River Corridor Plan for Tubbs and Ladd Brook in Pownal and Bennington, Vermont

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Executive Summary

The Hoosic River is one of three large basins draining to the Hudson River in southwestern Vermont. The Vermont portion of the 500-square mile watershed drains the towns of Bennington, Pownal, and Stamford. The Battenkill – Waloomsac – Hoosic Tactical Basin Plan released in 2016 identified sediment loading as a primary concern for the Hoosic watershed. Tubbs Brook and Ladd Brook were identified in the plan as specific areas of concern for sediment loading and were listed as stressed and impaired respectively. Tubbs Brook drains a relatively steep and rural watershed (5.8 mi^2) flowing south from Mount Anthony and joining the Hoosic River in North Pownal. Ladd Brook drains a small rural watershed (1.8 mi^2) and enters the Hoosic River in Pownal after flowing through a commercial and residential district along Route 7 and Route 346.

The Hoosic watershed has experienced several large floods including the devastating Christmas eve flood in 1948, and a major flood during Tropical Storm Irene in 2011. Flooding damages within Vermont were not as severe as those observed in Massachusetts and New York. Undersized culverts and gravel road erosion are the primary concerns for flooding and water quality issues within the tributary watersheds. A series of undersized culverts in the lower portion of Ladd Brook have caused repeat flooding within the Alta Gardens and Green Mountain Trailer Park.

Fitzgerald Environmental Associates, LLC (FEA) was hired by the Bennington County Regional Commission (BCRC) to complete a River Corridor Plan including Phase 1 and Phase 2 Stream Geomorphic Assessments (SGA) for the Tubbs Brook and Ladd Brook watersheds. The Phase 1 study and Phase 2 assessments were completed in spring/summer of 2016. This report describes the results of the Phase 1 and Phase 2 studies and the Hoosic River Tributaries River Corridor Plan. The plan objectives are described below:

1) Develop baseline watershed and reach-scale data for the study reaches.
2) Identify river reaches where more detailed field data collection (Phase 2) is needed.
3) Develop a basis for understanding the overall causes of channel instability and habitat degradation along the river corridors in the watershed.
4) Collect the information needed to improve river corridor mapping in the study area.
5) Develop a list of preliminary river corridor restoration projects that can be further developed in the future to mitigate flood and erosion hazards and improve ecological integrity and water quality.
6) Prioritize river corridor restoration projects for each area in the watershed.
7) Develop five (5) project packets for high priority restoration sites.

Below is a summary of key findings from the Phase 1 and Phase 2 SGA and River Corridor Plan:

<u>Phase 1 Study</u>

- A total of 10 reaches along 8.5 river miles were delineated during the Phase 1 SGA analysis. Full Phase 1 data and windshield survey data were collected by FEA for these portions of Tubbs Brook and Ladd Brook, and four (4) sub-tributaries to Tubbs Brook.
- The Phase 1 SGA approach resulted in watershed-scale data about the landscape (e.g., soils and land cover) and the stream channel (e.g., slope and form), providing a basis for understanding the

natural and human-impacted conditions within the watershed. The Phase 1 data also aided in the identification of specific stressors affecting the physical conditions of the stream channels and structures (e.g., bridges and culverts, bank armoring, etc.).

- One (1) reach is found in a confined valley setting that would normally support sediment and transport channels with A or B-type channel geometry. Five (5) of the reaches are found in narrow valleys with B-type channel geometry. The remaining four (4) reaches are found in an unconfined valley setting with meandering, depositional, C-type channel geometry.
- Approximately 75-80% of the tributary watersheds are forested, with agricultural land use representing approximately 10-20% of the watersheds. Developed lands represent 2% of the Tubbs Brook watershed and 9% of the Ladd Brook watershed, including concentrated residential and commercial development along the Route 7 corridor.
- Impact ratings were developed for each reach using the Phase 1 parameters representing four classes of watershed and reach-scale impacts: 1) Land Cover and Reach Hydrology; 2) Channel Modifications; 3) Floodplain Modifications and Planform Changes; 4) Bed and Bank Conditions. Out of a total possible impact score of 32, the maximum score was 20 (poor) and the minimum score was 6 (reference).
- Based on the Phase 1 impact ratings, a total of 7 high-priority reaches covering 6.0 miles on Ladd Brook, Tubbs Brook, and Tributary 4 to Tubbs Brook were selected for Phase 2 assessment.

Phase 2 Study

- During the Phase 2 field assessments, the 7 reaches were further subdivided into 10 segments based on variability in stream type, channel slope and confinement, and other factors. One (1) segment was not fully assessed due to a bedrock gorge.
- Tropical Storm Irene in 2011 was a major flood along the Hoosic River, however damages within Vermont were moderate and were mostly related to inundation damage. The Alta Gardens and Green Mountain Trailer Parks have experienced repeat flooding damages from Ladd Brook.
- Sediment loading to Tubbs Brook and Ladd Brook was a primary focus of the Phase 2 study. Potential sediment sources from channel and bank instability and from stormwater inputs were mapped along the study reaches.
- The channels of Tubbs Brook and Ladd Brook are still adjusting their width, depth, and planform to the following historical and ongoing impacts: 1) aggradation of sediment in the valleys due to European settlement and deforestation that occurred during the 1700's and 1800's; 2) channel straightening, dredging, and corridor encroachment associated with adjacent roads, agriculture, and other land uses; 3) floods in recent years which have triggered valley erosion, sending increased volumes of sediment and woody debris into the lower valleys in Pownal.
- Overall Phase 2 geomorphic ratings indicate a range of river stability from fair to good along the study reaches. The two reaches on Ladd Brook had fair stability. The lowest reach of Tubbs Brook was rated as fair due to incision. Active channel adjustments and aggradation in the three upper segments on Tubbs Brook and the tributary to Tubbs Brook resulted in fair ratings. The middle section of Tubbs Brook was rated as good and the gorge section was given a preliminary rating of reference.

- 3 bridges and 20 culverts were assessed for geomorphic compatibility and aquatic organism passage (AOP) as part of the Phase 2 SGA work. Two (2) of the bridges had spans less than the reference bankfull channel width, indicating an increased degree of structure vulnerability to flooding and erosion. All of the culverts represented significant bankfull constrictions, and 15 of the structures had widths less than 50% of bankfull. Twelve (12) culverts do not allow for any aquatic organism passage (AOP) and six (6) of the remaining culverts have reduced AOP. The summary of structures in this report, including the reference bankfull channel width listed for each one, provides a means for towns to understand the relative flood vulnerability and prioritize structure replacements with these criteria in mind.

River Corridor Planning and Overall Flood Resiliency Recommendations

- Based on flood damages incurred during Tropical Storm Irene and previous floods in the study area, the Tubbs Brook and Ladd Brook watersheds are vulnerable to flooding during prolonged rainstorms and flashy thunderstorms. The National Flood Insurance Program (NFIP) study for the Hoosic River only covers the lower portions of Tubbs Brook (confluence to 200ft upstream of Route 346) and Ladd Brook (confluence to Church Road). No flood study information exists for the remainder of the watersheds. The existing mapped 100-year floodplain covers a large portion of the development in each watershed; we recommend that the Town of Pownal considers flood hazard ordinances that prevent encroachment within the entire 100-year floodplain (i.e., floodway and floodplain fringe).
- River corridor protection ordinances should be considered by the Town of Pownal to better map flood and erosion risks for both the safety and protection of their citizens, and the infrastructure controlled by the municipality.
- The current Emergency Relief and Assistance Fund (ERAF) for state aid to cover flood damage costs in Pownal is 7.5%. BCRC is working with the Town to update the Local Hazard Mitigation Plan, upon approval the ERAF rate will increase to 12.5%. Implementation of river corridor protection ordinances will increase the ERAF rate to the maximum of 17.5%.
- Site level approaches to river corridor restoration were evaluated in detail at the reach scale, and are organized in the report by watershed. The projects were developed based on the Phase 2 results and watershed-scale mapping of stressors on channel stability. The list of projects is intended to provide a “roadmap” of restoration projects that will reduce future flood hazards and improve ecological conditions in the river corridor. This effort resulted in the identification of 34 restoration project areas, including 10 projects that do not require significant further study (i.e., passive approaches such as buffer plantings and corridor protection), and 24 projects requiring further feasibility study or engineering design (i.e., active restoration approaches such as bridge replacements).
- Project packets were developed for five (5) of the high-priority sites. This process required additional site visits and landowner outreach, mapping, field surveys, and other data collection. The project packets include more detailed information for project implementation, cost estimates, and potential funding partners.

1.0 Project and Watershed Background

1.1 Project Introduction and Study Goals

1.1.1 Project Introduction

In 2016 the Bennington County Regional Commission (BCRC) and the Vermont Department of Environmental Conservation (VTDEC) identified Tubbs Brook and Ladd Brook, both tributaries to the Hoosic River in southwest Vermont for assessment of fluvial geomorphic conditions. Tubbs Brook and Ladd Brook were respectively identified as stressed and impaired due to sediment loading in the Battenkill – Walloomsac – Hoosic Tactical Basin Plan (VTANR, 2016). Prior to this, geomorphic assessment data had been collected for the 7.5-mile long section of the Hoosic River within Vermont, flowing from the Massachusetts border to the New York border (Gomez and Sullivan, 2009). In addition to the sediment loading concerns, flooding and erosion damage sustained during Tropical Storm Irene (TSI) in the Town of Pownal led to the selection of these tributaries for further study. Infrastructure along the river and tributaries was impacted by flooding and erosion, and therefore this information will serve to help the town better understand existing flood vulnerabilities, and plan for future improvements with flood risks in mind.

Fitzgerald Environmental Associates, LLC. (FEA) was retained by BCRC in 2016 to complete river assessments on Tubbs Brook and Ladd Brook following the Phase 1 Stream Geomorphic Assessment (SGA) Protocols (VTDEC, 2009) developed by the VTDEC. FEA used the Stream Geomorphic Assessment Tool (SGAT) to develop the baseline GIS data for the watershed in 2016. A total of 10 reaches along 8.5 river miles were assessed during the Phase 1 analysis.

Following this study, a subset of the Phase 1 reaches was selected for field-based, Phase 2 SGA data collection. FEA completed the Phase 2 field work in 2016 for 7 reaches (approximately 6 river miles), and developed a River Corridor Plan (RCP) for these reaches. Bridge and Culvert Assessments were completed for all the Phase 1 reaches which included three (culverts) in addition to the 20 structures assessed during the Phase 2 SGA. This report summarizes watershed background information, SGA results, and the RCP into one planning document. Definitions and descriptions for the technical terminology found in this report are provided in Section 8.0.

1.1.2 Study Goals

Watershed restoration projects are most successful when carried out within a context for understanding how reach and watershed-scale stressors cause channel instability. The VTDEC SGA Protocols and River Corridor Planning Guide provides sound, scientifically-defensible methods for identifying stressors on channel stability and restoration projects that will address them appropriately (VTANR, 2010). The overall goal of the VTDEC Rivers Program is to "manage toward, protect, and restore the fluvial geomorphic equilibrium condition of Vermont rivers by resolving conflicts between human investments and river dynamics in the most economically and ecologically sustainable manner," (VTANR, 2010) achieved through:

- Fluvial erosion hazard mitigation;
- Sediment and nutrient load reduction; and

- Aquatic and riparian protection and restoration

The Phase 1 SGA approach results in watershed-scale data about the landscape (e.g., soils and land cover) and the stream channel (e.g., slope and form), providing a basis for understanding the natural and human-impacted conditions within the watershed. The SGA data also aids in the identification of specific stressors affecting the physical conditions of the stream channels and structures (e.g., bridges and culverts). Ultimately, the Phase 1 results help guide planners in selected reaches for more detailed Phase 2 data collection where this information can be valuable for flood vulnerability mapping, identification of river restoration projects, and long-term river corridor planning. The goal of the Phase 2 and RCP effort is to provide:

1) A basis for understanding the overall causes of channel instability and habitat degradation along the river corridors in the watershed.
2) A list of preliminary corridor restoration projects that can be further developed in the future to mitigate flood and erosion hazards.
3) Information needed to map fluvial erosion hazard zones in Pownal and Bennington.

1.2 Background Watershed Information

1.2.1 Geographic Setting and Land Use History

The Hoosic River watershed drains approximately 500 square miles of Massachusetts, Vermont, and New York. At the Vermont/New York state line the watershed drains approximately 230 square miles, including 70 square miles within the Vermont towns of Stamford, Pownal, and Bennington (Figure 1.1). The tributaries described in this report are located within the Town of Pownal. Ladd Brook drains approximately 1.8 square miles starting in the hills east of the Pownal town center. Tubbs Brook drains 5.8 square miles flowing from the southern slopes of Mt. Anthony in the Town of Bennington (Figure 1.2).

Land cover data based on imagery from 2006 (NOAA, 2008) are summarized in Table 1.1 and shown in Figure 1.3. Tubbs Brook and Ladd Brook are drained by rural watersheds, with forests representing the dominant land cover type (75% and 80% respectively). Agricultural lands cover 22% of the Tubbs Brook watershed, however this is predominantly classified as pasture/hayfield. Cultivated crops are not widespread in either watershed. Ladd Brook flows through a relatively dense commercial and residential area as it passes through the Route 7 corridor.

Table 1.1: Percent Land Cover for Tubbs and Ladd Brook watersheds.

Watershed	Drainage Area (mi^2)	Agriculture	Development	Forest	Open Water	Scrub/ Shrub	Wetland
Tubbs Brook*	5.81	22%	2%	75%	0%	0%	1%
Ladd Brook	1.82	9%	9%	80%	0%	1%	1%

*Land cover data for sub-tributaries are included.

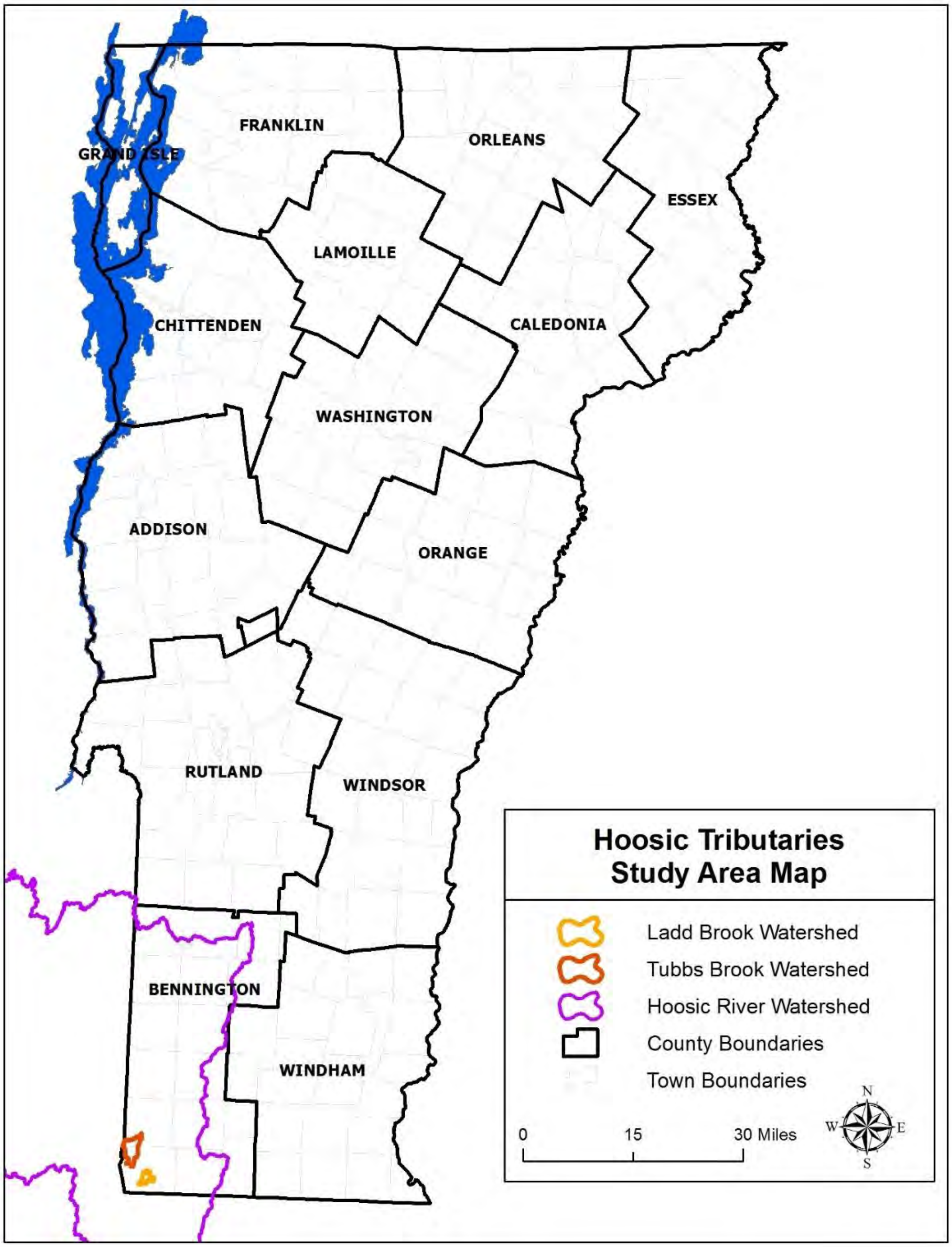

Figure 1.1: Location map for the Ladd and Tubbs Brook watersheds.

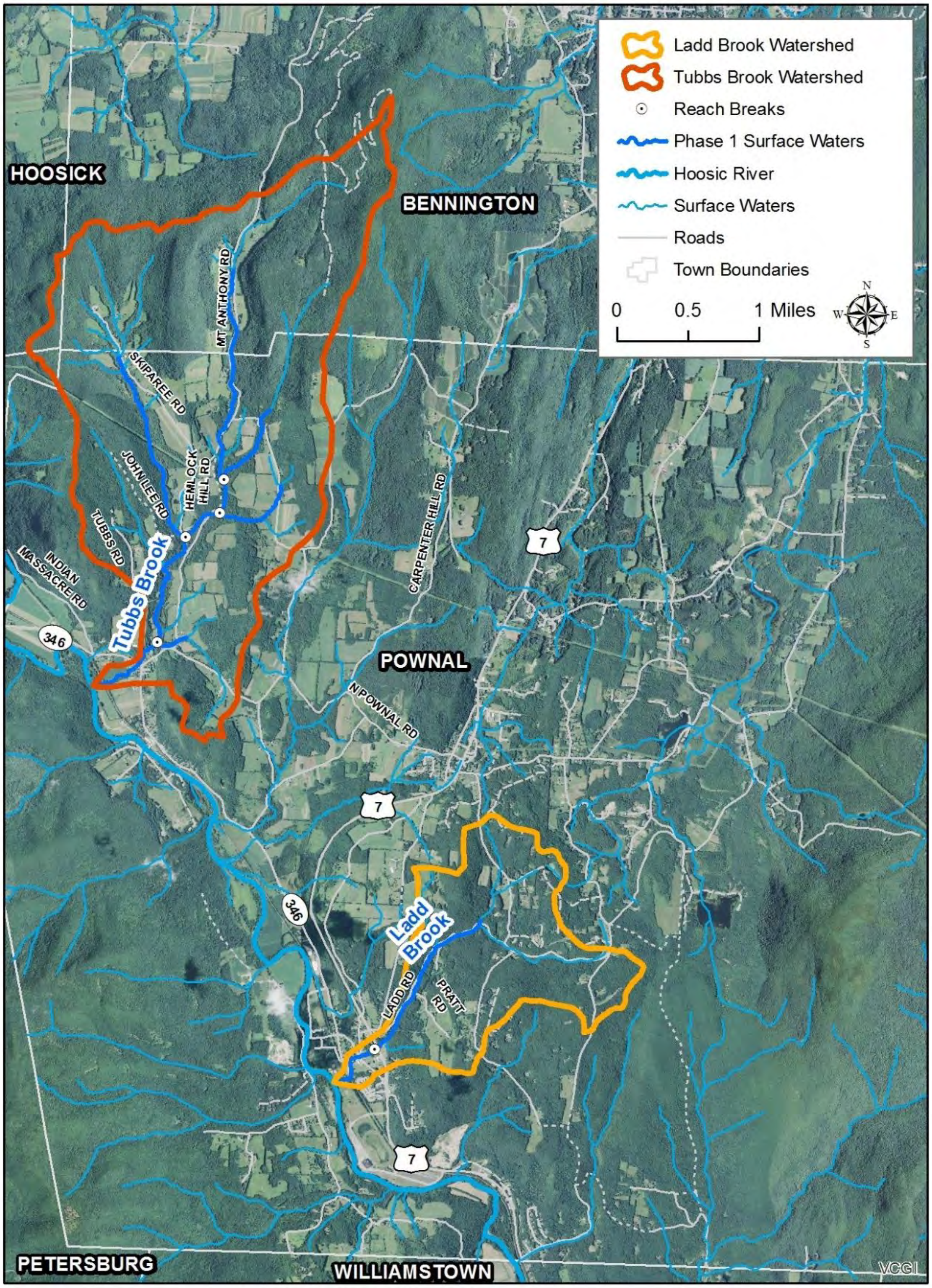

Figure 1.2: Tubbs and Ladd Brook watersheds, Phase 1 surface waters, and town boundaries.

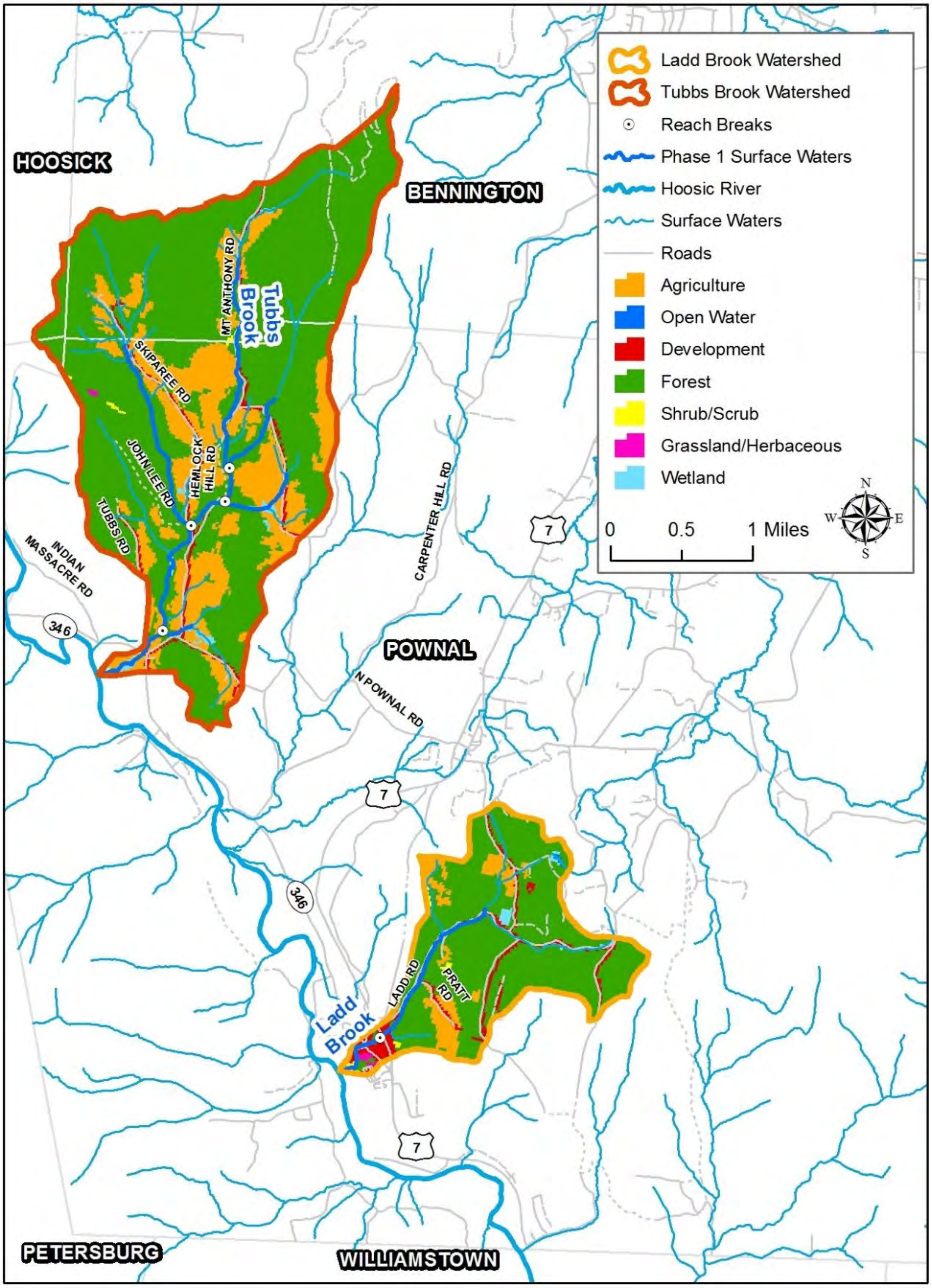

Figure 1.3: Land cover data for the Tubbs and Ladd Brook watersheds.

Historically, the impacts of agricultural practices on the Vermont landscape left a lasting legacy on waterways like Tubbs Brook and Ladd Brook. Prior to the deforestation associated with human settlement, the watershed would have been a mixture of deciduous forest on the valley floors, coniferous forest along the mountain spines, and a mixture of both along the slopes. Deforestation and grazing, largely from sheep farms, likely left over 90 percent of the watershed devoid of trees at one time or another (Albers, 2000). This landscape change had a tremendous impact on waterways like Tubbs Brook and Ladd Brook. Exposed, highly-erodible soils (e.g. glacial tills) on steep slopes were carried to the valley floors and aggraded on river bottoms; a legacy that still influences the way Vermont's rivers are managed today.

As Vermont's farmers began to move to the Midwest in search of more productive farmland in the mid to late 1800's, the deciduous forests along the mountain slopes began to recover (Albers, 2000). Throughout the early and mid-1900's, as more family farms on marginal lands were given up, the forests continued to recover. Today, approximately 75-80 percent of the watershed is covered by forest. With the increasing tourism sector in the state, and the need for lumber for second-homes and construction, forestry has replaced agriculture in many of the rural hill slopes of Vermont.

1.2.2 Geologic Setting

The underlying geology of the Tubbs Brook and Ladd Brook watersheds is comprised of a range of sedimentary and metasedimentary bedrock types. Shale and phyllite are found throughout the Ladd Brook watershed and through much of the Tubbs Brook watershed (Ratcliffe et al., 2011 and Riggs, 1995).

Surficial geologic deposits in the study watershed were governed largely by glacial activity. During the Wisconsin glaciation, glaciers one mile in thickness extended across New England, reaching their maximum extents approximately 20,000 years ago. This glacial event left the Taconic Mountains with a physical imprint that is clearly evident today. In the Tubbs Brook and Ladd Brook watersheds glacial till, dense till, and outwash areas reflect the dynamic nature with which glaciers shaped the landscape (Figure 1.4). Most of the surficial geology of the watershed is dominated by till and the stream corridors are primarily till, outwash and alluvium. As the glaciers retreated, Lake Bascomb filled the Hoosic River Valley with a maximum elevation of approximately 1,050 feet (DeSimone and Dethier, 1992). Glaciolacustrine deposits associated with this lake are visible in the study watersheds. The resultant soils in the study watersheds are primarily loams, many of which are very stony (Macomber-Taconic, Georgia, Dutchess channery, Pittstown, and Stockbridge).

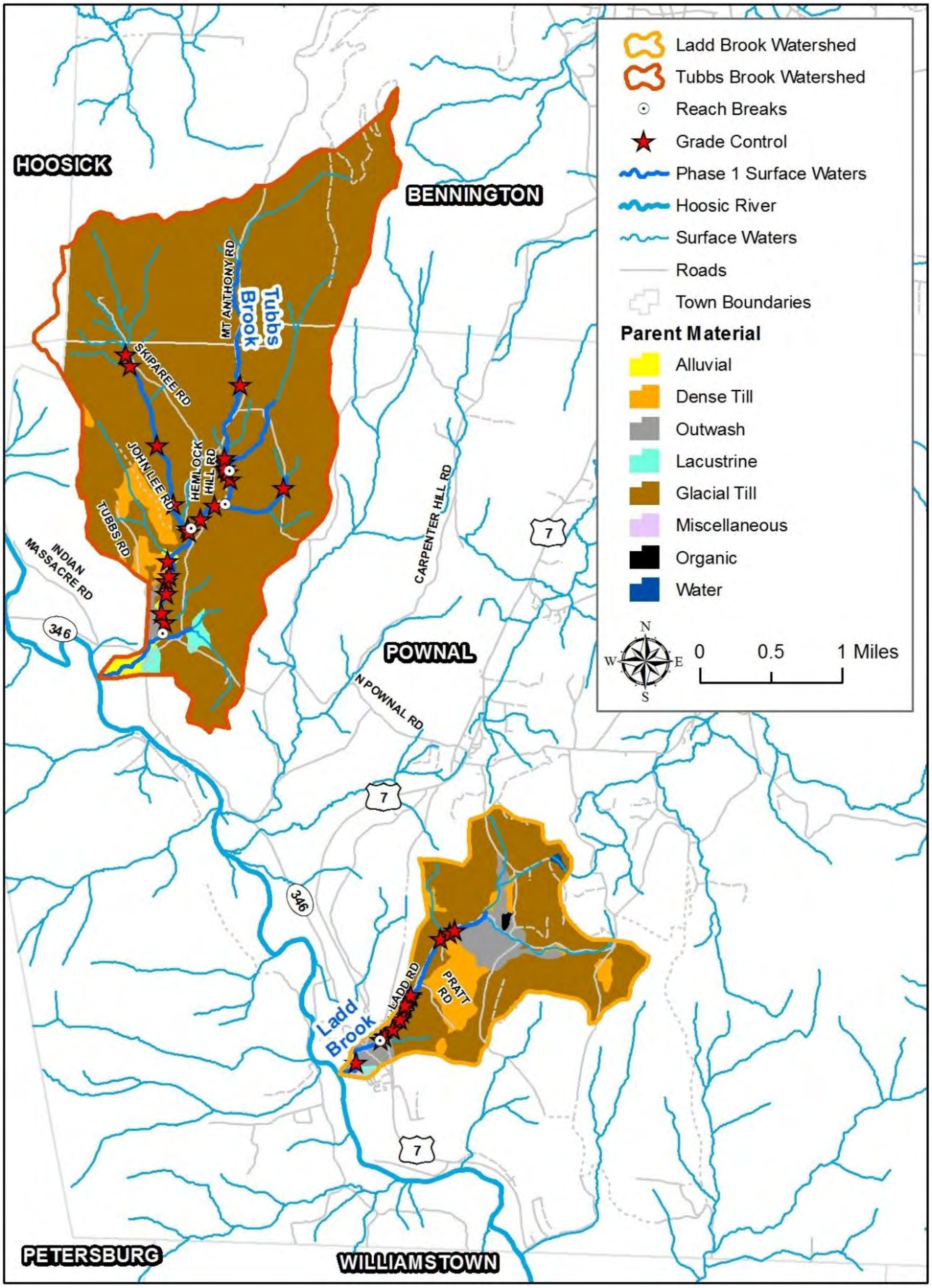

Figure 1.4: Parent surficial materials and grade controls in the Ladd and Tubbs Brook watersheds.

1.2.3 Geomorphic Setting

The Hoosic Tributaries Phase 1 study area contains two major tributaries (Ladd Brook and Tubbs Brook) and four additional sub-tributaries (Tubbs Brook Tributaries 1 - 4) as shown in Figures 3.1 and 3.2. Average slopes for the study reaches are presented in Table 1.2. The first reach of Tubbs Brook begins in a wide channel at the Hoosic River. The stream flows through a low gradient (1.1% slope) very broad valley to the top of the first reach. The middle reaches (M01T1.02 & M01T1.03) flow through an unconfined narrow valley and climb through a series of bedrock cascades. Channel slope increases further in M01T1.04 (6.0% slope), where the stream flows through a series of large bedrock cascades. Above the gorge, the reach has a lower slope as it flows through an unconfined narrow valley shared with Fowler and Mount Anthony roads. The sub-tributaries to Tubbs Brook range have higher slopes than the reaches they flow into, ranging from 5.3 to 8.4% slope, and are similarly in narrow unconfined valleys.

The first reach of Ladd Brook begins in a very broad valley at the Hoosic River and steepens as it approaches the end of the reach at Route 7. The second reach (M05S1.02) flows through a steeper semi-confined valley (6.8% slope) shared with Ladd Road.

Table 1.2: Average channel slopes for major and sub tributaries.

Channel (SGA Reaches)	Average Slope
Ladd Brook (M05S1.01-M05S1.02)	5.2%
Lower Tubbs Brook (M01T1.01-M01T1.02)	1.9%
Upper Tubbs Brook (M01T1.03-M01T1.04)	5.3%
M01T1.01S1.01	5.3%
M01T1.02S1.01	5.5%
M01T1.03S1.01	6.8%
M01T1.04S1.01	8.4%

1.2.4 Hydrology and Flood History

The United States Geological Survey (USGS) operates real-time flow monitoring stations on the Hoosic River in Williamstown MA and Eagle Bridge NY (downstream of Walloomsac River confluence) and on the Walloomsac River in North Bennington VT. These basins are all considerably larger than the study watersheds and are regulated by impoundments to varying degrees; however, the peak flows recorded at these nearby stations are useful for estimating the size and frequency of flood events for Tubbs Brook and Ladd Brook. Peak flow recurrence intervals for all nearby USGS stream gaging stations are shown below in Table 1.3. Peak flows were estimated at the mouth of Tubbs Brook and Ladd Brook using the USGS StreamStats program, which calculates flows from a statewide regression equation (Olson, 2014).

Table 1.3: Frequency and magnitude of flow events in gaged basins near Pownal, VT.

	Discharge (cfs)				
Return Frequency	[1]Hoosic River (Eagle Bridge, NY)	[1]Hoosic River (Williamstown, MA)	[1]Walloomsac River (N. Bennington, VT)	[2]Tubbs Brook	[2]Ladd Brook
Drainage Area (mi2)	**512**	**127**	**116**	**5.8**	**1.8**
Data Period	**1911-2015**	**1940-2015**	**1932-2015**	**None**	**None**
2 year	11,900	4,030	3,380	258	81
5 year	17,700	6,090	4,990	409	130
10 year	22,400	7,740	6,180	527	169
25 year	29,300	10,200	7,830	703	228
50 year	35,400	12,300	9,150	856	279
100 year	42,200	14,600	10,600	1,020	335
200 year	49,800	17,300	12,100	1,210	397
500 year	61,600	21,300	14,200	1,490	491

Recurrence interval data sources: [1]Olson, 2014; [2]USGS StreamStats

Tropical Storm Irene was a significant flood event in southwestern Vermont. The nearby USGS stream gaging stations recorded flows estimated at the 50-year flood on the Walloomsac and at the 100-year flood at both locations on the Hoosic River. Additional major floods (greater than the 25-year event) were recorded in 1927, 1936, 1938, and 1948 in Eagle Bridge; 1948, 1951, and 1976 in Williamstown; 1938 and 1948 in North Bennington. Tropical Storm Irene produced the largest peak flows on record at the Williamstown and North Bennington monitoring stations. The New Years Eve 1948 flood on the Hoosic River in Eagle Bridge is estimated at a 200-year flood and had a peak stage of approximately 1 foot higher than Irene (Figure 1.5). Annual peak flows for the Hoosic River in Williamstown MA are shown in Figure 1.6

Figure 1.5: Buildings along the Hoosic in North Adams MA were destroyed in the 1948 flood (photo: P. Marino).

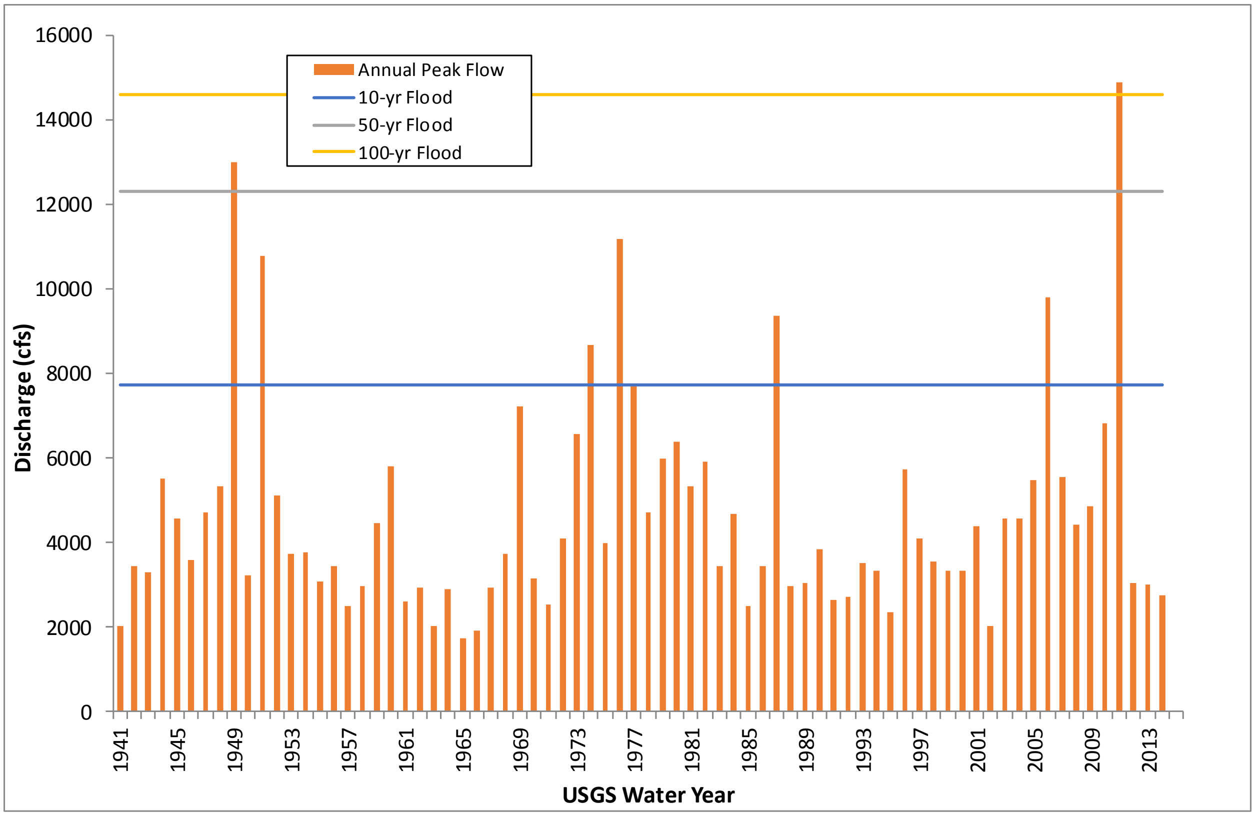

Figure 1.6: Annual peak streamflows from USGS gage on the Hoosic River in Williamstown MA.

1.2.5 Ecological Setting

The Ladd and Tubbs Brook watersheds are located in the Taconic Mountains (TM) biophysical region (Thompson and Sorenson, 2000). The TM region is found along the western border of Vermont and extends from Orwell Vermont down to Connecticut. It is characterized by variable climate, topography, and vegetation. At low elevations the warmer drier climate supports Mesic Maple-Ash-Hickory-Oak Forest communities, while areas with moister climates are dominated by Northern Hardwood Forest communities. Valleys were converted to agricultural use during European settlement in the late 18th and 19th centuries, with local economies supported by sheep farming, forestry, and slate quarrying. Bedrock is typically metamorphic, including slate, marble, and limestone. Glaciofluvial kame and other lake and alluvial sediments are common in TM valleys.

Elevations within the Tubbs Brook watershed range from 492 feet at the confluence of Tubbs Brook with the Hoosic River to over 2,300 feet at the top of Mount Anthony at the northern extent of the watershed. Elevations within the Ladd Brook watershed range from 532 feet at the confluence of Ladd Brook with the Hoosic River to over 1,600 feet near the top of Mason Hill on the watershed's southeastern border.

Macroinvertebrate and fish community assessments have been complete by the VT DEC Biomonitoring Division on Tubbs and Ladd Brook on reaches M01T1.01 and M05S1.01 respectively. One (1) fish community assessment was completed on Tubbs Brook in 2013, rating the health of the population as "very good". Four (4) macroinvertebrate assessments were conducted on Tubbs Brook, with two (2) pre-T.S. Irene (2008 & 2009) and two (2) post-T.S. Irene (2013 & 2015). The macroinvertebrate community did not show a decline, and improved from a “fair” to “good” rating between 2009 and 2013. One (1) fish community assessment was completed on Ladd Brook in 2009, rating the health of the population as “excellent”. No post-T.S. Irene macroinvertebrate assessments have been performed on Ladd Brook. Assessments performed between 2008 and 2009 showed slight improvements in the macroinvertebrate community from “poor” to “fair-poor”/“fair”.

Small areas of wetland are scattered throughout the Ladd and Tubbs Brook watersheds with a total land cover of approximately 1% of each watershed.

2.0 Data Collection

2.1 Data Collection Methods

The Vermont River Management Program (RMP) has invested many person-years of effort into developing a state-of-the-art system of Stream Geomorphic Assessment (SGA) protocols. The SGA protocols are intended to be used by resource managers, community watershed groups, municipalities and others to identify how changes to land use affect hydro-geomorphic processes at the landscape and reach scale, and how these changes alter the physical structure and biological habitat of streams in Vermont. The SGA protocols have become a key tool in the prioritization of restoration projects that will 1) reduce sediment and nutrient loading to downstream receiving waters such as Lake Champlain and the Hudson River, 2) reduce the risk of property damage from flooding and erosion, and 3) enhance the quality of in-stream biological habitat. The protocols are based on defensible scientific principles and have been tested widely in many watersheds throughout the state. Data collected for the Hoosic tributaries watersheds using the protocols formed the basis for preliminary project identification carried out during the Phase 2 SGA and River Corridor Planning efforts.

The SGA protocols include three phases (VTDEC, 2009):

- **Phase 1**: The Phase 1 SGA approach utilizes the Stream Geomorphic Assessment Tool (SGAT), a GIS extension developed by RMP for the collection of reach and watershed scale data. In addition to the GIS and remote sensing effort, a cursory field assessment (“windshield survey”) is included for the verification of stream and valley forms, significant channel features and the location of man-made infrastructure. The study watershed is divided into preliminary “reaches” based on major tributary confluences and significant changes in valley or channel geometry. The windshield survey verifies these reach break assignments through a rapid watershed tour and detailed site photographs wherever the stream channel is readily accessible (typically at stream crossings). The field verified reach breaks are then used to generate the SGAT inputs for subwatershed boundaries. The Phase 1 SGA approach results in watershed-scale data about the landscape (e.g., soils and land cover) and the stream channel (e.g., slope and form), which provides a basis for understanding the natural and human-impacted conditions within the watershed. The SGA data also aids in the identification of specific stressors affecting the physical conditions of the stream channels and structures (e.g., bridges and culverts). Table 2.1 summarizes the parameters collected in Phase 1 using the Feature Indexing Tool (FIT), which include those utilized to develop the final impact ratings.

- **Phase 2**: The Phase 2 approach builds upon Phase 1 data through the collection of reach-specific data about the current physical conditions. Characterization of reach conditions utilizes a suite of quantitative (e.g., channel geometry, pebble counts) and qualitative (e.g., pool-riffle habitat) measurements to calculate two indices: Rapid Geomorphic Assessment (RGA) Score; Rapid Habitat Assessment (RHA) score. Using the RGA scores in conjunction with knowledge about the background or "reference" conditions, a sensitivity rating is developed to predict the degree to which the channel will adjust to human and natural impacts in the future.

Table 2.1: Parameters collected with FIT.

Phase 1 Step	Phase 2 Step	Data Type	Impact	Sub-Impact
3.1	**1.2**	Point	Alluvial Fan	NA
3.2	**1.6**	Point	Grade Control	Dam Ledge Waterfall Weir
NA	**3.3**	Point	Mass Failure	NA
5.5	**5.5**	Point	Dredging	Dredging Gravel Mining Commercial Mining
NA	**4.4**	Point	Debris Jam	NA
NA	**4.6**	Point	Stormwater Input	NA
NA	**4.9**	Point	Beaver Dam	NA
NA	**5.2**	Point	Migration	Neck Cut Off Flood chute Avulsion Braiding
NA	**5.3**	Point	Steep Riffle or Head Cut	Head Cut Steep Riffle
NA	**5.4**	Point	Stream Crossing	Stream Ford Animal Crossing
NA	**3.3**	Point	Gully	NA
6.2	**1.3**	Line	Development	NA
6.1	**1.3**	Line	Encroachment	Berm Improved Path Road Railroad
5.3	**3.1**	Line	Bank Armoring or Revetment	Rip-Rap Hard Bank Other
7.2	**3.1**	Line	Erosion	NA
5.4	**5.5**	Line	Straightening	Straightening With Windrowing

- **Phase 3**: Phase 3 surveys involve the collection of detailed, reach-scale survey data to verify or build upon Phase 2 data. These surveys are typically carried out prior to project development for an "active" channel management approach (e.g., floodplain restoration), or for long-term monitoring purposes.

FEA developed a SGAT geodatabase using the SGAT 10.3 toolbar. The subwatersheds, valley walls, and meander centerline themes were created for the study reaches and reviewed by VTDEC staff. The VTANR Data Management System (DMS) database was populated from these themes and reference stream types were assigned. The remaining Phase 1 data was collected remotely by FEA and through windshield surveys for reaches along 8.5 river miles. All major human impacts and natural features were indexed in a GIS using the FIT.

2.2 Quality Assurance

The VTDEC Quality Assurance (QA) protocols outlined in the SGA protocols (VTDEC, 2009) were followed in order to ensure a complete and accurate dataset. FEA and VTDEC shared responsibility for QA for the SGAT shapefiles and the finalized Phase 1 and Phase 2 datasets. The DMS database for all Phase 1 assessed reaches in the watershed was finalized in September, 2016. The DMS database for all Phase 2 assessed reaches was finalized in March 2016. The QA summaries for Phase 1 and 2 are included in Appendix F.

2.3 Bridge and Culvert Assessments

FEA conducted bridge and culvert surveys on all private and public structures within the Phase 1 study area. This included three (3) culverts that were located on Phase 1 reaches that were not selected for the Phase 2 assessment. The Bridge and Culvert Assessment and Survey Protocols specified in Appendix G of the Vermont Stream Geomorphic Assessment Handbook (VTDEC, 2009) were followed. Latitude and Longitude of each structure was recorded in the field with a GPS unit or digitized based on aerial imagery. The assessment included various photographs documenting the condition of each structure.

2.4 Stressor and Departure Analysis

FEA followed the VTDEC methods for developing river corridor plans as outlined in the Vermont River Corridor Planning Guide (VTANR, 2010). This technical guide is directed towards river scientists, planners, and engineers engaged in finding economically and ecologically sustainable solutions to the conflicts between human investments and river dynamics. The guide provides explanations for the following:

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

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

2.4.1 Stressor Analysis

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

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

2.4.2 Departure Analysis

Much research has shown that alluvial river channels in wide valleys will adjust their geometry and planform to accommodate changes in the discharge and sediment loading from the upslope watershed (Dunne and Leopold, 1978). This concept was summarized by Lane (1955) to show that stream power and sediment (size and distribution) will seek a dynamic equilibrium condition in the absence of anthropogenic disturbance or catastrophic natural storm events. Slight changes from one year to another, such as variation in rainfall amounts (and a resulting variation in discharge), may cause subtle changes in channel form. However, the cross-sectional shape and profile of a river is typically stable under reference watershed conditions, and predictable given knowledge about: 1) the geologic conditions of the watershed and river corridor, 2) the topography of the watershed and river corridor, and 3) the regional climate.

Analysis of a watershed's sediment regime is a useful approach for summarizing the reach and watershed-scale stressors affecting the equilibrium conditions of river channels. Sediment regime mapping provides a context for understanding the sediment transport and channel evolution processes (Schumm, 1977) which govern changes in geometry and planform for river channels in a state of disequilibrium. The VTANR River Corridor Planning Guide (VTANR, 2010) outlines a methodology for understanding the reference and altered sediment regimes of reaches according to data collected during the Phase 2 field assessments. The sediment regime types used in this analysis are summarized below in Table 2.2.

Table 2.2: Sediment regime types for corridor planning (VTANR, 2010).

Sediment Regime	Narrative Description
Transport	Steeper bedrock and boulder/cobble cascade and step-pool stream types; typically in more confined valleys, do not supply appreciable quantities of sediments to downstream reaches on an annual basis; little or no mass wasting; storage of fine sediment is negligible due to high transport capacity derived from both the high gradient and/natural entrenchment of the channel.
Confined Source and Transport	Cobble step pool and steep plane bed streams; confining valley walls, comprised of erodible tills, glacial lacustrine, glacial fluvial, or alluvial materials; mass wasting and landslides common and may be triggered by valley rejuvenation processes; storage of coarse or fine sediment is limited due to high transport capacity derived from both the gradient and entrenchment of the channel. Look for streams in narrow valleys where dams, culverts, encroachment (roads, houses, etc.), and subsequent channel management may trigger incision, rejuvenation, and mass wasting processes.

Table 2.2: Sediment regime types for corridor planning (VTANR, 2010).

Sediment Regime	Narrative Description
Unconfined Source and Transport	Sand, gravel, or cobble plane bed streams; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to entrenchment or incision and associated bed form changes; these streams are not a significant sediment supply due to boundary resistance such as bank armoring, but may begin to experience erosion and supply both coarse and fine sediment when bank failure lead to channel widening; storage of coarse or fine sediment is negligible due to high transport capacity derived from the deep incision and little or no floodplain access. Look for straightened, incised or entrenched streams in unconfined valleys, which may have been bermed and extensively armored and are in Stage II or early Stage III of channel evolution.
Fine Source and Transport & Coarse Deposition	Sand, gravel, or cobble streams with variable bed forms; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to vertical profile and associated bed form changes; these streams supply both coarse and fine sediments due to little or no boundary resistance; storage of fine sediment is lost or severely limited as a result of channel incision and little or no floodplain access; an increase in coarse sediment storage occurs due to a high coarse sediment load coupled with the lower transport capacity that results from a lower gradient and/or channel depth. Look for historically straightened, incised, or entrenched streams in unconfined valleys, having little or no boundary resistance, increased bank erosion, and large unvegetated bars. These streams are typically in late Stage III and Stage IV of channel evolution.
Coarse Equilibrium (in = out) & Fine Deposition	Sand, gravel, or cobble streams with equilibrium bedforms; at least one side of the channel is unconfined by valley walls; these streams transport and deposit coarse sediment in equilibrium (stream power—produce as a result of channel gradient and hydraulic radius—is balanced by the sediment load, sediment size, and channel boundary resistance); and store a relatively large volume of fine sediment due to the access of high frequency (annual) floods to the floodplain. Look for unconfined streams, which are not incised or entrenched, have boundary resistance (woody buffers), minimal bank erosion, and vegetated bars. These streams are Stage I, late IV, and Stage V.
Deposition	Silt, sand, gravel, or cobble streams with variable and braided bed forms; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to changes in slope and/or depth resulting in the predominance of transient depositional features; storage of fine and coarse sediment frequently exceeds transport**. Floodplains are accessed during high frequency (annual) floods. Look for unconfined streams, which are not incised or entrenched, have become significantly over-widened, and if high rates of bank erosion are present, it is offset by the vertical growth of unvegetated bars. These regimes may be located at zones of naturally high deposition (e.g., active alluvial fans, deltas, or upstream of bedrock controls), or may exist due to impoundment and other backwater conditions above weirs dams and other constrictions.

** Use of the "Deposition" regime characterization may be rare, but valuable as a planning tool, where the reach is storing far more than it is transporting during some defined planning period. The extreme example would be that of an impounded reach where all of the coarse and a great percentage of the fine sediments are being deposited, rather than transported downstream. This man-made condition may change, thereby changing the sediment regime, but is not likely over the period at which the corridor plan will be used.

Channel evolution models (CEM) also provide a basis for understanding the temporal scale of channel adjustments and departure in the context of SGA Phase 2 results. Both the "D" stage and "F" stage CEMs (VTDEC, 2009) are helpful for explaining the channel adjustment processes underway in the Hoosic tributaries watersheds. The "F" stage CEM is used to understand the process that occurs when a stream degrades (incises) its bed. The more dominant adjustment process for the "D" stage channel evolution is aggradation, widening and planform change. D-stage CEM typically occurs where grade controls prevent severe channel incision and abandonment of the adjacent floodplain. The common stages of both CEMs are depicted in Figure 2.1 below.

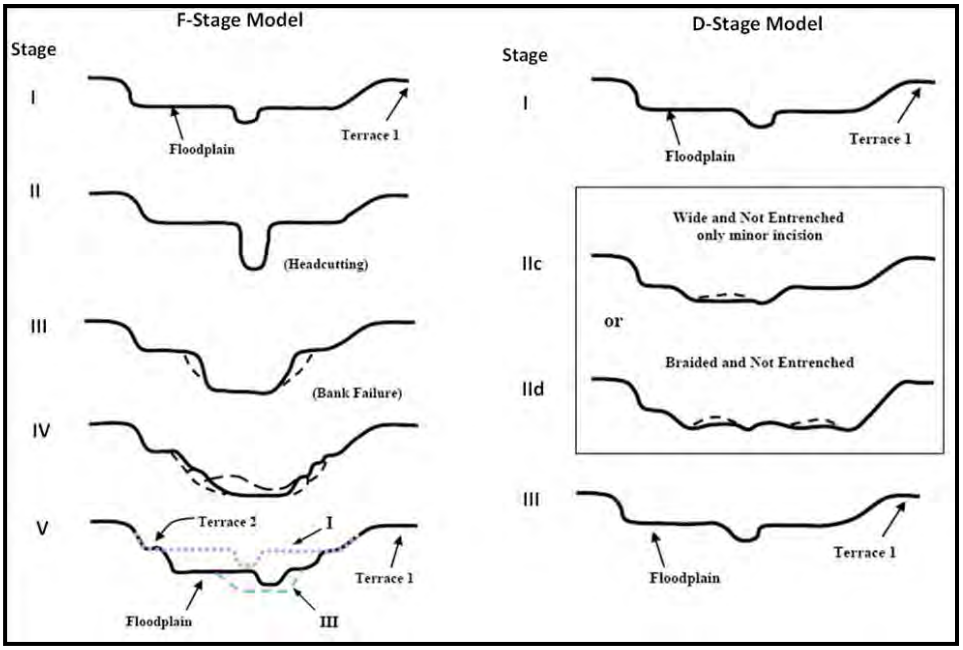

Figure 2.1: Typical channel evolution models for F-stage and D-stage (VTDEC, 2009).

2.4.3 Sensitivity Analysis

The following description of the sensitivity of various stream types to changes in sediment and flow regimes, boundary conditions and channel morphology, is included from the most recent version of the VTANR River Corridor Planning Guide (VTANR, 2010).

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

Stream sensitivity maps have been prepared for the Hoosic tributaries study area. Sensitivity ratings were assigned using the VTDEC Protocols (VTDEC, 2009).

2.5 Project Identification

Site-specific projects were identified using methods outlined by VTANR in Chapter 6 Preliminary Project Identification and Prioritization (VTANR, 2010). This planning guide is intended to aid in the development of projects that protect and restore river equilibrium conditions. The projects identified for the study reaches can be classified under one of the following categories: Active Geomorphic Restoration, Passive Geomorphic Restoration, and Conservation.

Active Geomorphic Restoration implies the management of rivers to a state of geomorphic equilibrium through active, physical alteration of the channel and/or floodplain. Often this approach involves the removal of human constructed constraints or the construction of meanders, floodplains or stable banks. Riparian buffer re-vegetation and long-term protection of a river corridor is essential to this alternative.

Passive Geomorphic Restoration allows rivers to return to a state of geomorphic equilibrium by removing factors adversely impacting the river and subsequently using the river's own energy and watershed inputs to re-establish its meanders, floodplains and equilibrium conditions. In many cases, passive restoration projects may require varying degrees of active measures to achieve ideal results. Riparian buffer re-vegetation and long-term protection of a river corridor (e.g., corridor easements) is essential to this alternative.

Conservation is an option to consider when stream conditions are generally "good" or "reference" and the channel is in a state of dynamic equilibrium. Typically, conservation is applied to minimally disturbed reaches where river structure and function and vegetation associations are relatively intact, and/or where high quality aquatic habitat is found.

3.0 Phase 1 Results

3.1 Reach Delineations

The 8.26 miles of surface waters within the Tubbs and Ladd Brook watersheds were divided into 10 reaches during the SGAT analysis carried out by VTANR and FEA. Reach divisions were based on changes in valley geometry, channel slope, and the size and influence of tributaries entering the mainstem channel. Ladd Brook, Tubbs Brook, and four (4) unnamed tributaries to Tubbs Brook were included in the SGAT analysis. Table 3.1 summarizes data for the study watersheds. Detailed information about each reach location is found in the reach reports in Appendix A.

Table 3.1: Tributary and sub-tributary summary data.

DMS ID	Name	Watershed Area (square miles)	Assessed River Length (mi)	Number of Assessed Reaches
M05S1	Ladd Brook	1.82	1.68	2
M01T1	Tubbs Brook	5.81	3.7	4
M01T1.01S1	1st Unnamed Trib to Tubbs Br	0.43	0.23	1
M01T1.02S1	2nd Unnamed Trib to Tubbs Br	1.46	1.41	1
M01T1.03S1	3rd Unnamed Trib to Tubbs Br	0.56	0.59	1
M01T1.04S1	4th Unnamed Trib to Tubbs Br	0.67	0.65	1

3.2 Reference Stream Types

Windshield survey measurements and observations as well as remotely collected data of valley confinement, channel slope, and sinuosity were used to develop reference stream types for the assessed reaches according to the Rosgen (1994) and Montgomery and Buffington (1997) classification systems. Characterization of reference stream types is based on the channel forms and processes we would expect in a particular geologic and geomorphic setting without human influences. Detailed information about each reach reference stream type is found in the reach reports in Appendix A. Table 3.2 presents general valley and channel characteristics associated with reference stream types found in the Hoosic tributary watersheds. Table 3.3 describes the reference stream conditions for each study reach.

Table 3.2: Reference stream type characteristics.

Stream Type	Valley Confinement	Channel Slope	Sinuosity	Bedform	Number of Study Reaches*
A	Confined	> 4%	Low	Cascade or Step-pool	0
B	Confined	2 – 4%	Low	Step-pool or Plane bed	6 (60%)
C	Unconfined	< 2%	Moderate	Riffle Pool	4 (40%)
E	Unconfined	<2%	Highly	Dune Ripple	0

* Number of reaches and percentage of total reaches represented by type.

Table 3.3: Reach and watershed characteristics.

Surface Water	Reach ID	Watershed Area (Mi^2)	Channel Length (Mi)	Channel Width (ft)	Channel Slope (%)	Sinuosity	Valley Type*	Reference Stream Type†	Bedform‡
Ladd Brook	M05S1.01	1.82	0.46	17.0	3.64	1.18	VB	C	Riffle-Pool
	M05S1.02	1.73	1.22	16.7	6.80	1.01	SC	B	Riffle-Pool
Tubbs Brook	M0T1.01	5.81	0.63	28.4	1.12	1.70	VB	C	Riffle-Pool
	M0T1.02	5.28	0.90	27.2	2.64	1.06	NW	C	Riffle-Pool
	M0T1.03	2.91	0.32	20.9	4.65	1.00	NW	C	Riffle-Pool
	M0T1.04	2.26	1.85	18.8	5.97	1.02	NW	B	Step-Pool
1st Trib to Tubbs Brook	M0T1.01S1.01	0.43	0.23	9.0	5.28	1.01	NW	B	Riffle-Pool
2nd Trib to Tubbs Brook	M0T1.02S1.01	1.46	1.41	15.5	5.45	1.03	NW	B	Riffle-Pool
3rd Trib to Tubbs Brook	M0T1.03S1.01	0.56	0.59	10.2	6.80	1.00	NW	B	Riffle-Pool
4th Trib to Tubbs Brook	M0T1.04S1.01	0.67	0.65	11.0	8.42	1.01	NW	B	Riffle-Pool

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

Figures 3.1 and 3.2 present the location of the reference stream types developed for the Hoosic tributary watersheds. B-type reaches are the most common (60%) within the study area under reference conditions. B-type streams are typically characterized by a low to moderately sinuous channel that is dominated by sediment transport processes. B-type streams are typically located within confined valleys, however all of the reference B-type reaches along Tubbs Brook and the associated tributaries are classified as flowing through narrow (unconfined) valleys. C-type reaches represent the remaining 40% of the study area and are typically characterized by a moderately sinuous channel found in a broad, unconfined valley setting with a balance between the upslope sediment supply and the transport capacity. The study reaches did not contain any A-type streams which are typically found in the steep headwater areas or E-type reaches which are typically found in broad valleys with low slope and depositional environments. Outside of the headwater areas; channel slope is relatively consistent through most of the study area, therefore reference stream type is primarily influenced by confinement. C-type reaches typically have broad and very broad confinement, and B-type reaches are typically found in semi-confined or narrow valleys.

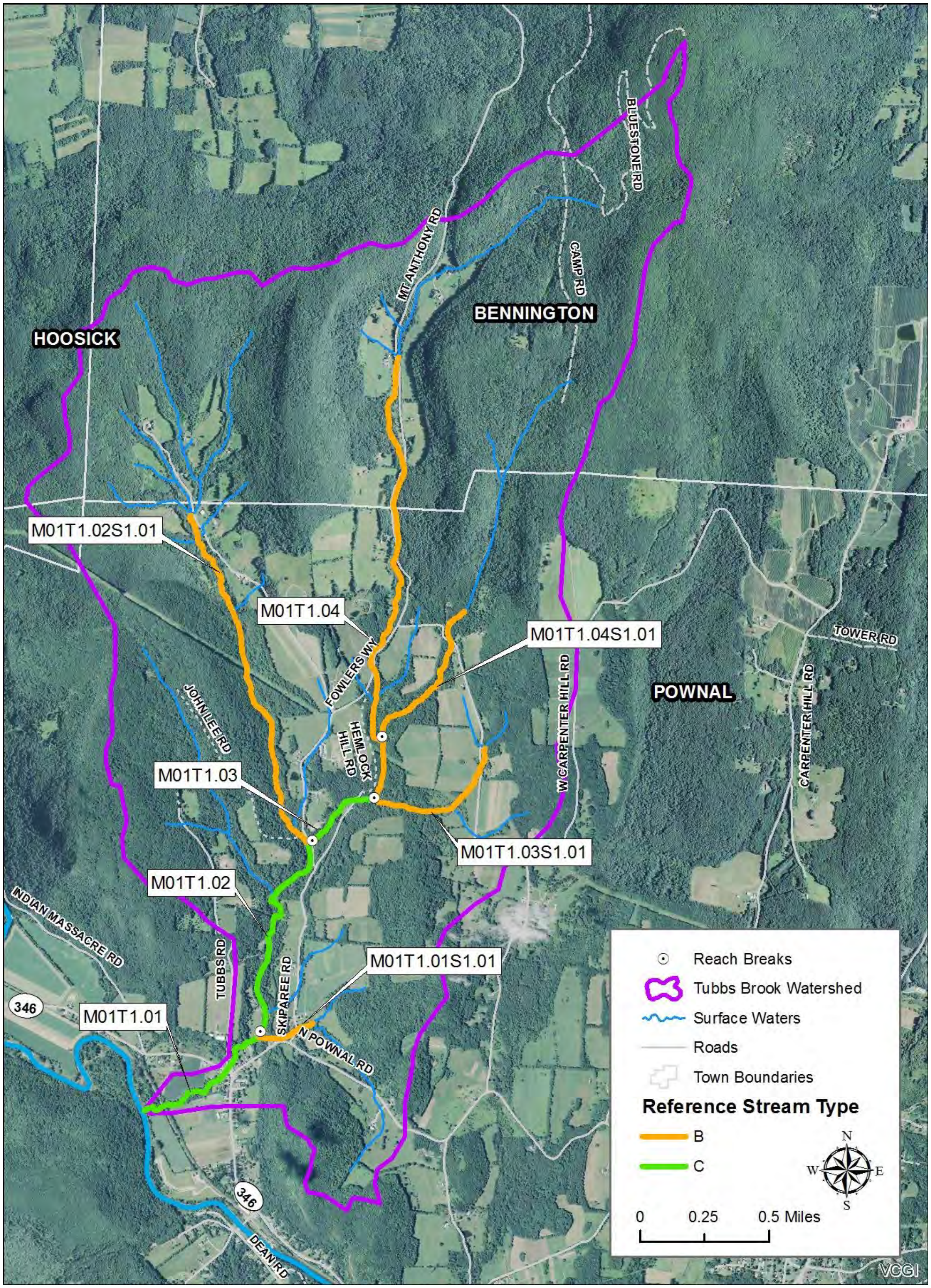

Figure 3.1: Reference stream types per Rosgen (1994) for the Tubbs Brook watershed.

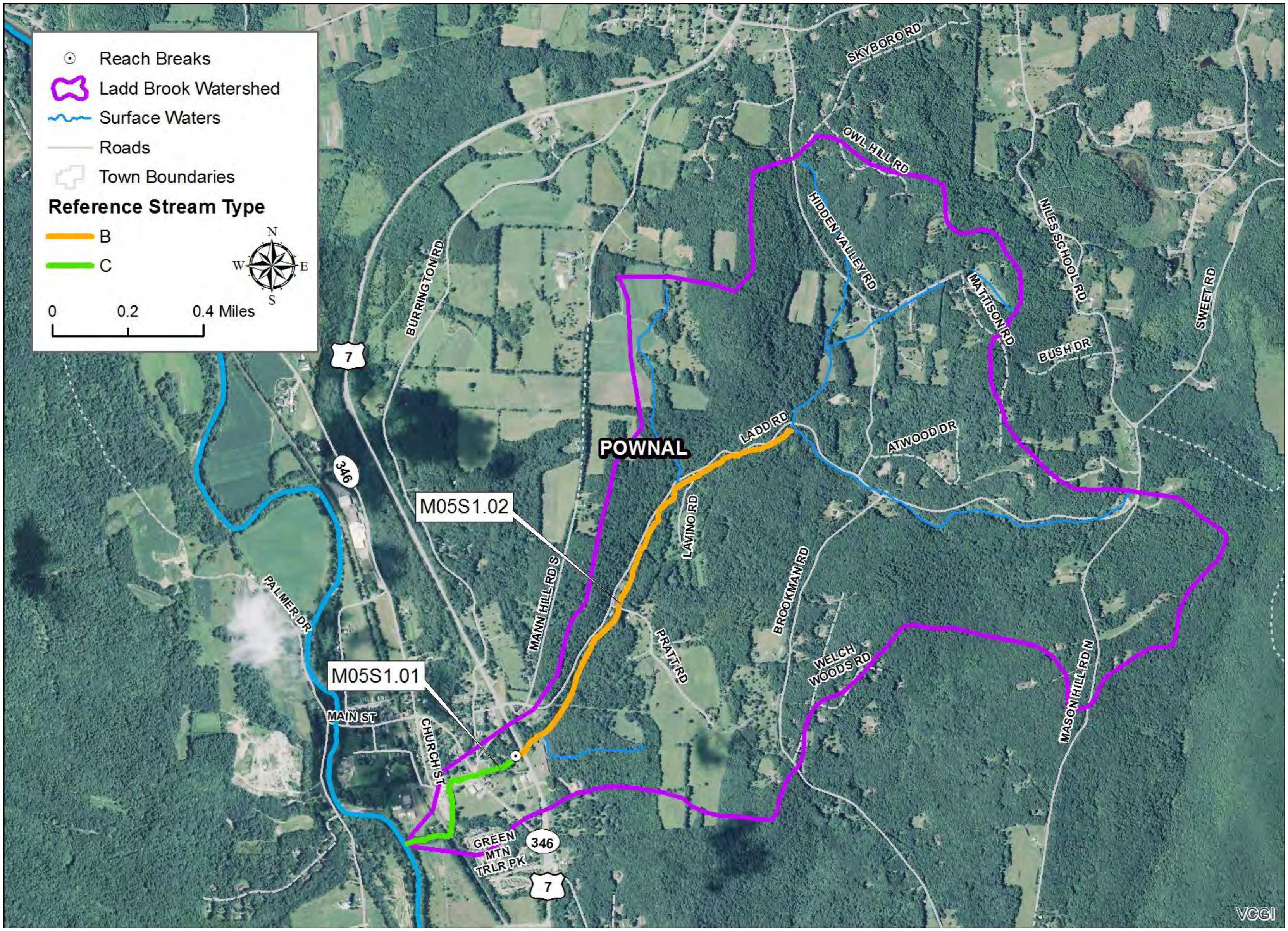

Figure 3.2: Reference stream types per Rosgen (1994) for the Ladd Brook watershed.

3.3 Phase 1 Impacts Summary

Based on the Phase 1 impact scores, the DMS also develops predictions for channel adjustment processes (VTDEC, 2009). These predictions are based on the dominant impacts recorded for each reach, and are categorized based on the impacts typically associated with the following four channel adjustment processes: 1) Degradation (e.g., channel incision); 2) Aggradation (e.g., increased sediment deposition); 3) Channel widening (e.g., increased bank erosion); 4) Planform Changes (e.g., irregular meander patterns) (Table 3.4 and Figures 3.3 and 3.4). Impacts are scored from 0-2 (Insignificant to Major) and the total score (0-32) is indicative of the total degree of impact, however there are no qualitative ratings assigned to a particular Phase 1 impact score.

Table 3.4: Final Impact Score Parameters for Phase 1 Dataset.

Phase 1 Step	Phase 1 Parameter	Impact Category
4.1	Local Watershed Land Cover/Land Use	Land Use
4.2	Corridor Watershed Land Cover/Land Use	
4.3	Riparian Buffer Width	
5.1	Flow Regulations	Channel Modifications
5.2	Bridges and Culverts	
5.3	Bank Armoring	
5.4	Channel Straightening	
5.5	Dredging and Gravel Mining	
6.1	River Corridor Encroachments	Floodplain Modifications and Planform Changes
6.2	River Corridor Development	
6.3	Depositional Features	
6.4	Meander Migration	
6.5	Meander Belt Width Departure	
6.6	Meander Wavelength Departure	
7.2	Bank Erosion	Bed and Bank Conditions
7.3	Debris and Ice Jam Potential	

In the Hoosic tributaries watersheds, the most pervasive impacts mapped during Phase 1 assessment were river corridor and floodplain encroachments (Figures 3.5 and 3.6), and riparian buffer degradation (Figures 3.7 and 3.8). These are commonly the most widespread impacts in rural Vermont watersheds due to the presence of roadways along river networks and development and agricultural land uses found along the flat river valleys. Using the channel adjustment process ratings, a provisional geomorphic rating is developed for each reach based on the methods outlined in the SGA Phase 1 protocols (VTDEC, 2009). Table 3.5 outlines the four possible geomorphic ratings based on the SGA methods, and Figures 3.9 and 3.10 present the provisional geomorphic condition for all study reaches.

Table 3.5: SGA Reach Condition Ratings.

SGA Rating (Score)	Predicted Conditions and Processes
Reference (0.85-1.0)	In Equilibrium – no apparent or significant channel, floodplain, or land cover modifications; channel geometry is likely to be in balance with the flow and sediment produced in its watershed.
Good (0.65-0.84)	In Equilibrium but may be in transition into or out of the range of natural variability – minor erosion or lateral adjustment but adequate floodplain function; any adjustment from historic modifications nearly complete.
Fair (0.35-0.64)	In Adjustment – moderate loss of floodplain function; or moderate to major planform adjustments that could lead to channel avulsions.
Poor (0.00-0.34)	In Adjustment and Stream Type Departure - may have changed to a new stream type or central tendency of fluvial processes – significant channel and floodplain modifications may have altered the channel geometry such that the stream is not in balance with the flow and sediment produced in its watershed.

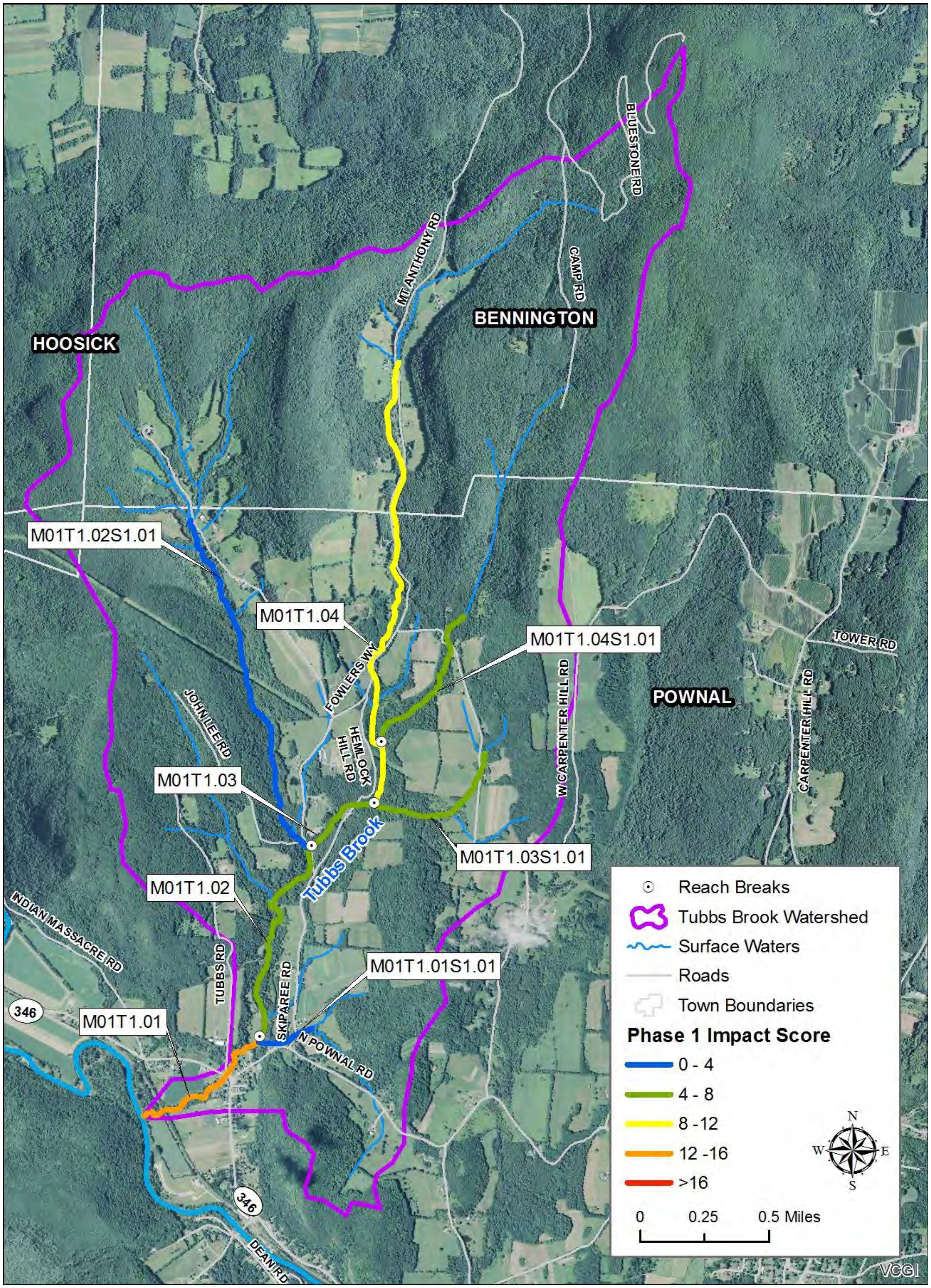

Figure 3.3: Phase 1 impact scores for the Tubbs Brook watershed.

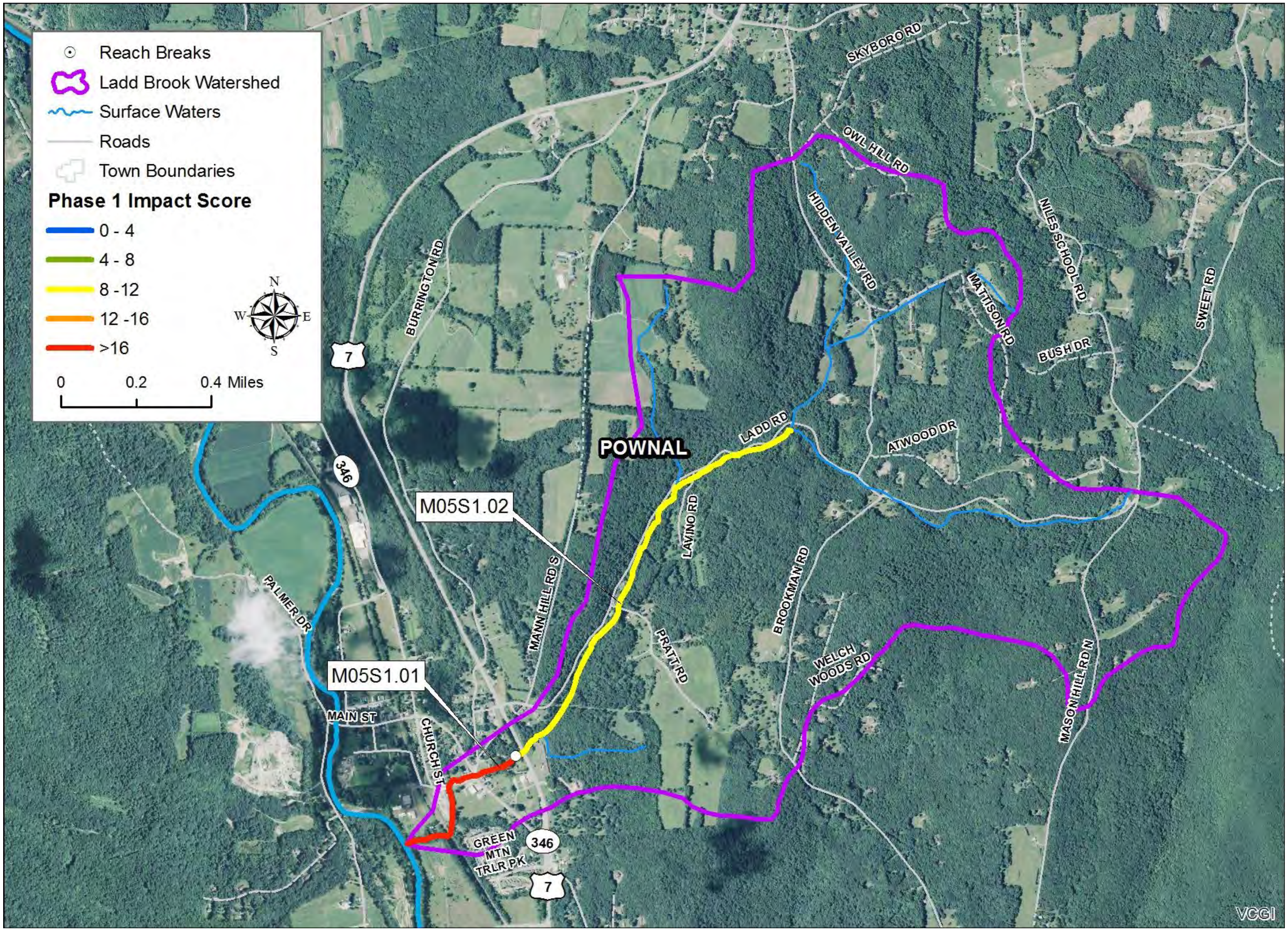

Figure 3.4: Phase 1 impact scores for the Ladd Brook watershed.

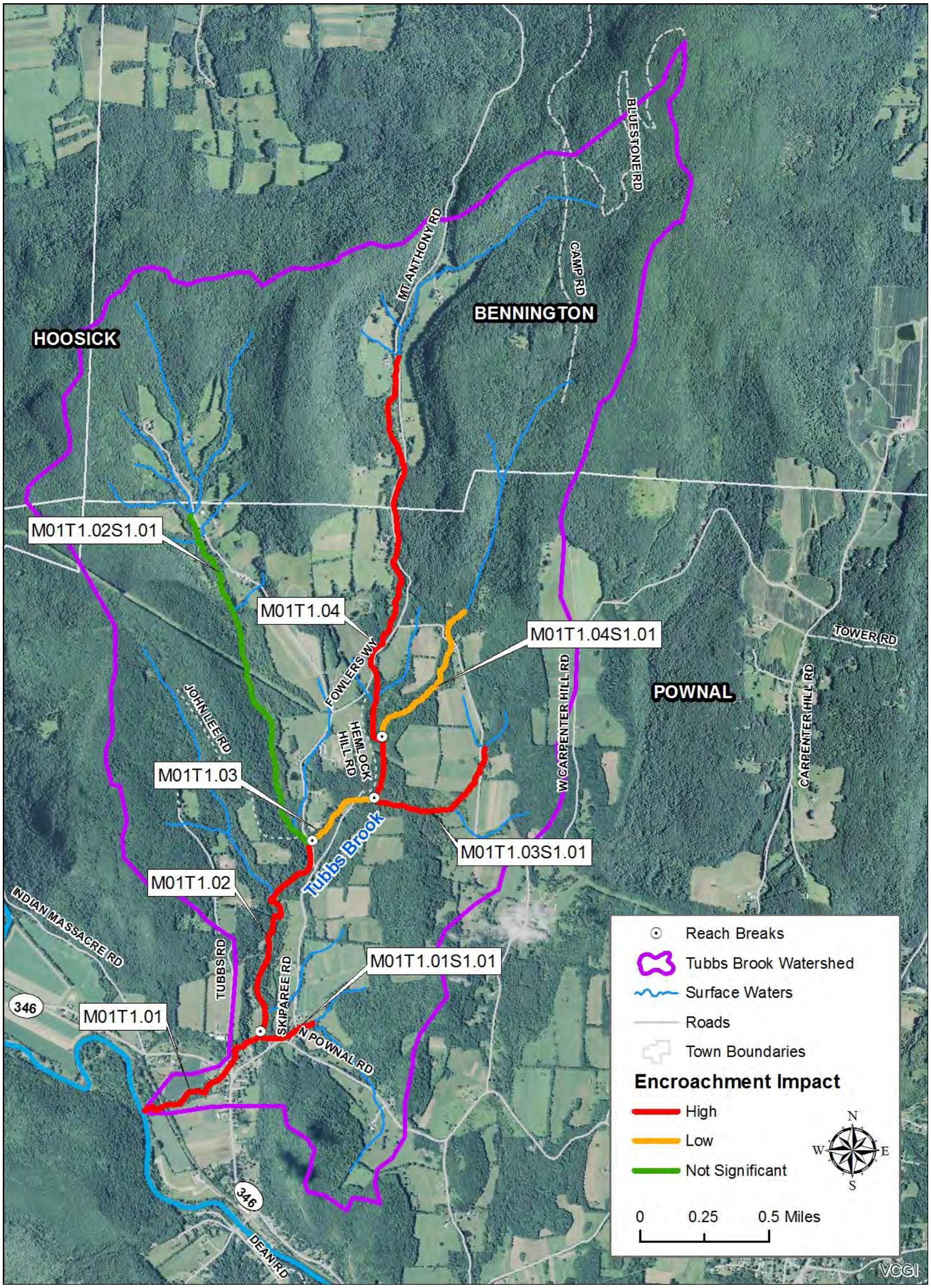

Figure 3.5: Phase 1 encroachment impacts for the Tubbs Brook watershed.

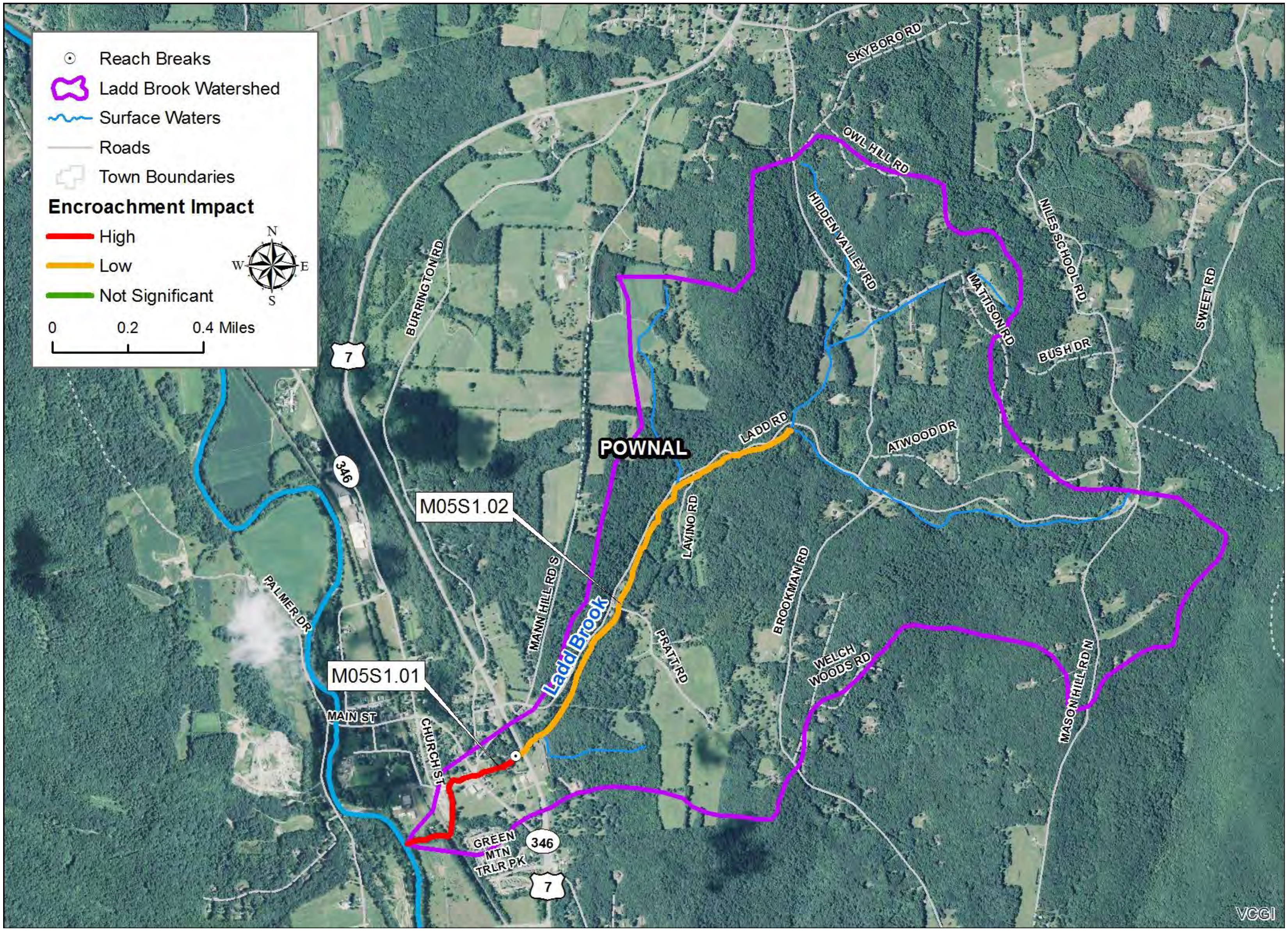

Figure 3.6: Phase 1 encroachment impacts for the Ladd Brook watershed.

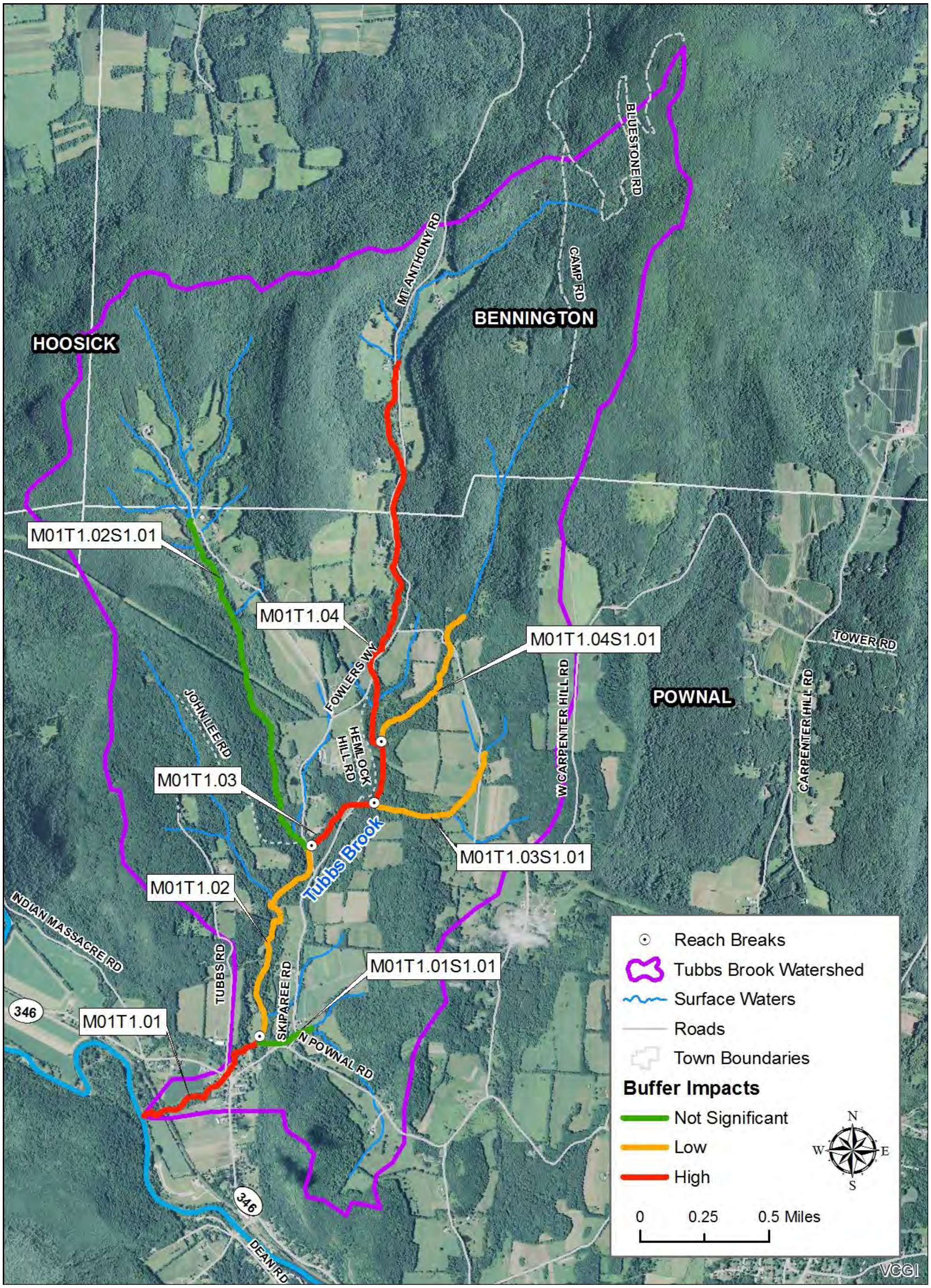

Figure 3.7: Phase 1 buffer impacts for the Tubbs Brook watershed.

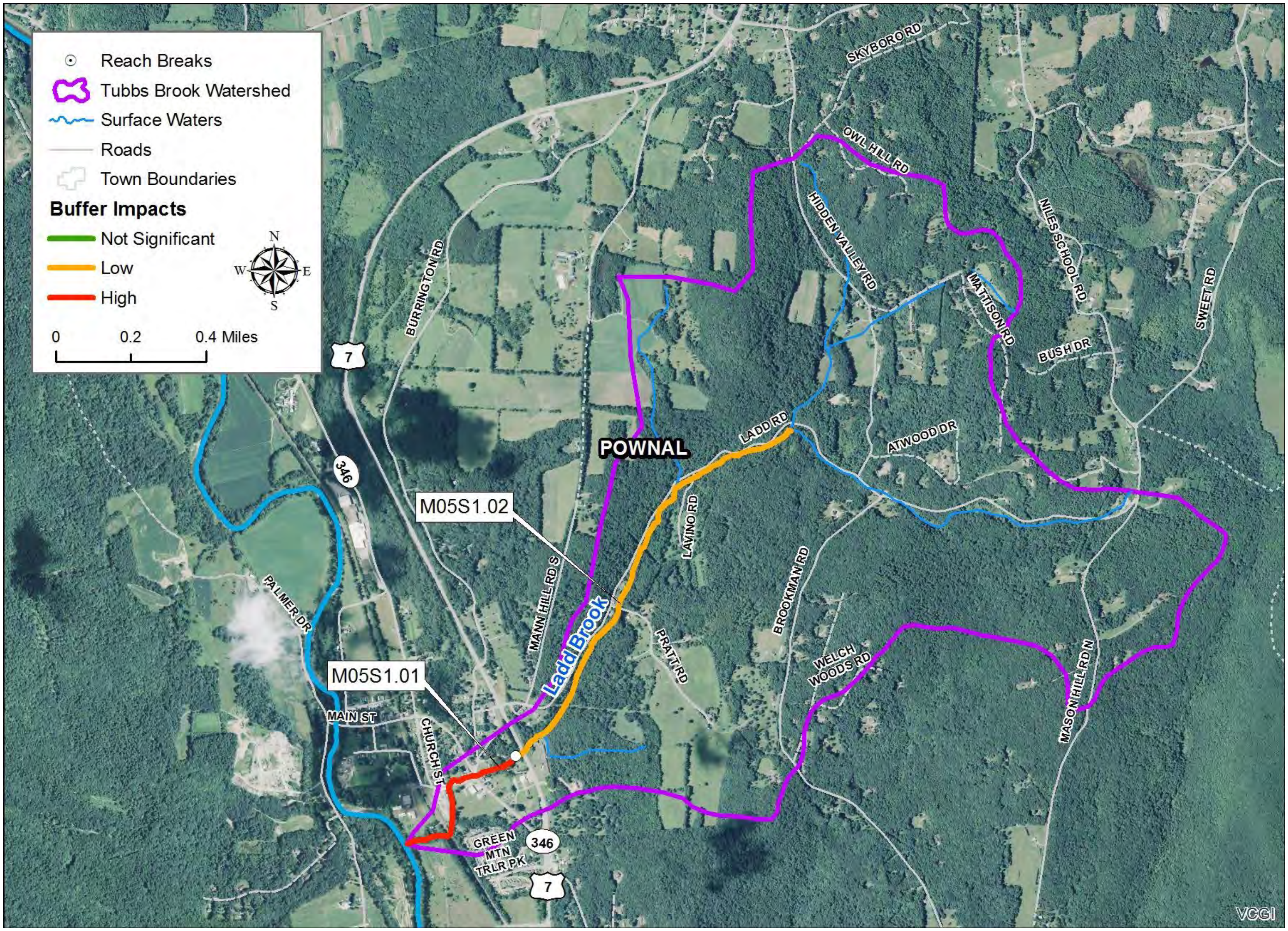

Figure 3.8: Phase 1 buffer impacts for the Ladd Brook watershed.

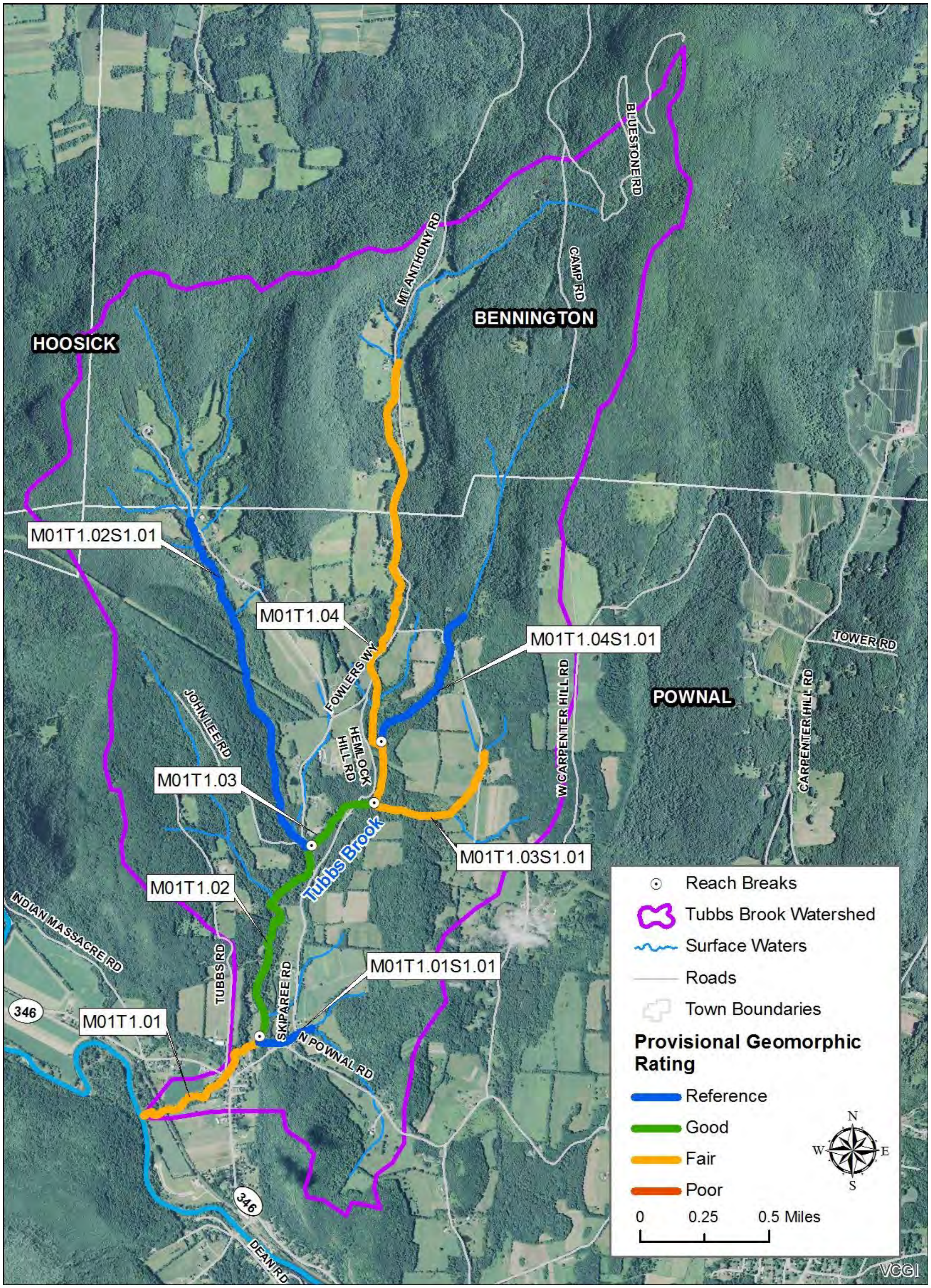

Figure 3.9: Provisional geomorphic ratings for the Tubbs Brook watershed.

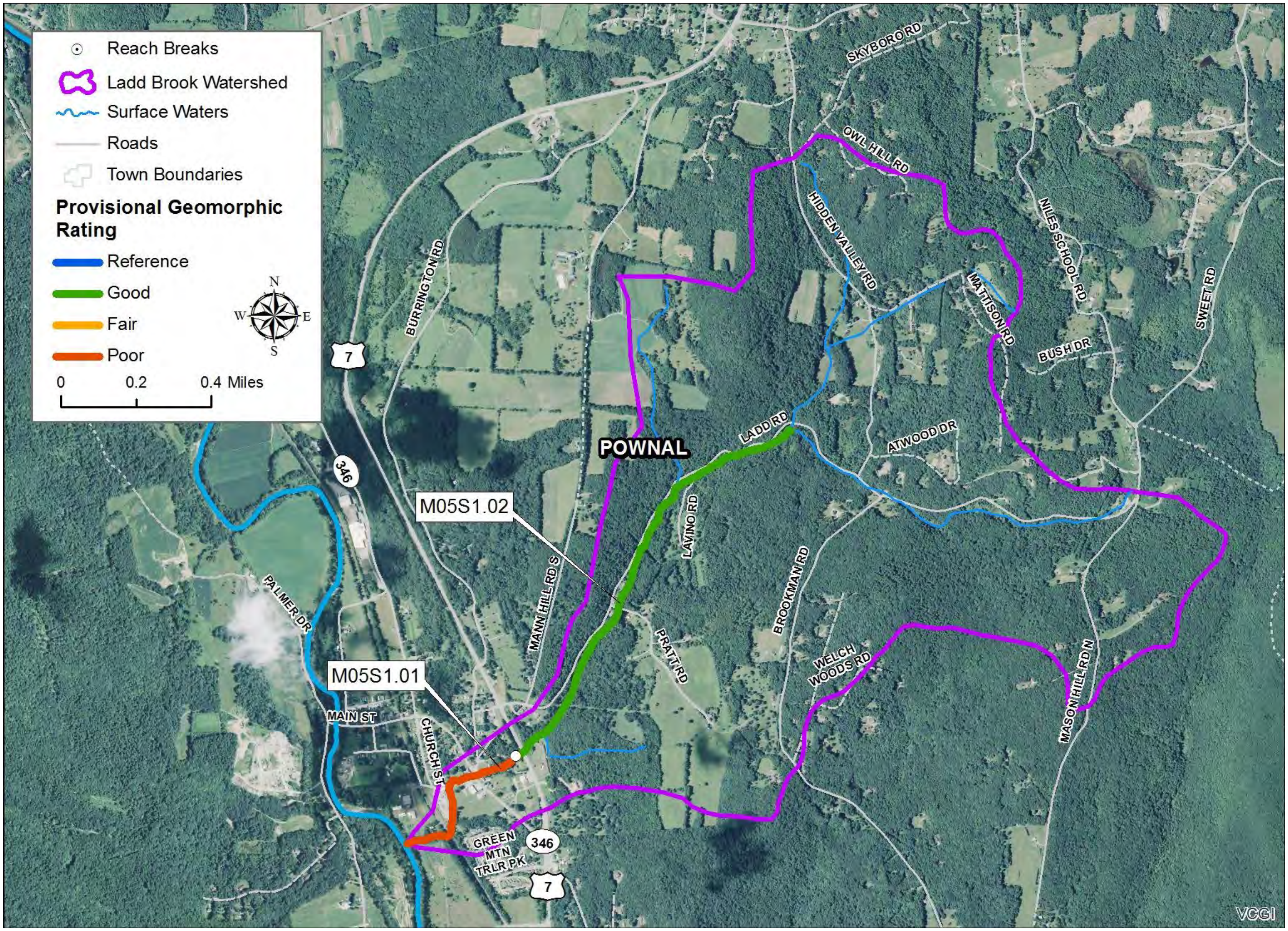

Figure 3.10: Provisional geomorphic ratings for the Ladd Brook watershed.

3.4 Phase 2 Reach Recommendations

Using the Phase 1 Impact Ratings as the primary basis for reach selection, a list of reaches was developed for Phase 2 surveys within the Ladd and Tubbs Brook watersheds. Table 3.6 summarizes the seven (7) selected reaches covering 6.0 miles based on watershed location, channel length, channel slope, valley type, and preliminary reference stream type.

Table 3.6: Phase 2 reach recommendations and Phase 1 Impact Ratings.

Surface Water	Reach ID	Channel Length (Mi)	Channel Slope (%)	Valley Type*	Reference Stream Type†	Bedform‡	Impact Score (Geo Condition)
Ladd Brook	M05S1.01	0.46	3.64	VB	$C4_b$	Riffle-Pool	20 (Poor)
	M05S1.02	1.22	6.80	SC	$B3_a$	Riffle-Pool	9 (Good)
Tubbs Brook	M01T1.01	0.63	1.12	VB	C4	Riffle-Pool	15 (Fair)
	M01T1.02	0.90	2.64	NW	$C3_b$	Riffle-Pool	8 (Good)
	M01T1.03	0.32	4.65	NW	C3	Riffle-Pool	8 (Good)
	M01T1.04	1.85	5.97	NW	B3	Step-Pool	12 (Fair)
4th Trib to Tubbs	M01T1.01S1.01	0.65Δ	8.42	NW	B3	Riffle-Pool	6 (Ref)

* SC= Semi-confined; NW= Narrow; BD=Broad; VB=Very Broad, NC=No Confinement; † per Rosgen, 1994
‡ per Montgomery and Buffington, 1997; Δ denotes that the uppermost segment of each reach was not planned for Phase 2 assessment

4.0 Phase 2 Results and River Corridor Planning

Phase 2 assessments were conducted on 7 reaches from June through October, 2016. Reach M01T1.04 was broken into multiple segments, for a total of 10 reaches and segments covering 6.0 miles (Figures 4.1 and 4.2). One (1) segment was not fully assessed due to a bedrock gorge (M01T1.04.A).

4.1 Phase 2 Segment Summary Sheets

One page summaries for each Phase 2 segment/reach are presented in this section. The impact summary section includes color-coded designations of Not Significant, Low, or **High** levels of impact based on data collected during the Phase 2 assessments. Impact levels were assigned based on the longitudinal effect (<5% - Not Significant, 5-20% - Low, and >20% - High), and the overall impact of discrete features on the reach/segment (constrictions, stormwater inputs, steep riffles, etc.). Based on our professional judgment; potential impacts for bridges (B), culverts (C), and other (O) constrictions were summarized with the following abbreviations:

- **AOP**: Aquatic organism passage
- **D**: Deposition upstream and/or downstream
- **E**: Bank erosion upstream and/or downstream
- **I**: Ice/Debris jamming
- **R/R**: Failing bank armor upstream and/or downstream
- **S**: Scour upstream and/or downstream

Incision Ratio and Entrenchment Ratios are important indicators of the degree of stream departure from reference condition. Incision ratio describes the degree of floodplain accessibility: values close to 1.0 represent reference conditions with an accessible floodplain, values greater than 2.0 indicate an extreme disconnection of floodplain typically associated with a stream type departure. Entrenchment ratio describes the width of the floodprone area in relation to the bankfull channel width. Reference entrenchment ratios vary with stream type and valley setting. Stream impacts such as encroachment, incision, widening, and straightening may all lower the entrenchment ratio. C-type streams typically have entrenchment ratios greater than 2.0 and values below 2.0 or 1.4 represent stream type departures to B or F-type respectively. Definitions for technical terminology within the summary sheets are provided in the Glossary of Terms in Section 8.0.

Habitat assessment rankings for large woody debris and pool counts (measured in reference to predicted bankfull width - wbkf) are defined in Table 4.1.

Table 4.1: LWD and Pool Ranking for RHA.

Rank	**LWD**		**Pool**	
	Diameter (ft)	**Length (relative to wbkf)**	**Depth (ft)**	**Length/Width (relative to wbkf)**
1	0.5≤D<1.0	<0.5	1.0≤D<2.0	<0.5
2	0.5≤D<1.0	≥0.5	1.0≤D<2.0	≥0.5
3	1.0≤D<2.0	<0.5	2.0≤D<3.0	<0.5
4	1.0≤D<2.0	≥0.5	2.0≤D<3.0	≥0.5
5	D≥2.0	<0.5	D≥3.0	<0.5
6	D≥2.0	≥0.5	D≥3.0	≥0.5
7	--	--	D≥3.0	≥1.0

Preliminary projects identified for each reach/segment are included in the following summary sheets. These projects were identified during the Phase 2 field data collection effort and during follow-up site visits with the Town of Pownal Road Foreman and BCRC. These projects, and the basis for selecting and evaluating them, are discussed in greater detail in Section 5.2.

4.1.1 Tubbs Brook Phase 2 Assessment Summary

The Phase 2 assessed reaches/segments on Tubbs Brook within the Towns of Pownal and Bennington are described below (Figure 4.1). Reach M01T1.04A was not assessed due to continuous bedrock grade control.

- Reach M01T1.01
  - This reach flows from the confluence with the first unnamed tributary to Tubbs Brook to the Hoosic River confluence. Historic straightening and armoring caused channel incision that appears to be slowing, with widening and deposition processes increasing in some areas.
  - T.S. Irene damage was minimal in North Pownal, but there is evidence of increased sediment loads still making their way through the channel.
- Reach M01T1.02
  - This reach flows from the confluence with the second unnamed tributary to Tubbs Brook to the confluence with the first unnamed tributary. Widening and planform adjustment are increased by the aggradation of coarse sediments working through the reach.
  - The channel flows throughs bedrock grade controls with deep pools downstream. We observed large trout residing in these pools during a period of relatively low flow.
- Reach M01T1.03
  - This reach flows from the confluence of the third unnamed tributary to Tubbs Brook to the confluence of the second unnamed tributary to Tubbs Brook. This reach was characterized by aggradation of coarse sediment where the channel slope lowers downstream of large grade controls.
- Reach M01T1.04
  - Reach M01T1.04 was divided into four segments based on grade controls and channel characteristics. The first segment (A) is relatively stable due to a continuous bedrock gorge. Segment B was wider with a lower slope than the upstream segment (C). Segment D was a lower-gradient braided E-type channel through a cow pasture.
  - Sub-tributary M01T1.04S1.01 flows from the upstream of the inlet of the Mount Anthony Road culvert to the confluence with Tubbs Brook. The reach is characterized by near-continuous grade controls and high coarse sediment loads.

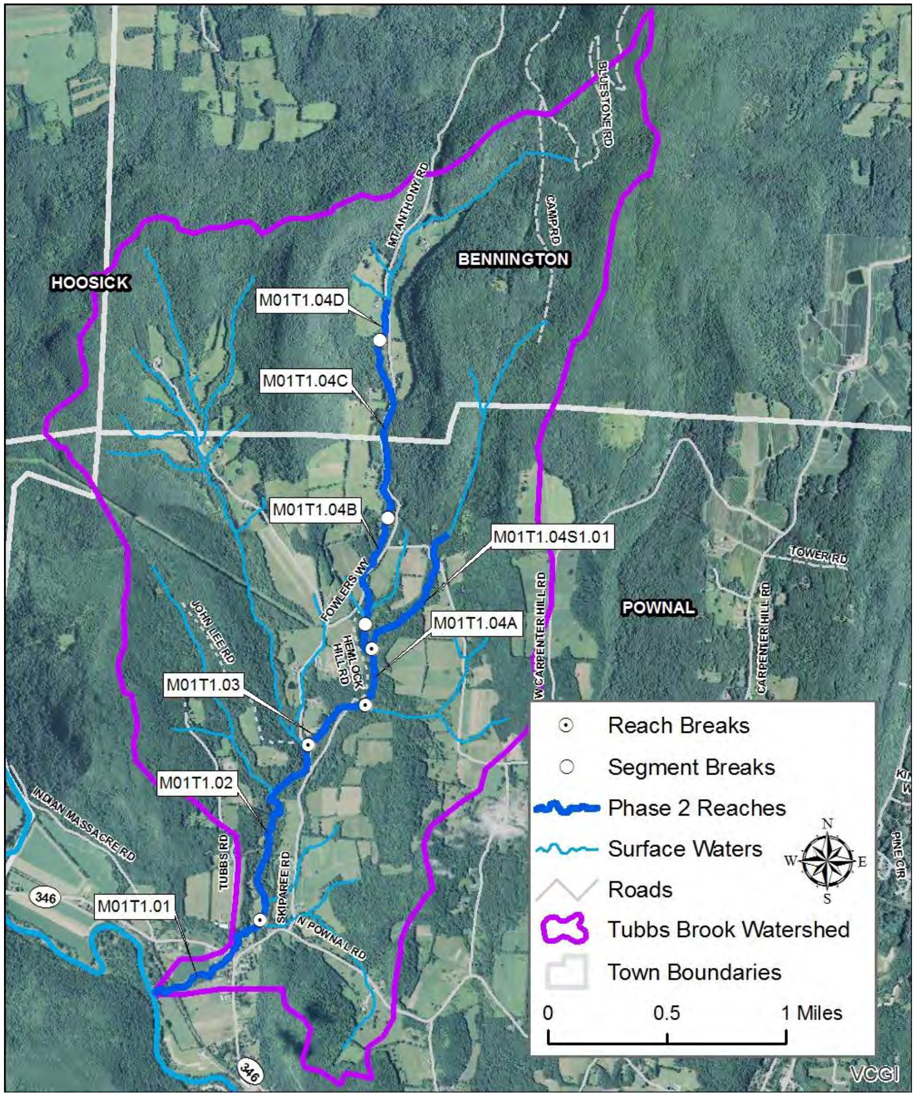

Figure 4.1: Tubbs Brook reach and segment locations.

Stream: Tubbs Brook **Reach:** M01T1.01 **Town:** Pownal **Date Assessed:** 8/18/16

Channel Length (ft): 3,347 **Channel Slope (%):** 1.12 **Sinuosity:** 1.70 **Watershed Area (mi²):** 5.81

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Very Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	C	Bc

Ph2 Cross-Section Data

Curve Width (ft)	28.4
Bankfull Width (ft)	24
Max Depth (ft)	2.1
Width/Depth Ratio	15.3
Entrenchment Ratio	1.8
Incision Ratio	2.7

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Railroad	74%	D
B	Rt 345	79%	D,E
B	Private	169%	D,E

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	10	1
2	11	7
3	7	0
4	3	6
5	1	0
6	0	0
7	0	3
#/mile	50	26

Number of Debris Jams: 4

Step 6/7 Summary

RHA Score/Condition	51/Fair
Habitat Type Departure	None
RGA Score / Condition	49/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	C to B
Stream Sensitivity	High

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- **TB 1:** Corridor Protection and Buffer Planting – Establishing and protecting a vegetated floodplain buffer will allow for further meander development between the railroad and Hoosic River.
- **TB 2:** Bridge Replacement – High coarse sediment loads increase the risk of the railroad bridge jamming and flooding due to its floodprone constriction and low clearance.
- **TB 3:** Infrastructure Resiliency – Bank stability and erosion may threaten a home in North Pownal. The banks should be monitored and possibly armored.

Reach Highlights: Historically this reach was incised due to straightening through agricultural fields. There is evidence of deposition from sediment loads working their way through the channel following T.S. Irene. We assessed this reach as stage II progressing towards stage III due to the channel's relatively stable banks and little evidence of planform adjustment. The stream departed from a C to a F-type channel due to incision and entrenchment.

Incised channel in a very broad valley

F-type channel; partially dry during assessment

Stream: Tubbs Brook **Reach:** M01T1.02 **Town:** Pownal **Date Assessed**: 10/3/16

Channel Length (ft): 4,776 **Channel Slope (%):** 2.2 **Sinuosity:** 1. 06 **Watershed Area (mi²):** 5.28

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	C_b	C_b

Ph2 Cross-Section Data

Curve Width (ft)	27.2
Bankfull Width (ft)	23.8
Max Depth (ft)	2.1
Width/Depth Ratio	15.6
Entrenchment Ratio	2.4
Incision Ratio	1.5

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
C	Skiparee	31%	D,E,R/R,S

\# of Other Constrictions: 0
\# of Grade Controls: 7

Rapid Habitat Assessment

Rank	LWD	Pools
1	13	8
2	26	15
3	3	1
4	11	5
5	1	0
6	5	0
7	0	2
#/mile	65	34

Number of Debris Jams: 5

Step 6/7 Summary

RHA Score/Condition	61/Fair
Habitat Type Departure	None
RGA Score / Condition	71/Good
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	None
Stream Sensitivity	High

Impact Summary

Bank Erosion	**Stormwater**
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- **TB 4:** Gully Stabilization – A small tributary is severely incised and is likely to deliver sediment to Tubbs Brook. Gully stabilization would arrest further incision and erosion.
- **TB 5:** Cattle Exclusion – Cattle access has damaged banks. Fencing cattle out of stream would reduce nutrient loading and erosion.
- **TB 6:** Stormwater Treatment and Gully Stabilization –Reconfiguring a stormwater pipe on Skiparee Road would reduce scour at the outlet. Stabilizing the resulting gully would reduce erosion.
- **TB 7:** Culvert Replacement – Two culverts under Skiparee road are bankfull constrictions and completely block AOP.

Reach Highlights: This reach flows through a narrow unconfined valley with several large grade controls. The upper part of the reach is affected by encroachment from Skiparee Road. We assessed this reach as stage IV because of the ongoing aggradation of coarse sediment loads from upstream that are increasing the rate of widening and planform adjustment.

C-type channel in a narrow unconfined valley

Bedrock cascade grade control

Stream: Tubbs Brook **Reach:** M01T1.03 **Town:** Pownal **Date Assessed:** 10/03/16

Channel Length (ft): 1,703 **Channel Slope (%):** 1.5 **Sinuosity:** 1. 00 **Watershed Area (mi^2):** 2.91

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Narrow
Bedform	Step-Pool	Riffle-Pool
Median Substrate	Cobble	Gravel
Stream Type	C	C

Ph2 Cross-Section Data

Curve Width (ft)	20.9
Bankfull Width (ft)	24
Max Depth (ft)	1.6
Width/Depth Ratio	20.7
Entrenchment Ratio	3.6
Incision Ratio	1.0

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
C	Hemlock Hill	28%	AOP,D,E,R/R ,S

# of Other Constrictions: 0
# of Grade Controls: 2

Rapid Habitat Assessment

Rank	LWD	Pools
1	12	7
2	13	6
3	3	0
4	10	1
5	2	0
6	1	0
7	0	1
#/mile	41	46

Number of Debris Jams: 5

Step 6/7 Summary

RHA Score/Condition	63/Fair
Habitat Type Departure	None
RGA Score / Condition	69/Good
Dominant Adjustment	Aggradation
CEM Model Stage	F/III
Stream Type Departure	None
Stream Sensitivity	High

Impact Summary

Bank Erosion	**Stormwater**
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- **TB 8:** Stormwater Treatment and Gully Stabilization – Stormwater runoff from Hemlock Hill Road is creating a gully. Installing check dams would trap sediment and reduce runoff velocities.

Reach Highlights: This reach flows through a narrow unconfined valley with a large grade control. We assessed this reach as stage III because of the ongoing aggradation upstream of grade controls and downstream of the bedrock gorge in the upstream reach.

C-type channel in an unconfined valley

Stormwater runoff from Hemlock Hill Road

Stream: Tubbs Brook **Reach:** M01T1.04B **Town:** Pownal **Date Assessed**: 8/17/16

Channel Length (ft): 2,644 **Channel Slope (%):** 3.4 **Sinuosity:** 1.02 **Watershed Area (mi^2):** 2.26

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Narrow
Bedform	Step-Pool	Step-Pool
Median Substrate	Cobble	Gravel
Stream Type	B	B

Ph2 Cross-Section Data

Curve Width (ft)	18.8
Bankfull Width (ft)	17.37
Max Depth (ft)	1.4
Width/Depth Ratio	18.3
Entrenchment Ratio	1.3
Incision Ratio	1.7

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
C	Fowlers Way	64%	D
C	Private	32%	D,E
C	Private	32%	D,E

\# of Other Constrictions: 0
\# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	17	15
2	19	10
3	2	0
4	8	1
5	2	0
6	3	0
7	0	0
#/mile	101	51

Number of Debris Jams: 7

Step 6/7 Summary

RHA Score/Condition	53/Fair
Habitat Type Departure	None
RGA Score / Condition	39/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	None
Stream Sensitivity	High

Impact Summary

Bank Erosion	**Stormwater**
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- **TB 10:** Stormwater Treatment – Stormwater runoff from Fowlers Way and Mt. Anthony Road spills onto the floodplain through a ditch turnout. Installing dams and a collection area would trap sediment and slow runoff.
- **TB 11:** Culvert Replacement/Retrofit – A steel tank culvert constricts the channel and a sand embankment is likely contributing a large amount of sediment to the channel. Replacing the culvert with a larger structure would reduce constriction. Replacing and vegetating the fill material may reduce sediment losses.

Reach Highlights: Upstream of the gorge the reach has a lower slope and flows through a narrow unconfined valley that it shares with Fowler Road. We assessed this reach as stage IV because of ongoing aggradation and planform adjustment processes increased by high coarse sediment loads.

Broader valley upstream of bedrock gorge

Poorly sorted sediment in an aggrading channel

Stream: Tubbs Brook **Reach:** M01T1.04C **Town:** Pownal, Bennington **Date Assessed**: 8/17/16

Channel Length (ft): 4,199 **Channel Slope (%):** 4.0 **Sinuosity:** 1.02 **Watershed Area (mi^2):** 2.26

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Narrow
Bedform	Step-Pool	Riffle-Pool
Median Substrate	Cobble	Gravel
Stream Type	B	B

Ph2 Cross-Section Data

Curve Width (ft)	18.8
Bankfull Width (ft)	14.5
Max Depth (ft)	1.7
Width/Depth Ratio	13.3
Entrenchment Ratio	1.6
Incision Ratio	1.5

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
C	Mt. Anthony	35%	D
C	Mt. Anthony	43%	D,E,S
C	Private	27%	D,E

# of Other Constrictions: 0
# of Grade Controls: 1

Rapid Habitat Assessment

Rank	LWD	Pools
1	43	29
2	50	5
3	12	0
4	12	0
5	0	0
6	1	0
7	0	0
#/mile	148	42

Number of Debris Jams: 10

Step 6/7 Summary

RHA Score/Condition	57/Fair
Habitat Type Departure	Riffle-Pool
RGA Score / Condition	38/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	None
Stream Sensitivity	High

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- **TB 12:** Road Maintenance – Sediment loading from a steep road embankment may be decreased by installing a barrier on the edge of the slope, clearing loose material, and vegetating the bank.
- **TB 13:** Road Resiliency – Undermining of the road embankment is causing trees to lean and should be monitored for slope failures.
- **TB 14:** Culvert Replacement and Driveway Relocation – Undersized culverts are constricting the channel and arresting AOP.
- **TB 15:** Gully Stabilization – Runoff from hayfield has formed a gully

Reach Highlights: This reach flow through a narrow unconfined valley and is affected by historic straightening and encroachment from Mount Anthony Road. We assessed this reach as stage IV because of the ongoing aggradation and planform adjustments increased by high coarse sediment loads.

Adjusting channel in an unconfined valley

Aggradation of gravel

Stream: Tubbs Brook **Reach:** M01T1.04D **Town:** Bennington **Date Assessed**: 8/18/16

Channel Length (ft): 959 **Channel Slope (%):** 1.5 **Sinuosity:** 1.02 **Watershed Area (mi²):** 2.26

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Gravel
Stream Type	E	E

Ph2 Cross-Section Data

Curve Width (ft)	18.8
Bankfull Width (ft)	14
Max Depth (ft)	1.9
Width/Depth Ratio	11.6
Entrenchment Ratio	2.6
Incision Ratio	1.3

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
C	Mt. Anthony	64%	D,S

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	7	1
2	2	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
#/mile	49	5

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	44/Fair
Habitat Type Departure	None
RGA Score / Condition	44/Fair
Dominant Adjustment	Aggradation
CEM Model Stage	F/III
Stream Type Departure	None
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- **TB 16:** Corridor Protection – The channel and floodplain are openly accessed by pastured cattle. Excluding cattle from the stream and establishing native woody vegetation in the floodplain area would reduce sediment and nutrient loading.

Reach Highlights: This reach was historically straightened and is currently affected by encroachment from Mount Anthony Road and bank erosion due to cattle activity in and around the channel. We assessed the reach as E-type based on the valley setting and the low slope. The channel has relatively large substrate and a high sediment load reducing incision potential, despite the ongoing damage from cattle grazing. We assessed this reach as stage III because of the ongoing aggradation with no evidence of active incision.

Channel braiding and aggradation

Cow paths adjacent to and crossing the reach

Stream: 4th Unnamed Tributary to Tubbs Brook **Reach:** M01T1.04S1.01 **Town:** Pownal **Date Assessed**: 8/17/16

Channel Length (ft): 3,439 **Channel Slope (%):** 5 **Sinuosity:** 1.01 **Watershed Area (mi^2):** 0.67

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Narrow
Bedform	Step-Pool	Riffle-Pool
Median Substrate	Cobble	Gravel
Stream Type	B	B

Ph2 Cross-Section Data

Curve Width (ft)	11
Bankfull Width (ft)	17
Max Depth (ft)	0.6
Width/Depth Ratio	27.4
Entrenchment Ratio	1.6
Incision Ratio	1.4

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
C	Mt. Anthony	45%	AOP,D,E

\# of Other Constrictions: 0
\# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	27	10
2	80	10
3	11	0
4	35	0
5	1	0
6	7	0
7	0	0
#/mile	232	31

Number of Debris Jams: 12

Step 6/7 Summary

RHA Score/Condition	68/Good
Habitat Type Departure	None
RGA Score / Condition	36/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	None
Stream Sensitivity	High

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- **TT 1:** Gully Stabilization – Driveway runoff to a steep valley has formed a gully. Lining the gully would stabilize it and reduce sediment inputs.

Reach Highlights: This reach flows through a narrow unconfined valley, despite its high slope. The upper part of the reach is affected by encroachment from Mount Anthony Road. We assessed this reach as stage IV channel widening and planform adjustment processes increased by high coarse sediment loads and near-continuous debris jams throughout the reach.


Narrow valley with a widening channel


Scoured banks and poorly sorted sediment

4.1.2 Ladd Brook Phase 2 Assessment Summary

The Phase 2 assessed reaches on Ladd Brook within the Town of Pownal are described below (Figure 4.2).

- Reach M05S1.01
  - This reach flows from the outlet of the Route 7 culvert to the confluence with the Hoosic River through an unconfined very broad valley. Historic straightening and development caused channel incision, but fairly stable and vegetated banks suggest this process is slowing.
  - Major flooding during T.S. Irene occurred in the Alta Gardens and Green Mountain Trailer Park off Post Drive. where the channel slope and confinement decrease. Several undersized culverts, as well as the sharp bend in the channel from historic straightening may have increased flooding.
- Reach M05S1.02
  - This reach flows from the confluence of the third unnamed tributary to the outlet of the Route 7 culvert through a narrow to semi-confined valley. The reach is characterized by relatively steep slopes and numerous grade controls. Despite encroachment and development in the valley, this reach maintains some ability to adjust planform and access floodplains.

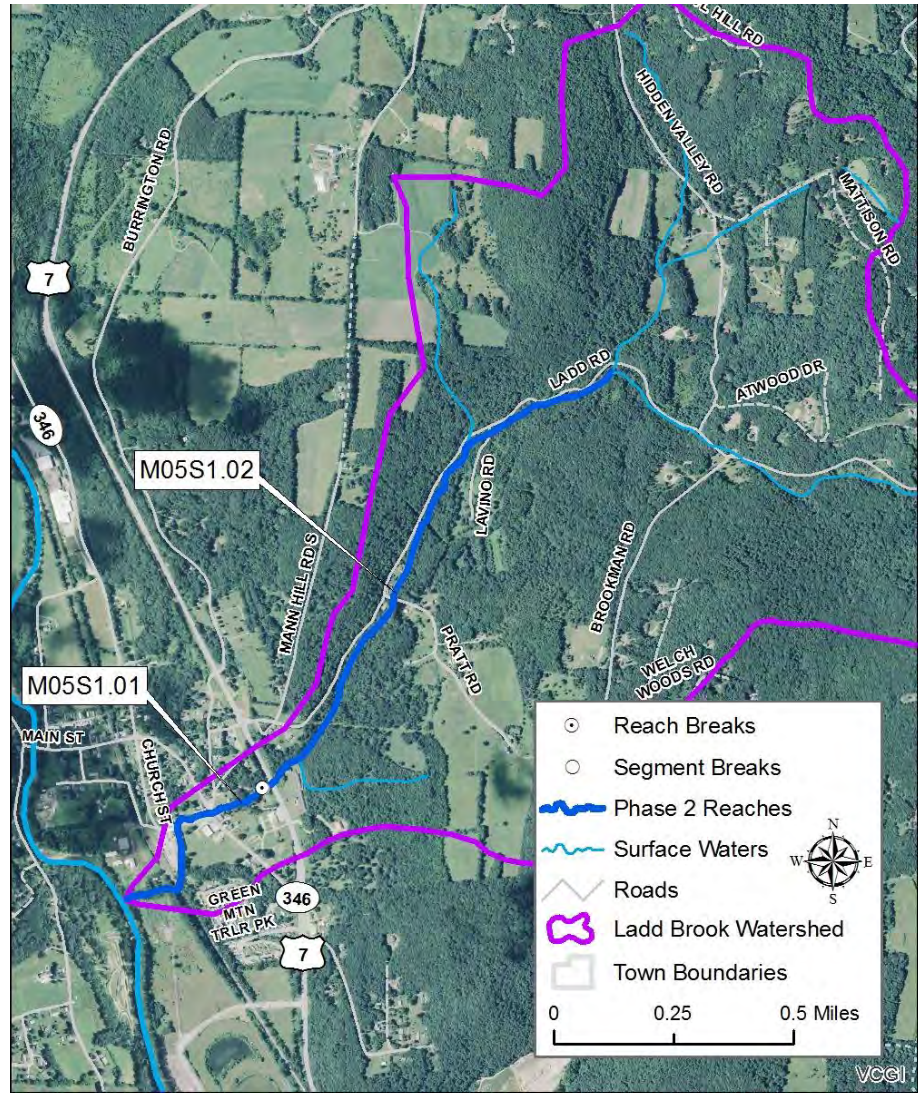

Figure 4.2: Ladd Brook reach locations.

Stream: Ladd Brook **Reach:** M05S1.01 **Town:** Pownal **Date Assessed:** 10/04/16

Channel Length (ft): 2,430 **Channel Slope (%):** 3.64 **Sinuosity:** 1.18 **Watershed Area (mi^2):** 1.82

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Very Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	17
Bankfull Width (ft)	12
Max Depth (ft)	1.4
Width/Depth Ratio	12.5
Entrenchment Ratio	1.7
Incision Ratio	3.1

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
C	Private	47%	AOP,D,E,I
C	Railroad	35%	D,E,R/R
C	Church	59%	D,R/R
C	Route 346	59%	

\# of Other Constrictions: 0
\# of Grade Controls: 1

Rapid Habitat Assessment

Rank	LWD	Pools
1	23	6
2	30	5
3	5	0
4	4	0
5	0	0
6	0	0
7	0	0
#/mile	134	23

Number of Debris Jams: 5

Step 6/7 Summary

RHA Score/Condition	53/Fair
Habitat Type Departure	None
RGA Score / Condition	52/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	C to F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	**Stormwater**
Armoring	**Constrictions**
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- **LB 1:** Culvert Removal – Two culverts under a potentially abandoned crossing are a major constriction and are likely increasing flooding in the mobile home park.
- **LB 2:** Culvert Retrofit/Replacement – The railroad culvert is a major constriction and is increasing flooding in the mobile home park.
- **LB3:** Dam Removal – A makeshift dam is increasing channel aggradation and exacerbating flooding in the mobile home park.
- **LB4:** Buffer Planting – A residential property has mowed lawn to the stream bank.

Reach Highlights: Historically this reach was incised due to straightening and armoring. We assessed this reach as stage II because of low deposition and planform adjustment processes. The stream departed from a C to an F-type channel due to incision and entrenchment. The lower reach is severely manipulated near the mobile home park, which has exacerbated flood risks upstream of the railroad crossing.


Incised channel in a very broad valley


Constrictions affecting channel drainage

Stream: Ladd Brook **Reach:** M05S1.02 **Town:** Pownal **Date Assessed**: 10/04/16

Channel Length (ft): 6,421 **Channel Slope (%):** 6.8 **Sinuosity:** 1.01 **Watershed Area (mi²):** 1.73

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Semi-Confined	Semi-Confined
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	B	B

Ph2 Cross-Section Data

Curve Width (ft)	16.7
Bankfull Width (ft)	17
Max Depth (ft)	0.9
Width/Depth Ratio	17.6
Entrenchment Ratio	2.1
Incision Ratio	1.0

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
C	Route 7	35%	AOP,D
C	Pratt Rd	36%	D,I,R/R
C	Lavino Rd	30%	D

# of Other Constrictions: 0
# of Grade Controls: 13

Rapid Habitat Assessment

Rank	LWD	Pools
1	140	23
2	122	10
3	23	1
4	33	1
5	8	0
6	5	0
7	0	0
#/mile	276	29

Number of Debris Jams: 13

Step 6/7 Summary

RHA Score/Condition	59/Fair
Habitat Type Departure	None
RGA Score / Condition	65/Good
Dominant Adjustment	Planform
CEM Model Stage	F/I
Stream Type Departure	None
Stream Sensitivity	Moderate

Impact Summary

Bank Erosion	**Stormwater**
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- **LB 5:** Dam Removal – Defunct dam is an AOP barrier
- **LB 6 and 10:** Buffer Planting – Buffer vegetation is lacking along a portion of the channel
- **LB 7, 8, and 11:** Road Maintenance – Very steep road shoulder is eroding into channel
- **LB 9:** Culvert Retrofit/Replacement – Undersized structure is also an AOP barrier
- **LB 12:** Road Maintenance – Excess road material was dumped down the bank and is eroding into the channel

Reach Highlights: This reach is located in a naturally semi-confined valley that it shares with Ladd Road. Encroachment and development have narrowed this valley, but the channel maintains some ability to move and access floodplains within the valley. We assessed this reach as stage I. Grade controls throughout much of the reach maintain vertical stability; in some areas minor widening and planform adjustment processes were observed where sediment is aggrading behind the grade controls.

Planform adjustment in a semi-confined valley

Stormwater outlet and steep embankment along Ladd Rd

4.2 Phase 2 Results Summary

Rapid Habitat Assessment (RHA) and Rapid Geomorphic Assessment (RGA) scores for all Phase 2 reaches/segments are summarized in Table 4.2 and Figures 4.3 – 4.6. FEA divided the "Fair" category into "Low Fair" and "High Fair" to better indicate which reaches were closer to "Poor" or "Good" respectively. The "Fair" scores were split at the numerical mean for the categories (49%). Detailed summaries of geomorphic data for each segment are provided in Appendix B. Habitat assessment summary data is provided in Appendix C.

Table 4.2: Summary RHA and RGA data for all Phase 2 Reaches and Segments.

Stream	Reach/Segment	RHA Score	RHA Condition	RGA Score	RGA Condition
Ladd Brook	M05S1.01	53%	High-Fair	52%	High-Fair
	M05S1.02	59%	High-Fair	57%	High-Fair
Tubbs Brook	M01T1.01	51%	High-Fair	49%	Low-Fair
	M01T1.02	61%	High-Fair	71%	Good
	M01T1.03	63%	High-Fair	69%	Good
	M01T1.04A		Good*		Reference*
	M01T1.04B	53%	High-Fair	39%	Low-Fair
	M01T1.04C	57%	High-Fair	38%	Low-Fair
	M01T1.04D	44%	Low-Fair	44%	Low-Fair
Tubbs Brook Tributary 4	M01T1.04S1.01	68%	Good	36%	Low-Fair

*RHA and RGA assigned based on administrative judgment, full assessment not conducted on M01T1.04A

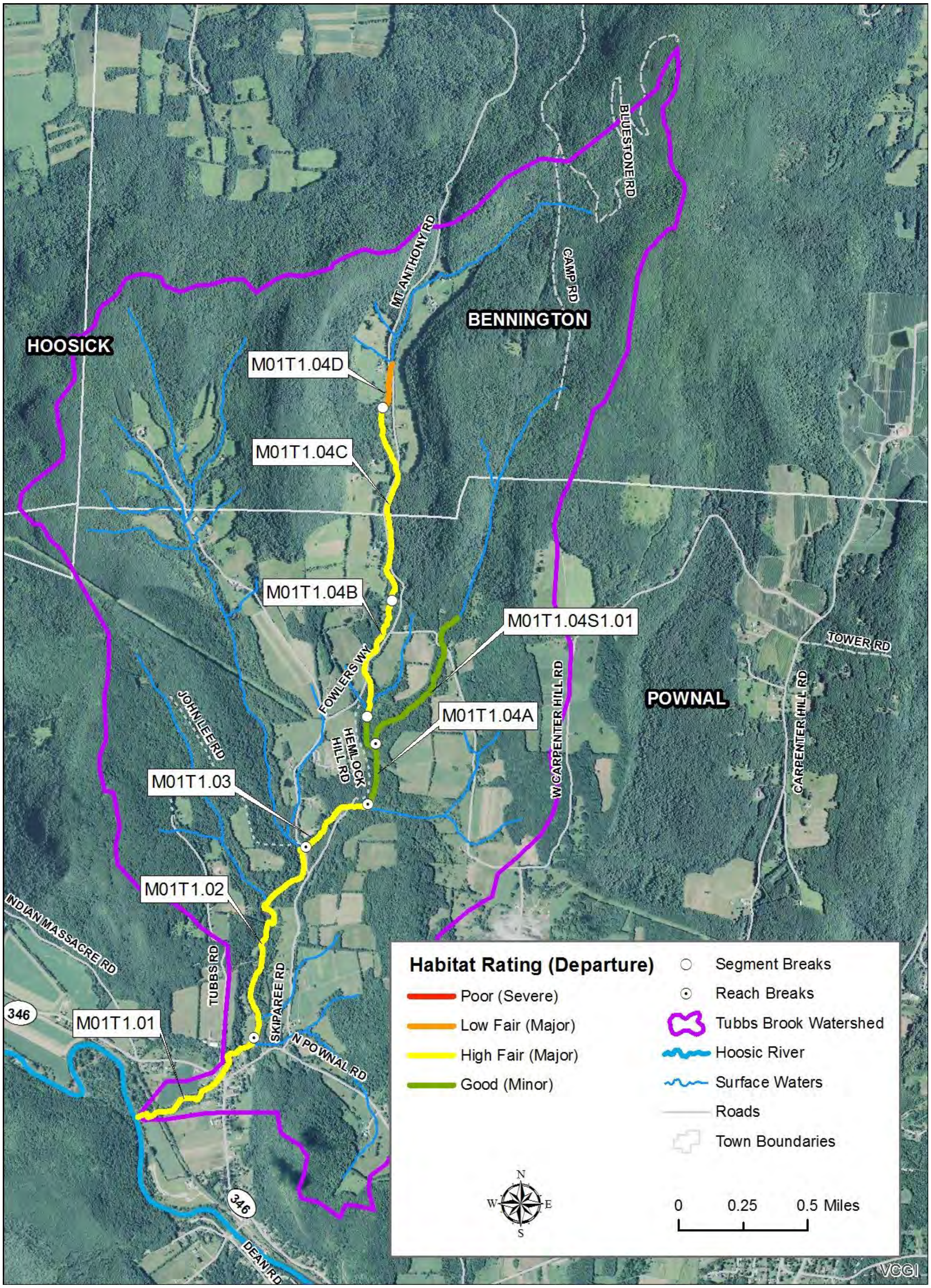

Figure 4.3: Rapid Habitat Assessment Ratings for the Tubbs Brook Watershed

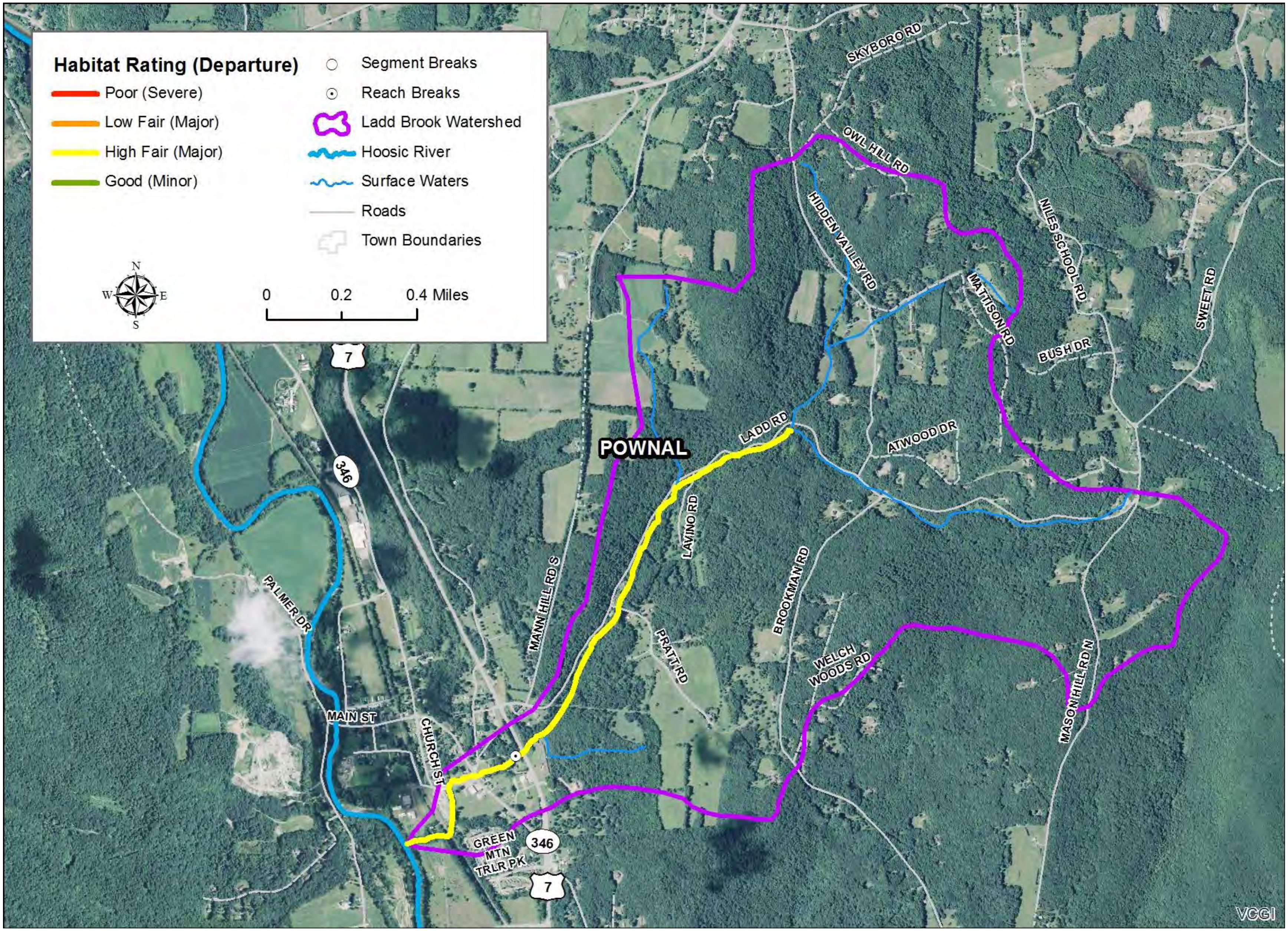

Figure 4.4: Rapid Habitat Assessment Ratings for the Ladd Brook Watershed.

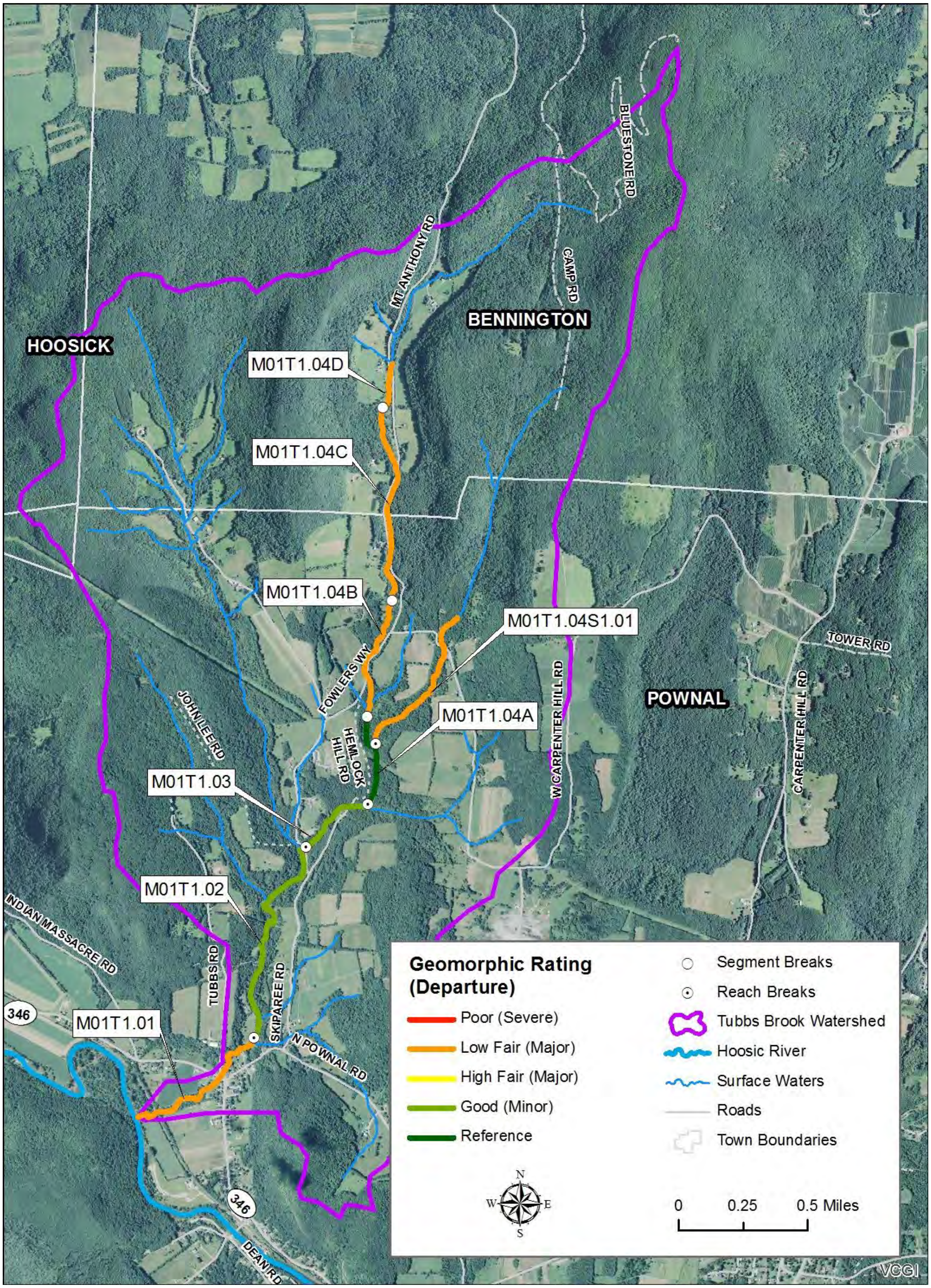

Figure 4.5: Rapid Geomorphic Assessment Ratings for the Tubbs Brook Watershed.

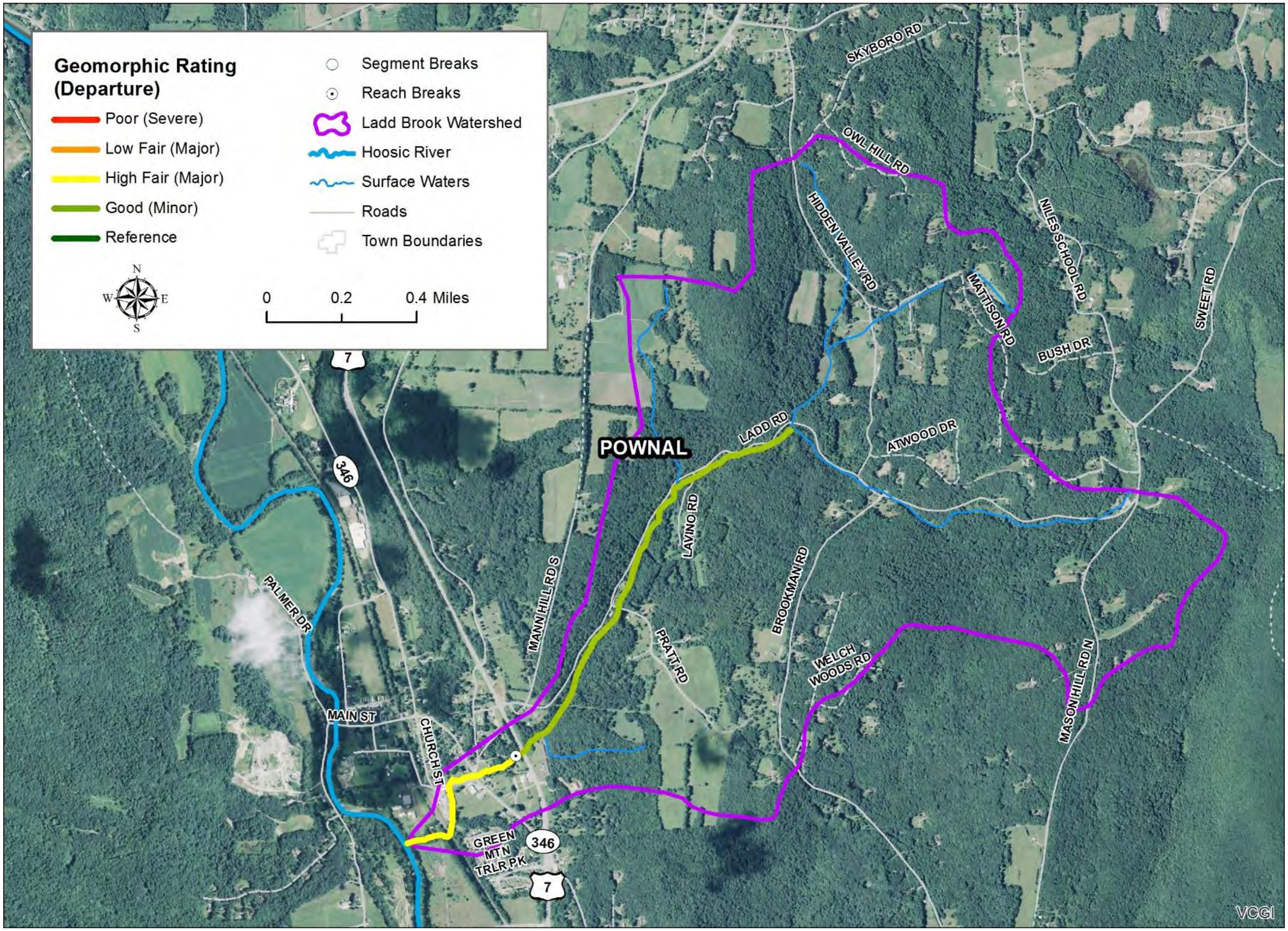

Figure 4.6: Rapid Geomorphic Assessment Ratings for the Ladd Brook Watershed.

4.3 River Corridor Planning

The following sections summarize the stressor identification and departure maps. The data collected through the Phase 1 and 2 SGA studies provides the basis for assessing the impacts to the hydrologic and sediment regimes, and the channel riparian and boundary conditions. These data, when combined with other watershed-scale data developed in this study, allows for the assessment of physical departure from reference conditions, and serves to validate watershed-scale patterns and stream conditions observed in the field. The mapping of physical stressors and natural or human constraints allowed for 1) a process-based approach to understanding stream conditions at different scales, and 2) an evaluation of the connectivity of stressors along the channel network. The maps were referenced during the project identification process summarized in Section 5.0.

4.3.1 Stressor Maps

Modifications to Riparian and Boundary Condition

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

Alterations to the channel boundary conditions and riparian areas in the Hoosic tributaries study area have been mapped using the variables extracted from the Phase 2 field dataset (Figures 4.17 and 4.18). Bank armoring (e.g., rip-rap) highlights areas of increased resistance to lateral migration, whereas bank erosion highlights reaches where significant lateral adjustments are found. Additional data showing the location of natural and man-made channel features (e.g., ledges and dam) depict areas that have a resistance to channel change.

Areas influencing riparian zone and boundary conditions include:

Increased Boundary Resistance

- Areas with numerous natural grade control on segments: M01T1.02, M01T1.04A, M05S1.02 (Figures 4.7 and 4.8).
- Small on-stream dams are located on reach M05S.01 (Figure 4.9) and M05S1.02 (Figure 4.10).
- High bank armoring on segment M01T1.04C (Figures 4.11 and 4.12).

Decreased Boundary Resistance

- High bank erosion in segment: M01T1.04D. Moderate bank erosion in segments: M01T1.01, M01T1.02, M01T1.04S1.01, M05S1.01 (Figures 4.13 and 4.14).

- Multiple mass failures in segments: M01T1.04B, M01T1.04C, M01T1.04S1.01, M05S1.02 (Figures 4.15 and 4.16).
- High density of riparian buffer width impacts in segments: M01T1.01, M01T1.04D, M05S1.01, M05S1.02.

Figure 4.7: Grade controls in reach M01T1.02.

Figure 4.8: Grade controls in segment M01T1.04A.

Figure 4.9: Small wooden dam in reach M05S1.01.

Figure 4.10: Small concrete dam in reach M05S1.02.

Figure 4.11: Bank armoring pinching channel along Mt. Anthony Road on segment M01T1.04C.

Figure 4.12: Church Street bank armoring in reach M05S1.01.

Figure 4.13: Bank erosion and buffer impacts in reach M01T1.01.

Figure 4.14: Bank erosion and buffer impacts in reach M05S1.01.

Figure 4.15: Mass failure on reach M01T1.04C.

Figure 4.16: Mass failure on reach M05S1.02.

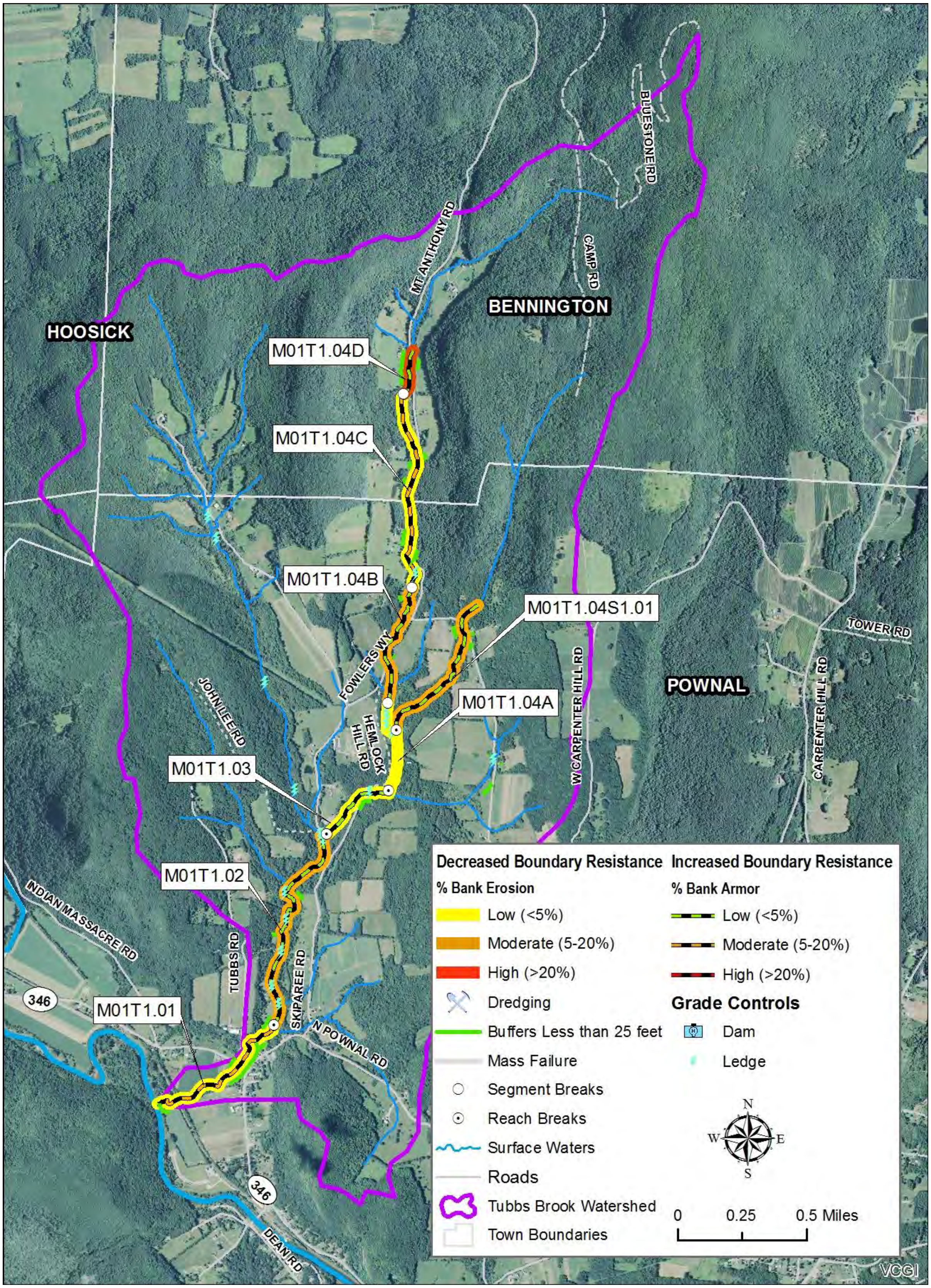

Figure 4.17: Riparian and boundary condition modifiers for the Tubbs Brook watershed.

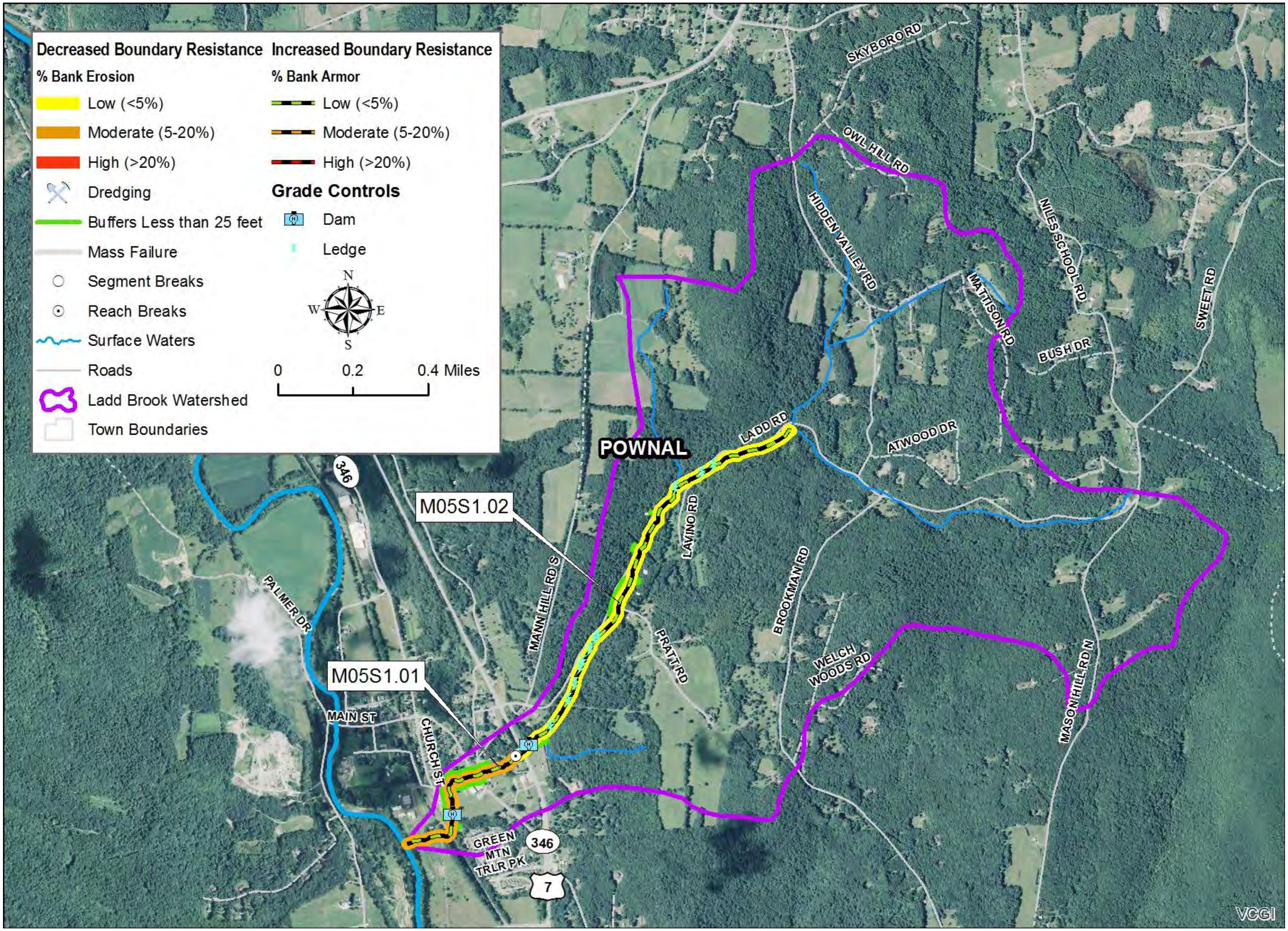

Figure 4.18: Riparian and boundary condition modifiers for the Ladd Brook watershed.

Channel Slope and Depth Modifiers

Many of Vermont's rivers and streams have been historically manipulated and straightened to maintain an unnaturally steep slope, allowing for a short term sense of security from flooding and subsequent encroachment of infrastructure in the floodplain. Over time, many alluvial rivers will seek to redevelop a sinuous planform through the deposition of sediments in unconfined valleys. Following flood events when alluvial rivers become energized enough to transport large amounts of coarse sediment into depositional zones of the watershed, lateral channel migration intensifies and further channel straightening is required to protect infrastructure found in the floodplain. In larger alluvial rivers of Vermont, straightening and channelization typically ranges between 25 and 75 percent of the total river channel length in Vermont (VTANR, 2010).

In addition to historic alterations to channel slope in Vermont's alluvial rivers, the lowering of stream beds (e.g., dredging) and the raising of floodplains (e.g., encroachments) have resulted in an increase in channel depth (VTANR, 2010). Channel depths have typically been increased through the encroachment on the floodplain by roads and railroads and subsequent filling and armoring required to construct and maintain this infrastructure. Increases in impervious cover have also led to the deepening and eventual widening of channels throughout urbanized areas of Vermont (Fitzgerald, 2007).

Alterations to channel slope and depth in the Hoosic Tributaries study area have been mapped using the variables extracted from the Phase 2 field dataset (Figures 4.23 and 24). Areas of channel straightening mapped during the Phase 1 and 2 assessments are included to depict areas of increased channel slope. Corridor encroachment data highlights where roads and development have reduced the floodplain area, typically resulting in increased stream power and channel deepening. Additional data showing the location of natural channel features (ledges) and man-made features such as dams which depict areas that have a resistance to vertical channel change.

Areas impacted by increases in slope and depth or influenced by controls on slope and depth include:

Increases in Slope and Depth

- Extreme channel straightening in segment: M05S1.01 (Figures 4.19).
- High straightening in segments: M01T1.04B, M01T1.04C (Figure 4.20.
- Extreme corridor encroachments from berms and adjacent roadways and embankments in segment: M01T1.04D. (Figure 4.21).
- Very high corridor encroachments in segment: M01T1.04C. (Figure 4.22).

Controls on Slope and Depth

- Areas with numerous natural grade control on segments: M01T1.02, M01T1.04A, M05S1.02 (Figures 4.7 and 4.8).
- Small on-stream dams are located on reach M05S.01 (Figure 4.9) and M05S1.02 (Figure 4.10).

Figure 4.19: Extreme straightening along reach M05S1.01.

Figure 4.20: High straightening along segment M01T1.04C.

Figure 4.21: Extreme encroachment from Mt. Anthony Road embankment in Bennington on segment M01T1.04D.

Figure 4.22: High encroachment along Mt. Anthony Road on reach M01T1.04C.

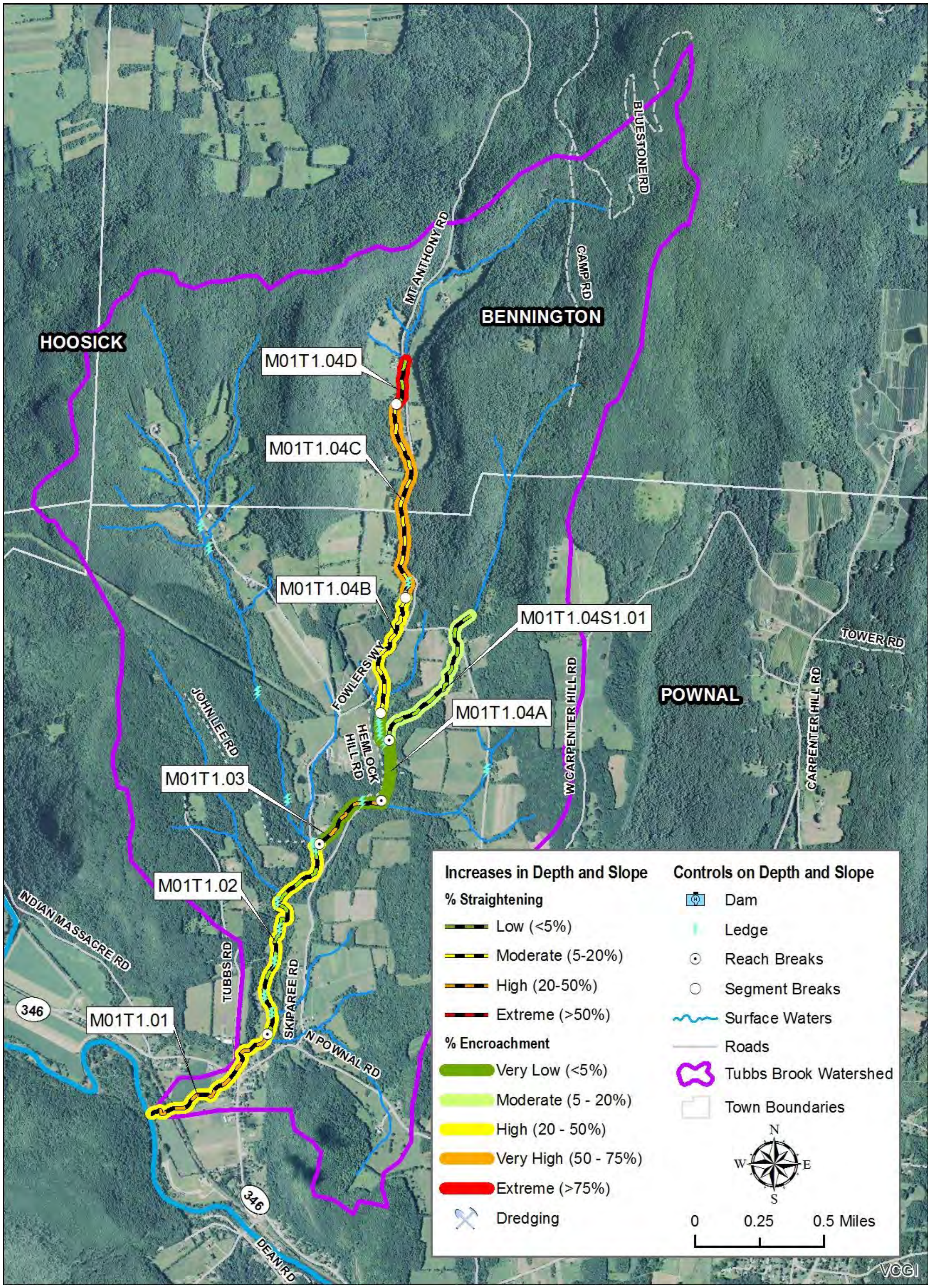

Figure 4.23: Controls on slope and depth for the Tubbs Brook Watershed.

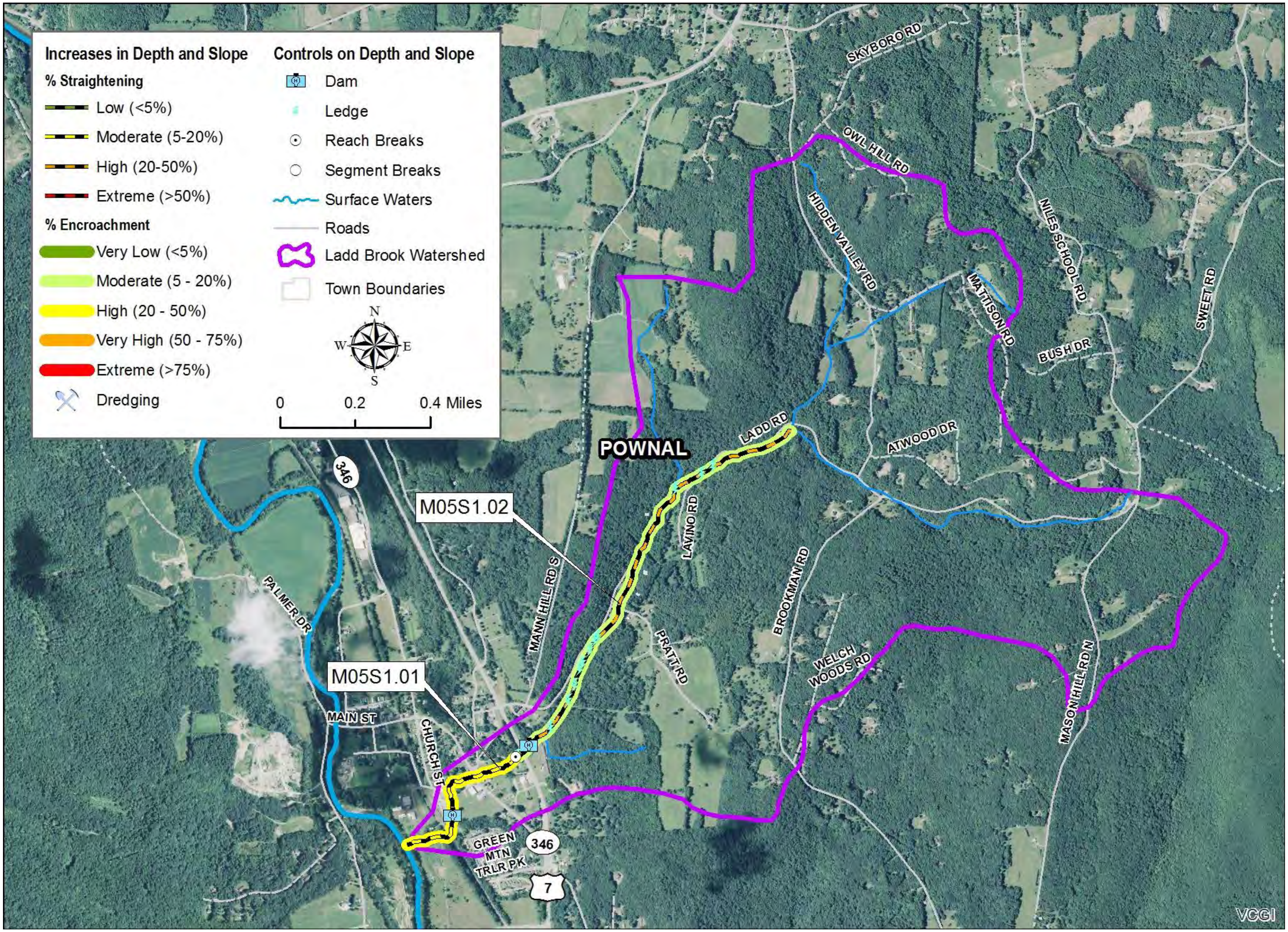

Figure 4.24: Controls on slope and depth for the Ladd Brook Watershed.

Sediment Supply and Transport

The following description of the sediment regime of a river, and the general response to watershed-scale land use changes and stressors is included from the most recent version of the VTANR River Corridor Planning Guide (VTANR, 2010).

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

Sediment loading has been identified as an important stressor for both Tubbs Brook and Ladd Brook. Common sources of sediment in rural watersheds include runoff from agricultural fields, bank erosion, channel incision, and erosion from dirt/gravel roads. Row crops (i.e., corn) are not prevalent in either watershed and in-channel sources of sediment (i.e., bank erosion and mass failure) were not extensive during the Phase 2 assessments. Runoff from gravel roads is likely an important source of sediment loading within the Tubbs Brook and Ladd Brook watersheds (VTANR, 2016). Several gullies were also observed where concentrated runoff from roadside ditches and stormwater pipes is causing erosion along the valley wall and floodplain.

Alterations to sediment supply and transport within the Hoosic Tributaries study area have been mapped using the variables extracted from the Phase 2 field dataset (Figure 4.29 and 4.30). Potential sources of sediment include stormwater inputs, gullies, bank erosion, and channel incision. Debris jams and grade controls were mapped as features that may trap and store sediment within the channel.

Areas impacted by high sediment load and transport stressors include:

Increases in Sediment Supply

- Large gullies: M01T1.02, M01T1.03, M01T1.04.C, M01T1.04S1.01 (Figure 25 and 26).
- High bank erosion in segment: M01T1.04D. Moderate bank erosion in segments: M01T1.01, M01T1.02, M01T1.04S1.01, M05S1.01.
- Multiple mass failures in segments: M01T1.04B, M01T1.04C, M01T1.04S1.01, M05S1.02.
- Cattle access to stream in segments: M02T1.02 and M01T1.04.D (Figure 4.27).

Sediment Transport Modifiers

- Areas with high density of debris jams on segments: M01T1.03, M01T1.04.A, M01T1.04.B, M01T1.04.C, M01T1.04.S1.01, M05S1.02 (Figure 4.28).
- Areas with numerous natural grade control on segments: M01T1.02, M01T1.04A, M05S1.02.
- Small on-stream dams are located on reach M01T1.04.D.

Figure 4.25: Turbid water entering channel from gully on M01T1.03.

Figure 4.26: Gully on M01T1.04.C.

Figure 4.27: Cattle path along floodplain and across channel on M01T1.04.D.

Figure 4.28: Woody debris trapping sediment within the channel on M05S1.02.

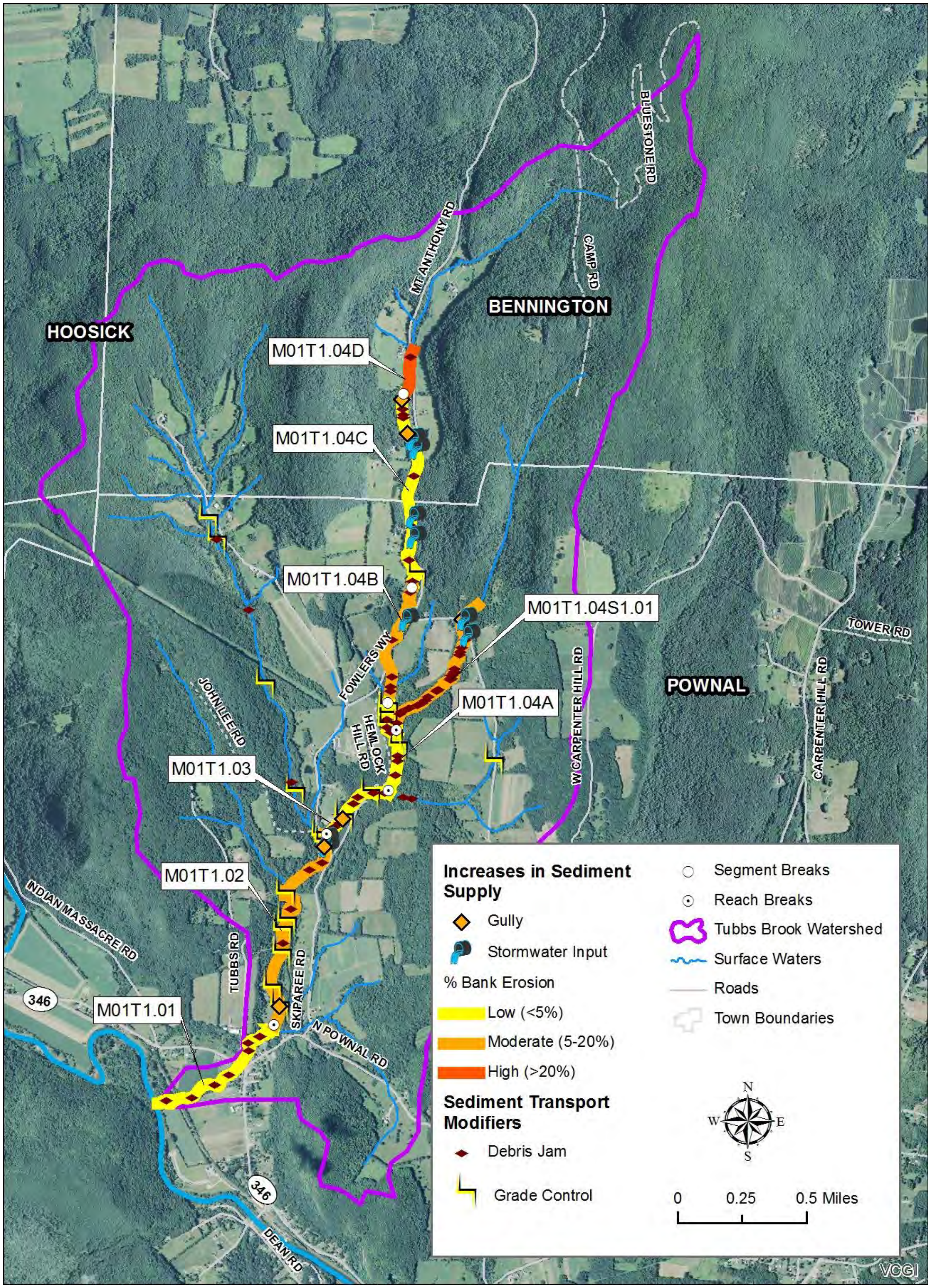

Figure 4.29: Controls on sediment load and transport for the Tubbs Brook Watershed.

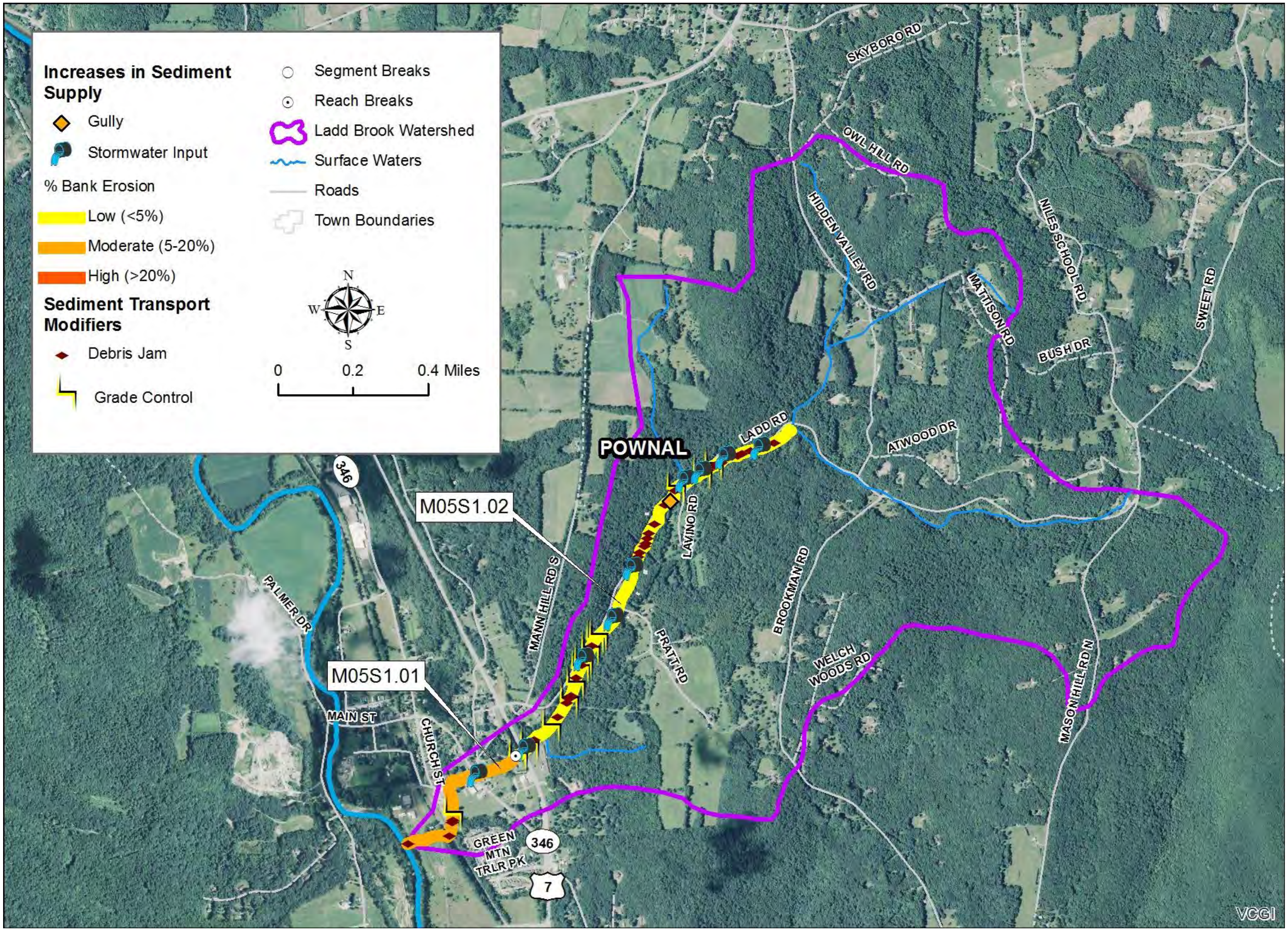

Figure 4.30: Controls on sediment load and transport for the Ladd Brook Watershed.

4.3.2 Departure Analysis

The reference and existing sediment regime types have been mapped using data from the Phase 1 and 2 assessments (Figures 4.31 – 4.34). Two reaches in the Hoosic Tributaries study area have undergone a departure in both sediment regime and stream type due to channel incision as a result of: 1) historical land uses, 2) encroachments or development in the river corridor, or 3) extensive straightening and bank armoring.

Stream type departures (per Rosgen, 1994) are summarized below (Table 4.3) to better describe the reaches where physical changes in channel morphology have accompanied sediment regime changes.

Table 4.3: Summary of stream type departures from reference conditions.

Phase 2 Segment ID	Stream Type Departure	Dominant Adjustment Type
M01T1.01	C to B	Historic Straightening/Incision
M05S1.01	C to F	Historic Straightening/Incision

In addition to these morphological stream type departures, several reaches/segments in the Tubbs Brook and Ladd Brook watersheds have undergone departures in sediment regimes in the absence of stream type departures. All sediment regime departures are summarized below in Table 4.4.

Table 4.4: Summary of Sediment Regime Departures.

Phase 2 Segment ID	Reference Sediment Regime	Existing Sediment Regime	Cause of Departure
M01T1.01	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic straightening/armoring
M01T1.02	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Historic encroachment and ongoing widening/planform
M01T1.03	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent aggradation
M01T1.04B	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening and aggradation
M01T1.04C	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening and aggradation
M01T1.04D	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening
M01T1.04S1.01	Coarse Equilibrium and Fine Deposition	Deposition	Recent widening and aggradation/braiding
M05S1.01	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic straightening/development
M05S1.02	Transport	Confined Source and Transport	Historic encroachment and active widening/planform

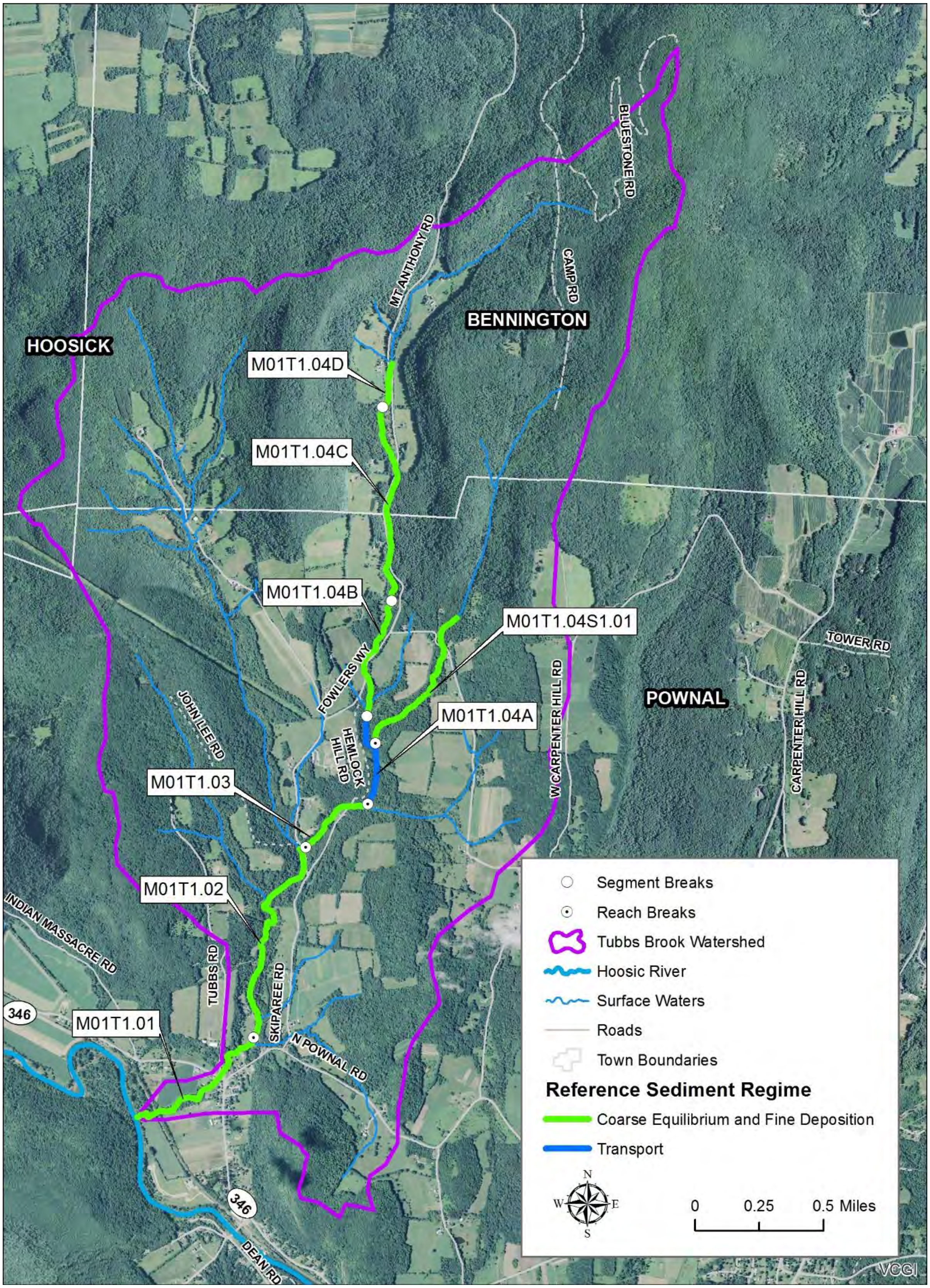

Figure 4.31: Reference Sediment Regime for the Tubbs Brook watershed.

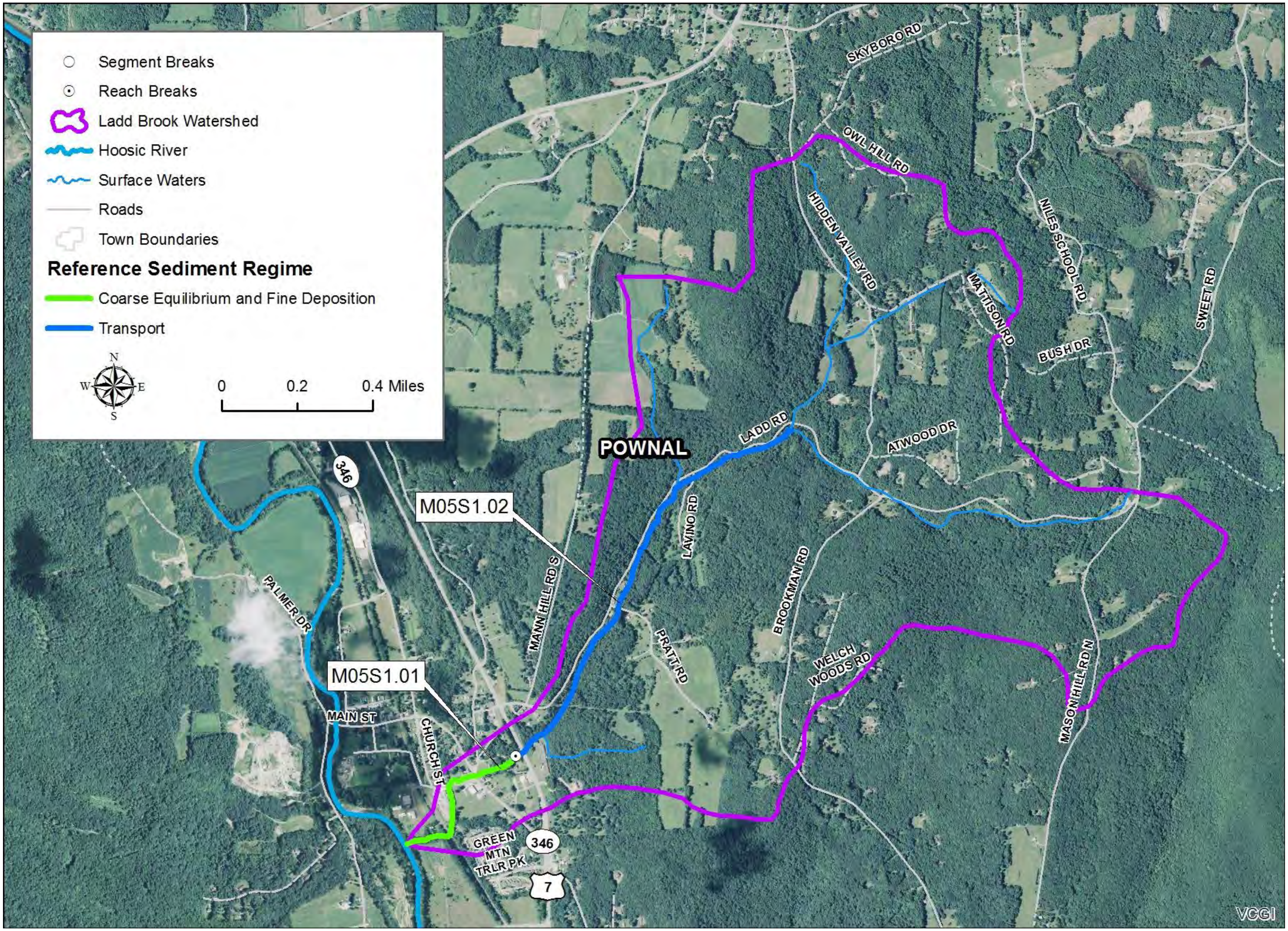

Figure 4.32: Reference Sediment Regime for the Ladd Brook watershed.

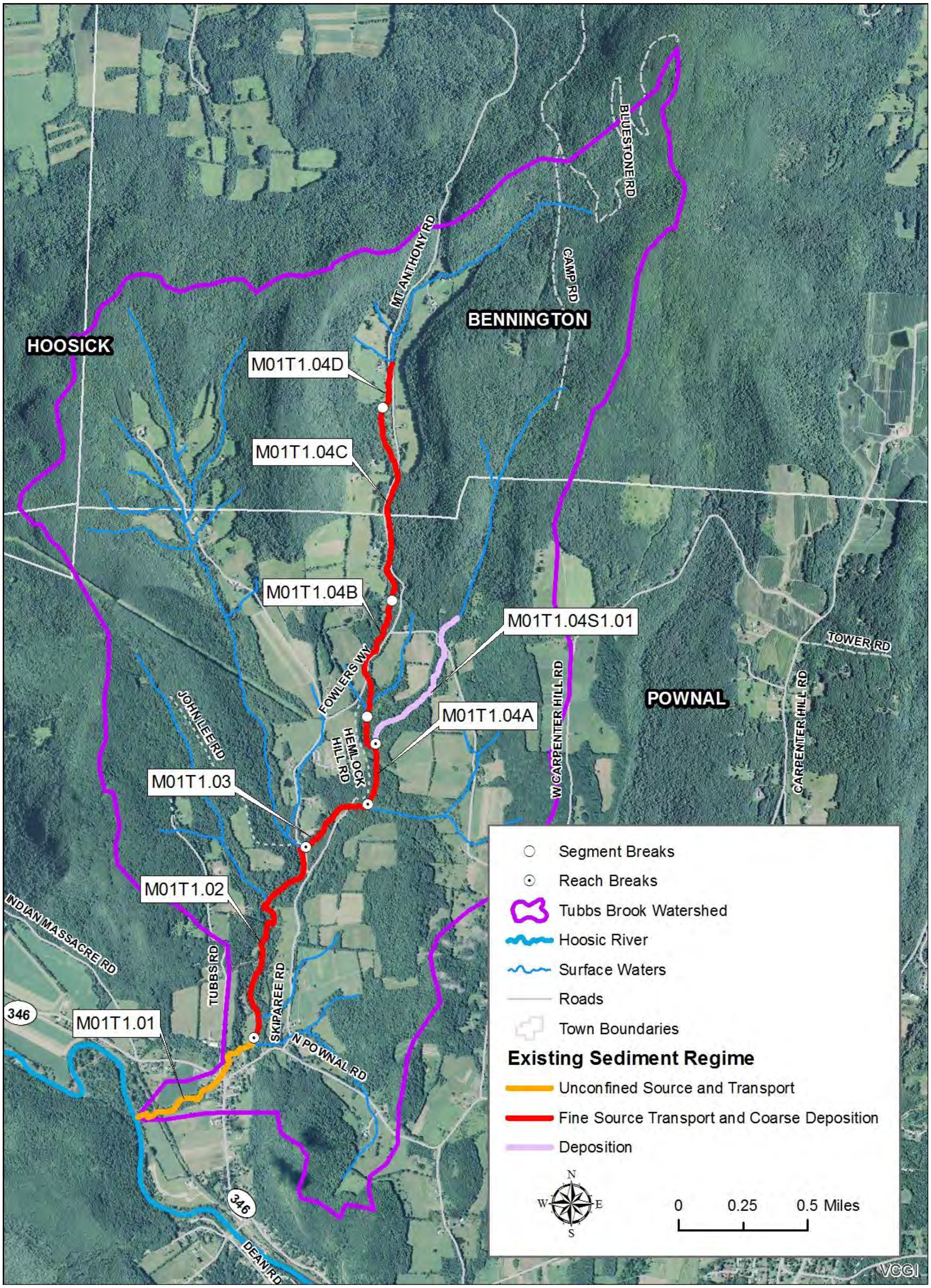

Figure 4.33: Existing Sediment Regime for the Tubbs Brook watershed.

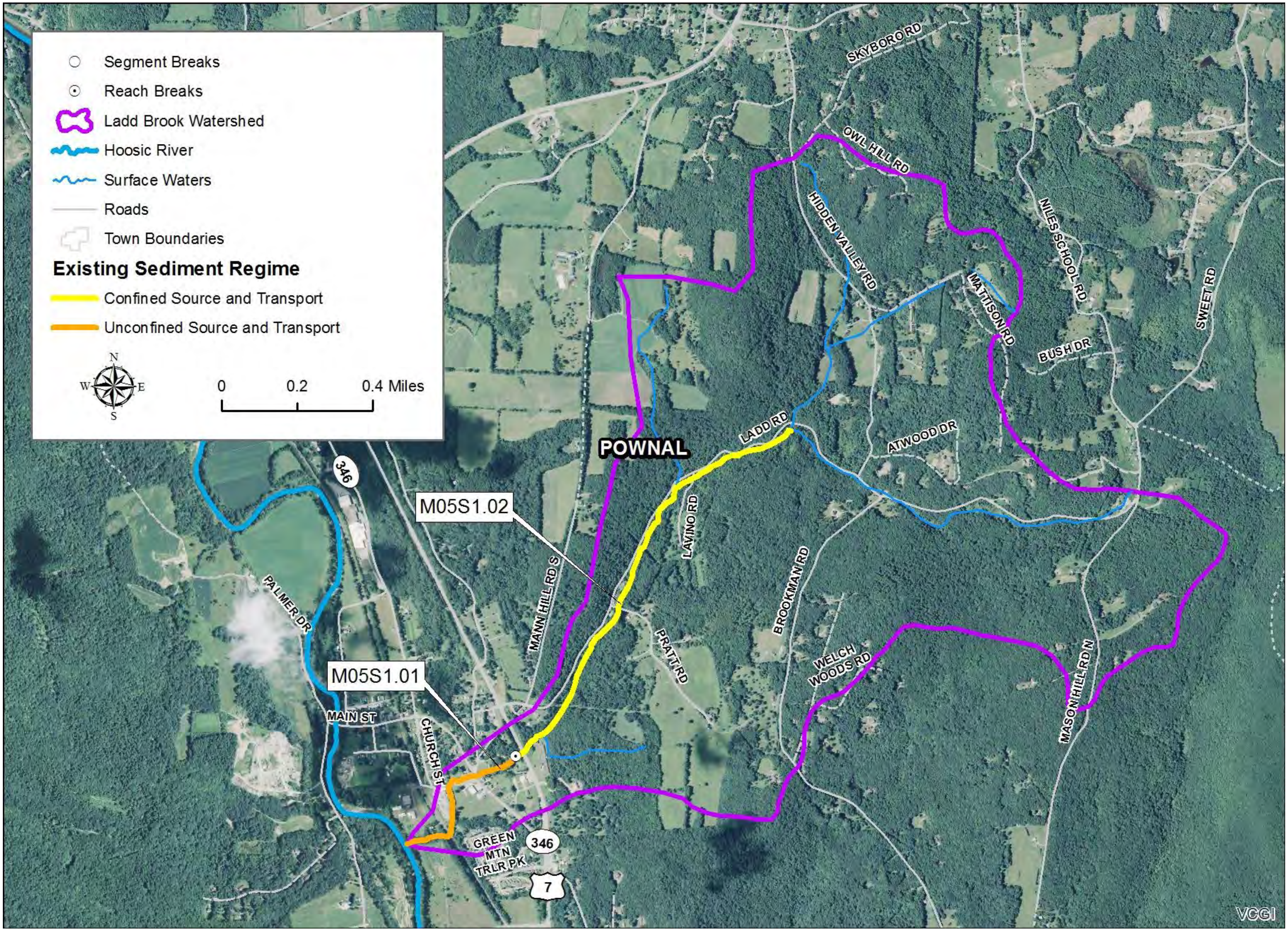

Figure 4.34: Existing Sediment Regime for the Ladd Brook watershed.

4.3.3 Sensitivity Analysis

The methods outlined in the VTANR Corridor Planning Guide have been used to describe the stream sensitivities of the segments in the Hoosic Tributaries study area. Using the stream geometry and substrate data in conjunction with overall geomorphic stability (RGA score) as determined during the Phase 2 surveys, stream sensitivity ratings have been assigned to each segment (Figures 4.35 and 4.36). Three (3) segments have heightened sensitivities of “Extreme” due to human impacts. The “Extreme” stream sensitivity ratings are most often because of stream type departures (STD) (Table 4.5). Seven (7) segments have “High” sensitivity ratings due to human impacts.

Incision due to encroachment, armoring, and/or straightening was the most common driver for “Extreme” sensitivity ratings in the study area. One segment of high sediment load E-type channel coupled with aggradation also led to an "Extreme" sensitivity rating. Aggradation caused by encroachment and straightening within the reach or in upstream reaches was the most common driver for “High” sensitivity ratings. Planform adjustments and bank armoring in one reach contributed to a “High” sensitivity rating.

Table 4.5: Extreme sensitivity segments and descriptions of the specific impacts and adjustments.

Phase 2 Segment ID	Stream Sensitivity	Description of Impacts
M01T1.04D	Extreme	Aggradation, Encroachment, Bank Erosion
M05S1.01	Extreme	STD, Straightening, Encroachment

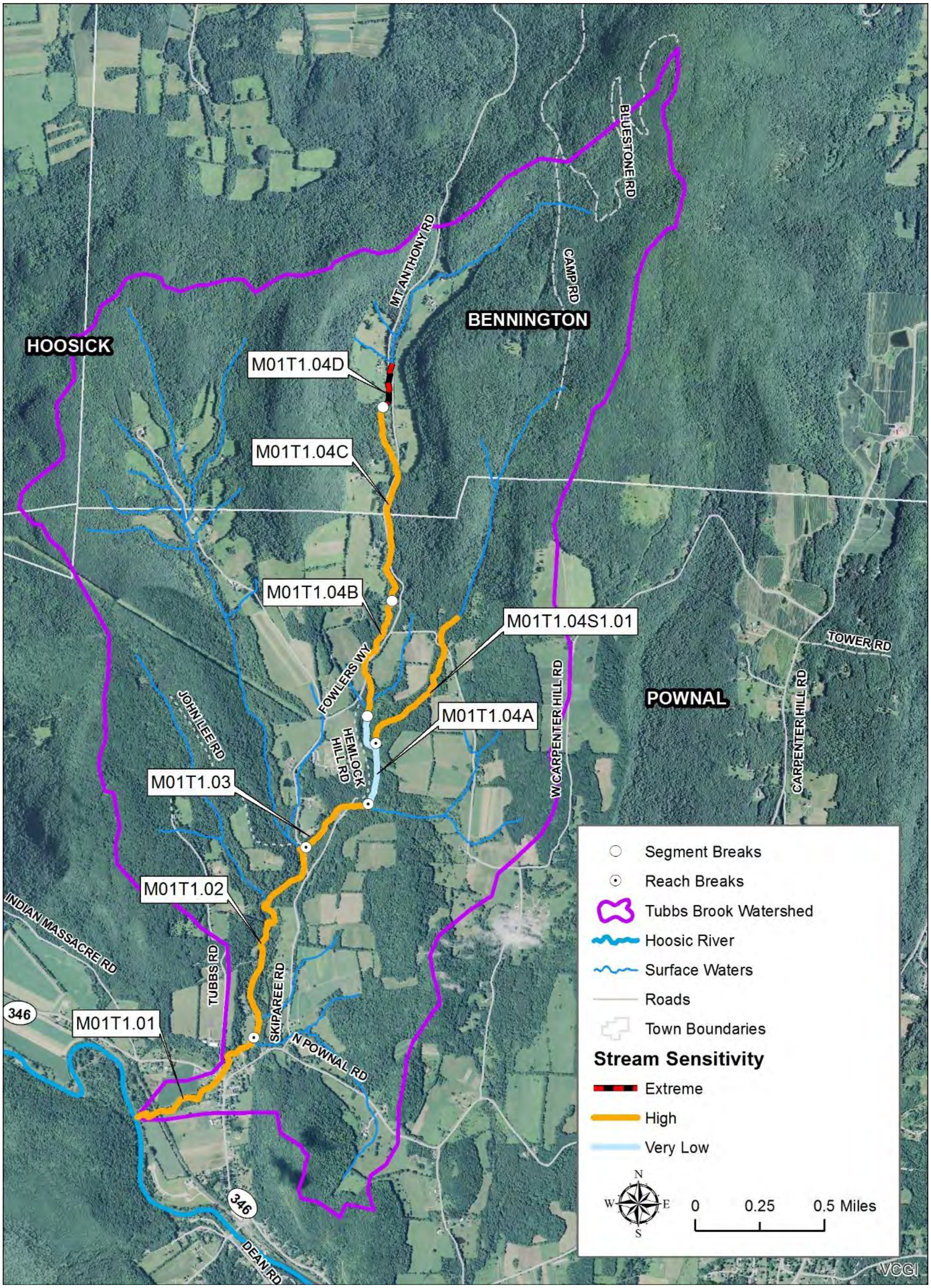

Figure 4.35: Stream Sensitivity Ratings for the Tubbs Brook study area.

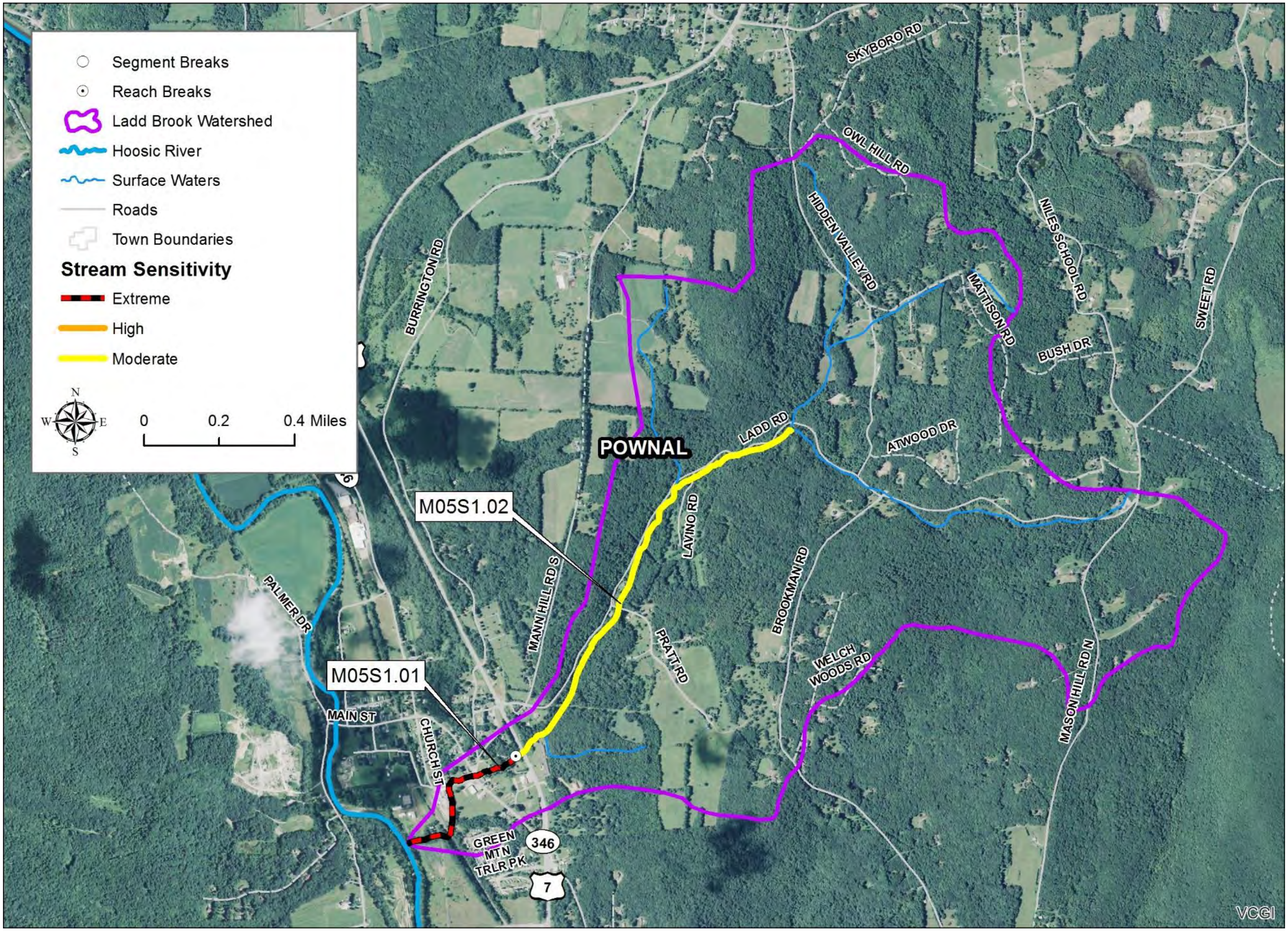

Figure 4.36: Stream Sensitivity Ratings for the Ladd Brook study area.

5.0 Preliminary Project Identification

5.1 Watershed Level Opportunities

5.1.1 Stormwater Runoff

Increased stormwater runoff, even in less developed and rural areas of Vermont such as the Towns of Pownal and Bennington, can increase peak flood flows and the erosive power of the streams. Stormwater runoff and the associated sediment loading from gravel roads is a primary management concern for the Tubbs Brook and Ladd Brook watersheds. Increasing development results in more driveways and roads, which funnel sediment and runoff directly into streams. Sediment from roads and driveways can be addressed with improved drainage ditch networks, limiting future driveway lengths in sensitive areas, and other approaches. The Vermont Better Roads program provides assistance to towns seeking ways to reduce rural stormwater problems.

In the future, if development pressures heighten concerns about impacts from stormwater runoff, the towns in the watershed could consider enacting local standards and guidelines for stormwater treatment or mitigation. Alternatively, concerns about stormwater management can be raised during local development review as necessary. Local planning efforts are important to control and monitor stormwater and development impacts on natural resources. By planning proactively, towns can reduce long-term costs and risks associated with stormwater runoff. Options that the towns could consider at the local level include:

- Requiring stormwater controls for development projects which are not large enough in size to fall under state regulatory permits (less than 1 acre impervious cover), but likely have a measurable impact on the conditions of adjacent waterbodies (e.g., habitat, water quality).
- Encouraging low impact development and use of green stormwater infrastructure through development density incentives for projects with reduced impervious cover footprints.

Beginning in 2018, VTDEC will begin phasing in the Municipal Roads General Permit (MRGP), and towns will need to begin taking steps toward meeting the permit’s requirements. This MRGP is intended to achieve significant reductions in stormwater-related erosion from municipal roads. Municipalities will be required to develop and implement a multi-year plan to stabilize road drainages to reduce erosion and meet water quality standards.

5.1.2 Floodplain and River Corridor Protections

<u>FEMA Mapped Floodplains</u>

Many Vermont communities found along rivers large and small have faced significant property losses and risks to public safety during past flood events. The Tubbs Brook and Ladd Brook watersheds are flashy due to the small and relatively steep watersheds with poor infiltration through moderately heavy soils. The National Flood Insurance Program (NFIP) study for the Hoosic River includes Reach M01T1.01 on Tubbs Brook and a small portion of Ladd Brook up to Church Road. No NFIP data is available for the remainder of each study watershed. Given the hydrologic characteristics of the watersheds, and the flood damage witnessed during Tropical Storm Irene, we recommend that the Town of Pownal considers flood hazard ordinances that prevent encroachment in the entire Special Flood Hazard Area (SFHA), including the floodway and floodplain fringe.

River Corridors

While inundation-related flood loss is a significant component of flood disasters, the predominant mode of damage during floods in Vermont is fluvial erosion. Towns can reduce flood recovery and infrastructure maintenance costs and increase public safety by limiting development in areas adjacent to rivers with a high potential for vertical and lateral adjustment. The statewide river corridor developed by VTDEC represents a useful "first-cut" mapping of the area a river or stream requires to redevelop or maintain equilibrium (i.e., least erosive) conditions over the long term. The statewide corridor is generated based on the meander belt width of the channel and includes an additional 50-foot buffer on each side. River corridor mapping can be improved with field survey data of existing channel morphology and valley walls, such as the data compiled for this project. Town zoning regulations based on the statewide or an improved river corridor map should be considered by the Town of Pownal to better map flood and erosion risks for both the safety and protection of their citizens, and the infrastructure controlled by the municipality.

By implementing at least one of the above-mentioned zoning recommendations (preventing new development in SFHAs or River Corridors), Pownal can qualify for increased state aid (from 12.5% to 17.5%) from the Emergency Relief and Assistance Fund (ERAF) to cover future flood damages. More information is available through VTDECs Flood Ready website (http://floodready.vermont.gov/). The Town of Bennington has adopted interim River Corridor protection.

5.1.3 Stream Crossings

Throughout Vermont, undersized and poorly aligned river crossings interrupt flood flows, sediment and woody debris movement downstream, and fish and wildlife migration. These conditions result in: 1) channel instability and/or damage to infrastructure and personal property; 2) increased flooding; and 3) decreased fish and wildlife population health. Two bridges and all 20 of the culverts in the study area are currently undersized and causing various problems such as upstream sediment/debris deposition, excessive erosion, and limited aquatic organism passage (Figure 5.1 and Tables 5.1 and 5.2). Debris jams formed during T.S. Irene on some of the larger bridges - particularly those with piers - exacerbating area flooding and infrastructure damage. As such structures come up for replacement, resizing them to accommodate expected discharge and sediment loads and placing them in proper alignment with stream channels is highly recommended.

Figure 5.1: Partially plugged undersized culverts on Ladd Brook.

Table 5.1: Summary of culvert data in the Tubbs and Ladd Brook watersheds.

Map ID	SGA Reach/Segment	Town	SGAID	Location	% Bankfull Width	Geomorphic Compatibility	Aquatic Organism Passage* (AOP)	AOP Retrofit Potential**
1	M01T1.02	Pownal	100000000002081	Skiparee Rd	22	Mostly Incompatible (10)	No AOP	LLL
2	M01T1.03	Pownal	700000000702083	Hemlock Hill	28	Mostly Incompatible (6)	No AOP	LLL
3	M01T1.04.B	Pownal	100015000002081	Fowlers Way	64	Partially Incompatible (14)	Full AOP	MML
4	M01T1.04.B	Pownal	700000000502083	Driveway	32	Mostly Compatible (16)	No AOP	MLL
5	M01T1.04.B	Pownal	700000000602083	Driveway	32	Partially Incompatible (13)	Reduced AOP	MLL
6	M01T1.04.C	Pownal	100016000102081	Mt Anthony Rd	35	Partially Incompatible (13)	No AOP	MLL
7	M01T1.04.C	Bennington	100046000002021	Mt Anthony Rd	43	Partially Incompatible (12)	No AOP	MLL
8	M01T1.04.C	Bennington	700000000002023	Driveway	27	Partially Incompatible (13)	No AOP	LLL
9	M01T1.04.D	Bennington	100046000102021	Mt Anthony Rd	64	Partially Incompatible (12)	No AOP	LLL
10	M01T1.01S1.01	Pownal	100010000002081	Skiparee Rd	56	Mostly Compatible (16)	No AOP	MLL
11	M01T1.02S1.01	Pownal	100013000002081	John Lee Rd	48	Partially Incompatible (13)	No AOP	MLL
12	M01T1.03S1.01	Pownal	100016000002081	Mt Anthony Rd	25	Partially Incompatible (12)	Reduced AOP	LLL
13	M01T1.04S1.01	Pownal	100016000202081	Mt Anthony Rd	46	Partially Incompatible (13)	No AOP	MLL
14	M05S1.01	Pownal	700000000802083	Private Road	24	Partially Incompatible (15)	Reduced AOP	LLL
15	M05S1.01	Pownal	700000000902083	Railroad	35	Mostly Incompatible (10)	Reduced AOP	MLL
16	M05S1.01	Pownal	100000000102081	Church St.	59	Mostly Incompatible (10)	Full AOP	MML
17	M05S1.01	Pownal	200346000302082	Route 346	59	Mostly Compatible (21)	Reduced AOP	MML
18	M05S1.02	Pownal	200007000802082	Route 7	35	Mostly Compatible (16)	Reduced AOP	LLL
19	M05S1.02	Pownal	100000000202081	Pratt Rd	36	Partially Incompatible (12)	No AOP	MLL
20	M05S1.02	Pownal	100000000302081	Lavino Rd	30	Partially Incompatible (12)	No AOP	LLL

*Notes on AOP
Green: Full AOP for all aquatic organisms
Gray: Reduced AOP for all aquatic organisms
Orange: No AOP for all aquatic organisms except adult salmonids
Red: No AOP for all aquatic organisms including adult salmonids

** Notes on AOP Retrofit Potential:
H: High probability the existing culvert can be retrofitted
M: Medium probability the existing culvert can be retrofitted
L: Low probability the existing culvert can be retrofitted
Position 1 (left): For strong swimmers
Position 2 (Center): For moderate swimmers
Position 3 (right): For weak swimmers

Table 5.2: Summary of Bridge Data in the Tubbs Brook watershed.

Map ID #	SGA Reach/ Segment	Town	SGAID	Road	Material	Curve Channel Width (ft)	Road Width (ft)	Structure Height (ft)	Structure Span (ft)	% Bankfull Width
1	M01T1.01	Pownal	700000000402083	Railroad	Steel	28.4	67	5.8	21	74
2	M01T1.01	Pownal	200346000202082	Route 346	Concrete	28.4	26	5.6	22.5	79
3	M01T1.01	Pownal	700000000302083	Farm Access	Steel	28.4	48	6.5	16	169

5.2 Site-Level Project Opportunities

The site-level projects developed for the Tubbs Brook and Ladd Brook watersheds are provided in Tables 5.3 and 5.4. Additional project opportunities were developed for the Vermont portion of the Hoosic River (Table 5.5). The project strategy, technical feasibility, and priority for each project are listed by project number and reach/segment. A total of 32 projects were identified to reduce sediment loading to Tubbs Brook and Ladd Brook and to promote the restoration or protection of channel stability and aquatic habitat within Tubbs Brook, Ladd Brook, and the Hoosic River. These tables summarize key information for each project, including the site stressors and constraints, project strategy, priorities for hazard mitigation and ecological benefit, relative costs (i.e., low, moderate, and high), and potential partners and funding sources.

Tables 5.3 to 5.5 include a ranking of project priority, using our best professional judgment (and input from VTDEC, BCRC, and other local stakeholders), of hazard mitigation and ecological benefits. Many river corridor restoration projects help mitigate flood and erosion hazards **and** improve the ecological conditions of the reach and watershed as a whole (e.g., improved habitat, protection of water quality, etc.). However, some project types provide a greater benefit to one over the other. While it is difficult to place a specific value on each project, rankings of “low,” “medium,” and “high” are intended to provide a means to compare the types of benefits each project provides relative to the others. A summary of what is meant by these two priority types is provided below.

> *Hazard Mitigation Priority:* refers to the potential for the project to mitigate flood and erosion hazards for the river corridor in the reach and in downstream areas. For example, replacing an undersized culvert with an appropriately sized structure could reduce flood/erosion hazards around the structure and downstream.
>
> *Ecological Benefits Priority:* refers to the potential for the project to improve aquatic habitat conditions and water quality in the reach and watershed. For example, a riparian buffer planting will improve habitat by increasing shading along the river and reducing long-term bank erosion.

The project locations for the study area are included on the maps provided in Appendix D. The 34 projects are further broken down by category as follows: twenty-two (22) active geomorphic restoration projects, two (2) infrastructure resiliency projects, and ten (10) passive geomorphic restoration projects, including one (1) conservation project. Additional information for the twelve (12) high priority projects is included in Appendix E.

The two (2) infrastructure resiliency projects were identified to protect municipal and private infrastructure along Tubbs Brook, and are included in Appendix H. Note that the infrastructure resiliency projects were identified primarily for hazard mitigation purposes. These projects are not primarily focused on improving channel dynamics or water quality, and thus they are not suitable for Vermont State Clean Water Initiative funding.

Five (5) high-priority project areas were selected by the project steering committee and further scoped. Project summaries are included in Appendix G. Each project summary includes:

- A description of the site location and river reach
- A brief technical summary of the stressors on channel stability and aquatic habitat
- A description of channel and floodplain restoration alternatives
- Preliminary cost opinions for restoration alternatives
- A list of current and potential technical partners and funding
- A review of regulatory requirements

5.2.1 Tubbs Brook River Corridor Project Opportunities

Table 5.3: Site-Level Project Identification for the Tubbs Brook Watershed in the Towns of Pownal and Bennington, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Project Priorities			Project Benefits	Costs	Potential Partners & Funding
				Hazard Mitigation	Ecological Benefits	Overall			
TB 1 **Farm Field** Reach M01T1.01 42.80315 N 73.27258 W	**Passive Restoration** Corridor Protection and Buffer Planting	The channel is developing a meander sequence in the short section between the railroad at the Hoosic River. The farm field to the south is very close to the channel and the lack of woody vegetation may increase bank erosion	Establish and protect a vegetated floodplain buffer to allow for meander development.	Low	Medium	Medium	Protect active corridor from agricultural encroachment and reduce sediment inputs from bank erosion.	Low	VTANR; Private Landowner
TB 2 **Railroad Crossing** Reach M01T1.01 42.80341 N 73.27189 W	**Active Restoration** Bridge Replacement	The railroad bridge is a moderate bankfull constriction (74%) and has a low clearance (5ft). The channel has a high load of coarse sediment increasing the risk of the bridge jamming which could cause flooding in North Pownal.	Replace bridge with a larger structure that will improve sediment and debris transport, and conveyance of flood waters through the reach.	Medium	Low	Low	Reduced risk of debris or sediment accumulation at bridge during a storm event, improve sediment transport through reach.	High	PanAm Railroad
TB 4 **Skiparee Road** Reach M01T1.02 42.80876 N 73.26412 W	**Active Restoration** Gully Stabilization	A small tributary entering from the east is severely incised for approximately 40ft. This erosion is likely to continue and deliver large volumes of sediment to Tubbs Brook.	Stabilize the gully to arrest further incision and erosion. Wood structures may be appropriate for the site to reduce cost and improve habitat features.	Low	Medium	Medium	Reduce sediment inputs and improve habitat in the tributary	Low to Moderate	VTANR ERP; Private Landowner; VYCC
TB 5 **North Pownal Rd Farm** Reach M01T1.02 42.81022 N 73.265 W	**Passive Restoration** Cattle Exclusion	Cattle access along approximately 400ft of channel has damaged banks increasing erosion and nutrient loading.	Install a fence to protect banks and channel from cattle. A stone lined area can be constructed if water access is required.	Low	Medium	Medium	Reduce sediment and nutrient inputs to the channel	Low	Private Landowner; VTANR ERP

Table 5.3: Site-Level Project Identification for the Tubbs Brook Watershed in the Towns of Pownal and Bennington, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Project Priorities			Project Benefits	Costs	Potential Partners & Funding
				Hazard Mitigation	Ecological Benefits	Overall			
TB 6 **Skiparee Road** Reach M01T1.02 42.81774 N 73.26077 W	**Active Restoration** Stormwater Treatment and Gully Stabilization	A stormwater pipe carrying runoff from Skiparee Rd has caused significant erosion of the valley wall and along the floodplain leading to Tubbs Brook.	Stabilize the gully and install rock check dams to trap sediment and reduce runoff velocities. The pipe may need to be reconfigured to reduce scour at the outlet. BCRC has submitted an application for a Watershed Grant to address this site.	Low	**High**	**High**	Large reduction in sediment loading to the channel from an active gully.	Low to Moderate	Town of Pownal; VT Watershed Grant Program
TB 7 **Skiparee Road** Reach M01T1.02 42.81837 N 73.26081 W	**Active Restoration** Culvert Replacement	The two culverts (5ft and 4ft diameter) under Skiparee Rd are a major bankfull constriction and completely block upstream AOP.	Replace the two culverts with a single structure that is large enough to accommodate flood flows and associated debris and sediment. Structure should be sloped appropriately to establish a native bed and allow for full AOP.	**High**	**High**	**High**	Remove a major flood hazard and barrier to AOP. Improve conveyance of floodwaters and debris through the reach and reduce risk to Skiparee Rd.	High	Town of Pownal; VTANR ERP; VTrans Structures
TB 8 **Hemlock Hill Rd** Reach M01T1.03 42.8193 N 73.25939 W	**Active Restoration** Stormwater Treatment and Gully Stabilization	Stormwater runoff from Hemlock Hill Rd is creating a gully as it flows down the valley wall and across a terrace and floodplain to Tubbs Brook.	Stabilize the gully and install rock check dams to trap sediment and reduce runoff velocities. Additional check dams installed along the roadside ditch would further reduce sediment loading and scour potential.	Low	Medium	Medium	Large reduction in sediment loading to the channel from an active gully.	Low to Moderate	Town of Pownal; VTANR ERP
TB 9 **Gorge along Hemlock Hill Trail** Segment M01T1.04.A 42.82379 N 73.25537 W	**Passive Restoration** Conservation	The gorge along Tubbs Brook is an important scenic and recreational feature. It also provides numerous areas for sediment and debris storage behind large grade controls and debris jams.	Protect the parcel to ensure that debris jams are left in place and to allow for continued access to the popular swimming areas along the gorge.	Low	Medium	Medium	Protect public access to the site and ongoing sediment and debris storage to reduce downstream flood risk and sediment loading.	Low to Moderate	Private Landowner; VLT; Town of Pownal

Table 5.3: Site-Level Project Identification for the Tubbs Brook Watershed in the Towns of Pownal and Bennington, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Project Priorities			Project Benefits	Costs	Potential Partners & Funding
				Hazard Mitigation	Ecological Benefits	Overall			
TB 10 **Fowlers Way at Mt Anthony Rd** Segment M01T1.04.B 42.8305 N 73.25457 W	**Active Restoration** Stormwater Treatment	Stormwater runoff from Fowlers Way and Mt Anthony Rd spill on to the floodplain through a ditch turnout. Large plumes of a fine sediment are visible on the floodplain and into the channel.	Construct stone check dams along the roadside ditch to trap sediment and slow runoff. Construct a stone lined collection area at the base of the turnout to collect sediment before reaching the channel.	Low	**High**	**High**	Reduce sediment loading from a large drainage area of gravel roads	Low to Moderate	Town of Pownal; Better Roads Program
TB 11 **Driveway** Segment M01T1.04.B 42.83153 N 73.25458 W	**Active Restoration** Culvert Replacement/ Retrofit	A steel tank culvert under a driveway is a major constriction and appears to have been backfilled with very fine material. The downstream embankment is exposed sand and is likely contributing a large amount of sediment to the channel.	Assess the stability of the fill material and replace if necessary. Establish native vegetation on the exposed soil. Replace the culvert with a larger structure if private landowner is willing to assist.	Low	Medium	Medium	Reduce sediment inputs to the channel including a potentially large amount of sediment if the culvert were to wash out. Potentially replace with a larger structure to increase conveyance of floodwaters and sediment through the segment.	Low to High	Private Landowner; VTANR ERP; BCCD Trees for Streams
TB 12 **Mt Anthony Rd** Segment M01T1.04.C 42.83467 N 73.25443 W	**Active Restoration** Road Maintenance and Erosion Control	The road shoulder immediately upstream of the culvert is very steep and is eroding directly into the channel. Road grading likely pushes material further onto this slope increasing sediment loading.	Install a barrier along the edge of the road to stop fine sediment from being directly pushed in to the stream. Clear loose material from slope and assess integrity of bank armoring. Establish vegetation on slope.	Low	Medium	Medium	Reduce sediment inputs to channel.	Low	Town of Pownal; Better Roads Program

Table 5.3: Site-Level Project Identification for the Tubbs Brook Watershed in the Towns of Pownal and Bennington, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Project Priorities			Project Benefits	Costs	Potential Partners & Funding
				Hazard Mitigation	Ecological Benefits	Overall			
TB 14 **Mt Anthony Rd** Segment M01T1.04.C 42.83948 N 73.25388 W	**Active Restoration** Culvert Replacement and Driveway Relocation	Tubbs Brook flows through two undersized culverts approximately 30ft apart. The downstream stone box culvert (8ft wide) under Mt Anthony Rd is scoured and losing material from the lower portions of the culvert walls. The upstream driveway culvert (5ft CMP) is a major bankfull constriction. Both culverts are perched and are full AOP barriers.	Replace the Mt Anthony Rd culvert with a larger structure that allows for full AOP. The driveway culvert could also be replaced or the driveway could be relocated approximately 30ft south and connect directly to Mt Anthony Rd without crossing the stream.	Medium	**High**	**High**	Remove two significant constrictions to improve conveyance of floodwaters and debris, remove two full AOP barriers. Replace aging stone lined culvert before it fails.	High	Town of Bennington; Private Landowner
TB 15 **Mt Anthony Rd** Segment M01T1.04.D 42.84151 N 73.25633 W	**Active Restoration** Gully Stabilization	A moderately incised gully has formed along the west valley wall where concentrated runoff from the hayfield and pasture flows to the stream. The banks of the gully appear stable.	Install wood or stone grade controls to stabilize the gully and stop further incision.	Low	Low	Low	Reduce sediment inputs to channel	Low to Moderate	Private Landowner; VTANR ERP; VYCC
TB 16 **Mt Anthony Rd** Segment M01T1.04.D	**Passive Restoration** Corridor Protection	Approximately 800ft of the channel is openly accessed by pastured cattle. The channel and floodplain are impacted by trampling leading to increased erosion and likely significant nutrient inputs. Much of the stream corridor appears to be wetland.	Work with the landowner to exclude cattle from the floodplain area and reestablish native woody vegetation. Stone lined water access areas can be constructed to retain water access and minimize damage to the floodplain and channel.	Low	**High**	**High**	Reduce what is likely a major source of sediment and nutrient loading. Establish an important vegetated floodplain area in the upper portion of the watershed.	Moderate	Private Landowner; VTANR ERP
TT 1 **Driveway at Mt Anthony Rd** Reach M01T1.04S1.01	**Active Restoration** Gully Stabilization	Runoff from the driveway flows down a steep valley forming a gully.	The gully slope is likely too high for wood or other “natural” structures. Line the gully with appropriately sized stone from the edge of the driveway down to the stream.	Low	Medium	Medium	Stabilize the gully and reduce sediment inputs	Low	Private Landowner; VTANR ERP

5.2.2 Ladd Brook River Corridor Project Opportunities

Table 5.4: Site-Level Project Identification for the Ladd Brook Watershed in the Town of Pownal, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Project Priorities			Project Benefits	Costs	Potential Partners & Funding
				Hazard Mitigation	Ecological Benefits	Overall			
LB 1 **Abandoned Crossing west of Railroad** Reach M05S1.01 42.76320 N 73.23768 W	**Active Restoration** Culvert Removal	The two culverts (4ft diameter) under an old, unutilized crossing west (downstream) of the railroad crossing are causing sediment and debris deposition at the inlet. Constriction may exacerbate flooding upstream in the mobile home park.	Investigate land ownership and use of crossing. If crossing is no longer needed, remove culverts and restore reference stream channel morphology.	**High**	Medium	**High**	Remove a flood hazard and barrier to AOP. Improve conveyance of floodwaters and debris through the reach and reduce risk to upstream properties in mobile home park.	High	Landowner; FEMA HMGP; VTANR ERP
LB 2 **Railroad Crossing** Reach M05S1.01 42.76310 N 73.23707 W	**Active Restoration** Culvert Retrofit or Replacement	The railroad culvert is 6ft in diameter, while the bankfull channel width is 17ft (structure width is 35% of reference). Major flooding occurs in the adjacent mobile home park during large floods.	Coordinate with Pan American Railways regarding potential to replace or retrofit culvert to provide greater hydraulic capacity. Alternatively, could additional structures under the railroad bed provide adequate capacity to reduce flood risks?	**High**	Medium	**High**	Reduce a major flood hazard. Improve conveyance of floodwaters and debris through the reach and reduce risk to upstream properties in mobile home park.	High	Landowner; FEMA HMGP; VTANR ERP; Pan Am Railways
LB 3 **Dam east of Railroad** Reach M05S1.01 42.76410 N 73.23716 W	**Active Restoration** Barrier/Dam Removal	A makeshift dam built from railroad ties, stumps, and a rubber liner is located just upstream of the mobile home park. Dam is causing aggradation upstream and may exacerbate flooding to nearby mobile homes.	Remove illegal structure and restore natural bedforms in channel.	**High**	Medium	**High**	Remove a flood hazard and barrier to AOP. Improve conveyance of floodwaters and debris through the reach and reduce risk to nearby properties in mobile home park.	High	Landowner; Mobile home park association
LB 4 **North of Church Street** Reach M05S1.01 42.76533 N 73.23726 W	**Passive Restoration** Buffer Planting	Approximately 100 feet of stream bank (north side) upstream of the Church Street crossing lacks a healthy riparian buffer. Property is residential.	Plant the banks and buffer with native woody vegetation and work with the landowner to protect the corridor from future development.	Low	Medium	Medium	Reduce nutrient inputs to channel and increase shading.	Low	BCCD Trees for Stream; Private Landowner; VTANR ERP

Table 5.4: Site-Level Project Identification for the Ladd Brook Watershed in the Town of Pownal, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Project Priorities			Project Benefits	Costs	Potential Partners & Funding
				Hazard Mitigation	Ecological Benefits	Overall			
LB 5 **Dam east of Route 7** Reach M05S1.02 42.76681 N 73.23322 W	**Active Restoration** Dam Removal	An old, abandoned 4ft tall concrete dam is located just east of the Rt 7 crossing. The pool behind the dam is filled with fine sediment. The structure is a significant AOP barrier.	Remove dam and restore natural bedforms in channel.	Medium	Medium	Medium	Remove a barrier to AOP. Improve conveyance of sediment and debris through the reach. AOP benefits may be marginal because of AOP barrier at Rt 7 culvert just downstream.	High	Landowner; BCRC; BCCD; VTANR ERP; USFWS
LB 6 **Ladd Brook Inn** Reach M05S1.02 42.76696 N 73.23304 W	**Passive Restoration** Buffer Planting	Approximately 50 feet of stream bank (south side) upstream of the Route 7 crossing lacks a healthy riparian buffer. Property appears to be associated with Ladd Brook Inn to the south.	Plant the banks and buffer with native woody vegetation and work with the landowner to protect the corridor from future development.	Low	Low	Low	Reduce nutrient inputs to channel and increase shading.	Low	BCCD Trees for Stream; Private Landowner; VTANR ERP
LB 7 **Ladd Brook Road** Reach M05S1.02 42.77008 N 73.23059 W	**Active Restoration** Road Maintenance and Erosion Control	The road shoulder along Ladd Brook Road is extremely steep and eroding directly into the channel. Road grading likely pushes material further onto this slope increasing sediment loading. Town has attempted to stabilize with log terracing and makeshift soil nails.	Install a barrier along the edge of the road to stop fine sediment from being directly pushed in to the stream. Clear loose material from slope and assess integrity of bank armoring. Establish vegetation on slope where possible. Site is very shaded by hemlock trees.	Low	**High**	**High**	Reduce Town road maintenance. Reduce sediment inputs to channel.	Moderate	Town of Pownal; VTrans/VTANR Better Roads Program
LB 8 **Ladd Brook Road** Reach M05S1.02 42.77094 N 73.22994 W	**Active Restoration** Road Maintenance and Erosion Control	The road shoulder along Ladd Brook Road is steep and eroding down the bank into riprap along the channel. Road grading likely pushes material further onto this slope increasing sediment loading. Town has stabilized the lower slope with riprap.	Install a barrier along the edge of the road to stop fine sediment from being directly pushed in to the stream. Establish vegetation on upper slope where possible. Site is very shaded by hemlock trees.	Low	Medium	Medium	Reduce Town road maintenance. Reduce sediment inputs to channel.	Low to Moderate	Town of Pownal; VTrans/VTANR Better Roads Program

Table 5.4: Site-Level Project Identification for the Ladd Brook Watershed in the Town of Pownal, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Project Priorities			Project Benefits	Costs	Potential Partners & Funding
				Hazard Mitigation	Ecological Benefits	Overall			
LB 9 **Pratt Road** Reach M05S1.02 42.77217 N 73.22856 W	**Active Restoration** Culvert Retrofit or Replacement	The culvert is 6ft in diameter, while the bankfull channel width is 17ft (structure width is 35% of reference). The outlet is perched 2 feet above the water surface and is a major AOP barrier.	AOP retrofit potential is low for most fish species and age classes, except for adult trout. As structure comes up for replacement, replace with an at-grade bankfull structure to reduce flood hazards and improve AOP.	Medium	Medium	Medium	Improve AOP and reduce flood risks to adjacent properties.	High	Town of Pownal; VTrans
LB 10 **Residence along Ladd Brook Road** Reach M05S1.02 42.77297 N 73.22804 W	**Passive Restoration** Buffer Planting	Approximately 100 feet of stream bank (west bank) upstream of the Pratt Road crossing lacks a healthy riparian buffer. Property is residential.	Plant the banks and buffer with native woody vegetation and work with the landowner to protect the corridor from future development.	Low	Medium	Medium	Reduce nutrient inputs to channel and increase shading.	Low	BCCD Trees for Stream; Private Landowner; VTANR ERP
LB 11 **Ladd Brook Road** Reach M05S1.02 42.77394 N 73.22763 W	**Active Restoration** Road Maintenance and Erosion Control	The road shoulder along Ladd Brook Road is extremely steep and eroding directly into the channel. Road grading likely pushes material further onto this slope increasing sediment loading. Town has attempted to stabilize with log terracing.	Install a barrier along the edge of the road to stop fine sediment from being directly pushed in to the stream. Clear loose material from slope and assess integrity of bank armoring. Establish vegetation on slope where possible.	Medium	**High**	**High**	Reduce Town road maintenance. Reduce sediment inputs to channel.	Moderate	Town of Pownal; VTrans/VTANR Better Roads Program
LB 12 **Lavino Road** Reach M05S1.02 42.77714 N 73.22473 W	**Active Restoration** Road Maintenance and Erosion Control	A pile of sediment was dumped along the bank just west (downstream) of the Lavino Road crossing. Sediment pile is not vegetated and is rilling fine sediment into the channel.	Remove sediment pile or vegetate to reduce sediment inputs.	Low	**High**	**High**	Reduce sediment inputs to channel.	Low	Town of Pownal

5.2.3 Hoosic River Mainstem River Corridor Project Opportunities

Table 5.5: Site-Level Project Identification for the Hoosic River Mainstem in the Town of Pownal, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Project Priorities			Project Benefits	Costs	Potential Partners & Funding
				Hazard Mitigation	Ecological Benefits	Overall			
HR 1 **Farm Field along Route 346** Reach M01 42.806145 N 73.279407 W	**Passive Restoration** River Corridor Protection	A large, undeveloped floodplain and river corridor is found just east of the state line. A flood chute in the upper reach indicates planform adjustment and meander redevelopment. The reach is very incised (IR=2.1)	Protect corridor from future development and plant buffer with native woody vegetation where appropriate. This area is approximately 75 acres including the farm field and forested floodplain south and west of Route 346.	Medium	Medium	Medium	Protect floodplain area from future development and increase shading and woody debris inputs to channel. Provide minor to moderate flood water and sediment/debris storage.	Low to Moderate	Landowner; VTANR ERP; VLT; BCCD
HR 2 **Pownal Wastewater Treatment Plant** Reach M02 42.798689 N 73.270649 W	**Active Restoration** Berm Removal or Relocation	A large berm was installed along the right (north) river bank to protect a remediated historic waste site (Pownal Tannery) from flooding. The berm constricts flood flows and may be exacerbating erosion along a mass failure on the opposite river bank.	Explore options for removing berm while protecting hazardous waste from being exposed to erosion flood flows or inundation. Can the berm be offset to re-establish some floodplain? What flood storage benefits are achieved?	Medium	Medium	Medium	Improved flood storage and reduction of high velocity and shear stress along the south bank at the mass failure.	High	Town of Pownal; EPA; VTANR; BCRC; FEMA
HR 3 **Pownal Wastewater Treatment Plant** Reach M02 42.797521 N 73.270374 W	**Active Restoration** Mass Failure Stabilization	A large berm installed along the right (north) bank constricts flood flows and may be exacerbating erosion along a mass failure on the opposite river bank. Slope failure is approximately 300 feet long and 35-40 feet tall. The failure was initiated at the toe of slope but is now eroding from above as trees fall and pull the upper slope down.	Explore options for stabilizing the toe of slope with bioengineering methods, such as engineered log jams, terracing and live plant staking. This project would need to be completed in tandem with project HR 2 to reduce erosive forces along the bank. Otherwise this project is likely not viable.	Medium	Medium	Medium	Reduce significant source of fine sediment to river.	Moderate to High	Town of Pownal; Landowner; EPA; VTANR; BCRC; FEMA Note: The project may not improve channel dynamics or water quality, and thus may not qualify for Vermont State Clean Water Initiative funding

Table 5.5: Site-Level Project Identification for the Hoosic River Mainstem in the Town of Pownal, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Project Priorities			Project Benefits	Costs	Potential Partners & Funding
				Hazard Mitigation	Ecological Benefits	Overall			
HR 4 Floodplains north of Pownal Village Reach M04-B and M05 42.777317 N 73.249028 W	**Passive Restoration** River Corridor Protection	A large, undeveloped floodplain and river corridor is found just north of Pownal Village, in between Palmer Drive and Rt. 346. The floodplain and river corridor is intensively used for agriculture. This portion of the Hoosic River is the least incised portion in Vermont, indicating good floodplain access.	Protect corridor from future development and plant buffer with native woody vegetation where appropriate. There are three (3) farm fields that each cover 30-40 acres along the inside of the river bends.	**High**	Medium	**High**	Protect floodplain area from future development and increase shading and woody debris inputs to channel. Provide moderate to large flood water and sediment/debris storage.	Low to Moderate	Landowner; VTANR ERP; VLT; BCCD
HR 5 Floodplains west of Pownal Village Reach M05 42.762419 N 73.238135 W	**Passive Restoration** Floodplain Protection	It appears that fill is being placed in the Hoosic River floodplain west of Alta Gardens trailer park and the railroad tracks. This floodplain provides valuable storage to protect downstream properties.	Coordinate with the Town and VTDEC to ensure that the 15-20 acre floodplain is not being filled, resulting in increased flood risks downstream.	Medium	**Low**	Medium	Protect floodplain area from future development. Maintain moderate to large flood water and sediment/debris storage.	Low	Town of Pownal; VTANR ERP

6.0 Conclusions and Recommendations

The information in this plan is intended to assist local, regional, state, and federal partners and stakeholders in planning and project development to address water quality and flood resiliency concerns in the Town of Pownal. While the Hoosic River is the dominant riverine feature in the Town of Pownal, the tributaries studied in detail in this project have degraded water quality as well as flood and erosion risks. Both Ladd and Tubbs Brooks have been identified as being stressed or impaired by fine sediment loading in the watershed. The problem areas and corresponding project opportunities from this study span from riparian buffer plantings to bridge and culvert replacements. While a few of the projects identified in this report address infrastructure resiliency specifically, most of the projects would have benefits for both water quality and hazard mitigation.

Below are some key water quality planning and flood resiliency recommendations specific to the Town of Pownal, as well as each of the brooks studied in detail during this project.

<u>Town of Pownal</u>

- Most of the bridges and culverts we assessed in the Ladd and Tubbs Brooks watersheds are undersized compared to the stable channel width upstream and downstream of the crossing. While this is common across Vermont, we recommend the Town utilize this information in their planning for structure replacements. The summary of structures in this report includes the reference bankfull channel width for each one, as culverts that are undersized compared to the bank channel width are more likely to fail. The structures list provides a means for towns to understand the relative flood vulnerability and prioritize structure replacements with these criteria in mind.
- The current Emergency Relief and Assistance Fund (ERAF) for state aid to cover flood damage costs in Pownal is 7.5%. BCRC is working with the Town to update the Local Hazard Mitigation Plan, and upon approval the ERAF rate will increase to 12.5%. Implementation of river corridor protection ordinances would increase the ERAF rate to the maximum of 17.5%. Additional ERAF assistance from the State can significantly reduce the financial burden faced by towns during federally-declared flood disasters; i.e., during a large flood resulting in 2 million dollars in recovery expenses (approximate Irene damages in several southern Vermont towns), the increased State share from 12.5% to 17.5% can reduce a Town’s match to Federal Public Assistance funding by $100,000.

<u>Tubbs Brook</u>

- The overall geomorphic stability and aquatic habitat of Tubbs Brook was “good” to “fair”, with significant variability along the channel.
  - In the downstream reach above and below Route 346, historical channel straightening and riparian buffer impacts indicated fair conditions.
  - The middle stretches of the brook, where the swimming holes or “tubs” are found, have relatively good channel stability. This is likely due to the bedrock providing grade control that may have limited historic channel downcutting.

  - The upper stretches of Tubbs Brook were notably impacted by fine sediment sources from nearby gravel roads and culvert outlets. In addition, some agricultural impacts in the corridor were present.
- The two high priority projects in the upper watershed that were further scoped in Appendix G will be helpful in reducing fine sediment loading to the channel over time. These projects are important for restoring water quality in an area known to have sedimentation impacts on in-stream biota.

Ladd Brook

- The overall geomorphic stability and aquatic habitat of Ladd Brook was “good” to “fair”, with significant differences between the lower reach and the upper reaches.
  - In the downstream reach below Route 346, historical channel straightening, berming, undersized culverts, and riparian buffer impacts indicated fair conditions.
  - The middle stretches of the brook along Ladd Brook Road have relatively good channel stability. This is likely due to the coarse native sediment (i.e., cobbles and boulders) and bedrock in the channel that may have limited historic channel downcutting.
- The three high priority projects in the lower watershed that were further scoped in Appendix G are associated with severe flood risks in the Alta Gardens trailer park. The most important project to reduce flood risks in Alta Gardens is the replacement of the railroad culvert with a bankfull structure. However, even with the implementation of all three projects, significant flood risks will remain due to the setting of the park in the floodplain.

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8.0 Glossary of Terms

Adapted from:

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

And

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

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

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

Aggradation -- A progressive buildup or raising of the channel bed and floodplain due to sediment deposition. The geologic process by which streambeds are raised in elevation and floodplains are formed. Aggradation indicates that stream discharge and/or bed-load characteristics are changing. Opposite of degradation.

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

Alluvial -- Deposited by running water.

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

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

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

Armoring -- A natural process where an erosion-resistant layer of relatively large particles is established on the surface of the streambed through removal of finer particles by stream flow. A properly armored streambed generally resists movement of bed material at discharges up to approximately 3/4 bank-full depth. Augmentation (of stream flow) – Increasing flow under normal conditions, by releasing storage water from reservoirs.

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

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

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

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

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

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

Bankfull discharge -- The stream discharge corresponding to the water stage that overtops the natural banks. This flow occurs, on average, about once every 1 to 2 years and given its frequency and magnitude is responsible for the shaping of most stream or river channels.

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

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

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

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

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

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

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

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

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

Bedform -- Individual patterns which streams follow that characterize the condition of the stream bed into several categories. (*See*: braided, dune-ripple, plane bed, riffle-pool, step-pool, and cascade)

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

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

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

Boulder -- A large substrate particle that is larger than cobble, between 10 and 160 inches in diameter.

Boundary resistance -- The ability a stream bank has to withstand the erosional forces of the flowing water at varying intensities. Under natural conditions boundary resistance is increased due to stream bank vegetation (roots), cohesive clays, large boulder substrate, etc.

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

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

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

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

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

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

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

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

Channel evolution model (CEM) -- A series of stages used to describe the erosional or depositional processes that occur within a stream or river in order to regain a dynamic equilibrium following a disturbance.

Clay -- Substrate particles that are smaller than silt and generally less than 0.0001 inches in diameter.

Coarse gravel -- Substrate that is smaller than cobble, but larger than fine gravel. The diameter of this stream-bottom particulate is between 0.63 and 2.5 inches.

Cobble -- Substrate particles that are smaller than boulders and larger than gravels, and are generally between 2.5 and 10 inches in diameter.

Confinement -- *see* Valley confinement

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

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

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

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

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

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

Cross-section -- A series of measurements, relative to bankfull, that are taken across a stream channel that are representative of the geomorphic condition and stream type of the reach.

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

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

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

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

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

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

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

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

Dike -- (1) (Engineering) An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of lowlands; a levee. (2) A low wall that can act as a barrier to prevent a spill from spreading. (3) (Geology) A tabular body of igneous (formed by volcanic action) rock that cuts across the structure of adjacent rocks or cuts massive rocks.

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

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

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

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

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

Dune-ripple -- A bedform associated with low-gradient, sand-bed channels; the low gradient nature of the channel causes the sand to form a sequence of dunes and small ripples; significant sediment transport typically occurs at most stream stages.

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

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

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

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

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

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

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

Equilibrium Condition -- The state of a river reach in which the upstream input of energy (flow of water) and materials (sediment and debris) is equal to its output to downstream reaches. Natural river reaches without human impacts tend towards a "stable" state where predictable channel forms are maintained over the long term under varying flow conditions.

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

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

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

Fine gravel -- Is substrate which is larger than sand, but smaller than coarse gravel. It is between 0.08 and 0.63 inches in diameter.

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

Floodplain -- Land built of fine particulate organic matter and small substrate that is regularly covered with water as a result of the flooding of a nearby stream.

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

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

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

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

Fluvial Geomorphology—The study of how rivers and their landforms interact over time through different climatic conditions.

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

Fry -- A recently hatched fish.

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

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

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

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

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

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

Grade control -- A fixed feature on the streambed that controls the bed elevation at that point, effectively fixing the bed elevation from potential incision; typically bedrock, dams. or culverts.

Gradient -- Vertical drop per unit of horizontal distance.

Grass/forb -- Herbaceous vegetation.

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

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

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

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

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

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

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

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

Headcut -- A sharp change in slope, almost vertical, where the streambed is being eroded from downstream to upstream.

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

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

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

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

Hydric -- oil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper horizon.

Hydrograph -- A curve showing stream discharge over time.

Hydrologic balance -- An accounting of all water inflow to, water outflow from, and changes in water storage within a hydrologic unit over a specified period of time. Hydrologic region -- A study area, consisting of one or more planning subareas, that has a common hydrologic character.

Hydrologic unit Code (HUC) -- A distinct watershed or river basin defined by an 8-digit code.

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

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

Impoundment -- An area where the natural flow of the river has been disrupted by the presence of human-made or natural structure (e.g. weir or beaver dam). The impoundment backwater extends upstream causing sediment to be deposited on the stream bottom.

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

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

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

Infiltration (soil) -- The movement of water through the soil surface into the soil.

Inflow -- Water that flows into a stream, lake,

Instream cover -- The layers of vegetation, like trees, shrubs, and overhanging vegetation, that are in the stream or immediately adjacent to the wetted channel.

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

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

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

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

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

Kame – a deposit of stratified glacial drift in isolated mounds or steep-sided hills.

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

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

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

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

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

Low gradient -- streams typically appear slow moving and winding, and have poorly defined riffles and pools.

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

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

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

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

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

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

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

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

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

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

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

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

Moraine – a mass of till either carried by an active glacier or deposited on the land after a glacier recedes.

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

Neck cutoff -- A channel migration feature where the land that separates a meander bend is cut off by the lateral migration of the channel. This process may be part of the equilibrium regime or associated with channel instability.

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

Outwash – water-transported material carried away from the ablation zone of a melting glacier.

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

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

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

Perennial streams -- Streams that flow continuously.

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

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

Planform -- The channel shape as if observed from the air. Changes in planform often involve shifts in large amount of sediment, bank erosion, or the migration of the channel. A channel straightened for agricultural purposes has a highly impacted planform.

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

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

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

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

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

Railroads – Used or unused railroad infrastructure.

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

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

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

Reference stream type --Uses preliminary observations to determine the natural channel form and process that would be present in the absence of anthropogenic impacts to the channel and the surrounding watershed.

Refuge area -- An area within a stream that provides protection to aquatic species during very low and/or high flows.

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

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

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

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

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

Riparian area -- An area of land and vegetation adjacent to a stream that has a direct effect on the stream. This includes woodlands, vegetation, and floodplains. Riparian buffer is the width of naturally vegetated land adjacent to the stream between the top of the bank (or top of slope, depending on site characteristics) and the edge of other land uses. A buffer is largely undisturbed and consists of the trees, shrubs, groundcover plants, duff layer, and naturally uneven ground surface. The buffer serves to protect the water body from the impacts of adjacent land uses. Riparian corridor includes lands defined by the lateral extent of a stream's meanders necessary to maintain a stable stream dimension, pattern, profile, and sediment regime. For instance, in stable pool-riffle streams, riparian corridors may be as wide as 10-12 times the channel's bankfull width. In addition the riparian corridor typically corresponds to the land area surrounding and including the stream that supports (or could support if unimpacted) a distinct ecosystem, generally with abundant and diverse plant and animal communities (as compared with upland communities).

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

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

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

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

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

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

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

River reach -- Any defined length of a river.

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

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

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

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

Rock -- A naturally formed mass of minerals.

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

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

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

Sand -- Small substrate particles, generally from 0.002 to 0.08 in diameter. Sand is larger than silt and smaller than gravel.

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

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

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

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

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

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

Silt -- Substrate particles smaller than sand and larger than clay; between 0.0001 and 0.002 inches in diameter.

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

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

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

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

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

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

Spillway -- A channel for reservoir overflow.

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

Stone -- Rock or rock fragments used for construction.

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

Stream -- A general term for a body of water flowing by gravity; natural watercourse containing water at least part of the year. In hydrology, the term is generally applied to the water flowing in a natural narrow channel as distinct from a canal. Stream banks are features that define the channel sides and contain stream flow within the channel; this is the portion of the channel bank that is between the toe of the bank slope and the bankfull elevation. The banks are distinct from the streambed, which is normally wetted and provides a substrate that supports aquatic organisms. The top of bank is the point where an abrupt change in slope is evident, and where the stream is generally able to overflow the banks and enter the adjacent floodplain during flows at or exceeding the average annual high water.

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

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

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

Stream morphology -- The form and structure of streams.

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

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

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

Stream type departure -- When the current stream type differs from the reference stream type as a response to anthropogenic or severe natural disturbances. These departures are often characterized by large-scale incision, deposition, or changes in planform.

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

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

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

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

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

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

Stressor – Range of physical factors that influence (increase or decrease) channel stability at the watershed and reach scale.

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

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

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

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

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

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

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

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

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

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

Turbidity -- A measure of the content of suspended matter that interferes with the passage of light through the water or in which visual depth is restricted. Suspended sediments are only one component of turbidity.

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

Valley confinement -- Referring to the ratio of valley width to channel width. Unconfined channels (confinement of 4 or greater) flow through broader valleys and typically have higher sinuosity and area for floodplain. Confined channels (confinement of less than 4) typically flow through narrower valleys.

Valley wall -- The side slope of a valley, which begins where the topography transitions from the gentle-sloped valley floor. The distance between valley walls is used to calculate the valley confinement.

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

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

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

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

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

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

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

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

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

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

Wetland -- Areas adjacent to, or within the stream, with sufficient surface/groundwater influence to have present hydric soils and aquatic vegetation (e.g. cattails, sedges, rushes, willows or alders).

Width/depth ratio -- The ratio of channel bankfull width to the average bankfull depth. An indicator of channel widening or aggradation, and used for stream type classification.