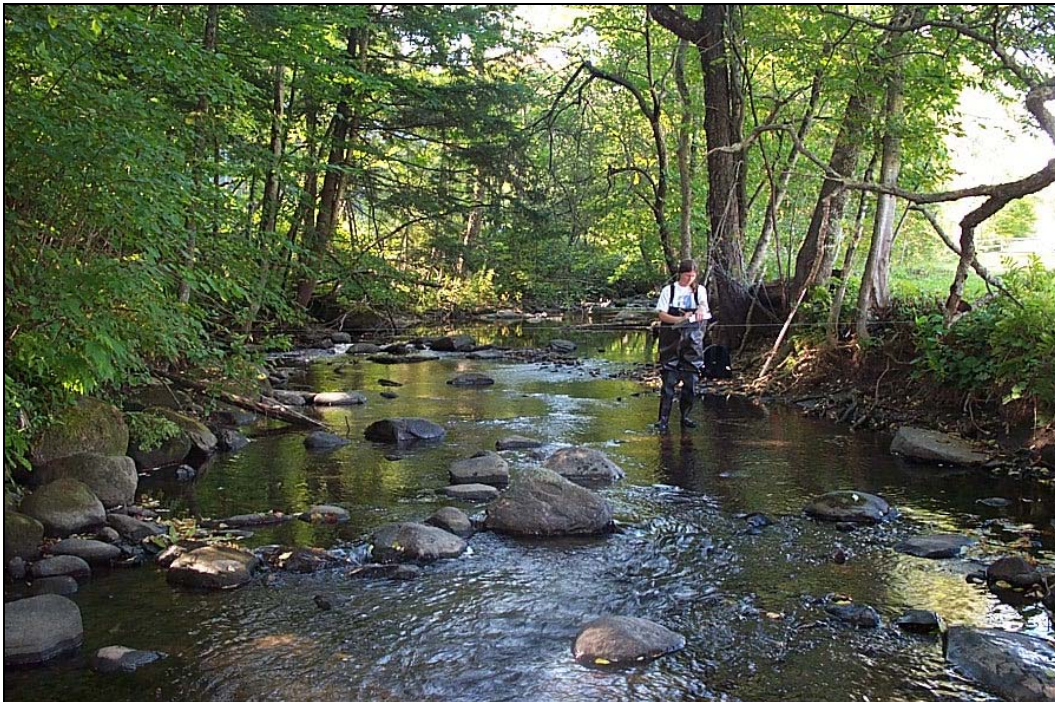
Figure 20. Undersized structures, bank armoring, channel straightening and corridor encroachment have impacted reach M10.

#### 4.9 Reach MII

West Branch Ompompanoosuc reach MII was split into three segments by BCE scientists due to beaver activity which has impacted the middle (segment B) of this reach.

##### Segment MII-A

Reach MII-A begins at the mouth of Old City Brook and continues up the main stem of the Ompompanoosuc River for 1200 feet to where active beaver dams disrupt the flow and sediment transport of the river. This segment was found to be an “E” type stream. The riparian buffer, which is impacted by residences on both sides ranged from 5 to 50 wide depending on the location within the segment. Due to its naturally steeper slopes (~2.5%) and narrower valley, this lower segment of reach MII should have a cobble bottom by reference (Figure 21). Large amounts of fine sediment, however, have caused a bimodal distribution with fine gravels and sands making up 35% of the channel bottom. Despite the non-reference substrates, the reach was found to not be incised, and be in good geomorphic condition.



**Figure 21. MII-A is a naturally steep, “E3” channel by reference.**

### Segment MII-B

Due to beaver activity, which inhibits water and sediment transport, a full Phase 2 geomorphic assessment was not conducted on segment MII-B (see Figure 22). Overall, the characteristics of this segment are similar to MII-C. The Phase I assessment found this to be an “E” channel by reference. Riparian buffer width ranged from 5-25 feet on both sides of the river and consisted of herbaceous species with a few mixed trees along the top of the bank.



**Figure 22. Flows and sediment transport through segment MII-B were affected by beaver dams at the time of this study.**

### Segment MII-C

WBOR reach MII-C is a highly sinuous reach that runs through hay and crop fields for about 5000 feet in length until the confluence with Tunbridge Brook (T8.01) (Figure 23). This segment of the main stem of the WBOR is the first reach with a wide, flat valley floor. With a flatter slope and more sinuous planform the reach is responding to sediment coming down from the headwaters streams. The incision ratio of this reach was 1.29 indicating some degree of historic channel degradation. Currently the stream is undergoing major planform adjustment (there are multiple impending neck cut-offs) with minor aggradation and widening. Sediment storage is occurring in the form of

multiple mid, point, and diagonal bars. While there are no physical impacts to the river corridor, the riparian buffer of this segment has been altered and averages only 5-25 feet wide. Additionally, sections of the stream have been straightened with 15% of each bank containing riprap. BCE scientists found lots of old rip-rap in the stream channel, documenting historic planform adjustment in the reach.



**Figure 23.** M11-C is a highly sinuous “E” type channel.

#### **4.10 Reach M12**

Main stem reach M12 is situated high up in the valley. The reach begins at the confluence with Tunbridge Brook (T8.01) and continues to a point just upstream of the Justin Morrill Highway bridge. It is the short (800 feet) transitional reach between the steeper sloped streams of the upper WBOR headwaters, and the flat meandering channel of the valley floor. This reach, a C3b channel, was found to be in reference geomorphic condition (Figure 24). The major impact to this reach is from riparian buffer disturbance. The buffer, although comprised mostly of mature deciduous trees

and saplings, averaged less than five feet wide on each side of the riverbank. Beyond the buffer, the river corridor is kept in hay fields.



**Figure 24. M12 is in good geomorphic condition, although its riparian buffer is very narrow.**

## **Tributaries**

### **4.11 Reach T2.01**

Reach T2.01 (Downer Forest Brook) was broken into two segments by BCE scientists. The first segment, A, is a highly entrenched channel that flows through the residences and businesses of South Strafford Village. Higher up, in segment B, the stream becomes less entrenched and the dominant land use is forest.

#### **Segment T2.01-A**

Reach T2.01-A (Downer Forest Brook) begins at the confluence of the WBOR and continues upstream for 600 feet until a major change in entrenchment and sinuosity occurs. This stream segment, a “C” type channel by reference, has been extensively straightened and impacted by land use within South Strafford Village (Figure 25). Historic degradation (incision ratio is 2.4) associated with this straightening has created an entrenched “G” type channel. Along with the historic straightening that has

occurred, most of the reach has been rip-rapped along both banks. Some evidence of widening is suggested by areas of failing rip-rap where the stream power has caused the rock to fail. This reach has also been impacted by the removal of riparian vegetation along both banks. The left bank only averages 5 feet in width.



**Figure 25. Segment T2.01-A (Downer Forest Brook) has been extensively straightened and is impacted by land use within the South Strafford Village**

### Segment T2.01-B

Segment T2.01-B (Downer Forest Brook) begins where the historic channelization of the reach ends and continues upstream for approximately 3566 feet to where the stream type changes. This segment is a “C” channel, however, due to excess sediment of autochthonous and allochthonous<sup>8</sup> sources, it has lost its reference bedform (riffle-pool) and is now a plane bed stream that is providing little habitat and depth cover for aquatic organisms (Figure 26). At the corridor scale, this reach seems to have all the necessary components for stream health. There are no major impacts to the river corridor. The riparian buffer, comprised of mixed trees, is well over 100 feet wide. There are, however, numerous mass failures within the riparian corridor, as well as several large gullies that have formed on the adjacent terrace. The result is an excess of

---

<sup>8</sup> Of rocks, deposits, etc.; found in a place other than where they and their constituents were formed.

sediment in the stream channel. This sediment is causing minor widening and planform adjustment to take place as the stream attempts to transport the excess sediment through the system.



**Figure 26. T2.01-B (Downer Forest Brook) is in fair geomorphic condition due to aggradation of sediment in the stream channel.**

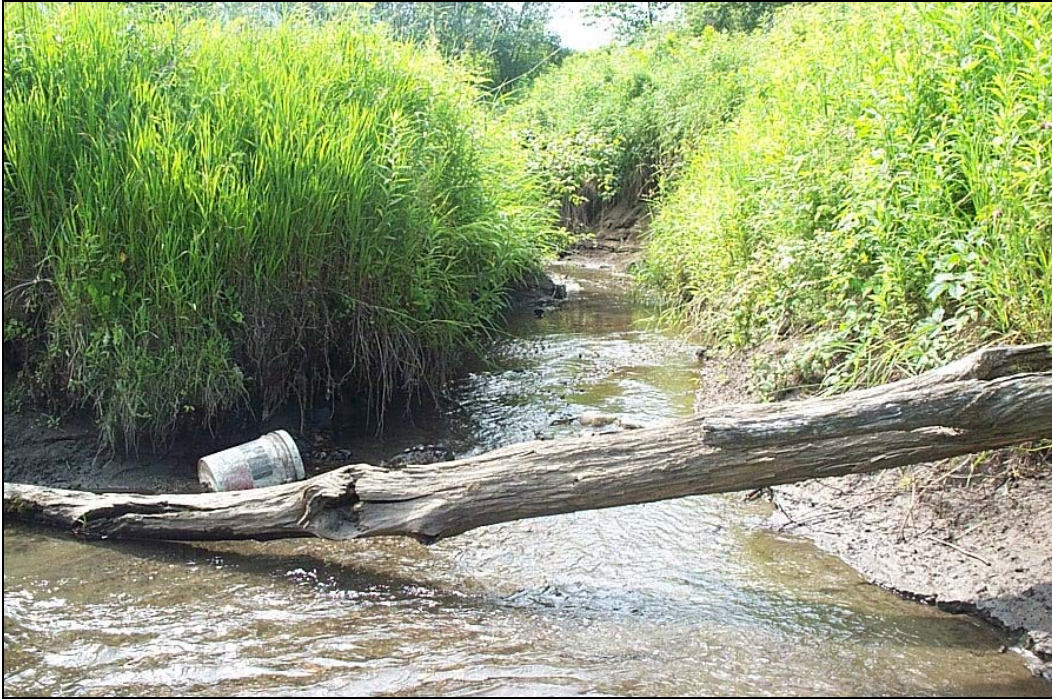
#### **4.12 Reach T3.01**

Reach T3.01 (Route 132 Brook), was broken into two segments by BCE scientists based on a change in stream type associated with historic channelization.

##### Segment T3.01-A

Segment T3.01-A (Route 132 Brook) begins at the confluence with the WBOR and continues upstream for 600 feet to the segment break below an old mill site in the village. The lower segment of reach T3.01 spills out on the floodplain of the WBOR. Here it has undergone significant incision (see Figure 27), however, has rebuilt a new small floodplain. The stream has redeveloped an “E” type channel with moderate sinuosity (Figure 28). Because of the extent of historic degradation, the stream is still actively adjusting. BCE scientists found major planform adjustment and minor widening and aggradation processes occurring as the stream works to expand the new low

floodplain benches that it has developed. Riparian conditions along this reach were inadequate with only 1-25% bank canopy cover and an average buffer width of only 5 to 25 feet wide, which consisted mostly of herbaceous species.



**Figure 27.** At the mouth of T3.01-A (Route 132 Brook), channel incision is still very evident.



**Figure 28.** T3.01-A (Route 132 Brook) is an E channel with active widening, planform adjustment, and aggradation in response to historic channel degradation.

### Segment T3.01-B

Segment B of reach T3.01 (Route 132 Brook) has been extensively altered by historic channelization projects. The segment runs for approximately 900 feet from an old mill site upstream to the end of the reach. Stone walls and rip-rap line both banks of almost the entire segment (Figure 29). Residential development, berms, and roads have also eliminated much of the historic floodplain access of this reach. Riparian conditions were generally very poor; the average buffer width is less than 5 feet wide. This reach has departed from its reference “E” type and is now a “G” channel. Planform adjustment and widening of the reach have been limited by the retaining walls.



**Figure 29. T3.01-B (Route 132 Brook) is a “G” channel due to historic channelization. The rock wall on the left bank of this photograph is evidence of such activity.**

### **4.13 Reach T4.01**

Reach T4.01 (Carpenter Hill Brook) was also divided into two segments by BCE scientists because of a change in stream type.

### Segment T4.01-A

Segment A begins at the confluence with the WBOR and continues upstream for 1200 feet to a point several hundred feet upstream from the Justin Morrill Highway where a change in incision and entrenchment lead to a change in stream type. This lower portion of the reach has an incision ratio of 2. This major historic degradation is likely associated with historic channel straightening efforts to drain the agricultural fields that lie on both sides of the stream. The resulting channel has departed from its reference “E” type and is now a “G” channel (Figure 30). Currently, there is major evidence of channel widening and minor planform adjustment as the stream works to recreate floodplain.

In addition to the geomorphic impairment, the streamside vegetation of this segment have also been highly impacted. On average there is less than five feet of riparian buffer and it is mainly dominated by herbaceous species.



**Figure 30.** T4.01-A (Carpenter Hill Brook) is a “G” channel due to historic channelization and degradation.

### Segment T4.01-B

Segment B of reach T4.01 (Carpenter Hill Brook) is approximately 1100 feet long and flows through pasture, forest, and residential lands. The upper section of this reach has been straightened causing localized degradation (incision ratio of 1.58). There is currently minor planform widening, and aggradation occurring (sand comprised 27% of the pebble count). The segment, however, has remained an “E” type channel with a riffle-pool bedform (Figure 31). Riparian conditions though this segment are poor. The buffer width averages only between 0 and 25 feet in width on both sides of the stream.



**Figure 31. T4.01-B (Carpenter Hill Brook) is an “E” channel that has retained its riffle-pool bedform.**

### **4.14 Reach T5.01**

Reach T5.01, Alger Brook, begins at the confluence with the WBOR and continues upstream for just over 1000 feet to a major change in stream slope. This short reach, which drains through a pasture and hay fields, has been historically straightened near the mouth. There is also some evidence of berming in order to reduce flooding of the surrounding land. This short reach was found to be highly incised (incision ratio of 2). The historic degradation may have occurred due to a lowering of the elevation of the

main stem of the WBOR or due to increased stream power associated with the straightening of this reach. Despite these alterations, the stream is still an “E” type. It has, however, lost its reference bedform and is now considered a plane bed stream (Figure 32). The riparian buffer of this reach has been greatly altered; it averages less than 5 feet wide along the entire reach and consists mostly of herbaceous species. In response to historic degradation, BCE scientists found evidence of minor planform adjustment and widening.



**Figure 32. T5.01, Alger Brook, is an “E” channel that has been straightened.**

#### **4.15 Reach T6.01**

Reach T6.01 (Brook Road Tributary) begins at the confluence of the tributary with the WBOR near the Upper Village and continues upstream for several thousand feet to a change in corridor land use. The land use that this reach flows through is predominately pasture with some residential lands. This reach was found to be a “C” type channel that is only slightly incised (incision ratio 1.3). In addition to this minor degradation, there is also evidence of minor planform adjustment and aggradation that has led to a few steep

riffles, and multiple point and side bars (Figure 33). The pebble count documented 38% of the substrates to be fine gravels and sands.



**Figure 33. T6.01 (Brook Road Tributary) is a “C” channel that has been rebuilding point bars.**

#### **4.16 Reach T7.01**

Reach T7.01, Old City Brook, begins at the confluence with the WBOR and continues upstream for 1000 feet to a culvert under a private driveway. This lower portion of the reach is a “C” channel by reference, however, due to floodplain encroachment has become a “B” type channel (Figure 34). Much of the lower portion of this reach has been straightened leading to major historic degradation. The current incision ratio is 1.68. There are also several structures (see Figure 35) located in the stream corridor. Currently there is evidence of major aggradation and minor planform change and widening. The riparian corridor of this reach has been reduced to 5 to 25 feet wide by residential and agricultural land use that borders both sides of the stream.



**Figure 34. T7.01, Old City Brook, is a “C” channel with riffle-pool features.**



**Figure 35. T7.01, Old City Brook, has several structures located within the stream corridor.**

## **5.0 GEOMORPHIC CONDITION**

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

### **5.1 Channel and Floodplain Management History**

Natural and anthropogenic impacts may alter the delicate equilibrium of sediment and discharge in natural stream systems and set in motion a series of morphological responses (aggradation, degradation, and widening and/or planform adjustment) as the channel tries to reestablish a dynamic equilibrium. Small to moderate changes in slope, discharge, and/or sediment supply can alter the size of transported sediment as well as the geometry of the channel; while large changes can transform reach level channel types (Ryan 2001). Human-induced practices that have contributed to stream instability within the West Branch Ompompanoosuc watershed include:

- Forest clearing
- Channelization and bank armoring
- Removal of woody riparian vegetation
- Flood plain encroachments
- Urbanization
- Poor road maintenance and installation of infrastructure (Figure 36)
- Loss of wetlands

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



**Figure 36: Undersized culverts disrupt the sediment transport capacity of the stream and may lead to both upstream and downstream destabilization. Improperly sized structures, such as this one on T3.01-A, can become plugged and lead to a channel avulsion.**

## **5.2 Reach Condition**

The reach condition is determined using the Rapid Geomorphic Assessment protocol, and is based on the degree of departure of the channel from its reference stream type (ANR 2005). Of the 21 assessed segments, only M12 was found to be in reference geomorphic condition. M12 is located at the top of the study area in a transition zone between the valley floor and the steeper headwaters of the WBOR. Only three reaches (M03, M11-A, and T6.01) were found to be in good geomorphic condition, exhibiting only minor adjustment processes. Reach M03 is located at the lower end of the study area at the Strafford/Thetford town lines and is naturally a more stable “B” type stream channel. M11-A is on the main stem just above the confluence of Old City Brook at the upper end of the watershed. Reach T6.01 is the lower end of the Brook Road tributary that enters the main stem, just above the Coffin Farm. Despite historic changes, the stream appears to be reestablishing a stable channel. Seventeen segments were in only in fair condition, currently undergoing major adjustments through aggradation, widening,

or a change in their planform. No segments were found to be in poor geomorphic condition. Table 2 and Figure 37 illustrate the geomorphic condition of the streams within the study area. There does not appear to be any correlation between location in the watershed and condition of the reach. Instead, stream condition in the WBOR seems more related to corridor land use, floodplain encroachment, the reference stream type and its inherent sensitivity to stressors in the watershed (Figure 37).

**Table 2. Phase 2 Geomorphic Condition for West Branch Ompompanoosuc**

Segment Number	Existing Stream Type	RGA Score	Reach Condition
M03	B3c	0.71	Good
M04	B3c	0.50	Fair
M05	B4c	0.48	Fair
M06	C5	0.49	Fair
M07	C5	0.49	Fair
M08	C4	0.41	Fair
M09-A	E4	0.63	Fair
M09-B	E4	0.63	Fair
M10	C4	0.45	Fair
M11-A	E4b	0.84	Good
M11-C	E4	0.58	Fair
M12	C3b	0.90	Reference
T2.01-A	G3	0.48	Fair
T2.01-B	C4b	0.63	Fair
T3.01-A	E4b	0.59	Fair
T3.01-B	G3	0.50	Fair
T4.01-A	G4	0.53	Fair
T4.01-B	E4b	0.58	Fair
T5.01	E4b	0.48	Fair
T6.01	C4b	0.68	Good
T7.01	B3	0.56	Fair

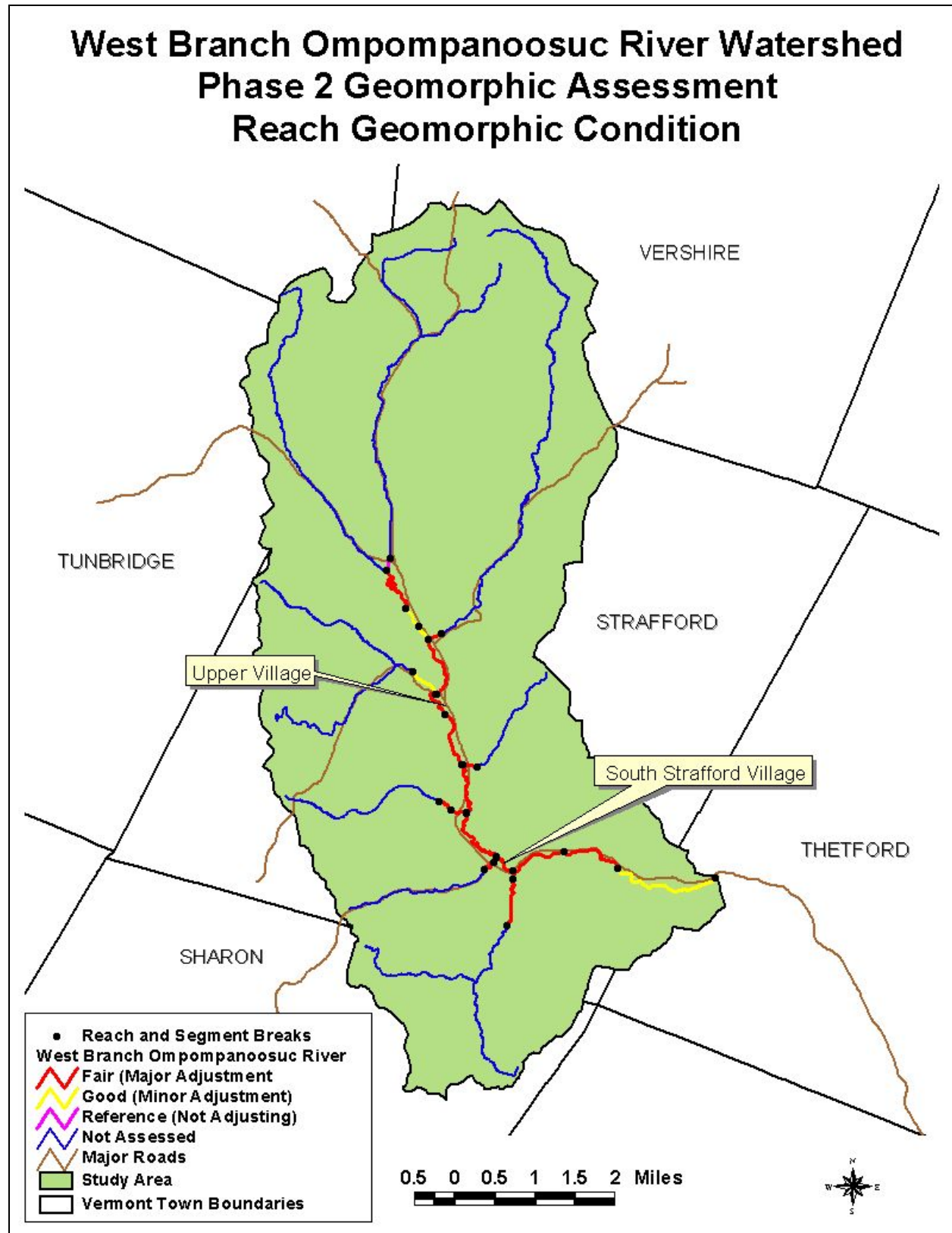


Figure 37: Phase 2 Geomorphic Condition of the West Branch Ompompanoosuc Watershed

### **5.3 Channel Evolution**

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

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

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

Most of the reaches studied in the WBOR watershed are undergoing a channel evolution process in response to large scale changes in its sediment, slope, and/or discharge associated with the human influences on the watershed. Table 3 below and

page 45 of Appendix B summarize the channel evolution of each study reach and the primary adjustment processes that are occurring.

<b>Table 3. Stream Type and Channel Evolution Stage</b>						
<b>Segment Number</b>	<b>Entrenchment Ratio</b>	<b>Width to Depth Ratio</b>	<b>Reference Stream Type</b>	<b>Existing Stream Type</b>	<b>Channel Evolution Stage</b>	<b>Major Active Adjustment Process</b>
M03	1.8	24.8	B	B3c	I	None
M04	2.4	24.8	C	B3c	III	<b>Aggradation</b> Planform Widening
M05	1.8	21.3	C	B3c	III	<b>Aggradation</b> <b>Widening</b> <b>Planform</b>
M06	7.6	11.7	E	C5	IV	<b>Aggradation</b> <b>Widening</b> <b>Planform</b>
M07	21.4	18.5	E	C5	III	<b>Aggradation</b> <b>Widening</b> <b>Planform</b>
M08	9.7	13.0	E	C4	III	<b>Aggradation</b> <b>Widening</b> <b>Planform</b>
M09-A	15.8	8.7	E	E4	III	<b>Aggradation</b> <b>Planform</b>
M09-B	18.3	9.0	E	E4	IId	Aggradation Planform
M10	4.4	12.5	E	C4	III	<b>Aggradation</b> <b>Widening</b> Planform
M11-A	6.5	10.0	E	E4b	I	None
M11-C	30.3	10.8	E	E4	III	Aggradation Widening <b>Planform</b>
M12	50.0	12.0	C	C3b	I	None
T2.01-A	1.6	8.9	C	G3	II	<b>Aggradation</b> Widening Planform
T2.01-B	3.8	15.5	C	C4b	IId	<b>Aggradation</b> Widening Planform
T3.01-A	3.6	7.4	E	E4b	IV	Aggradation Widening <b>Planform</b>
T3.01-B	1.6	10.1	E	G3	II	<b>Widening</b>
T4.01-A	2.1	5.8	E	G4	II	<b>Widening</b> Planform

<b>Table 3. Stream Type and Channel Evolution Stage</b>						
<b>Segment Number</b>	<b>Entrenchment Ratio</b>	<b>Width to Depth Ratio</b>	<b>Reference Stream Type</b>	<b>Existing Stream Type</b>	<b>Channel Evolution Stage</b>	<b>Major Active Adjustment Process</b>
T4.01-B	2.5	9.3	E	E4b	III	Aggradation Widening Planform
T5.01	3.3	7.8	C	E4b	II	<b>Aggradation</b> Widening Planform
T6.01	12.9	10.9	C	C4b	IV	Planform
T7.01	1.4	23.0	C	B3	III	<b>Aggradation</b>
<p><b>Bold Black lettering</b> – denotes major adjustment process                      Black lettering (no bold) – denotes minor adjustment process</p>						

In terms of the ANR channel evolution model, the WBOR and the lower reaches of its tributaries are predominately between stages II and IV of the “F-stage” channel evolution model (see Appendix D). In many reaches the channel has undergone historic degradation. Many of the cross sections on study reaches were found to be incised. The incision ratio ranged form 1.0 to 2.4. Four of the segments were found to have a bankfull elevation that was at least one mean bankfull depth lower than the top of the low bank indicating a high level of bed degradation. Along many of the main stem reaches and near the mouths of the tributaries, the system is actively adjusting to this lower bed elevation by moving laterally and widening in order to create a new floodplain at a lower elevation. This widening and planform adjustment is leading to another adjustment process, aggradation. Aggradation in the WBOR study area seems to be a combination of autochthonous sediment that is created as the stream widens and erodes its banks to reestablish a new floodplain as well as from allochthonous sources such as gravel roads and land clearing. Unvegetated mid channel bars, point bars in “E” type channels, side bars and impending neck cutoffs confirm the channel is undergoing extensive lateral migration.

Several segments within the WBOR study area fell into another channel evolution model. The “D-stage” channel evolution model (See Appendix D) applies to reaches where there may have been some minor historic incision; however, the more dominant

active adjustment process is aggradation, which then in turn leads to channel widening and planform adjustment. This evolution is occurring in reaches M09-B and T2.01-B where aggradation is a major channel adjustment process (Table 3). In the IId stage, a stream channel becomes extremely depositional. Lateral migration is extensive as the stream shifts through different channels and flood chutes and actively erodes its outside banks. Eventually, if the sediment supply stabilizes, the channel width will begin to narrow through the development of large bar features, which will eventually recolonize with shrubs and trees. A riffle-pool sequence will redevelop as the stream reconnects with a floodplain. Both segments M09-B and T2.01-B appear to be in the IId stage.

#### **5.4 Stream Sensitivity**

Sensitivity refers to the likelihood that a stream will respond to a watershed or local disturbance or stressor, such as; floodplain encroachment, channel straightening or armoring, changes in sediment or flow inputs, and/or disturbance of riparian vegetation. Assigning a sensitivity rating to a stream is done with the assumption that some streams, due to their setting and location within the watershed, are more likely to be in an episodic, rapid, and/or measurable state of change or adjustment. A stream's inherent sensitivity may be heightened when human activities alter the setting characteristics that influence a stream's natural adjustment rate including: boundary conditions; sediment and flow regimes; and the degree of confinement within the valley. Streams that are currently in adjustment, especially those undergoing degradation or aggradation, may become acutely sensitive (ANR 2005).

Figure 38 is a map presenting the existing stream types found in the WBOR watershed. The stream sensitivity of these reaches, generalized according to stream type and condition as per the ANR protocol, is depicted in Table 4 and in Figure 39.

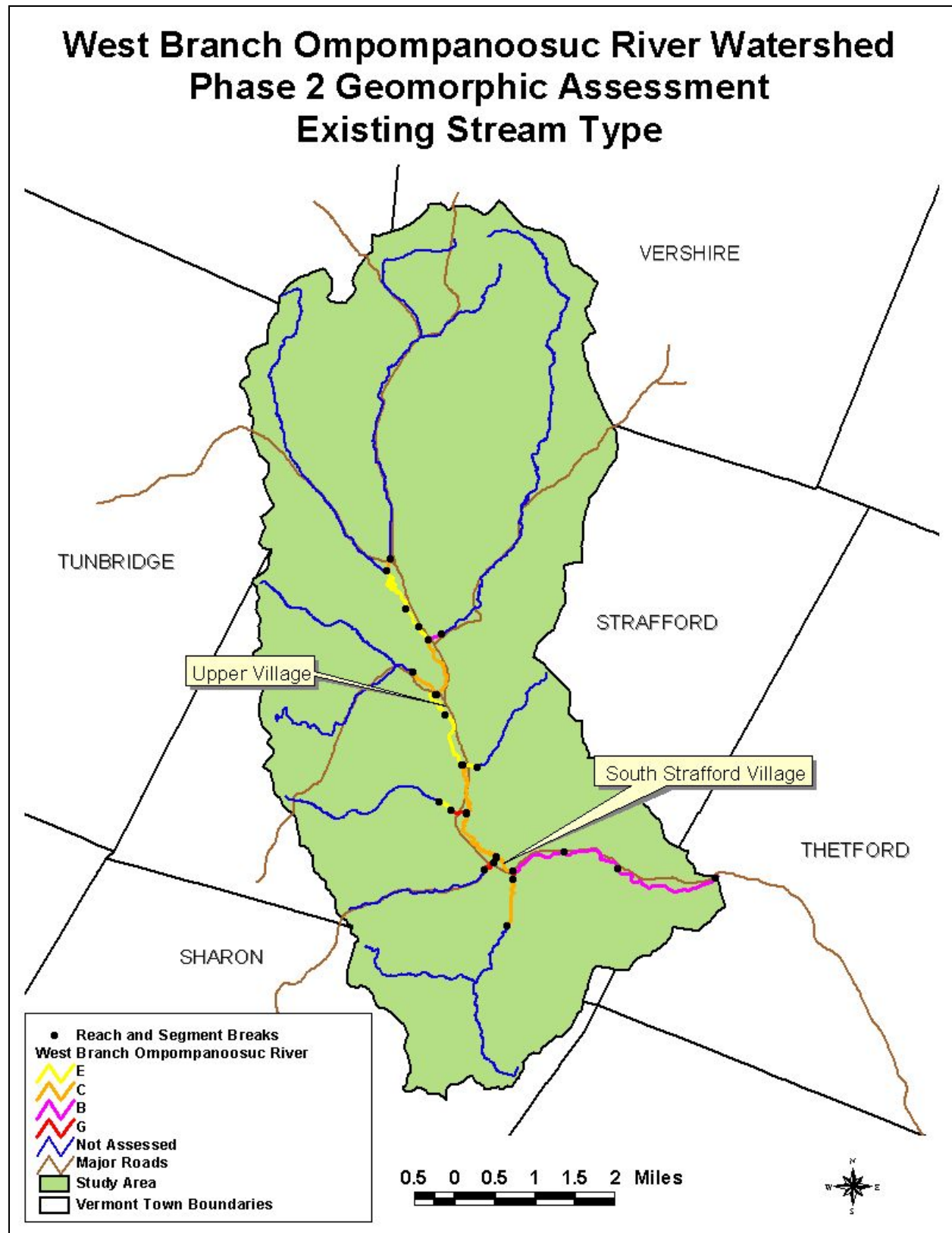


Figure 38. Phase 2 Existing Stream Types

<b>Table 4. Stream Sensitivity for Phase 2 Reaches</b>				
<b>Segment Number</b>	<b>Existing Stream Type</b>	<b>Stream Type Departure</b>	<b>Geomorphic Condition</b>	<b>Sensitivity</b>
M03	B3c	No	Good	Moderate
M04	B3c	Yes	Fair	High
M05	B4c	Yes	Fair	High
M06	C5	Yes	Fair	Very High
M07	C5	Yes	Fair	Very High
M08	C4	Yes	Fair	Very High
M09-A	E4	No	Fair	Very High
M09-B	E4	No	Fair	Very High
M10	C4	Yes	Fair	Very High
M11-A	E4b	No	Good	High
M11-C	E4	No	Fair	Very High
M12	C3b	No	Reference	Moderate
<b>T2.01-A</b>				
T2.01-A	G3	Yes	Fair	Extreme
T2.01-B	C4b	No	Fair	Very High
<b>T3.01-A</b>				
T3.01-A	E4b	No	Fair	Very High
T3.01-B	G3	Yes	Fair	Extreme
<b>T4.01-A</b>				
T4.01-A	G4	Yes	Fair	Extreme
T4.01-B	E4b	No	Fair	Very High
<b>T5.01</b>				
T5.01	E4b	Yes	Fair	Very High
<b>T6.01</b>				
T6.01	C4b	No	Good	High
<b>T7.01</b>				
T7.01	B3	Yes	Fair	High

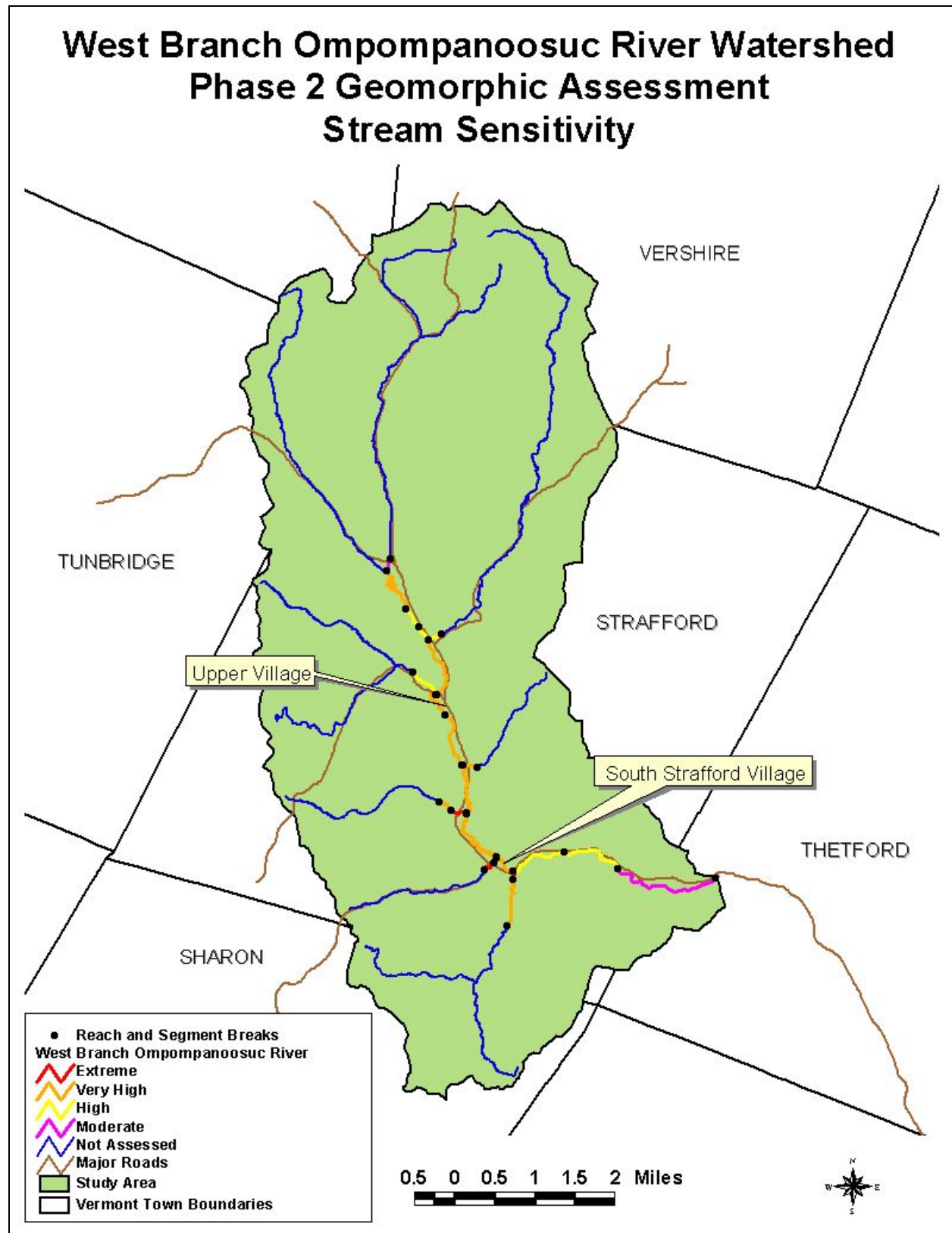


Figure 39: Phase 2 Stream Sensitivity Map

## 6.0 HABITAT EVALUATION

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

Table 5 (below) and page 46 of Appendix B, show a comparison of the habitat condition based on the Rapid Habitat Assessment (RHA) and the geomorphic condition based on the Rapid Geomorphic Assessment (RGA). For sixteen of the twenty-one segments, both the RHA and the RGA resulted in ratings of fair. Reach M05 had a rating of fair for geomorphic condition, but a rating of poor for habitat. Only one reach, M12, resulted in a good rating for habitat condition (Figure 40). In general the study reaches lacked a strong riffle-pool bedform (many were plane bed or had pools that were filled with fine sediments) and the diversity of habitat features that this brings. Additionally, sediment contributions of sand and fine gravel from the watershed, as well as localized contributions from banks that were eroding as the river adjusts, have created an embedded river bottom along much of the study area (Figure 41). Most reaches had significant intrusion into their river corridor and lacked adequate riparian buffers. Overall, the RHA score was similar to the RGA score, implying that the ecological health of the WBOR is intricately tied to the geomorphic condition of the stream.

<b>Segment Number</b>	<b>Score RGA</b>	<b>Score RHA</b>	<b>Rating RGA</b>	<b>Rating RHA</b>
M03	0.71	0.64	Good	Fair
M04	0.50	0.54	Fair	Fair
M05	0.48	0.32	Fair	Poor
M06	0.49	0.37	Fair	Fair
M07	0.49	0.48	Fair	Fair
M08	0.41	0.46	Fair	Fair
M09-A	0.63	0.58	Fair	Fair

<b>Table 5. Comparison of RHA and RGA for Phase 2 Reaches</b>				
<b>Segment Number</b>	<b>Score RGA</b>	<b>Score RHA</b>	<b>Rating RGA</b>	<b>Rating RHA</b>
M09-B	0.63	0.49	Fair	Fair
M10	0.45	0.45	Fair	Fair
M11-A	0.84	0.56	Good	Fair
M11-C	0.58	0.49	Fair	Fair
M12	0.90	0.67	Reference	Good
T2.01-A	0.48	0.43	Fair	Fair
T2.01-B	0.63	0.55	Fair	Fair
T3.01-A	0.59	0.55	Fair	Fair
T3.01-B	0.50	0.41	Fair	Fair
T4.01-A	0.53	0.50	Fair	Fair
T4.01-B	0.58	0.50	Fair	Fair
T5.01	0.48	0.42	Fair	Fair
T6.01	0.68	0.51	Good	Fair
T7.01	0.56	0.42	Fair	Fair



**Figure 40: Reach M08 rated “fair” for habitat. The reach lacked in-stream woody habitat, riparian vegetation, a riffle-pool system due to historic straightening, and was heavily embedded with fine particles of sand, as researched in a pebble count being conducted by BCE scientist Alyssa Borowske.**



**Figure 41: Reach M12 rated “good” for habitat. The reach had in-stream woody habitat, excellent riparian vegetation and riparian buffer, a diversity of substrates, and a diversity of habitat types including several deep pools.**

## **7.0 OUTREACH AND EDUCATION**

Prior to the start of the WBOR watershed assessment, Bear Creek Environmental met with Sally Mansur of the SCC and Pete Spatz, ANR River Management, to generate a discussion of the project, listen to Strafford's concerns and input, and to provide Strafford with an introduction to the Geomorphic Assessment protocol. A public meeting to discuss the findings of the Phase 2 Assessment is scheduled for March 2006.

## **8.0 RECOMMENDATIONS**

Based on the 2005 Phase 2 Assessment of the West Branch of the Ompompanoosuc River watershed, Bear Creek Environmental recommends the following:

1. Develop and implement a river corridor protection plan. The implementation of a river corridor protection plan goes a long way towards toward reducing fluvial erosion hazards and minimizing land use conflicts. As a starting point, fluvial geomorphic relationships can be used to determine the width of a river corridor which is needed to accommodate the meander geometry under equilibrium conditions. As discussed in the Defining River Corridors Fact Sheet, prepared by the Vermont DEC River Management Programs, rivers with gentle gradients and narrow to broad valleys require a meander belt width of 6 times the channel width to accommodate the meanders. Within the middle of the Phase 2 study area (reach M06), this equates to a meander belt width of 336 feet (or approximately 168 feet on each side of the meander center line). The River Corridor Plan would also provide some structure for identifying river restoration and corridor protection project types and effective approaches.
2. The reference stream type for much of the main stem of the West Branch Ompompanoosuc between the Strafford/Thetford town lines is an "E". "E" type stream channels are highly dependent upon vegetation for stability. For this reason, the establishment and protection of vegetated buffers should be high priority in restoration planning and design work. Riparian buffers provide many benefits. Some of these benefits are protecting and enhancing water quality, providing fish and wildlife habitat, providing streamside shading, and providing root structure to prevent bank erosion.
3. Conduct a bridge and culvert survey of private structures to gather specific information about undersized structures in the West Branch Ompompanoosuc watershed. Replace undersized structures when opportunities and/or funding become available.
4. Floodplain access is the most effective means at controlling streambank erosion and for streams to attenuate excess sediment. Encroachment in the WBOR watershed has led to loss of habitat and geomorphic instability. Reconnecting floodplains and floodplain wetlands would provide critical stormwater retention, sediment reduction, and overall stream system health.

5. Carefully consider the stream type, evolution stage, and sensitivity before conducting any active geomorphic restoration projects within the WBOR watershed.

## 9.0 REFERENCES

- EPA. Website. EPA New England Superfund Sites.  
<http://www.epa.gov/region1/superfund/findsite/fndindex.htm>
- Bear Creek Environmental 2005. Bridge and Culvert Assessment Using Agency of Natural Resources' Protocol, Strafford Conservation Commission, Town of Strafford, Vermont: West Branch of Ompompanoosuc River Watershed. Bear Creek Environmental. Middlesex, VT 11 pp.
- Bear Creek Environmental. 2004. Phase I Stream Geomorphic Assessment, Strafford Conservation Commission, Town of Strafford, Vermont: West Branch of Ompompanoosuc River Watershed. Final Report, November 29, 2004. Bear Creek Environmental, Middlesex, VT 30 pp.
- Fischenich, C. 2000. ERDC TN-EMRRP-SR-01 I- Glossary of Stream Restoration Terms. USAE Research and Development Center, Environmental Laboratory, Vicksburg, MS.
- Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.
- Ryan, J. 2002. Stream stability assessment of Lamoille County, Vermont. Washington, Vermont.
- Schumm, S.A. 1977. The fluvial system. John Wiley and Sons, New York.
- Schumm, S.A. 1984. Incised Channels: Morphology, Dynamics and Control. Water Resources Publication (ISBN-0918334-53-5), Littleton, CO.
- Vermont Agency of Natural Resources. 2005. Vermont Stream Geomorphic Assessment Phase 2 Handbook and Appendixes. Rapid Stream Assessment, Field Protocols. Waterbury, Vermont.
- Vermont Agency of Natural Resources. 2004. Vermont Stream Geomorphic Assessment Phase 2 Handbook. Rapid Stream Assessment, Field Protocols. Waterbury, Vermont.
- Vermont Agency of Natural Resources. (not dated). Defining River Corridors Fact Sheet. Vermont DEC River Management Program. Waterbury, Vermont.
- Vermont Water Quality Division. 2001. Vermont Regional Hydraulic Geometry Curves. Waterbury, Vermont.

# APPENDIX A

## Glossary of Terms

(From Vermont Agency of Natural Resources – Appendix Q, April 2004)

# Glossary of Terms

## Adapted from:

ERDC TN-EMRRP-SR-01 1

## Glossary of Stream Restoration Terms

by *Craig Fischenich*.. February 2000

USAE Research and Development Center,  
Environmental Laboratory, 3909 Halls Ferry  
Rd., Vicksburg, MS 39180

## OVERVIEW

Following is a glossary of terms commonly used in stream geomorphic assessment.

## TERMS

**Acre** -- A measure of area equal to 43,560 ft<sup>2</sup> (4,046.87 m<sup>2</sup>). One square mile equals 640 acres.

**Adjustment process** -- or type of change, that is underway due to natural causes or human activity that has or will result in a change to the valley, floodplain, and/or channel condition (e.g., vertical, lateral, or channel plan form adjustment processes)

**Aggradation** -- A progressive buildup or raising of the channel bed and floodplain due to sediment deposition. The geologic process by which streambeds are raised in elevation and floodplains are formed.

Aggradation indicates that stream discharge and/or bed-load characteristics are changing. Opposite of degradation.

**Algae** -- Microscopic plants that grow in sunlit water containing phosphates, nitrates, and other nutrients. Algae, like all aquatic plants, add oxygen to the water and are important in the fish food chain.

**Alluvial** -- Deposited by running water.

**Alluvium** -- A general term for detrital deposits made by streams on riverbeds, floodplains, and alluvial fans; esp. a deposit of silt or silty clay laid down during time of flood. The term applies to stream deposits of recent time. It does not include subaqueous sediments of seas or lakes.

**Anadromous** -- Pertaining to fish that spend a part of their life cycle in the sea and return to freshwater streams to spawn.

**Aquatic ecosystem** -- Any body of water, such as a stream, lake, or estuary, and all organisms and nonliving components within it, functioning as a natural system.

**Armoring** -- A natural process where an erosion-resistant layer of relatively large particles is established on the surface of the streambed through removal of finer particles by stream flow. A properly armored streambed generally resists movement of bed material at discharges up to approximately 3/4 bank-full depth.

**Augmentation (of stream flow)** -- Increasing flow under normal conditions, by releasing storage water from reservoirs.

**Avulsion** -- A change in channel course that occurs when a stream suddenly breaks through its banks, typically bisecting an overextended meander arc.

**Backwater** -- (1) A small, generally shallow body of water attached to the main channel, with little or no current of its own, or (2) A condition in subcritical flow where the water surface elevation is raised by downstream flow impediments.

**Backwater pool** -- A pool that formed as a result of an obstruction like a large tree, weir, dam, or boulder.

**Bank stability** -- The ability of a streambank to counteract erosion or gravity forces.

**Bankfull channel depth** -- The maximum depth of a channel within a riffle segment when flowing at a bank-full discharge.

**Bankfull channel width** -- The top surface width of a stream channel when flowing at a bank-full discharge.

**Bankfull discharge** -- The stream discharge corresponding to the water stage that first overtops the natural banks. This flow occurs, on average, about once every 1 to 2 years.

**Bankfull width** -- The width of a river or stream channel between the highest banks on either side of a stream.

**Bar** -- An accumulation of alluvium (usually gravel or sand) caused by a decrease in sediment transport capacity on the inside of meander bends or in the center of an overwide channel.

**Barrier** -- A physical block or impediment to the movement or migration of fish, such as a waterfall (natural barrier) or a dam (man-made barrier).

**Base flow** -- The sustained portion of stream discharge that is drawn from natural storage sources, and not affected by human activity or regulation.

**Bed load** -- Sediment moving on or near the streambed and transported by jumping, rolling, or sliding on the bed layer of a stream. See also suspended load.

**Bed material** -- The sediment mixture that a streambed is composed of.

**Bed material load** -- That portion of the total sediment load with sediments of a size found in the streambed.

**Bed roughness** -- A measure of the irregularity of the streambed as it contributes to flow resistance. Commonly expressed as a Manning "n" value.

**Bed slope** -- The inclination of the channel bottom, measured as the elevation drop per unit length of channel.

**Benthic invertebrates** -- Aquatic animals without backbones that dwell on or in the bottom sediments of fresh or salt water. Examples: clams, crayfish, and a wide variety of worms.

**Berms** -- mounds of dirt, earth, gravel, or other fill built parallel to the stream banks designed to keep flood flows from entering the adjacent floodplain.

**Biota** -- All living organisms of a region, as in a stream or other body of water.

**Boulder** -- A large substrate particle that is larger than cobble, 256 mm in diameter.

**Braided channel** -- A stream characterized by flow within several channels, which successively meet and divide. Braiding often occurs when sediment loading is too large to be carried by a single channel.

**Braiding (of river channels)** -- Successive division and rejoining of riverflow with accompanying islands.

**Buffer strip** -- A barrier of permanent vegetation, either forest or other vegetation, between waterways and land uses such as agriculture or urban development, designed to intercept and filter out pollution before it reaches the surface water resource.

**Canopy** -- A layer of foliage in a forest stand. This most often refers to the uppermost layer of foliage, but it can be used to describe lower layers in a multistoried stand. Leaves, branches and vegetation that are above ground and/or water that provide shade and cover for fish and wildlife.

**Cascade** -- A short, steep drop in streambed elevation often marked by boulders and agitated white water.

**Catchment** -- (1) The catching or collecting of water, especially rainfall. (2) A reservoir or other basin for catching water. (3) The water thus caught. (4) A watershed.

**Channel** -- An area that contains continuously or periodically flowing water that is confined by banks and a streambed.

**Channelization** -- The process of changing (usually straightening) the natural path of a waterway.

**Clay** -- Substrate particles that are smaller than silt and generally less than 0.003 mm in diameter.

**Coarse woody debris (CWD)** -- Portion of a tree that has fallen or been cut and left in the woods. Usually refers to pieces at least 20 in. in diameter.

**Cobble** -- Substrate particles that are smaller than boulders and larger than gravels, and are generally 64-256 mm in diameter. Can be further classified as small and large cobble.

**Confluence** -- (1) The act of flowing together; the meeting or junction of two or more streams; also, the place where these streams meet. (2) The stream or body of water formed by the junction of two or more streams; a combined flood.

**Conifer** -- A tree belonging to the order Gymnospermae, comprising a wide range of trees that are mostly evergreens. Conifers bear cones (hence, coniferous) and have needle-shaped or scalelike leaves.

**Conservation** -- The process or means of achieving recovery of viable populations.

**Contiguous habitat** -- Habitat suitable to support the life needs of a species that is distributed continuously or nearly continuously across the landscape.

**Cover** – “cover” is the general term used to describe any structure that provides refugia for fish, reptiles or amphibians. These animals seek cover to hide from predators, to avoid warm water temperatures, and to rest, by avoiding higher velocity water. These animals come in all sizes, so even cobbles on the stream bottom that are not sedimented in with fine sands and silt can serve as cover for small fish and salamanders. Larger fish and reptiles often use large boulders, undercut banks, submerged logs, and snags for cover.

**Critical shear stress** -- The minimum amount of shear stress exerted by stream currents required to initiate soil particle motion. Because gravity also contributes to streambank particle movement but not on streambeds, critical shear stress along streambanks is less than for streambeds.

**Crown** -- The upper part of a tree or other woody plant that carries the main system of branches and the foliage.

**Crown cover** -- The degree to which the crowns of trees are nearing general contact with one another.

**Cubic feet per second (cfs)** -- A unit used to measure water flow. One cubic foot per second is equal to 449 gallons per minute.

**Culvert** -- A buried pipe that allows flows to pass under a road.

**Debris flow** -- A rapidly moving mass of rock fragments, soil, and mud, with more than half of the particles being larger than sand size.

**Deciduous** -- Trees and plants that shed their leaves at the end of the growing season.

**Degradation** -- (1) A progressive lowering of the channel bed due to scour. Degradation is an indicator that the stream's discharge and/or sediment load is changing. The opposite of aggradation. (2) A decrease in value for a designated use.

**Detritus** -- is organic material, such as leaves, twigs, and other dead plant matter, that collects on the stream bottom. It may occur in clumps, such as leaf packs at the bottom of a pool, or as single pieces, such as a fallen tree branch.

**Dike** -- (1) (Engineering) An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of lowlands; a levee. (2) A low wall that can act as a barrier to prevent a spill

from spreading. (3) (Geology) A tabular body of igneous (formed by volcanic action) rock that cuts across the structure of adjacent rocks or cuts massive rocks.

**Dissolved oxygen (DO)** -- The amount of free (not chemically combined) oxygen dissolved in water, wastewater, or other liquid, usually expressed in milligrams per liter, parts per million, or percent of saturation.

**Ditch** -- A long narrow trench or furrow dug in the ground, as for irrigation, drainage, or a boundary line.

**Drainage area** -- The total surface area upstream of a point on a stream that drains toward that point. Not to be confused with watershed. The drainage area may include one or more watersheds.

**Drainage basin** -- The total area of land from which water drains into a specific river.

**Dredging** -- Removing material (usually sediments) from wetlands or waterways, usually to make them deeper or wider.

**Ecology** -- The study of the interrelationships of living organisms to one another and to their surroundings.

**Ecosystem** -- Recognizable, relatively homogeneous units, including the organisms they contain, their environment, and all the interactions among them.

**Embankment** -- An artificial deposit of material that is raised above the natural surface of the land and used to contain, divert, or store water, support roads or railways, or for other similar purposes.

**Embeddedness** -- is a measure of the amount of surface area of cobbles, boulders, snags and other stream bottom structures that is covered with sand and silt. An embedded streambed may be packed hard with sand and silt such that rocks in the stream bottom are difficult or impossible to pick up. The spaces between the rocks are filled with fine sediments, leaving little room for fish, amphibians, and bugs to use the structures for cover, resting, spawning, and feeding. A streambed that is **not** embedded has loose rocks that are easily removed from the stream bottom, and may even “roll” on one another when you walk on them.

**Entrenchment ratio** --The width of the flood-prone area divided by the bankfull width.

**Epifaunal** – “epi” means surface, and “fauna” means animals. Thus, “epifaunal substrate” is structures in the stream (on the stream bed) that provide surfaces on which animals can live. In this case, the animals are aquatic invertebrates (such as aquatic insects and other “bugs”). These bugs live on or under cobbles, boulders, logs, and snags, and the many cracks and crevices found in these structures. In general, older decaying logs are better suited for bugs to live on/in than newly fallen “green” logs and trees.

**Ephemeral streams** -- Streams that flow only in direct response to precipitation and whose channel is at all times above the water table.

**Erosion** -- Wearing away of rock or soil by the gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical, chemical, or biological forces.

**Eutrophic** -- Usually refers to a nutrient-enriched, highly productive body of water.

**Eutrophication** -- The process of enrichment of water bodies by nutrients.

**Flash Flood** -- A sudden flood of great volume, usually caused by a heavy rain. Also, a flood that crests in a short length of time and is often characterized by high velocity flows.

**Floodplain** -- Land built of sediment that is regularly covered with water as a result of the flooding of a nearby stream.

**Floodplain (100-year)** -- The area adjacent to a stream that is on average inundated once a century.

**Floodplain Function** – Flood water access of floodplain which effects the velocity, depth, and slope (stream power) of the flood flow thereby influencing the sediment transport characteristics of the flood (i.e., loss of floodplain access and function may lead to higher stream power and erosion during flood).

**Flow** -- The amount of water passing a particular point in a stream or river, usually expressed in cubic feet per second (cfs).

**Fluvial** -- Migrating between main rivers and tributaries. Of or pertaining to streams or rivers.

**Ford** -- A shallow place in a body of water, such as a river, where one can cross by walking or riding on an animal or in a vehicle.

**Fry** -- A recently hatched fish.

**Gabion** -- A wire basket or cage that is filled with gravel or cobble and generally used to stabilize streambanks.

**Gaging station** -- A particular site in a stream, lake, reservoir, etc., where hydrologic data are obtained.

**Gallons per minute (gpm)** -- A unit used to measure water flow.

**Geographic information system (GIS)** -- A computer system capable of storing and manipulating spatial data.

**Geomorphology** -- A branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and the buildup of erosional debris.

**Glide** -- A section of stream that has little or no turbulence.

**Gradient** -- Vertical drop per unit of horizontal distance.

**Grass/forb** -- Herbaceous vegetation.

**Gravel** -- An unconsolidated natural accumulation of rounded rock fragments, mostly of particles larger than sand (diameter greater than 2 mm), such as boulders, cobbles, pebbles, granules, or any combination of these.

**Groundwater** -- Subsurface water and underground streams that can be collected with wells, or that flow naturally to the earth's surface through springs.

**Groundwater basin** -- A groundwater reservoir, defined by an overlying land surface and the underlying aquifers that contain water stored in the reservoir. In some cases, the boundaries of successively deeper aquifers may differ and make it difficult to define the limits of the basin.

**Groundwater recharge** -- Increases in groundwater storage by natural conditions or by human activity. See also artificial recharge.

**Groundwater table** -- The upper surface of the zone of saturation, except where the surface is formed by an impermeable body.

**Habitat** -- The local environment in which organisms normally live and grow.

**Habitat diversity** -- The number of different types of habitat within a given area.

**Habitat fragmentation** -- The breaking up of habitat into discrete islands through modification or conversion of habitat by management activities.

**Headwater** -- Referring to the source of a stream or river.

**High gradient streams** -- typically appear as steep cascading streams, step/pool streams, or streams that exhibit riffle/pool sequences. Most of the streams in Vermont are high gradient streams.

**Hydraulic gradient** -- The slope of the water surface. See also streambed gradient.

**Hydraulic radius** -- The cross-sectional area of a stream divided by the wetted perimeter.

**Hydric** -- Wet.

**Hydrograph** -- A curve showing stream discharge over time.

**Hydrologic balance** -- An accounting of all water inflow to, water outflow from, and changes in water storage within a hydrologic unit over a specified period of time.

**Hydrologic region** -- A study area, consisting of one or more planning subareas, that has a common hydrologic character.

**Hydrologic unit** -- A distinct watershed or river basin defined by an 8-digit code.

**Hydrology** -- The scientific study of the water of the earth, its occurrence, circulation and distribution, its chemical and physical properties, and its interaction with its environment, including its relationship to living things.

**Hyporheic zone** -- The area under the stream channel and floodplain where groundwater and the surface waters of the stream are exchanged freely.

**Improved paths** -- Paths that are maintained and typically involve paved, gravel or macadam surfaces.

**Incised river** -- A river that erodes its channel by the process of degradation to a lower base level than existed previously or is consistent with the current hydrology.

**Incision ratio** -- The low bank height divided by the bankfull maximum depth.

**Infiltration (soil)** -- The movement of water

through the soil surface into the soil.

**Inflow** -- Water that flows into a stream, lake,  
**Instream cover** -- The layers of vegetation, like trees, shrubs, and overhanging vegetation, that are in the stream or immediately adjacent to the wetted channel.

**Instream flows** -- (1) Portion of a flood flow that is contained by the channel. (2) A minimum flow requirement to maintain ecological health in a stream.

**Instream use** -- Use of water that does not require diversion from its natural watercourse. For example, the use of water for navigation, recreation, fish and wildlife, aesthetics, and scenic enjoyment.

**Intermittent stream** -- Any nonpermanent flowing drainage feature having a definable channel and evidence of scour or deposition. This includes what are sometimes referred to as ephemeral streams if they meet these two criteria.

**Irrigation diversion** -- Generally, a ditch or channel that deflects water from a stream channel for irrigation purposes.

**Islands** -- mid-channel bars that are above the average water level and have established woody vegetation.

**Lake** -- An inland body of standing water deeper than a pond, an expanded part of a river, a reservoir behind a dam

**Landslide** -- A movement of earth mass down a steep slope.

**Large woody debris (LWD)** -- Pieces of wood at least 6 ft. long and 1 ft. in diameter (at the large end) contained, at least partially, within the bankfull channel.

**Levee** -- An embankment constructed to prevent a river from overflowing (flooding).

**Limiting factor** -- A requirement such as food, cover, or another physical, chemical, or biological factor that is in shortest supply with respect to all resources necessary to sustain life and thus "limits" the size or retards production of a population.

**Low gradient** -- streams typically appear slow moving and winding, and have poorly defined riffles and pools. These streams are usually found in the large valley bottoms of the Champlain Valley and occasionally in high wet meadows. The lower reaches of the Otter Creek,

Lewis Creek, and Poultney River are all areas you are likely to find low gradient streams.

**Macroinvertebrate** -- Invertebrates visible to the naked eye, such as insect larvae and crayfish.

**Macrophytes** -- Aquatic plants that are large enough to be seen with the naked eye.

**Mainstem** -- The principal channel of a drainage system into which other smaller streams or rivers flow.

**Mass movement** -- The downslope movement of earth caused by gravity. Includes but is not limited to landslides, rock falls, debris avalanches, and creep. It does not however, include surface erosion by running water. It may be caused by natural erosional processes, or by natural disturbances (e.g., earthquakes or fire events) or human disturbances (e.g., mining or road construction).

**Mean annual discharge** -- Daily mean discharge averaged over a period of years. Mean annual discharge generally fills a channel to about one-third of its bank-full depth.

**Mean velocity** -- The average cross-sectional velocity of water in a stream channel. Surface values typically are much higher than bottom velocities. May be approximated in the field by multiplying the surface velocity, as determined with a float, times 0.8.

**Meander** -- The winding of a stream channel, usually in an erodible alluvial valley. A series of sine-generated curves characterized by curved flow and alternating banks and shoals.

**Meander amplitude** -- The distance between points of maximum curvature of successive meanders of opposite phase in a direction normal to the general course of the meander belt, measured between center lines of channels.

**Meander belt width** -- the distance between lines drawn tangential to the extreme limits of fully developed meanders. Not to be confused with meander amplitude.

**Meander length** -- The lineal distance downvalley between two corresponding points of successive meanders of the same phase.

**Mid-channel Bars** -- bars located in the channel away from the banks, generally found in areas where the channel runs straight. Mid-channel bars caused by recent channel instability are unvegetated.

**Milligrams per liter (mg/l)** -- The weight in milligrams of any substance dissolved in 1 liter of liquid; nearly the same as parts per million by weight.

**Natural flow** -- The flow past a specified point on a natural stream that is unaffected by stream diversion, storage, import, export, return flow, or change in use caused by modifications in land use.

**Outfall** -- The mouth or outlet of a river, stream, lake, drain or sewer.

**Oxbow** -- An abandoned meander in a river or stream, caused by cutoff. Used to describe the U-shaped bend in the river or the land within such a bend of a river.

**Peat** -- Partially decomposed plants and other organic material that build up in poorly drained wetland habitats.

**Perched groundwater** -- Groundwater supported by a zone of material of low permeability located above an underlying main body of groundwater with which it is not hydrostatically connected.

**Perennial streams** -- Streams that flow continuously.

**Permeability** -- The capability of soil or other geologic formations to transmit water.

**pH** -- The negative logarithm of the molar concentration of the hydrogen ion, or, more simply acidity.

**Point bar** -- The convex side of a meander bend that is built up due to sediment deposition.

**Pond** -- A body of water smaller than a lake, often artificially formed.

**Pool** -- A reach of stream that is characterized by deep, low-velocity water and a smooth surface.

**Pool/riffle ratio** -- The ratio of surface area or length of pools to the surface area or length of riffles in a given stream reach; frequently expressed as the relative percentage of each category. Used to describe fish habitat rearing quality.

**Potential plant height** -- the height to which a plant, shrub or tree would grow if undisturbed.

**Probability of exceedence** -- The probability that a random flood will exceed a specified magnitude in a given period of time.

**Railroads** -- Used or unused railroad infrastructure.

**Rapids** -- A reach of stream that is characterized by small falls and turbulent, high-velocity water.

**Reach** -- A section of stream having relatively uniform physical attributes, such as valley confinement, valley slope, sinuosity, dominant bed material, and bed form, as determined in the Phase 1 assessment.

**Rearing habitat** -- Areas in rivers or streams where juvenile fish find food and shelter to live and grow.

**Regime theory** -- A theory of channel formation that applies to streams that make a part of their boundaries from their transported sediment load and a portion of their transported sediment load from their boundaries. Channels are considered in regime or equilibrium when bank erosion and bank formation are equal.

**Restoration** -- The return of an ecosystem to a close approximation of its condition prior to disturbance.

**Riffle** -- A reach of stream that is characterized by shallow, fast-moving water broken by the presence of rocks and boulders.

**Riffle/step frequency** -- ratio of the distance between riffles to the stream width.

**Riparian area** -- An area of land and vegetation adjacent to a stream that has a direct effect on the stream. This includes woodlands, vegetation, and floodplains.

**Riparian buffer** is the width of naturally vegetated land adjacent to the stream between the top of the bank (or top of slope, depending on site characteristics) and the edge of other land uses. A buffer is largely undisturbed and consists of the trees, shrubs, groundcover plants, duff layer, and naturally uneven ground surface. The buffer serves to protect the water body from the impacts of adjacent land uses.

**Riparian corridor** includes lands defined by the lateral extent of a stream's meanders necessary to maintain a stable stream dimension, pattern, profile, and sediment regime. For instance, in stable pool-riffle streams, riparian corridors may

be as wide as 10-12 times the channel's bankfull width. In addition the riparian corridor typically corresponds to the land area surrounding and including the stream that supports (or could support if unimpacted) a distinct ecosystem, generally with abundant and diverse plant and animal communities (as compared with upland communities).

**Riparian habitat** -- The aquatic and terrestrial habitat adjacent to streams, lakes, estuaries, or other waterways.

**Riparian** -- Located on the banks of a stream or other body of water.

**Riparian vegetation** -- The plants that grow adjacent to a wetland area such as a river, stream, reservoir, pond, spring, marsh, bog, meadow, etc., and that rely upon the hydrology of the associated water body.

**Ripple** -- (1) A specific undulated bed form found in sand bed streams. (2) Undulations or waves on the surface of flowing water.

**Riprap** -- Rock or other material with a specific mixture of sizes referred to as a "gradation," used to stabilize streambanks or riverbanks from erosion or to create habitat features in a stream.

**River channels** -- Large natural or artificial open streams that continuously or periodically contain moving water, or which form a connection between two bodies of water.

**River miles** -- Generally, miles from the mouth of a river to a specific destination or, for upstream tributaries, from the confluence with the main river to a specific destination.

**River reach** -- Any defined length of a river.

**River stage** -- The elevation of the water surface at a specified station above some arbitrary zero datum (level).

**Riverine** -- Relating to, formed by, or resembling a river including tributaries, streams, brooks, etc.

**Riverine habitat** -- The aquatic habitat within streams and rivers.

**Roads** - Transportation infrastructure. Includes private, town, state roads, and roads that are dirt, gravel, or paved.

**Rock** -- A naturally formed mass of minerals.

**Rootwad** -- The mass of roots associated with a tree adjacent to or in a stream that provides refuge for fish and other aquatic life.

**Run (in stream or river)** -- A reach of stream characterized by fast-flowing, low-turbulence water.

**Runoff** -- Water that flows over the ground and reaches a stream as a result of rainfall or snowmelt.

**Sand** -- Small substrate particles, generally from 0.06 to 2 mm in diameter. Sand is larger than silt and smaller than gravel.

**Scour** -- The erosive action of running water in streams, which excavates and carries away material from the bed and banks. Scour may occur in both earth and solid rock material and can be classed as general, contraction, or local scour.

**Sediment** -- Soil or mineral material transported by water or wind and deposited in streams or other bodies of water.

**Sedimentation** -- (1) The combined processes of soil erosion, entrainment, transport, deposition, and consolidation. (2) Deposition of sediment.

**Seepage** -- The gradual movement of a fluid into, through, or from a porous medium.

**Segment:** A relatively homogenous section of stream contained within a reach that has the same reference stream characteristics but is distinct from other segments in the reach in one or more of the following parameters: degree of floodplain encroachment, presence/absence of grade controls, bankfull channel dimensions (W/D ratio, entrenchment), channel sinuosity and slope, riparian buffer and corridor conditions, abundance of springs/seeps/adjacent wetlands/stormwater inputs, and degree of channel alterations.

**Sensitivity** --of the valley, floodplain, and/or channel condition to change due to natural causes and/or anticipated human activity.

**Shoals** -- unvegetated deposits of gravels and cobbles adjacent to the banks that have a height less than the average water level. In channels that are over-widened, the stream does not have the power to transport these larger sediments, and thus they are deposited throughout the channel as shoals.

**Silt** -- Substrate particles smaller than sand and larger than clay (3 to 60 mm).

**Siltation** -- The deposition or accumulation of fine soil particles.

**Sinuosity** -- The ratio of channel length to

direct down-valley distance. Also may be expressed as the ratio of down-valley slope to channel slope.

**Slope** -- The ratio of the change in elevation over distance.

**Slope stability** -- The resistance of a natural or artificial slope or other inclined surface to failure by mass movement.

**Snag** -- Any standing dead, partially dead, or defective (cull) tree at least 10 in. in diameter at breast height and at least 6 ft tall. Snags are important riparian habitat features.

**Spawning** -- The depositing and fertilizing of eggs (or roe) by fish and other aquatic life.

**Spillway** -- A channel for reservoir overflow.

**Stable channel** -- A stream channel with the right balance of slope, planform, and cross section to transport both the water and sediment load without net long-term bed or bank sediment deposition or erosion throughout the stream segment.

**Stone** -- Rock or rock fragments used for construction.

**Straightening** -- the removal of meander bends, often done in towns and along roadways, railroads, and agricultural fields.

**Stream** -- A general term for a body of water flowing by gravity; natural watercourse containing water at least part of the year. In hydrology, the term is generally applied to the water flowing in a natural narrow channel as distinct from a canal.

**Stream banks** are features that define the channel sides and contain stream flow within the channel; this is the portion of the channel bank that is between the toe of the bank slope and the bankfull elevation. The banks are distinct from the streambed, which is normally wetted and provides a substrate that supports aquatic organisms. The top of bank is the point where an abrupt change in slope is evident, and where the stream is generally able to overflow the banks and enter the adjacent floodplain during flows at or exceeding the average annual high water.

**Stream channel** -- A long narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.

**Stream condition** -- Given the land use, channel and floodplain modifications documented at the assessment sites, the current degree of change in the channel and floodplain from the reference condition for parameters such as dimension, pattern, profile, sediment regime, and vegetation.

**Stream gradient** -- A general slope or rate of change in vertical elevation per unit of horizontal distance of the bed, water surface, or energy grade of a stream.

**Stream morphology** -- The form and structure of streams.

**Stream order** -- A hydrologic system of stream classification. Each small unbranched tributary is a first-order stream. Two first-order streams join to make a second-order stream. A third-order stream has only first-and second-order tributaries, and so forth.

**Stream reach** -- An individual segment of stream that has beginning and ending points defined by identifiable features such as where a tributary confluence changes the channel character or order.

**Stream type** -- Gives the overall physical characteristics of the channel and helps predict the reference or stable condition of the reach.

**Streambank armoring** -- The installation of concrete walls, gabions, stone riprap, and other large erosion resistant material along stream banks.

**Streambank erosion** -- The removal of soil from streambanks by flowing water.

**Streambank stabilization** -- The lining of streambanks with riprap, matting, etc., or other measures intended to control erosion.

**Streambed** -- (1) The unvegetated portion of a channel boundary below the baseflow level. (2) The channel through which a natural stream of water runs or used to run, as a dry streambed.

**Streamflow** -- The rate at which water passes a given point in a stream or river, usually expressed in cubic feet per second (cfs).

**Step (in a river system)** -- A step is a steep, step-like feature in a high gradient stream (> 2%). Steps are composed of large boulders lines across the stream. Steps are important for providing grade-control, and for dissipating energy. As fast-shallow water flows over the

steps it takes various flow paths thus dissipating energy during high flow events.

**Substrate** -- (1) The composition of a streambed, including either mineral or organic materials. (2) Material that forms an attachment medium for organisms.

**Surface erosion** -- The detachment and transport of soil particles by wind, water, or gravity. Or a group of processes whereby soil materials are removed by running water, waves and currents, moving ice, or wind.

**Surface water** -- All waters whose surface is naturally exposed to the atmosphere, for example, rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc., and all springs, wells, or other collectors directly influenced by surface water.

**Suspended sediment** -- Sediment suspended in a fluid by the upward components of turbulent currents, moving ice, or wind.

**Suspended sediment load** -- That portion of a stream's total sediment load that is transported within the body of water and has very little contact with the streambed.

**Tailwater** -- (1) The area immediately downstream of a spillway. (2) Applied irrigation water that runs off the end of a field.

**Thalweg** -- (1) The lowest thread along the axial part of a valley or stream channel. (2) A subsurface, groundwater stream percolating beneath and in the general direction of a surface stream course or valley. (3) The middle, chief, or deepest part of a navigable channel or waterway.

**Tractive Force** --The drag on a streambed or bank caused by passing water, which tends to pull soil particles along with the streamflow.

**Transpiration** -- An essential physiological process in which plant tissues give off water vapor to the atmosphere.

**Tributary** -- A stream that flows into another stream, river, or lake.

**Turbidity** -- A measure of the content of suspended matter that interferes with the passage of light through the water or in which visual depth is restricted.

Suspended sediments are only one

component of turbidity.

**Urban runoff** -- Storm water from city streets and gutters that usually carries a great deal of litter and organic and bacterial wastes into the sewer systems and receiving waters.

**Variable stage stream** -- Stream flows perennially but water level rises and falls significantly with storm and runoff events.

**Velocity** -- In this concept, the speed of water flowing in a watercourse, such as a river.

**Washout** -- (1) Erosion of a relatively soft surface, such as a roadbed, by a sudden gush of water, as from a downpour or floods. (2) A channel produced by such erosion.

**Water quality** -- A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

**Waterfall** -- A sudden, nearly vertical drop in a stream, as it flows over rock.

**Watershed** -- An area of land whose total surface drainage flows to a single point in a stream.

**Watershed management** -- The analysis, protection, development, operation, or maintenance of the land, vegetation, and water resources of a drainage basin for the conservation of all its resources for the benefit of its residents.

**Watershed project** -- A comprehensive program of structural and nonstructural measures to preserve or restore a watershed to good hydrologic condition. These measures may include detention reservoirs, dikes, channels, contour trenches, terraces, furrows, gully plugs, revegetation, and possibly other practices to reduce flood peaks and sediment production.

**Watershed restoration** -- Improving current conditions of watersheds to restore degraded habitat and provide long-term protection to aquatic and riparian resources.

**Weir** -- A structure to control water levels in a stream. Depending upon the configuration, weirs can provide a specific "rating" for discharge as a function of the upstream water level.