West Branch Passumpsic River & Calendar Brook Corridor Plan
Caledonia County, Vermont

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List of Figures and Tables

Executive Summary

Tributary to the Connecticut River, the Passumpsic River is one of the dominant landscape features in the Northeast Kingdom of Vermont. Numerous towns are found within its alluvial valley and along its steep banks, including St. Johnsbury and Lyndonville. In the upper watershed, the West Branch of the Passumpsic River drains a 66 square mile subwatershed spanning 7 towns in 2 counties. Within the West Branch drainage area, four significant tributaries drain to the river, including Quimby Brook, Calendar Brook, Roundy Brook, and the Sutton River. The West Branch and its tributaries provide recreational opportunities in the form of fishing and boating, natural beauty and aesthetics, and significant historical and cultural value.

Since a major flood occurred along the Passumpsic River in Lyndon and in St. Johnsbury Center in 2002, the watershed has been the subject of numerous studies and efforts to mitigate flooding and erosion hazards. Following the flood, a mitigation study was prepared by Gomez and Sullivan Engineers, PC to understand causes of flooding and potential mitigation measures. Concurrently, the Caledonia County Natural Resources Conservation District (CCNRCD), with assistance from the Vermont Department of Environmental Conservation's (DEC) River Management Program (RMP), began assessing channel stability and floodplain access in the Passumpsic River watershed upslope of Lyndon. The purpose of the geomorphic assessments, consistent with the Gomez and Sullivan recommendations, was to: a) determine the river's stability, b) identify floodplains that provide key attenuation assets, and c) compute the total belt width along each river that would define the river corridor.

The CCNRCD completed Phase 2 Stream Geomorphic Assessments (SGA) following the RMP protocols for portions of the East Branch, Miller's Run, the West Branch and Calendar Brook between 2003 and 2008. CCNRCD prepared final River Corridor Plans for the East Branch in January, 2009 (CCNRCD, 2009a) and for Miller's Run in October, 2009 (CCNRCD, 2009b). This report presents a River Corridor Plan for seven (7) reaches of the West Branch and five (5) reaches of Calendar Brook. Fitzgerald Environmental Associates, LLC was retained by CCNRCD in spring of 2010 to review the data collected from the field work and develop a summary report of the study findings that includes restoration project recommendations. The following is a summary of the Phase 2 findings and the stressor and project identification effort:

- The surficial geology of the West Branch subwatershed has a strong influence on channel morphologies in this section of the Passumpsic River and its tributaries. A high degree of hydrologic group A and B-type soils are found within the West Branch drainage area. These sandy soils with high infiltration rates limit runoff volumes to the river during channel forming rainfall events. The Phase 2 measurements indicated that the bankfull channel widths in the West Branch are consistently narrow relative to the predicted values (from the hydraulic geometry curves). This observation is important in recommendations for bridge replacements and future creation of Fluvial Erosion Hazard (FEH) zones. On the other hand, bankfull channel widths on Calendar Brook are wider than predicted, which is consistent with the channel adjustment and evolutionary processes observed in the field.

- The West Branch study reaches are predominately C-type (Rosgen, 1994) by reference with broad and narrow valleys. The channel slope of main stem within the study area is 0.4%. Based on the Rapid Geomorphic Assessment (RGA) scores, one segment had "reference" channel stability (T3.07-A), six (6) segments had “good” channel stability, and three (3) segments had “fair” channel stability. Reaches with “fair” RGA scores are all found in the lower West Branch watershed and had corresponding “extreme” sensitivities to due to severe departures in channel morphology. Rapid Habitat Assessment (RHA) scores ranged from “fair” to “reference” and were generally consistent with RGA scores.

- The Calendar Brook reaches assessed for Phase 2 data have an average channel slope of 1.2%. The valley setting of the lower reaches is very broad by reference with fluctuations in valley dimensions moving upstream, supporting C and B-type stream morphologies. Based on the RGA scores, one (1) reach had “reference” channel stability (T3.S1.03), three (3) segments had “good” channel stability, and one (1) segment had “fair” channel stability. The greatest impacts to the Calendar Brook corridor have occurred in the lower subwatershed where channel straightening, dredging, and encroachments have all resulted in historical channel incision.

- The stressor identification analysis revealed limited watershed-scale impacts from recent land use changes; however corridor encroachments and channel straightening has impacted the lower reaches of both channels. Three (3) segments on the lower West Branch have departed from reference conditions due to channel incision. These departures result in a conversion of river segments to effective transporters of sediment to downstream areas, with a subsequent loss of storage of sediment and floodwaters within the floodplain.

- A total of 14 bridges were noted during the Phase 2 field effort. None of the structures have widths equal to or greater than the bankfull channel width. Based on individual structure data, and a review of the erosion and deposition noted around each structure, full bridge assessments following the SGA protocols are recommended for four (4) of the 14 bridges.

- Watershed-level approaches to restoration of dynamic equilibrium conditions were evaluated, including mitigation of stormwater runoff, implementation of FEH zones, and the above-described analysis of structure data. FEH zones are recommended for the Towns of Sutton, Lyndon and Burke to encourage long-term channel stability, reduce flood recovery and infrastructure maintenance costs, and increase public safety.

- Site level approaches to restoration of dynamic equilibrium conditions were evaluated in detail at the reach scale. This resulted in the identification of 16 unique projects for the study area, including 11 projects that do not require significant further study (i.e., passive approaches such as buffer plantings and corridor protection), and five (5) projects requiring further feasibility study or engineering design (i.e., active restoration approaches such as bridge replacements).

- As with river reaches in the East Branch and Miller’s Run, the West Branch Passumpsic and Calendar Brook channels and floodplains are adjusting their slope and dimensions in response to historical impacts such as corridor encroachments and straightening. The corridor protection areas noted in this plan focus on undeveloped areas along the corridor that are a high priority for floodwater attenuation to help mitigate these impacts and protect downstream villages from further flooding and erosion risks. A holistic approach to managing river corridors in the Passumpsic River watershed, one which includes the West Branch and Calendar Brook, will be critical for increasing public safety in the Town of Lyndon and other downstream villages.

1.0 Project Background

1.1 Introduction

The Passumpsic River watershed has been the subject of numerous studies over the last eight years since a major flood occurred in Lyndon in June of 2002. Following this flood event, the Caledonia County Natural Resources Conservation District (CCNRCD), with assistance from the Vermont Department of Environmental Conservation's (DEC) River Management Program (RMP) established the East Branch Corridor Protection Project with funding from the Upper Connecticut Mitigation and Enhancement Fund. This project targeted a two-mile stretch of the East Branch for restoration and protection efforts. The project included initial geomorphic assessments, targeted outreach to streamside landowners, installation of buffers along the river, relocation of a logging road that was previously along the edge of the river, as well as an effort to protect streamside land with conservation easements through the support and involvement of the Passumpsic Valley Land Trust (PVLT).

Since this initial project, and in response to ongoing concerns about flooding and river stability in the watershed, the CCNRCD has worked with RMP to conduct geomorphic assessments on various branches and tributaries of the Passumpsic River. A number of related activities and projects provided momentum for the assessment work in the watershed. First, feasibility studies and public meetings had been taking place for the potential removal of the East Burke Dam, located on the East Branch in East Burke Village. PVLT acquired the dam from Northern Star Burke Mountain Ski Area in 2000 and has been working to secure required permits and evaluate the potential of its removal. As this project came to the table, there was more interest in acquiring geomorphic assessment data upstream and downstream of the dam, as well as the tributary just upstream of the dam, Dishmill Brook. Second, The Passumpsic River Flood Mitigation Study was prepared for the town of Lyndon by Gomez and Sullivan Engineers, P.C. in November of 2006 (Gomez and Sullivan, 2006).

This Flood Mitigation Study came about as a result of frequent flooding in the town of Lyndon, particularly the flood in June of 2002. The study was intended to assist the town of Lyndon in understanding the reasons for the flooding and outline recommendations for structural and nonstructural alternatives. The Flood Mitigation Study discussed the need for more information on the upper main tributaries into Lyndon; the Miller's Run River, as well as the East and West Branches of the Passumpsic River. It was unknown what impact the West Branch and Miller's Run were having on the Passumpsic main stem, and more information was necessary to fully explore the tributary impacts and potential for flood attenuation. The following are excerpted recommendations from The Flood Mitigation Study that are pertinent to geomorphic assessments and river corridor planning for the East and West Branches of the Passumpsic River:

- Using the East Branch Phase 2 geomorphic assessment results, along with some follow-up field work, estimate the storage capacity on the East Branch. Quantify how much storage capacity could be gained in those areas where the East Branch currently cannot access its floodplain. Quantify the overall floodplain storage capacity and the benefit relative to curtailing flooding in Lyndon.
- Work with the Vermont Rivers Management department to conduct geomorphic assessments on the other major tributaries- West Branch and Miller Run- to determine if these rivers can access their floodplains. Conduct the same evaluations described above for

the East Branch, including quantifying the floodplain storage capacity that could be made available.

- It is recommended that first geomorphic studies be conducted on Miller Run and the West Branch to a) determine the river's stability, b) identify floodplains that provide key attenuation assets and c) compute the total belt width along each river that would define the river corridor. It is recognized that some floodplains are already occupied by houses or roads, thus emphasis should be placed on floodplains that remain relatively undeveloped.

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 VTANR River Corridor Planning Guide provides sound, scientifically-defensible methods for identifying stressors on channel stability and restoration projects that will address them appropriately (VTDEC, 2010). The overall goal of the VTDEC RMP 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," (VTDEC, 2010) achieved through:

- Fluvial erosion hazard mitigation;
- Sediment and nutrient load reduction; and
- Aquatic and riparian protection and restoration

The CCNRCD completed Phase 2 Stream Geomorphic Assessments (SGA) following the RMP protocols for portions of the East Branch, Miller's Run, the West Branch and Calendar Brook between 2003 and 2008. CCNRCD prepared River Corridor Plans for the East Branch in January, 2009 (CCNRCD, 2009a) and for Miller's Run in October, 2009 (CCNRCD, 2009b). This report presents a River Corridor Plan for seven (7) reaches of the West Branch and five (5) reaches of Calendar Brook, a tributary to the West Branch. The goal of the SGA and River Corridor Planning effort for these watersheds is to provide:

1) A basis for understanding the overall causes of channel instability and habitat degradation
2) The data needed to develop Fluvial Erosion Hazard Zones for the study area
3) A list of preliminary corridor restoration projects that can be further developed in the future to mitigate flood and erosion hazards in the Passumpsic River watershed

1.3 Project Partners

The planning team for the ongoing SGA and River Corridor Planning work in the Passumpsic River watershed includes the following groups:

- Caledonia County Natural Resources Conservation District (CCNRCD)
- Vermont Department of Environmental Conservation (VTDEC)
- Town of Lyndon Planning Commission and Development Review Board
- Northeastern Vermont Development Association (NVDA)

2.0 Background Watershed Information

2.1 Geographic Setting and Land Use History

The Passumpsic River watershed is located in the Upper Connecticut River Basin in Northeastern Vermont (Figure 2.1). The West Branch of the Passumpsic River drains the northern portion of the watershed from Orleans County down into Caledonia County, where the majority of the watershed is found. At the confluence with the East Branch of the Passumpsic River in Lyndon, the West Branch watershed drains 66.0 square miles. The main stem of West Branch Passumpsic flows in a southerly direction along Route 5A and Route 5 from the headwaters, which are found in the southeastern portion of Westmore near Lake Willoughby. The watershed in its entirety spans the towns of Westmore, Newark, Sutton, Sheffield, Wheelock, Burke, and Lyndon. Several significant tributaries flow into the main stem of the West Branch Passumpsic River, making up much of the total watershed area. Approximately 3 miles upstream from the confluence with the East Branch the West Branch forks downstream of the Route 5 Crossing. The tributary entering here, Calendar Brook (T3.S1), extends upstream to the northwest portion of the watershed. Farther upstream in the town of Burke the West Branch is met by Roundy Brook (T3.S2), which extends to the northeast. Finally, in the Village of East Burke the main stem is met by the Sutton River which extends to the north.

Land cover data based on imagery from 2006 (NOAA, 2008) are summarized in Table 2.1. The West Branch Passumpsic River is drained by a rural watershed, with forests representing the dominant land cover type (77.4%). Agricultural lands cover 13.5% of the watershed, with a majority of larger farmlands found in the lower portion of the West Branch reaches and Calendar Brook. Quimby Brook (T3.S1.S1.01) also has a high degree of agricultural land use. Development is limited throughout the watershed (2.4%). The river corridors in the southern portion of the watershed and the corridor of the Sutton River subwatersheds in West Burke village have the highest amount of development in the West Branch watershed.

Table 2.1 Land use/Land cover data for the West Branch Passumpsic River watershed and its tributaries

Land Cover/ Land Use Type	West Branch Passumpsic		Calendar Brook		Quimby Brook		Roundy Brook		Sutton River		Entire Watershed
	Reach	Corridor	Reach	Corridor	Reach	Corridor	Reach	Corridor	Reach	Corridor	
Agriculture	14.1%	6.4%	15.3%	8.3%	21.4%	2.1%	13.7%	2.4%	7.5%	1.0%	13.5%
Development	2.8%	4.1%	1.7%	5.6%	4.3%	3.2%	1.1%	1.8%	3.3%	14.7%	2.4%
Forest	75.8%	63.0%	76.9%	74.8%	69.3%	85.2%	77.6%	81.7%	83.2%	59.2%	77.4%
Open Water	1.1%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.8%	0.4%
Scrub/Shrub	3.9%	5.4%	4.9%	6.8%	3.9%	4.9%	5.6%	7.8%	4.1%	5.6%	4.5%
Wetland	2.3%	20.7%	1.2%	4.5%	1.1%	4.6%	2.0%	6.2%	1.7%	18.8%	1.8%
Branch Area (Mi^2)	22.82	0.94	20.78	0.50	2.07	0.12	9.32	0.22	10.98	0.29	65.97

*West Branch Passumpsic: reaches T3.01-T3.17; Calendar Brook: reaches T3.S1.01-T3.S1.10; Quimby Brook: reaches T3.S1.S1.01-T3.S1.S1.03; Roundy Brook: reaches T3.S2.01-T3.S2.07; Sutton River: reaches T3.S3.01-T3.S3.07

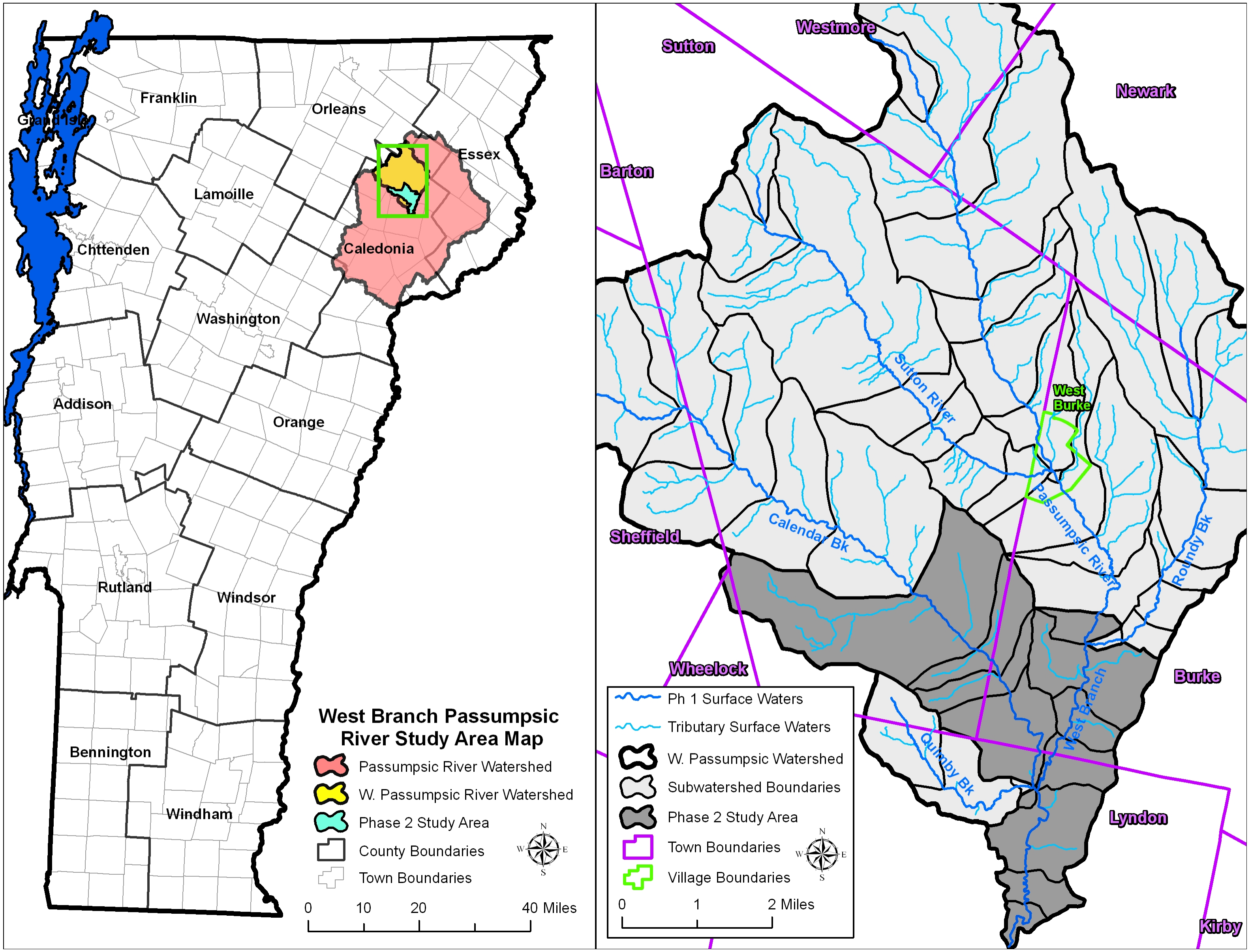

Figure 2.1 West Branch Passumpsic River Watershed Locus Map; Northeastern Vermont

Land Use History

Historically, the impacts of agricultural practices on the Vermont landscape played an important role in the legacy effects on waterways like the West Branch. 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 80 percent of the watershed devoid of trees at one time or another (Albers, 1998). This landscape change had a tremendous impact on waterways like the West Branch. Exposed, highly-erodible soil (e.g., glacial tills) on steep slopes was carried to the valley floors where it 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, 1998). Throughout the early and mid 1900's, as more family farms found on marginal lands were given up, the forests continued to recover. Today, approximately 80 percent of the West Branch watershed is covered by forest. Only 13.5% of the watershed is occupied by agricultural land uses today.

2.2 Geologic Setting

The underlying geology of the West Branch Passumpsic River watershed is comprised of mixture of rock types from the Silurian-Devonian era including igneous rock types (Doll et al., 1961). The Waits River Formation, which contains a mixture of schist and marble, is found in the majority of the watershed. The weathering of calcium carbonate rich (sea bottom) sediments in these formations results in basic soils that typically support communities of rich woods species. The undifferentiated granitic (igneous) rock types are found in the northern portion of the watershed in the Lake Willoughby region and Newark Pond. These rock types are much stronger and often are found on the mountain peaks.

The presence of Glacial Lake Hitchcock also had a significant effect on the surficial geology of the West Branch Passumpsic watershed (Figure 2.2). This lake occupied the Connecticut River Valley from central Connecticut to north of St. Johnsbury during the retreat of the Laurentide ice sheet beginning approximately 18,000 years ago (Ridge and Larson, 1990). The great size of the lake, combined with the erosive forces of the glacier moving over bedrock surfaces allowed for the development of annual layering of fine sediments (e.g., varves) throughout the area affected by the lake.

Surficial geologic deposits of the West Branch Passumpsic River 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 Green Mountains with a physical imprint that is clearly evident today. In the West Branch Passumpsic River watershed dense till, glacial till, and outwash areas reflect the dynamic nature with which glaciers shaped the landscape (Figure 2.3). Most of the surficial geology of the lower West Branch watershed is dominated by outwash. The resultant soils are largely sands (Adams series) and sandy loams (Colton-Duxbury complex) due to the lack of cohesive material in the outwash (Figure 2.4). The hydrologic A-type soils have very high infiltration rates, but are also highly erodible due to lack of soil cohesion.

Figure 2.2 Extent of Glacial Lake Hitchcock (NPS, 2010)

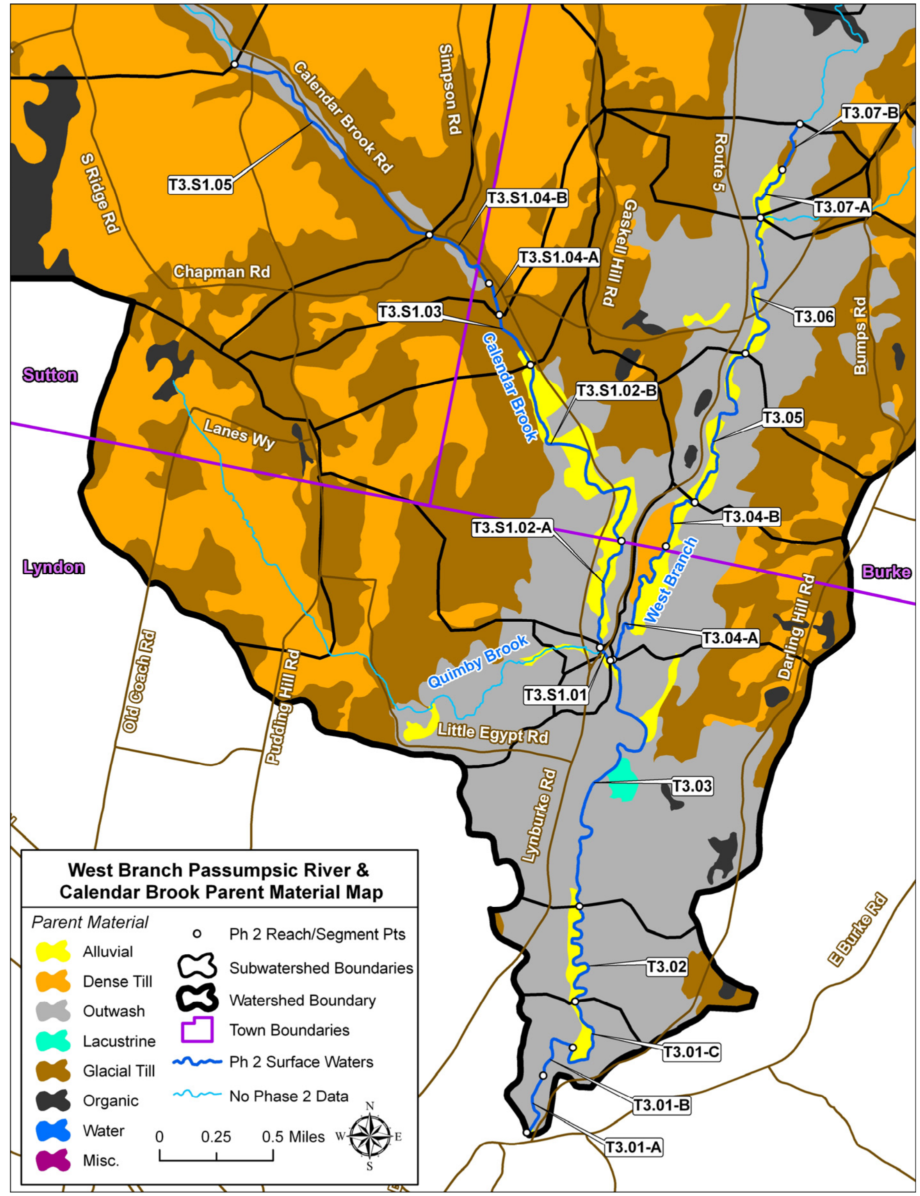

Figure 2.3 Parent surficial materials in the West Branch Passumpsic River and Calendar Brook

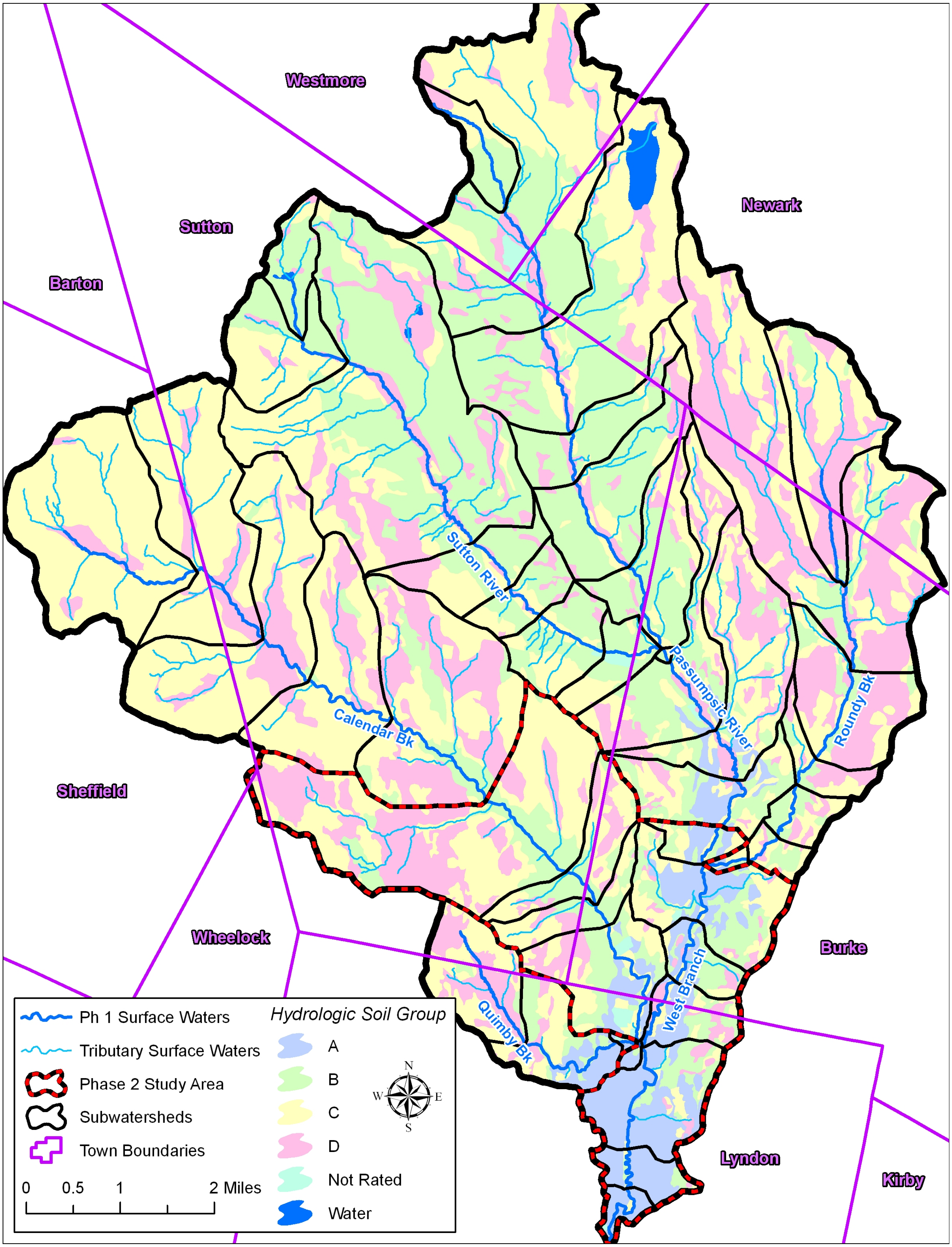

Figure 2.4 Hydrologic soil groups the West Branch Passumpsic River watershed

2.3 Geomorphic Setting

The West Branch Passumpsic River has three significant tributaries (Calendar Brook, Roundy Brook, and Sutton River) and one significant sub-tributary (Quimby Brook). Phase 2 geomorphic assessments were conducted only on the lower reaches of the main stem (T3.01-T3.07) and Calendar Brook (T3.S1.01-T3.S1.05). The entire main stem of the West Branch has an average channel slope of 2.0%. The channel slope of main stem within the study area is 0.4%. The West Branch study reaches are predominately C-type by reference with broad and narrow valleys. One reach (T3.05) had a semi-confined setting where the valley walls constricted the channel considerably. This reach has B-type morphology by reference even with the low slope. In the study reaches the sandy soil types and fine outwash parent material has led to reference substrate of sands and gravels. The high infiltration rates typical of the surrounding (and upslope) A and B-type hydrologic soils have caused the channel width to be slightly lower than predicted by the hydraulic geometry curves due to below average runoff during channel forming precipitation events. Under reference conditions the sandy and gravelly channels would tend to have excellent bar formation and an equilibrated sediment regime.

The Calendar Brook subwatershed has an average channel slope of 1.8%, and within the Phase 2 study area the channel slope is 1.2%. The valley setting of the lower reaches is very broad by reference with fluctuations in valley dimensions moving upstream. Reference stream morphology is mostly C-type where the valley is broad or very broad and B-type where the valley is narrow or semi-confined. Substrate is predominately gravel in the lower reaches near the confluence with the main stem. Upstream where the parent material is comprised of glacial and dense tills along with outwash the bed substrate is coarser (cobble). The denser parent material may have led to the abundance of B and C-type soils throughout the Calendar Brook watershed. The lower infiltration rates of these hydrologic soil groups result in greater runoff potential compared to the West Branch reaches.

The river reaches assessed in this study are found in varied topographic terrain. Variation in topography and valley slope influences the channel morphologies that would be expected under reference (i.e., undisturbed) conditions. A Phase 1 SGA study was previously carried out by CCNRCD, and included summary data of the topographic characteristics that influence valley and channel morphology, including watershed area, channel/valley slopes, predicted channel widths, and sinuosity. Following the Phase 2 SGA work completed as the basis for this study, reference reach characteristics for some of the reaches were refined based on improved knowledge of the reach and valley setting. The reach characteristics were used to classify natural channels using two classification systems developed by Rosgen (1994) and Montgomery and Buffington (1997).

The Rosgen system (Figure 2.5) uses measurements of channel and floodplain dimensions to make predictions about river processes. This classification system is used widely by federal and state agencies as a way of communicating about river form and function in the context of restoration management. The Montgomery and Buffington classification system is based on a river's "bedform", whereby the shape of the bed and its features (e.g., riffle and pools) are used to understand the dominant hydraulic and sediment processes of the river. This system is also used widely in Vermont and other states as part of geomorphic assessment methods.

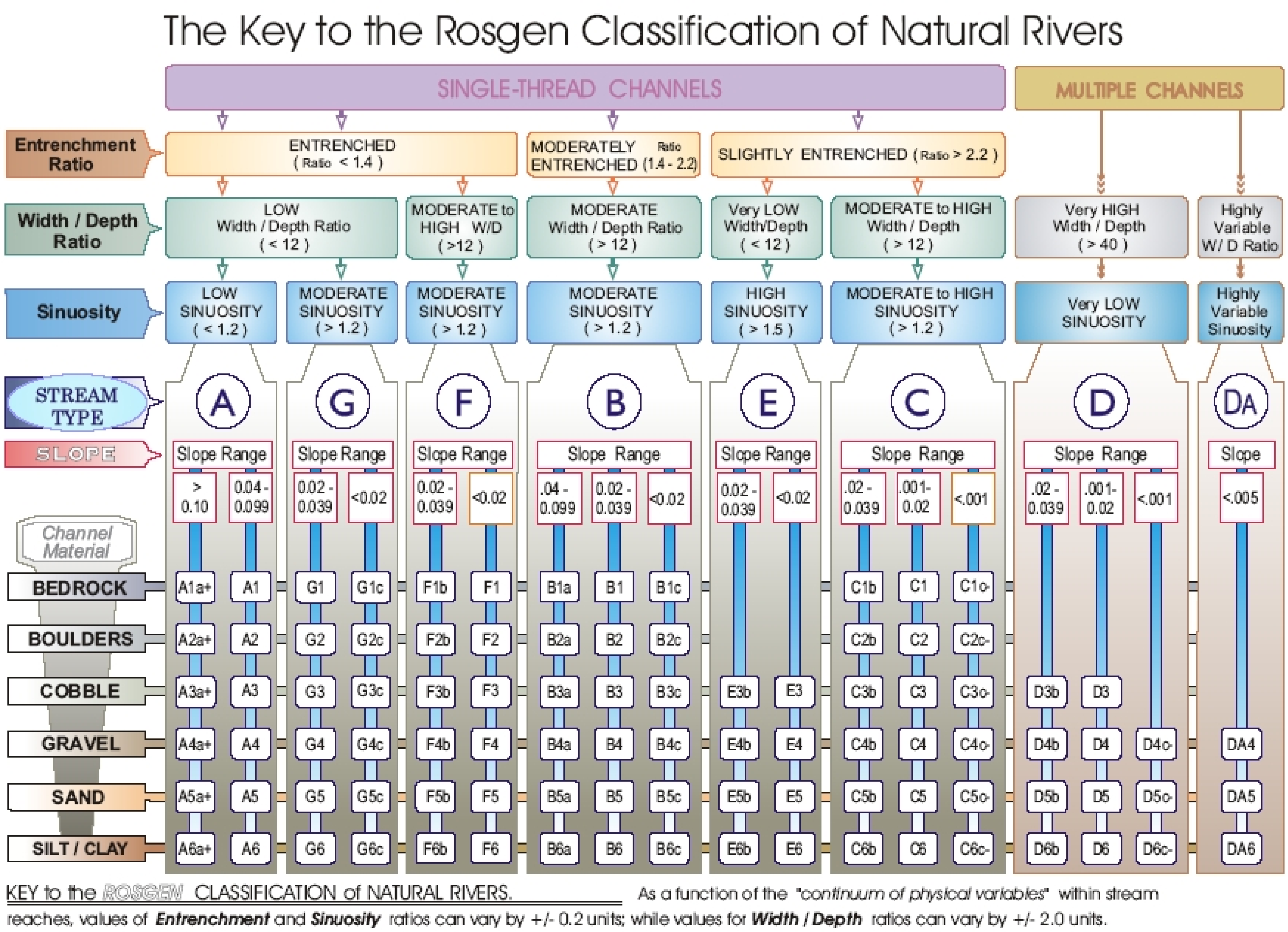

Figure 2.5 The Rosgen (1994) classification of streams based on channel morphology. Key parameters for classification include 1) the entrenchment ratio (floodprone width / bankfull channel width), 2) width to depth ratio (bankfull width / mean channel depth), and 3) channel sinuosity (channel length / straight-line valley length). Entrenched channels are typically dominated by sediment transport processes, whereas slightly entrenched channels (C and E types) have sediment transport and depositional processes.

Table 2.2 provides a summary of the reference reach data for the 12 reaches assessed in the watershed. The West Branch Passumpsic River reaches are found in a fairly consistent setting with unconfined or narrow valleys, B and C-type stream types and riffle-pool bedform. Lower Calendar Brook had a very broad valley setting and C-type morphology, which became slightly more confined moving upstream with B-type morphology.

Table 2.2 Reference reach characteristics for the West Branch Passumpsic River and Calendar Brook

Surface Water	Reach ID	Watershed Area (Mi^2)	Channel Length (Mi)	Channel Width (ft)	Channel Slope	Sinuo-sity	Valley Type*	Reference Stream Type†	Bedform‡
West Branch Passumpsic	T301	66.0	1.0	82.8	0.28	1.16	NW	C	Riffle-Pool
	T302	65.8	0.7	82.6	0.13	1.62	NW	C	Riffle-Pool
	T303	65.4	1.5	82.4	0.21	1.15	BD	C	Riffle-Pool
	T304	41.3	1.0	67.3	0.07	1.23	BD	C	Riffle-Pool
	T305	40.7	0.9	66.9	0.78	1.12	SC	B	Plane Bed
	T306	40.2	0.7	66.6	0.38	1.15	NW	C	Plane Bed
	T307	29.5	0.5	58.1	0.93	1.07	BD	C	Plane Bed
Calendar Brook	T3.S1.01	22.9	0.1	51.9	0.50	1.04	VB	C	Riffle-Pool
	T3.S1.02	20.7	1.7	49.7	0.42	1.13	VB	C	Riffle-Pool
	T3.S1.03	19.4	0.3	48.3	1.75	1.03	NW	B	Plane Bed
	T3.S1.04	18.8	0.5	47.7	1.93	1.04	BD	C	Riffle-Pool
	T3.S1.05	18.0	1.2	46.7	2.02	1.04	NW	B	Plane Bed

* SC= Semi-confined; NW= Narrow; BD=Broad; VB=Very Broad; † per Rosgen, 1994

‡ per Montgomery and Buffington, 1997

2.4 Hydrology and Flood History

USGS Gaging Data

The United States Geological Survey (USGS) operates a real-time flow monitoring gage on the East Branch Passumpsic River near the intersection of Route 114 and Worden Road in the town of Burke. The gage is located several miles upstream of the confluence of the East Branch with the West Branch in Lyndon. Although the gage is close in proximity to the West Branch Passumpsic watershed, the geologic settings of the two basins differ greatly. The East Branch watershed does not have as much glacial outwash and hydrologic soils that have high infiltration rates (e.g., A and B-type soils). The data from the East Branch Passumpsic gage serves to highlight years in which flow events on the West Branch would be significant (Figure 2.6).

Flooding history

Figure 2.6 summarizes the annual peak discharges on the East Branch Passumpsic River during its 48-year period of record. There are several historical flood events that are noteworthy. The June 30 flood of 1973 is the largest flood on record. Its discharge exceeded the 100-Year recurrence interval for the gage site. The most recent flood on record occurred in 2002. This flood exceeded the 50-year recurrence interval and caused extensive property damage along the Passumpsic River in Lyndon and St Johnsbury. Like all Rivers in Vermont, the Passumpsic River would have likely been devastated by the flood of 1927. However, no extrapolation of discharge of the 1927 flood was done for this watershed.

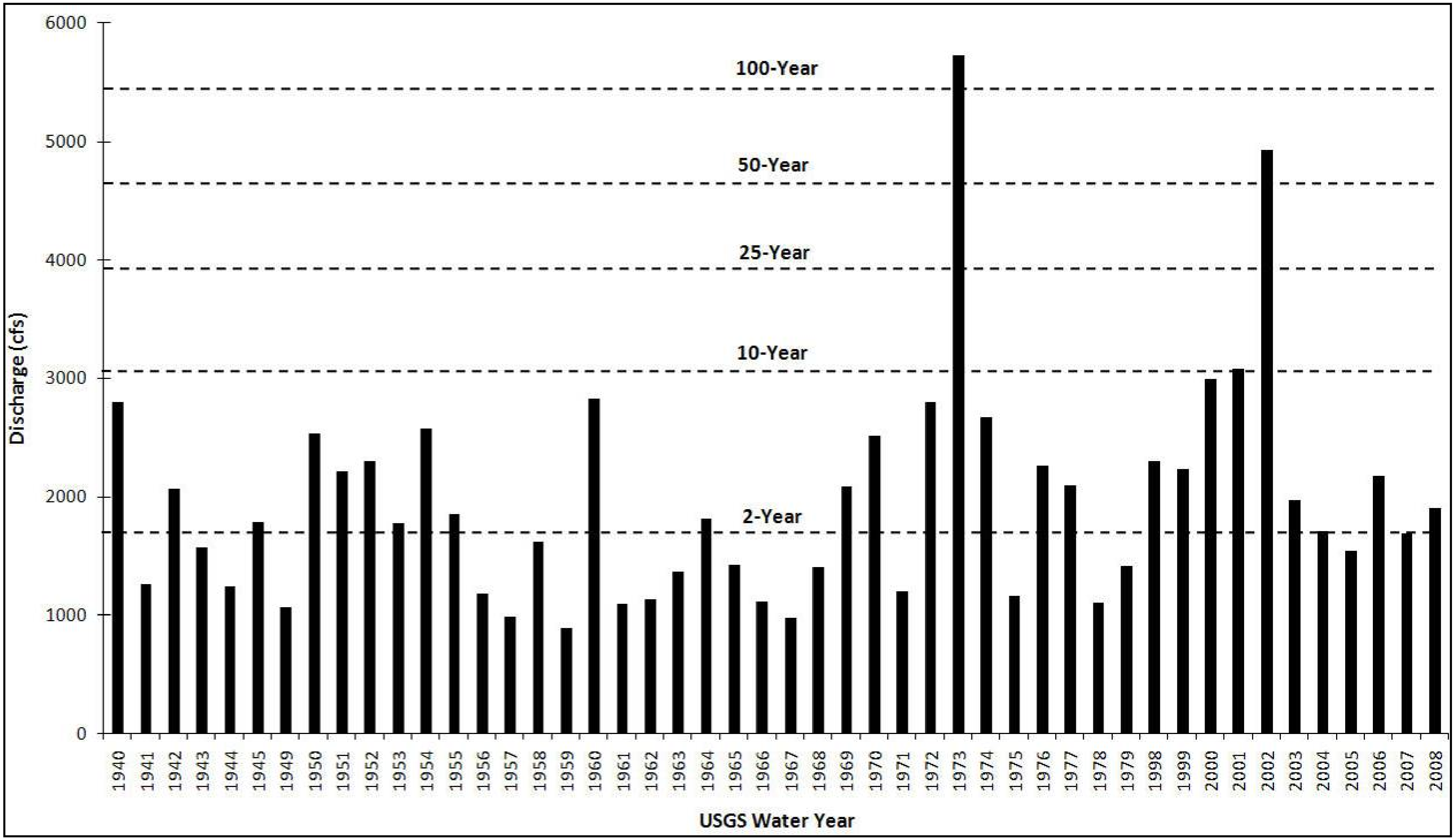

Figure 2.6 Annual peak discharges for USGS Gage # 01080102 on the East Branch Passumpsic River in Burke, Vermont; Recurrence intervals from Olsen (2002)

2.5 Ecological Setting

The West Branch Passumpsic River watershed is split between two distinct Biophysical Regions: the Northern Vermont Piedmont (NVP) and the Northeastern Highlands (NEH; Thompson and Sorenson, 2000). The NVP occupies the southwest portion of the watershed including the majority of the Calendar Brook subwatershed and all of the Phase 2 study area. The NVP is characterized by many rolling hills and calcareous bedrock geology that supports Northern Hardwood Forest communities. Some areas of igneous intrusions are much harder to weather and comprise some of the regions highest peaks; such as Knox Mountain, Spruce Mountain, Blue Mountain, and Black Hills. Rich soils of loam and silt along the Connecticut River that once supported extensive areas of silver maple (*Acer saccharinum*) and ostrich fern (*Matteuccia struthiopteris*) were converted to agricultural use during European settlement in the late 18th century. The accumulation of sand and gravel from the melting glaciers (e.g., moraines) are not typically found in Vermont. However, the NVP has one of the largest moraines in the state.

The NEH biophysical region, which occupies the northeastern portion of the West Branch Passumpsic watershed, has similar geologic characteristics as the NVP. However, in addition to calcareous underlying rocks that help form the rich northern hardwood forests, the NEH has extensive granite bedrock. The NEH region has greater relief in the topography and its colder temperature is suited for lowland spruce-fir forests. The NEH is often compared to the White Mountains of New Hampshire having similar climate, vegetation, and wildlife.

Elevations within the West Branch Passumpsic watershed range from 710 feet at the confluence with the East Branch, up to approximately 2,750 feet in the headwaters area near Lake Willoughby. The watershed is comprised primarily of mixed hardwood tree species, with areas of white pine (*Pinus strobus*) and eastern hemlock (*Tsuga canadensis*) found within younger growth and along steeper slopes, respectively. In the northern portions of the watershed and at high elevations spruce-fir forests are found composed mostly of red spruce (*Picea rubens*) and balsam fir (*Abies balsamea*). Much of the lowlands and river valleys are occupied by wetlands and hydric soils, especially in the corridor of the study area. These large wetland areas provide important flood control and water quality protection functions, and support continued inputs of subsurface and groundwater during the low flow periods of the year. These functions are maximized in areas where the wetland is contiguous with the channel and undisturbed by agricultural ditching or development, such as in reaches T3.02 and T3.04.

3.0 Methods

The Vermont River Management Program (RMP) has invested many 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 biotic 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 Connecticut River, 2) reduce the risk of property damage from flooding and erosion, and 3) enhance the quality of in-stream biotic habitat. The protocols are based on defensible scientific principles and have been tested widely in many watersheds throughout the state.

3.1 Phase 1 and 2 SGA Methods

Phase 1 assessments employ remote sensing techniques, along with limited field verification, to identify background conditions in the watershed. The Phase 1 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 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 describe the degree to which the channel is likely to adjust to human impacts in the future.

Phase 1 data were previously collected by CCNRCD for the entire West Branch Passumpsic River watershed in 2008 and summarized in the VTDEC Database Management System (DMS). A total of 12 reaches were identified for Phase 2 assessment conducted in the summer of 2008. A total of 15 segments on the West Branch and Calendar Brook were assessed for Phase 2 data, and data were entered into the Data Management System (DMS). All major human impacts and natural features noted during the Phase 2 surveys were indexed in a GIS using the Feature Indexing Tool (FIT; VTDEC, 2009).

3.2 Phase 2 Quality Assurance/Quality Control

Vermont's River Management Program conducted quality assurance/quality control (QA/QC) checks on the West Branch data in March and April of 2010. The QA/QC tools were developed by the VT ANR and are partially built into the online database management system. The spatial (GIS) database of the watershed and uploaded spatial data are also reviewed through the QA/QC process.

3.3 Bridge and Culvert Assessments

Full Bridge and Culvert Assessments (following SGA protocols) were not conducted on West Branch and Calendar Brook crossings during the Phase 2 assessments. However, data collected for structure width and observations of upstream/downstream erosion and deposition have been used to evaluate the geomorphic compatibility of bridges in the study area. This summary has been used to prioritize structures for replacement or retrofit, and for further data collection.

3.4 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
- 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.

3.4.1 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 West Branch 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.

3.4.2 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 3.1.

Table 3.1 Corridor plan sediment regime types and description

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/or 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.
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 leads 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 bed forms; 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 Stage 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 s transporting during some defined planning period. The extreme example would be that of an impounded reach where all of the coarse nd a great percentage of the fine sediments are being deposited, rather than transported downstream. This man-made condition may hange, 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 West Branch watershed. 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 3.1 below.

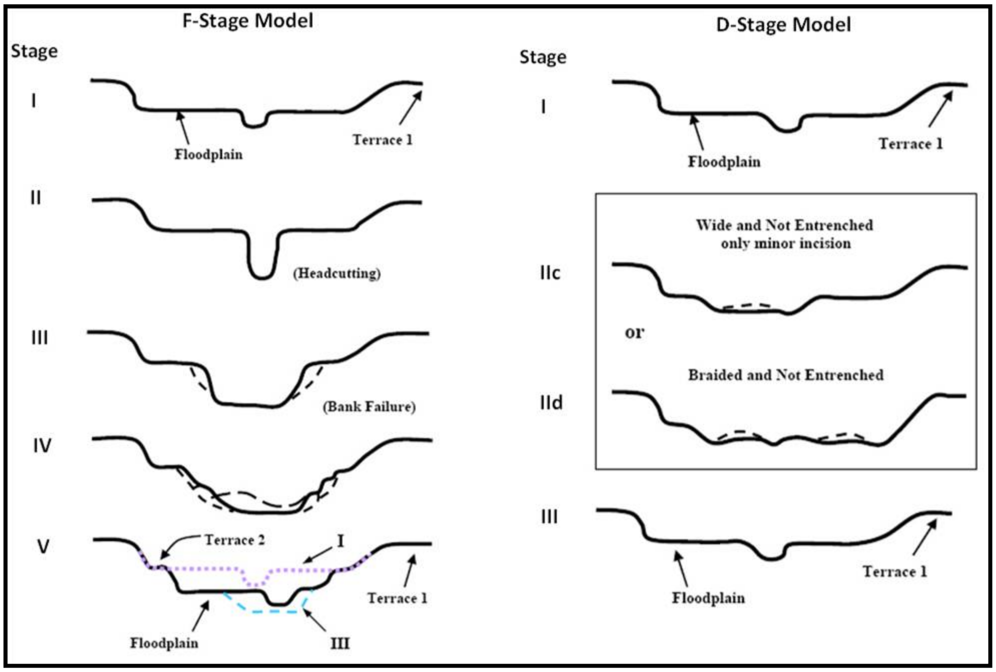

Figure 3.1 Typical channel evolution models for F-stage and D-stage (VTDEC, 2009)

3.4.3 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 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 competence 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 West Branch study area. Sensitivity ratings were assigned using the VTDEC Protocols (VTDEC, 2009).

3.5 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.

4.0 Results

The following section includes Phase 2 SGA results and a summary of the watershed and reach-scale stressors on channel stability. Detailed summaries of geomorphic data for each segment are provided in Appendix A.

4.1 Phase 2 SGA Results

A complete summary of the individual Rapid Habitat Assessment (RHA) and Rapid Geomorphic Assessment (RGA) scores are shown below (Table 4.1). Additional, segment-specific data summaries are provided in Appendix A for each reach assessed for Phase 2 data.

Table 4.1 RHA and RGA scores for Phase 2 assessed reaches/segments

Surface Water	Phase 2 Segment ID	RHA Score	RHA Condition	RGA Score	RGA Condition	Stream Sensitivity
West Branch Passumpsic River	T3.01-A	43%	Fair	63%	Fair	Extreme
	T3.01-B	67%	Good	64%	Fair	Extreme
	T3.01-C	49%	Fair	71%	Good	High
	T3.02	48%	Fair	66%	Good	High
	T3.03	59%	Fair	49%	Fair	Extreme
	T3.04-A	81%	Good	76%	Good	High
	T3.04-B	82%	Good	84%	Good	High
	T3.05	83%	Good	79%	Good	Moderate
	T3.06	85%	Reference	84%	Good	Moderate

Table 4.1 RHA and RGA scores for Phase 2 assessed reaches/segments

Surface Water	Phase 2 Segment ID	RHA Score	RHA Condition	RGA Score	RGA Condition	Stream Sensitivity
	T3.07-A	84%	Good	89%	Reference	Moderate
	T3.07-B	--	NA	--	NA	NA
Calendar Brook	T3.S1.01	--	NA	--	NA	NA
	T3.S1.02-A	49%	Fair	69%	Good	High
	T3.S1.02-B	70%	Good	64%	Fair	Very High
	T3.S1.03	77%	Good	91%	Reference	Moderate
	T3.S1.04-A	--	NA	--	NA	NA
	T3.S1.04-B	81%	Good	75%	Good	Moderate
	T3.S1.05	83%	Good	70%	Good	Moderate

Note: RHA = Rapid Habitat Assessment; RGA = Rapid Geomorphic Assessment; NA = Not Assessed

4.2 River Corridor Planning

The following sections summarize the stressor identification and departure maps. 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.

4.2.1 Stressor Maps

Land Use

The West Branch Passumpsic River watershed contains a mixture of land cover types (Table 4.2; NOAA, 2008) typical of rural Vermont watersheds. The upslope subwatersheds and highlands are predominately forested, while the river corridors and valley bottoms have much greater agricultural and developed land (Figure 4.1). Lands classified as scrub/shrub are typically found in areas of transition from old field to forest or in telephone/utility line right-of-ways. Developed lands (including road corridors) occupy only 2.4% of the watershed, with lesser amounts occupied by wetlands (1.8%) and open water (0.4%). Land use distribution is fairly consistent across each of the assessed tributaries.

The Phase 1 river corridor (SGAT output “s09”) has a much higher degree of agriculture and development land use for the main stem, because the corridor of the West Branch has been a valuable resource for fertile farmlands and other anthropogenic uses. Calendar Brook and the West Branch Passumpsic both have high percentages of agricultural land use in the corridor.

Table 4.2 Land use/land cover data for the West Branch Passumpsic River watershed and its tributaries

Land Cover/ Land Use Type	West Branch Passumpsic		Calendar Brook		Quimby Brook		Roundy Brook		Sutton River		Entire Watershed
	Reach	Corridor	Reach	Corridor	Reach	Corridor	Reach	Corridor	Reach	Corridor	
Agriculture	14.1%	6.4%	15.3%	8.3%	21.4%	2.1%	13.7%	2.4%	7.5%	1.0%	13.5%
Development	2.8%	4.1%	1.7%	5.6%	4.3%	3.2%	1.1%	1.8%	3.3%	14.7%	2.4%
Forest	75.8%	63.0%	76.9%	74.8%	69.3%	85.2%	77.6%	81.7%	83.2%	59.2%	77.4%
Open Water	1.1%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.8%	0.4%
Scrub/Shrub	3.9%	5.4%	4.9%	6.8%	3.9%	4.9%	5.6%	7.8%	4.1%	5.6%	4.5%
Wetland	2.3%	20.7%	1.2%	4.5%	1.1%	4.6%	2.0%	6.2%	1.7%	18.8%	1.8%
Branch Area (Mi^2)	22.8	0.9	20.8	0.5	2.1	0.1	9.3	0.2	11.0	0.3	66.0

*West Branch Passumpsic: reaches T3.01-T3.17; Calendar Brook: reaches T3.S1.01-T3.S1.10; Quimby Brook: reaches T3.S1.S1.01-T3.S1.S1.03; Roundy Brook: reaches T3.S2.01-T3.S2.07; Sutton River: reaches T3.S3.01-T3.S3.07

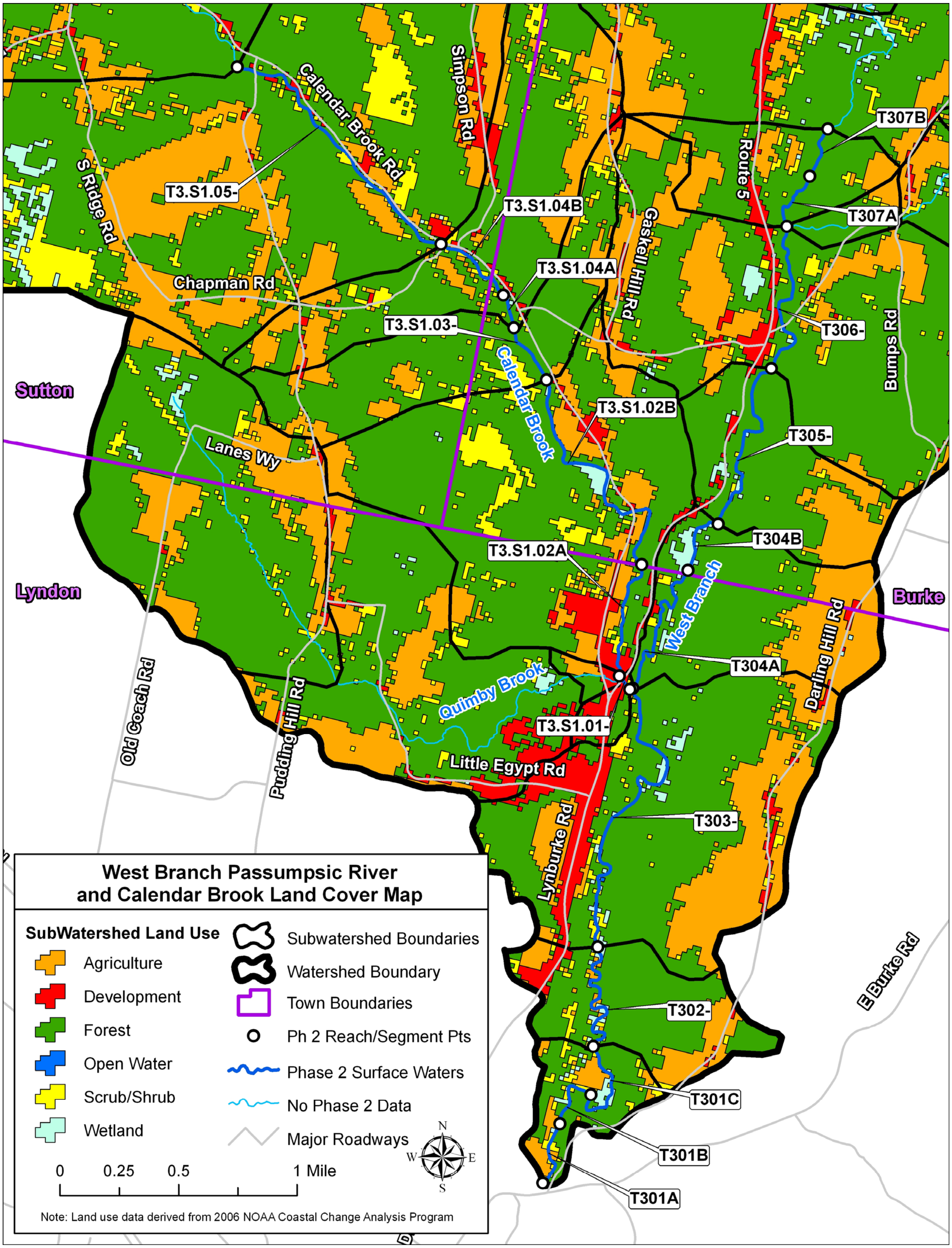

Figure 4.1 Land use/Land cover data for the lower West Branch Passumpsic River watershed

Hydrologic Regime Stressors

The following description of the hydrologic 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 hydrologic regime may be defined as the timing, volume, and duration of flow events throughout the year and over time. The hydrologic regime may be influenced by climate, soils, geology, groundwater, watershed land cover, connectivity of the stream, riparian, and floodplain network, and valley and stream morphology. The hydrologic regime, as addressed in this section, is characterized by the input and manipulation of water at the watershed scale and should not be confused with channel and floodplain "hydraulics," which describes how the energy of flowing water affects reach-scale physical forms and is affected by reach-scale physical modifications (e.g., bridges modify channel and floodplain hydraulics).

When the hydrologic regime has been significantly altered, stream channels will respond by undergoing a series of channel adjustments. Where hydrologic modifications are persistent, the impacted stream will adjust morphologically (e.g., enlarging when stormwater peaks are consistently higher) and often result in significant changes in sediment loading and channel adjustments in downstream reaches. The current day stressors to the hydrologic regime have been mapped using the variables extracted from the Phase 2 field dataset (e.g., stormwater outfalls), watershed-scale loss of wetlands, and density of the road network within each subwatershed. Wetland loss was mapped as the area where hydric soils (NRCS mapping) and National Wetland Inventory (NWI) areas intersected with urban or agricultural land uses in the watershed, with the remaining areas assumed to be intact wetland. This approach allows for the interpretation of loss of hydrologic attenuation of surface runoff at the reach and watershed scale. Stormwater outfall locations mapped during the Phase 2 assessments are included to depict areas of increased stormflows (Figure 4.2).

Areas of impact to the hydrologic regime include:

- High road density in T3.S1.01 (10.4 $Mi/Mi1^2$)
- High road density in T3.S1.S1.01 (6.1 $Mi/Mi1^2$)
- Localized corridor wetland loss in T3.01-B because of gravel mining operation
- Localized corridor wetland loss in T3.S1.02-A because of development and channel straightening along Calendar Brook Road
- Localized corridor wetland loss in T3.S1.02-B because of agriculture and channel straightening to the west of Calendar Brook Road
- Upslope reach wetland loss in reach T3.04 to the east along Darling Hill Road

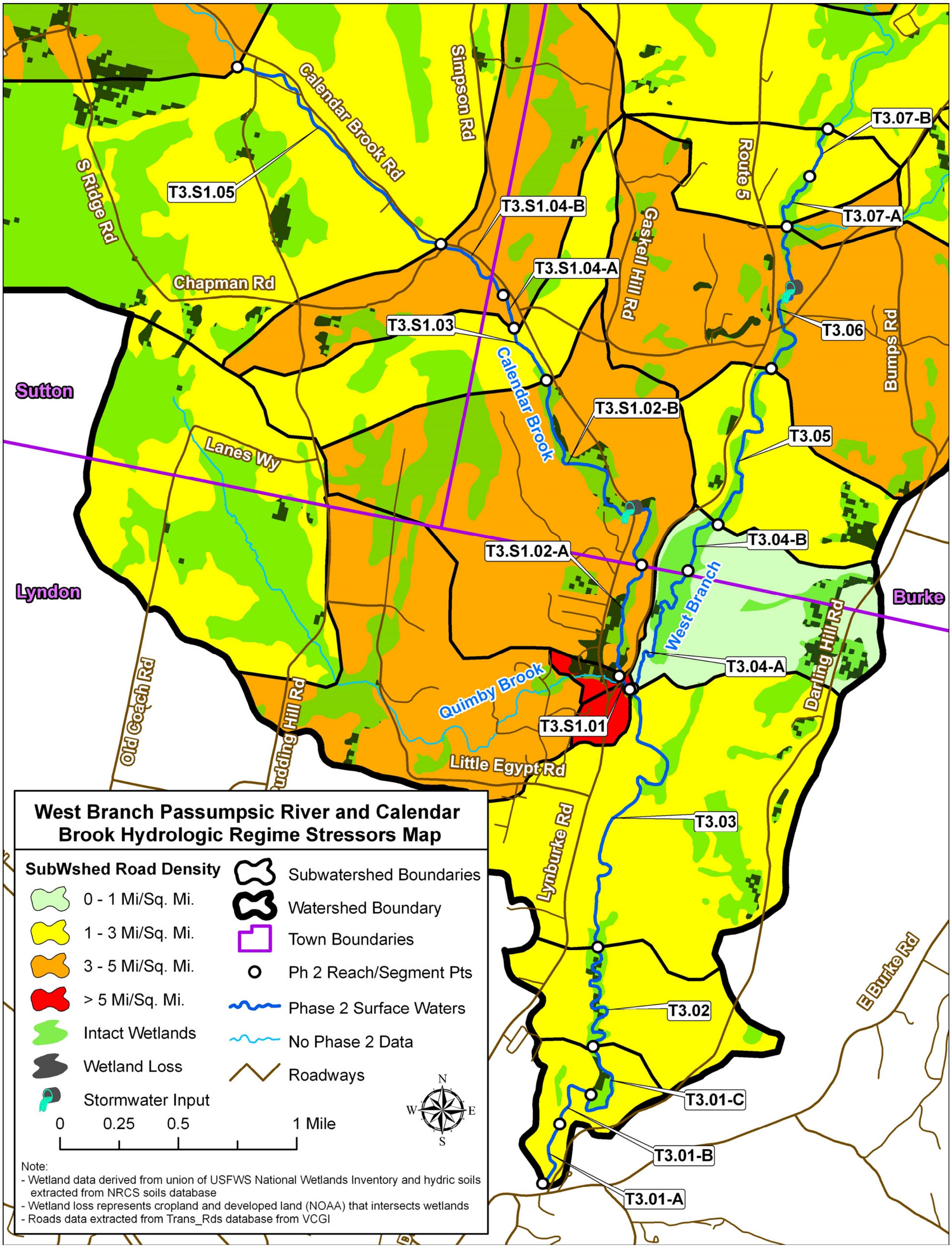

Figure 4.2 Hydrologic regime stressors for the lower West Branch Passumpsic River watershed

Sediment Load Indicators

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.

The current day stressors to the sediment regime have been mapped using the variables extracted from the Phase 2 field dataset, and the percent of agriculture (cropland and bare land) within each subwatershed. Four classes of percent agriculture were mapped to depict the relative impact of sediment delivery from agricultural lands at the reach and watershed-scales. In addition, depositional and migration features mapped during the Phase 2 assessments are included to depict areas of increased vertical and lateral channel adjustments due to sediment aggradation. Mass failures, gullies and bank erosion depict where sediment delivery from the channel boundaries is occurring (Figure 4.3).

Areas impacted by high sediment load stressors include:

- Very high agricultural land use in reach T3.06 (20.7%)
- Very high agricultural land use in reach T3.S1.S1.01 (26.9%)
- High agricultural land use in West Branch Passumpsic reaches T3.01, T3.04, T3.05, and T3.07 (19.9%, 15.0%, 11.7%, and 18.2%, respectfully)
- High agricultural land use in reach T3.S1.04 (11.8%).
- Several segments with a high density of depositional features (T3.01-B, T3.04-A, T3.04-B, T3.07-A, T3.S1.02-A, T3.S1.02-B, and T3.S1.04-B; Figure 4.4)
- High bank erosion on reach T3.02 (33.7%); Large mass failure downstream of crossings in T3.06 (8.0%; Figure 4.5)

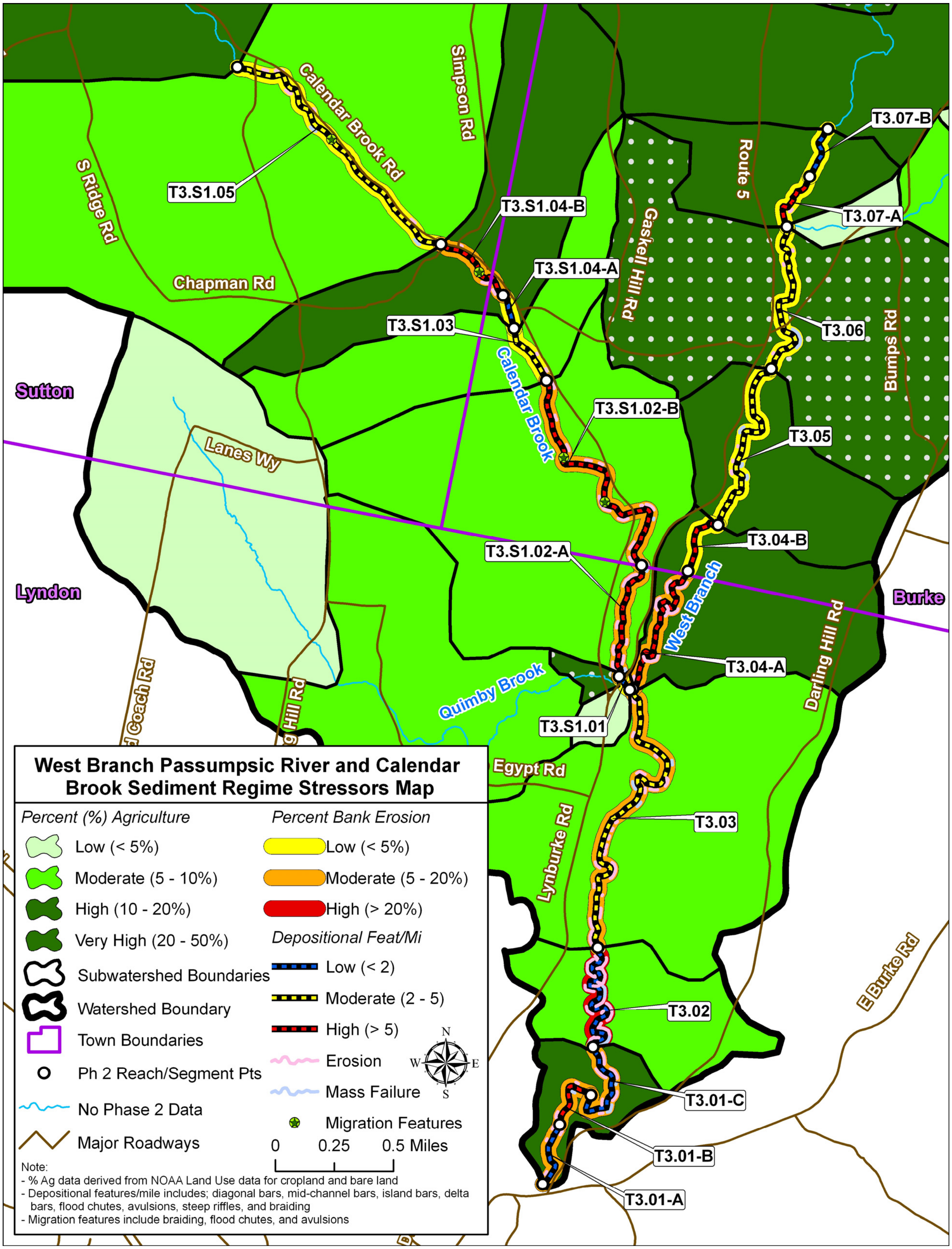

Figure 4.3 Sediment regime stressors for the lower West Branch Passumpsic River watershed

Figure 4.4 Looking upstream at large point bar feature located in reach T3.S1.02-B

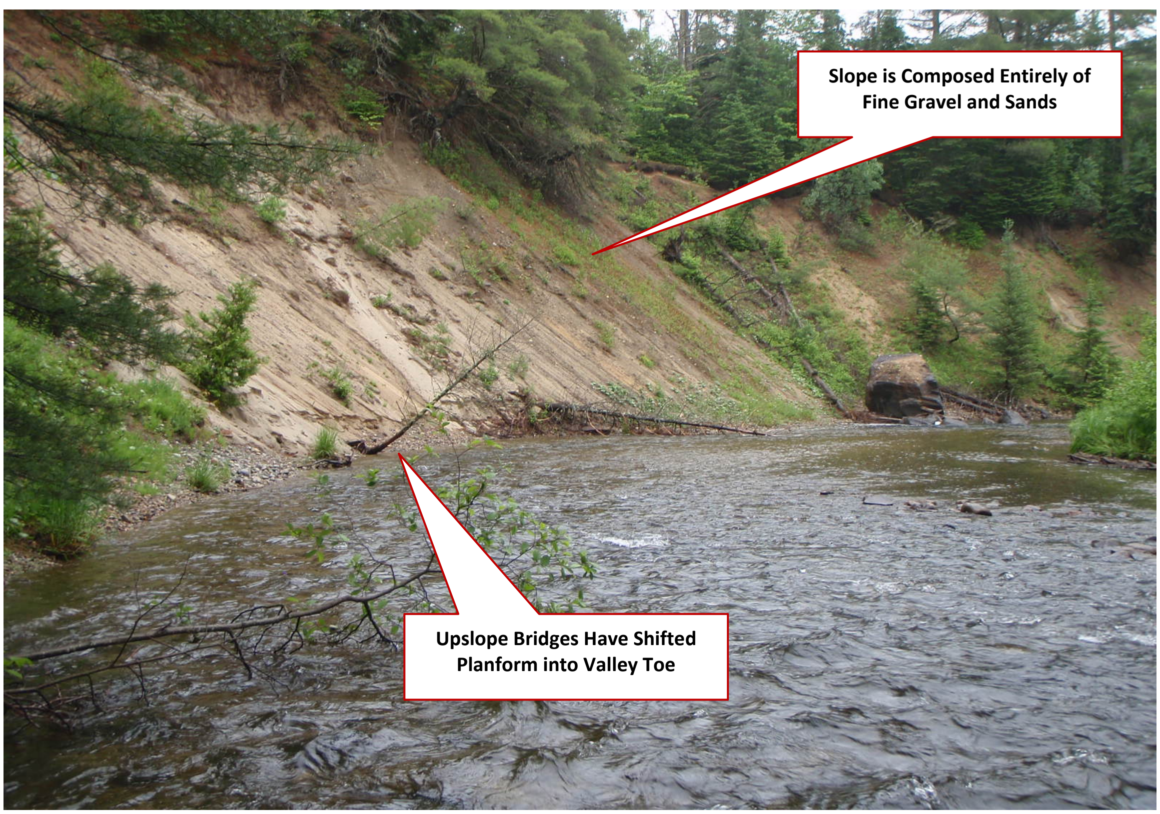

Figure 4.5 Mass failure (60’ H x 312’ L) located on the left bank downstream of the crossings in T3.06

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 West Branch study area have been mapped using the variables extracted from the Phase 2 field dataset (Figure 4.6). 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 (e.g., ledges and waterfalls) depict areas that have a natural 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 lower West Branch Passumpsic segments T3.01-A and T3.01-B (100 and 86.7%, respectfully)
- Extreme channel straightening in lower Calendar Brook segments T3.S1.01 and T3.S1.02-A (91.6 and 79.2%, respectfully)
- Extensive corridor encroachments throughout the lower reaches of the West Branch Passumpsic River from the Canadian Pacific Railroad (Figure 4.7)
- Extensive corridor encroachments along Calendar Brook from Calendar Brook Road and associated development along the road
- Corridor development near the confluence of Quimby and Calendar Brook (Figure 4.8)

Controls on Slope and Depth

- Some grade controls on upper Calendar Brook segments T3.S1.03, T3.S1.04-B, and T3.S1.05; West Branch reaches T3.04, T3.05 and T3.06

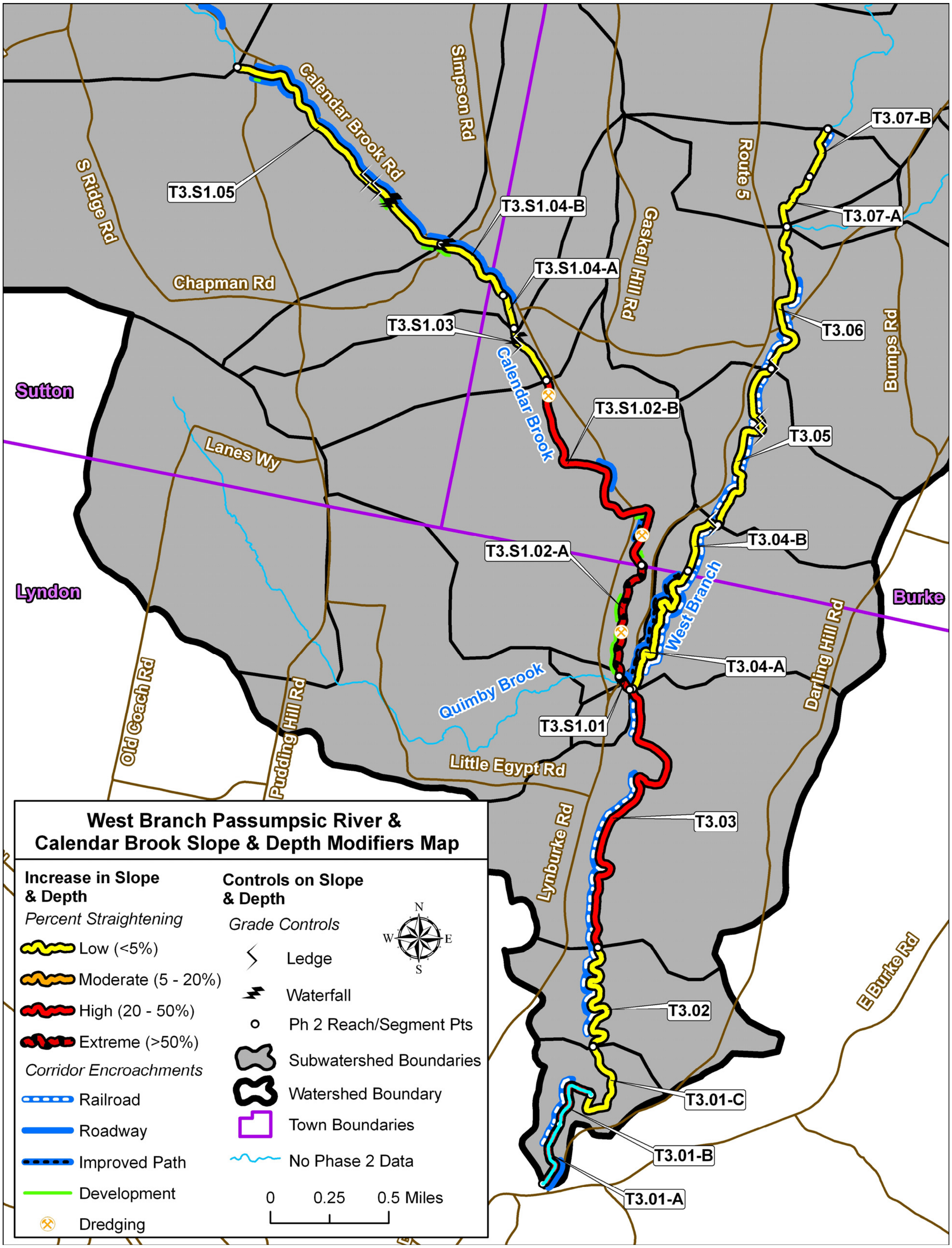

Figure 4.6 Slope and depth modifiers for the lower West Branch Passumpsic River watershed

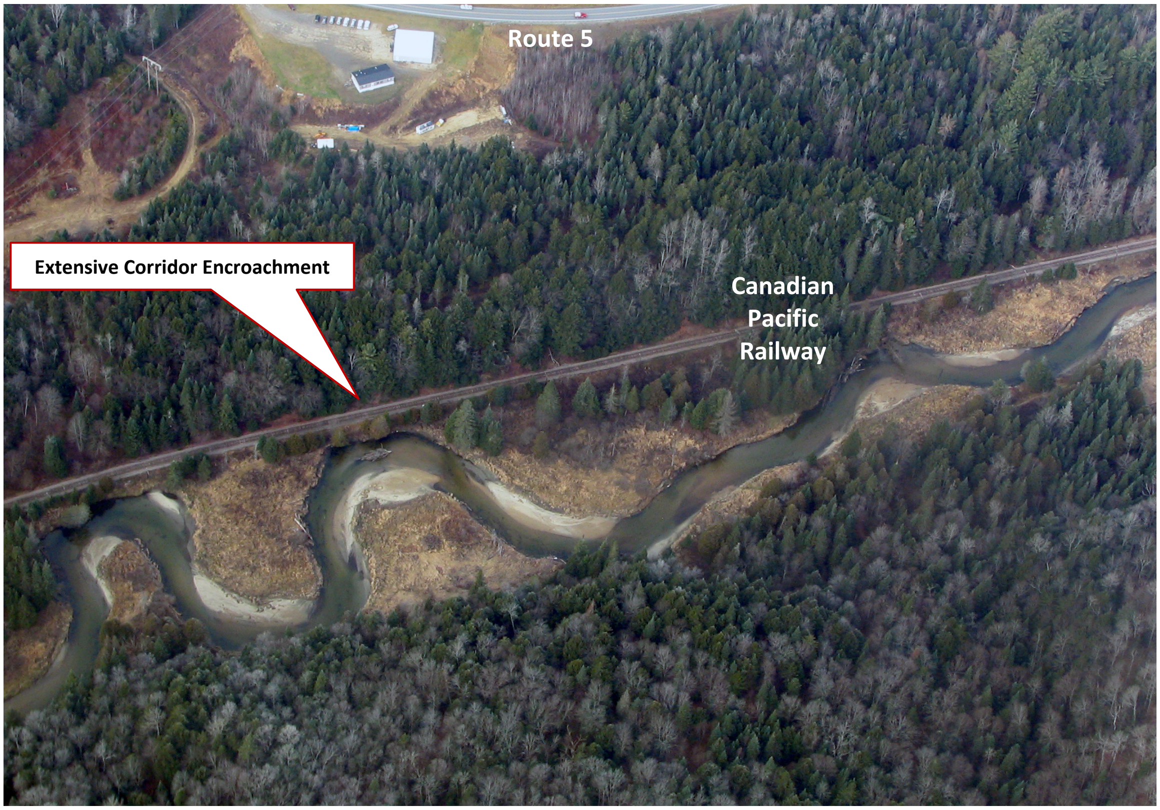

Figure 4.7 Corridor encroachments along the west side of the channel in reach T3.02 and T3.03

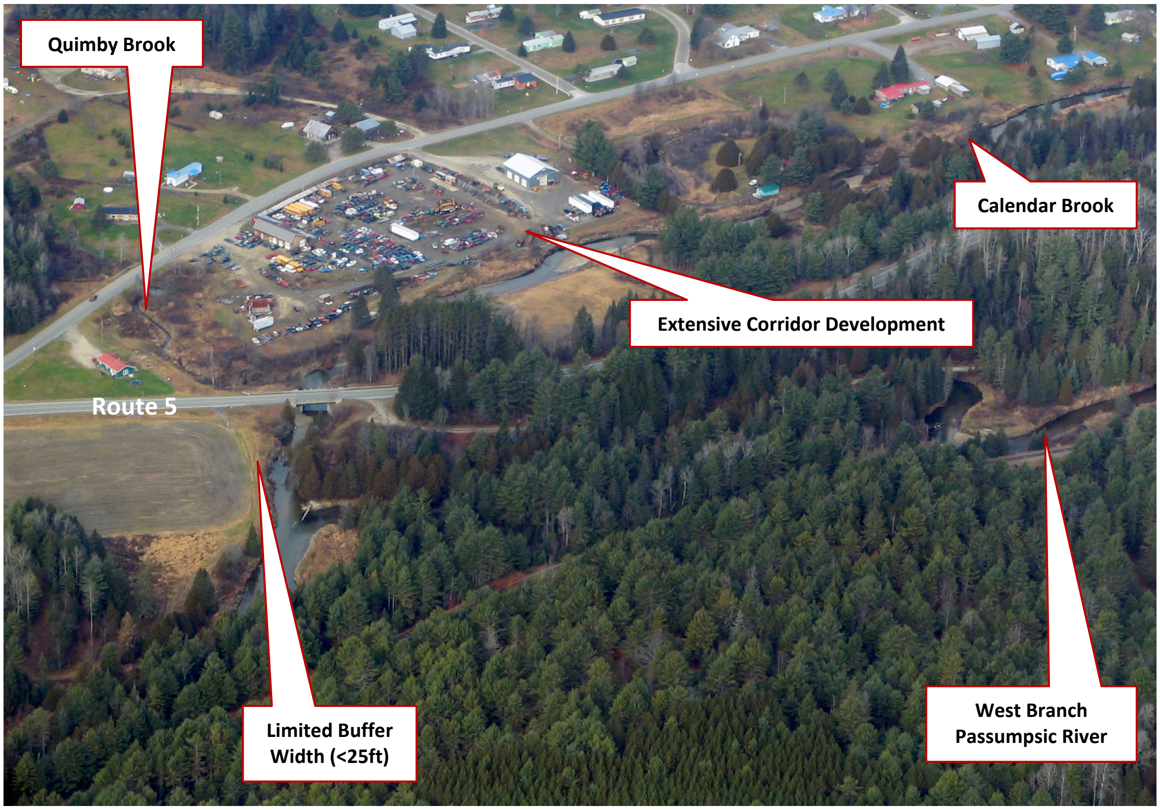

Figure 4.8 Corridor development along the west side of Calendar Brook T3.S1.02-A

Modifications to Channel Boundary and Riparian Conditions

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 (Figure 4.9). 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 West Branch Passumpsic and Calendar Brook study area have been mapped using the variables extracted from the Phase 2 field dataset (Figure 4.10). Relative bank armoring (e.g., rip-rap) highlights areas of increased resistance to lateral migration, whereas relative bank erosion highlights reaches where significant lateral adjustments are found. Additional data showing the location of natural channel features (e.g., ledges and waterfalls) depict areas that have a natural resistance to channel change.

Areas influencing riparian zone and boundary conditions include:

Increased Boundary Resistance

- Some grade controls on upper Calendar Brook segments T3.S1.03, T3.S1.04-B, and T3.S1.05; West Branch reaches T3.04, T3.05 and T3.06
- Moderate bank armoring on segments T3.01-B and T3.04-B (6.7 and 12.2%, respectfully)

Decreased Boundary Resistance

- High bank erosion on reach T3.02 (33.7%)
- Buffer width less than 25 feet on the right bank along segment T3.S1.02-A
- Buffer width impacts along the right and left banks in segment T3.01-A
- Dredging activity on T3.S1.02-A and T3.S1.02-B

Figure 4.9 Calendar Brook T3.S1.02-A: No riparian buffer and development in the corridor

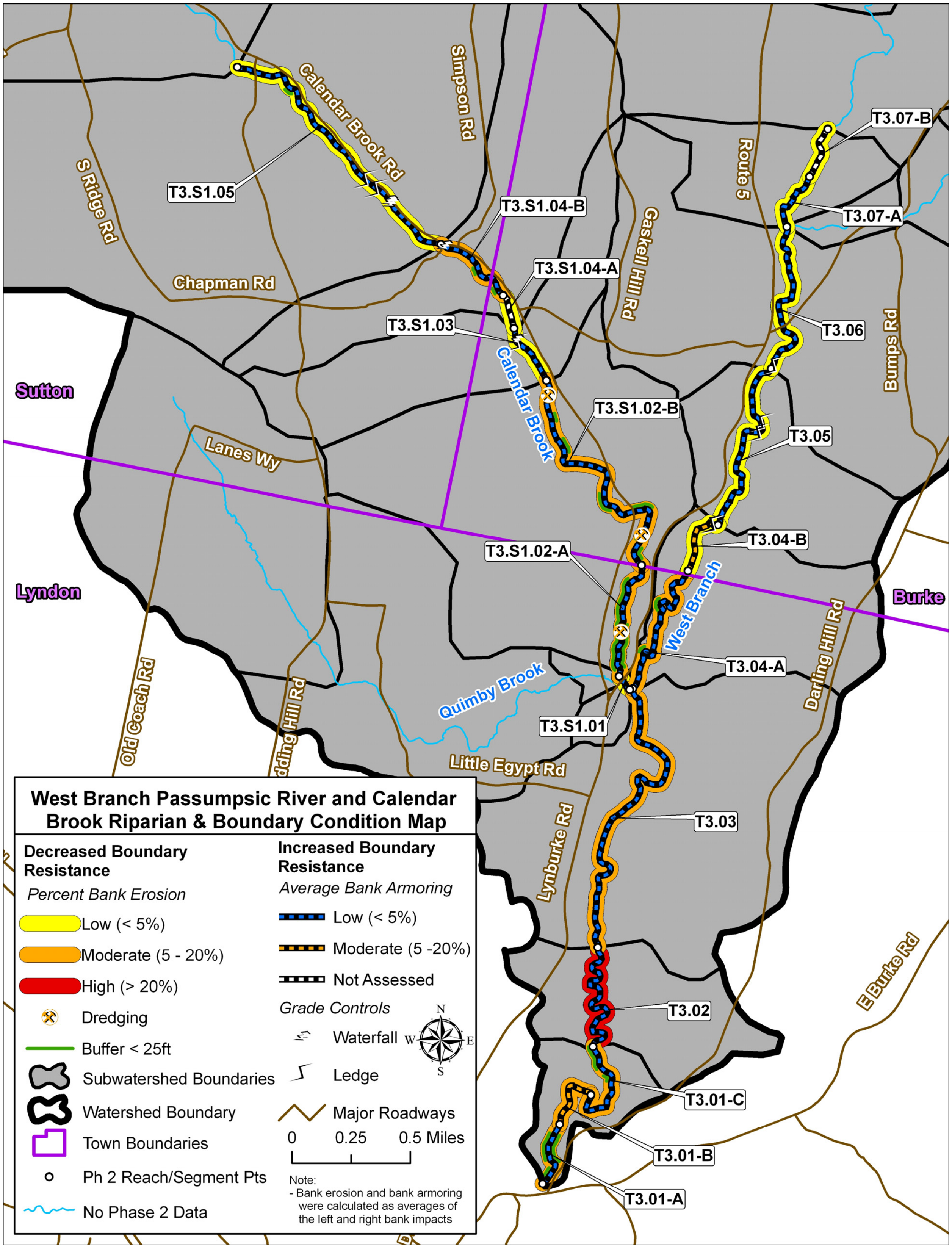

Figure 4.10 Riparian and boundary condition stressors for the lower West Branch Passumpsic River watershed

4.2.2 Departure Analysis

The reference and existing sediment regime types have been mapped using data from the Phase 1 and 2 assessments (Figures 4.11 & 4.12). Several segments in the West Branch have undergone a departure in sediment regime type due to channel incision and/or widening as a result of: 1) historical land uses, 2) encroachments or development in the river corridor, or 3) extensive straightening and bank armoring. Reach stream type departures are summarized below to better describe the reaches where physical changes in channel morphology have accompanied sediment regime changes (Table 4.3).

Table 4.3 Summary of Stream Type Departures from Reference Conditions

Surface Water	Phase 2 Segment ID	Stream Type Departure	Dominant Adjustment Type
West Branch Passumpsic River	T3.01-A	C to F	Degradation
	T3.01-B	C to F	Degradation
	T3.03	C to F	Degradation

West Branch Passumpsic Main Stem (T3.01-T3.07): The lower West Branch Passumpsic reaches have a sediment regime driven by unconfined source and transport processes, with some equilibrium deposition processes occurring in Segment T3.01-C. These reaches have been impacted by channel straightening and the sediment supply is both coarse and fine-sized particles. Most areas have not yet reestablished equilibrium and are predicted to continue widening and migrating as the endogenous sediment load is balanced with upstream stressors such as river corridor encroachment and loss of floodplain. Reach T3.02 has a fine source and transport sediment regime. The reach is sinuous and dynamic and is regaining a stable planform in stage IV of the channel evolution model. Corridor encroachments from the railroad have historically impacted this reach, but the valley has remained broad enough to allow for a good meander profile. The upper portion of the West Branch study area is largely stable, with coarse equilibrium and fine depositional processes in an unconfined valley setting. Where the valley is more confined the sediment regime is largely transport based.

Calendar Brook (T3.S1.01-T3.S1.05): Lower Calendar Brook has seen significant impacts from historical straightening, encroachments and is now re-developing sinuosity along rapidly eroding banks. Boundary resistance in T3.S1.02-A is very limited, and fine source and transport is the dominant sediment regime. In segment T3.S1.02-B the channel is beginning to widen and unconfined source and transport is the principle regime. Dredging has occurred in both of these segments which has further impacted the vertical profile of the river. Upper Calendar Brook has minor corridor encroachments from Calendar Brook Road, but is largely stable with coarse equilibrium and fine deposition processes. Segment T3.S1.04-A has transport regime resulting from the confined valley setting and steep slope.

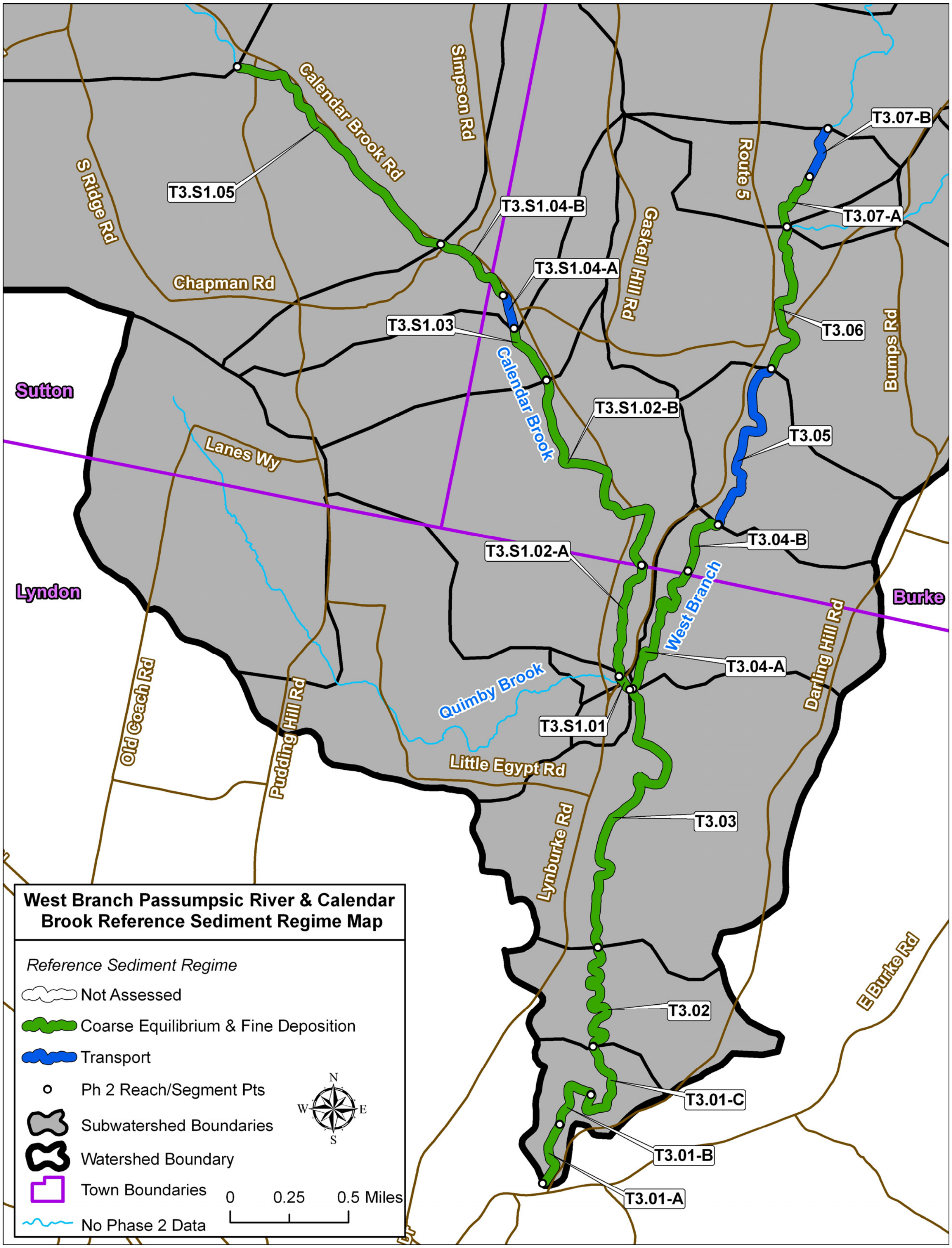

Figure 4.11 Reference sediment regime map for the West Branch Passumpsic River and Calendar Brook

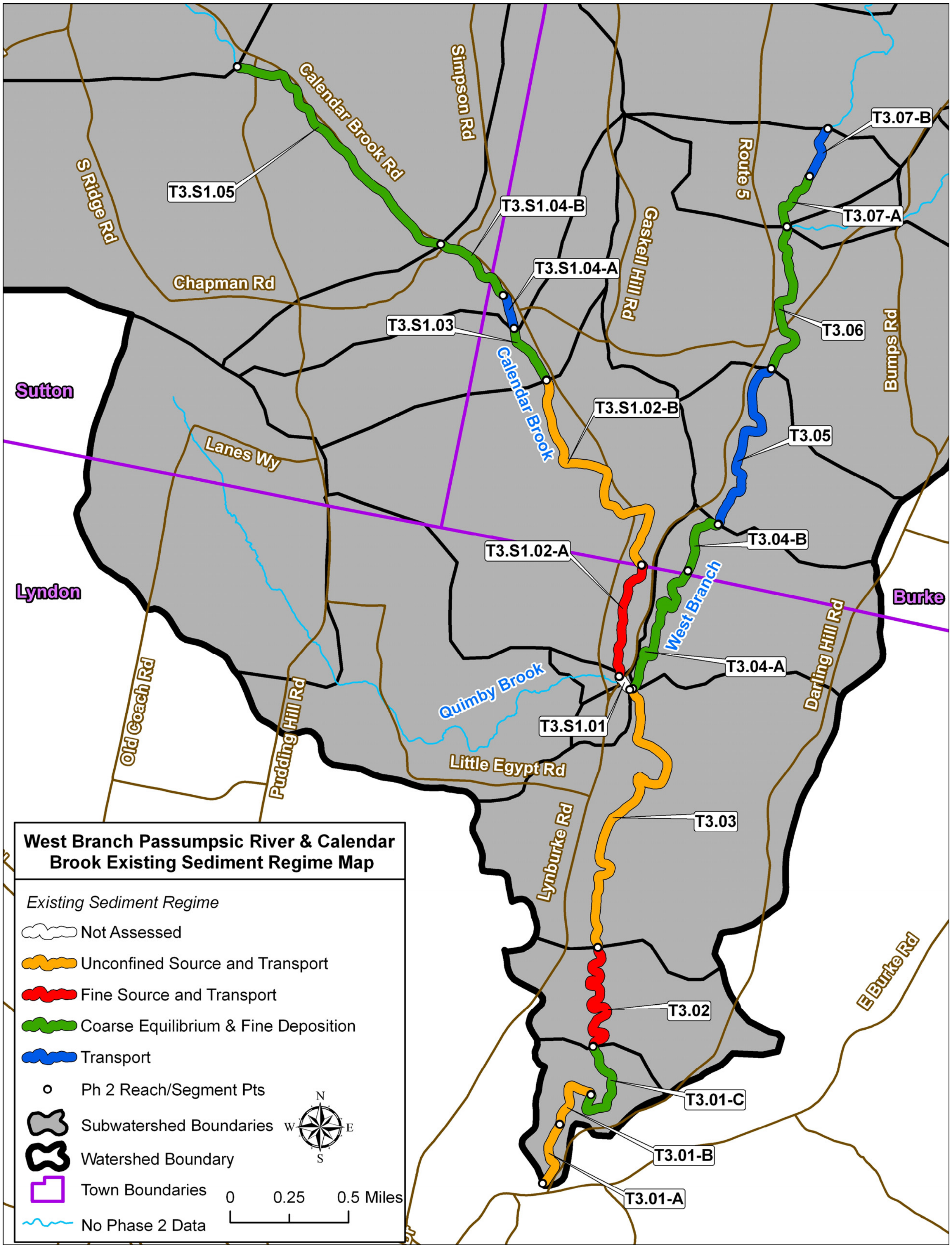

Figure 4.12 Existing sediment regime map for the West Branch Passumpsic River and Calendar Brook

4.2.3 Sensitivity Analysis

The methods outlined in the VTANR Corridor Planning Guide have been used to describe the stream sensitivities of the segments in the West Branch Passumpsic and Calendar Brook 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 (Figure 4.13). Three (3) segments have heightened sensitivities of "Extreme" due to human impacts. The heightened stream sensitivity ratings are most often because of stream type departures (STD) and channel degradation resulting from historical channel straightening, corridor encroachments, and incision. Reach T3.01-A had a large portion of the channel completely disconnected by the Canadian Pacific Railway (Figure 4.14). Similarly, reach T3.03 has been impacted by encroachments and incision (Figure 4.15).

Table 4.4 Extremely sensitive segments and descriptions of the specific impacts and adjustments that are occurring to the stream

Surface Water	Phase 2 Segment ID	Stream Sensitivity	Description of Impacts
West Branch Passumpsic River	T3.01-A	Extreme	Stream Type Departure C to F; Straightening and Incision
	T3.01-B	Extreme	Stream Type Departure C to F; Straightening and Incision
	T3.03	Extreme	Stream Type Departure C to F; Encroachments and Incision

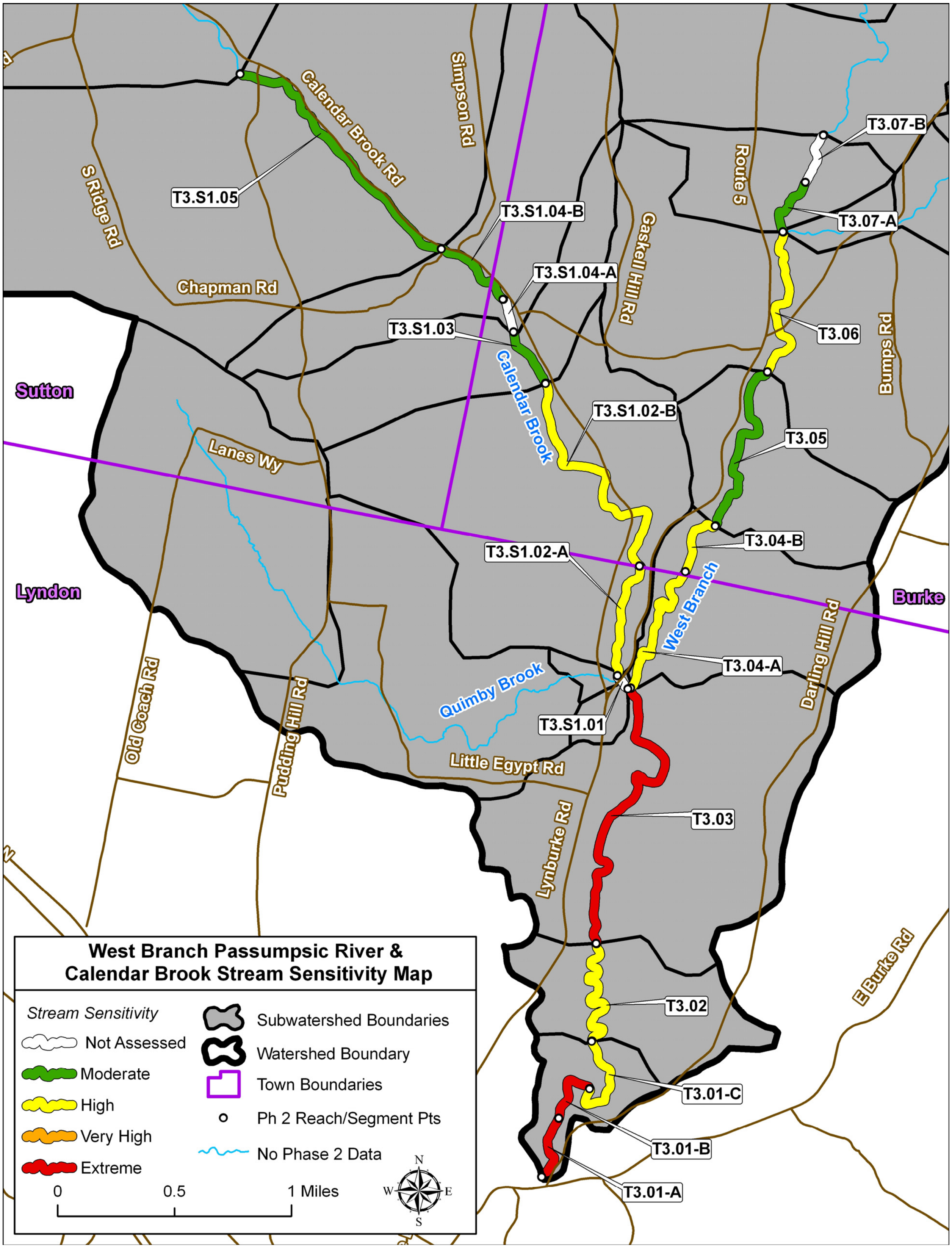

Figure 4.13 Stream Sensitivity map for the West Branch Passumpsic River and Calendar Brook

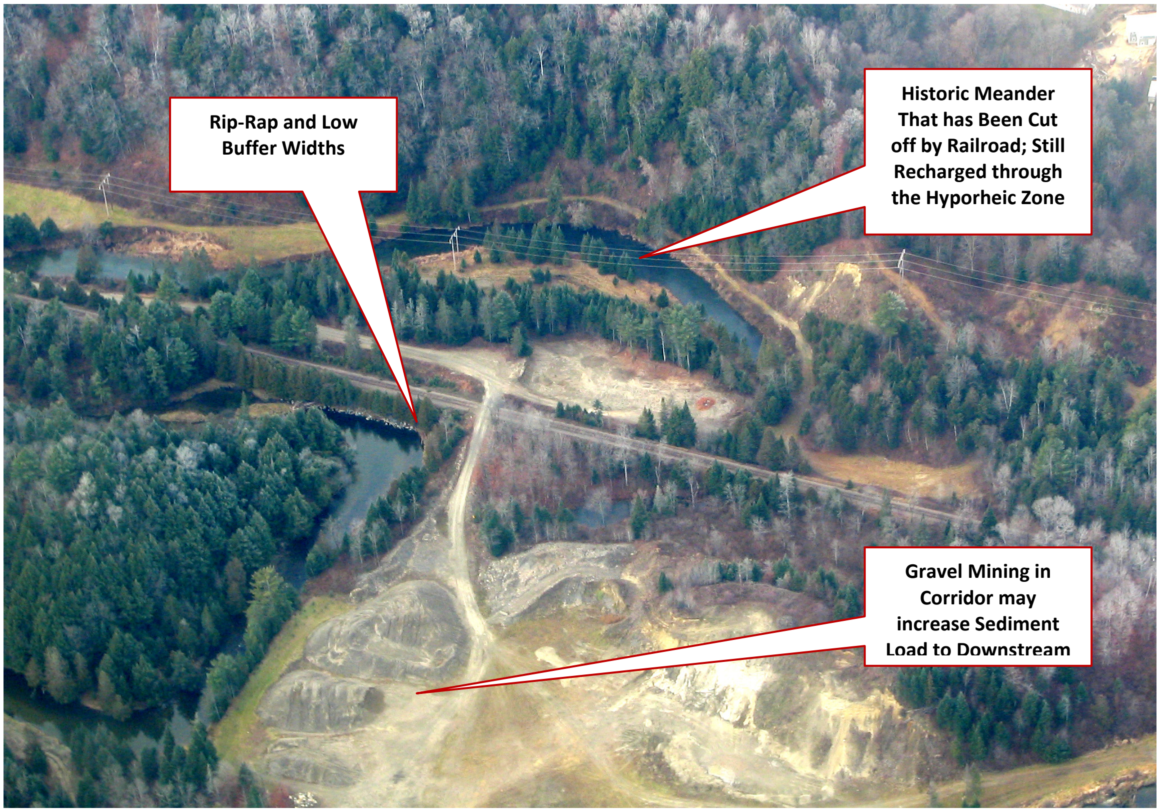

Figure 4.14 Segment T3.01-A has been disconnected from its original channel and manipulated by straightening

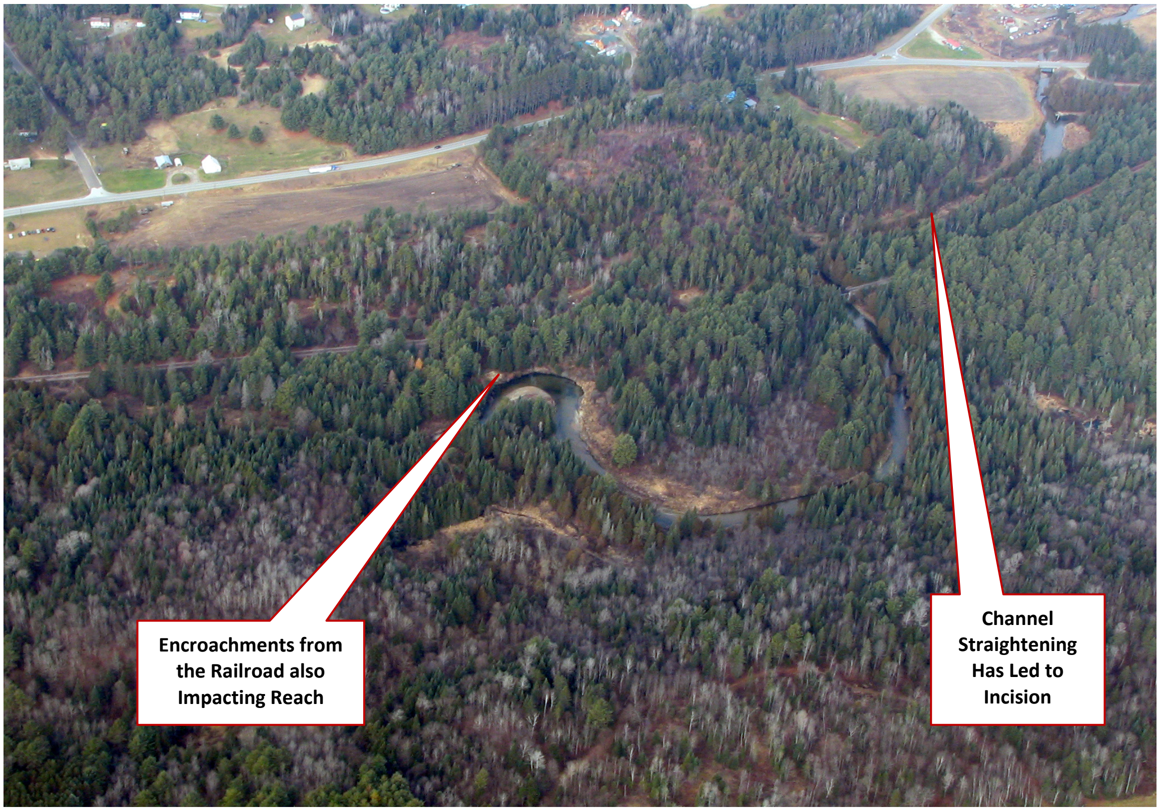

Figure 4.15 Reach T3.03 has corridor encroachments and channel straightening, which has led to channel incision

5.0 Preliminary Project Identification

5.1 Watershed Level Opportunities

5.1.1 Stormwater Runoff

Increased stormwater runoff, even in rural areas of Vermont, can increase peak flood flows and the erosive power of the streams. Stormwater runoff originating from gravel roads and exposed soil during development, or over farm fields can add significant sediment inputs to streams. Increasing development results in more driveways and roads, which funnels 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 Back Roads program provides assistance for towns seeking ways to reduce rural stormwater problems.

The Upper Passumpsic River watershed generally has limited stormwater impacts because of the largely forested watershed and low road densities. In the future, if development pressures heighten concerns about impacts from stormwater runoff, the Towns of Lyndon and Burke could consider enacting local standards and guidelines for stormwater treatment or mitigation. 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).
- Incorporating more rigorous requirements for stormwater control of new development in headwaters areas. Research in Vermont has shown that physical and biotic conditions in small watersheds (< 5 square miles in area) are impacted by very low levels of impervious cover (as low as 5 percent; Fitzgerald, 2007).
- Encouraging Low Impact Development (LID) by offering development density incentives for those projects which result in reduced footprints of impervious cover.

5.1.2 Fluvial Erosion Hazard Zones

Many Vermont communities found along large rivers have faced significant property losses and risks to public safety during past flood events. While inundation-related flood loss is a significant component of flood disasters, the predominant mode of damage during floods is fluvial erosion. Fluvial erosion hazards have been increased and exacerbated by historical channel management practices in Vermont such as channel straightening, berming, and floodplain encroachment.

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 Fluvial Erosion Hazard (FEH) zone can be thought of as the corridor a river or stream requires to redevelop or maintain equilibrium conditions over the long term. FEH zones also indicate which reaches that have a higher propensity for severe migration during flood events. These reaches, which are given elevated ratings of “very high” or “extreme”, are high priority reaches for protection, especially when there is little existing protection afforded by wetlands or conservation easements.

5.2.3 Stream Crossings

Throughout Vermont, undersized and poorly aligned river crossings prevent critical sediment and woody debris transport processes 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. Some bridges in the West Branch study area are currently undersized and causing various problems such as upstream deposition, excessive erosion and downstream bed degradation (Table 5.1). Further detailed data collection is recommended for these structures using the VTANR SGA protocols. 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.

Table 5.1 Summary of bridge data in the West Branch Passumpsic & Calendar Brook Watersheds

Surface Water	Phase 2 Reach ID	Structure Width (ft)	Percent of Channel Width*	Location/Comments	Recommend Full Bridge Assessment?
West Branch Passumpsic River	T3.01-A	60.0	72.5%	Farm crossing located 870 ft upstream of confluence w/ East Branch	Yes
	T3.03	40.0	48.5%	Railroad crossing located 1,650 ft downstream of the Rt. 5 crossing of Calendar Brook	No
	T3.04-B	30.0	44.6%	Railroad crossing east of Route 5	No
	T3.05	30.0	44.8%	Railroad crossing east of Route 5	No
	T3.05	30.0	44.8%	Railroad crossing east of Route 5	No
	T3.05	30.0	44.8%	Railroad crossing east of Route 5	No
	T3.05	31.5	47.1%	Railroad crossing east of Route 5	No
	T3.06	27.6	41.4%	Railroad crossing east of Route 5	No
	T3.06	31.0	46.5%	Bugbee Crossing Road	Yes
Calendar Brook	T3.S1.01	32.0	61.7%	Route 5 crossing	Yes
	T3.S1.02-B	45.0	90.5%	Calendar Brook Road crossing	Yes
	T3.S1.04-B	47.0	98.5%	Fiddlehead Lane crossing	No
	T3.S1.05	36.0	77.1%	TH-50 Crossing	No
	T3.S1.05	39.0	83.5%	Pudding Hill Road Crossing	No

*Phase 1 hydraulic geometry curve data was used for channel width for consistency throughout reaches; however, Phase 2 channel width data suggests that the main stem has lower channel widths because of the presence of hydrologic soil group A-type soils in the watershed.

5.2 Site-Level Project Opportunities

The site-level projects developed for the West Branch Passumpsic River and Calendar Brook study area are provided below in Table 5.2. The project strategy, technical feasibility, and priority for each project are listed by project number and reach/segment. A total of 16 projects were identified to promote the restoration or protection of channel stability and aquatic habitat. The table summarizes key information for each project, including the site stressors and constraints, project strategy, priority (for both hazard mitigation and ecological benefit), relative costs, and potential partners.

The project locations for the study area are included on the maps provided in Appendix B. The 16 projects are further broken down by category as follows: five (5) active geomorphic restoration projects; eleven (11) passive geomorphic restoration projects.

Table 5.2 Site-specific Opportunities for River Restoration and Protection								
Project #, Location, Reach, Lat/Long	**Type of Project**	**Site Description Including Stressors and Constraints**	**Project or Strategy Description**	**Hazard Mitigation Priority**	**Ecological Benefits Priority**	**Project Benefits**	**Costs**	**Potential Partners & Funding**
#1 **West of Darling Hill Road** West Branch Segment T3.01-A 44.55164 N 71.99106 W	**Passive Restoration** *Buffer Plantings*	Areas of limited woody vegetation along river edge in vicinity of farm bridge crossing. Approx. 930 ft on right bank and 800 ft on left bank contributing to degraded habitat and elevated stream temperatures.	Plant stream buffer with native woody vegetation in areas lacking canopy cover; Coordinate with adjacent landowners to assess interest and cooperation.	Low	Moderate	Improved biotic habitat within reach (overhanging vegetation) and downstream (shading for lower water temp.)	Relatively low costs for native plant materials and labor.	CCNRCD; NRCS (CREP or Tress for Streams); VTDEC Clean and Clear; VYCC
#2 **Adjacent Gravel Pit** West Branch Segment T3.01-B 44.55585 N 71.98812 W	**Passive Restoration** *Corridor Protection*	Channel likely historically straightened and manipulated to accommodate rail tracks. Channel currently incised. Adjacent gravel pit encroaches on channel in upper segment (within 100 feet of north bank)	Work with landowner to ensure no further encroachment of gravel pit on river to the south in the areas just east of railroad.	**High**	Moderate	Potentially reduced property loss from ongoing bank erosion; Mitigation of floodplain loss upstream and downstream along incised channel.	None.	CCNRCD; Landowner
#3 **Adjacent Gravel Pit** West Branch Segment T3.01-B 44.55619 N 71.98893 W	**Active Restoration** *Floodplain Restoration*	Prior to the railroad construction the river channel likely occupied abandoned channel to north and west. Limited flood storage in this reach leading to incised channel downstream and increased flooding downstream in Lyndon.	Explore possibility of reconnecting current channel to old channel to north and west for flood storage capacity during large runoff events. Three (3) culvert installations would be required: 1) under gravel pit access rd. east of rail, 2) under railroad northwest of gravel pit, 3) under railroad south of gravel pit. Engineers log jams (ELJs) at 90° bend in river could help divert additional flood flows into abandoned channel.	**High**	Moderate	Potentially reduced flooding and property damage downstream (i.e., Lyndon village) if significant flood flow attenuation can be achieved.	High costs for design/permitting and construction. Preliminary feasibility study is recommended to determine, through topo-graphic surveys, potential for hydraulic connectivity and flood flow storage in old channel.	CCNRCD; Town of Lyndon; Landowner

Table 5.2 Site-specific Opportunities for River Restoration and Protection								
Project #, Location, Reach, Lat/Long	**Type of Project**	**Site Description Including Stressors and Constraints**	**Project or Strategy Description**	**Hazard Mitigation Priority**	**Ecological Benefits Priority**	**Project Benefits**	**Costs**	**Potential Partners & Funding**
#4 **Adjacent Gravel Pit** West Branch Segment T3.01-C 44.55773 N 71.98684 W	**Passive Restoration** *Corridor Protection & Buffer Plantings*	Channel currently has minor incision. Adjacent gravel pit encroaches on channel in upper segment (within 25 feet of north bank), limited woody vegetation and shading along the banks, and reducing bank resistance. Moderate degree of bank erosion.	Work with landowner to ensure no further encroachment of gravel pit on river in the upper segment. Replant western buffer with native woody vegetation.	**High**	Moderate	Potentially reduced property loss from erosion; Improved biotic habitat within reach and downstream	Relatively low costs for native plant materials and labor	CCNRCD; Landowner; VYCC
#5 **East of Route 5** West Branch Segment T3.03 44.57686 N 71.98249 W	**Active Restoration** *Bridge Retrofit/ Replacement*	Bridge beneath railroad located ~1,400 ft south of West Branch-Calendar Bk confluence. Bridge width is 60% of measured channel bankfull width. Sediment deposition noted upstream, and erosion noted downstream.	If structure comes up for replacement, it should be resized according to the VTANR River Management Program (RMP) recommendations.	Moderate	Low	Reduced risk of debris catchment during large flood which could cause severe flooding and erosion, and damage to rail tracks and bed.	High cost for structure redesign and replacement.	CCNRCD; Canadian Pacific Railroad
#6 **East of Route 5** West Branch Segment T3.04-A 44.58038 N 71.98334 W	**Active Restoration** *Removal of Old Abutments*	Old bridge abutments located ~100 ft north of West Branch-Calendar Bk confluence. Not a severe channel constriction, but sediment deposition noted upstream, and erosion noted upstream and downstream.	Landowner constraints unknown. Given limited channel constriction, abutment removal should only be considered if nearby erosion becomes significantly worse.	Low	Low	Reduced risk of debris catchment during large flood which could cause severe flooding and erosion.	Moderate costs for structure removal.	CCNRCD; Landowner
#7 **Along Private Driveway East of Route 5** West Branch Reach T3.04 44.58436 N 71.98112 W	**Passive Restoration** *Corridor Protection*	Very good channel stability and fish habitat throughout reach, despite driveway encroachment in the lower segment. Very high wood density in channel (>200/mile). Good pools and cover observed throughout reach.	Work with landowner to protect stream corridor from further development and channel management (i.e., armoring or encroachment). Assess parcel configuration in upper reach (segment B) to determine extents of corridor easement.	Moderate	**High**	Important sediment and floodwater attenuation reach. Protection of excellent aquatic habitat.	Potentially moderate to high costs for easements due to private ownership and reach length; Needs further investigation.	CCNRCD; Landowner; VTDEC; PVLT

Table 5.2 Site-specific Opportunities for River Restoration and Protection								
Project #, Location, Reach, Lat/Long	**Type of Project**	**Site Description Including Stressors and Constraints**	**Project or Strategy Description**	**Hazard Mitigation Priority**	**Ecological Benefits Priority**	**Project Benefits**	**Costs**	**Potential Partners & Funding**
#8 **East of Route 5 along Railroad** West Branch Segment T3.05 Multiple Locations	**Active Restoration** *Bridge Retrofit/ Replacement*	Bridges (4) beneath railroad throughout reach are 60% of measured channel bankfull width. Some scour and sediment deposition noted near structures. Grade controls in reach may limit impact from constrictions on channel.	As structures come up for replacement, they should be resized according to the RMP recommendations.	Moderate	Low	Reduced risk of debris catchment during large flood which could cause severe flooding and erosion.	Potentially high costs for structure redesign and replacement.	CCNRCD; Canadian Pacific Railroad
#9 **Bugbee Crossing Road & Railroad** West Branch Segment T3.06 44.60240 N 71.97042 W	**Active Restoration** *Bridge Retrofit/ Replacement*	Bridges (2) beneath Town road and railroad are ~65% of measured channel bankfull width. Alignment problems and a very large mass failure on the north bank downstream of crossings. Nearest grade control found approx. 1,300ft downstream.	As structures come up for replacement, they should be resized according to the RMP recommendations, and alignment issues between the two should be corrected.	**High**	Moderate	Reduced risk of ongoing mass failure becoming worse and threatening road. Reduced risks of debris catchment during large flood.	High cost for structure redesign and replacement.	CCNRCD; Canadian Pacific Railroad; Town of Burke
#10 **Along Railroad East of Route 5** West Branch Segment T3.06 & T3.07-A 44.60760 N 71.97037 W	**Passive Restoration** *Corridor Protection*	Stable channels with "good" to "reference" aquatic habitat noted near confluence with Roundy Brook. High wood density in channel (~100/mile), and good pools and cover observed in both reaches. Excellent riparian buffer.	Assess parcel configuration to determine if easements would be appropriate. If possible, work with landowners (found along east side of Rt. 5) to protect stream corridor from further development.	Moderate	**High**	Protection of excellent aquatic habitat and stable channels.	Potentially moderate to high costs for easements due to private ownership and reach length; Needs further investigation.	CCNRCD; Landowner(s); Canadian Pacific Railroad; VTDEC; PVLT

Table 5.2 Site-specific Opportunities for River Restoration and Protection

Project #, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
#11 **East of Calendar Brook Road** Calendar Brook Segment T3.S1.02-A 44.58599 N 71.98391 W	**Passive Restoration** *Buffer Plantings*	Channel historically straightened but redeveloping meanders in upper part of segment. Many areas of bank lack woody vegetative cover, especially on the west bank in lower segment (~2,000 contiguous feet).	Plant stream buffer with native woody vegetation in areas lacking canopy cover; Coordinate with adjacent landowners to assess interest and cooperation. **Important: Need to assess near term bank stability and possible failure of plantings; natural re-vegetation may be appropriate in some areas that are actively eroding.**	Moderate	Moderate	Improved biotic habitat within reach (overhanging vegetation) and downstream (shading for lower water temp.)	Relatively low costs for native plant materials and labor. However, area for plantings could be large.	CCNRCD; NRCS (CREP or Tress for Streams); VTDEC Clean and Clear
#12 **East of Calendar Brook Road** Calendar Brook Segment T3.S1.02-A 44.58794 N 71.98285 W	**Passive Restoration** *Corridor Protection*	Area of undeveloped corridor straddling segment break and town line. Large depositional features and severe bank erosion, with stage IV of channel evolution. Future lateral channel migration highly likely.	Assess parcel configuration to determine if easement is possible for approx. 1000 linear feet of channel. If possible, work with landowners to protect stream corridor from further development and channel management (i.e., armoring or encroachment).	**High**	Moderate	Attenuation of sediments and increased flood-plain access over long-term.	Potentially moderate costs for easements due to private ownership; Needs further investigation.	CCNRCD; Landowner(s); VTDEC; PVLT
#13 **Near Calendar Brook Road Crossing** Calendar Brook Segment T3.S1.02-B 44.59104 N 71.98367 W	**Passive Restoration** *Buffer Plantings*	Channel aggrading and redeveloping meanders in segment B. Banks lack woody vegetative cover upstream and downstream of Calendar Brook road crossing. Approx. 350 feet on north bank downstream of bridge, and 350 feet on south bank upstream of bridge.	Plant stream buffer with native woody vegetation in areas lacking canopy cover; Coordinate with adjacent landowners to assess interest and cooperation. **Important: Need to assess near term bank stability and possible failure of plantings; natural re-vegetation may be appropriate in some areas that are actively eroding.**	Moderate	Moderate	Improved biotic habitat within reach (overhanging vegetation) and downstream (shading for lower water temp.)	Relatively low costs for native plant materials and labor.	CCNRCD; NRCS (CREP or Tress for Streams); VTDEC Clean and Clear

Table 5.2 Site-specific Opportunities for River Restoration and Protection								
Project #, Location, Reach, Lat/Long	**Type of Project**	**Site Description Including Stressors and Constraints**	**Project or Strategy Description**	**Hazard Mitigation Priority**	**Ecological Benefits Priority**	**Project Benefits**	**Costs**	**Potential Partners & Funding**
#14 **West of Calendar Brook Road** Calendar Brook Segment T3.S1.02-B 44.59236 N 71.98583 W	**Passive Restoration** *Corridor Protection*	Channel historically straightened along farm field and highly depositional upstream of road crossing. Channel widening and developing meanders. Key depositional zone to accommodate increased sediment transport from upslope.	Assess parcel configuration to determine if easement is possible from Calendar Brook Road crossing up to farm field. If possible, work with landowners to protect stream corridor from further development and channel management (i.e., armoring or encroachment).	**High**	Moderate	Attenuation of sediments and increased flood-plain access over long-term. Reduced long-term channel instability at Calendar Brook Road crossing, where bridge abutments are deteriorating.	Potentially moderate to high costs for easements due to private ownership and reach length; Needs further investigation.	CCNRCD; Landowner(s); VTDEC; PVLT
#15 **West of Calendar Brook Road** Calendar Brook Segment T3.S1.02-B 44.59509 N 71.98940 W	**Passive Restoration** *Buffer Plantings*	Channel straightened in upper segment B. Banks lack woody vegetative cover along farm field. Total approx. 430 feet on east bank in two locations adjacent farm field.	Plant stream buffer with native woody vegetation in areas lacking canopy cover; Coordinate with adjacent landowner to assess interest and cooperation. **Important: Need to assess near term bank stability and possible failure of plantings; natural re-vegetation may be appropriate in some areas that are actively eroding.**	Moderate	Moderate	Improved biotic habitat within reach (overhanging vegetation) and downstream (shading for lower water temp.)	Relatively low costs for native plant materials and labor.	CCNRCD; NRCS (CREP or Tress for Streams); VTDEC Clean and Clear
#16 **South of Calendar Brook Road** Calendar Brook Segment T3.S1.04-B 44.60549 N 71.99543 W	**Passive Restoration** *Corridor Protection*	Channel stability controlled by bedrock ledges upstream at Fiddlehead Lane. River corridor at town line very active, with multiple large depositional features, meanders, and a wide floodplain.	Assess parcel configuration to determine if easement is possible for approx. 800 linear feet of channel. Work with landowners to protect stream corridor from further development and channel management (i.e., armoring or encroachment).	Moderate	Moderate	Attenuation of sediments and increased flood-plain access over long-term.	Potentially moderate costs for easements due to private ownership; Needs further investigation.	CCNRCD; Landowner(s); VTDEC; PVLT

6.0 Conclusions & Recommendations

The West Branch Passumpsic River and its tributaries in Lyndon, Burke and Sutton have great diversity in form, function, and condition. Historical land uses in the watershed, floods, and various types of human land use in the river corridor have all left a lasting imprint on the morphology and stability of the river channels. In order to understand how to sustainably manage these channels over the long-term, a holistic perspective of the causes of current day conditions is very important.

The West Branch and Calendar Brook channels are still adjusting their width, depth, and planform to the following historical impacts: 1) aggradation of sediment in the valley due to settlement and deforestation that occurred during the 1700's and 1800's; 2) channel straightening, dredging and corridor encroachment from railroads and other land uses; 3) significant floods such as the 1973 and 2002 events. Within certain areas of the West Branch river corridor, moderate to severe lateral channel migration is likely in the future. Given the current state of the channel and predicted future adjustments, the following watershed-scale and site-specific management actions are recommended:

- Implementation of FEH zones for the Towns of Lyndon, Burke and Sutton
- Protection of specific areas of river corridor (see "high priority" projects in Table 5.2) along the lower West Branch and Calendar Brook that are more prone to lateral adjustments
- Areas of buffer plantings along the West Branch and Calendar Brook to improve stream bank shading and cover for fishes; and long term bank stability.

The corridor restoration projects have been prioritized in terms of ecological benefits and hazard mitigation, with particular attention paid to potential flood mitigation benefits for the watershed and the Town of Lyndon. Unlike the East Branch of the Passumpsic River, where severe channel incision and widening was commonly observed, the West Branch has many reaches with stable forms and quality aquatic habitat (especially in the upper reaches). Restoration potential for regaining floodplain access is limited to the lower reaches near the confluence with the East Branch. Similarly, channel instability and loss of floodplain function on Calendar Brook is concentrated in the lower reaches near the confluence with the West Branch. High priority corridor protection projects on lower Calendar Brook represent good opportunities to protect and maintain critical floodplain function in light of recent corridor encroachments in this area.

Finally, additional data collection for four (4) of the 14 bridges is recommended using the SGA Bridge and Culvert Assessment Protocol (VTDEC, 2009). These structures have been identified as being problematic or potentially problematic in the future, and additional detailed data will serve the towns for prioritizing structures for replacement in the future.

7.0 References

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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 exceedence -- The probability that a random flood will exceed a specified magnitude in a given period of time.
Railroads – Used or unused railroad infrastructure.
Rapids -- A reach of stream that is characterized by small falls and turbulent, high-velocity water.

Reach -- A section of stream having relatively uniform physical attributes, such as valley confinement, valley slope, sinuosity, dominant bed material, and bed form, as determined in the Phase 1 assessment.
Rearing habitat -- Areas in rivers or streams where juvenile fish find food and shelter to live and grow.
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.
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.