# SECOND BRANCH WHITE RIVER WATERSHED

## STREAM GEOMORPHIC ASSESSMENT and RIVER CORRIDOR PLAN 2019-2021

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## 1.0 EXECUTIVE SUMMARY

In May 2019 the White River Partnership (WRP), as part of a project funded by the Vermont Agency of Natural Resources Clean Water Initiative Program, began a Phase 2 Stream Geomorphic Assessment (SGA) of the mainstem of the Second Branch of the White River in east central Vermont (overview map in Fig. 1 on p. 3) and to produce a Phase 2 SGA report and River Corridor Management Plan (RCMP).

The WRP is a community-based, non-profit organization whose mission is to bring together people and local communities to improve the long-term health of the White River and its watershed in central Vermont. The Second Branch corridor planning project builds on almost 25 years of community-based efforts undertaken by the WRP and partners throughout the White River watershed. Key partners in the Second Branch basin have included riparian landowners, local water-quality monitors and other volunteers formerly active in the 'Tween (Mid-White) Stream Team, town road crews and Conservation and Planning Commissions in Brookfield, Randolph, Bethel and Royalton, the Vermont River Conservancy, the Vermont Department of Environmental Conservation, the Vermont Department of Fish & Wildlife, the Vermont Agency of Agriculture, Food and Markets, the White River Natural Resources Conservation District, Ducks Unlimited, the Orianne Society, local elementary and high schools and Verdana Ventures, the Vermont Law School, the Vermont Youth Conservation Corps, Two Rivers-Ottauquechee Regional Commission, the Connecticut River Conservancy and Joint Commissions, the USDA Forest Service, and Trout Unlimited.

### *Stream Geomorphic Assessment and River Corridor Planning*

Fluvial (= flow-related) geomorphology (geo = earth, morphology = shape) is the study of the physical river forms and processes that explain many of the current conditions observed in streams. Streams have a natural tendency to maintain equilibrium between the amount and power of water moving through the system and the amount and type of sediment being carried by that water. With significant changes in the landscape and development patterns in the last 250 years, many streams in Vermont, including the Second Branch and many of its tributaries, have been confined to deeper, straighter channels and limited access to historic floodplains. In addition, changes in precipitation timing and patterns have contributed to increased flash flooding in portions of the Second Branch basin - notably in 2007, 2011, 2013, 2017 and 2019. Damage from Irene in 2011 was significant, but lower in this basin than in nearby communities - largely due to the distribution of rainfall.

The work reported here is based on protocols and guidelines developed by the Vermont River Management Program, designed to identify a range of high-priority issues with a goal of managing toward, protecting, and restoring the fluvial geomorphic equilibrium condition of Vermont's rivers and streams as a means to help resolve conflicts between human investments and river dynamics in an economically and ecologically sustainable manner. Objectives following from this goal include:

1. fluvial erosion hazard mitigation;
2. sediment and nutrient load reduction; and
3. aquatic and riparian habitat protection and restoration

Assessments typically proceed through a series of phases that integrate information from an overarching watershed context down to project-specific scales, with each previous stage informing the successors. Phase 1 is a preliminary analysis of the condition of the stream through remotely sensed data such as aerial photographs, maps, and 'windshield survey' data. Phase 2 involves "rapid assessment fieldwork" to inform a more detailed analysis of adjustment processes that may be taking place, whether the stream has departed from its reference conditions, and how the river might continue to evolve in the future. River Corridor Plans analyze the data from the Phase 1 and 2 assessments to inform project prioritization and methodology. Phase 3 involves detailed fieldwork for projects requiring survey and engineering-level data and is not included with this report.

***Assessment summary***

Seventeen reaches (a reach is a relatively homogenous section of stream, based primarily on physical attributes such as valley confinement, slope, sinuosity, dominant bed material, and bedform) comprising roughly 29.8 linear miles of stream along the Second Branch mainstem were included in Phase 2 assessment. Based on field assessment of current physical conditions these reaches were divided into 22 segments (a segment is a relatively homogenous section of stream, within a reach, that differs from other portions of the reach based on parameters other than those mentioned above for reach classification; e.g., degree of floodplain encroachment from roads or structures, presence/absence of ponds or other impoundments including extensive beaver presence with active dams, or degree of channel alterations).

Current physical conditions on the assessed portions of the Second Branch mainstem indicate:

- Five of twenty fully assessed reaches or segments appeared in relatively stable condition (stage IV channel evolution), though all assessed have Very High to Extreme sensitivity to any changes in water or sediment inputs.
- Two segments toward the upstream end of the mainstem (M16-B, beaver-dominated wetlands by Brown Dr., and M17-C, Staples Pond and surrounding wetlands) were excluded from full assessment due to beaver and human impoundments. Although these were excluded from full assessment per protocols used for assessment, these areas play an important role in providing stability further downstream and merit protection as important attenuation assets.
- Segment M11-B (upstream of Ferris Rd.) was assessed in Poor geomorphic condition (i.e., undergoing Extreme current adjustments)
- All other reaches or segments were assessed in Fair condition (undergoing Major adjustments).

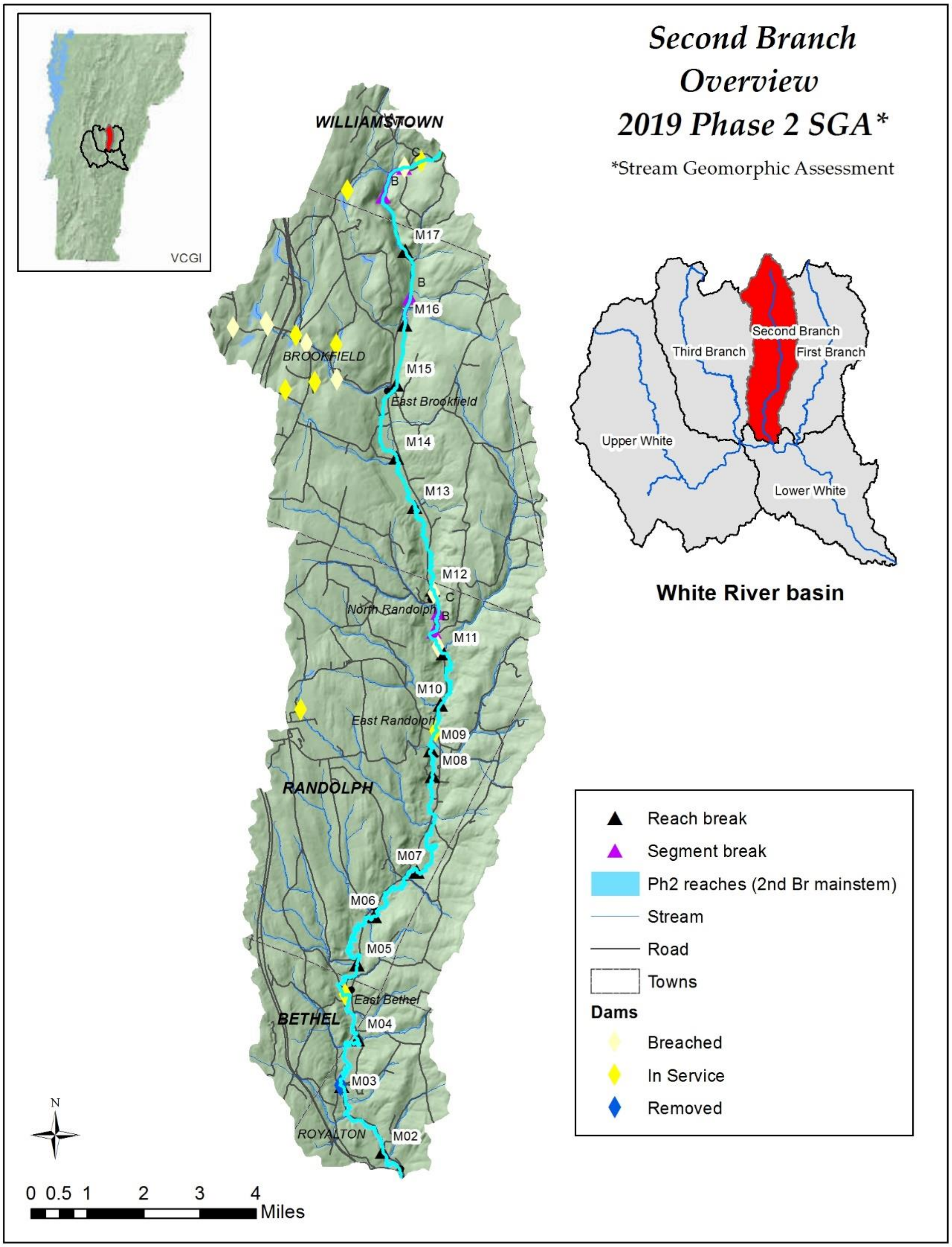



**Figure 1. Overview map for Second Branch stream geomorphic assessment and corridor planning.**

Current geomorphic conditions along the Second Branch mainstem are largely related to several key factors:

1) Low slope gradients and an abundance of fine sediments left as a legacy of glacial Lake Hitchcock;

2) Significant sedimentation behind historic and current dams, particularly in downstream portions of the mainstem; and

3) widespread and pervasive channel straightening, largely related to an abundance of bridges and culverts spaced intermittently along the mainstem as well as road encroachments and historic channelization

A dense road network and diffuse settlement pattern in the basin amplify water and sediment inputs through increased rate and intensity of water delivered to the stream network, especially along tributaries on steep valley walls flanking the mainstem, to dispose the basin to flash flooding.

These factors place the highest priority (in terms of project prioritization) on protection or restoration of optimal floodplain functions (primarily attenuation of high flows and storage of sediment and nutrients) and accommodation of stable planform geometries (especially allowing establishment and migration of meanders). Along the Second Branch mainstem, this largely translates to accommodating streams that are widening and/or migrating at this point in time (relatively rapid downstream migration of meanders is common).

### *Project recommendation summary*

Project prioritization based on the assessment and analysis conducted for this study is reported in Chapter 6 (section 6.2), and the Project and Strategy Summary Table presented at the end of that section can be considered the heart of this Corridor Plan. While numerous maps are included in this report, readers are highly encouraged to utilize the online interactive Natural Resource Atlas hosted by the Vermont Agency of Natural Resources (VT-ANR 2020) for specific areas of interest; data from these assessments can be viewed within the 'Rivers Management Theme' and displayed against a variety of background imagery.

Due to the widespread nature of current stressors along the Second Branch mainstem, as well as Very High to Extreme Sensitivity in all assessed reaches and segments, the success of localized project implementation is contingent on moving toward best management practices on a watershed scale. High priority recommendations thus feature watershed strategies that may be most efficiently effected at a municipal level, as well as a strong need for better wooded buffers.

Priority projects for this 2021 River Corridor Plan for the Second Branch mainstem include:

***Watershed strategies***

- River Corridor overlay in conjunction with updated Flood Hazard Bylaws; 50-foot setback for streams draining less than 2 square miles. As of 2019, a preliminary statewide River Corridor model exists for reference as a starting point, and data from the assessment reported here refine the recommended extent along the Second Branch mainstem.

- Hazard mitigation planning, capital planning, and prioritization for addressing undersized stream crossing structures (on tributaries as well as the mainstem, as these strongly influence discharges to streams). All towns in the study area have adopted 2019 Bridge and Culvert Standards (VTrans 2019), which will help stream dynamics as well as qualify towns for a higher level of Emergency Relief Assistance Fund match (Flood Ready VT 2020).

- On the mainstem, stream crossings include a number of aging state structures along VT Rte. 14, three covered bridges that were recently renovated, and numerous private structures that complicate capital planning and its interaction with hazard mitigation; these areas should be clearly identified in plans (such as the frequently overtopped bridge on VT Rte. 14 in South Randolph and several structures along VT Rte. 14 south of the Brookfield-Williamstown Gulf).

- Funding options for replacement of private bridges will be a challenging issue for long-term stream health and stability as well as economic feasibility for farms especially; it is recommended that an effort be made to understand how recent replacements were designed, implemented and funded. It is further recommended that a summary report of relevant compiled information be provided to Road Commissioners, Selectboard and Planning Commission members in the five towns of the study area as well as relevant staff of Two Rivers-Ottauquechee and Central Vermont Regional Planning Commissions, White River Natural Resources Conservation District, and USDA Natural Resources Conservation Service.

***Buffer establishment and protection***

- Establishment and protection of woody vegetated buffers are prominent priorities in widespread agricultural and developed areas along the mainstem. These projects are almost always beneficial to stream health and can generally be implemented independently of other considerations, but highest priority is given to efforts in conjunction with integrated reach-scale corridor protection and/or restoration; buffer establishment and protection are assumed as a part of those projects.

- Notwithstanding the prioritization emphasis on buffers being integrated with larger projects, stand-alone buffer projects could be implemented to particularly good effect in portions of any of the reaches from M12 (North Randolph) upstream to M14 (East Brookfield). Buffer implementation in reaches further downstream should get consideration of additional corridor protections in conjunction with planting as they are more likely to be subject to lateral adjustments along the stream.

***Reach-scale corridor protection and/or restoration***

- Windrow removal/wetland restoration in segment M17-A, downstream of a highly confined, steep ledge drop coming out of the Brookfield-Williamstown Gulf;
- Corridor protection, buffer establishment and evaluation of possibilities for more active floodplain restoration in segment M11-B, upstream of Ferris Rd. along VT Rte. 14
- Tire removal, corridor protection and buffer establishment in reach M10
- Removal of Hyde Dam in reach M04, sediment removal upstream, corridor protection
- Evaluate feasibility of Gulf Road Dam removal in reach M09
- Evaluate options to address stream ford location at Gifford Covered bridge in reach M07 and remediate flood capture of field sediments
- Though lower priority, there are also multiple opportunities for intermittent wetland restorations to provide connectivity for migratory waterfowl and important habitat for riparian-dependent species of concern along the Second Branch, which could greatly benefit stream stability at the same time.

A more complete table of prioritized projects can be found in Section 6.2 (Project Prioritization) of this report. A "catalogue" of projects, with varying priorities, can be found in Appendix 6. A full list of assessed bridges and culverts, findings of the assessments, and potential for retrofitting culverts that impede passage for fish and other aquatic organisms can be found in Appendix 8. Primary analyses leading to the project recommendations are found in Sections 5.1.3, Existing Sediment Regime Departure Analysis (summarized in tables at the end of the section), and Section 5.2, Sensitivity Analysis.

# Chapter 2: PROJECT OVERVIEW

## *2.1 INTRODUCTION*

Despite relatively good overall water quality throughout the White River watershed, the Second Branch of the White River has historically seen some of the highest *E. coli* concentrations in the White River watershed. The 2018 White River Tactical Basin Plan identified 4 major stressors as likely drivers of declining water quality in the White River basin, including the Second Branch:

> 1. Unpermitted stream alterations, non-buffered agricultural fields, and encroachments and development within river corridors, floodplains, wetlands, and lake shores;
> 2. Stream channel erosion due to undersized crossing structures, lack of riparian vegetation for bank stabilization, and unmitigated increases in stormwater flow and volume;
> 3. Land erosion due to unmanaged stormwater runoff from roads, developed lands, and agricultural lands; and
> 4. Pathogens from sources that likely stem from bacterial communities in soils, waste runoff from domesticated animals and livestock, and out-of-date and failed septic systems. (VT DEC-WMD 2018)

In addition to water quality concerns, flooding has periodically impacted the Second Branch of the White River. When Tropical Storm Irene swept through Vermont in August 2011, large scale and rapid changes occurred in many portions of the state and incurred hundreds of millions of dollars in damages. With changing climate and increasingly unpredictable rain events, flooding is a major and natural driver in ongoing processes of stream channel evolution – one that both affects and is affected by the landscape in which the channel is located.

Estimates in Orange County, Vermont (where the majority of the Second Branch is located) indicate that flooding from 1960-2012 accounted for only 5% of the total number of natural hazard events but nearly 78% of the reported monetary damages from those events (Hazards & Vulnerability Research Institute 2013).

The data and planning processes presented here aim to broaden our understanding and help break an escalating cycle that requires an increasing level of investment to rebuild and/or protect property, livelihoods and ecosystems from damage and hazards caused by flooding, erosion, nutrient loading and poor water quality.

Large-scale changes involving rivers and streams (including land clearing, damming, dredging, straightening and filling of floodplains) have altered the balance of water and sediment in those systems, and many of the heightened erosion and flood impacts being felt in Vermont today are related to such changes. While streams eventually return to some sort of balance, the adjustment processes for that to happen are currently active in many areas and are often the drivers of impacts felt on a local level (though the reasons for the adjustment processes are often not evident at the local scale). These changes often unfold on a time-scale measured in decades, and many of the processes evident today are related to significant land and water use changes that occurred over the last 200 years.

Stream Geomorphic Assessment (SGA) is part of a science-based process that can help elucidate these relationships and make communities more flood resilient, and by "combining it with knowledge from local landowners, we can develop sound plans for restoring and protecting important streams while respecting the concerns and interests of the local community" (WRP 2020).

Fluvial geomorphology is the study of how water and sediment move within the landscape, both over distance and over time

- Fluvial: of or related to rivers and streams (i.e., flowing waters)
- Geomorphology: Geo = earth; morphology = shape

Extensive experience and observation indicate that a stream with a balance of these inputs will erode its banks and change course to a relatively minor degree, even in flood situations. Erosion impacts from Irene, in particular, are one indicator of the degree to which the current state of streams in Vermont diverges from this type of equilibrium (Fig. 2).


**Figure 2. Sediment plume entering Long Island Sound from the Connecticut River basin (including the White River) nearly a week after Irene** (*Photo credit: NASA 2011*)

The data and analyses presented here identify a range of top-priority issues to help achieve a goal of managing toward, protecting, and restoring the fluvial geomorphic equilibrium condition of Vermont's rivers and streams as a means to help resolve conflicts between human investments and river dynamics in an economically and ecologically sustainable manner (Kline 2010; VT-RMP Alternatives 2003). Objectives following from this goal include:

1. fluvial erosion hazard mitigation;
2. sediment and nutrient load reduction; and
3. aquatic and riparian habitat protection and restoration

The work reported here is based on protocols and guidelines developed by the Vermont River Management Program (VT-RMP 2009; Kline 2010), which are designed to guide assessments through a series of phases that integrate information from an overarching watershed context down to project-specific scales, with each previous stage informing the successors. By assessing underlying causes of channel instability at both watershed and localized scales, management efforts can be directed toward long-term solutions that help curb escalating costs and efforts directed toward resolving conflicts with ongoing stream processes.

Assessment results are summarized in this report, and preliminary analysis is presented through the use of stressor, departure, and sensitivity analysis maps to integrate the findings in a more understandable and intuitive manner. This analysis informs a process designed to identify, catalogue, and prioritize technically feasible projects that can help reduce flood and erosion hazards along stream corridors, improve water quality and aquatic habitat, and enhance recreational opportunities.

### *2.2 PROJECT OVERVIEW*

In the summer of 2019 the White River Partnership (WRP), as part of a project funded by the Vermont Agency of Natural Resources Clean Water Initiative Program, conducted fieldwork on the Phase 2 Stream Geomorphic Assessment (SGA) on the White River's Second Branch to produce this Phase 2 SGA report and River Corridor Plan.

The WRP is a community-based, non-profit organization whose mission is to bring together people and local communities to improve the long-term health of the White River and its watershed in central Vermont. The Second Branch corridor planning project builds on almost 25 years of community-based efforts undertaken by the WRP and partners throughout the White River watershed.

The 2002 White River Basin Plan (VT-ANR 2002) provides historical insight on basic background on planning efforts preceding the work described in this report, paraphrased here:

> The Vermont Agency of Natural Resources initiated planning efforts to improve or maintain water quality at a watershed level in the 1960's….
>
> In the 1970s basin planning was conducted in Vermont to address point sources of pollution.... The White River Basin Plan was completed in 1975, and contained several conclusions and recommendations…still relevant today…. (including) a recommendation for an assessment of stream bank erosion…and revegetation for disturbed stream bank areas….
>
> The collaborative process in the White River Basin began with the work of the White River Partnership. The Partnership formed in 1995 as a group of local citizens interested in preserving the quality of life in the White River Basin. It has become a forum for bringing

> together the community, local, State, and federal government agencies, and their resources to protect common interests.
>
> To identify common interests or concerns in the community, the Partnership held a series of public forums in 1996. The public forum results and public input during the basin planning process provided…primary concerns…as follows:
> • Stream channel instability and streambank erosion
> • Lack of awareness of water quality problems
> • Extent and quality of public access to recreational opportunities on the water
> • Impacts to fisheries

Stream Geomorphic Assessment is divided into phases (phases of the geomorphic assessment process are further discussed in section 4, Methods, of this report). A Phase 1 assessment is a preliminary analysis through remotely sensed data such as aerial photographs, maps, and 'windshield survey' data collection. Phase 2 involves rapid assessment fieldwork. River Corridor Plans analyze the data from the Phase 1 and 2 assessments to inform project prioritization and methodology.

Phase 1 geomorphic assessment of the full White River watershed was conducted by River Scientist Shannon (Hill) Pytlik and other members of the Vermont River Management Program, USDA Forest Service, and White River Partnership from 2001-2005. Based on priorities derived from this phase of assessment (as well as other water quality assessments, VT-ANR WMD 2013, p. 16) Phase 2 assessments of portions of the overall White River basin have been continuing since that time.

In preparation for Phase 2 work, review of the original Phase 1 data for the Second Branch was conducted in 2019 by the White River Partnership along with River Scientist Gretchen Alexander. This work prioritized 17 reaches (a reach is a relatively homogenous section of stream, based primarily on physical attributes such as valley confinement, slope, sinuosity, dominant bed material, and bed form) in the Second Branch basin for inclusion in Phase 2 assessment.

As of 2020 the White River Partnership listed the following completed River Corridor Plans based on Stream Geomorphic Assessments and knowledge from local landowners (WRP 2020):

Ayers Brook River Corridor Plan (2007)
Tweed River Corridor Plan (2008)
Upper White River Corridor Plan (2008)
Town of Sharon River Corridor Plan (2010)
First Branch River Corridor Plan (2014)
Bethel River Corridor Plan (2014)
Upper-Middle White River Corridor Plan (2015)

The 2018 White River Basin Tactical Plan notes that:

> "The SGAs provide data for incorporation into River Corridor Plans which help identify projects to reduce bacteria, sediment, and nutrients in the river. River Corridor Plans help

> to manage toward stream equilibrium which is essential for good water quality, healthy aquatic habitat, and flood resilience in the basin and will help mitigate impacts of increased runoff and stream flow. The Regional Plan supports the improved identification and mapping of surface water resources and development of river corridor plans and local river corridor ordinances. Phase II SGA data is a critical planning resource and tool for towns and watershed groups." (VT DEC-WMD 2018, p 161)

The 2018 White River Basin Tactical Basin Plan also identified a Phase 2 geomorphic assessment of the Second Branch of the White River as a primary strategy to address and restore impaired waters.

With this background, the White River Partnership started work on the Phase 2 geomorphic assessment in 2019.

### *2.3 PROJECT OBJECTIVES*

The main objectives of this report are as follows:

1. Identify stream types and condition for all included reaches
2. Identify major stressors in the watershed
3. Assess aquatic habitat and health
4. Understand riparian corridor condition and health

From these objectives projects have been identified and prioritized with the hope to provide a source of information to resource managers, watershed groups, community partners, municipalities and more in order to protect and enhance the quality of the Second Branch White River basin.

## 3.0 BACKGROUND INFORMATION

### *3.1 GEOGRAPHIC SETTING*

#### *3.1.1 Watershed description*

The Second Branch of the White River begins in Williamstown and forms into one channel at the outlet of Staples Pond. The main stem of the Second Branch flows south through Williamstown, Brookfield, Randolph, Bethel, and Royalton. The Second Branch is about 29 miles long and drains a 74 square mile watershed.

The following named tributaries flow into the main stem of the Second Branch of the White River:

- Sunset Brook
- Snows Brook
- Halfway Brook
- Blaisdell Brook
- Penny Brook
- Peak Brook

The Second Branch is one of four major tributaries of the White: The First, Second and Third Branches (as well as the Upper White mainstem, upstream of the confluence with the Tweed) are roughly parallel and similarly elongated on the north-south axis; the Tweed flows into the mainstem from the southwest portion of the overall White basin, and the Lower White mainstem flows primarily east-southeast into the Connecticut River (Fig. 1 on p. 3).

### *3.1.2 Political jurisdiction*

The Second Branch basin includes portions of the following towns: Royalton, Bethel, Randolph, Brookfield, and Williamstown. The Second Branch basin is primarily split between Brookfield (North) and Randolph (South). The villages of North Royalton and East Bethel sit at the southern tip of the basin while Williamstown is at the northern tip of the basin. All of these towns are within Orange County with the exception of Royalton and East Bethel, which are part of Windsor County. Besides Williamstown, all of the towns in the Second Branch basin are served by the Two Rivers-Ottauquechee Regional Commission. Williamstown is served by the Central Vermont Regional Planning Commission.

*Town Populations:*

Royalton: 2,766

Bethel: 2,131

Randolph: 4,794

Brookfield: 1,147

Williamstown: 3,397

(Vermont Indicators Online 2020)

### *3.1.3 Land use history and current general characteristics*

Land cover/land use in the Second Branch watershed is roughly 75.8% forested, 15.9% agricultural, and 5.4% developed (based on Phase 1 data, UVM-SAL 2002). Included in the developed category are transportation corridors and small villages clustered along the Second Branch in East Brookfield, North Randolph, East Randolph and South Randolph, East Bethel, and North Royalton. Table 1 breaks down percentage land use along the river corridor for each reach along the Second Branch.

A broad overview of land cover/land use in the White River basin indicates that the Second Branch shares a relatively high concentration of intermixed agricultural and “developed” lands common to all three of “the Branches”, especially along the river corridors (Fig. 3; UVM-SAL 2002).

**Table 1: Second Branch river corridor Land Cover/Land Use**

| Reach ID | Commercial (%) | Crop (%) | Field (%) | Forest (%) | Industrial-Residential (%) | Shrub (%) | Water (%) | Wetland (%) |
|---|---|---|---|---|---|---|---|---|
| M01 | 1 | 15.3 | 8.2 | 33.8 | 21 | 0.9 | 19.3 | 0.5 |
| M02 | | 4.3 | 10.3 | 46.8 | 17.6 | 1.4 | 19.6 | |
| M03 | | 12 | 21.7 | 45.5 | 1.3 | 1.5 | 17.1 | 0.8 |
| M04 | | 6.9 | 14.2 | 36.2 | 23.7 | 1.1 | 15.5 | 2.5 |
| M05 | | 6 | 5.4 | 67.6 | 5.2 | 0.3 | 12.5 | 3 |
| M06 | | 6.6 | 15.6 | 48.4 | 8.8 | 1.3 | 14 | 5.3 |
| M07 | | 26.4 | 19.4 | 32.1 | 4.1 | 0.4 | 17.6 | |
| M08 | | 10.9 | 15.5 | 51.9 | 0.5 | 0.5 | 20.6 | |
| M09 | 0.3 | 15 | 23.6 | 29.7 | 12.7 | | 18.7 | |
| M10 | 0.2 | 12.2 | 20.3 | 36.1 | 12.4 | 0.5 | 18.3 | |
| M11 | | 7.6 | 8.3 | 45.3 | 12.3 | 0.7 | 25.5 | 0.2 |
| M12 | | 20.4 | 3 | 41.6 | 5.4 | 0.2 | 18.7 | 10.7 |
| M13 | | 19.6 | 17.3 | 33.6 | 1.6 | 0.9 | 23.8 | 3.2 |
| M14 | 0.2 | 10.2 | 13.6 | 44.6 | 5.9 | 0.8 | 23.8 | 0.9 |
| M15 | | 11.4 | 13.8 | 39.2 | | 0.4 | 32.4 | 2.8 |
| M16 | | 9.5 | 1.5 | 30.1 | 23.3 | | 24.5 | 11.1 |
| M17 | | 4.2 | | 44.6 | 34.3 | | 9.1 | 7.8 |

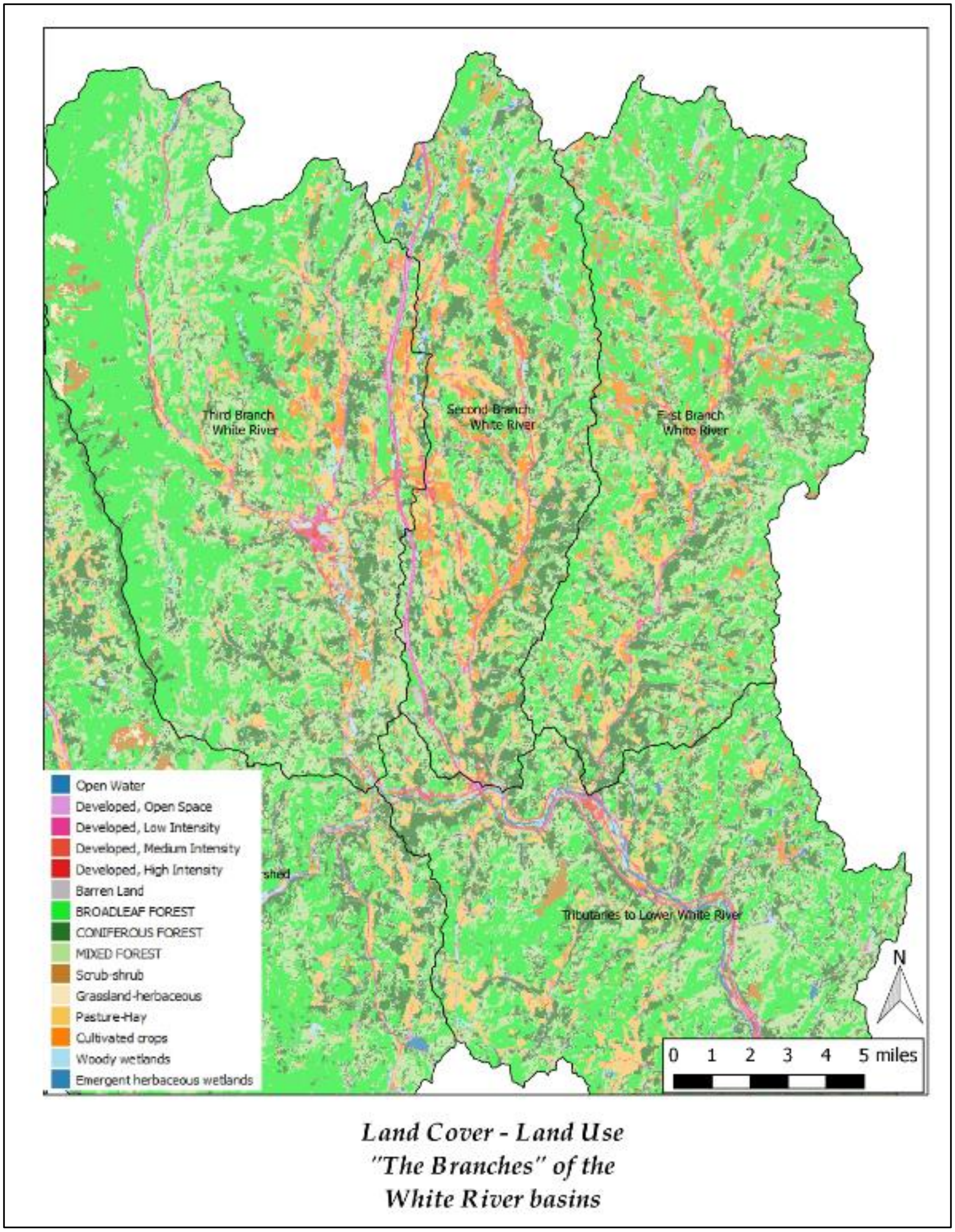



**Figure 3. Land Cover/Land Use – "The Branches" of the White River basin**

A nineteenth century portrayal of Randolph gives a pertinent sense of the history of the Second Branch Basin:

> The Town of Randolph was organized March 31, 1783, and contains 28,596 acres. The surface is considerably elevated, but is less broken than that of the land generally in this

vicinity. The soil is productive and the farming interest extensive. The town is watered by the second and third branches of White river, the former running through the eastern and the latter through the western part. These streams and their tributaries afford a number of advantageous situations for mills. There are four villages — Randolph, East Randolph, West Randolph, and Farwell Village…. Randolph East Village is situated on the second branch of White river, is compactly built, and a place of considerable business. Mills of various kinds are in operation. West Randolph also has an academy, as well as some manufactories and mills. There are seven church edifices — Methodist, Free-will Baptist, Universalist, Christian, Episcopalian, and two Congregational; twenty-four school districts; and four post-offices — at Randolph, and at the east, west, and north villages: also, three grist- mills, one oil mill, and one carding mill. The Vermont Central Railroad passes through the town. (Coolidge & Mansfield 1859)

Defining characteristics of the Second Branch include heavy agricultural use and historic damming that was pervasive to power the mills mentioned above. Modifications to land and river in the Second Branch basin have largely been related to the manipulation of water through damming, historic channel straightening, and ditching of agricultural fields and attendant wetlands, notably in the mainstem valley. In addition, a widespread road network contributes to channel straightening and restriction of floodplain access in the narrow valleys of many of the tributaries along steep valley sidewalls. The late 1800's in the Second Branch basin saw heavy deforestation that resulted in extreme runoff into the rivers, and this was accompanied by the proliferation of milldams along many of the streams of the region during a similar time period (Beers 1869; Beers 1877; Walter and Merritts 2008). These dams served to trap significant amounts of sediment from upstream, through which later incision cut single thread channels. Extensive research in a similar setting for streams in the Pennsylvania and Maryland Piedmont region indicates that,

"before European settlement, the streams were small anabranching channels within extensive vegetated wetlands that accumulated little sediment but stored substantial organic carbon. Subsequently, 1 to 5 meters of slackwater sedimentation, behind tens of thousands of 17th- to 19th-century milldams, buried the presettlement wetlands with fine sediment. These findings show that most floodplains along mid-Atlantic streams are actually fill terraces, and historically incised channels are not natural archetypes for meandering streams." (Walter and Merritts 2008)

Today the Second Branch basin, and the small villages that occupy it, rely heavily on agriculture. The 2017 Census of Agriculture for Orange County helps to paint a picture of the current state of agriculture in the Second Branch Basin. Table 2 shows the number of farms, land in farms, and average size of farms in Orange County as of 2017; most notably the number of farms and the land in farms has decreased by 24% and 19% respectively in just five years. As this decline in number and acres of farms is happening, the average size of a farm is growing by 7% as larger farming operations are consolidating (USDA 2017).

**Table 2: Orange County Vermont, Farm Overview**

**Total and Per Farm Overview, 2017 and change since 2012**

| | 2017 | % change since 2012 |
|---|---|---|
| Number of farms | 569 | -24 |
| Land in farms (acres) | 85,629 | -19 |
| Average size of farm (acres) | 150 | +7 |

The agricultural future of the Second Branch basin will play a large role in the health of the watershed, highlighting the importance of understanding the trends and future of farming in the region.

It is worth noting that this SGA and corridor planning was completed during the SARS-CoV-2 (COVID-19) pandemic. Although the lasting impacts of the pandemic are currently unknown, Vermont has already seen changes that may impact the health of our waterbodies, notably including the likelihood of land use change as rural Vermont communities see an increase in real estate transactions. Reporting from the Middlebury area has been echoed elsewhere, as "Vermont real estate agents are reporting unusually high consumer interest and record low availability as many rethink their living situations amid the COVID-19 pandemic" (Summersby 2020). With work from home options increasing, the Second Branch basin may see an uptick of development for residential use, changing the land use balance that we see today.

### *3.2 GEOLOGIC SETTING*

The Second Branch is located in the Vermont Piedmont physiographic region, which comprises eastern portions of the overall White River basin (Lower White mainstem and First, Second and eastern half of Third Branches) (Stewart and MacClintock 1969; Thompson et al 2019).

Calcium carbonate is the dominant bed material in much of the Second Branch river basin (Fig. 4). The White River is thought to be the highest pH watershed in the Connecticut River watershed with its calcareous setting (VTDEC 2016). The bedrock underlying eastern portions of the White River basin tend toward calcareous, carbonate-rich formations relatively easily weathered to fertile soils (Thompson et al 2019). This has much to do with an intensive agricultural and forestry history and "few large areas of wild nature" (Thompson et al 2019). The Second Branch basin comprises a large proportion of the agricultural land use, along with being more densely populated than the western portions, of the overall White River basin.

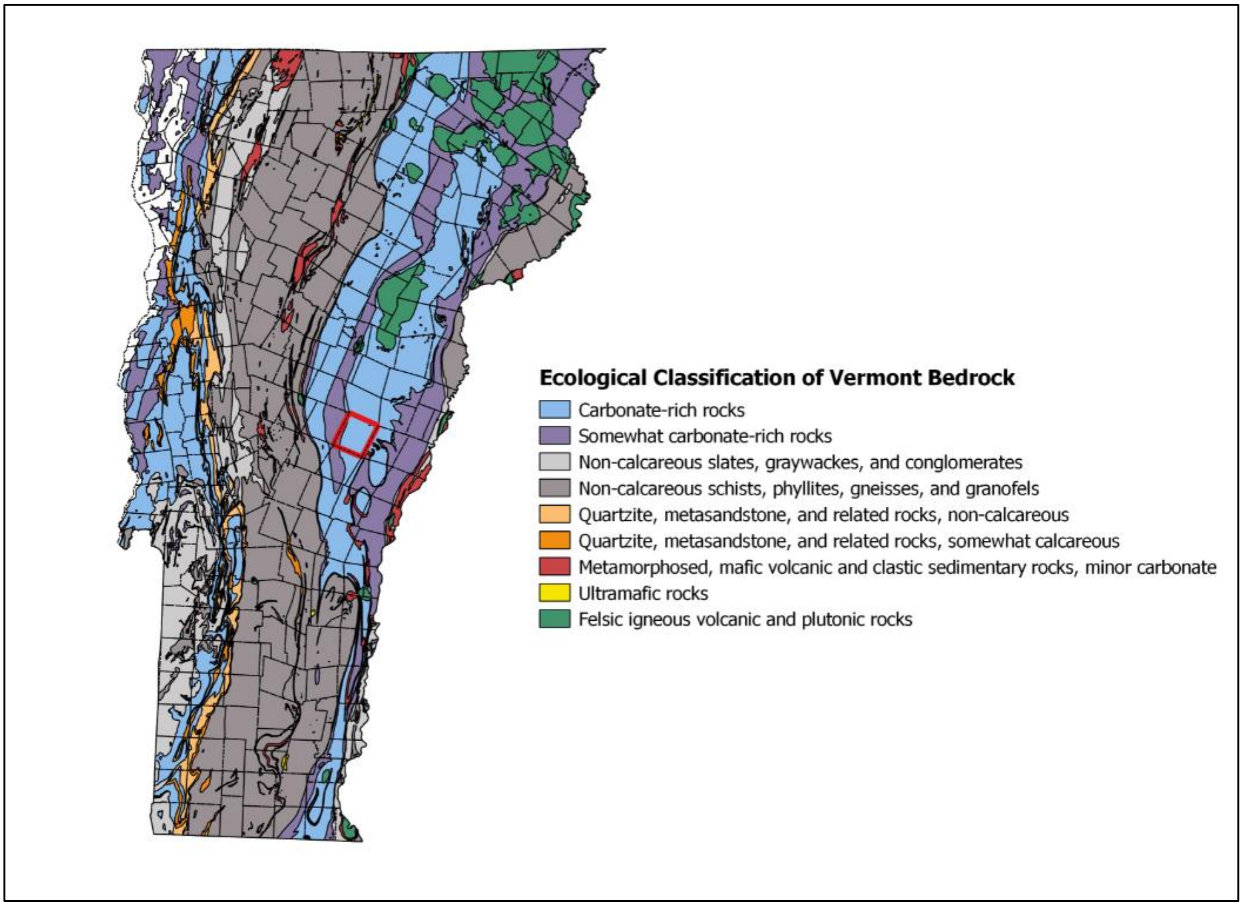



**Figure 4. Vermont Bedrock Ecological Classification (Thompson and Sorenson 2000)**

The surficial sediments and soils present in the White River basin reflect a complex glacial and post-glacial history. Factors particularly affecting all three 'Branches', but the Second Branch in particular, are related to the heavy presence of fine sediments (clays, silts, and sands) due to the presence and subsequent draining of glacial Lake Hitchcock. Lake Hitchcock formed as an impoundment behind large volumes of glacial deposits in central Connecticut that dammed the Connecticut River valley. At its maximum extent, the lake body stretched from Rocky Hill, CT for 200 miles northward to the mouth of the Nulhegan River in Bloomfield, VT, and as far west as the Upper White mainstem in Pittsfield/Rochester and the Third Branch in Braintree. Sediments in and along the edges of the glacial Lake tend to be dominated by the stratification of fine silts, sands and gravels that settled out differentially in the still waters of the Lake as glacial streams fed it.

The finest silt loams and silty-clay components required quiet waters in the stillest portions of the Lake to settle out, and are prominent along the Second Branch as far north as the village of North Randolph. Frequently these soils have restrictive layers with low infiltration rates, leading to seasonal high water tables and generating runoff on steeper slopes. Sandier soils of greater permeability but high erodibility tend to be associated with localized deposits of glaciofluvial and alluvial origin interspersed along the river corridors of all three Branches in their present locations (Stewart, 1973; Stewart & MacClintock, 1969; USDA 2013, 2011).

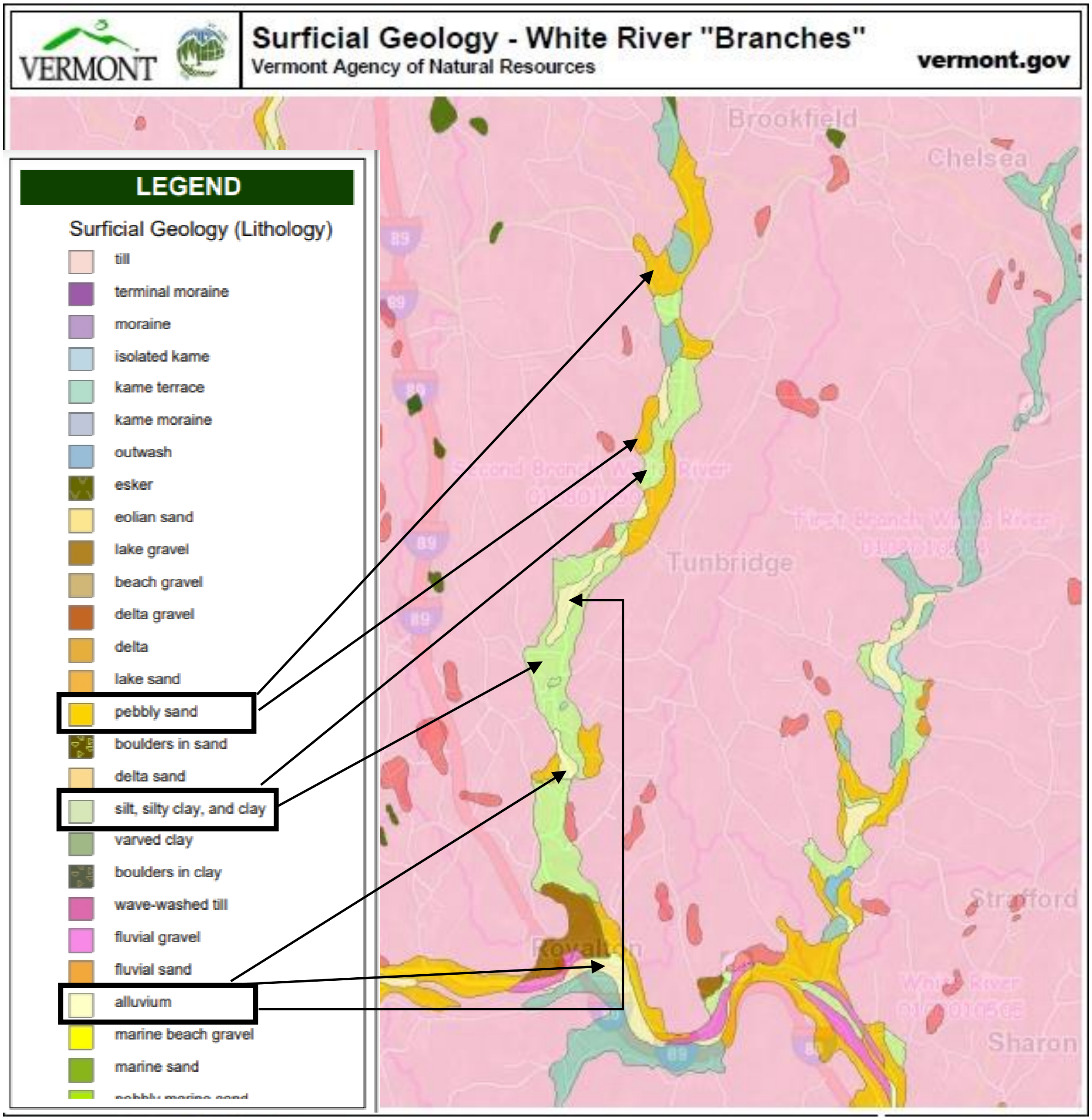



**Figure 5. Surficial Geology (Lithology) of the White River "Branches", highlighting preponderance of glaciolacustrine soils (especially 'silt, silty clay, clay') and other fine-grained soils along significant portions of the Second Branch.**

## *3.3 GEOMORPHIC SETTING*

### *3.3.1 Location of assessed reaches*

For the purposes of geomorphic assessment and corridor planning, streams in the study area were divided into "reaches". Reaches selected for Phase 2 assessment in 2019 included the entire Second

Branch mainstem. This assessment does not include any of the tributaries that run into the main stem of the Second Branch. The Phase 1 assessment of the main stem of the Second Branch divided the river into 17 separate reaches. This assessment assessed all 17 reaches and further divided 3 of the 17 reaches into segments.

### *3.3.2 Longitudinal profile and natural grade controls*

The longitudinal profile of the Second Branch mainstem indicates a low gradient for almost the entire length of the river. This is somewhat unusual for the White River, as Figure 6 indicates; most of the Branches of the White River maintain a low gradient through their lower and middle sections and then transition to a high gradient profile in the upper reaches. This is not the case for the Second Branch, with the only significant increases in gradient along the majority of the entire mainstem occurring at former or current dam sites.

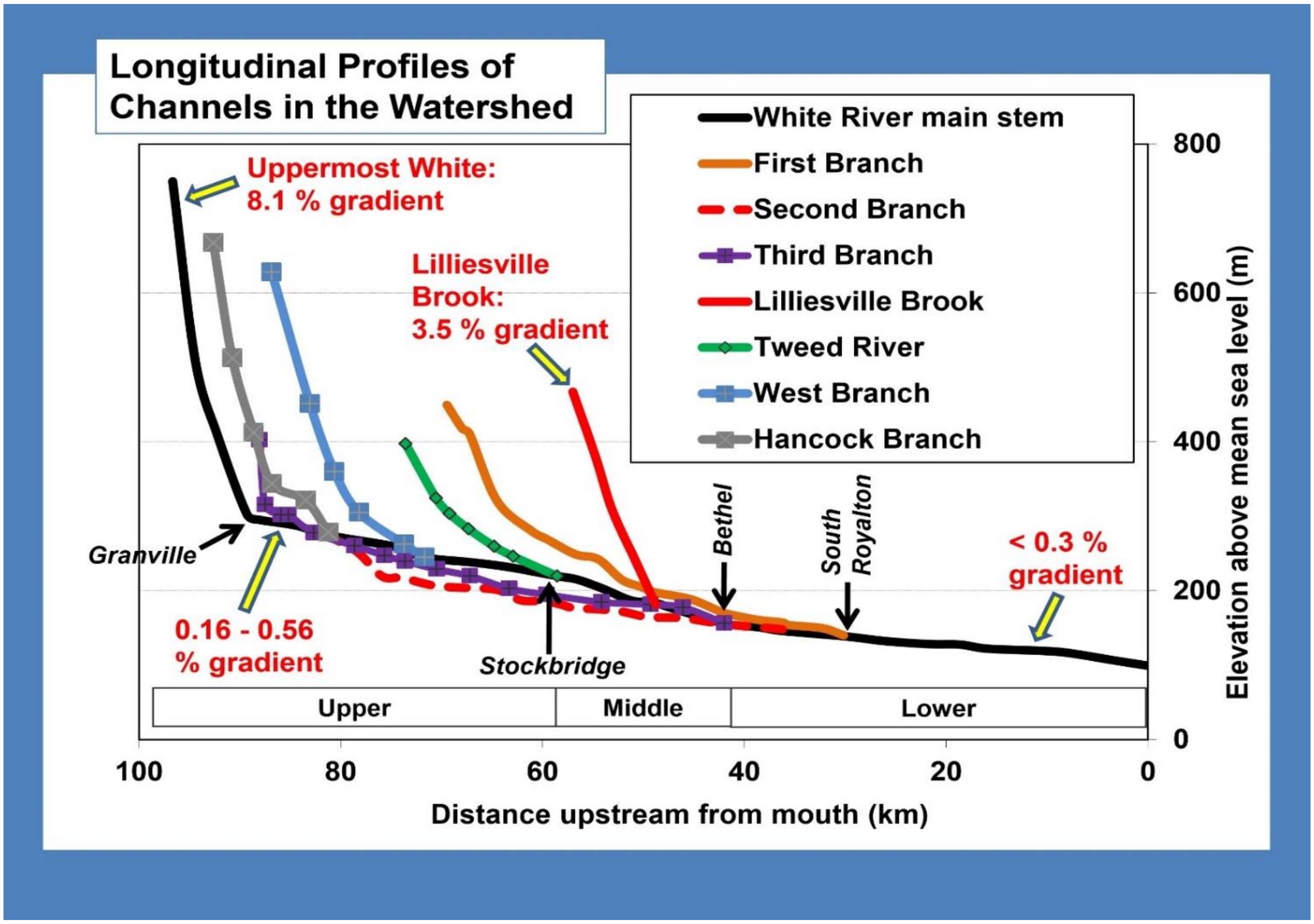



**Figure 6. White River watershed longitudinal profiles highlighting relatively low gradient of Second Branch (dotted red line).** ***Credit: George Springston.***

In most stream systems, natural grade controls are channel-spanning features that can be present in the form of bedrock or ledge exposures, or as steeper cascades or waterfalls. Grade controls are important in providing vertical stability for a stream, ensuring that streams do not lose access to floodplains due to incision (downcutting) - frequently one of the effects of straightening and artificial confinement. If major floods or straightening and encroachment amplify the effects of erosion in upstream portions of the watershed, grade controls may mean that streams will aggrade (build up their beds) due to sediment inputs. The low gradient nature of the Second Branch somewhat mitigates the need for extensive grade controls and in fact, very few natural grade controls were identified during this assessment. Gulf Road Dam in East Randolph village, and ledges in the most upstream reach M17. A ledge grade control was located beneath sediments upstream of the Hyde Dam

Reach M03 has a natural grade control (ledge/waterfalls at former Stoughton Mills/Royalton-5 dam site in North Royalton), at the approximate height of 15 feet. This waterfall is currently under a VT-14 bridge at the start of M03. Possible channel spanning ledge was identified underneath sediments upstream of the Hyde Dam in East Bethel village (M04) and may act as a grade control, but it is currently unknown if similar exists at the Gulf Road dam in East Randolph village (reach M09). M17-A (a slightly steeper slope section) at the top of the watershed has multiple ledge grade controls within the Brookfield-Williamstown Gulf that separates the White and Winooski watersheds. In addition to the natural grade controls, remnants of former dams in North Randolph (M11-A and M11-C) act as grade controls and it was not clear if these were located on channel-spanning ledge. It is possible that natural grade controls were missed during the assessment due to the sedimentation that often made it difficult to see channel spanning ledge, especially in the heavily silted reaches above Hyde and Gulf Road Dam.

### *3.3.3 Valley and reference stream types*

A reach is a relatively homogenous section of stream, based primarily on physical attributes such as valley confinement, slope, sinuosity, dominant bed material, and bed form, as well as predicted morphology based on hydrologic characteristics and drainage basin size (methods are further discussed in Section 4.0 of this report). Primary classification parameters pertinent to establishing these reference stream types are listed in Table 3.

**Table 3: Valley Confinement Type**

| Reference stream type | Confinement (Valley Type) | Slope |
|---|---|---|
| A | Confined (NC) | Very Steep: 4.0–6.5% |
| B | Confined or Semiconfined (NC, SC) | Steep: 3.0–4.0% |
| B | Confined, Semiconfined, or Narrow (NC, SC, NW) | Moderate–Steep: 2.0–3.0% |
| C or E | Unconfined (NW, BD, VB) | Moderate–Gentle: <2.0% |

NC: Narrowly Confined; SC: Semi-Confined; NW: Narrow; BD: Broad; VB: Very Broad

A and B type streams (steeper slopes) are primarily expected to be sediment Transport reaches, and only two B type reaches (under reference conditions) were identified during 2019 fieldwork refinement of the 2004 remote data Phase 1 assessment (M02 and M17).

Stream reaches with C and E reference types utilize their floodplains extensively in stream processes and would be expected to store sediment, high flows and nutrients within the watershed under reference conditions. "Stream Type Departures" identified in Phase 2 fieldwork frequently highlight loss of access to historic floodplains in these types of streams, increasing the impacts of flood flows in a more confined floodplain and/or converting them to "transport" reaches.

**Table 4: Second Branch Reference Conditions – Phase 1**

| Stream | Reach ID | Valley Type | Calculated Channel width (ft.) | Reference Stream Type | Bedform | Bed Form |
|---|---|---|---|---|---|---|
| Second Branch mainstem | M01 | BD | 87.2 | C | Gravel | Riffle-Pool |
| | M02 | NC | 86.3 | B | Sand | Dune-Ripple |
| | M03 | BD | 84.6 | E | Sand | Riffle-Pool |
| | M04 | BD | 83.2 | E | Sand | Dune-Ripple |
| | M05 | BD | 81.5 | E | Sand | Dune-Ripple |
| | M06 | BD | 76.7 | E | Sand | Dune-Ripple |
| | M07 | BD | 75.4 | C | Gravel | Riffle-Pool |
| | M08 | NW | 71.3 | C | Gravel | Riffle-Pool |
| | M09 | BD | 70.8 | C | Sand | Dune-Ripple |
| | M10 | VB | 65.6 | C | Gravel | Riffle-Pool |
| | M11 | NW | 59.4 | C | Gravel | Riffle-Pool |
| | M12 | VB | 55.1 | E | Sand | Dune-Ripple |
| | M13 | VB | 53 | E | Sand | Dune-Ripple |
| | M14 | VB | 49 | C | Gravel | Riffle-Pool |
| | M15 | VB | 39 | E | Sand | Dune-Ripple |
| | M16 | VB | 34.6 | E | Sand | Dune-Ripple |
| | M17 | NW | 25.9 | C | Cobble | Riffle-Pool |

The Phase 1 assessment indicated a strong preponderance of the lower gradient stream types (C and E) along the Second Branch mainstem, and it should be noted that these are the "Reference" conditions; Phase 2 assessments indicated that a number of these stream sections have departed from reference conditions and no longer fulfill the same functions in the landscape (discussed in detail in Section 5 "Results" and in Section 6 "Reach Descriptions").

### *3.4. HYDROLOGY*

Hydrology describes the movement and storage of water in and around the earth, which is subject to both natural fluctuations and human modification (Dunne & Leopold 1978). The information presented in this section deals briefly with the basis and interplay of natural fluctuations, while human modifications are discussed further in section 5.1.1, Watershed-scale hydrologic regime stressors. There are no stream gages operated by the United States Geological Survey (USGS) in the Second Branch basin. The USGS administers a StreamStats website, which is designed to help compute streamflow and drainage basin characteristics for ungaged sites (https://streamstats.usgs.gov/ss/). Drainage basin characteristics for the Second Branch basin are indicated in Table 5.

**Table 5: Second Branch Basin Characteristics Report and estimated flows for different return frequencies (USGS Streamstats)**

| Parameter | Value |
|---|---|
| Area in Square Miles | 74 |
| Mean Annual Precipitation, in inches | 41.9 |
| Percentage of water bodies and wetlands | 1.13 |

| | | 90-Percent Prediction Interval | |
|---|---|---|---|
| Statistic | Flow (ft^3/s) | Minimum | Maximum |
| 50 Percent AEP Flood | 1900 | 1140 | 3490 |
| 20 Percent AEP Flood | 3010 | 1690 | 5360 |
| 10 Percent AEP Flood | 3770 | 2030 | 6990 |
| 4 Percent AEP Flood | 4870 | 2490 | 9530 |
| 2 Percent AEP Flood | 5810 | 2860 | 11800 |
| 1 Percent AEP Flood | 6810 | 3250 | 14300 |
| .5 Percent AEP Flood | 7900 | 3590 | 17400 |
| .2 Percent AEP Flood | 9560 | 4090 | 22400 |

The above report provides estimates of flood discharges at selected annual exceedance probabilities (AEPs) for streamgages in and adjacent to Vermont, with equations estimating flood discharges at AEPs of 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent (recurrence intervals of 2-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-years, respectively) for ungaged, unregulated, rural streams in Vermont. The equations were developed using generalized least-squares regression. Flood-frequency and drainage-basin characteristics from 145 streamgages were used in developing the equations. The drainage-basin characteristics used as explanatory variables in the regression equations include drainage area, percentage of wetland area, and the basin-wide mean of the average annual precipitation. (Olson 2014).

Lakes, ponds and wetlands can help store flow and sediment discharges in extreme weather events. With only ~1.13% of the watershed in waterbodies and mostly small wetlands (Table 5; many of the wetlands have been altered by agricultural conversion, primarily through ditching), such buffering capacity within the Second Branch basin is limited. Despite relatively moderate to low levels of annual precipitation (Fig. 7) this factor combines with the steep/dissected character of the upland topography, localized nature of intermittent storms, and cultural relationship to streams to predispose the Second Branch basin to flash flooding. In fact, 34 years of flood data (1975-2009) in an area covering Vermont and portions of New Hampshire and upstate New York indicated that Orange and Essex County, VT (the Second Branch basin is largely in Orange County) are toward the low end of total events but have the highest damage per flood event (Breitbach 2010).

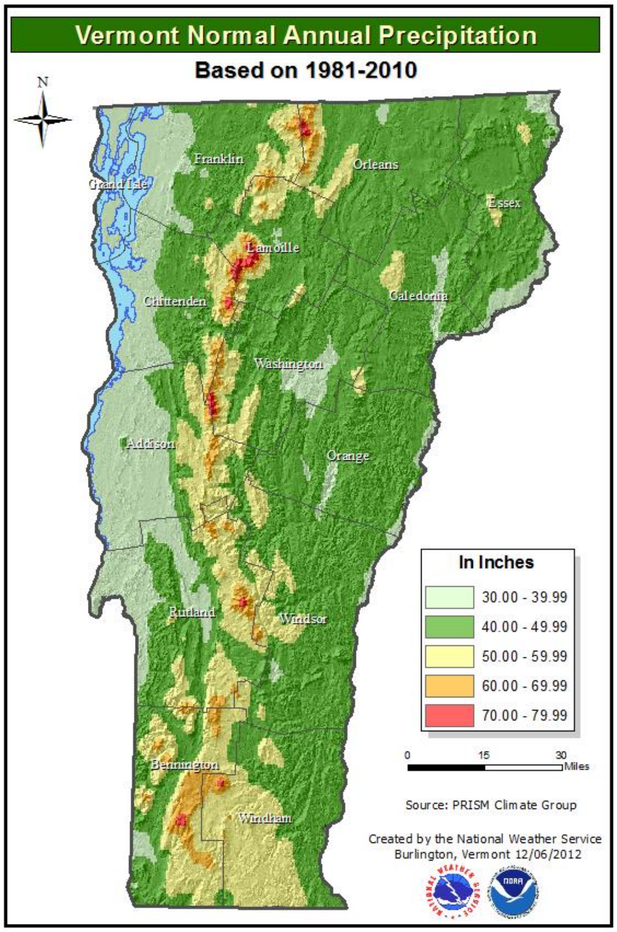



**Figure 7. Vermont Annual Precipitation**

The Second Branch basin is in the low to moderate range for Vermont in total annual precipitation over the last 40 years with a mean of 41.9 inches/year (Table 5; Fig. 7). Although the total rain amount is not high for the state of Vermont, short and intense rain storms have been particularly damaging to the Second Branch. Flash flooding in the upper part of the Second Branch Basin in June and July of 2013 resulted in $294,00 of damage in Brookfield, a larger amount than total damage from Tropical Storm Irene (Brookfield LHMP 2015).

### *3.4.1 Second Branch basin flood history*

The nearest continuous monitoring USGS streamflow gaging station to the Second Branch of the White River is at Ayers Brook in Randolph, within roughly 5 miles of the Second Branch basin. This station (# 01142500) measures flow from an approximate drainage area of 30.5 square miles and has daily flow records dating back to 1939. The Peak flow chart for the Ayers Brook gage (Fig. 8) shows the highest annual peak flow readings from 1940 to 2019, for context on some of the larger flow events in the area. Although the Ayers Brook gage is not a perfect representation of the Second Branch basin, it helps put the frequency and magnitude of high flow and flood events into perspective. Note in particular that flooding at Ayers Brook was worse in Tropical Storm Irene (2011) than flooding in June-July 2013, July 2017, and April 2019 flash floods that had much higher impacts in the Second Branch basin.

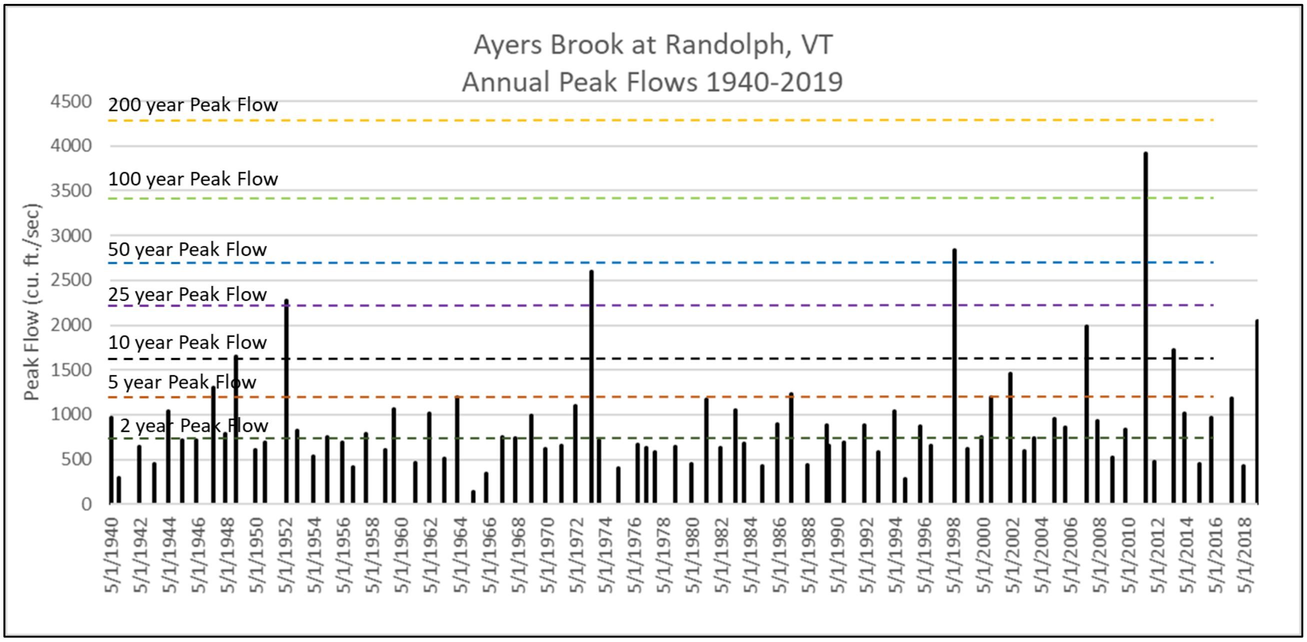



**Figure 8. Ayers Brook Annual Peak Flows (1940-2019)**

Preceding fieldwork for this project the White River basin experienced high flows during late winter and spring 2019, with rapid snow melt contributing to a FEMA disaster declaration due to flooding (PK10<flows <PK25) for most of the basin on April 15 (FEMA-DR-4445-VT). High flows continued through the beginning of July, as indicated by sampling dates for the White River Partnership water quality season that corresponded most closely to the fieldwork dates for the Phase 2 assessment reported here (Fig. 9). From July on water levels steadily declined, and by late summer 2019 saw continuation of a trend of abnormally dry conditions in much of the White River basin (6 of the last 7 years have seen abnormally dry to moderate drought conditions by September-October; NDMC 2021).

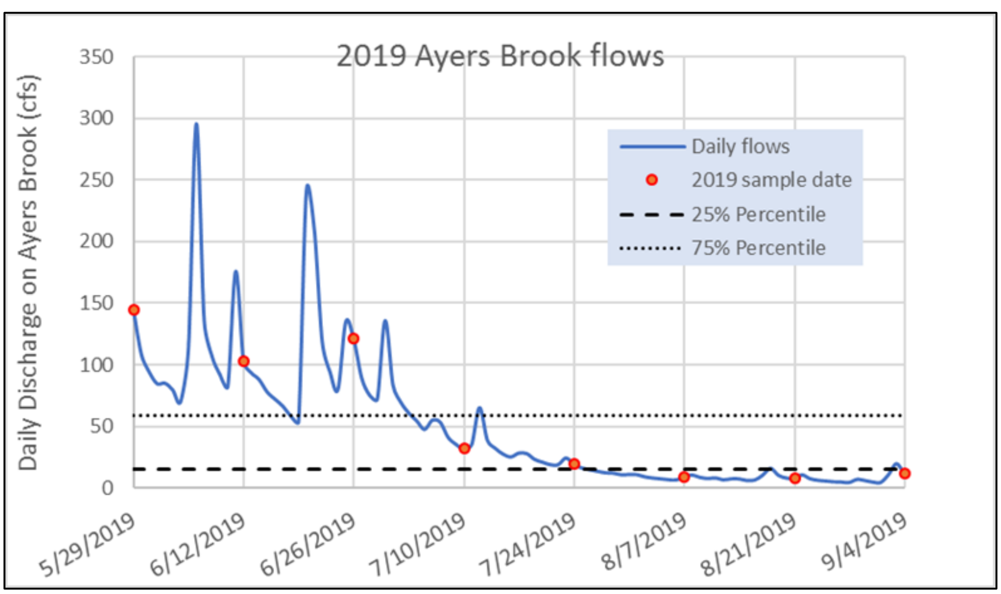



**Figure 9. Ayers Brook mean daily flows, spring-summer 2019**

This pattern of localized flash flooding is characteristic of the area, indicating the variable nature of precipitation events due in large part to orographic effects as well as a level of "flashiness" related to a variety of factors including steepness of valley walls in the basin, the relatively minimal buffering capacity of wetlands and other waterbodies, narrow tributary valley widths and limited floodplain accessibility, and the effects of a variety of human influences. Without the availability of gage information in the Second Branch basin, documented flood events become highly valuable. Town records were not able to be researched thoroughly within the time and funding constraints of this corridor plan, but excellent discussions of local flood history can often be found in Local Hazard Mitigation Plans that regional planning commissions assist in compiling (TRORC 2021).

The following flood event history (Table 6) from the Brookfield Hazard Mitigation Plan (Brookfield LHMP 2015) gives a sense of the flood history in the area. Not all of these events directly impacted the Second Branch basin, as most of the data were aggregated at a county level. Second Branch flash floods in 2017 and 2019 occurred after this plan was prepared.

**Table 6: Orange County Vermont Flood History**

| Date | Event | Location | Extent and Impacts |
|---|---|---|---|
| 04/15/2014—04/18/2014 (DR-4178) | Severe Storms and Flooding | County-wide | Severe storms caused flooding throughout the region, causing damage to some infrastructure and facilities. Flooding from heavy rainfall and snowmelt closed state highways in Orange County and damaged unpaved secondary roads. $300k in damage reported countywide. .81 inches of rain fell in 24 hours. |
| 06/25/2013—07/11/2013 (DR-4140 VT)* | Severe Storms and Flooding | Brookfield, County-wide | Severe storms caused flooding throughout the region, causing damage to some infrastructure and facilities. Brookfield incurred more damage during DR-4140 VT than during Tropical Storm Irene, approximately $294,000. 7.48 inches of rain fell during the disaster period. There was only one affected Green Mountain Power customer in Brookfield who lost power for 3 hours. |
| 08/28/2011 (DR-4022 VT, TS Irene)* | Tropical Storm | Brookfield, County-wide | Widespread rainfall amounts of 3-5 inches occurred across Vermont with 5 to 7+ inches across much of southern, central Vermont. Devastating flash flooding occurred across much of central and southern Vermont mountain valleys with substantial and some record breaking flood stages on larger rivers. This flood event will likely rank second to the November 1927 flood in the scope of meteorological and hydrological conditions/impacts as well as loss of life (84 in 1927), but likely first in monetary damage ((approx. $500. million statewide v. $350 million (1927 in 2010 dollars)). There were nearly 2,400 roads, 800 homes/businesses, 300 bridges and a half dozen railroad tracks destroyed or damaged from the flooding caused by Irene. Approximately 5" to 7" of rain was reported in Brookfield. There was $69,507.14 in public damages according to FEMA's Public Assistance database (captures at least 70% of the total damage). Green Mountain Power outages in Brookfield affected 24 customers and lasted over 91 hours. |
| 05/26/2011—05/27/2011 (DR-4001) | Severe Storms and Flooding | County-wide | Severe storms caused flooding throughout the region, causing damage to some infrastructure and facilities. 4.15 inches of rain fell in in the region. There were no power outages in Brookfield. |
| 04/27/2011 | Flooding | County-wide | Heavy rains, snowmelt from an above-normal snowpack, and high temps caused significant flooding in the region. 1.15 inches of rain fell in Brookfield in 24 hours. 1 power customer lost power for 1.5 hours. |
| 10/01/2010 | Flooding | County-wide | Heavy rains from the remnants of TS Nicole hit Vermont, dumping multiple inches of rain in the White River Valley, and washing out local roads. 4.58 |

| Date | Event | Location | Extent and Impacts |
|---|---|---|---|
| | | | inches of rain fell in Brookfield in 48 hours. 17 power customers were without power for 2.38 hours. |
| 07/21/2010 | Flash Flooding | County-wide | Several storms strengthened into super cells that produced widespread wind damage to trees, power poles and structures as well as large hail in excess of golf ball size in diameter. Very heavy localized rains caused some temporary problems in many communities. 2.86 inches of rain fell in 24 hours. There were widespread power outages in Brookfield that affected 227 customers from between 6 to 13 hours. |
| 08/21/2009 | Flash Flooding | County-wide | Numerous showers and scattered thunderstorms developed and moved across southern and central Vermont. Some of these showers were accompanied by very heavy rainfall rates of over 2 inches per hour. An official NWS Cooperative Observer reported a rainfall total of 2.79 inches, and other unofficial reports of 4 inches of rain within 2 hours were common. Flash Flooding resulted, causing local roads, culverts, and bridges to wash out. County-wide damage reported at $350k. A fallen tree limb caused power outages to 20 customers for 4.23 hours. |
| 08/07/2008 (Part of DR-1790 VT) | Flash Flooding | County-wide | Thunderstorms with heavy rainfall in a moist atmosphere moved through central and southern Vermont during the afternoon and evening hours, falling on already heavily saturated soils. 2.73 inches of rain fell in Brookfield in 48 hours. |
| 07/21/2008—08/12/2008 (DR-1790 VT) | Flooding | County-wide | Showers and thunderstorms produced significant rainfall across the region, causing sever flash flooding in places. 1.71 inches of rain fell on 7/21 in Brookfield, and another 3.35 inches of rain fell in 48 hours from 7/24-7/25. Widespread power outages occurred, affecting 396 customers in Brookfield. Outages lasted 1.8 to 4.9 hours. Flood waters originating in Addison County traveled down the White River. |
| 07/11/2007 (DR 1715 VT)* | Flash Flooding | Brookfield, County-wide | Localized heavy rainfall exceeded 3 inches within a two hour time frame with some localized storm totals approaching 6 inches across a very hilly or mountainous terrain, which resulted in flash flooding of several communities. Numerous roads in Brookfield and surrounding communities washed out, including portions of Rte. 14. No significant power outages occurred. |
| 04/15/2007—04/21/2007 (DR-1698 VT) | Severe Storms and Flooding | County-wide | Severe storms caused flooding throughout the region, causing damage to some infrastructure and facilities. 2.15 inches of rain fell in 24 hours. A power outage occurred on 4/18 that affected 15 customers for 3 hours. |
| 01/18/2006 | Flooding | County-wide | A powerful storm and rising temperatures led to rainfall of 1.5-2.5" and additional snowmelt. This led to field flooding and ponding of water on area roadways in the region. $2k in damages reported for Orange County. No power outages occurred. |
| 07/21/2003—08/18/2003 (DR-1488) | Severe Storms and Flooding | County-wide | Severe storms caused flooding throughout the region, causing damage to some infrastructure and facilities. Consistent rain fell during the disaster period in Brookfield, including .54 inches on 8/9/2003. Power outage data for this event are not known. |
| 04/13/2002—04/14/2002 | Flooding | County-wide | Snowmelt and 1-3" of rainfall across the region led to flooding along rivers in the county. $40k in damages was reported throughout the county, including some gravel road washouts. Power outage data for this event are not known. |
| 07/11/2001 (DR-1715) | Flash Flooding | County-wide | Tropical-like showers and thunderstorms caused heavy localized flooding. Rainfall exceeded 3" within a 2 hour time frame, with some areas getting nearer to 6". Many washed out roads, flooded basements, and homes damaged or destroyed. Power outage data for this event are not known. |
| 07/14/2000— | Flash | County-wide | Slow-moving thunderstorms resulted in heavy rainfall, 1.16 inches from 7/16- |

| Date | Event | Location | Extent and Impacts |
|---|---|---|---|
| 07/18/2000 (DR-1336) | Flooding | | 7/17, particularly across mountainous portions of the region. Flooding ensued, causing a reported $75k in damage across Orange County. Power outage data for this event are not known. |
| 04/04/2000 | Flash Flooding | County-wide | A storm system moved across New York and New England Tuesday, April 4th, with steady rain. Mild temperatures resulted in melting mountain snows. As a result, many streams and rivers rose to bankfull or above with some flooding. $1k in damage reported across Orange County. Power outage data for this event are not known. |
| 09/16/1999—09/21/1999 (DR-1307) | Severe Storms and Flooding | County-wide | TS Floyd brought heavy rains, high winds, and flooding to the region, causing extensive damage to public property. 5.37 inches fell in 24 hours, and 7.7 inches fell during the disaster period. Power outage data for this event are not known. |
| 06/27/1998 (part of DR-1228) | Flash Flooding | County-wide | An area of low pressure tracked across New York and New England during the late night of Friday (June 26) and morning of Saturday (June 27). Heavy convective rains fell with 3 to 6 inches across northern portions of the county. Extensive flooding occurred along the county's waterways. Many properties were flooded, and residents lost power. National Guard members assisted with clean-up efforts, and $2m in damage reported county-wide. Power outage data for this event are not known. |
| 01/08/1998—01/09/1998 (DR-1201 VT) | Flooding | County-wide | Up to 3 to 5 inches of precipitation fell in the region, causing flooding in Orange County. Power outage data for this event are not known. |
| 07/15/1997—07/16/1997 (DR-1184) | Flash Flood | County-wide | Heavy rains over this period caused numerous road washouts, particularly in northern portions of Orange County and causing $500k in property damage. 1 inch of rain fell in 48 hours. Power outage data for this event are not known. |
| 01/19/1996—01/20/1996 (DR-1101) | Flooding | County-wide | A deadly storm brought above normal temperatures, strong winds, and flooding to the region. Snowmelt and rainfall hit the region, washing out numerous roads and flooding other areas. Numerous power outages were reported. $250k in damage was reported for the county. Heavy snow had fallen earlier in January, and this coupled with 1 inch of rain that fell in 24 hours to caused damage in Brookfield. Power outage data for this event are not known. |
| 03/11/1992 (DR-938 VT) | Flooding | County-wide | Damage to Town roads caused by heavy rain, ice jams and flooding (cost of damage unknown). 1.42 inches of rain fell in 48 hours. Power outage data for this event are not known. |
| 10/02/1989 (DR-840 VT) | Flooding | County-wide | Damage to Town roads (cost of damage unknown). .67 inches of rain fell in 24 hours. Power outage data for this event are not known. |
| 06/28/1973—06/30/1973 (DR-397) | Flooding | County-wide | Rainfall as much as 6 inches in 24 hours in some locations. State declared disaster area. Deaths, 3; damage, $64 million. Power outage data for this event are not known. |
| 11/02/1927—11/04/1927 ("Flood of 1927")* | Flooding | Brookfield, County-wide | Considered to be on of VT's most devastating events, the flood took out 1285 bridges, miles of roads and railways, and countless homes and buildings. 84 people were killed, including Lt. Gov. S. Hollister Jackson. Rainfall totaled 4-9" statewide, following a month with 150% the normal amount of rain. Brookfield and the nearby areas saw between 7" to 9" of rainfall during the storm. Power outage data for this event are not known. |

With relatively little development close to the mainstem, primary impacts in the Second Branch basin have been to crops and roads, bridges, culverts, and other infrastructure - especially along steep valley sidewall tributaries, with significant sediment discharges to the mainstem. The July 1, 2017 storm was very localized but hit the Second Branch basin directly. It registered as a 100-yr Peak Flow just west in Rochester (pers. comm. Bob Gubernick, National AOP & Restoration Team Leader, USDA Forest Service) and forced evacuation of attendees at a music event at the Tunbridge Fairgrounds on the First Branch immediately to the east.

## *3.5 ECOLOGY*

### *3.5.1 Distribution of instream, riparian and wetland habitats*

Rapid Habitat Assessment (RHA) data collected during the Phase 2 assessments indicate all but one reach or segment assessed 'Fair' condition in the Second Branch basin (Appendix 1 RHA data). Segment M11-B upstream of Ferris Rd. rated 'Poor' due to lack of buffers and extreme planform adjustments driving erosion and sedimentation, with impacts from April 2019 flash flooding clearly evident. Fine-grained sediments along most of the mainstem provide little stability for riffle and bar formation, and sediments frequently fill and scour back out of pools easily.

The Second Branch basin does have beaver controlled areas, particularly in the upper portions of the basin. M16-B was not assessed in Phase 2 due to the multi-channel wetland created as a result of beaver control. In addition, other assessed beaver-controlled wetlands exist along the Second Branch; most of these areas are part of Class 2 wetlands (VSWI 2010) that have some legal protections. These areas help provide flood resiliency, and in particular, M17-A and M16-B create a break from transfer of stormwater and erosion impacts to downstream reaches.

The Second Branch does not have any USGS water quality monitoring gages to help detect temperature fluctuations and other water quality parameters, but the White River Partnership has maintained a number of water quality sampling sites along the mainstem for more than a decade. Results from these sites have indicated historically high *E. coli* readings and notable spikes in *E. coli* and turbidity readings following any heavy precipitation events. While there was no temperature data recorded during the field work for this assessment in 2019, qualitative observations indicated the stretches of river with little to no buffer had large changes in temperature from morning to afternoon, with particularly warm sections of water in upper reaches when water depths were low.

### *3.5.2 Aquatic Life*

Habitat connectivity is fragmented in the basin by the influence of two intact dams (Hyde Mill Dam in East Bethel, M04, and Gulf Road Dam in East Randolph, M09), as well as areas of ledge including the waterfall located at the southern end of M03 in North Royalton and a steep run of ledge under VT-14 about 0.2 mi south of the mouth of Staples Pond in Williamstown (M17-B). Heavy agricultural use with frequent poor buffers, extensive erosion, and warm water temperatures do not make the Second Branch an ideal location for native brook trout populations. However, many tributaries have cooler water and do contain native brook trout, and some are likely to be found along the Second Branch main stem. At one time brook trout were stocked by Vermont Fish and Wildlife along the main stem of the Second Branch annually at the Route 14 Bridge near Ferris Road (reach M11) down to the confluence with the main stem of the White River, however Vermont Fish and Wildlife no longer indicate that the Second Branch of the White River is stocked.

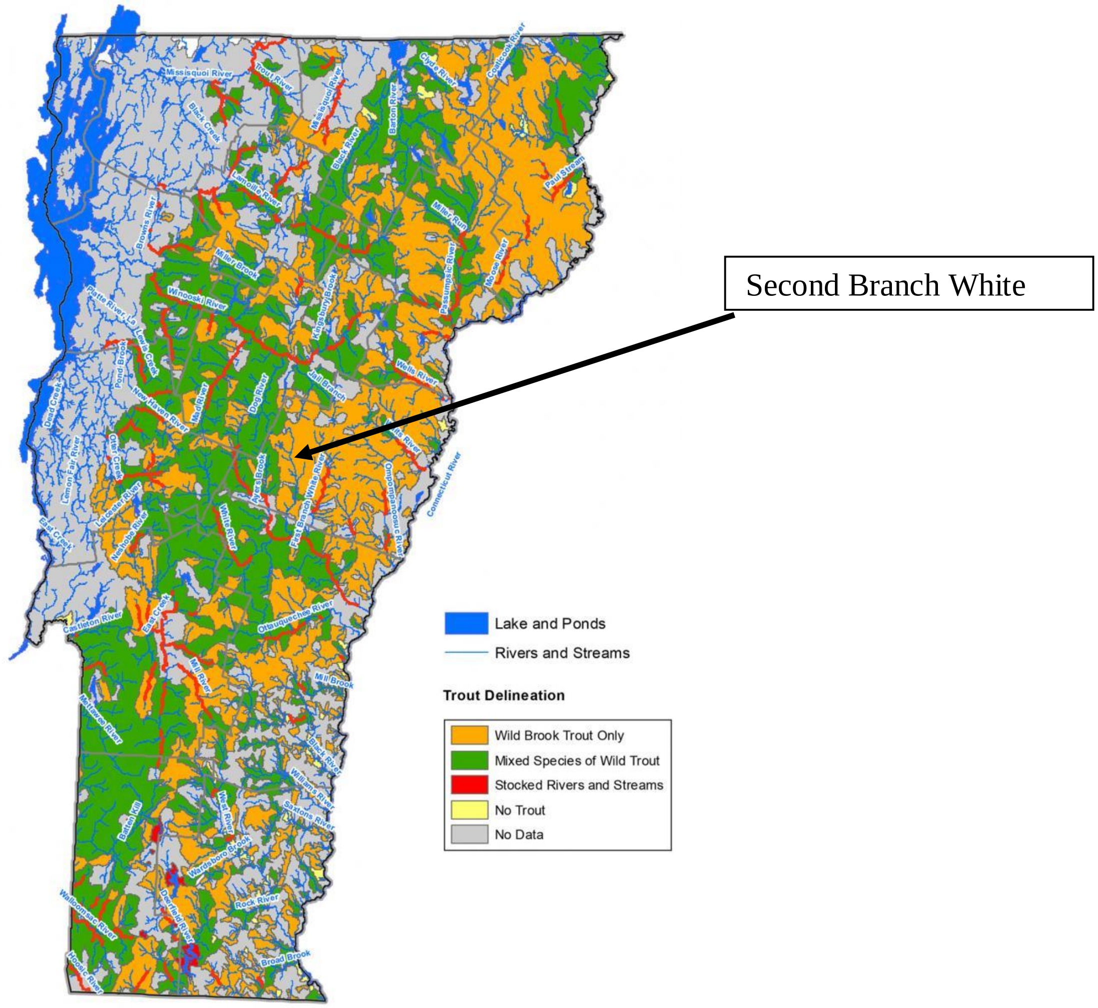



**Figure 10. Vermont Wild Brook Trout Habitat (VTFWD 2020)**

### *3.5.3 Unique plant and animal communities*

There are five significant natural communities identified in the Second Branch watershed including three different swamp types and a rich fen. There are 5 rare, threatened, or endangered (RTE) species in the Second Branch basin, all benefitted by riparian or wetland habitats common along the Second Branch, and an additional 4 uncommon species of which 2 particularly benefit from riparian or wetland habitat.

An additional species of note found during the Phase 2 assessment informing this report was an Eastern elliptio freshwater mussel, located in reach M02. This freshwater mussel was the only one found during the assessment. Eastern elliptio are Vermont's most common freshwater mussel, often times found in low gradient streams, along banks, and in silt, sand, clay or gravel bed material (VCE 2020). The mussel found during our assessment was in a very low gradient stretch of the Second Branch in a silty area along the left bank of the river.

Although no sea lampreys were found during this assessment, they have been found along upper portions of the White mainstem in Rochester and Hancock (pers. comms. Jeremy Mears, Fisheries Biologist USDA Forest Service, and John Hirsch, Clearfield Farm) and have the potential to be a species of note along the Second Branch if the last two dams are removed. Each year sea lampreys spawn during the spring in the main stem of the Connecticut River as well as in many of its tributaries including the White River. Larval lampreys are found in freshwater the first few years of their lives, and their most common habitat is in areas with sandy or silty substrate, which is prevalent in the Second Branch of the White River. At around 5 years of age, they transform into juveniles and emigrate to the ocean where they attach to and feed on fish, lampreys are a food source in the estuarine and marine environment for a number of fish, marine mammals, and bird species. (VTFWD 2018)

Along every reach of the mainstem of the Second Branch of the White River invasive plant species were identified, although the frequency and impact varied from reach to reach and tended to be less prevalent in upstream reaches M16 and M17. The two main invasive species identified were Japanese knotweed and wild chervil. The wild chervil is particularly prevalent along VT-14 and had spread along the roadway down the entire length of the Second Branch mainstem. Two non-native rusty crayfish (*Faxonius rusticus*) were observed while conducting an assessment of the VT-14 bridge in reach M02.

# SECTION 4: METHODS

## *4.1 STREAM GEOMORPHIC ASSESSMENT*

In an effort to provide a sound basis for decision-making and project prioritization and implementation, the Vermont Agency of Natural Resources River Management Program (VT-RMP) has developed protocols for conducting geomorphic assessments of rivers. The results of these assessments provide the scientific background to inform planning in a manner that incorporates an overall view of watershed dynamics as well as reach-scale, or localized, dynamics. Incorporating upstream and downstream dynamics in the planning process can help increase the effectiveness of implemented projects by addressing the sources of river instability that are largely responsible for erosion conflicts, increased sediment and nutrient loading, and reduced river habitat quality (Kline 2010, p.1). Trainings have been held to provide consultants, regional planning commissions, and watershed groups with the knowledge and tools necessary to make accurate and consistent assessments of Vermont's rivers.

The stream geomorphic assessments are divided into phases. A Phase 1 assessment is a preliminary analysis of the condition of the stream through remotely sensed data such as aerial photographs, maps, and 'windshield survey' data collection. This phase of work identifies a 'reference' stream type for each reach assessed. A reach is a similar section of stream, primarily in terms of physical attributes such as valley confinement, slope, sinuosity, dominant bed material, and bed form, as well as predicted morphology based on hydrologic characteristics and drainage basin size.

Phase 2 involves rapid assessment fieldwork to inform a more detailed analysis of adjustment processes that may be taking place, whether the stream has departed from its reference conditions, and how the river might continue to evolve in the future. This sometimes requires further division of 'reaches' into 'segments' of stream, based on such field-identified parameters as presence of grade controls, change in channel dimensions or substrate size, bank and buffer conditions, or significant corridor encroachments. The Phase 2 fieldwork includes the use of the Rapid Geomorphic Assessment (RGA) protocol and the Rabid Habitat Assessment (RHA) protocol.

As part of the Phase 2 data collection process, bridge and culvert assessments were conducted by the White River Partnership on all public stream crossings (public and private) within the Second Branch watershed. The Agency of Natural Resources Bridge and Culvert protocols were followed. Location data using latitude and longitude at each of the structures was determined using a Garmin GPSMAP 76 and verified after fieldwork using Google Earth. All assessed structures include photo documentation of the inlet, outlet, upstream, and downstream.

The data collected in Phase 2 also help identify the inherent sensitivity to changes in watershed inputs of a given stream segment, and these data can be used to map and classify erosion hazards within a River Corridor (VT-RMP FEH 2010; 10 V.S.A. Chapter 32 § 752. Definitions). River Corridor Plans analyze the data from the Phase 1 and 2 assessments to inform project prioritization and methodology. Phase 3 involves detailed fieldwork for projects requiring survey and engineering-level data for identification and implementation of management and restoration alternatives.

All Phase 1 and Phase 2 data were entered into the most current version of the VTANR Stream Geomorphic Assessment (SGA) Data Management System (DMS) (https://anrweb.vt.gov/DEC/SGA/Default.aspx), where they are available for public review. Phase 1 data were updated, where appropriate, using the field data from Phase 2 assessments; these changes were tracked and documented within the DMS. Spatial data for bank erosion, grade control structures, bank revetments, beaver dams, debris jams, depositional features, and other important features were documented within field-assessed segments and entered into the spatial component of the statewide data base using the Feature Indexing Tool of the Stream Geomorphic Assessment Tools (SGAT) ArcMAP extension, which permits geographic information systems implementation of the data. Using data from both Phase 1 and 2 assessments, maps displaying this information are being made available for public use as well, through the Vermont ANR Natural Resource Atlas (http://anrmaps.vermont.gov/websites/anra/).

### *4.2 QUALITY ASSURANCE, QUALITY CONTROL, AND DATA QUALIFICATIONS*

VT-RMP is committed to providing watershed groups, towns, regional planning commissions, consultants and other interested parties with technical assistance and shares responsibility for a thorough quality assurance/quality control (QA/QC) procedure for data collected in geomorphic assessments. Checks were initially conducted by the White River Partnership utilizing the QA/QC tools developed by VTANR and implemented through the online Data Management System. Documentation of these quality control checks is maintained within the DMS. Further review was conducted by Gretchen Alexander of the Vermont-RMP to verify integrity of the data, and this process was completed in spring of 2021. General questions about data collection methods can be answered by referencing the SGA Protocols (VT-RMP 2009).

### *4.2.1 Data Qualifications*

Due to the legacy of glacial Lake Hitchcock extending throughout most of the length of the Second Branch mainstem, sediments tend to be fine and depositional features are highly transient. Data collection for the Second Branch mainstem in 2019 included paddling much of the mainstem downstream of East Brookfield (from reach M14 down) during early summer to take advantage of moderate flow levels. While efforts were made to subsequently verify depositional features, these may be somewhat under-reported for this portion of the mainstem.

The protocols developed for Stream Geomorphic Assessment in Vermont base stream typing on a combination of Rosgen and Montgomery-Buffington classification systems (VT-RMP_ApxI 2004). Under this system, braided rivers are assumed to be highly depositional and may not account for smaller, low gradient and multi-threaded channels as a reference type (Walter and Merritts 2008). This is an evolving area of exploration regarding effective stream restoration that is highly applicable to dynamics along the Second Branch, and it is highly recommended that floodplain restoration projects in this basin consider recent developments in this area as part of project scoping. This is particularly important in considering historic sedimentation behind dams, which appear to play a large role in current stream dynamics in portions of the Second Branch mainstem extending downstream from North Randolph.

Based on the above factors, Phase 1 stream typing along the Second Branch mainstem, particularly in regards to distinguishing between reference C and E stream types, should be considered with some latitude – but the vast majority of the Second Branch mainstem reaches are low gradient and primarily only differ in degree of valley and floodplain confinement.

Due to low elevational gradients along the mainstem no alluvial fans were attributed to these reaches, but due to Lake Hitchcock influences (post-glacial deltaic deposits at edges of the Lake) fans at the bases of tributaries notably influence dynamics in M01, M03, M07, M11 and M16.

## 5.0 RESULTS

The following sections summarize pertinent results of Phase 1 and 2 SGA data collection in the Second Branch watershed. Stressor, departure, and sensitivity maps are presented as a means to integrate data that have been collected and show the interplay of watershed and reach-scale dynamics. These maps help identify and prioritize practical restoration and protection actions that can move the river toward a healthy equilibrium (Kline 2010). Single page (8.5 x 11 in.) maps are included with the text for ease of reference in regards to the text; larger maps can be found in Appendix 7.

Alterations to watershed-scale hydrologic and sediment regimes can profoundly influence reach-scale dynamics, and greater understanding of these processes is vital to increasing the effectiveness of protection and restoration efforts at a reach level (Kline 2010). Section 5.1 presents an analysis of stream departure from reference conditions. **Sections 5.1.1 and 5.1.2 summarize watershed-scale stressors** contributing to current stream conditions. Two points are important to keep in mind in using these maps:

1) The watershed-scale maps attempt to convey patterns rather than details; more detailed impacts appear in the reach maps in section 6.0, *Project identification.*
2) A "zoomed in" map (such as the reach maps in section 6) is easier to read in some respects, but does not fully capture indications of watershed-scale alterations. Because fluvial geomorphic processes often unfold over decades, the "bigger picture" relationships are critical to understanding how upstream processes (either historic or current) affect what may be happening further upstream and/or downstream.

**Sections 5.1.3–5.1.6 characterize reach-scale stressors**. Section 5.1.7 characterizes the hydrologic and sediment regime departures for reaches included in Phase 2 assessment within the Second Branch watershed. Section 5.2 presents a sensitivity analysis of these reaches, indicating the likelihood that a stream will respond to a watershed or local disturbance or stressor as well as an indication of the potential rate of subsequent channel evolution (VT-RMP 2009, Phase 2, Step 7.7; Kline 2010, Section 5.2).

Data used for the analyses can be found in the appendices. Reach/segment summary statistics and channel geometry data are found in Appendix 1. Phase 1 observations, assembled at a reach scale, are summarized in Appendix 2. Reach/segment scale data from Phase 2 fieldwork are provided as summary sheets in Appendix 3. Plots of channel cross sections are found in Appendix 4. Appendix 5 includes Quality Assurance review notes. Appendix 6 is a consolidated list of projects identified in Chapter 6. Appendix 7 contains 11x17 in. maps for analysis (Chapter 5 maps). Appendix 8 contains the results of bridge and culvert assessments for structures located on Phase 2 reaches.

## *5.1 DEPARTURE ANALYSIS*

### *5.1.1 Hydrologic regime stressors*

The hydrologic regime involves the timing, volume, and duration of flow events throughout the year and over time; as addressed in this section, the regime is characterized by the input and manipulation of water at the watershed scale. When the hydrologic regime has been significantly changed, stream channels will respond by undergoing a series of channel adjustments. Where hydrologic modifications are persistent, an impacted stream will adjust morphologically (e.g., enlarging through either downcutting or widening when stormwater peaks are consistently higher) and often result in significant changes in sediment loading and channel adjustments in downstream reaches (Kline 2010). In the Second Branch basin the mainstem has become primarily a single thread channel, incised in numerous locations and widening through lateral bank erosion in numerous others, in response to hydrologic alterations.

Hydrologic modifications in the Second Branch basin have largely been related to the **manipulation** of water through damming, historic channel straightening, and ditching of agricultural fields and attendant wetlands, notably in the mainstem valley. In addition, a widespread road network contributes to channel straightening and restriction of floodplain access in the narrow valleys of many of the tributaries along steeper valley sidewalls.

Historical clearing initially contributed to higher runoff of both water and sediment (USDA-FS 2001). As in much of Vermont, the Second Branch basin was heavily deforested during the 19th century, with "sweet" soils in this area leading to particularly heavy agricultural development (Thompson et al 2019, pp.23-24, 71, 74-75; Randolph 2019, p.4). While this situation tended to diminish with reforestation, it is likely that the initial downcutting and transport of sediment out of uplands extended the stream network, initiating or furthering channel formation in areas that formerly had a broader absorptive base, and deposited thick layers of sediment in the valleys.

During a similar timeframe there was a proliferation of milldams along many of the streams of the region (Beers 1869; Beers 1877; Walter and Merritts 2008; Fig. 11). These dams served to trap significant amounts of the sediments from upstream, through which later incision cut single thread channels (Fig. 12). Extensive research in a similar setting for streams in the Pennsylvania and Maryland Piedmont region indicates that,

"before European settlement, the streams were small anabranching channels within extensive vegetated wetlands that accumulated little sediment but stored substantial organic carbon. Subsequently, 1 to 5 meters of slackwater sedimentation, behind tens of thousands of 17th- to 19th-century milldams, buried the presettlement wetlands with fine sediment. These findings show that most floodplains along mid-Atlantic streams are actually fill terraces, and historically incised channels are not natural archetypes for meandering streams." (Walter and Merritts 2008)

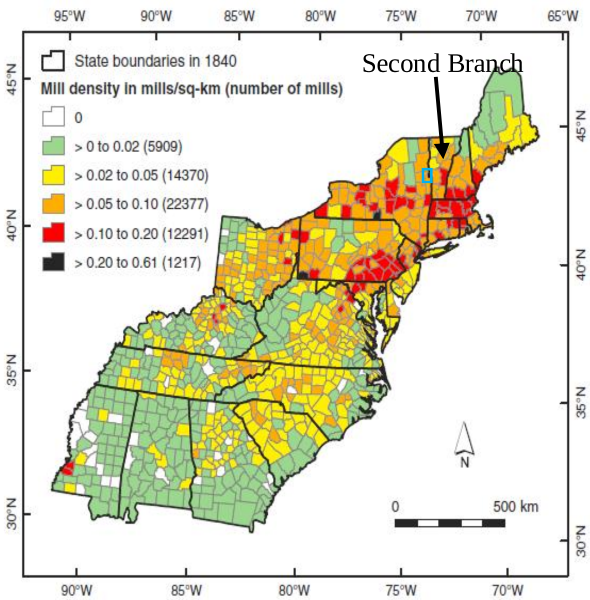



**Fig. 1.** Density of water-powered mills along eastern U.S. streams by 1840 by county (872 county boundaries are shown for 1840). The highest densities are in the Piedmont and the Ridge-and-Valley physiographic provinces of Maryland, Pennsylvania, New York, and central New England.

**Figure 11. Map of historic milldam density in eastern US, from Walter and Merritts (2008).**

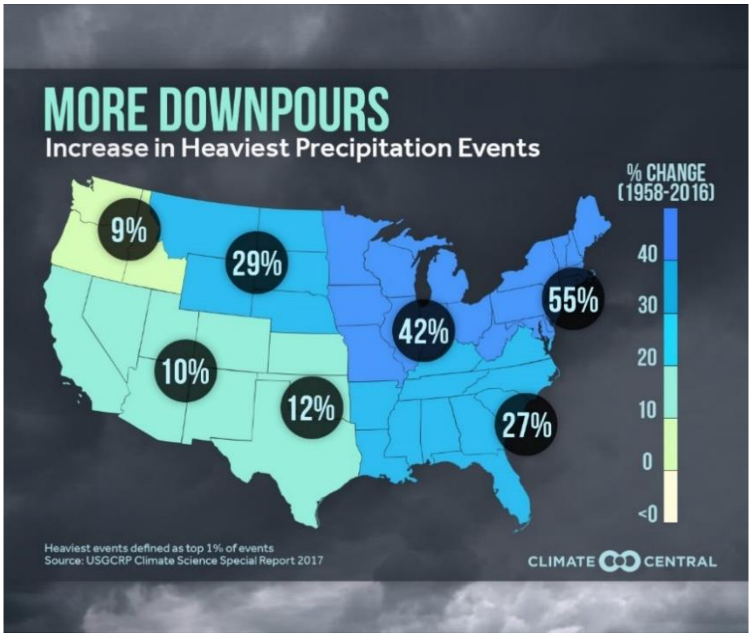

**Figure 12. Small, anabranching channels and extensive vegetated wetlands like those in currently beaver-occupied portions of reaches M16 and M17 (left) are likely closer to pre-European settlement conditions along much of the Second Branch than the incised single-thread channel in M03 (right), upstream of the now-removed Stoughton Mills/Royalton-5 dam in North Royalton.**

Hydric soils in the basin that overlap with agricultural or developed lands, and are not indicated as current wetlands, frequently represent some of the lost wetland functions contributing to this change in stream morphology. Current morphology (frequently incised, single thread channel) along the mainstem is further influenced by numerous undersized bridges that contribute to maintenance of the channel in its current location and straightened planform.

“Sediment starving” above and consequent “hungry water” below dams, exacerbated by pulse flows, plus increased scour at undersized bridges, have contributed to downcutting and restriction of floodplain access – manipulation of water that has increased the erosive power of water contained in a deeper channel. The current single thread channel form along the majority of the mainstem of the Second Branch is likely in contrast with the current approximation of probable original reference conditions along much of the mainstem in the Second Branch basin: the multi-thread channels in beaver-dominated wetland complexes now most apparent in portions of reaches M16 and M17, near the headwaters of the Second Branch originating in the Brookfield-Williamstown Gulf (Walter and Merrits 2008; Cluer and Thorn 2014).

Historical documentation indicates that deforestation was extensive at the peak of sheep farming in the area, roughly 1840s-70s, likely on a rough par with overall estimations of 70% or more deforestation statewide (Thompson and Sorenson 2019; Cronon 1983; Landscape Change Program), but the basin was reforested relatively rapidly in the 20th century. The Second Branch watershed is roughly 77% forested today. Despite this relatively high degree of current forest cover, however, the historic legacy in the Second Branch basin contributes to a high degree of “flashiness” in the watershed. In narrow valleys where roads were added alongside the stream network, impervious surfaces and stormwater inputs increase the rate of discharges to adjacent streams. These alterations amplify “flashiness” in response to heavy precipitation events, delivering concentrated discharges in a shortened time frame, with frequent downcutting (and/or widening) in response to heightened discharges.

Although it appears rural due to diffuse settlement patterns, the (Northern and Southern) Vermont Piedmont biophysical region, which includes the Second Branch watershed, is a relatively densely “roaded” portion of Vermont (Thompson and Sorenson 2019, pp. 71, 75). Stormwater inputs from this road system are a significant contributor to hydrologic alterations, although much of the mainstem is distant enough from roads that these impacts were often not directly apparent in the Phase 2 assessment of the mainstem reported here. The mainstem (and entire stream network) is affected by these hydrologic stressors however, and mapping of “hydrologically connected roads” as part of the Municipal Roads General Permit enacted by Vermont (VT DEC-MRP 2018) is an explicit acknowledgement of, and effort to address, these impacts to stream dynamics and water quality. Bridge and culvert inventories compiled by towns, regional planning commissions, and contractors help clarify the widespread extent of these contributions (VTCulverts).




More recent changes to the hydrologic regime (last 60 years; Fig. 13) have influenced **inputs**, with a notably significant increase in localized, high intensity but short duration precipitation events manifesting as a series of flash flood events of increasing frequency since the turn of the 21st century in the Second Branch basin (see section 3.4.2, *Flood history*).

**Figure 13. Heavy precipitation events in the northeast US have increased significantly in the last 60 years.**

The Hydrologic Alterations map (Fig. 14) indicates these primary stressors commonly associated with stream channel adjustments (Kline 2010, pp. 26-27). While stormwater inputs are not directly portrayed, road density in the various subwatersheds of the basin gives a sense of where impacts are amplified. Dams and diversions are a hydrologic stressor primarily due to their contribution to legacy sedimentation and subsequent channel incision; flow regulations are relatively minor contemporary contributor to changes in water inputs, as the two remaining intact dams along the mainstem are both run-of-river. Crop land and "Urban" land use (primarily residential and small businesses in the Second Branch basin) are also relatively minor contemporary hydrologic stressors, but the Hydrologic Alterations map indicates areas where impacts are more elevated. These are primarily subwatersheds associated with more concentrated development in the small historic village settlements of the basin.

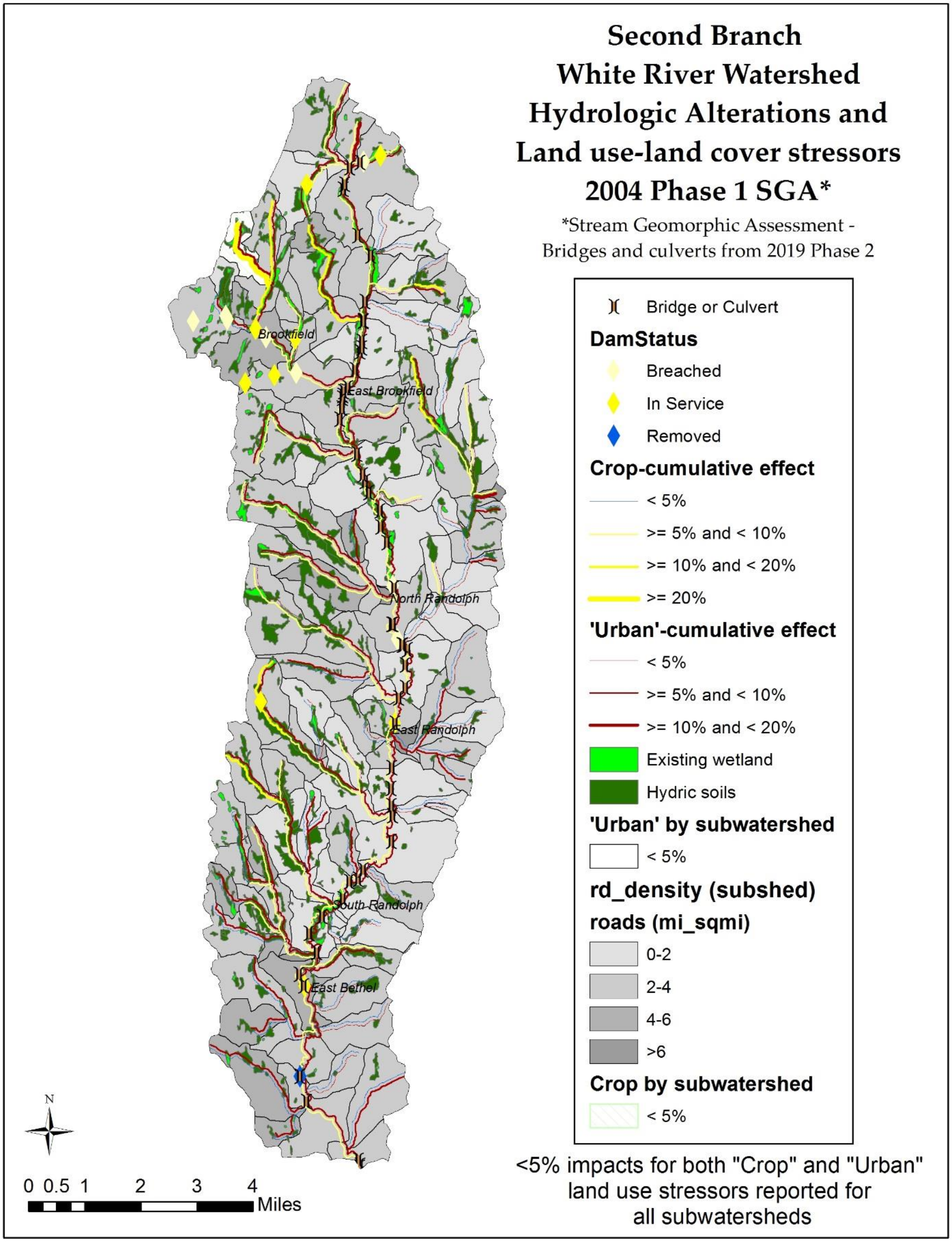



**Figure 14. Combined Hydrologic Alterations/Land Use Stressors Map of the Second Branch basin.**

### *5.1.2 Sediment regime stressors*

At a watershed scale, the Second Branch basin is a relatively high wash load system, with overall sediment transport volume mitigated primarily by a decent percentage of forest cover and stretches of relatively intact, vegetated wetlands. Large wood in channels and shrubs in some of the intact wetlands play a vital role in trapping and storing fine sediments as well as frequently enabling what floodplain access is available.

Along the Second Branch mainstem the sediment regime is closely tied to the preponderance of fine sediments left behind by glacial Lake Hitchcock. Even with areas influenced by gravel from kame terraces (reaches M01, M02, M08, M11) and valley train gravels (M14), every representative cross-section measured in Phase 2 assessment showed a cumulative particle distribution (D50) of sediments equivalent to fine gravel or smaller. With few grade controls present, the historically straightened, single thread channel has cut down into these fine sediments and exposed glacial lacustrine soils (especially downstream from reach M11 in North Randolph to the mouth in North Royalton) or buried former wetland soils in numerous areas, prominently in upstream reaches where beavers are active currently and were likely extensive pre-European settlement (Fig. 15).


**Figure 15. Left: Cohesive silty clays indicating lake bottom (glaciolacustrine) soils underlie coarser alluvial sediments backed up behind the former Stoughton Mills/Royalton-5 dam in reach M03. Right: Cohesive, mottled organic soils in reach M14 likely indicate former wetlands similarly overlain by alluvium but not impounded by a dam.**

With much of the current single-thread channel at least moderately incised, areas lacking wooded buffers are especially subject to erosion that is not being replenished by overbank flooding. These rich soils are largely being transported out of the watershed, and it is not uncommon to see sediment plumes entering the White mainstem from the Second Branch in hard rainstorms. These areas additionally lack raw materials to rebuild floodplain access or dampen stream power in moderately high floods. Erosion can accelerate when cohesive materials in the bed and lower banks, or coarser sediments washed in from tributaries, are more resistant than the banks.

"Sediment slugs" of coarser sediments from tributaries are moved slowly due to the low slope gradients along the mainstem. When these do move in larger flood events it is not uncommon for these slugs to divert high flows onto erodible banks, at times leading to channel avulsions and neck cut-offs. One of the best examples of these dynamics was the mouth of Snow's Brook in North Randolph (reach M11), which joins the mainstem just downstream of a former mill complex (VWRC 1921) with high volumes of very fine sediments upstream. Downstream of the mouth of Snow's Brook, the high banks along the un-buffered fields north of Ferris Rd. are indicative of fine sediments backed up behind another former dam impoundment by the Creamery in North Randolph (VWRC 1921). When a sediment slug from Snow's Brook plugged the main channel (Fig. 16), water rapidly cut through the fine bank sediments to cause a sudden neck cut-off.


**Figure 16. Sediment plug from Snow's Brook led to rapid neck cut-off through former dam-impounded fine sediments in segment M11-B.**

A short distance downstream, fine sediments impounded by the same former dam were being eroded rapidly along a valley sidewall, possibly due to a small tributary diverted by road ditching and culverts along Ferris Rd. (Fig. 17; needs further investigation).


**Figure 17. Eroded fine sediments from former dam impoundment in segment M11-B near Ferris Rd. were traced back to this headcut, possibly due to diversion of a small tributary (needs further investigation).**

Sediment load along the mainstem thus largely features fine particles contributing to high levels of transitory, unstable depositional features such as mid-channel bars, point and side bars, and areas of "braiding". These features appear to largely indicate the effects of channel widening and planform adjustments, with high amounts of post-glacial alluvium throughout the system. Historic floodplain access is restricted in most areas, so low velocity conditions for fine sediments to drop out have notably occurred at dams and undersized stream crossings and similar channel constrictions. Numerous locations had high volumes of very fine sediments related to transitory beaver dams likely busted in recent flash floods (July 1, 2017, April 15, 2019).

A limited number of coarser sediments derive from a few kame terraces along the mainstem channel, but primarily derive from eroded roads and ditches, as well as incised channels themselves, along steep sidewall tributaries that have been stripped in flash flood events (Fig. 18).

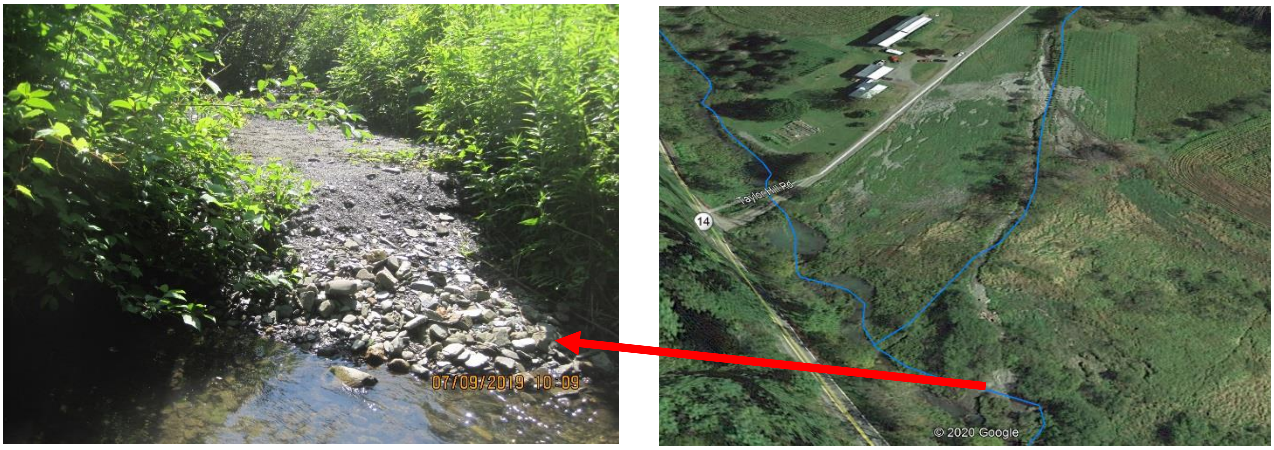



**Figure 18. Coarse sediments entering the Second Branch in M16-B appeared to be related to repeat flood discharges along Taylor Hill Rd., deposited in an alluvial fan at the base of the stream off the steep valley sidewall.**

The following description of issues related to the sediment regime is taken from the most current version of the VT ANR River Corridor Planning Guide (VT ANR 2010):

> The sediment regime may be defined as the quantity, size, transport, sorting, and distribution of sediments…. 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…
>
> …. During high flows, when sediment transport typically takes place, small sediments become suspended in the water column. These wash load materials are easily transported and typically deposit under the lowest velocity conditions, which exist on floodplains and the inside of meander bendways at the recession of a flood. When these features are missing or disconnected from the active channel, wash load materials may stay in transport until the low velocity conditions are encountered…. This … unequal distribution of fine sediment has a profound effect on aquatic plant and animal life. Fine-grained wash load materials typically have the highest concentrations of organic material and nutrients.
>
> Bed load is comprised of larger sediments, which move and roll along the bed of the stream during floods…. The fact that it takes greater energy or stream power to move different sized sediment particles results in the differential transport and sorting of bed materials…. When these patterns are disrupted, there are direct impacts to existing aquatic habitat, and the lack of equal distribution and sorting may result in abrupt changes in depth and slope leading to vertical instability, channel evolution processes, and a host of undesirable erosion hazard and water quality impacts.

Evolving research indicates that fine-grained wash load materials not only have high levels of organic material and nutrients, but are correlated with high *E. coli* bacteria levels as well (Stocker et al 2018). White River Partnership's long-term water quality monitoring program has indicated consistently elevated *E. coli* bacteria levels on portions of the First, Second and Third Branches, and these were listed for impairment starting in 2016 (VT DEC WQD 2018). The two highest level sites in the monitoring program (throughout the larger White River basin) over time have been at Dugout Rd. (Second Branch reach M06) and near the mouth of the Second Branch (reach M01). White River Partnership continues to probe the role of fine sediments in these bacteria readings, as well as intermittent elevated nutrient levels (VT DEC WMD 2018).

The high volume and frequent transport of fine sediments in the Second Branch basin are a prominent factor in the overall sediment regime of the watershed. Just three reaches (M01, M15 and M17, which has frequent bank armoring) showed low levels of erosion on both banks; all other reaches had moderate to high levels of erosion on at least one bank (Table 7). Erosion levels were generally higher in areas downstream of reach M12, where mill legacy sediments and glaciolacustrine soils are more prominent.

**Table 7. Levels of erosion on reaches assessed during 2019 Phase 2 assessment on the Second Branch**

| Stream segment | Left bank erosion (% of length) | Right bank erosion (% of length) |
|---|---|---|
| M01 | <5% | <5% |
| M02 | >5% <=20% | <5% |
| M03 | >5% <=20% | >20% |
| M04 | >5% <=20% | >5% <=20% |
| M05 | >5% <=20% | >5% <=20% |
| M06 | >20% | >20% |
| M07 | >5% <=20% | >5% <=20% |
| M08 | >5% <=20% | >5% <=20% |
| M09 | >5% <=20% | >5% <=20% |
| M10 | >20% | >20% |
| M11-A | >5% <=20% | <5% |
| M11-B | >20% | >20% |
| M11-C | <5% | >5% <=20% |
| M12 | >5% <=20% | >5% <=20% |
| M13 | >5% <=20% | >5% <=20% |
| M14 | >5% <=20% | >5% <=20% |
| M15 | <5% | <5% |
| M16-A | <5% | >5% <=20% |
| M17-A | <5% | <5% |
| M17-B | <5% | <5% |

With production and transport of fine sediments and the dynamics of coarser sediment slugs in mind, the Sediment Load Indicators Map (Fig. 19) includes locations of both present and former dams in the basin.

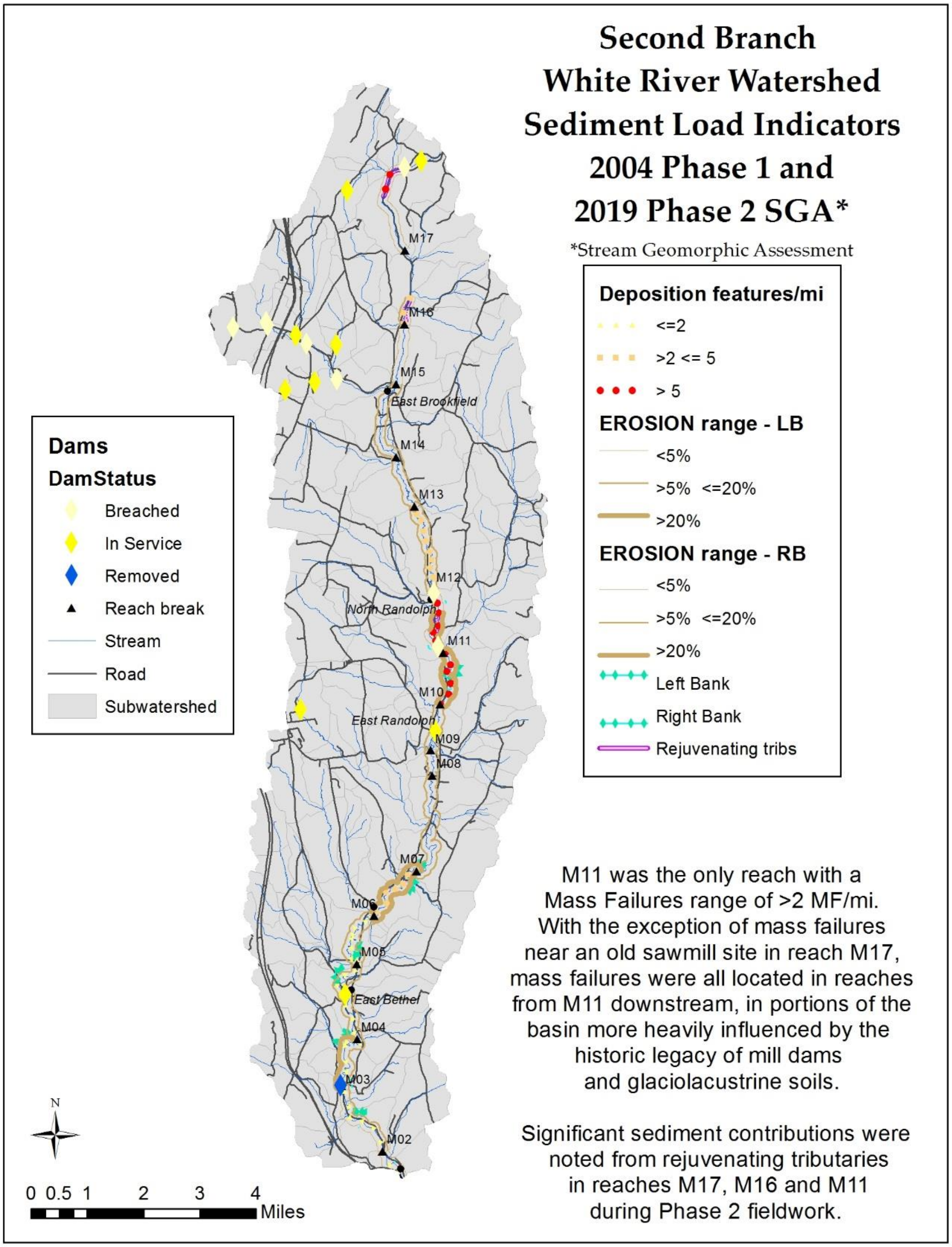



**Figure 19. Sediment load indicators map for the Second Branch basin.**

The hydrologic and sediment load watershed-scale stressors described above form a hierarchical pretext for understanding the timing and degree to which reach-scale modifications are contributing to field-observed channel adjustments (Kline 2010). Modifications to the valley, floodplain, and channel, as well as boundary (bank and bed) conditions, can change the hydraulic geometry, and thus change the way sediment is transported, sorted, and distributed (Table 8). Phase 1 and Phase 2 assessments provide semi-quantitative datasets for examining stressors and their effects on sediment regime when channel hydraulic geometry is modified.

| | | **Sediment Transport Increases** | **Sediment Transport Decreases** |
|---|---|---|---|
| | **Stream power as a function of:** | **Stressors that lead to an increase in power** | **Stressors that lead to a decrease in power** |
| **Energy Grade** | **Slope** | • Channel straightening,<br>• River corridor encroachments,<br>• Localized reduction of sediment supply below grade controls or channel constrictions | • Upstream of dams, weirs,<br>• Upstream of channel/floodplain constrictions, such as bridges and culverts |
| **Energy Grade** | **Depth** | • Dredging and berming,<br>• Localized flow increases below stormwater and other outfalls | • Gravel mining, bar scalping,<br>• Localized increases of sediment supply occurring at confluences and backwater areas |
| **Boundary Conditions** | **Resistance to power by the:** | **Stressors that lead to a decrease in resistance** | **Stressors that lead to an increase in resistance** |
| **Boundary Conditions** | **Channel bed** | Snagging, dredging, windrowing | Grade controls and bed armoring |
| **Boundary Conditions** | **Stream bank and riparian** | Removal of bank and riparian vegetation (influences sediment supply more directly than transport processes) | Bank armoring (influences sediment supply more directly than transport processes) |

**Table 7: Reach level stressors: relationship of energy grade and boundary conditions in sediment transport regime (Kline 2010).**

Channel Slope and Depth Modifier Maps (Sections 5.1.2a and b, respectively) can be used to determine whether stream power has been significantly increased or decreased. A Channel Boundary and Riparian Modifiers Map (Section 5.1.2c) can help explain whether the resistance to stream power has been increased or decreased. The analysis here portrays general contributions of these features to stream dynamics, but the specific features are decidedly reach-scale, rather than watershed-scale, stressors. Primary stressors in each reach are thus noted in sec. 6 for Project Identification.

### *5.1.2a Channel slope modifiers*

Analysis of channel slope modifiers along the Second Branch mainstem indicates that channel straightening is the predominant stressor, with indications of straightening observed in at least some portion of every reach except M08 (Fig. 20).

Channel straightening occurred historically through direct channel manipulation to supply mills in downstream portions of the mainstem, and through agriculture related ditching and channelization along much of the mainstem. In addition, 56 bridges and

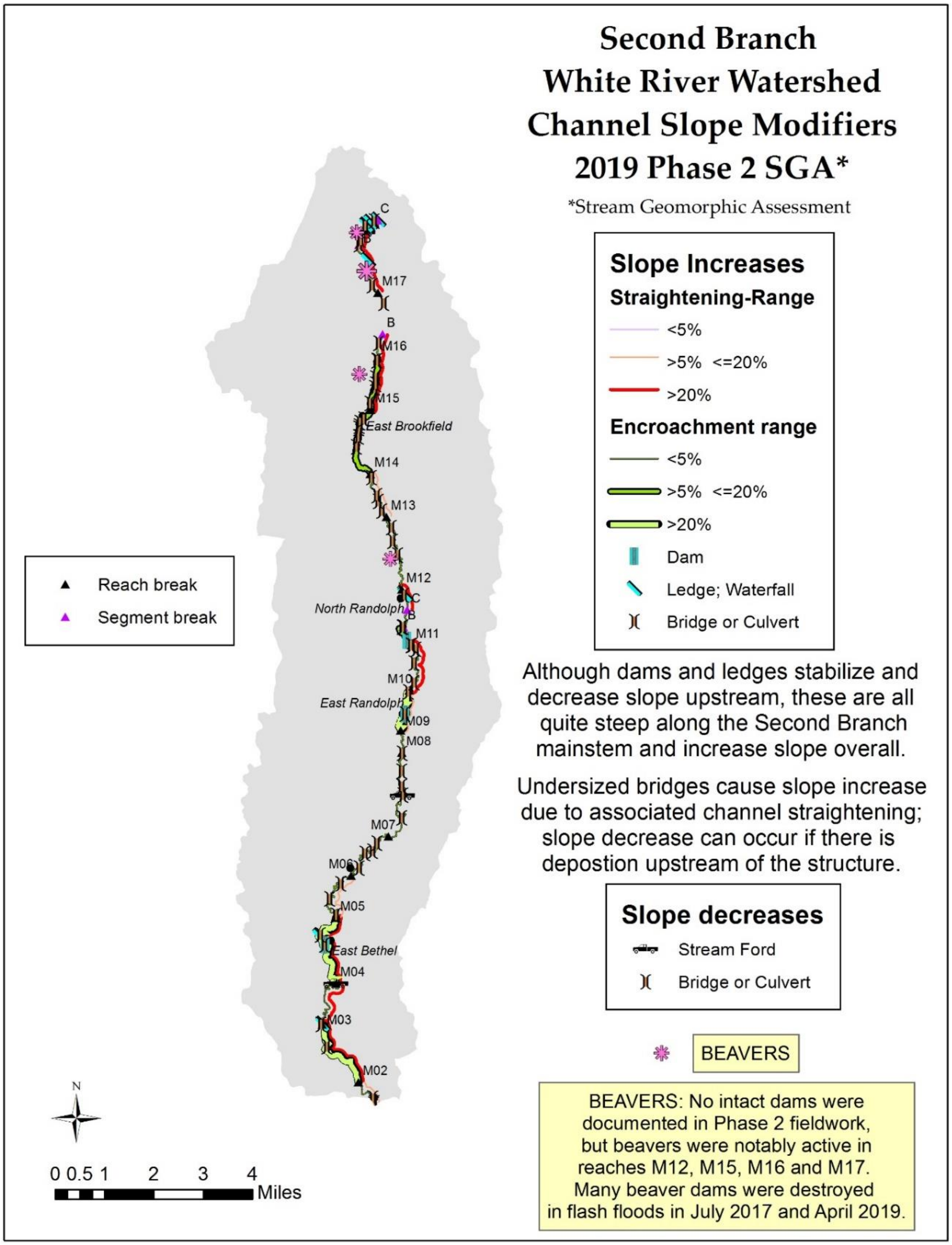



**Figure 20. Channel Slope Modifiers map for the Second Branch mainstem.**

culverts were documented along the mainstem in 2019 fieldwork (31 were privately owned structures: farm bridges, snowmobile bridges, private driveways). Many of these are situated in the valley in such a way as to help maintain the stream against a valley wall or road embankment (especially along VT-14, the main north-south highway that parallels the Second Branch along much of its length), or to help channel the stream across the valley. The majority of these structures pre-date 2014 changes to Vermont's stream crossing standards that began requiring most structures to be a minimum of bankfull width, and these undersized structures frequently contribute to extensive scour, channel incision and erosion in the fine sediments of this valley.

Channel straightening can heighten stream power when slope increases occur as a stream loses its meanders (similar to putting a driveway straight up a steep slope rather than installing switchbacks). In areas with erodible bed materials, elevated stream power may contribute to bed downcutting (channel incision) that further enhances stream power and sediment transport capacity as a result of the increased slope and depth at flood stage. The combined effects of culvert and bridge impacts (measured as visual assessment of channel length affected by dynamics associated with the structure during field assessment) and other channel straightening are significant (Table 9).

| Reach/Segment | Bridge/ Culvert Count | Pct. length impacted by stream xings | Pct. length straightened |
|---|---|---|---|
| M01 | 3 | 52.93% | 20.36% |
| M02 | 1 | 7.84% | 26.42% |
| M03 | 1 | 9.17% | 25.06% |
| M04 | 2 | 7.63% | 32.18% |
| M05 | 3 | 15.31% | 8.34% |
| M06 | 4 | 10.44% | 0.00% |
| M07 | 5 | 12.22% | 0.00% |
| M08 | 0 | 0.00% | 0.00% |
| M09 | 2 | 10.71% | 13.75% |
| M10 | 4 | 10.20% | 33.21% |
| M11-A | 3 | 24.70% | 0.00% |
| M11-B | 0 | 0.00% | 4.93% |
| M11-C | 1 | 20.86% | 94.77% |
| M12 | 3 | 5.55% | 0.00% |
| M13 | 4 | 16.78% | 15.26% |
| M14 | 6 | 10.82% | 0.00% |
| M15 | 6 | 43.79% | 45.34% |
| M16-A | 1 | 34.18% | 32.58% |
| M16-B | 1 | 10.00% | 0.00% |
| M17-A | 1 | 7.93% | 59.97% |
| M17-B | 4 | 98.04% | 61.97% |

**Table 8: Combined effects of channel straightening and bridge/culvert impacts (which contribute to additional straightening) on Second Branch mainstem reaches. Color coding corresponds to impact ranges on Channel Slope Modifiers map (<5%, ≥5% ≤20%, >20% of reach).**

Additional impacts contributing to straightening (and thereby increasing slope) include:

- road and development encroachments (prominent in M02, M04, M09, M11-A, M14, M15);
- structural measures such as riprap and bank toe stabilization (M04, M07, M08, M09, M10, M15, M16, M17);
- less direct maintenance of the channel "in its place" through field cultivation and ditching (portions of every mainstem reach); and
- remediation of flood damage through windrowing of stream sediments, removal of debris jams, and channel "clean-outs" in the areas of bridges and culverts damaged in floods and subsequently repaired or replaced (widespread and common).

A recent of example of these type of impacts was evident in segment M17-B, where windrowed sediments were helping channel the stream against the valley wall and away from a multi-threaded, beaver influenced wetland area (Fig. x). It appeared that more recent flooding (April 2019) in the same location had broken part of the berm created previously, and higher flows (>75% on long-term flow duration curve) may now re-access the wetland area.


**Figure 21. Windrowed sediments below a steep ledge drop (jammed against the side of Rte. 14 in the Brookfield-Williamstown Gulf) funnel the stream toward the valley wall and away from a multithread beaver area. April 2019 flooding appeared to have broken part of the berm, allowing high flows at least to once again access the wetland.**

Although no intact beaver dams were noted in 2019 fieldwork, beaver-dominated areas offer the most prominent reductions in slope along the Second Branch mainstem, notably through the presence of multi-thread channels. Although the intact Gulf Road (base of VT-66 at VT-14 in East Randolph) and Hyde (East Bethel village) Dams present slope reductions just above the dams, the channel straightening associated with them and the sediment starving below the dams have created slope increases and channel incision that offset the effect of these slope reductions.

Similarly, slope reductions caused by sediment deposition upstream of undersized bridges and culverts is comprised largely of very fine sediments. Associated channel straightening, bank armoring and constriction effects of abutments at these structures largely offsets the slope reductions, as evidenced by frequent scour impacts and heightened sediment transport in their vicinity.

Overall, the predominant slope modifications of the current, largely single-thread channel along the Second Branch mainstem thus trend heavily toward a steeper slope than would be present under reference conditions, increasing overall sediment transport and erosion dynamics.

### *5.1.2b Channel depth modifiers*

As noted in several portions of this analysis, the current single-thread, largely incised channel of the Second Branch along much of the mainstem is very different from likely pre-European settlement (and undammed) reference conditions characterized by multi-thread channels and extensive vegetated wetlands. As such, the most prominent depth modification along the mainstem is depth increases due to the containment of moderate to high level flood flows within the channel rather than accessing channel adjacent floodplains or anabranching channels. This is particularly amplified in the vicinity of the 55 stream crossings along the mainstem, many of which are significantly undersized (in comparison with the bankfull channel width) and feature substantial concrete abutments.

Road encroachments along the Second Branch are primarily due to the presence of a major thoroughfare, VT-14, that parallels the mainstem for virtually its entire length, though often being distant from the road in broader portions of the valley (Fig. 22). Depth increases due to road encroachment are most notable in the villages of North Royalton, East Bethel, East Randolph, and East Brookfield, and were particularly evident in reach M17 where the road occupies a majority of the former stream valley passing through the Brookfield-Williamstown Gulf. Bank armoring was prominent in these areas due to road-stream conflicts exacerbated by the enhanced stream power of these elevated depths.

Depth increases due to stormwater appear minimal along the mainstem, though flash flood impacts from tributaries were noted and may be effectively extending the stream network through incision in narrow valleys shared by roads (see discussion regarding Hydrologic Alterations in sec. 5.1. above). Field ditch outlets were not always evident in the field, but no signs of active field drain tiles were noted and overall levels of stormwater inputs never reached ‘high’ thresholds of >5 inputs/mile. Only three reaches or segments (M13, M15, M17-A) had moderate levels of 2-5 inputs/mile.

Less common modifiers toward decreased channel depths along the Second Branch were most evident in areas of beaver activity, accompanied by multi-thread channels, primarily in upstream reaches M16 and M17. Although depth decreases were also noted at three stream fords (M04, M07, and M17) the gravels and small cobbles present appear to be subject to erosion and make these likely to be subject to ongoing maintenance. Sediment retention at the intact Hyde Dam (M04) and Gulf Road Dam (M09) also offset what would likely be significantly deeper flows upstream of these structures.

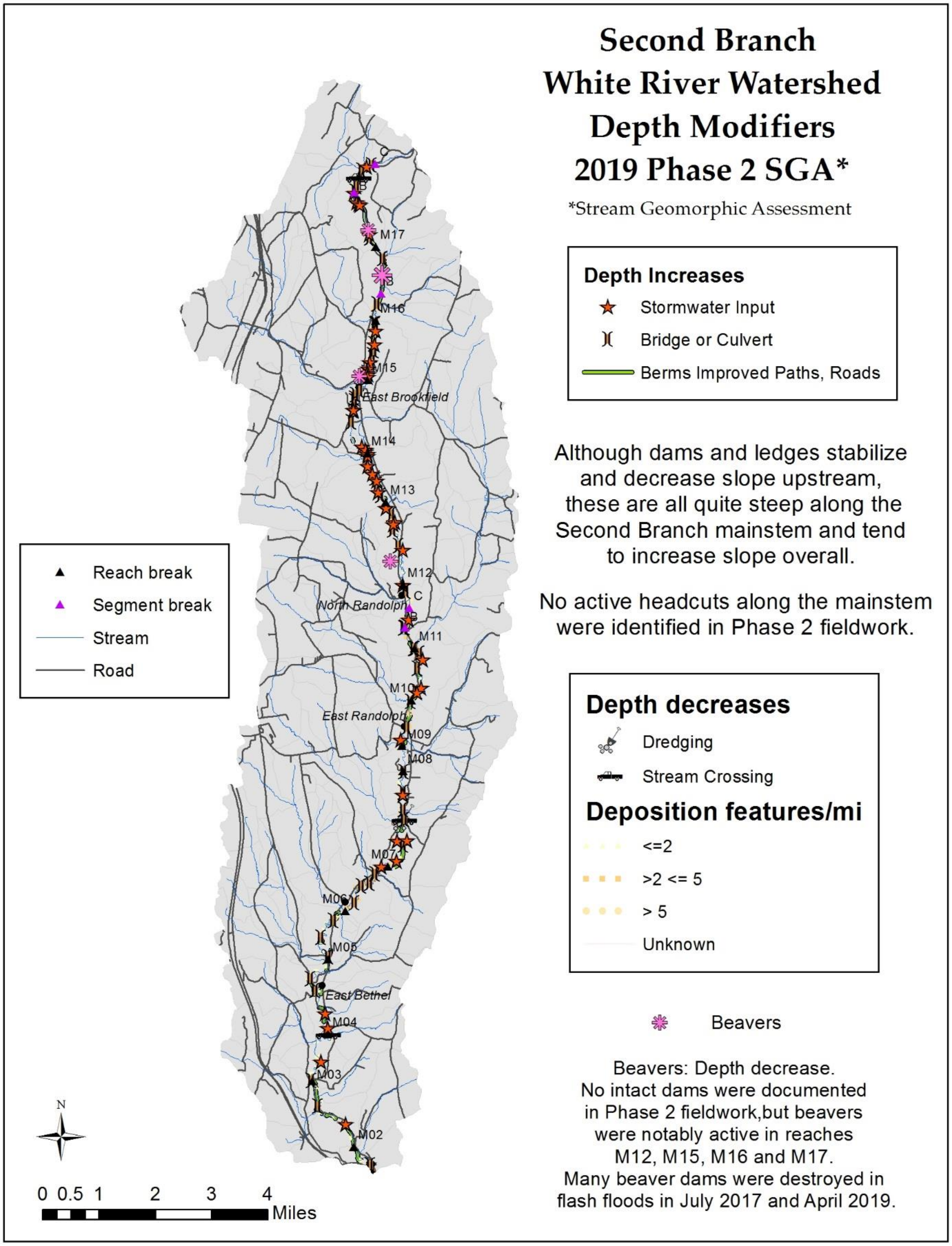



**Figure 22. Channel Depth Modifiers Map for the Second Branch mainstem**

### *5.1.2c Boundary condition and riparian modifiers*

Stream boundaries include bed and banks, and are strongly affected by the underlying geology and the state of buffer vegetation in the riparian corridor. Root systems from woody vegetation (and, to a lesser extent, herbaceous vegetation) help bind stream bank soils and diffuse stream power. The Second Branch mainstem is remarkable for its lack of evident widespread natural grade controls (Fig. 23). Evident grade controls are very widely spaced, though half (4 of 8)

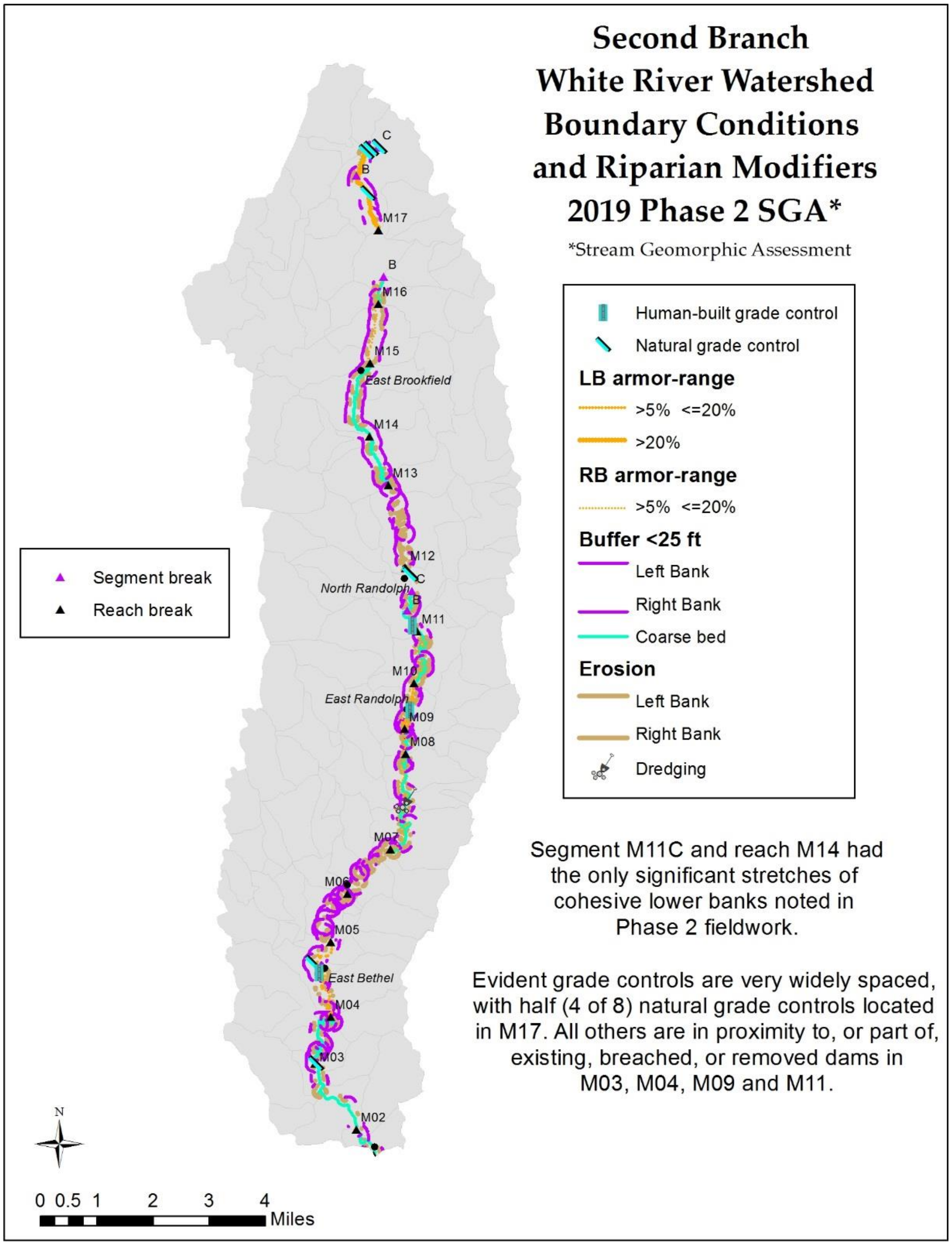



**Figure 23. Boundary Conditions and Riparian Modifiers Map for the Second Branch mainstem.**

of the natural grade controls are located in reach M17 in the Brookfield-Williamstown Gulf. All others are in proximity to, or part of, existing, breached, or removed dams in M03, M04, M09 and M11. In combination with the fine sediments left behind by glacial Lake Hitchcock, this scarcity of grade controls leaves the bed of much of the mainstem subject to rapid incision (downcutting), but also frequently finds these impacts quickly offset by deposition of mobile sediments from nearby banks or further upstream.

Coarse bed sediments were found in more than half (12 of 22) of the reaches and segments along the mainstem, but "coarse" is a relative term including gravel and larger sediments. None of the representative cross-sections measured in Phase 2 had a cumulative distribution D50 sediment size larger than fine gravel, and the rare areas where cobble and larger sediments were observed were generally due to flash flood impacts from steep tributaries or areas of failed rip-rap or other bank armoring. With the low slope gradients along the Second Branch contributing to a generally low-energy sediment transport system along the mainstem, these larger sediments are primarily moving only in higher level floods and typically as "sediment slugs" that amplify localized transfer of stream power to enhance bank shear.

Due to a combination of the fine soils left behind by glacial Lake Hitchcock and significant deposition of alluvial soils behind dams and other channel constrictions, banks along the mainstem tend to be even more erodible than the bed. These soils tend to be deeper, and exposed banks higher, upstream of the dams – but pronounced incision downstream of the dams is also clearly evident in the fine soils along the mainstem (Fig. 24; Walter and Merritts 2008).


**Figure 24. Highly erodible banks comprised of alluvial and glaciolacustrine soils upstream of the former Creamery dam in North Randolph (left) and downstream of the Gulf Road dam in East Randolph (right).**

These exposed banks are particularly susceptible to erosion during freeze/thaw cycles, and emerging research has documented significant soil and nutrient export in winter (Walter et al 2018).

These factors make it remarkable that every reach and segment along the mainstem had significant portions (more than 25% of total length along at least one bank) lacking a woody vegetated buffer of at least 25 ft. width. Some of these areas are due to road encroachments that present difficult planting conditions or conflicts with maintenance of infrastructure, but establishing and maintaining good wooded buffers generally can help stabilize stream banks, physically diffuse stream power in high flows, reduce maintenance costs or needs for armoring and similar practices, and help provide woody materials vital to stream dynamics in a system like this. The current single thread channel of the Second Branch is incised in many areas and has restricted floodplain access; stream bank erosion is not being replenished by overbank flooding, and is exporting fine sediments and associated nutrients. Large woody debris from wooded buffers can also help retain fine sediments within the watershed, maintain or rebuild access to floodplain, and moderate slope changes, and was playing a notable role in doing this in portions of reaches M01, M08, M12, M16-A and M17-B.

“High” levels (>20% of reach or segment length) of bank armoring were found in reach M17 (in and downstream of the Brookfield-Williamstown Gulf), and “moderate” levels (5-20% of reach or segment length) were found in reaches M04, M07, M08, M09, M10, M15, and segment M16-A – primarily along VT-14 and up and downstream of bridges and culverts. Although bank armoring can temporarily increase boundary resistance, it requires maintenance under the best of conditions. In the presence of the type of soils present along much of the Second Branch, it can require increased maintenance or proper installation costs, or be subject to increased risk of failure (Fig. 25). In addition, bank armoring frequently hinders of channel evolution processes (which might reduce slope or increase floodplain access), and transfer impacts (notably elevated stream power) to areas further downstream.


**Figure 25. Failing bank toe stabilization, concrete culvert headers, and granite slabs along Rte. 14 in M04 and M17 (top) and failed brush and tire revetments in M10 (bottom) indicate the installation and maintenance challenges of bank armoring in the soils along the Second Branch.**

Given the observed dynamics and impacts along the Second Branch it would be hard to overstate the benefits to be gained from adequate buffers along the mainstem.

### *5.1.3 Sediment regime departure, constraints to sediment transport, and attenuation assets*

Changes to hydrologic inputs and channel geometry along the Second Branch mainstem in particular (historically extended stream network, increase in heavy downpours, ditching and straightening, current frequently incised single-thread channel cut through fine sediments) have converted almost the entire mainstem to a sediment transport regime, with elevated erosion from widening stream banks. Deposition is primarily localized at channel constrictions and dams, and appears highly transient, or in beaver-influenced wetlands.

Within a reach, the principals of stream equilibrium dictate that stream power and sediment will tend to distribute evenly over time (Kline 2010; Leopold 1994). Changes or modifications to watershed inputs and hydraulic geometry create disequilibrium in the balance of these forces and lead to an uneven distribution of power and sediment (Fig. 26). Whether a project works with or against the physical processes at play in a watershed is primarily determined by examining the source, volumes, and attenuation of flood flows and sediment loads from one reach to the next within the stream network. If increasing loads are transported through the network to a sensitive reach, where conflicts with human investments are creating a management expectation, little success can be expected unless the restoration design accommodates the increased load or finds a way to attenuate the loads upstream (Kline 2010).

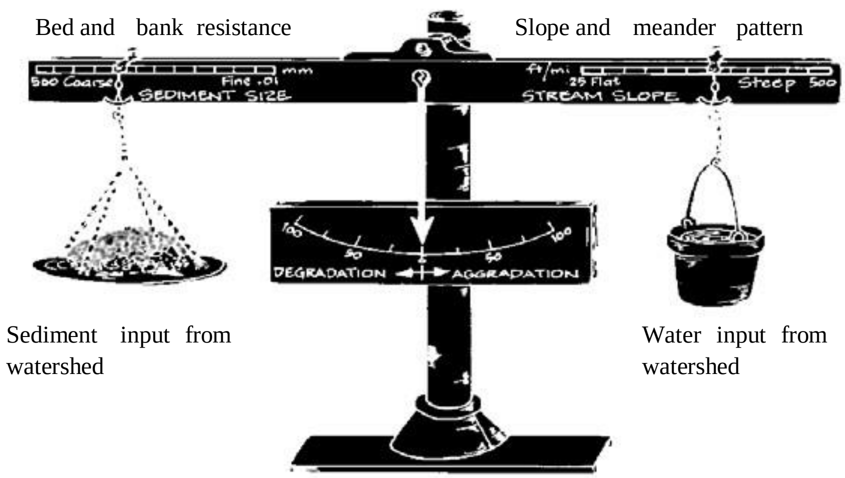



**Figure 26. The channel balance indicates how changes in watershed inputs influence channel adjustment processes (Lane 1955).**

When stream power and sediment are relatively balanced, streams located in narrower valleys on steeper gradients in a watershed (primarily A- and some B-type streams) tend to exhibit a "Transport" sediment regime, contributing minor amounts of various sized sediments to downstream reaches but not storing many sediments. Streams in wider valleys with lower slope gradients (primarily C- and E- type streams) provide for sediment storage in a dynamic balance with water moving through the system (in = out: i.e., stream power, which is produced as a result of channel gradient and hydraulic radius, is balanced by the sediment load, sediment size, and channel boundary resistance). Under reference conditions, these streams would provide for coarse particle equilibrium and fine sediment deposition at annual flood flows, largely on the floodplains and at bendways and meanders (Coarse Equilibrium and Fine Deposition sediment regime, Table 10; Kline 2010, p.43).

The legacy of glacial Lake Hitchcock in the confined valley of reach M02 along the Second Branch in North Royalton contributes to very highly erodible valley walls, making that reach an unusual 'Confined Source and Transport' reach even under likely reference conditions.

| **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. |
| **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. |

**Table 9: Pertinent characteristics for Phase 1 classification of reference sediment regimes on Second Branch mainstem reaches.**

Besides reach M02, M08 south of East Randolph village (and upstream of the Braley Covered Bridge) is the only reach that might have a Transport sediment regime under reference conditions (again due to a narrow valley, and borderline due to varying width of floodplain). Reach M17 near the Brookfield-Williamstown Gulf might also be a Transport reach, except that it is interspersed with several beaver-influenced wetland areas and broader valley areas in relatively short intervals between bedrock-controlled ledge runs, allowing for sediment deposition and flow attenuation through much of the reach under reference conditions.

*Sediment regime departures*

Due to incision through abundant fine sediments, especially in downstream reaches, Phase 2 assessment indicated that loss of floodplain access and channel straightening has converted roughly half of assessed reaches and segments to sediment transport regimes, leaving 10 of 22 reaches or segments with current Coarse Equilibrium and Fine Deposition sediment regimes (Fig. 27). Of these ten (M05, M06, M10 and upstream reaches from M12 through M17), many have significant lateral constraints to further channel evolution on at least one side of the channel, increasing the importance of protecting corridors from further encroachment or bank armoring on the opposite bank. Efforts to lock the channel into place on both sides will increase risks for further channel incision and subsequent widening, given a dearth of bed grade controls in all but reach M17 (Fig. 27).

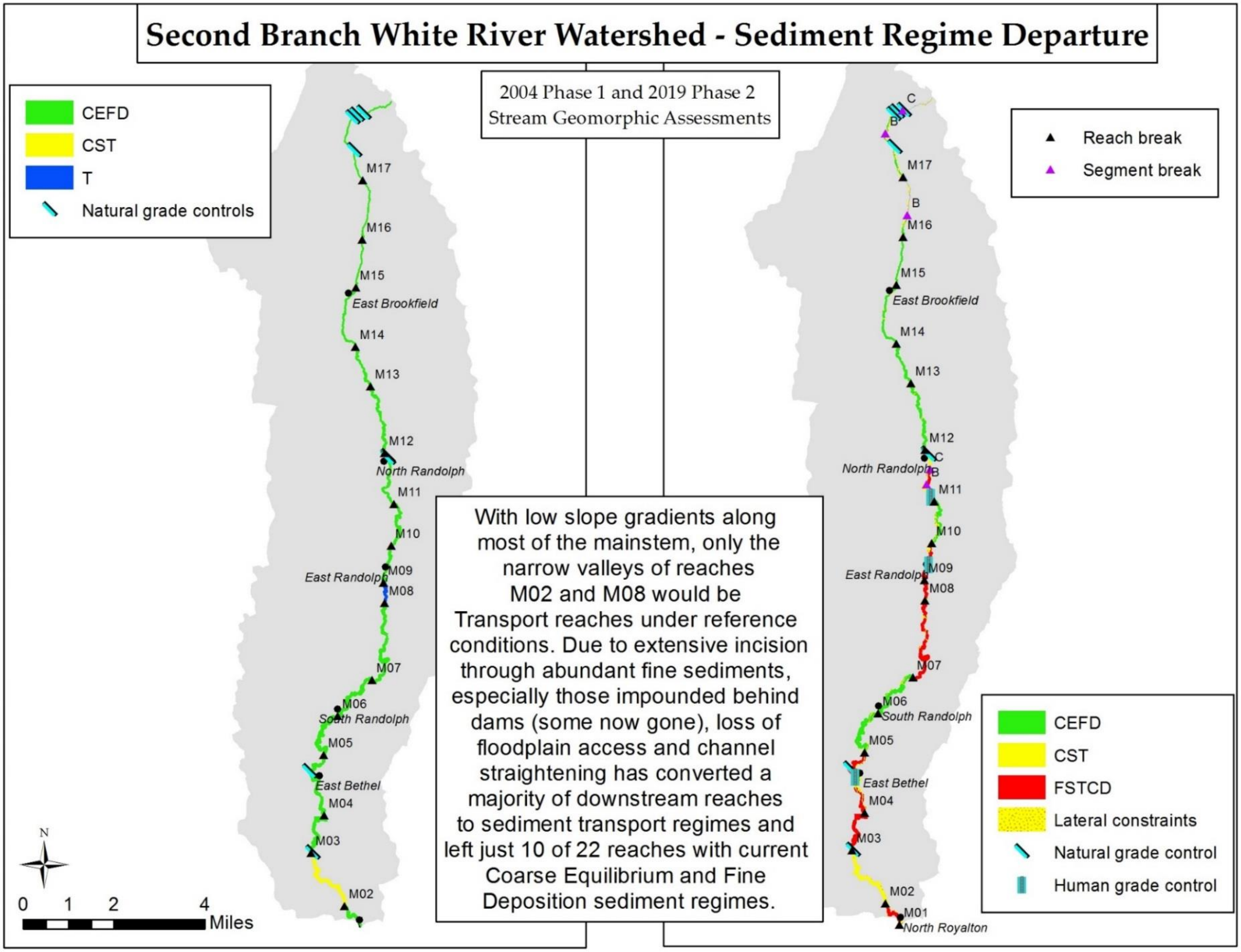



**Figure 27. Sediment Regime Departure Map for the Second Branch mainstem. See accompanying text for description of abbreviated sediment transport regimes.**

Phase 2 sediment regimes (which help identify current departures from reference conditions) are determined based on a number of parameters measured in rapid field assessments (Kline 2010, p. 44). These include signs of active adjustment processes indicating that streams are in a state of disequilibrium, including a likely stage of channel evolution (Table 11; criteria listed left to right in order of relative importance).

| **Sediment Regime** | Delimiting criteria related to sediment supply, transport, and storage | Stage of Channel Evolution, Geomorphic Condition | Common Existing Stream Type | Natural Valley Type |
|---|---|---|---|---|
| **Confined Source and Transport (CST)** | Incision ratio > 1.3 | Stage II-IV Fair-Good | A3, B3* | NC, SC, NW |
| | Incision ratio > 1.3 | Stage II-IV Fair-Good | A4, A5 B4*, B5* | Any Type |
| **Fine Source & Transport and Coarse Deposition (FSTCD)** | Bank armor < 50%<br>W/d > 30**<br>Incision ratio > 1.3 | Stage II-IV<br>Poor-Fair | E3, E4, E5<br>C3, C4, C5<br>B3c, B4c, B5c<br>F3, F4, F5 | NW, BD, VB |
| | Bank armor < 50%<br>Incision ratio > 1.3 | Stage II-IV Poor-Fair | D3, D4, D5 | NW, BD, VB |
| **Coarse Equilibrium (in = out) & Fine Deposition (CEFD)** | Incision ratio < 1.3 | Stage I -V<br>Fair-Good-Ref | D3, D4, D5 | NW, BD, VB |
| | W/d < 30<br>Incision ratio < 1.3 | Stage I -V<br>Fair-Good-Ref | C2, C3, E3 | NW, BD, VB |
| | W/d < 30<br>Incision ratio < 1.3 | Stage I -V<br>Fair-Good-Ref | C4, C5 E4, E5 | NW, BD, VB |

**Table 10: Pertinent parameters for characterizing existing sediment regimes along the Second Branch mainstem using Phase 2 data.**

*B streams with the slope of a C stream, or a Bc stream type, in an unconfined valley setting (NW, BD, VB) may be classed as either "unconfined source and transport" or "fine source and transport & coarse deposition" depending on other delimiting criteria.

When a stream has entered a state of disequilibrium, it will begin a series of channel adjustments or evolutions to fulfill the physical mandates of restoring equilibrium. This is the central message of Lane's balance: these channel adjustments are *physical mandates* triggered by changes to inputs or conditions of the stream, and adjustments continue until balance is restored.

Schumm (1977; Schumm et al 1984) has described five stages of channel evolution for reaches where the stream has a bed and banks that are sufficiently erodible to be shaped by the stream over time ("F-model" evolution; Fig. 28). The five stages of channel evolution for F-model evolution are paraphrased from the SGA protocols (VT-RMP_ApxC 2007) as follows:

**I. Stable** — In regime, reference to good condition. Insignificant to minimal adjustment; planform is moderately to highly sinuous.

**II. Incision** — Fair to poor condition, major to extreme channel degradation. High flow events are contained in the channel, and channel slope is typically increased.

**III. Widening/Migration** — Fair to poor condition, major to extreme widening and aggradation. (An incised, entrenched and widened channel is an "F-type stream", hence F-model evolution)

**IV. Stabilizing** — Fair to good condition, major reducing to minor aggradation, widening and planform adjustments

**V. Stable** — In regime, reference to good condition. Insignificant to minimal adjustment.
Channel Cross Section Plan View

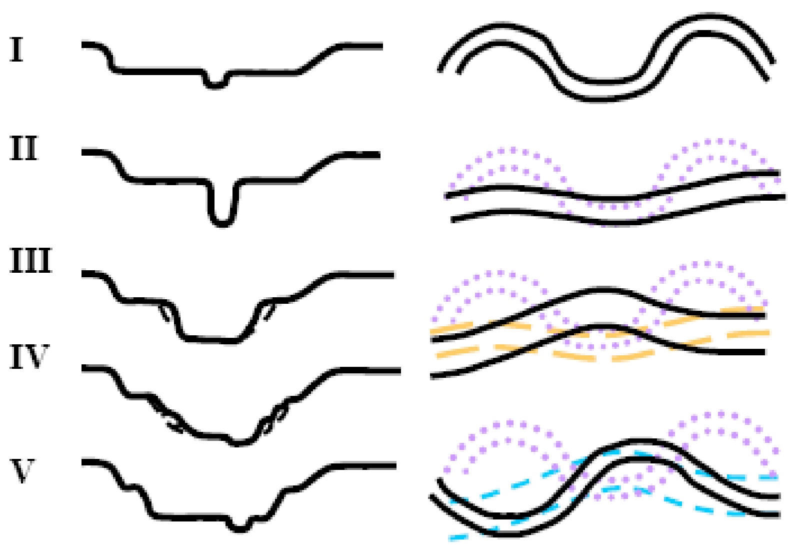



**Figure 28. Channel evolution process showing channel downcutting or incision in Stage II (cross section), widening through Stages III and IV, and floodplain reestablishment in Stage V. Stages I and V represent equilibrium conditions. Plan view shows straightening and meander redevelopment that accompany cross-section changes, a primarily flood-driven process often taking place over decades (VT-RMP_ApxC 2007).**

None of the stream segments fully assessed in 2019 along the Second Branch mainstem were deemed to be in a stable stage (stage I or stage V) of channel evolution (bear in mind that segments M16-B and M17-C were excluded from full Phase 2 geomorphic assessment due to extensive beaver presence and large ponds, per protocols; VT-RMP 2009). This is primarily due to historic straightening, ditching and channel snagging (removal of large woody debris from the channel) leading to channel incision and loss of planform. With so many fine sediments along the mainstem, however, channel incision is frequently offset quickly by subsequent deposition in scoured areas, typically through sediments from the highly erodible banks. High exposed banks, prominent upstream of former dams in M03 and M11, are particularly prone to erosion during freeze-thaw cycles (Walter et al 2018). No active incision was noted in 2019, but widening and planform adjustments were widespread and common; 15 of 20 fully assessed reaches or segments were noted in stage III evolution due to these dynamics.

The additional 5 of 20 fully assessed reaches or segments were characterized with stage IV development (M01, M12, M13, M16-A and M17-B). Reach M13 is well upstream of sedimentation impacts from any existing or historic dams and appears to have re-established good floodplain access, not having incised through deeper layers of sedimentation. M16-A and M17-B similarly have largely reconnected floodplain access; the former benefits from frequent beaver activity, and the latter (though severely encroached by roads) benefits from both multiple ledge grade controls and interspersed, small river-adjacent wetlands. M01 and M12 benefit from well-established buffers through much of each reach.

The significant conversion of "Coarse Equilibrium (In=Out) and Fine Deposition" (CEFD) sediment regimes to various transport sediment regimes along the Second Branch leads to fine grained "washload" materials frequently being transported long distances and into the White River mainstem. These washload sediments drop out primarily when low velocity conditions are encountered (insides of meander bendways, undersized stream crossings) and frequently contribute to infilling of planebeds (sedimented areas of the stream with no major elevations or depressions) throughout the mainstem. The Second Branch is remarkable for a lack of stable bed features in general, and these features tend to be highly transient.

Coarser "bedload" sediments appear to mostly be deriving from tributary discharges following flash floods, primarily in upstream portions of the basin (especially upstream of reach M10). Due to low slope gradients along the mainstem, these coarser sediments are only slowly redistributed, and are primarily moving through the stream network in sediment "slugs". These sediments did not appear to be evenly distributed and are:

- moved primarily in flash flood events, and frequently drive planform changes (braiding, neck cut-offs, channel avulsions, meander extensions) as the stream evolves;
- accruing primarily at overwidened sections of stream and on large point bars;
- disrupted from setting up stable bed features by more flash flooding, gravel removal, or "cleaning out" of the stream above constrictions (particularly following flood events). The relatively small amounts of these materials along the mainstem can be notably diminished by currently permitted gravel removal limits for private landowners (VT DEC-WMD 2013; 10 VSA, Section 1021)

Fine Source and Transport and Coarse Deposition regimes (coded red in Fig. 27) now exist in 10 (of 22) stream reaches or segments that lack extensive bank armoring and are characterized by channel widening, elevated levels of erosion and concentrated deposition at meander bends, channel constrictions (including upstream of undersized bridges and culverts as well as current and breached dams), tributary mouths, and overwidened sections of the stream. These are concentrated in portions of the mainstem from reach M14 (East Brookfield) downstream to reach M03 in North Royalton. It should be emphasized again, however, that "coarse deposition" is a


relative term along the Second Branch and these sediments are largely gravel or small cobbles on the larger end (Fig. 29).

**Figure 29. Dredging at a stream ford in reach M04 exposes the relatively small "coarse deposition" in "Fine Source and Transport and Coarse Deposition (FSTCD) sediment regime reaches along the Second Branch.**

Due again to these relatively fine sediments, the "Coarse Equilibrium (In=Out) and Fine Deposition" (CEFD) reaches, coded green on the Sediment Regime Departure Map (Fig. 27), are subject to rapid change in response to changes in watershed inputs, particularly heightened stream power or discharges that can quickly scour out the channel and lead to disequilibrium that translates to heightened bank erosion again. There are currently seven reaches or segments with this CEFD sediment regime: M01, M10, M13, M15, M16-A, M17-A and M17-B. Of these, the three upstream segments (M16-A, M17-A and M17-B) greatly benefit from the ability of adjacent beaver-dominated wetlands to attenuate both sediments and high flows in maintaining the equilibrium of this sediment regime. Reach M15 similarly benefits from beaver activity in segment M16-A, abetted by corridor protections placed along that segment, but also likely benefits from (what could be transitory) bed aggradation that currently affords good floodplain access. This bed aggradation may be partly due to the removal or destruction of former constrictions in the reach (Fig. 30).


**Figure 30. Larger coarse sediments in M15 (cobble and some boulder size) were present at several current and likely former (as here) stream crossings that have now released sediments contributing to bed aggradation and better floodplain access for the time being, but most are fine and subject to being scoured out again.**

In the CEFD reaches further downstream (M13, M10, M01), current sediment regime is largely due to decent floodplain access (incision ratio <1.3) due to bed aggradation, a situation that can quickly change due to the transient status of many of the fine grained depositional features. Restriction of floodplain access with further incision quickly converts these type of reaches to sediment transport instead of "Fine Deposition" on accessible floodplains.

Due to these dynamics, heightened hydrologic inputs and stream power elevation due to straightening and channelization are a key factor along the Second Branch. Flash flooding appears to be playing a prominent role in upstream portions of the mainstem and on steeper tributaries of the basin, and the value of beaver-dominated wetland areas in attenuating these impacts bears careful consideration and protection when possible. Windrowing of coarse materials (i.e., pulling or pushing them to the edges of the stream, a common response to sediment slugs following flash floods) and bank armoring are likely to greatly curtail the rate of channel evolution and exacerbate the impacts of increased stream power on downstream reaches.

Channel adjustments due to increased flows can be difficult to remediate in downstream reaches (Booth and Jackson 1997), prolonging the stages of disequilibrium in these areas. This places a premium on attenuation of high flows and sediment discharges in the shortest distance downstream possible, and along the Second Branch particularly increases the importance of:

a) protecting and maintaining floodplain access high in the watershed, especially current beaver-controlled areas;
b) establishing and maintaining woody buffers in riparian corridors;
c) limiting development and encroachments within stream corridors; and
d) managing stormwater inputs to minimize direct discharges to streams

*Constraints to channel evolution*

Ledge outcrops that help limit bed incision (thus providing constraints to vertical channel evolution) are rare along the Second Branch mainstem, with most occurring in upstream reach M17 (including location of a former sawmill). Additional grade controls are all associated with

a) current intact dams:

East Bethel, Hyde Mill dam, reach M04; and
East Randolph, Gulf Road Dam, reach M09; or

b) former, now breached or removed, dams:

North Royalton, former Stoughton Mills/Royalton-5 dam now removed, reach M03
North Randolph, former Creamery power dam now mostly gone, segment M11-A
North Randolph, former saw-shingle-grist mill dam mostly gone, segment M11-C

This lack of grade controls leaves the bed highly susceptible to incision, but the highly erodible nature of the banks also limits the amount of downcutting that will occur before banks begin to slough or collapse; localized incision is often quickly offset by aggradation of fine sediments.

Only one reach and one segment in the assessment area were listed with a lateral constraint of dominantly cohesive banks: M11-C (former mill site in North Randolph) and M14 (East Brookfield). The former still has stone infrastructure remnants in the bed and along portions of the left bank. Though the very steep walls in this relatively narrow valley are cohesive they are not impervious to the possibility of mass failure. The bed is clearly more erodible overall, however; ledge and remaining dam remnants are playing a large role in maintaining stability in this reach, as the primary trigger for mass failures is likely to be undercutting. The dam remains do not appear to be an impediment to aquatic organism passage (Fig. 31).


**Figure 31. Ledge and old dam remains in North Randolph segment M11-C (left looking DS, right looking US), now carrying a log and plank footbridge, limit bed incision that could undercut and trigger mass failures on the cohesive but still erodible silts along the valley sidewalls.**


In M14 banks are cohesive and grade controls are lacking, leaving the bed often more erodible than the banks. Floodplain access was diminished during 2019 fieldwork (incision ratio 1.5) so that only higher level floods will achieve overbank sediment deposition, and stream power is enhanced due to containment in the channel in moderate level floods. As in M11-C, banks are cohesive due to silt content, but ultimately are erodible under sufficient stream power or undercutting, tending to slough (Fig. 32).

**Figure 32. Silt content makes banks cohesive along M14, presenting constraints to lateral adjustments, but they are still erodible under sufficient stream power or undercutting.**

This dynamic contributes to rapid cycling of localized scour and subsequent infilling. Lateral constraints to channel adjustments (such as meander extension to reduce slope and thus lessen stream power) come not only from the cohesive banks but also a series of six bridges in reach M14, most with substantial concrete or stone abutments.

No natural bedrock constrictions were noted along the Second Branch mainstem. Given an overall low level of natural lateral constraints, reference conditions in the Second Branch basin would largely feature unrestricted lateral movement and floodplain access to achieve the adjustment processes and channel evolution that maintain channel equilibrium. Human-constructed constraints to lateral channel evolution are thus primary stressors along much of the mainstem, ranging from the numerous bridges and culverts throughout to multiple stretches of road encroachment. These impacts are more concentrated in the small villages situated close to the stream, but occur intermittently along the entire length.

The primary impact of these human-constructed constraints to lateral channel evolution is due to straightening and restriction of floodplain access. The largely Broad to Very Broad valley of the Second Branch still permits a good deal of lateral movement even in areas where the original valley is effectively cut in half, but containment in an incised, single-thread channel dictates that lateral movement primarily occurs through heavy erosion of the fine-grained banks, particularly in areas lacking woody vegetated buffers. These sediments quickly offset some of the incision so that the channel does not generally appear severely incised for long periods of time, but overall dynamics contribute to significant export of sediment and nutrients through, and eventually out of, this channelized system. These dynamics are greatly exacerbated upstream of breached or removed dams where channel incision is visibly more pronounced through formerly impounded sediments.

***Attenuation assets***

With a relatively low of lateral constraints along the Second Branch mainstem, along with frequently moderate to high levels of channel incision and few grade controls, establishment of woody vegetated buffers plays a key means to not only limiting accelerated erosion but also to providing raw materials to diffuse stream power and reconnect floodplains. Lateral channel adjustments are likely to be common and widespread, and accommodation of these dynamics places a high value on protecting attenuation assets below reaches that have been converted to transport systems due to straightening and encroachment – a common scenario in this basin. Given the role that increasing frequency of flash floods is playing in this basin, particularly in upstream portions of the basin, protection and maintenance of the beaver-influenced wetlands and stream segments in reaches M16 and M17 appear to be a priority.

In reality, a large majority of the reaches along the mainstem of the Second Branch have the potential to play important roles as attenuation assets (Table 12) but prioritization would favor reaches that are a) currently less incised; and b) are more upstream along the mainstem.

| | **Constraints** | | **Transport** | | **Attenuation (storage)** | | |
|---|---|---|---|---|---|---|---|
| **Reach or Segment** | **Vertical** | **Lateral** | **Natural** | **Converted** | **Natural** | **Increased** | **Asset** |
| M01 | none | human | | | x | x | limited |
| M02 | none | human | x | | | | |
| M03 | natural | limited | | x | x | | limited (incised) |
| M04 | natural, human | human | | x | x | x (dam) | limited (incised) |
| M05 | none | human | | x | x | x | x |
| M06 | none | human | | x | x | x | x |
| M07 | none | human | | x | x | | limited (incised) |
| M08 | none | human | | x | x | | limited (incised) |
| M09 | human | human | | x | x | x (dam) | limited (incised) |
| M10 | none | human | | | x | x | x |

| | Constraints | | Transport | | Attenuation (storage) | | |
|---|---|---|---|---|---|---|---|
| **Reach or Segment** | **Vertical** | **Lateral** | **Natural** | **Converted** | **Natural** | **Increased** | **Asset** |
| M11-A | human | human | | x | x | x | |
| M11-B | none | none | | x | x | x | x |
| M11-C | natural | human | | x | x | | |
| M12 | none | human | | x | x | x | x |
| M13 | none | human | | | x | x | x |
| M14 | none | human | | x | x | | limited (incised) |
| M15 | none | human | | | x | x | x |
| M16-A | none | human | | | x | x | x |
| M17-A | natural | human | | | x | x | x |
| M17-B | natural | human | | | x | x | x |

**Table 11: Departure Analysis Table for the Second Branch mainstem, indicating where river segments are constrained from adjustment, converted to transport streams, and/or have existing or future potential as a place to attenuate sediment load and high flows. Shaded segments are higher priority.**

*M16-B (beaver dominated) and M17-C (human and beaver ponds) were excluded from full assessment, per protocols

Upstream portions of the mainstem currently have attenuation assets interspersed with converted transport regime reaches (Fig. 27), and prioritization further downstream would benefit from leveraging opportunities to create similar patterns. Segment M11-B plays an important role as an attenuation asset not only for reaches upstream along the mainstem, but also for sediment and water discharges from tributaries off both banks. The position of this segment relatively high in the watershed, with other attenuation assets interspersed upstream of it (and its sedimentation history due to damming), suggests possibilities for an active floodplain restoration – or at least an alternatives analysis.

The fact that reach M10 still has decent floodplain access suggests increased priority for protecting possibilities for lateral adjustments in relatively un-impinged portions of the reach, particularly as mass failures have been triggered in more constricted portions of the reach. In addition, properly sizing any bridge or culvert replacements will be important (these are currently contributing to significant straightening impacts). These stream crossings should be covered by changes in Vermont's Stream Alteration permits since 2014 (VT DEC-RMP 2014).

Reaches further downstream also have possibilities for valuable benefits as attenuation assets but are frequently constrained by current more limited access to floodplain, primarily due to straightening. The value of woody vegetated buffers in these reaches cannot be overstated, as large wood is likely to be fundamental to re-establishing geomorphic equilibrium in this portion of the mainstem. Reach M06 has elevated values for prioritization of attenuation assets due to its position in a stretch of converted transport reaches, as well as being downstream of several in-reach and additional tributary impacts, but reach M05 has similar assets and is currently less incised. The upstream end of reach M05 and lower end of reach M06 includes a low-lying section of VT-14 that is frequently overtopped and requires temporary closure during floods, indicating value as an attenuation asset but conflicts with infrastructure likely to impact water quality. This area also includes the location of "Brickyard Farm", and though the history of brick-making in New England is poorly documented it is conceivable that ongoing pronounced adjustments in this vicinity may be in part due to historic dredging of the channel for brick materials.

Reach M03 is currently very incised due to historic sedimentation upstream of the Stoughton Mills/Royalton-5 dam (now removed), but this reach may have increased value if the Hyde Dam in reach M04 is removed, as the next two reaches downstream (M02 and M01) are far more limited for attenuation. Although reach M01 still has some floodplain access off the left bank in upstream portions of the reach there is limited capacity for attenuation and the corridor has some limited protection as it is mapped within the FEMA designated Regulatory Floodway (FEMA MSC 2020).

### *5.2 SENSITIVITY ANALYSIS*

The preceding departure analysis identifies the watershed and reach-scale stressors that help explain current sediment regime departure in the 2012-13 Phase 2 assessment area of the First Branch basin. Designing stream corridor protection and restoration projects that are compatible with channel evolution processes, and prioritizing them at the watershed scale, also require an understanding of stream sensitivity.

Sensitivity refers to the likelihood that a stream will respond to a watershed or local disturbance or stressor, and an indication as to the potential rate of channel evolution (VT-RMP 2009, Phase 2, Step 7.7; Kline 2010, Section 5.1.3). While every stream changes in time, a sensitivity rating indicates that some streams, due to their setting and location within the watershed, are more likely to be in an episodic, rapid, and/or measurable state of change or adjustment.

All fully assessed stream segments in the Second Branch basin are Very Highly to Extremely sensitive to disturbance and stressors, and thus also capable of a relatively rapid response (channel evolution to reestablish equilibrium conditions) if stressors are addressed (Table 8, p.43). This is in part due to the low elevation gradients along the Second Branch; C- and E-type streams are by nature relatively sensitive and capable of recovery to equilibrium conditions in response to restoration efforts (Rosgen 1994).

The relatively high sensitivity of streams along the Second Branch mainstem indicates good possibilities for success of passive geomorphic projects, which allow the river to utilize its own energy and watershed inputs to reestablish meanders, fuller access to floodplains, and self-maintaining equilibrium conditions over time. The widespread nature of this assessment indicates that the most effective approach to restoring balanced conditions along the mainstem of the Second Branch would be aided by municipal approaches that would limit further encroachments along stream corridors of upland tributaries and addressing undersized structures along the mainstem. Due to the widespread and cumulative nature of the primary stressors in the basin (particularly changes to hydrology due to road density, encroachment, and drainage and stormwater management associated with diffuse settlement patterns and the maintenance of a dense road network) such an approach is in fact strongly indicated for increasing the possibilities of success on projects implemented on a parcel by parcel basis along the mainstem.

# CHAPTER 6: REACH SUMMARIES AND PROJECT IDENTIFICATION

## *6.1 REACH SUMMARIES*

Within the context of the overarching considerations discussed in previous sections of this report, reach descriptions highlighting factors leading to preliminary project identification are presented on a reach-by-reach basis in the following pages. “Left bank” and “right bank” in the reach descriptions are referenced looking downstream.

Single page maps are included with the text for ease of reference in regards to the text. Background imagery for these maps is from 2016, best available composite hillshade of a Digital Surface Model from lidar-derived data of the earth's surface, including structures and vegetation; sun angle is multidirectional (VCGI Lidar 2021).

For more detail and flexibility in choosing areas of interest and background imagery, readers are highly encouraged to utilize the online interactive Natural Resource Atlas hosted by the Vermont Agency of Natural Resources, where data from Stream Geomorphic Assessments (SGAs) can be viewed within the ‘Rivers Management Theme’ (VT-ANR 2021), or the Vermont Center for Geographic Information VCGI Interactive Map viewer (VCGI Interactive 2021; use this latter viewer for easier lidar access).

Reach maps in this report include a preliminary “ANR Corridor” (Flood Ready VT 2019) drawn on either side of the stream. The width of this corridor (generally a minimum of 3-4 times the stream channel width) is based on over 30 years of research and data collected from hundreds of streams around the world, and approximates the extent of lateral adjustments likely to occur over time in a meandering stream type (VT-RMP_ApxH 2009). “Corridors are the space in which streams and rivers WILL move, and corridor protection is the fundamental strategy by which we protect lives, property, water quality, habitat, and the economic value of our streams and rivers.” (Chris Campany, Executive Director, Windham Regional Commission, Jan.2016; Flood Ready VT 2019).

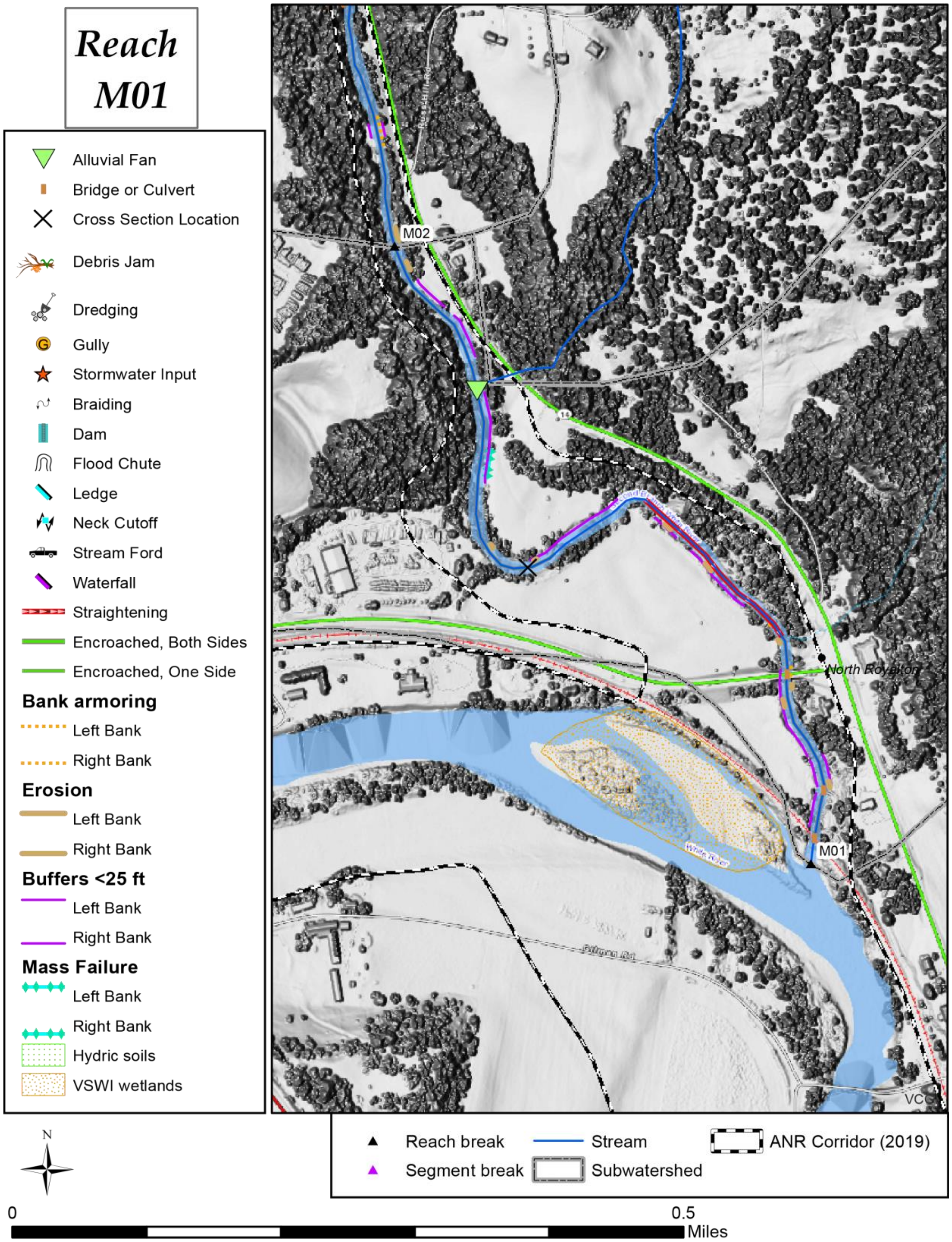



**Figure 33. M01 Reach Summary Graphic**

| M01 Data Summary | | Reference | Existing |
|---|---|---|---|
| Length: 3,779 ft.<br>Drainage Area: 74.29 sq. mi.<br>Evolution Stage: IV<br><br>Sensitivity: Very High | Confinement | Broad | Very Broad |
| | Stream Type | C | C |
| | Entrenchment Ratio | >2.2 | 10.8 |
| | Incision Ratio | <1.2 | 2.2 |
| | Dominant Bed Material | Gravel | Gravel |
| | Dominant Bedform | Riffle-Pool | Riffle-Pool |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 12: M01 Phase 2 Data Summary**

*Primary Stressors*

- Historic straightening of reach - possible berm (unclear) as well as large bridge/railroad abutments that cut off access to floodplain in lower sections of the reach
- Encroachment from VT-14 on river left that pins the upper portion of the reach against the right valley wall
- Historic incision amplified as a result of straightening

*M01 Summary:*

Reach M01 runs 3,779 feet starting at the confluence with the main stem of the White River in Royalton, VT and heads north upstream along VT-14. A short downstream portion of reach M01 passes under the New England Central Railroad bridge and the VT-107 bridge; these two bridges and their large abutments cut off access to a significant portion of the historic floodplain that was shared with the main stem of the White River. The resulting cut off from floodplain and the presence of bedrock on both sides of the channel give the impression of a deep canyon in the 500 feet preceding the Second Branch confluence with the White River main stem.

**Figure 34. VT-107 bridge, abutments cut off significant access to floodplain**

Heading upstream from the lower section of reach M01, the river is significantly straightened as it runs parallel to agricultural fields on the right bank and a buffered area on the left bank. At this location, there may be a historic berm, but it is obscured by some mature trees in a diminished buffer and cultivation of cornfields – could be plow headlands, but regardless helps channel the stream toward the left valley wall and through the bridges despite the right bank cropland being mapped as FEMA floodway.

After the straightened area, the river meanders and runs by the Lucky's Trailer Sales Lot in Royalton before the river turns north and runs parallel to VT-14 for the remaining upper portion of the reach. The upper portion of the reach that runs along VT-14 has a well-established buffer on river right and even though the road embankment sits on river left in the floodplain, there is still a buffer present in most of the upper portion between the road and river.

**Figure 35. Upper section of M01, buffers on both sides of river, road embankment limits floodplain access**

The reach opens into what was re-classed as a very broad valley, with a valley width of 650 feet measured at the Phase 2 cross-section, however the lower portion of the reach starting after the river flows under the VT-107 bridge is more confined for a short portion. This valley width affords accessible floodplain even though the river has incised historically and lost some floodplain to transportation infrastructure. The dominant buffer width for the reach is 25-50 feet on both the left and right bank, however at least 1/3 of the entire reach length does not have a buffer that is over 25 feet, and only a small portion of the reach has buffers that extend past 50 feet. In the upper part of the reach there is an alluvial fan at the confluence of an unnamed stream that enters the Second Branch north of the agricultural fields. This reach was likely a tributary deltaic formation on a 'finger lake' of glacial Lake Hitchcock, contributing to the presence of fine sediments which further lead to the deep incision in portions hemmed in by roads and railroad, highly straightened and cut off from a large majority of historic floodplain once shared with the main stem of the White.

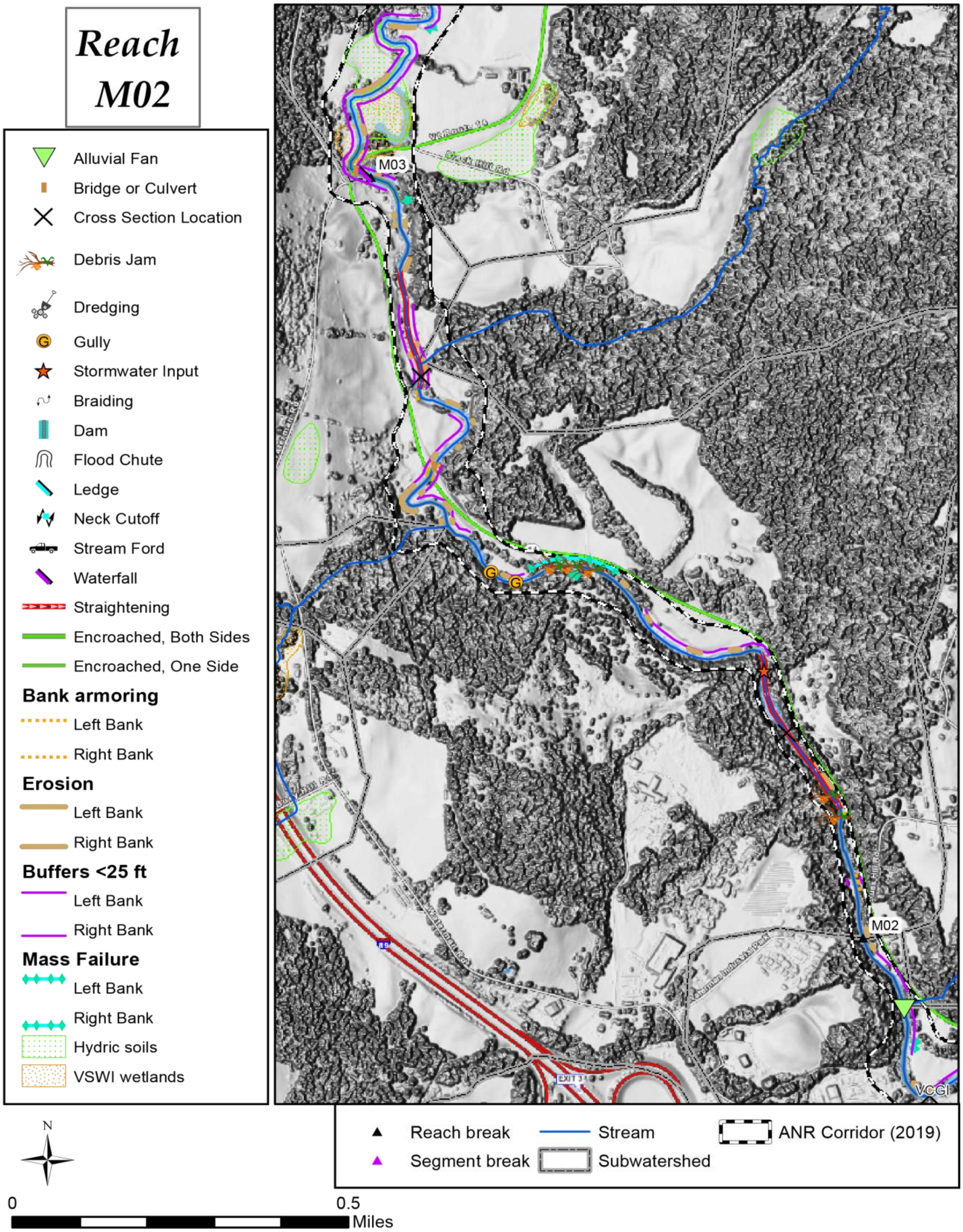



**Figure 36. M02 Reach Summary Graphic**

**Table 13: M02 Phase 2 Data Summary**

| M02 Data Summary | | Reference | Existing |
|---|---|---|---|
| Length: 9,245 ft.<br>Drainage Area: 72.61 sq. mi.<br>Evolution Stage: III<br><br>Sensitivity: Very High | Confinement | Narrowly Confined | Narrowly Confined |
| | Stream Type | B | C |
| | Entrenchment Ratio | >1.4 | 1.7 |
| | Incision Ratio | <1.2 | 1.2 |
| | Dominant Bed Material | Sand | Sand |
| | Dominant Bedform | Dune-Ripple | Dune-Ripple |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

*Primary Stressors:*

- Historic straightening of at least two locations along the reach
- Encroachment from VT-14 along entire length of reach
- Active widening and incision, somewhat mitigated by sediment retention by large woody debris

*M02 Summary:*

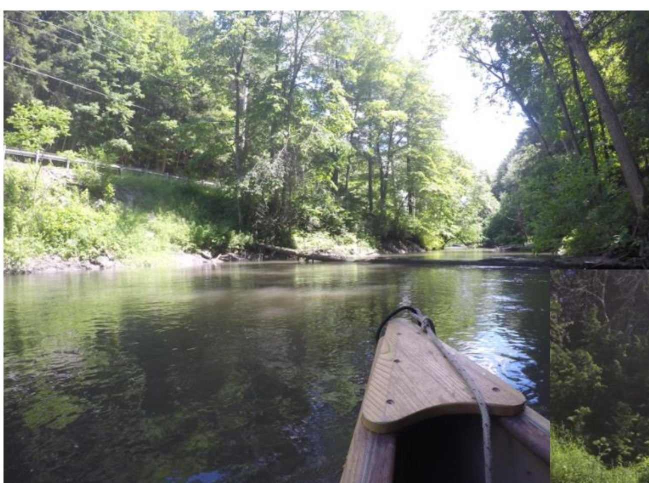


**Figure 37. Road embankment on river left, debris jam, and steep valley wall on river right – a typical stretch in M02**

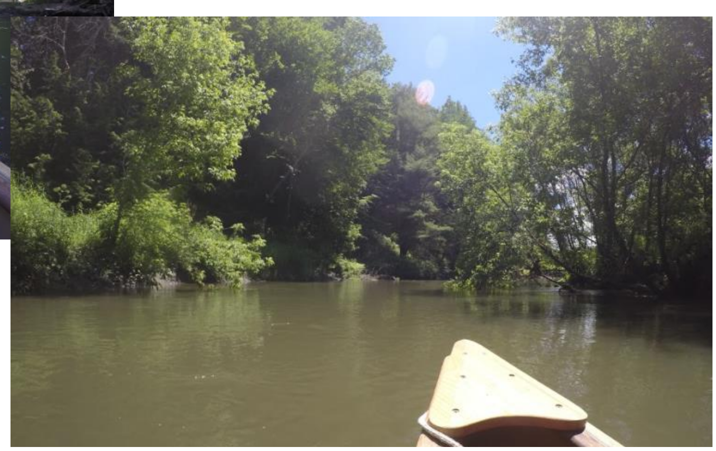


**Figure 38. Widened section in upper portion of M02, limited floodplain access on river left**

The downstream end of reach M02 starts at Russ Hill Road in Royalton, VT and runs north along VT-14 to the former dam site at the intersection of Waterman and Morse Roads. This reach extends over 9,245 feet and follows VT-14 for almost the entire length of the reach. The reach is defined by being in a narrowly confined valley with extremely steep slopes on both the right and left corridor walls. The valley does however have pockets of floodplain that are accessible at high flows. For over two-thirds of the reach length, VT-14 encroaches into the river corridor, which effectively reduces the valley to a Narrowly Confined category at many locations. The reach has a considerable amount of woody debris including 5 debris jams spread along the length of the reach. The high concentration of woody debris in this section of the Second Branch is aided by the over-100 foot (in width) dominant buffer type, with large sections of this reach having buffers on both sides of the river; only 3,000 feet on river left and 1,800 feet on river right have less than 25-foot-wide buffers. There is only one bridge in this reach, a 130-foot concrete structure that allows the Second Branch to cross underneath VT-14. Like reach M01, there is significant straightening present along M02, with almost 2,500 feet of straightening identified in this reach with the majority of the straightening found in the upper and lower portions. The middle portion of the reach meanders slightly as it alternates through areas of buffered forest and agricultural properties. In the middle of the reach there is a significant mass failure on river right that is found downstream of two gullies. The Bethel-Royalton landfill is present upstream of the gullies (which did not appear to be actively eroding), and though no obvious issues were noted along the Second Branch in the field this area is recommended for periodic monitoring if this is not already in place. The bank texture along the reach is sandy, creating some areas of erosion throughout the reach. Most of the significant erosion is found on river left, totaling over 1,000 feet of erosion at an average of 4 feet in height. Overall the reach can be described as actively widening with moderate planform adjustments following historic incision. The flood prone area has been established at a lower elevation in many areas, but large wood plays a prominent role in both contributing to and moderating widening and planform adjustments.

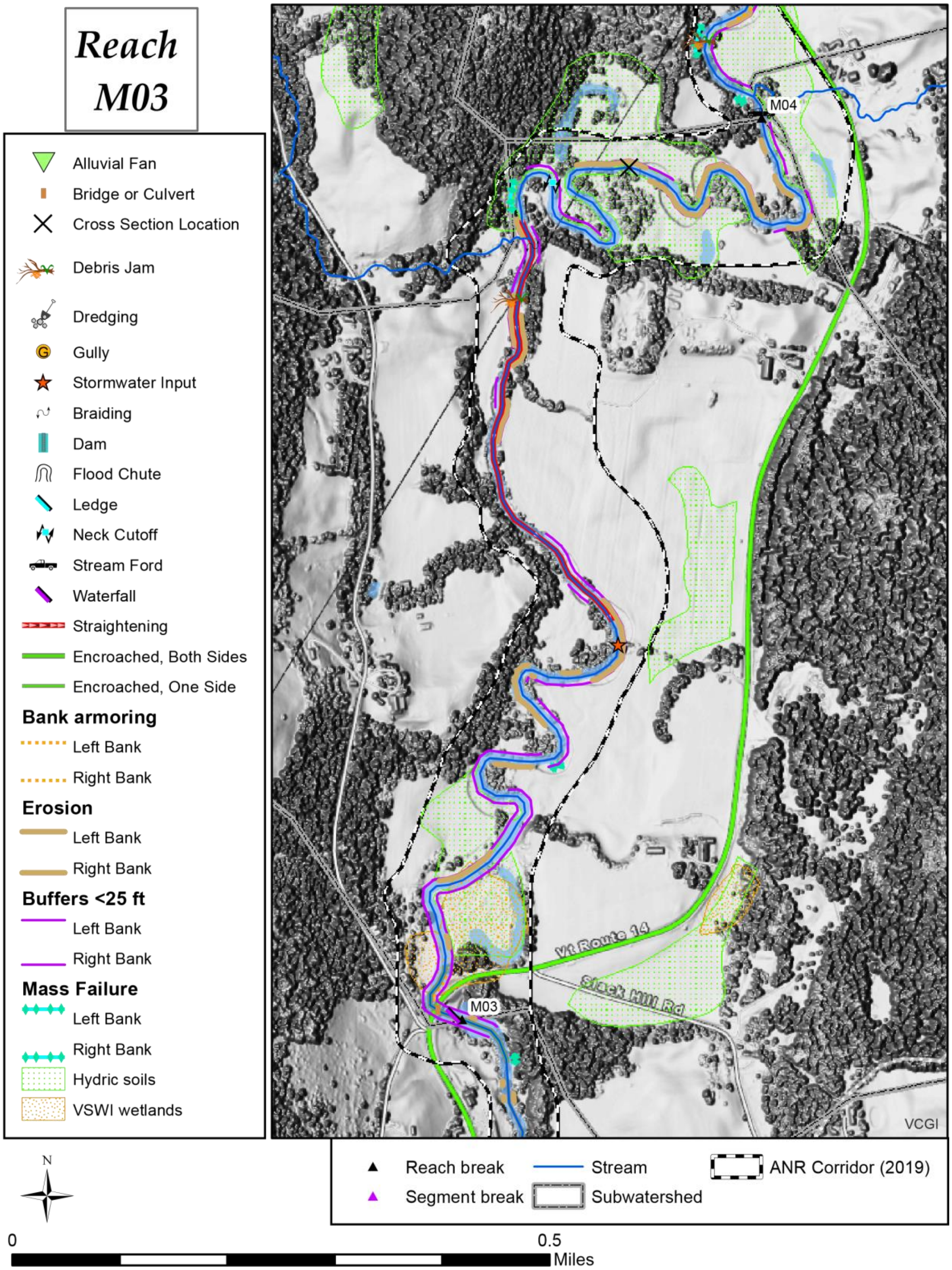



**Figure 39. M03 Reach Summary Graphic**

| M03 Data Summary | | Reference | Existing |
|---|---|---|---|
| Length: 8,939 ft.<br>Drainage Area: 69.42 sq. mi.<br>Evolution Stage: III<br><br>Sensitivity: Very High | Confinement | Broad | Very Broad |
| | Stream Type | E | C |
| | Entrenchment Ratio | >2.2 | 13.1 |
| | Incision Ratio | <1.2 | 1.5 |
| | Dominant Bed Material | Sand | Gravel |
| | Dominant Bedform | Riffle-Pool | Riffle-Pool |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 14: M03 Phase 2 Data Summary**

*Primary Stressors:*

- Aggradation, widening, and planform adjustments following incision
- Historic straightening, likely due to agricultural practices
- Insufficient buffers in upper sections of reach

*M03 Summary:*

**Figure 40. Site of former Stoughton Mills/Royalton-5 Dam – now a waterfall with a large scour pool**

Reach M03 starts on the downstream end at the site of the former Stoughton Mills/Royalton-5 Dam, which has since been removed, and runs upstream for almost 9,000 feet to an unnamed tributary entering the Second Branch of the White River just south of Post Farm Rd. This reach transitions from the narrowly confined M02 to a very broad valley field estimated to be around 800 feet in width. There is one stream crossing at the start of this reach where the VT-14 bridge sits atop the location of the former dam. The removed dam exposes waterfalls with a large scour pool beneath. The angle of the bridge and VT-14 here is almost perpendicular to the flow of the river, cutting off left floodplain access and reducing the effective width of the bridge though not

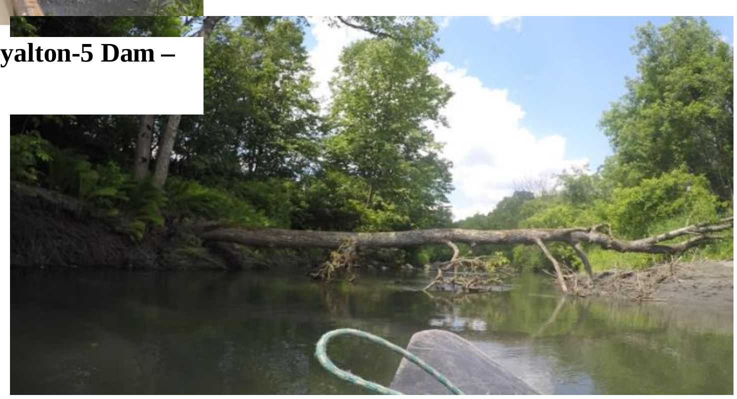


**Figure 41. Eroded left bank resulting in downed tree; over 150 pieces of large woody debris found in reach M03**

an apparent channel constriction. The waterfall under the VT-14 bridge is the only grade control along this reach and is approximately 15 feet in height. Heading upstream, after crossing under the VT-14 bridge the reach remains approximately .2 miles to the west of VT-14 for most of its length before taking a hard turn to the east at the top of the reach to come back towards VT-14. The reach contains over 150 pieces of large woody debris and 1 debris jam. Erosion is present on both river left and river right, with almost 2,000 feet of erosion on each bank. The reach is poorly buffered, with over 4,000 feet on both river right and left with less than 25-foot-wide buffers. The lower one-third section of the reach contains three large meanders and runs through a Class 2 wetland (VSWI 2010). Multiple projects were identified as part of the assessment in this section, including wetland restoration, river corridor protection, and buffer plantings. This lower third of the reach is poorly buffered and has some of the largest areas of erosion in the reach, with many over 4 feet in height and likely due in part to deposition behind the former dam (Walter and Merritts 2008). Upstream after three large meanders, the river continues north in a mostly straightened section. This middle third of the reach starts with a field ditch input at the southern end and runs approximately 0.2 miles north, with a buffer on river right and agricultural land on river left. The straightened middle section of the reach appears to be maintained against the valley wall, likely due in part to agricultural practices including plow headlands. The top third of the reach features the river turning east and coming back towards VT-14, and this section has pronounced meanders and features a neck cutoff and two unbuffered meanders that contribute to expanding erosion. The reach ends upstream where an unnamed tributary enters the Second Branch. Just south of the upper reach break, a new stream ford is in use that provides access between agricultural fields on opposite sides of the river.

**Figure 42. Erosion on right bank and heavy deposition of fine sediments on river left in M03; banks shown here on river right have no buffer**


**Figure 43. Renovated stream ford found at top of reach M03 close to M04 reach break**

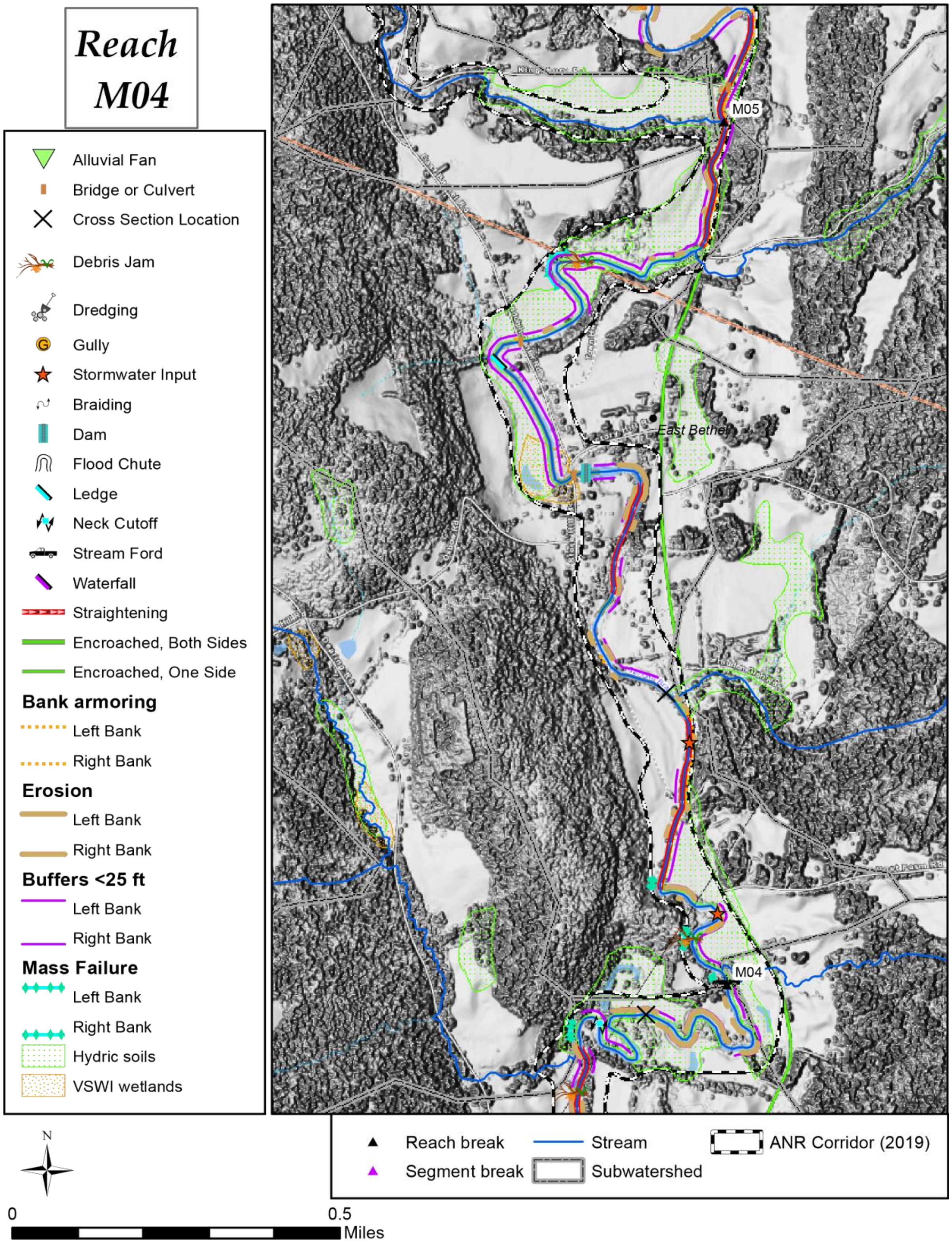



**Figure 44. M04 Reach Summary Graphic**

| M04 Data Summary | | Reference | Existing |
|---|---|---|---|
| Length: 10,807 ft.<br>Drainage Area: 66.84 sq. mi.<br>Evolution Stage: III<br><br>Sensitivity: Extreme | Confinement | Broad | Broad |
| | Stream Type | E | C |
| | Entrenchment Ratio | >2.2 | 14 |
| | Incision Ratio | <1.2 | 1.4 |
| | Dominant Bed Material | Sand | Sand |
| | Dominant Bedform | Dune-Ripple | Dune-Ripple |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 15: M04 Phase 2 Data Summary**

*Primary Stressors:*

- Severe erosion in poorly buffered sections of lower reach
- Historic berm in mid-section of the reach limits floodplain access
- Presence of Hyde Dam contributing to lack of sediment transport continuity

*M04 Summary:*

**Figure 45. Lower portion of M04 has actively eroding banks, notably worse in areas with no buffer. Buffered valley wall at right bank increases erosive pressure on agricultural fields.**

Reach M04 starts on the downstream end at an unnamed tributary that comes into the Second Branch south of Post Farm Road and runs 10,807 feet north until just south of the Kingsbury Covered Bridge. The reach sits in a broad valley almost 600 feet in width. Under reference conditions the reach would be an E-type stream, with highly erodible sand as the dominant bed material in a dune-ripple bedform. Under current conditions the reach is more straightened and follows VT-14, sometimes directly next to the road and at other times further west and closer to the buffered valley wall off the right bank. At the downstream end of the reach, the river meanders and is highly eroded in much the same way as the top of reach M03; this lower area is full of woody debris and features one large debris jam. The river then heads toward VT-14 in a stretch of approximately 0.2 miles that is highly straightened. Overall the reach has 3,500 feet of straightened portions. The reach as a whole is poorly buffered, with approximately 5,000 feet (or nearly half the reach) on both sides of the river lacking a buffer that is over 25 feet in width. Erosion in the reach is exacerbated by the silt bank texture, and on both river left and river right there are almost 1,000 feet of erosion with erosion often reaching a height of 4 to 5 feet. The reach contains a significant amount of rip rap revetment along the stretches of river left that are close to VT-14. As the reach heads north, there appears to be a historic berm that runs along the right bank along Store Hill Rd., but the berm is not easily visible in field due to mature trees and vegetation. This long-standing berm straightens and funnels the stream against VT-14 along the left valley wall. The middle section of the reach includes the village of East Bethel and the Hyde Mill Dam.

**Figure 46. View of Hyde Dam (downstream looking upstream), with portions of the old mill complex visible at right of photo.**

The Hyde Dam is located approximately 100 feet downstream from the Store Hill Rd bridge in East Bethel. The Hyde Dam is approximately 45 feet in length and 14 feet in height and historically provided water power to the village. Starting around 1860 the Hyde Dam was crucial in powering a gristmill, creamery, and woolen mill. The dam has long been out of use and in recent years the dam, adjoining property, and water rights were purchased by Vermont River Conservancy (VRC) with the intent of removing the dam and creating a historic public access site. The dam is the first of 2 intact dams on the Second Branch of the White River. Directly upstream of the Hyde Dam the stream runs under the first bridge of the reach and then takes a hard turn to the north and runs parallel to Randolph Center Road. This section of the reach is flat and has a large amount of sediment buildup as a result of Hyde Dam. The section is poorly buffered and highly erodible. This straightened run remains flat and highly sedimented for approximately 0.1 miles before it hits a section of ledge that may act as a grade control, and then turns east and crosses under the second bridge of the reach. This reach sees a stream type departure from planform E to C due to reduced sinuosity and widening related to straightening (apparently long-standing), exacerbated by sediments that are highly erodible. Cyclical rapid, localized incision seems to be offset by aggradation and widening. Down cutting along the reach is limited by grade controls (intact dam but also likely channel-spanning ledge upstream), and planform adjustments are limited by road encroachment and placement of vegetated berms pinning the stream to the valley wall. Progressive fining is exacerbated by the dam impoundment and lack of sediment transport continuity.

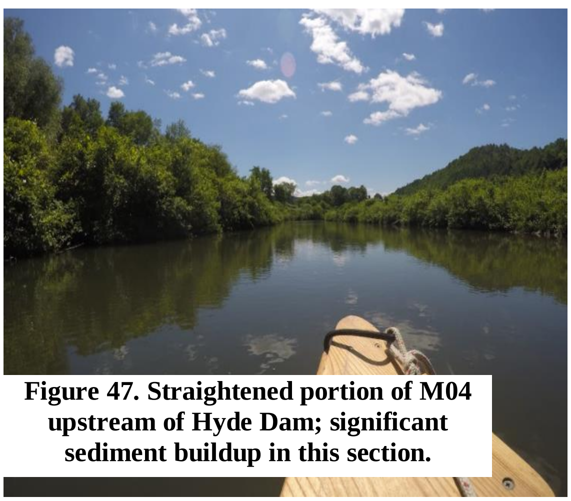


**Figure 47. Straightened portion of M04 upstream of Hyde Dam; significant sediment buildup in this section.**

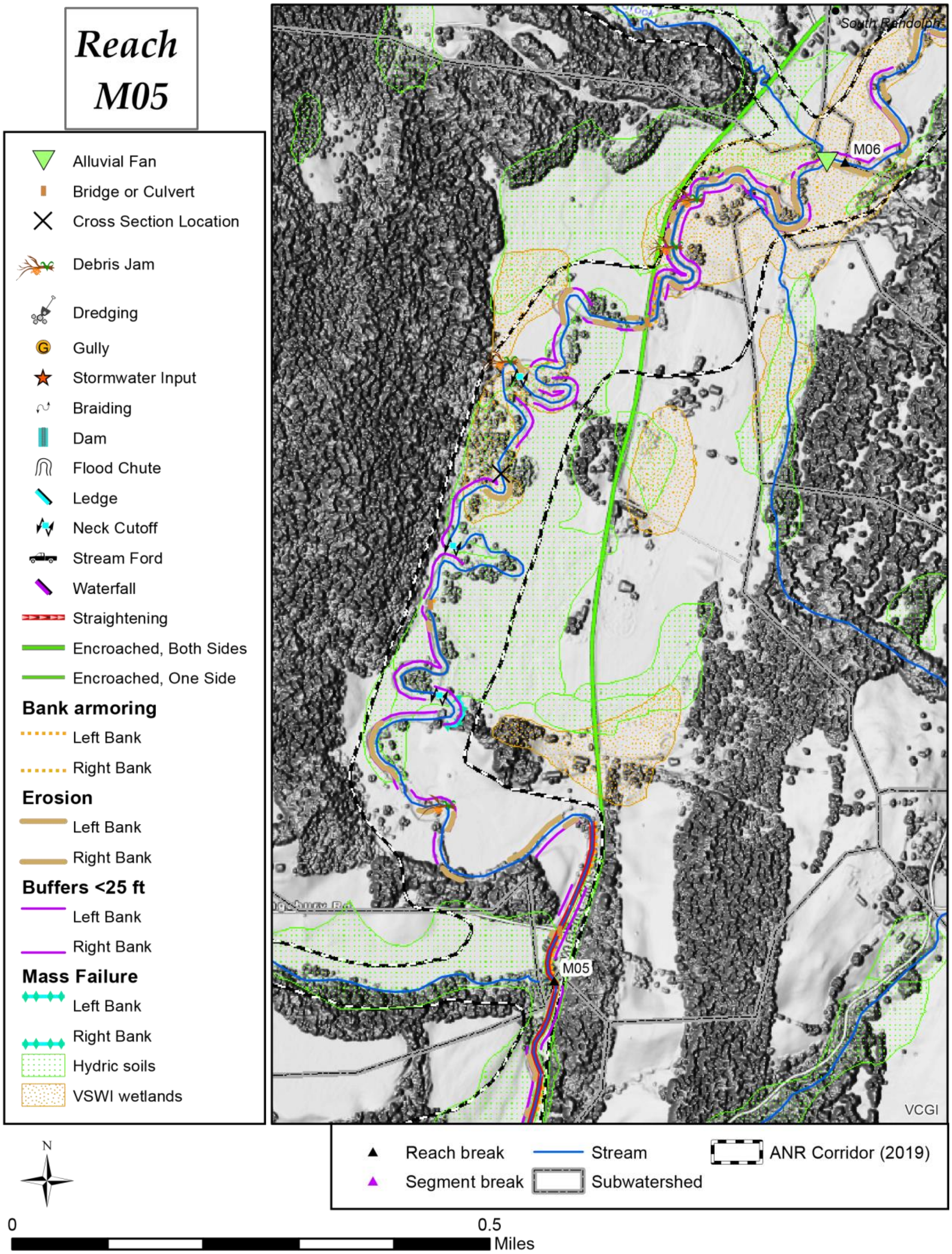



**Figure 48. M05 Reach Summary Graphic**

| **M05 Data Summary** | | **Reference** | **Existing** |
|---|---|---|---|
| Length: 11,266 ft.<br>Drainage Area: 63.71 sq. mi.<br>Evolution Stage: III<br><br>Sensitivity: Very High | Confinement | Broad | Very Broad |
| | Stream Type | E | E |
| | Entrenchment Ratio | >2.2 | 26.3 |
| | Incision Ratio | <1.2 | 1.1 |
| | Dominant Bed Material | Sand | Sand |
| | Dominant Bedform | Dune-Ripple | Dune-Ripple |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 16: M05 Phase 2 Data Summary**

*Primary Stressors:*

- River corridor encroachment in lower reach due to VT-14
- Loss of sinuosity, evidence of recent and impending neck cutoffs
- Three bridges acting as constriction points and contributing to widening and aggradation present along reach

*M05 Summary:*

**Figure 49. Power lines on river left indicate presence of VT-14 as a river corridor encroachment along M05**

Reach M05 starts on the downstream end at the tributary confluence south of the Kingsbury Covered Bridge and runs 11,266 feet north to the confluence of Peak Brook and the Second Branch. On the downstream end, this reach begins against VT-14 for approximately 0.1 miles as a straightened section crosses under the Kingsbury Covered Bridge. The river then turns west to the valley wall and runs parallel to VT-14 about 1,000 feet west of the road, up against the right valley wall. The E-type stream is a dune-ripple system with sand as the dominant bed material. The reach sits in a very broad valley that is estimated to be 1,400 feet in width. The middle section of the reach features 3 neck cutoffs as it meanders with a healthy buffer on river right and agricultural land to river left. This section features two large debris jams and a high concentration of woody debris. Although this section still has sinuosity, the

**Figure 50. One of three bridges in M05 with abutments that act as significant constriction points**

three neck cutoffs have greatly reduced the overall length and sinuosity of this reach leading to widening and aggradation. The reduced sinuosity and the strong predominance of very fine sediments create a very dynamic system bordering on an E to C stream type departure. Overall the reach has a large amount of erosion, both the left and right banks see over 1,000 feet of erosion at an average height of 3.5 feet. Though not well documented, it appears that a brickyard once operated in this reach ("Brickyard Farm" is located near the VT-14 bridge in the upstream portion of the reach) and the channel may have been dredged for clay (Ries and Merrill 1895). Pervasive erosion and high banks in this reach extend upstream to reach M06, and there are no records of dams in this area (similar to significant channel incision through impounded sediments behind other dams along the Second Branch). Despite large amounts of erosion there are few significant revetments present along this stretch of the Second Branch, with only a combined 700 feet of bank protected by rip-rap revetments for both the right and left bank combined. After the heavy meandering in the middle of the reach, the river passes by two Class 2 wetlands (VSWI 2010) - one on river left and one on river right - before turning to the east, crossing VT-14 under a concrete bridge, and moving to the center of the broad valley. After the reach crosses under VT-14, its runs another 0.2 miles north on the east side of VT-14 before reaching an alluvial fan created by the confluence of Peak Brook that signals the start of M06. The upper section of this reach runs directly through a Class 2 wetland (VSWI 2010) and has been identified as a potential area for wetland restoration. This upper section continues the trend of highly eroded banks and lack of an established buffer found in the lower portions of the reach as well. Extreme planform changes with major widening and aggradation characterize the reach overall. Multiple neck cutoffs (recent and impending) have created an extremely dynamic system with adjustments due to extensive lateral bank erosion and evidence of recent avulsions and multiple thread channels. While there is no stream type departure noted, the reach does border on an E to C stream type departure due to reduced sinuosity and a high degree of aggradation and widening. This reach also signals the beginning of a high concentration of farm bridges and VT-14 bridges that the Second Branch continually crosses under; in total there are 3 structures that M05 flows under, each of which restricts floodplain access. Substantial abutments on the VT-14 concrete bridge are characteristic of many of the older VT-14 bridges along the entire length of the Second Branch, some of which date back to the 1920s.

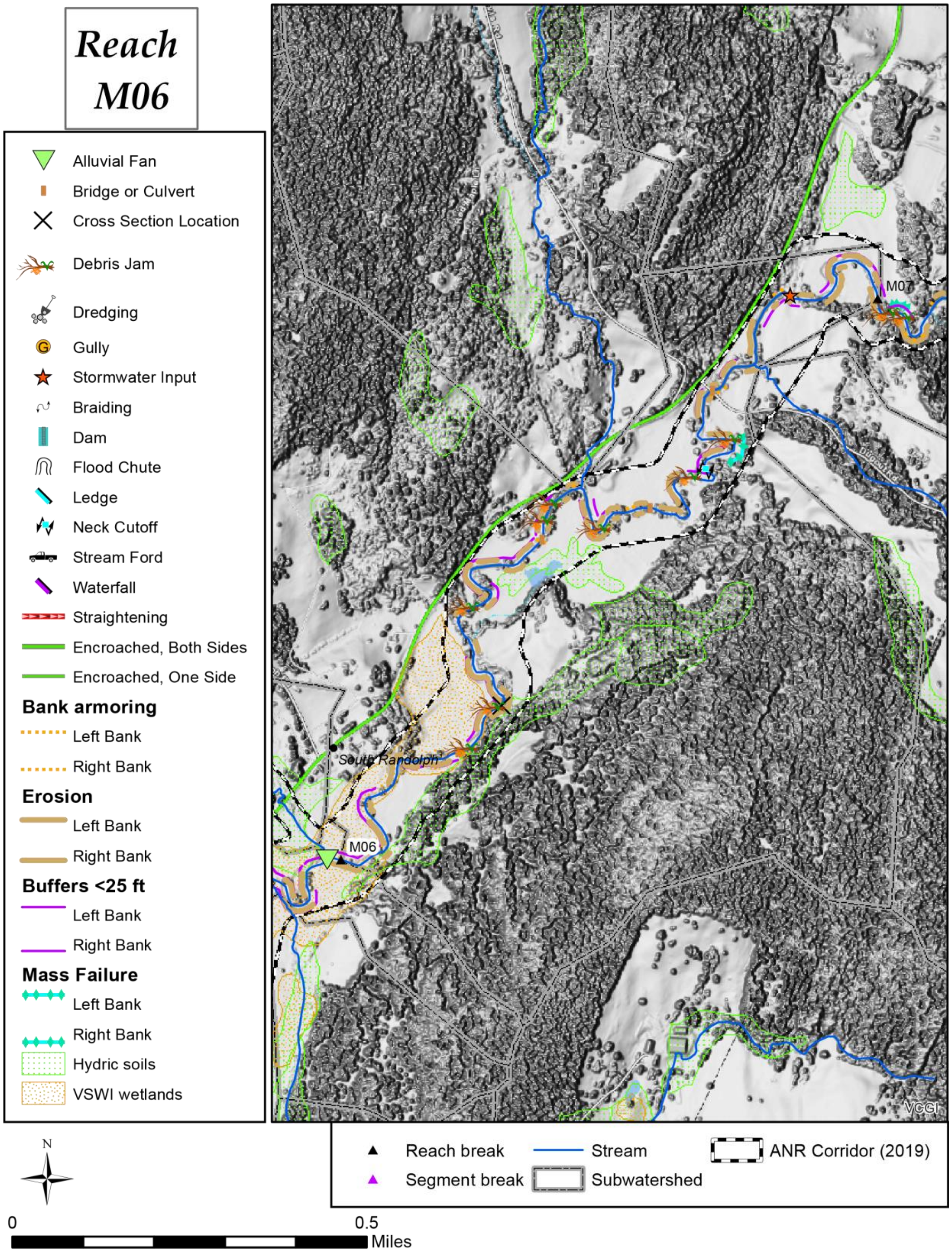



**Figure 51. M06 Reach Summary Graphic**

| M06 Data Summary | | Reference | Existing |
|---|---|---|---|
| Length: 9,815 ft.<br>Drainage Area: 55.53 sq. mi.<br>Evolution Stage: III<br><br>Sensitivity: Extreme | Confinement | Broad | Broad |
| | Stream Type | E | C |
| | Entrenchment Ratio | >2.2 | 10.2 |
| | Incision Ratio | <1.2 | 1.2 |
| | Dominant Bed Material | Sand | Sand |
| | Dominant Bedform | Dune-Ripple | Dune-Ripple |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 17: M06 Phase 2 Data Summary**

*Primary Stressors:*

- Agricultural use in river corridor with frequent poorly established buffers
- Loss of sinuosity, aggradation, and extensive widening
- High erosion and areas of mass failure

*M06 Summary:*

**Figure 52. Erosion (some active, some healed) lines the left bank of M06, fine sediments have increased the intensity of erosion and lead to multiple neck cut offs**

Reach M06 starts downstream at the mouth of Peak Brook, extends north for 9,815 feet, and ends 0.35 miles north of Dugout Road in South Randolph, VT. This reach sits in a broad valley, field estimated to be 500 feet in width. The stream is C-type with a dune-ripple dominant bedform and sand as a dominant bed material. This reach is an extremely dynamic system with fine sediments and extensive erosion. The reach has an E to C stream type departure due to over widening and reduced sinuosity. Old oxbows in surrounding fields were not easily observable during fieldwork but are apparent on aerials, particularly 1996 vintage aerial imagery (via Google Earth). Unlike the reaches downstream of M06, there is not extensive straightening along this reach. While the Second Branch in this reach does roughly follow VT-14, the river is less close to the road and instead meanders through the broad valley on the east side of VT-14 for the entirety of the reach. There is extensive erosion along this reach, including 3,600 feet averaging 3.8 feet in height on the right bank and 2,200 feet of erosion on the left bank averaging 3.9 feet in height. Despite the severe erosion, there is not a large amount of rip-rap present. The downstream section of the reach runs through a Class 2 wetland (VSWI 2010) for approximately 0.4 miles, before mainly running through agricultural land for the remainder of the reach. The middle section of the reach sees the river flowing against the right valley wall for 0.2 miles before turning east and heading towards the left valley wall until it crosses under Dugout Road. Short stretches of woody buffers dot the reach but there are long segments of river that have little to no buffer. There were 8 large debris jams that were spaced throughout the reach and over 30 large pieces of woody debris found. As the reach extends north, two different unnamed tributaries flow into the Second Branch and between those two tributaries is a stretch of river that includes a neck cutoff and severe erosion. This area is extremely dynamic and actively widening, with reduced sinuosity due to the neck cut off. This highly dynamic section also features a mass failure that is 122 feet in length along the left bank and extends over 50 feet in height. Upstream of this area, the river crosses under a bridge on Dugout Road. This is the location of the White River Partnership's highest long-term bacteria readings. A mix of highly erodible fine sediments, a lack of buffers in the reach, and dominant agricultural land use likely all contribute to this reach being a long term area for high bacteria readings. Reach M06 can be summarized as undergoing extreme widening and major planform adjustments, due primarily to meander extensions and aggradation. The E to C stream type departure identified in this reach can be attributed to over widening and reduced sinuosity. The wetlands present in the lower area of the reach make this area a candidate for wetland protection and restoration, while the highly erodible banks and lack of buffers in the upper section of the reach make this area a good candidate for large scale passive river restoration through corridor protection and buffer plantings.

**Figure 53. Severe erosion on left bank in M06, over 4 feet in height**

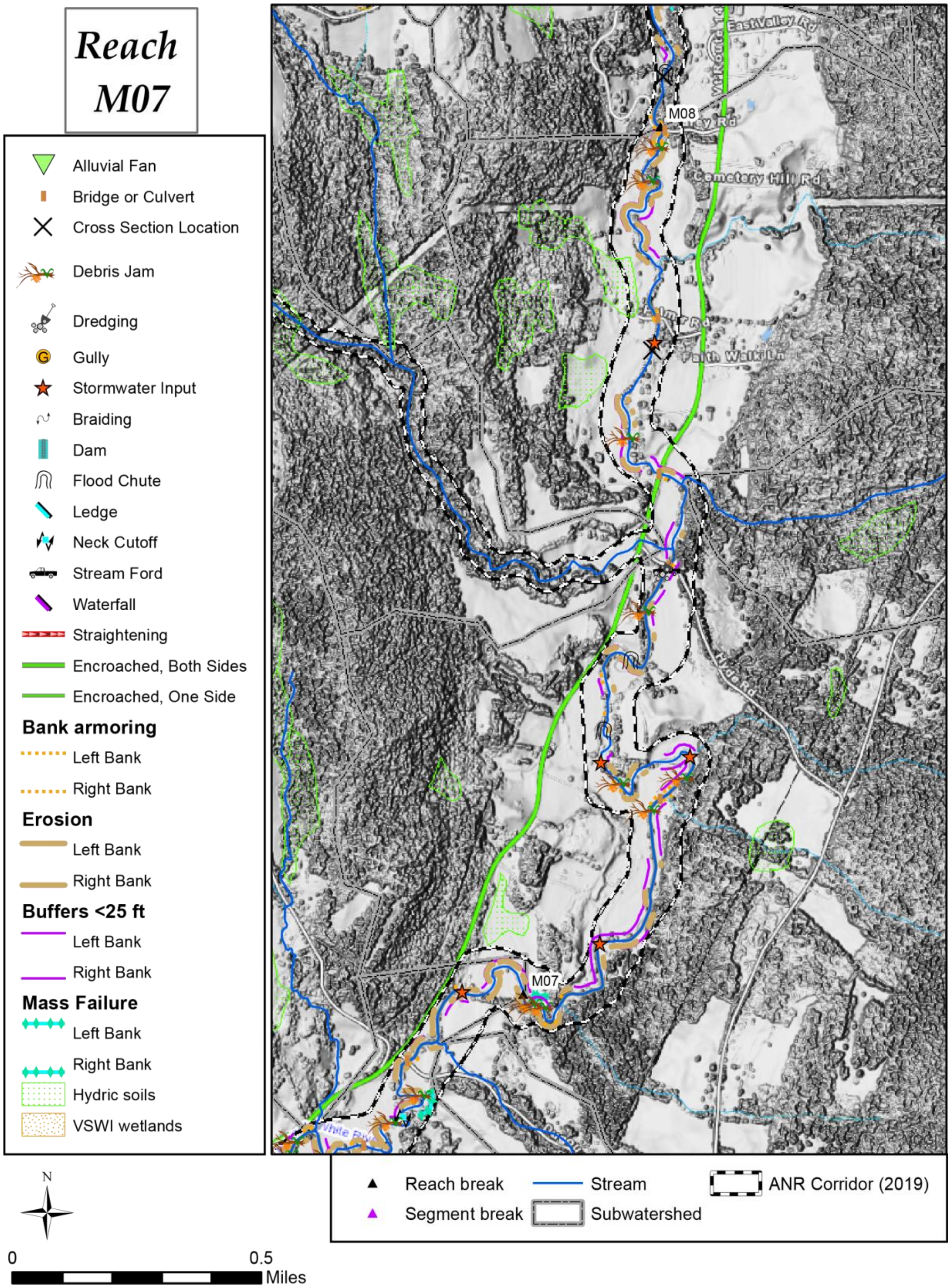



**Figure 54. M07 Reach Summary Graphic**

| **M07 Data Summary** | | **Reference** | **Existing** |
|---|---|---|---|
| Length: 14,323 ft.<br>Drainage Area: 53.47 sq. mi.<br>Evolution Stage: III<br><br>Sensitivity: Very High | Confinement | Broad | Very Broad |
| | Stream Type | C | C |
| | Entrenchment Ratio | >2.2 | 13 |
| | Incision Ratio | <1.2 | 1.5 |
| | Dominant Bed Material | Gravel | Gravel |
| | Dominant Bedform | Riffle-Pool | Riffle-Pool |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 18: M07 Phase 2 Data Summary**

*Primary Stressors:*

- Agricultural use in river corridor mixed with poorly established buffers
- Loss of sinuosity, historic straightening, and aggradation
- Multiple constriction points from both private and public bridges
- Stream ford leading to capture of adjacent farm fields

*M07 Summary:*

Reach M07 starts 0.25 miles north of Dugout Road and travels 14,323 feet north until it reaches the Braley Covered Bridge in East Randolph. This reach is a C-type stream with gravel as the dominant bed material and a riffle-pool dominant bedform. Like the preceding reaches, M07 follows VT-14: the lower half sits to the east of VT-14 and then crosses under the road to the west in the upper portion of the reach. The valley increases in width from M06 and moves into the Very Broad category with an estimated 700-foot valley width. While the corridor land use on river left is predominately forest, the river right corridor is dominated by agriculture (Fig. 55) with multiple historical farms lining this stretch of river starting north of Dugout Road and continuing past Hyde Road and up into the top portions of the reach. Large woody debris was common in M07, with 247 pieces of woody debris counted in the reach and 9 debris jams making the reach difficult to paddle but greatly benefitting habitat, diffusing high flows, and protecting banks in some areas (Fig. 55).

**Figure 55. Active erosion along un-buffered agricultural fields has not taken the banks behind a downed tree (large woody debris)**

This reach has large amounts of erosion with over 2,300 feet of erosion on river left and almost 1,700 feet of erosion on river right. Due to the erosion, rip-rap is common in this reach (Fig. 56), particularly where the river comes close to VT-14.

**Figure 56. Riprap revetments along the left bank and adjacent agricultural fields in M07**

Reach M07 is characterized by major to extreme planform adjustments with major widening and aggradation following historic degradation. Fine sediments mean cyclical channel adjustments wash out quickly, and current reduced sensitivity means long-standing straightening is still extensive; channel manipulations quickly undo channel adjustments. The lower section of the reach runs against the left valley wall and has a unique forested feel compared to the rest of the reach, however after the lower half mile of the reach the river moves to the west and sits closer to the middle of the Very Broad valley. Along this middle stretch of the reach there were areas of localized dredging noted streamside. A sand and gravel pit along this stretch is not visible from the stream or VT-14, as it has been excavated at a lower elevation than terraces comprising roadside fields. The river meanders through a highly eroded and poorly buffered stretch in the middle of the reach before it crosses under Hyde Road at the Gifford Covered Bridge and former Gifford farm property.

Reach M07 crosses under 5 different bridges including Gifford Covered Bridge at Hyde Road and the Braley Covered Bridge at Braley Road, both of which were placed on new, substantial concrete abutments shortly before Vermont revised Stream Alteration permits to accommodate full bankfull width when sizing stream crossing structures. All three covered bridges on the Second Branch (Kingsbury, Gifford and Braley) have spans significantly shorter than bankfull width and evidence significant scour and erosion in the vicinity of the structures., but the new abutments under all three are likely to be in place for quite a while.


Since most farm machinery can't fit, there is a stream ford directly downstream of the Gifford Covered Bridge (Fig. 57).

**Figure 57. Stream ford downstream of the Gifford Covered Bridge**

Recent channel avulsions initiated at the ford have captured portions of the adjacent left bank agricultural fields (Fig. 58).

**Figure 58. Field capture from ford at Gifford Covered Bridge; river can access this field in higher flows**


The area around the Gifford Covered Bridge and ford has been identified for river corridor protection, ford remediation, and buffer planting. Just upstream of the Gifford Covered Bridge, Penny Brook enters along the right bank. At the Penny Brook and Second Branch confluence, there appeared to be indications of dredging, possibly related to plugging at the bridge, or use for ford maintenance.

Upstream of the Penny Brook confluence, the river crosses under VT-14 to the west and continues upstream, passing under multiple farm bridges and two small bridges allowing the river to cross under Gilderdale Lane and Palmer Road. The upper portion of M07 is highly eroded but also has stretches of buffer covering both sides of the river (although most of the buffers do not extend more than 25 feet in width in this upper area). Heading north, the Second Branch passes two large agricultural fields before the reach ends at the Braley Covered Bridge.

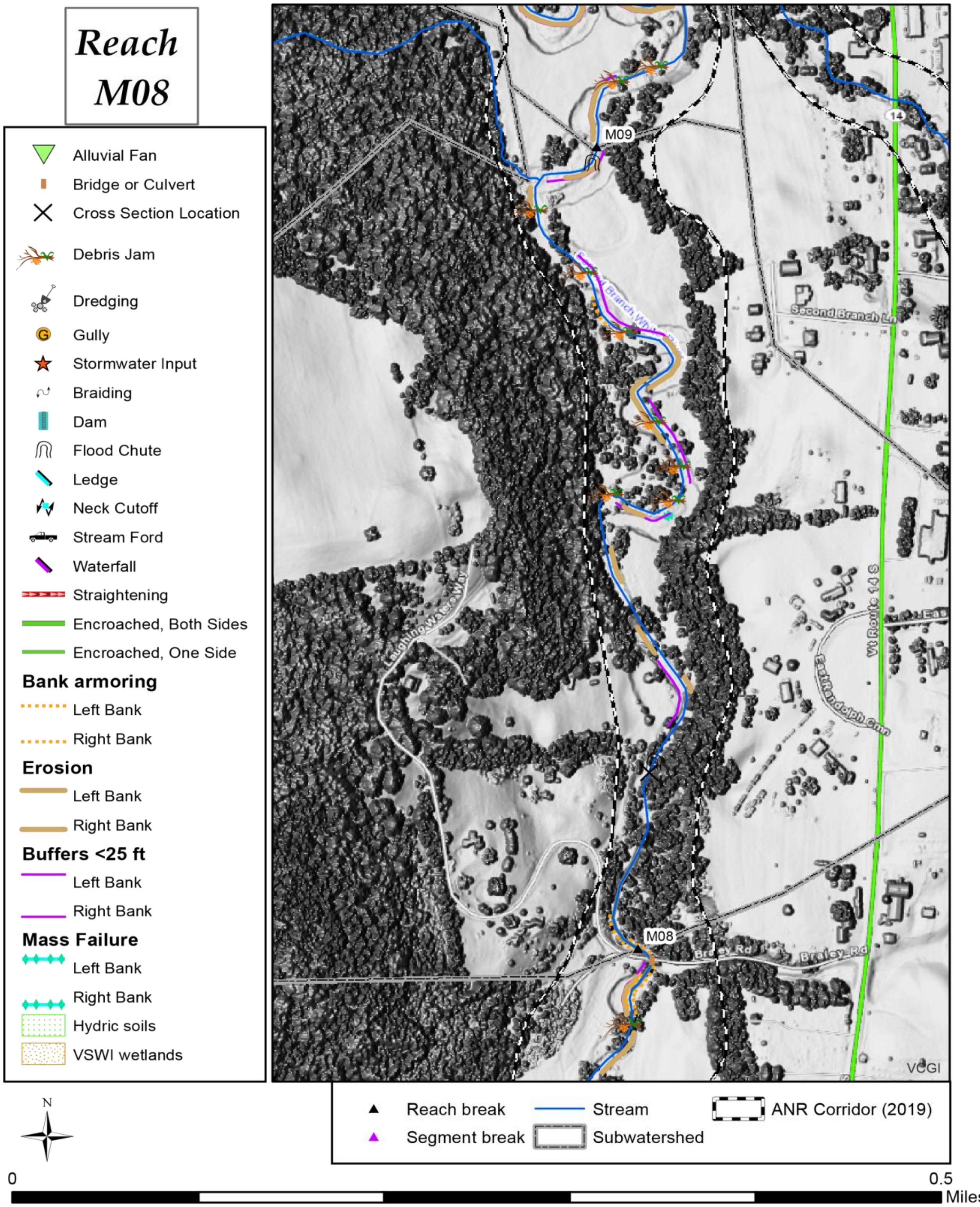



**Figure 59. M08 Reach Summary Graphic**

| M08 Data Summary | | Reference | Existing |
|---|---|---|---|
| Length: 3,162 ft.<br>Drainage Area: 46.99 sq. mi.<br>Evolution Stage: III<br><br>Sensitivity: Very High | Confinement | Narrow | Narrow |
| | Stream Type | C | C |
| | Entrenchment Ratio | >2.2 | 5.3 |
| | Incision Ratio | <1.2 | 1.3 |
| | Dominant Bed Material | Gravel | Gravel |
| | Dominant Bedform | Riffle-pool | Riffle-pool |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 19: M08 Phase 2 Data Summary**

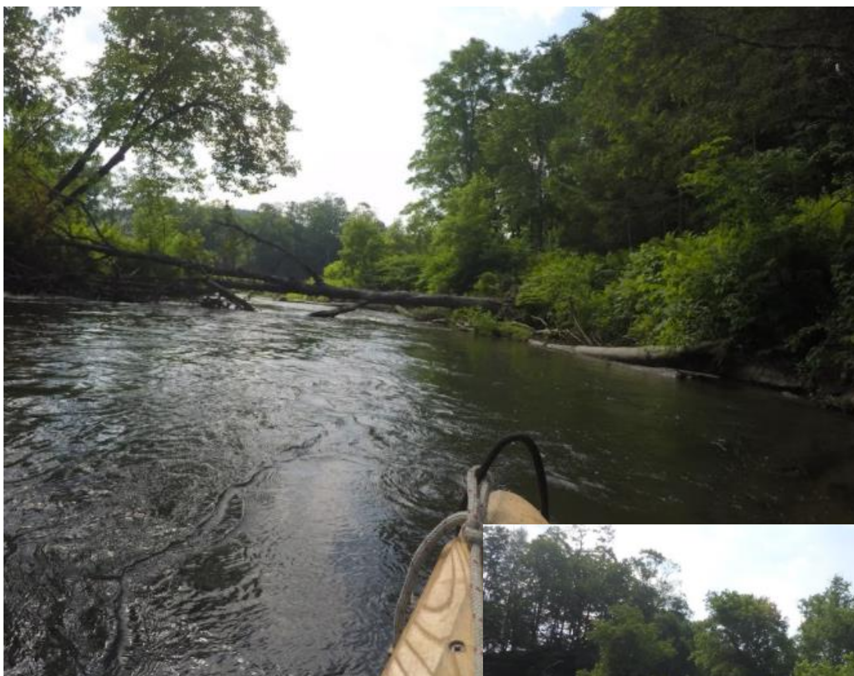
*Primary Stressors:*

- Historic incision
- Presence of Braley Covered Bridge downstream and Gulf Road Dam upstream, influencing sediment continuity
- Moderate aggradation and widening – tempered by buffers and woody debris

*M08 Summary:*

**Figure 60. VT-14 does not enter the river corridor (or even the river valley) in reach M08, a rarity in the Second Branch. The result is a stretch of stream that is a relatively well buffered, with minimal erosion**

On the downstream end, M08 starts at Braley Covered Bridge and continues 3,162 feet north until it ends due west of the Tunbridge Mtn. Road and VT-14 junction. This reach is relatively short and enters into a Narrow valley with field-estimated width of 300 feet. The entire river corridor is to the west of VT-14, representing the rare situation in which VT-14 lies completely outside of the Second Branch Valley. The adjacent slope in the valley is very steep on both the left and right sides, giving this reach a wooded valley feeling. The reach has low sinuosity and remains straight throughout most of its distance, with a few long meanders. The C-type stream has gravel for its dominant bed material and a riffle-pool dominant bedform. This reach has good buffers, with the dominant buffer width being over 100 feet on both right and left banks. Erosion on this stretch is present but minimal, with 346 feet of erosion on the left bank and 463 feet of erosion on the right bank. Many of the preceding reaches in the Second Branch are dominated by agricultural fields, which is less true in this reach and marks a distinct change in land use. Coarser sediments from a kame terrace in the upstream half of the reach have influenced and contribute to riffle/bar formation, but glacial lake bottom sediments in the downstream half of the reach lend to elevated channel incision due to fine sediments; alluvium on the terrace off the right bank are indicative of historic floodplain abandonment, now well elevated above the current channel. Braley covered bridge is technically in M07, but long-standing effects of this undersized structure influence planform in M08 (this reach). In this relatively short reach there were a total of 7 full woody debris jams and 76 pieces of large woody debris counted. Major planform change following primarily historic incision characterizes the reach, but the rate of aggradation and widening are moderated by decent buffers and sediment transport discontinuity at the Gulf Road dam (upstream in M09). It appears likely that a historic ford or bridge was once present at the M09 reach break and is now gone, and this location is now experiencing aggradation at the upstream end of M08. The presence of Braley bridge contributes to aggradation above, and scour at and downstream of this structure on the downstream end. Good buffers limit the rate of widening, and tipped trees are primary drivers of planform change.



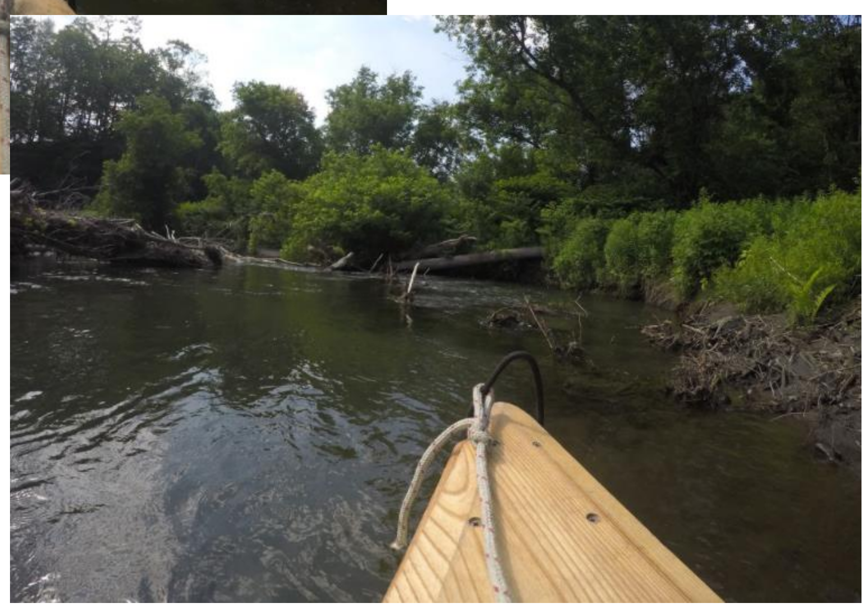


**Figure 61. The figures here demonstrate the presence of woody debris in reach M08, which had a total of 7 debris jams. Multiple pieces of large wood and good buffers slow widening process and add sinuosity.**

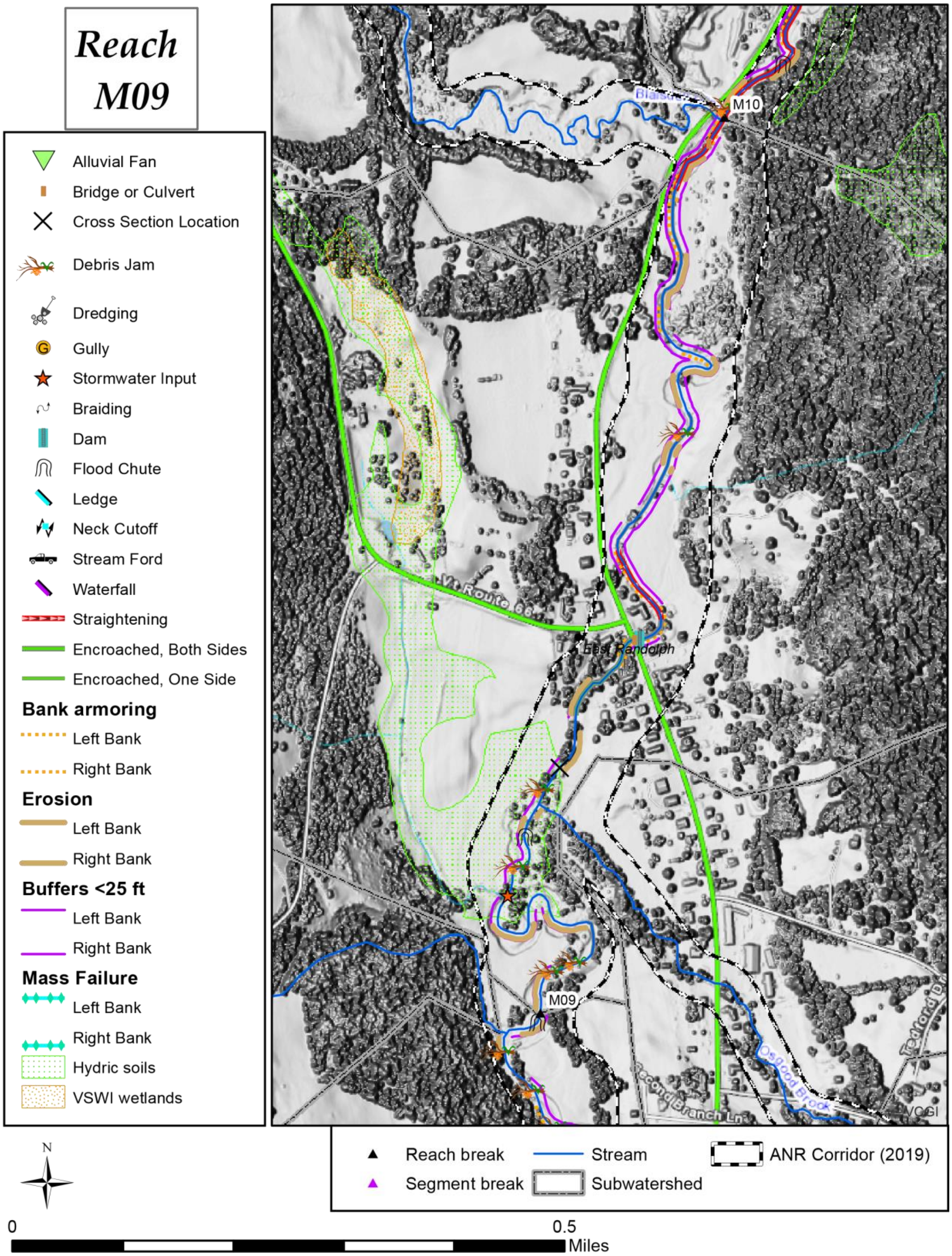



**Figure 62. M09 Reach Summary Graphic**

| **M09 Data Summary** | | **Reference** | **Existing** |
|---|---|---|---|
| | Confinement | Broad | Broad |
| Length: 6,067 ft. | Stream Type | C | C |
| Drainage Area: 46.32 sq. mi. | Entrenchment Ratio | >2.2 | 6.1 |
| Evolution Stage: III | Incision Ratio | <1.2 | 1.6 |
| Sensitivity: Very High | Dominant Bed Material | Sand | Sand |
| | Dominant Bedform | Dune-Ripple | Riffle-Pool |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 20: M09 Phase 2 Data Summary**

*Primary Stressors:*

- Gulf Road Dam, lending to reduced sediment transport and elevated floodplain terraces
- Historic incision, aggradation and widening
- Extensive erosion, worsened by fine sediments present

*M09 Summary:*


**Figure 63. Looking upstream at Gulf Road Dam and the VT-14 bridge that sits above it**

M09 runs through East Randolph village, from west of Tunbridge Mountain Road on the downstream end to the Mouth of Blaisdell Brook on the upstream end. The river valley widens to roughly 600 feet and the Second Branch once again runs along VT-14 (to the west in the lower portion and to the east in the upper portion). This reach is a C-type stream, with sand for the dominant bed material and a riffle-pool bedform. The lower part of the reach runs along primarily wooded and agricultural areas and for a short stretch is buffered on both the right and left bank. Moving upstream, the buffered area gives way to the residential area in the village of East Randolph.

At the junction of VT-66 and VT-14 is the Gulf Road Dam (Fig. 63). The dam spans under the VT-14 bridge that sits next to the Middle Branch Market and Deli. The 0.11-acre property downstream of the dam, as well as the dam rights, are owned by the Town of Randolph, and there


**Figure 64. The Gulf Road dam impounds a pool deep enough to maintain a dry hydrant for the East Randolph Fire Department (intake pipe at lower left of photo)**

is a dry hydrant at the upstream end of the dam that is maintained and utilized by the East Randolph Fire Department (Fig. 64). Gulf Road Dam is a low-hazard concrete structure that is 55 feet long and 8 feet in height. With projected removal of Hyde Dam in East Bethel in summer of 2021, the Gulf Road Dam would be the only remaining intact dam on the Second Branch of the White River.

The Gulf Road Dam has been identified as a possible removal project, and represents a larger initiative to improve water quality, sediment continuity, and aquatic organism passage in the White River watershed. Water quality sampling downstream of the Gulf Road Dam has historically had the highest *E. coli* readings in the watershed, and increased sediment continuity as a result of the dam removal may help address naturalized *E. coli* populations found in the fine sediments of the Second Branch. The Gulf Road Dam constricts what otherwise is a Very Broad valley.

**Figure 65. Upstream of the Gulf Road Dam, the river is flat and heavily sedimented. VT-14 encroaches intermittently on river right while a steep valley wall sits off river left.**

Although preparation for fieldwork originally anticipated segmentation of the reach due to this, the portions of the stream upstream and downstream of the dam are remarkably similar, likely due to glacial Lake Hitchcock influences on surficial geology with the reach dominated by fine sediments above and below.

Upstream of the Gulf Road Dam, M09 continues for another 0.5 miles up to the confluence of the Second Branch and Blaisdell Brook. This stretch has significant sediment build up due to the presence of the dam, the fine sediments left by glacial Lake Hitchcock, and the relatively flat slope of the Second Branch. While there are many benefits to the removal of the Gulf Road Dam, the Second Branch on a whole sees significant impacts from historic damming and constriction points, resulting in elevated terraces that are likely at elevations correlating to historic dam heights. Removal of the current dams along the reach without confirmed grade control upstream, may result in pervasive down cutting and fine sediments move downstream. This upper stretch of the reach is highly eroded with large sections having no buffer present. One large agricultural field dominates the river corridor in this section before the Second Branch gets pinned between VT-14 and the left valley wall at the top of the reach. Overall the reach can be described as having major planform adjustments thru aggradation and widening following primarily historic incision, the presence of the Gulf Road Dam plays a large role health and behavior of this reach.

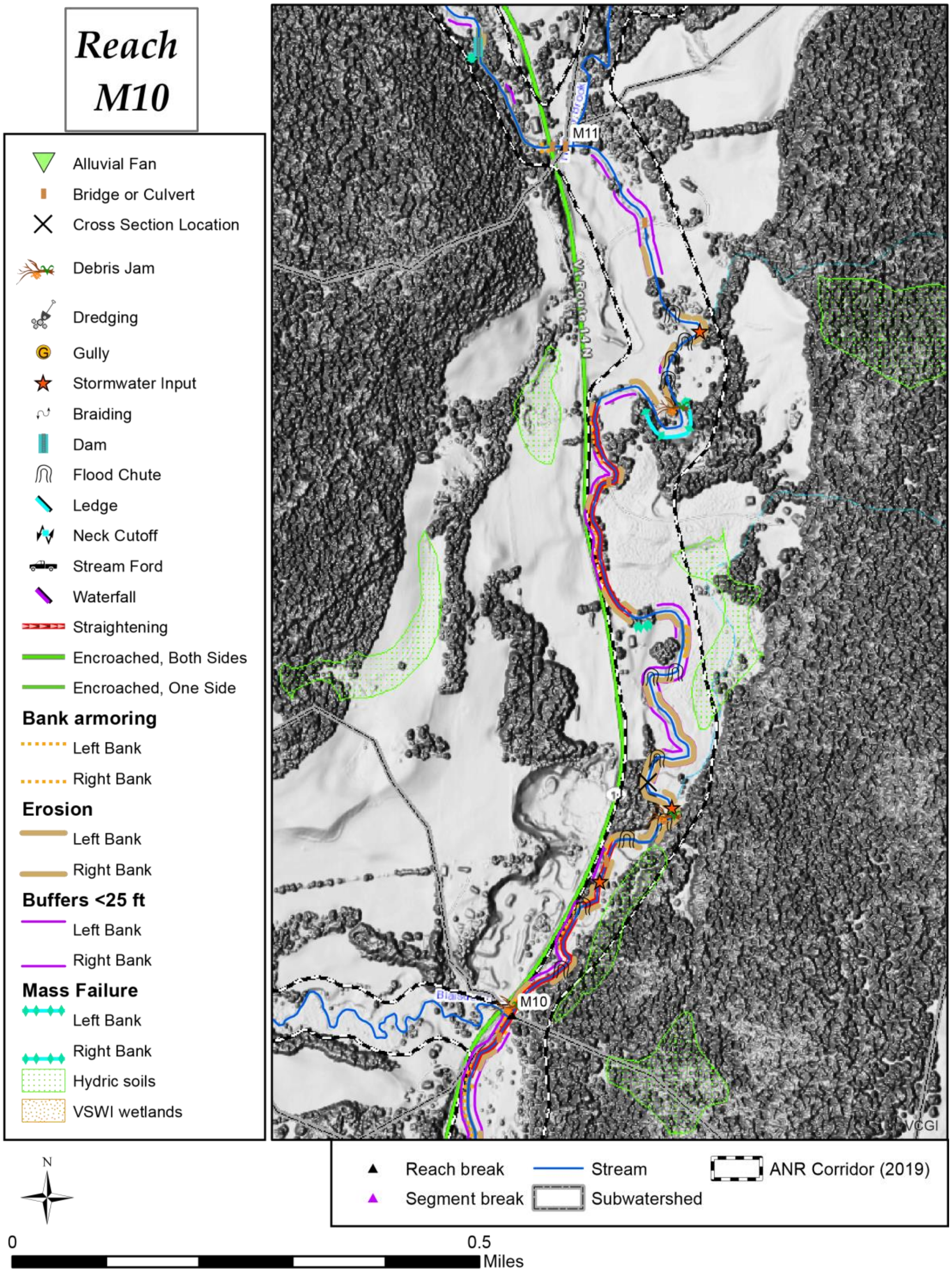



**Figure 66. M10 Reach Summary Graphic**

| M10 Data Summary | | Reference | Existing |
| --- | --- | --- | --- |
| Length: 7,595 ft.<br>Drainage Area: 38.89 sq. mi.<br>Evolution Stage: III<br><br>Sensitivity: Very High | Confinement | Very Broad | Broad |
| | Stream Type | C | C |
| | Entrenchment Ratio | >2.2 | 6 |
| | Incision Ratio | <1.2 | 1.3 |
| | Dominant Bed Material | Gravel | Gravel |
| | Dominant Bedform | Riffle-pool | Riffle-Pool |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 21: M10 Phase 2 Data Summary**

*Primary Stressors:*

- VT-14 restricts access to historic floodplains
- Severe erosion and in response extensive revetments to protect VT-14
- Tire dump (eroded after use as revetments) and lack of established buffer through agricultural fields along reach

*M10 Summary:*

**Figure 67. M10 is characterized by a lack of buffers - the wide open reach offers little in bank stability and habitat due to the lack of buffers.**

M10 runs from Blaisdell Brook on the downstream end up to the mouth of Halfway Brook on the upstream end. This reach is 7,595 feet in length and the reach stays to the east of VT-14 for the entirety of its length as it flows through the Broad valley. M10 is a C-type stream with gravel as the dominant bed material and a riffle-pool dominant bedform. M10 is both heavily eroding and heavily rip-rapped. Both the right and left bank have over 2,000 feet of erosion and most of the erosion measures over 4 feet in height. The right bank of the reach (adjacent to VT-14) has approximately 1,500 feet of rip-rap to protect its banks from further eroding and compromising the road. VT-14 cuts off access to the majority of the historic floodplain on river right, playing a major role in the function and health of the reach. The reach is poorly buffered with both the left and right banks having 0-25 feet as the dominant buffer width. Like most reaches in the upper Second Branch valley, the dominant land use for the reach is agricultural. At the halfway point along reach M10, a property was identified for multiple river restoration projects.

This property is a 72-acre parcel that starts south of Halfway Brook and is situated along VT-14. The Second Branch of the White River meanders through the property for approximately 1,500 feet. Most of the left bank of the river that runs through the property is experiencing severe erosion at a height of 3 to 4 feet. In an effort to mitigate the erosion, tires were placed along the banks as a form of rip-rap (Fig. 68). While some of the tires remain installed along the banks, the majority of the tires have fallen into the river creating an extensive dump. The suite of projects proposed for this location include a cleanup and removal of the tires in the banks and in the river. An estimated 50-100 tires are present on the property. In addition to the cleanup, buffer plantings and river corridor easements are recommended. The heavy erosion in this project area, with several stretches of revetments and bank armoring, have severely impacted the reach and lead to almost 2,500 feet of historic straightening resulting in reduced sinuosity. M10 also has 4 small, undersized private bridges amplify the straightening and erosion issues in the reach. The reach can be summarized as undergoing major widening and planform adjustments following primarily historic incision. Apparent successive floodplain abandonment (a likely older, higher abandoned floodplain was noted on the right bank in the area where the reach cross-section was taken) was probably offset by aggradation in recent flash flood events. Widening now appears as a more evident adjustment, with coarser sediment inputs ("sediment slugs"; Fig. 69) from tributaries increasing localized bed resistance relative to a lack of stability and increased erosion in adjacent banks. This dynamic lends to frequent cycling of widening and aggradation offsetting localized incision.

**Figure 68. Tire dump in M10, tires used for revetments are now in river bed or slumped along the banks**

**Figure 69. Larger bed material (gravel and cobble), likely originating from tributaries and discharged to the mainstem in flash floods, differentiate M10 from many of the sandy/fine sediments found along much of the Second Branch**

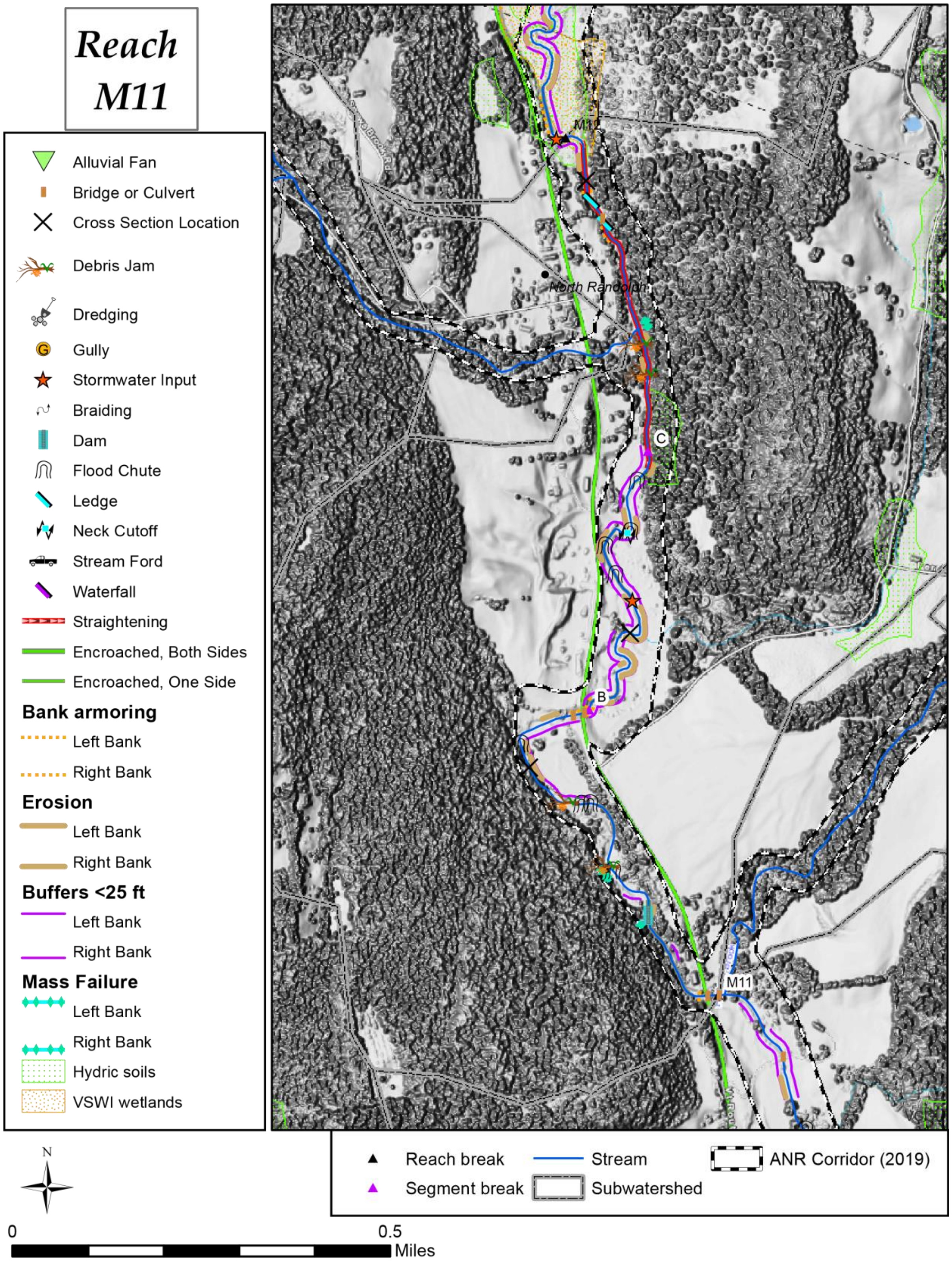



**Figure 70. M11 Reach Summary Graphic**

| M11-A Data Summary | | Reference | Existing |
|---|---|---|---|
| Length: 3,158 ft.<br>Drainage Area: 53.47 sq. mi.<br>Evolution Stage: III<br><br>Sensitivity: Extreme | Confinement | Narrow | Semi-Confined |
| | Stream Type | C | F |
| | Entrenchment Ratio | >2.2 | 1.1 |
| | Incision Ratio | <1.2 | 2.4 |
| | Dominant Bed Material | Cobble | Gravel |
| | Dominant Bedform | Riffle-Pool | Riffle-Pool |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

| M11-B Data Summary | | Reference | Existing |
|---|---|---|---|
| Length: 2,491 ft.<br>Drainage Area: 53.47 sq. mi.<br>Evolution Stage: III<br><br>Sensitivity: Extreme | Confinement | Narrow | Narrow |
| | Stream Type | C | C |
| | Entrenchment Ratio | >2.2 | 7 |
| | Incision Ratio | <1.2 | 1.6 |
| | Dominant Bed Material | Cobble | Gravel |
| | Dominant Bedform | Riffle-Pool | Riffle-Pool |
| **Geomorphic Stream Condition** | **Poor** | | |
| **Physical Habitat Condition** | **Poor** | | |

| M11-C Data Summary | | Reference | Existing |
|---|---|---|---|
| Length: 2,396 ft.<br>Drainage Area: 53.47 sq. mi.<br>Evolution Stage: III<br><br>Sensitivity: Extreme | Confinement | Narrow | Semi-Confined |
| | Stream Type | C | B |
| | Entrenchment Ratio | >2.2 | 1.4 |
| | Incision Ratio | <1.2 | 2.0 |
| | Dominant Bed Material | Cobble | Sand |
| | Dominant Bedform | Riffle-Pool | Dune-Ripple |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 22: M11-A, -B, -C Phase 2 Data Summary**

*Primary Stressors:*

- Large sidewall headcuts and severe erosion in M11-B
- Sediment discharges from steep valley walls in flash flood events
- Limited floodplain access (especially in M11-A)

*M11-A Summary:*

**Figure 71. The lower portion of M11-A is confined between the steep valley wall on river right, which still has remains of a historic dam and infrastructure, and the VT-14 road embankment on river left**

The downstream end of M11-A starts at the confluence of Halfway Brook and the Second Branch. Heading upstream, the river immediately passes under a snowmobile bridge and then under VT-14 where the reach runs along the right valley wall. The segment's upstream boundary features another snowmobile bridge just downstream of the VT-14 bridge near Ferris Road, where the valley width changes significantly (broader upstream). The segmentation of this reach is due to variable valley widths, in part due to the to the presence of historic dams in downstream (M11-A) and upstream (M11-C) sections. M11-A features the remains of a historic dam behind the Creamery in North Randolph (no longer present, first dam at this site in 1799; VWRC 1921) profoundly influencing the segment dynamics. Based on fieldwork for this report, it is suspected that a log crib dam was replaced by concrete after 1921 (based on VWRC 1921 and presence of Ransome bar remnants on-site), then destroyed in the 1927 flood and not rebuilt. The stream is very entrenched here and fine sediments cyclically deposit/wash out, while decent buffers actually limit the rate of channel evolution; floodplain access is likely to remain very limited. Significant large woody debris and debris jams were present in this segment, and buffers over 50 feet in width are dominant on both banks. It was not clear if ledge underlies the concrete apron remains at the old dam site (but seems likely).


**Figure 72. Not clear if channel-spanning ledge underlies the remains of a concrete apron at the former dam site behind the Creamery in North Randolph, in segment M11-A**

*M11-B Summary:*

M11-B boundaries span from the VT-14 bridge near Ferris Road at the downstream end to Snow's Brook on the upstream end where the valley changes from Narrow to Semi-confined in segment M11-C. The segment length is 2,491 feet and meanders with high sinuosity over that length. This reach has erosion totaling 723 feet on the left bank and 540 feet on the right bank. The midsection of the reach includes neck cutoffs, multiple flood chutes, and deep head cutting along the left valley sidewall. Significantly coarser sediment inputs at the mouth of Snows Brook off the right bank contribute to higher sinuosity and elevated planform adjustments. The Second Branch likely shared floodplain with an alluvial fan, possibly historically but certainly during the presence of glacial Lake Hitchcock, at the base of Halfway Brook off left bank toward the downstream end of this segment. The Second Branch has been historically routed under VT-14, toward the right valley wall, cut off from this former floodplain by Ferris Road. A large headcut present in deep, fine deposits along the left valley wall upstream of here may be due to a small tributary and/or stormwater inputs from further up Ferris Rd, but the source was not discovered.

**Figure 73. Severe head cut in M11-B, with areas of eroded banks over 6 feet in height**

*M11-C Summary:*

M11-C extends north from Snow's Brook to the upper boundary of the reach at the north end of North Randolph village. Snow's Brook enters the downstream end of this segment, contributing coarser sediments to the river bed. M11-C runs relatively straight with residential homes on river right sitting atop a kame terrace that confines the reach in combination with the remains of former dam-related infrastructure off the left bank. A log and plank bridge midway through the segment sits atop dam remains and channel-spanning ledge that act as a grade control for the segment.

**Figure 74. Log bridge and mid-channel abutment in M11-C sit atop old dam remains that appear to rest on a channel-spanning ledge grade control.**

"At North Randolph village a head of about 9 feet is obtained and a 40 horsepower water wheel is used for operating a saw mill, shingle mill, and grist mill." (VWRC 1921). The upstream portion of M11-C is the tail end of the old mill pond, and most of the segment is dominated by very fine silts. Infrastructure from mill buildings and a raceway are still present downstream off the left bank. Beers Atlas (1877) indicates a grist mill on the right bank, and carriage factory on the left bank just downstream; much of the remaining infrastructure would likely have been associated with the carriage factory.

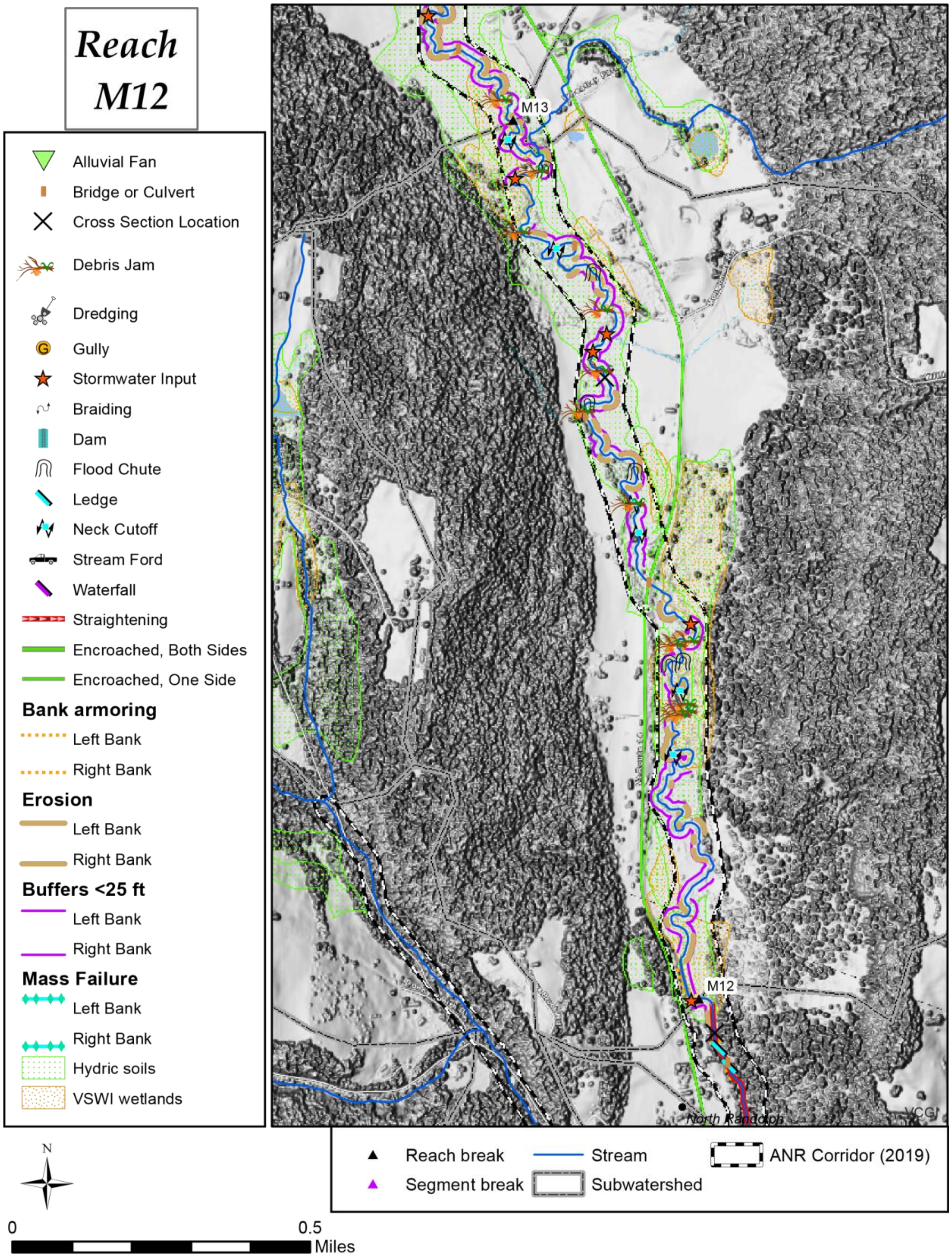



**Figure 75. M12 Reach Summary Graphic**

| M12 Data Summary | | Reference | Existing |
|---|---|---|---|
| Length: 13,706 ft.<br>Drainage Area: 26.14 sq. mi.<br>Evolution Stage: IV<br><br>Sensitivity: Very High | Confinement | Very Broad | Very Broad |
| | Stream Type | E | C |
| | Entrenchment Ratio | >2.2 | 33.1 |
| | Incision Ratio | <1.2 | 1.2 |
| | Dominant Bed Material | Sand | Sand |
| | Dominant Bedform | Dune-Ripple | Dune-Ripple |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 23: M12 Phase 2 Data Summary**

*Primary Stressors*

- VT-14 bisects reach, essentially cutting valley width in half
- Multiple bridges and culverts directing flow to valley wall
- Heavy agricultural use and lack of functioning buffers
- Erosion and neck cutoffs leading to decrease in sinuosity

*M12 Summary:*

**Figure 76. Example of a private bridge in M12 with low clearance; these bridges and their abutments significantly straighten the reach and restrict access to floodplain**

The downstream boundary of M12 is the north end of Randolph Village and the reach extends north for 13,706 feet until it reaches Wheatley Farm. The reach sits in a Very Broad valley at almost 1,500 feet. VT-14 bisects valley in this reach, cutting historic floodplain in half, but is borderline as an actual valley wall in many areas due to minimal elevation above existing floodplain. Highly sinuous stretches are interspersed with areas of straightening and ditching that are maintained by multiple bridges and a culvert that maintain flow along the valley perimeter. Downstream of the long culvert underneath VT-14 (Fig. 77) are more intact alder meadow Class 2 wetlands (VSWI 2010) that are likely closer to reference conditions for the reach, but even this


section shows effects of straightening by the culvert, historic farming practices, and a recently installed private bridge; this area was thus not segmented during assessment.

**Figure 77. Long culvert under VT-14 directs the stream toward the right valley wall, where it remains east of the road for the downstream portion of the reach**

M12 shows similar characteristics to many of the heavily farmed reaches in the upper portion of the Second Branch, including over 1,000 feet of erosion on each bank and diminished or absent woody vegetated buffers. This reach has an E to C stream type departure due to major reduction in sinuosity and minor aggradation, widening, and planform change driven in part by coarser sediment recruitment from steeper valley sidewall tributaries as a result of flash floods in upstream reaches. The typical soils within the reach are very fine silty loams (Fig. 78).

**Figure 78. Typical M12 segment: widenend, reduced sinuosity, and fine-grained sediments**

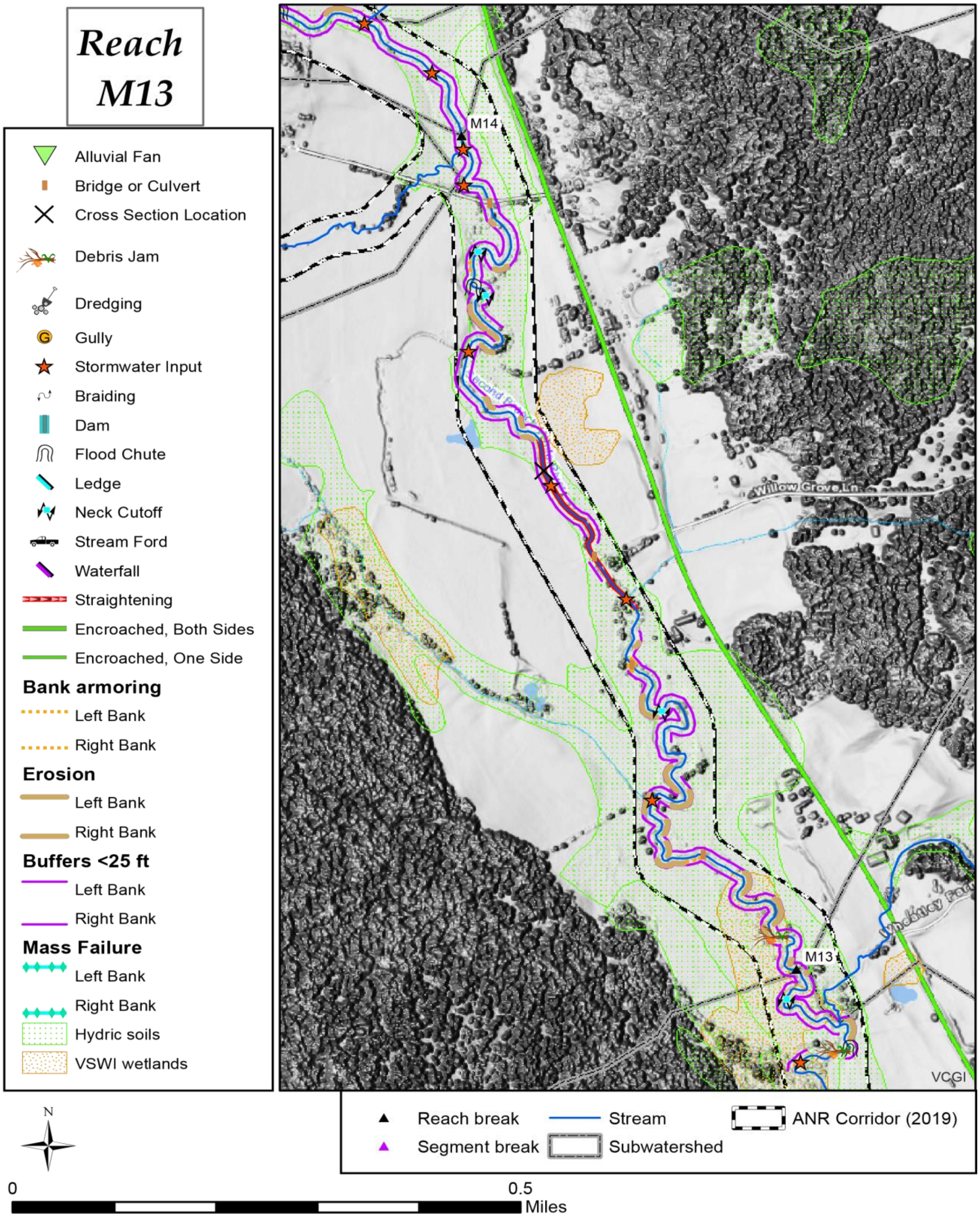



**Figure 79. M13 Reach Summary Graphic**

| M-13 Data Summary | | Reference | Existing |
|---|---|---|---|
| Length: 7,241 ft.<br>Drainage Area: 23.95 sq. mi.<br>Evolution Stage: IV<br><br>Sensitivity: Very High | Confinement | Very Broad | Very Broad |
| | Stream Type | E | C |
| | Entrenchment Ratio | >2.2 | 38.3 |
| | Incision Ratio | <1.2 | 1 |
| | Dominant Bed Material | Sand | Gravel |
| | Dominant Bedform | Dune-Ripple | Riffle-Pool |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 24: M13 Phase 2 Data Summary**

*Primary Stressors*

- Historic straightening
- Multiple farm bridges and constriction points maintaining straightening
- Heavy agricultural use and lack of functioning buffers
- Erosion and neck cutoffs leading to decrease in sinuosity

*M13 Summary:*

**Figure 80. Typical stretch of M13 and many upstream portions of the Second Branch as a whole: diminished buffers with eroded or recently healed banks bordering agricultural fields**

The downstream end of M13 starts due west of Wheatley Farm Road in Brookfield, VT and the upstream boundary is slightly north of McKeage Road. The reach extends for 7,421 feet and flows to the west of VT-14 for the entirety of the reach. M13 flows through a very broad valley, field estimated to be 1,500 feet in width. The moderate sinuosity stream sits in the middle of the valley for its entire length, never approaching either valley wall or VT-14. This C-type stream has gravel for the dominant bed material and a riffle-pool bedform. This reach runs through agricultural fields for the entirety of its length, leading to historic straightening and incision offset by subsequent aggradation due to widening and sediment contributions from upland tributaries. Multiple locations across the reach suffer from pronounced erosion and three neck cutoffs have contributed to the reduced sinuosity of the reach. While erosion can be severe at times, only 800 feet of active erosion was measured on each of the left and right banks. Many of the banks across the reach that were once more actively eroding showed signs of healing with vegetation stabilizing the banks, but a lack of woody buffers can leave the banks more exposed during the winter when herbaceous vegetation dies back, and steeper portions of banks can be prone to heavy erosion during freeze-thaw cycles (Walter and Merritts et al 2018). This reach has almost no established woody buffers, with over 6,000 feet on both rivers left and right identified as having buffers less than 25 feet in width. The reach has 4 small bridges that it crosses under, restricting localized access to the floodplain and contributing to reduced sinuosity (which can amplify erosion much like routing a trail straight down a slope). M13 would likely be an E-type stream under reference conditions, but long-term straightening via the presence of multiple bridges, as well as ditching of valley sidewall tributaries and seeps, contributes to a widened stream with reduced sinuosity in a primarily agricultural setting along the floodplain areas. Both the downstream and upstream section of the reach feature mapped Class 2 wetlands (VSWI 2010), and possible wetland restoration projects were identified as part of this report for M13.

**Figure 81. As seen in lower reaches as well, multiple farm, road and private bridges constrict reach M13 in places and contribute to straightening; herbaceous vegetation dominates buffers, few trees or shrubs**

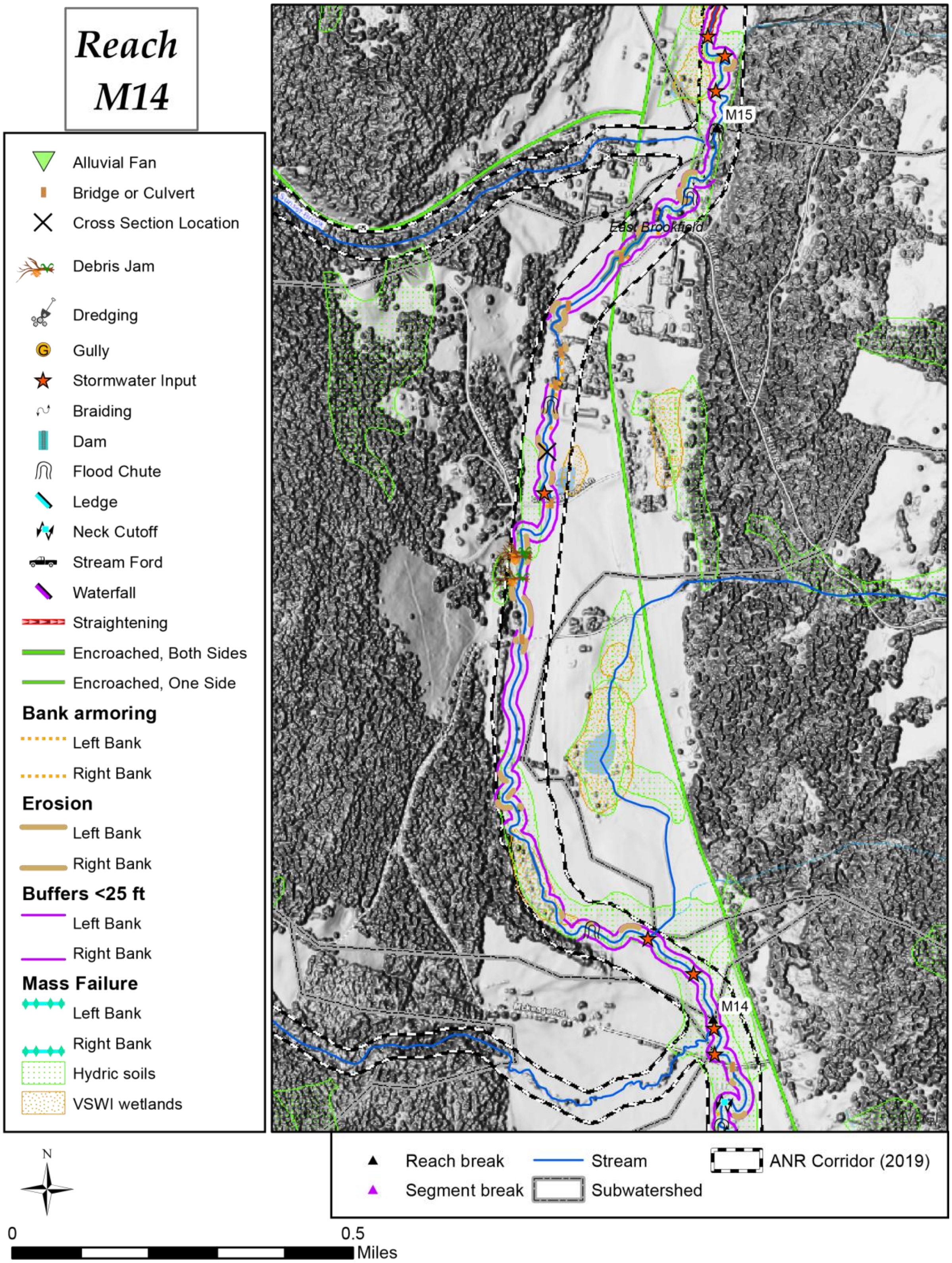



**Figure 82. M14 Reach Summary Graphic**

| **M14 Data Summary** | | **Reference** | **Existing** |
|---|---|---|---|
| Length: 9,611 ft.<br>Drainage Area: 20.09 sq. mi.<br>Evolution Stage: III<br><br>Sensitivity: Very High | Confinement | Very Broad | Very Broad |
| | Stream Type | C | C |
| | Entrenchment Ratio | >2.2 | 21.3 |
| | Incision Ratio | <1.2 | 1.2 |
| | Dominant Bed Material | Gravel | Gravel |
| | Dominant Bedform | Riffle-pool | Riffle-Pool |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 25: M14 Phase 2 Data Summary**

*Primary Stressors*

- Six bridges constricting river, restricting access to floodplain and contributing to straightening of the reach
- Encroachments, including a manure pit elevated above floodplain
- Lack of established woody buffers on left bank especially

*M14 Summary:*

**Figure 83. Steep banks make M14 feel entrenched as it meanders through agricultural fields to left and valley wall on river right**

Reach M14 runs for 9,611 feet from McKeage Road in Brookfield, VT at its downstream end to the mouth of Sunset Brook on its upstream end and includes the village of East Brookfield. This reach is a C-type stream with gravel as the dominant bed material and a riffle-pool bedform. Like M13, M14 continues in a Very Broad valley but the field estimated width is a more modest 700 feet in width. In addition, a notable difference is the geology of the reach as the surrounding soils are glacially-derived kame terrace and outwash gravels in comparison with the finer sands and silts found further downstream. Due to these factors, M14 would likely be a C-type stream under reference conditions as well as the current conditions. On the downstream end of the reach, the river runs to the west of VT-14 up against the right valley wall. On river left the Second Branch passes by primarily agricultural fields along its length with intermittent residential properties. Like M13, erosion can be severe at points throughout the reach with a total of 871 feet and 722 feet of erosion on river left and right respectively. Like M13, many eroded banks are now healed or healing with vegetation growth (Fig. 83) but with little woody vegetation are similarly prone to amplified erosion during freeze-thaw cycles when herbaceous vegetation has died back (Walter and Merritts et al 2018). The 3-4-foot-high vegetated banks give the reach an incised feeling, often making the stream feel "ditched" into the agricultural fields. There is almost no established woody buffer along the length of this reach, both the right and left bank have over 7,000 feet where less than 25 feet of buffer are present. This reach has six small bridges used to cross the stream to private residences or used as farm bridges, and these bridges create localized areas of constriction and limit access to floodplain in what otherwise functions as a Very Broad valley with moderate floodplain access (Fig. 84). Straightened planform (amplified and maintained by the six bridges in the reach, Fig. 85) lends to cyclic scour/deposition in response to flash flood events, which occur with some frequency due to a combination of orographic effects (particularly pronounced along the steep valley walls in upstream reaches approaching the Brookfield-Williamstown Gulf) and intermittent encroachments, both here and in upstream reaches, limiting floodplain access. In addition to the bridge constrictions, an elevated manure pit located in the upstream third of the reach further limits floodplain access. At the top of the reach, the river leaves the right valley wall, crosses under VT-14 and moves against the left valley wall where Sunset Brook runs into the Second Branch, forming the upstream boundary of the reach.

**Figure 84. Small sections of reach M14 have increased access to floodplain on river left, but overall the reach is moderately incised**

**Figure 85. Private bridge in upper portion of M14 has a small section of woody buffers on both banks, but presents localized constriction and diminished floodplain access that contribute to the straightened planform of the reach**

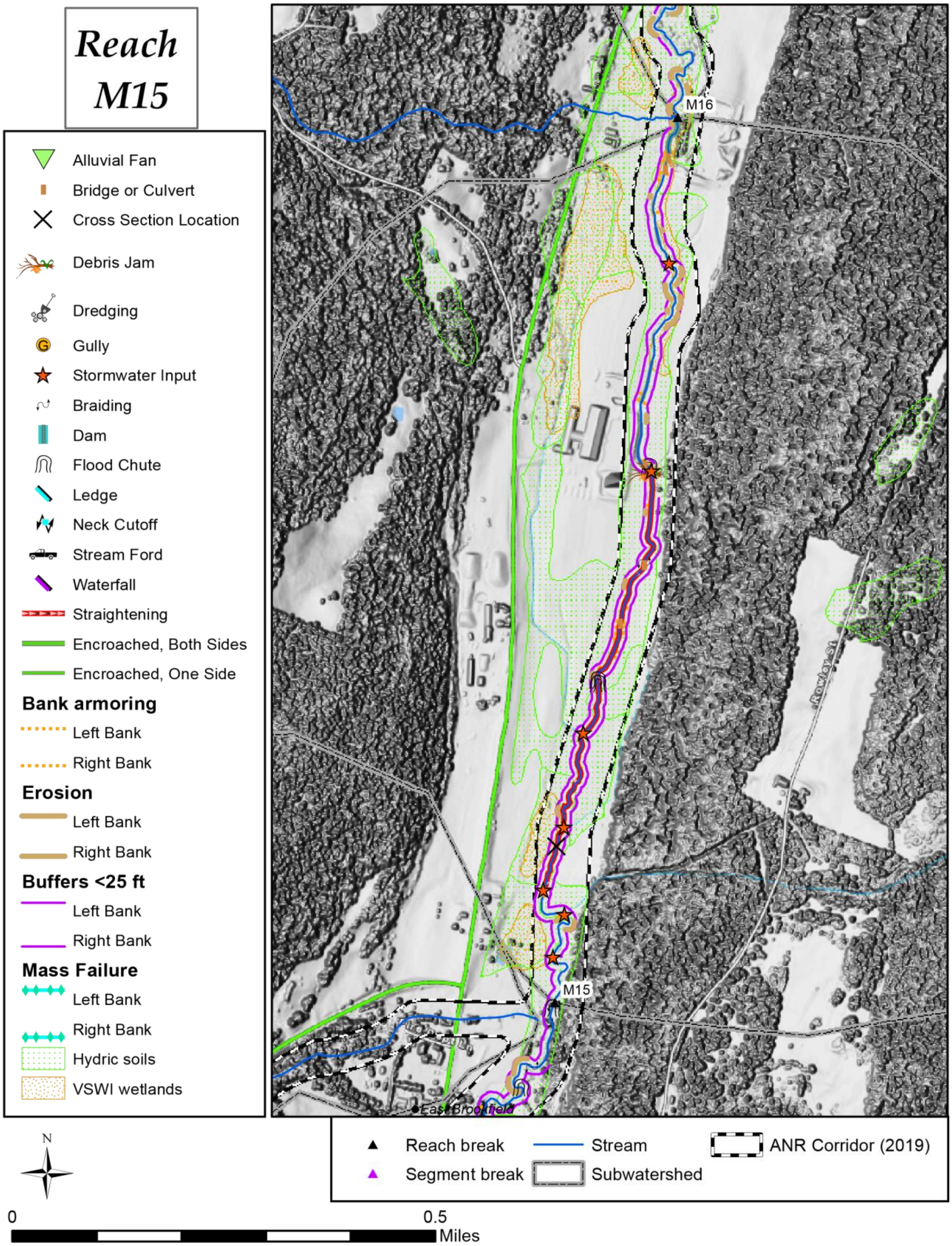



**Figure 86. M15 Reach Summary Graphic**

| M15 Data Summary | | Reference | Existing |
|---|---|---|---|
| Length: 6,394 ft.<br>Drainage Area: 11.93 sq. mi.<br>Evolution Stage: III<br><br>Sensitivity: Very High | Confinement | Very Broad | Very Broad |
| | Stream Type | E | E |
| | Entrenchment Ratio | >2.2 | 39.8 |
| | Incision Ratio | <1.2 | 1 |
| | Dominant Bed Material | Sand | Sand |
| | Dominant Bedform | Dune-Ripple | Dune-Ripple |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 26: M15 Phase 2 Data Summary**

*Primary Stressors*

- Historic ditching and straightening, altered wetlands
- Multiple channel constrictions including culverts and farm bridges
- Current agricultural use in river corridor lacks woody vegetated buffers

*M15 Summary:*

**Figure 87. An out of use farm culvert, no road runs atop this structure. The culvert constricts the reach and further straightens the "ditch" like stream**

M15 starts on the downstream end at the confluence of Sunset Brook and the Second Branch and runs 6,398 feet to the upstream boundary of the reach just north of Sprague Ranch. As in the preceding downstream reaches, the valley is Very Broad through M15, with an estimated 1,000 feet in width. The river follows east of VT-14 for the entirety of the reach and sits on the eastern side of the valley. The reach is an E-type stream with sand as the dominant bed material and a dune-ripple dominant bedform. The reach is extremely straightened, having little to no sinuosity and often times appearing to be a field ditch to the outside observer. There are very few woody vegetated buffers along the stream, with almost 6,000 feet on both left and right banks recording less than 25 foot buffers present. The reach has 3 instream culverts and 3 bridges, all formerly (Fig. 87) or currently (Fig. 88) used for farm crossings. These structures are largely in disrepair and act as localized channel constriction points, and the most upstream bridge in M15 is just 75 feet downstream of a very similar bridge accessing a gravel pit just across the abutting property line in reach M16.

It is likely the entirety of M15 has been ditched historically, and it is currently occupied entirely by the 'home farm' of a large dairy farming operation that is prominent in the northern portions of the Second Branch valley and surrounding uplands. An elevated manure pit encroaches on the outer edge of the stream corridor in the upstream portion of the reach, as does an active small gravel pit off the left bank at the top of the reach and extending into M16. Extensive altered wetlands are currently in agricultural use in M15, maintained with multiple drainage ditches, and streamside windrowing may have been obscured by agricultural use and tall, uncut hay at time of assessment (not much was evident and the floodplain appeared to be quite accessible). Reach M15 is on a likely post-glacial alluvial fan or deltaic formation at the base of multiple tributaries. The reach planform is highly altered by the aforementioned straightening and ditching, but channel adjustments are limited by good floodplain access dissipating energy of flood events (and likely, to an unknown degree, to ongoing maintenance of alterations). Frequent scour was noted around the stream constrictions (farm bridges and culverts) and accompanying several riffles comprised of failed former bank revetments. Beavers are active on the far upstream and downstream ends of the reach but impacts appear transient.


**Figure 88. Downstream of the active bridge shown here, surrounded by some of the very limited woody vegetation along M15, a series of farm bridges and culverts in varying states of use further constrict and straighten the reach.**

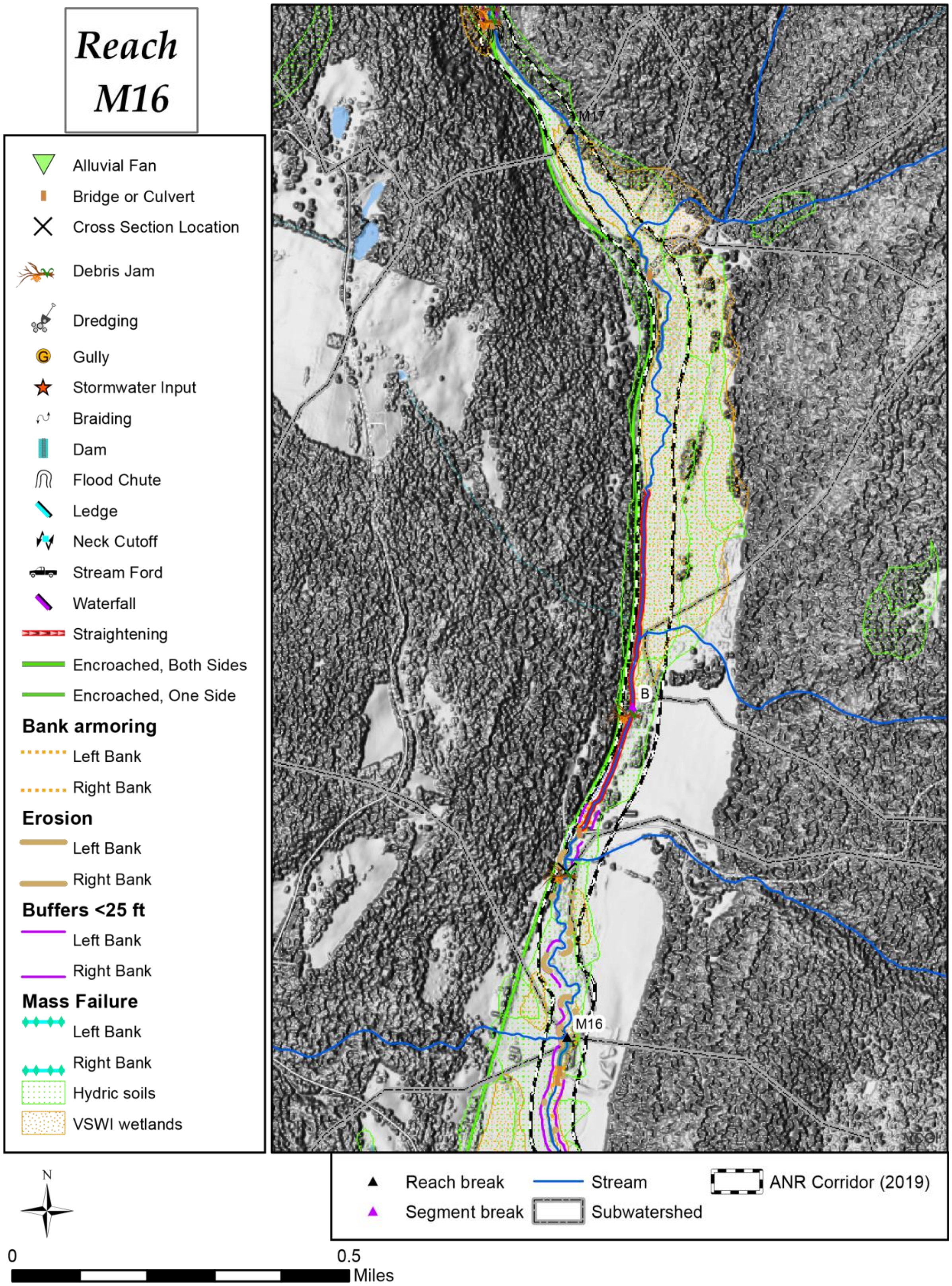



**Figure 89. M16 Reach Summary Graphic**

| **M16-A Data Summary** | | **Reference** | **Existing** |
|---|---|---|---|
| | Confinement | Very Broad | Very Broad |
| Length: 8,219 ft. | Stream Type | E | C |
| Drainage Area: 9.07 sq. mi. | Entrenchment Ratio | >2.2 | 34.9 |
| Evolution Stage: IV | Incision Ratio | <1.2 | 1 |
| Sensitivity: Very High | Dominant Bed Material | Sand | Gravel |
| | Dominant Bedform | Dune-Ripple | Riffle-Pool |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 27: M16-A Phase 2 Data Summary**

*Primary Stressors*

- Historic and pervasive straightening as river is pinned against right valley wall along with the presence of VT-14, also against the right valley wall
- Undersized Taylor Hill Road culvert
- Departure from multi-thread beaver inhabited environment found in upper section of reach

*M16 Summary:*

Reach M16 was divided into two segments due to extensive beaver presence in the upstream portions of the reach; upstream segment M16-B was excluded from full geomorphic assessment per protocols utilized for this assessment (VT-RMP 2009). This multithread channel area continues north for almost 5,00 feet until the channel returns to a single thread at the start of M17.

Downstream segment M16-A starts at the north end of Sprague Ranch and runs a length of 3,218 feet until the segment break north of Taylor Hill Road where the single channel yields to a multiple channel beaver influenced wetlands. While the river valley remains Very Broad throughout M16 (estimated at 800 feet in width) the river flows largely against the right valley wall in segment M16-A. The lower section of the reach suffers from extensive erosion for a short stretch opposite and upstream of a berm shielding a gravel pit on river left. The downstream portion of M16-A is sandwiched between two mapped Class 2 wetlands (VSWI 2010) and returns to an intermittent scrub-shrub buffered corridor after almost no buffer being present in the preceding downstream reaches. As the reach extends north, it crosses through a large culvert under Taylor Hill Road.

At 60 feet in length and 6 feet in diameter, this culvert is severely undersized for the 23-ft bankfull width stream. (Fig.90) The removal of the Taylor Hill Road culvert (ideally to be replaced by a bridge) was identified as a potential project as part of this assessment, although constraints due to road condition and orientation may make this process difficult. As mentioned above, the stream is


**Figure 90. The severely undersized Taylor Hill Road Culvert (looking downstream)**

pinned against the right valley wall which is also occupied by VT-14, further exacerbating the straightening effects on the stream and likely at least contributing to undermining the southwest corner of Taylor Hill Road. M16 was probably ditched historically and is now maintained in a straightened planform by the Taylor Hill Rd culvert (a large scour pool beneath the culvert is used as a swimming hole, deepened by beaver activity).

The left valley wall along M16-A has heavy sedimentation from flash flood impacts along Taylor Hill Rd, spilling out in an alluvial fan before emptying into the Second Branch -possibly in Irene (2011), but more notably in June 2013, July 2017, and again in April 2019. Sediments entering the stream from this area are much coarser than those present along the mainstem. A significant headcut through these sediments was observed not far off the left bank of the Second Branch during 2019 fieldwork, likely related to the April 2019 flooding (Fig. 91).


**Figure 91. Headcut through alluvial fan deposits below Taylor Hill Rd, off the left bank of M16-A, likely related to April 2019 flooding**

Headwater streams in this area are extremely sensitive, very steep, and prone to flashiness. A clear-cut pasture or house lot conversion upstream of the tributary along Taylor Hill Rd (visible in historical imagery around 2013 on Google Earth) may have contributed to greater flows that overwhelmed a small dam at ledges on a sharp corner of Taylor Hill Rd., and the dam break may have snowballed with high flows to contribute to the sediment discharge at the base of the hill. Despite inputs like this, M16-A exhibits the reduced sinuosity effects of straightening as the stream remains pinned against the right valley wall. Although the corner of Taylor Hill Rd is being undercut, good scrub-shrub buffer vegetation in M16-A actually seems to limit the rate of other channel adjustments such as meander development in response to sediment and high flow discharges.

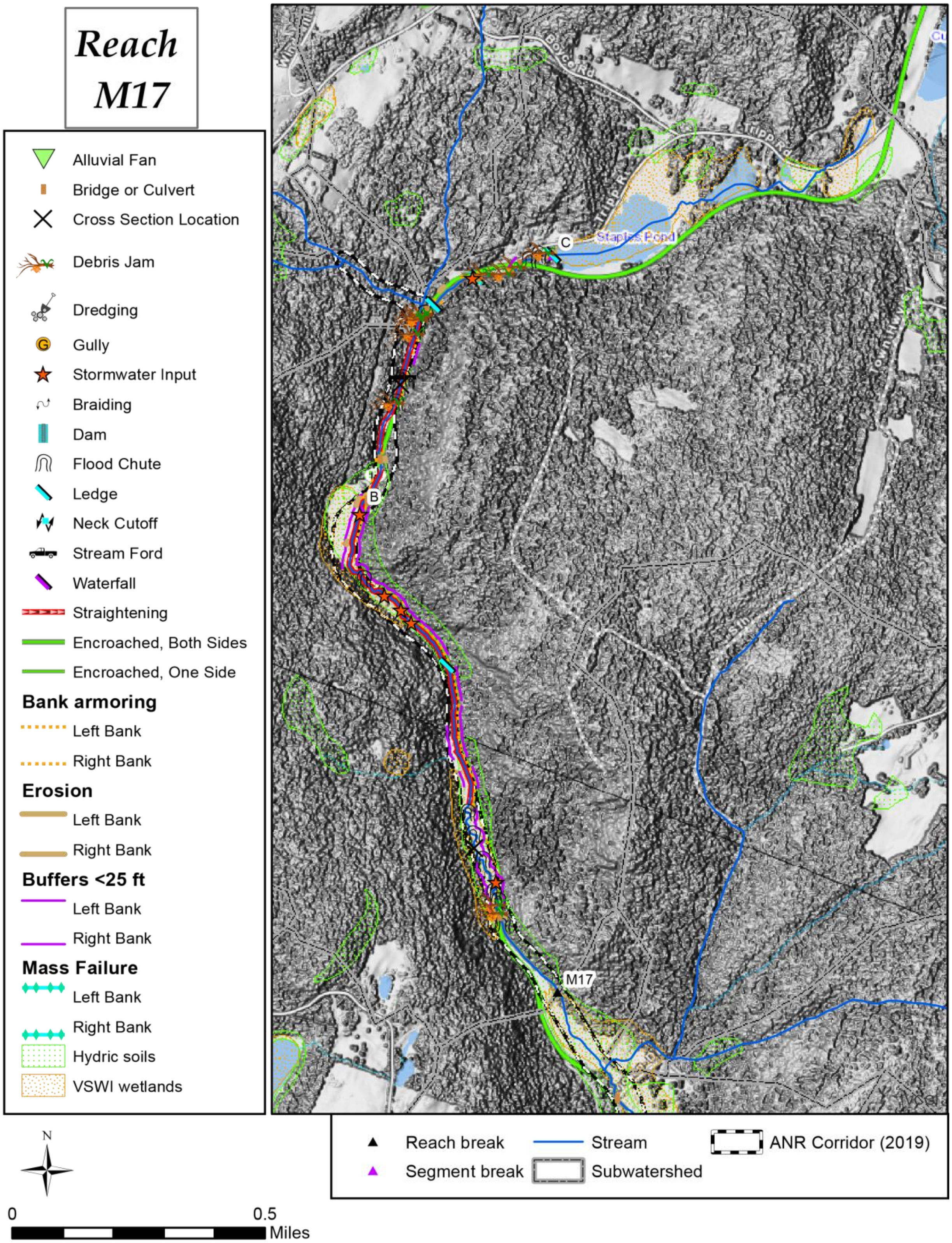



Figure 92. M17 Reach Summary Graphic

| **M17-A Data Summary** | | **Reference** | **Existing** |
|---|---|---|---|
| Length: 6,303 ft.<br>Drainage Area: 4.72 sq. mi.<br>Evolution Stage: III<br><br>Sensitivity: Extreme | Confinement | Very Broad | Broad |
| | Stream Type | E | E |
| | Entrenchment Ratio | >2.2 | 7.6 |
| | Incision Ratio | <1.2 | 1 |
| | Dominant Bed Material | Cobble | Sand |
| | Dominant Bedform | Plane Bed | Dune-Ripple |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |
| | | | |
| **M17-B Data Summary** | | **Reference** | **Existing** |
| Length: 3,823 ft.<br>Drainage Area: 4.72 sq. mi.<br>Evolution Stage: IV<br><br>Sensitivity: Very High | Confinement | Very Broad | Narrow |
| | Stream Type | C | C |
| | Entrenchment Ratio | >2.2 | 5.2 |
| | Incision Ratio | <1.2 | 1 |
| | Dominant Bed Material | Cobble | Gravel |
| | Dominant Bedform | Riffle-pool | Riffle-Pool |
| **Geomorphic Stream Condition** | **Fair** | | |
| **Physical Habitat Condition** | **Fair** | | |

**Table 28: M17-A, -B Phase 2 Data Summary**

*Primary Stressors*

- Encroachment from VT-14 along entire length of reach
- Berm or windrow found in lower area of reach, pushing river to right valley wall
- Stretches of steep ledge drops with historic straightening and heavy revetment

*M17 Summary:*

M17 was assessed as a reference C-type stream (with a higher gradient b-type subslope) based on typical Phase 1 remote sensing data (primarily valley width and slope), but was divided into 3 sections during Phase 2 assessment: M17-A, 17-B, and 17-C. M17-C is the most upstream reach of the Second Branch of the White River and includes Staples Pond as well as other human and beaver impoundments and associated wetlands (the headwaters of the Second Branch). M17-C was not assessed as part of this report, per protocols used for this assessment (VT-RMP 2009).

M17-A starts on the downstream end at the mouth of the Brookfield-Williamstown Gulf (slightly north of Brown Drive) and heads north to the beaver meadows near the residence at 6274 VT-14. M17-B starts on the downstream end at the northern end of these beaver meadows and heads north until the breached remains of a former dam at the outlet of Staples Pond.

M17-A was further classed as a sub-reach due to the presence of interspersed beaver meadows, which would appear to make this sub-reach an E-type stream under reference conditions. M17-A includes beaver meadows upstream and downstream of a long mid-segment ledge drop, pinned between VT-14 (cut out of the left valley wall) and a bedrock right valley wall continuous with the opposite bank, that comprises most of the elevation change (Fig. 93).

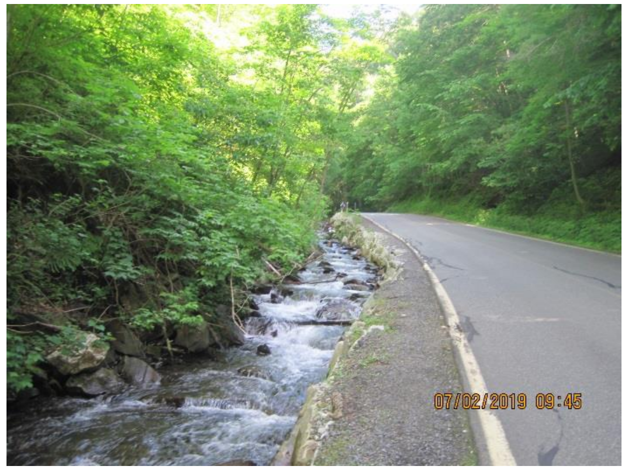



**Figure 93. Long ledge drop at this valley pinch-point mid-reach in M17-A comprises almost all the elevation change, with relatively level beaver meadows both upstream and downstream**

The presence of VT-14, accompanying bridges, and strategic post-flood windrowing at the base of the mid-reach ledge drop in M17-A encourage a single-thread channel in what would more likely be a series of connected beaver impoundments and multi-thread channels under reference conditions. The "berm" at the base of the ledge drop (likely created from "windrowed" materials dredged from the channel after a flood) was identified for potential removal as part of this assessment (Figs. 94. 95). This berm sits approximately 1.2 miles south of Staples Pond, very close to the Brookfield/Williamstown town line. The section of steep flow preceding the berm features a section of extensive rip-rap protecting VT-14. At the base of the steep section, the river outlets to a much gentler slope in a multi-channel beaver inhabited area. The berm extends for 200 feet and is approximately 2 feet high, constructed out of rocks, sediment, and recruited debris. The project would remove the berm and allow the flow coming from the steep rip-rapped section to disperse into the multi-channel wetland area that is found in much of the lower section of M-17A.


**Figure 95. This small berm was identified for removal; the berm pins the river against the right valley wall.**


**Figure 94. This figure shows the channel that runs to the left of the berm, even at moderate flows the berm is being outflanked**

The mid-segment ledge drop and continuous roadside riprap in M17-A lock the channel in beside the road, limiting further channel adjustments to cyclic scour/deposition/redistribution in high flows, amplified by the straightening and combined bed and bank armoring. This area is likely to be a repeat area for road-stream conflicts, and the beaver meadows upstream and downstream of this section play an important role in moderating these impacts to some extent but also bear the brunt of them as well; the majority of beaver dams appear quite transitory, and fine sediments are easily disturbed and moved in high flows.

M17-B was segmented as the valley transitions from a Broad to a Narrow valley measuring only 140 feet in width, hemmed in by adjacent roads (VT-14 primarily, along with Tripp Rd. in the upstream portion) Much like M17-A, M17-B is pinned against VT-14 and is significantly straightened and heavily armored with rip-rap along portions of the road. Sections of M17-B are steep, mostly in a series of ledge runs. that comprise the majority of elevation change. Notable are a ledge run below the outlet of Staples Pond (the former 10 ft. dam there is now breached and mostly gone), and a second, very steep run (bordering on waterfalls) now covered by a concrete culvert underneath VT-14; the remaining majority of the reach is likely < 2pct slope. Beers Atlas (1877) indicates a sawmill at base of ledges/waterfall under VT-14, which may have also been fed by a tributary from Rood Pond.
Cyclic scour and deposition now follow primarily historic incision in M17-B ("hungry water" effect downstream of the former dam at Staples Pond, and possibly the former mill site along VT-14 though this may have been an overshot wheel). Reference conditions would likely be a more extensive beaver complex, with stepped ponds, connected to the wetland complex surrounding upstream ponds; currently M17-B is instead maintained in a more straightened and constricted setting (single-thread channel) at a lower elevation.

### *6.2 PROJECT PRIORITIZATION*

Based on the foregoing analysis, project prioritization for this iteration of a River Corridor Plan for the Second Branch basin falls loosely into a three-pronged approach:

1. Watershed strategies
2. Buffer establishment and protection
3. Reach-scale corridor protection and/or restoration

A summary of the projects identified in each of the major approaches is below:

#### *Watershed strategies*

- River Corridor overlay in conjunction with updated Flood Hazard Bylaws; 50-foot setback for streams draining less than 2 square miles. As of 2019, a preliminary statewide River Corridor model exists for reference as a starting point, and data from the assessment reported here refine the recommended extent along the Second Branch mainstem.
- Hazard mitigation planning, capital planning, and prioritization for addressing undersized stream crossing structures (on tributaries as well as the mainstem, as these strongly influence discharges to streams). All towns in the study area have adopted 2019 Bridge and Culvert Standards (VTrans 2019), which will help stream dynamics as well as qualify

towns for a higher level of Emergency Relief Assistance Fund match (Flood Ready VT 2020).

- On the mainstem, stream crossings include a number of aging state structures along VT Rte. 14, three covered bridges that were recently renovated, and numerous private structures that complicate capital planning and its interaction with hazard mitigation; these areas should be clearly identified in plans (such as the frequently overtopped bridge on VT Rte. 14 in South Randolph and several structures along VT Rte. 14 south of the Brookfield-Williamstown Gulf).
- Funding options for replacement of private bridges will be a challenging issue for long-term stream health and stability as well as economic feasibility for farms especially; it is recommended that an effort be made to understand how recent replacements were designed, implemented and funded. It is further recommended that a summary report of relevant compiled information be provided to Road Commissioners, Selectboard and Planning Commission members in the five towns of the study area as well as relevant staff of Two Rivers-Ottauquechee and Central Vermont Regional Planning Commissions, White River Natural Resources Conservation District, and USDA Natural Resources Conservation Service.

***Buffer establishment and protection***

- Establishment and protection of woody vegetated buffers are prominent priorities in widespread agricultural and developed areas along the mainstem. These projects are almost always beneficial to stream health and can generally be implemented independently of other considerations, but highest priority is given to efforts in conjunction with integrated reach-scale corridor protection and/or restoration; buffer establishment and protection are assumed as a part of those projects.
- Notwithstanding the prioritization emphasis on buffers being integrated with larger projects, stand-alone buffer projects could be implemented to particularly good effect in portions of any of the reaches from M12 (North Randolph) upstream to M14 (East Brookfield). Buffer implementation in reaches further downstream should get consideration of additional corridor protections in conjunction with planting as they are more likely to be subject to lateral adjustments along the stream.

***Reach-scale corridor protection and/or restoration***

- Windrow removal/wetland restoration in segment M17-A, downstream of a highly confined, steep ledge drop coming out of the Brookfield-Williamstown Gulf;
- Corridor protection, buffer establishment and evaluation of possibilities for more active floodplain restoration in segment M11-B, upstream of Ferris Rd. along VT Rte. 14
- Tire removal, corridor protection and buffer establishment in reach M10
- Removal of Hyde Dam in reach M04, sediment removal upstream, corridor protection
- Evaluate feasibility of Gulf Road Dam removal in reach M09

- Evaluate options to address stream ford location at Gifford Covered bridge in reach M07 and remediate flood capture of field sediments
- Though lower priority, there are also multiple opportunities for intermittent wetland restorations to provide connectivity for migratory waterfowl and important habitat for riparian-dependent species of concern along the Second Branch, which could greatly benefit stream stability at the same time.

Due to the extensive and pervasive nature of current stressors in the Second Branch basin, the success of localized project implementation is highly dependent on moving toward best management practices on a watershed scale. The highest priority recommendations thus feature strategies that may be best or most efficiently effected at a reach level. Adaptive management should be used to periodically assess the feasibility and prioritization of localized projects based on stability gained from these larger efforts.

Table 29 outlines High Priority projects identified as part of this assessment, with a total of 31 projects included. From the complete High Priority projects list, there were five projects identified as Highest Priority. These Highest Priority projects were further explored as part of this assessment and developed into the project packets following the table.

**Table 29. High Priority projects from the 2019-2021 Second Branch mainstem assessment and Corridor Plan**

| Project Description | Project Type | SGA reach | Latitude | Longitude | Notes |
|---|---|---|---|---|---|
| Corridor protection | River Corridor Easement - Design | M-03 | 43.84871 | -72.5875826 | WRP has landowner connection |
| Wetland Restoration | Wetland Restoration - Preliminary Design | M-03 | 43.84871 | -72.5875826 | WRP has landowner connection |
| Corridor Protection | River Corridor Easement - Design | M-03 | 43.85185 | -72.5843598 | WRP has landowner connection |
| Buffer Planting | River - Planting | M-03 | 43.85185 | -72.5843598 | WRP has landowner connection |
| Berm removal | Floodplain/Stream Restoration - Preliminary Design | M-04 | 43.86561 | -72.583451 | US end of previous planting (have a landowner connection). Berm not very visible in field, mature trees, long-standing; straightens and pushes stream against VT- 14 and LVW |
| Removal of Hyde Dam in East Bethel and channel restoration | Dam Removal - Implementation | M-04 | 43.848647 | -72.5875826 | Hyde Dam will be removed in summer 2021 |
| Extensive wetlands restoration | Wetland Restoration - Preliminary Design | M-05 | 43.888658 | -72.582438 | Part of extensive multi-reach wetlands restoration and corridor protection. Possible partnership with Ducks Unlimited |

| Project Description | Project Type | SGA reach | Latitude | Longitude | Notes |
|---|---|---|---|---|---|
| Corridor Protection | River Corridor Easement - Design | M-05 | 43.888658 | -72.582438 | Part of extensive multi-reach wetlands restoration and corridor protection. Possible partnership with Ducks Unlimited |
| Extensive wetlands restoration | Wetland Restoration - Preliminary Design | M-06 | 43.891992 | -72.5775695 | Part of extensive multi-reach wetlands restoration and corridor protection. Possible partnership with Ducks Unlimited |
| Corridor Protection | River Corridor Easement - Design | M-06 | 43.891992 | -72.5775695 | Part of extensive multi-reach wetlands restoration and corridor protection. Possible partnership with Ducks Unlimited |
| Corridor protection and remediation of field capture as a result of the ford location and use | Floodplain/Stream Restoration - Preliminary Design | M-07 | 43.916091 | -72.555026 | Possible manure pit relocation near site as well. Further outreach needed to Gifford Farm to understand all aspects of project. |
| Buffer planting along area of field capture as a result of ford in use under Gifford Covered Bridge | River - Planting | M-07 | 43.916091 | -72.555026 | |

| Project Description | Project Type | SGA reach | Latitude | Longitude | Notes |
|---|---|---|---|---|---|
| Dam Removal and channel restoration at Gulf Road Dam | Dam Removal - Preliminary Design | M-09 | 43.939915 | -72.554242 | After Hyde Dam is removed in summer of 2021, Gulf Road dam will be the last remaining dam along the Second Branch of the White River. WRP has a landowner contact at dam. |
| Corridor protection along tire rip-rapped property | River Corridor Easement - Design | M-10 | 43.952317 | -72.548765 | Corridor Protection required to address erosion and river channel movement present at location. Tire riprap was used to address erosion and failed resulting in extensive tire dump in river. |
| Removal of extensive failed tire riprap along property | Floodplain/Stream Restoration - Preliminary Design | M-10 | 43.952317 | -72.548765 | Extensive failed tire riprap strewn along stream, recent channel avulsion. Prelim landowner id |
| Buffer Planting | River - Planting | M-10 | 43.952317 | -72.548765 | Buffer planting for area of failed tire riprap |
| Corridor Protection | River Corridor Easement - Design | M-11B | 43.967691 | -72.553796 | Attenuate dump outs from headcuts due to trib along Ferris Rd, (should drain to Halfway Brook?) (possible culvert replacements off mainstem) |

| Project Description | Project Type | SGA reach | Latitude | Longitude | Notes |
|---|---|---|---|---|---|
| Buffer planting along areas of Second Branch near Ferris Rd. with severe headcuts and erosion | River - Planting | M-11B | 43.967691 | -72.553796 | |
| Reach level project to protect large corridor | River Corridor Easement - Design | M-13 | 44.004839 | -72.5658229 | Multiple undersized structures, severe ditching, limited floodplain access across entire reach. Wetland restoration possible in multiple areas. |
| Reach level project to restore wetlands | Wetland Restoration - Preliminary Design | M-13 | 44.004839 | -72.5658229 | Multiple undersized structures, severe ditching, limited floodplain access across entire reach. Wetland restoration possible in multiple areas. |
| Reach level buffer planting | River - Planting | M-13 | 44.004839 | -72.5658229 | Multiple undersized structures, severe ditching, limited floodplain access across entire reach. Wetland restoration possible in multiple areas. |
| Replacement or removal of old/out of use bridges | Floodplain-Stream Restoration - Preliminary Design | M-13 | 44.004839 | -72.5658229 | Multiple undersized structures, severe ditching, limited floodplain access across entire reach. Wetland restoration possible in multiple areas. |

| Project Description | Project Type | SGA reach | Latitude | Longitude | Notes |
|---|---|---|---|---|---|
| Reach level project to protect large corridor | River Corridor Easement - Design | M-14 | 44.014175 | -72.573768 | Multiple undersized structures, severe ditching, limited floodplain access across entire reach. Wetland restoration possible in multiple areas. |
| Reach level project to restore wetlands | Wetland Restoration - Preliminary Design | M-14 | 44.014175 | -72.573768 | Multiple undersized structures, severe ditching, limited floodplain access across entire reach. Wetland restoration possible in multiple areas. |
| Reach level buffer planting | River - Planting | M-14 | 44.014175 | -72.573768 | Multiple undersized structures, severe ditching, limited floodplain access across entire reach. Wetland restoration possible in multiple areas. |
| Replacement or removal of old/out of use bridges | Floodplain-Stream Restoration - Preliminary Design | M-14 | 44.014175 | -72.573768 | Multiple undersized structures, severe ditching, limited floodplain access across entire reach. Wetland restoration possible in multiple areas. |
| Multiple old farm bridges and culverts (likely not in use) along farm to be removed or replaced | Floodplain-Stream Restoration - Preliminary Design | M-15 | 44.031346 | -72.568471 | |

| Project Description | Project Type | SGA reach | Latitude | Longitude | Notes |
|---|---|---|---|---|---|
| Undersized culvert under Taylor Hill Road | Floodplain-Stream Restoration - Preliminary Design | M-16A | 44.049053 | -72.565277 | Constraints of culvert location and road condition may make the culvert replacement difficult but culvert is severely undersized |
| Restoration of wetlands (beavers) downstream of Taylor Hill culvert | Wetland Restoration - Preliminary Design | M-16A | 44.054582 | -72.562262 | Section was excluded from geomorphic assessment but beaver habitat is worth protecting |
| Steep headcut downstream of Wmstown Gulf leading to a small berm/windrow to be removed | Floodplain-Stream Restoration - Preliminary Design | M-17 | 44.054582 | -72.562262 | Small project with high probability of success. Need to contact VTrans to understand history of berm and impacts on VT-14 if removed. |
| Identify potential wetland restoration downstream of berm/windrow identified for removal | Wetland Restoration - Preliminary Design | M-17 | 44.068817 | -72.569002 | |

## Project #1: Hyde Dam Removal

***Project Goal:*** Dam removal and channel restoration at Hyde Dam in East Bethel

***Project Location****:* 43.872168, -72.586293

***Landowner****:* Vermont River Conservancy
29 Main St. Unit 11
Montpelier, VT 05602
(802) 299-0820

***Background****:*

Dam is located along M04 of the Second Branch of the White River in East Bethel, VT. The dam is located approximately 100 feet down river from the Store Hill Rd bridge in East Bethel, VT.

The Hyde Dam is approximately 45 feet in length and 14 feet in height. Hyde Dam is a historic dam that provided water power to several former businesses and industry in the village of East Bethel, VT starting around 1790. The Hyde Dam powered a gristmill, creamery, woolen mill, and saw mill.

Improved Water Quality and Sediment Continuity

The dam removal will be accompanied by channel restoration and sediment removal upstream of the dam. The dam removal will result in increased sediment continuity and increased water quality benefits. The increased sediment continuity as a result of the dam removal may help address naturalized *E. coli* bacteria populations found in the fine sediments of the Second Branch. Additional co-benefits include aquatic organism passage.

Landowner Interest

The dam has long been out of use and is in disrepair. The Vermont River Conservancy (VRC) purchased the dam, adjoining property, and water rights from the previous owner with the intent of removing the dam and creating a public access site.

Project Constraints

Adjacent landowners have concerns about how the dam removal will affect their property. Although the dam and water rights are owned by VRC, adjacent landowners' concerns should be addressed.

Permits

A Dam Order from VT Dam Safety will be needed for the removal (obtained in 2020). The VT General Permit from US Army Corps of Engineers will also be needed (obtained in 2020).

Costs and Feasibility

The White River Partnership has worked with VRC, Matt Murawski of Ripple Natural Resource, and local landowners to develop plans to remove the dam in summer of 2021.

Next Steps

Implement dam removal project

*Photos:*


**Figure 96. Hyde Dam Removal Project Overview**

**Project #2: Gulf Road Dam Removal**

***Project Goal:*** Dam Removal and channel restoration at Gulf Road Dam in East Randolph

***Project Location:*** 43.940024, -72.554233

***Landowner*****:** Town of Randolph
7 Summer St.
Drawer B
Randolph, VT 05060

The East Randolph Fire District was listed as the owner on the Randolph Grand List up until 2016. The East Randolph Fire District is a Fire Department in the Town of Randolph.

***Background:***

The dam is located along M09 of the Second Branch of the White River in Randolph, VT. The dam is situated along the downstream end of the Rt-14 bridge that sits across from Middle Branch Market and Deli (Intersection of VT-14 and Route 66). The 0.11-acre property downstream of the dam as well as the dam rights are owned by the Town of Randolph and there is a dry hydrant just upstream of the dam that is maintained and utilized by the East Randolph Fire District. The Gulf Road Dam is a low-hazard concrete structure that is 55 feet long and 8 feet high. After the anticipated removal of Hyde Dam in summer of 2021, the Gulf Road Dam would be the only remaining dam on the Second Branch of the White River.

<u>Improved Water Quality and Sediment Continuity</u>

The plan to remove the Gulf Road Dam represents a larger initiative to improve water quality and sediment continuity in the White River watershed. Water quality sampling locations downstream of the Gulf Road Dam have historically had the highest *E. coli* bacteria readings in the watershed. The increased sediment continuity resulting from a dam removal may help address naturalized *E. coli* populations found in the fine sediments of the Second Branch. Additional co-benefits include aquatic organism passage.

<u>Landowner Interest</u>

Members of the East Randolph Fire District have in the past expressed regret in purchasing the dam. White River Partnership has reached out to a member of the East Randolph Fire District to see if there is any interest in a removal and are waiting to hear back.

<u>Project Constraints</u>

Factors that complicate the removal of the Gulf Road Dam include:

1) The presence of the dry hydrant just upstream of the dam making the maintenance of current water depth at the hydrant location important for the East Randolph Fire District
2) The dam is tied into the abutments of the VT-14 bridge

3) There is no known grade control upstream of the dam to mitigate a headcut created from a dam removal project
4) Pools upstream and downstream of the dam are local swimming holes, which will likely be impacted from a dam removal project

A series of weirs could be installed to provide pooling around the intake of the dry hydrant. These weirs could also act as grade controls and maintain a local swimming hole. Additional grade control may be needed further upstream.

<u>Permits</u>

The Gulf Road Dam has a listed impoundment of 6 acre-ft., which falls below the jurisdiction of VT Dam Safety. This would need to be confirmed. If the impoundment is under 11.47 acre-ft. (500,000 CF) then a Stream Alteration Permit will be needed from VT River Management. A VT General Permit will also be needed from the US Army Corps of Engineers.

<u>Costs and Feasibility</u>

A preliminary scope of work would establish feasibility both with the landowner and with some of the project constraints. Engineering costs would include design and permitting. As part of the Corps permit, Section 106 of the National Historic Preservation Act must be followed. This will include, but not be limited to, a Historic Resource Assessment, a Historic Sites & Structures Survey, and a historic interpretive panel. Implementation costs and potential funders would also impact feasibility.

<u>Next Steps</u>

Follow up with the East Randolph Fire District and the Town of Randolph Selectboard. An engineer with dam removal experience should also be engaged to determine a scope of work.

*Photos:*

**Figure 97. Gulf Road Dam - 2 views**

## Project #3: Tire Removal, River Corridor Easement and Riparian Tree Planting

***Project Goal***: River Corridor Restoration near 1114 VT Rte. 14, East Randolph property. Suite of projects includes the removal of tires used as armor eroding banks, development of a River Corridor Easement (RCE), and a riparian tree planting.

***Project Location:*** 43.952317, -72.548765; 1114 VT RTE 14 East Randolph

***Landowner:*** John & Sandra Race Sr
PO Box 314
East Randolph, VT 05061

***Background:***

This project site is located in East Randolph, VT along reach M10 of the Second Branch of the White River. Access to the property is approximately 1.1 miles north of the VT-14 and VT-66 intersection.

The Race property is a 72-acre parcel located along the river left side of the Second Branch. The Second Branch of the White River meanders through the property for approximately 2,500 feet. The downstream 1,500 feet of riverbank is experiencing heavy erosion at a height of 3 to 4 feet. In an effort to mitigate the erosion, tires were used to armor the bank. While some of the tires remain installed along the banks, the majority of the tires have fallen into the river, creating an extensive dump.

The suite of projects proposed for this location include:

1) Clean up and removal of the tires in the banks and in the river. An unknown number of tires are present at this location (preliminary estimate 50-100)
2) Protection of the river corridor through a River Corridor Easement which will provide financial incentive to the landowner for passive restoration of the riverbank
3) Establish a riparian buffer along the river to stabilize banks and mitigate erosion

<u>Improved Water Quality, flood resilience, and stream equilibrium</u>

Planting a riparian buffer would improve water quality by providing bank stability and reducing surface runoff of nutrients and sediment. Co-benefits of a riparian buffer would be lowering stream temperatures and improving habitat. A riparian buffer would also help slow flood waters. A RCE would provide long-term floodplain protection and also allow the river to move toward equilibrium over time.

<u>Landowner Interest</u>

White River Partnership (WRP) has reached out with a letter to make contact with the landowner. The letter provides more details about the three identified projects. WRP will be following up with the landowner to provide more information and to answer questions.

Project Constraints

Constraints include:

1) Determining landowner interest for one or all of the projects.
2) Removing the tires in the bank and stream could require heavy equipment and bank disturbance.
3) Due to the legacy of dams on the Second Branch and how that has affected the height of terraces along the river, removal of the downstream Gulf Road Dam could increase incision and negatively impact bank stability.

Permits

A stream alteration permit may be required if heavy equipment is used to remove the tires below bankfull. Otherwise no permits are needed for the RCE or buffer plantings.

Costs and Feasibility

Project costs for the tire removal would include heavy equipment or manual labor to remove the tires, disposal fees, and project management expenses. For the riparian planting, costs would include developing a planting plan; purchasing trees and shrubs; labor to plant the trees; and project management expenses. The RCE costs would include the necessary survey and baseline documentation work, legal fees, the easement payment, and project management expenses.

Next Steps

Follow-up with the landowners with more information about all three projects. If the landowner is interested in the RCE, VT River Management should be contacted about river corridor maps and valuation.

*Photos:*

**Figure 98. Race Property Project Overview**

## Project #4: Ferris Road River Corridor Easement(s) & Riparian Buffer Planting

***Project Goal:*** Implementation of a River Corridor Easement (RCE) and series of riparian buffer plantings along the heavily eroded banks located along reach 11-B of the Second Branch of the White River.

***Project Location:*** 43.967691, -72.553796

***Landowners:*** Joy M. Camp, Mary C. Camp
287 Grove St
Melrose, MA 02176

Lawrence G. Camp (Life Trust)
Cynthia Richardson, et al
2156 VT RTE 14 N
East Randolph, VT 05061

Daniel & Alison Skrill
2248 VT RTE 14 N
East Randolph, VT 05061

***Background:***

A set of highly-eroded banks, neck cutoffs, and headcuts are located along reach M11-B of the Second Branch of the White River. The area for restoration is slightly north of Ferris Drive in Randolph, VT. This stretch of river is approximately 0.78 miles long, starting at the confluence with Snow's Brook to the north and ending when the river crosses under VT-14 near Ferris Rd.

The proposed project would protect the river corridor through a RCE and develop a buffer planting to address the highly-eroding banks. This stretch of river has multiple headcuts along the left valley sidewall and neck cutoffs on the mainstem; some of the headcuts are 6 feet in height and river channel adjustments on the mainstem are pronounced. A potential active restoration project could include lowering the floodplain, particularly along the downstream section, but would need closer evaluation including investigation of the source of inputs.

Improved Water Quality, flood resilience, and stream equilibrium

A River Corridor Easement would provide long-term flood plain protection and also allow the river to move toward equilibrium over time. As part of a RCE, a riparian buffer would improve water quality by providing bank stability and reducing surface runoff of nutrients and sediment. Co-benefits of a riparian buffer would be lowering stream temperatures and improving habitat. A riparian buffer would also help slow flood waters.

Landowner Interest

White River Partnership (WRP) has reached out to each of the landowners about the possibility of a River Corridor Easement and riparian buffer planting on their properties. Although no responses have come from any of the landowners at the time of this report, WRP will follow up with more information.

Project Constraints

Multiple landowners on three separate parcels adds a level of complexity to the project. Project costs could also be a constraint.

Permits

No permits are needed for a RCE or riparian planting.

Costs and Feasibility

Costs for the RCE(s) would include the time to coordinate a multi parcel RCE, the necessary survey work, legal fees, and easement payment(s). For the riparian planting, costs would include developing a planting plan, the trees and shrubs, and any labor to plant the trees.

Next Steps

Follow up with each of the landowners about a potential RCE. If landowners are interested in moving forward, maps with valuation will be needed from VT River Management.

*Photos:*

**Figure 99. Ferris Road Project Overview**

## Project#5: M-17 Berm Removal

***Project Goal:*** Removal of the small berm that sits downstream of a steep ledge run through the Brookfield-Williamstown Gulf.

***Project Location:*** 44.07141, -72.56937

***Landowners:***

| Matthew & Mary Comerford | VT Dept. Forest Parks & Recreation |
| --- | --- |
| 597 Birch Meadow Rd | 1 Natural Life Dr, Davis 2 |
| Brookfield, VT 05036 | Montpelier, VT 05620 |

***Background:***

The berm is located in reach M17-A along the Second Branch of the White River. The berm sits approximately 1.2 miles south of Staples Pond, very close to the Brookfield-Williamstown town line. The Second Branch of the White River flows down a steep ledge run that is pinned between the valley wall and VT-14. The section of steep flow preceding the berm features a section of extensive rip-rap protecting VT-14. At the base of the steep section, the river outlets to a much gentler slope in a multi-channel beaver-inhabited area. The berm extends for 200 feet and is approximately 2 feet high, constructed out of rocks, sediment, and recruited debris (likely windrowed from the stream), and funnels the stream toward the right valley wall.

The project would remove the berm and allow the flow coming from the steep rip-rapped section to disperse into the multi-channel wetland area that is found in much of the lower section of M-17A.

<u>Improved flood resilience and stream equilibrium</u>

Removing the berm would allow stream flows to disperse into the multi-channel wetland area. This dispersal of flows would improve water storage near the top of the watershed and improve flood resilience downstream by attenuating high water and sediment discharges

<u>Landowner Interest</u>

White River Partnership (WRP) has reached out to the Comerfords about the berm removal and have not heard back as to their interest in allowing this project to happen.  WRP will follow up again.

<u>Project Constraints</u>

The berm is located at the Brookfield Town line and has possible multiple landowners, including VT Dept. Forest, Parks, & Recreation (Ainsworth State Park).  The berm currently directs the flow of water away from VT-14 and towards the valley wall. Removal of the berm would allow flows into the multi-channel area that runs parallel to VT-14. To ensure that the removal of the berm does not cause any adverse effects to VT-14, VTrans should be contacted.

Permits

A Stream Alteration Permit would be required to remove the berm. Depending on the size of the project below "ordinary high water," a General Permit from US Army Corps of Engineers might also be needed.

Costs and Feasibility

Costs would include some minimal design work to be included with the permit application(s). Removal of the berm would include machine time and hauling away material.

Next Steps

Follow-up with landowners and VTrans.

*Photos:*


**Figure 100. M17 Berm Removal Project Overview**

## Literature cited


Beers 1869. F.W. Beers Atlas of Windsor County, VT.

http://www.historicmapworks.com/Atlas/US/6828/

Beers 1877. F.W. Beers Atlas of Orange County, VT. http://www.historicmapworks.com/Atlas/US/760/

Booth, D.B. and C.R. Jackson 1997. Urbanization of Aquatic Systems: Degradation Thresholds, Stormwater Detention, and the Limits of Mitigation. J. Am. Water Resour. Assoc. Vol. 22, No. 5 (October 1997). http://clear.uconn.edu/projects/TMDL/library/papers/BoothJackson_1997.pdf

Bretibach, M. 2010. Flash Flood Climatology (1975-2009) for the WFO Burlington, VT County Warning Area. NOAA/National Weather Service, Burlington, VT. http://bgmresearch.eas.cornell.edu/research/ERFFW/posters/breitbach_maureen_ERFFW_poster3.pdf

Brookfield LHMP 2015. Town of Brookfield, Vermont Local Hazard Mitigation Plan 2015. https://www.trorc.org/wp-content/uploads/2013/08/Final_Brookfield.VT_.FINALCombined.pdf

Cluer, Brian & Thorne, Colin. 2014. A Stream Evolution Model Integrating Habitat and Ecosystem Benefits. River Research and Applications. 30. https://doi.org/10.1002/rra.2631

Coolidge, A. J. & Mansfield, J. B. 1859. A history and description of New England, General and Local. Boston, A. J. Coolidge. https://archive.org/details/bub_gb_OcoMAAAAYAAJ

Doll, C.G. (ed.) et al. 1961.Centennial Geologic Map of Vermont. http://www.anr.state.vt.us/DEC/geo/centmap.htm http://www.anr.state.vt.us/DEC/geo/centennialmap/smncmap.jpg

Doll, C.G. (ed.) et al. 1970. Surficial Geologic Map of Vermont. State of Vermont. http://www.anr.state.vt.us/DEC/geo/SurfMap.htm http://www.anr.state.vt.us/DEC/geo/SurficalMapVT/topc.jpg

Dunne, T.. & Leopold, L.B. (1978). Water in environmental planning. San Francisco: W. H. Freeman.

FEMA MSC 2017. Federal Emergency Management Agency Map Service Center. https://msc.fema.gov/portal/search?AddressQuery=North%20Royalton%20VT#searchresultsanchor

Flood Ready VT 2019. River Corridors page from the Vermont Flood Ready website. https://floodready.vermont.gov/flood_protection/river_corridors_floodplains/river_corridors

Flood Ready VT 2020. Flood Ready Vermont Expanded Community Reports. State of Vermont. https://floodready.vermont.gov/assessment/community_reports#Expanded

Grant, S. B., Litton-Mueller, R. M., and Ahn, J. H. (2011), Measuring and modeling the flux of fecal bacteria across the sediment-water interface in a turbulent stream, Water Resour. Res., 47, W05517 https://doi.org/10.1029/2010WR009460

Kline, M. 2010. Vermont ANR River Corridor Planning Guide: to Identify and Develop River Corridor Protection and Restoration Projects, 2nd edition. Vermont Agency of Natural Resources. Waterbury, Vermont. http://www.anr.state.vt.us/dec/waterq/rivers/docs/rv_rivercorridorguide.pdf

Landscape Change Program. https://glcp.uvm.edu/landscape_new/about/index.html

Lane, E.W. 1955. The Importance of Fluvial Morphology in Hydraulic Engineering, American Society of Civil Engineering, Proceedings, 81, paper 745 1-17. https://semspub.epa.gov/work/01/554355.pdf

Leopold, L.B. 1994. A view of the river. Cambridge, MA: Harvard University Press.

Milone & McBroom 2008. The Vermont Culvert Geomorphic Compatibility Screening Tool. Prepared for: Vermont Agency of Natural Resources Department of Environmental Conservation River Management Program, Waterbury, VT. https://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/rv_VTCulvertGCScreenTool.pdf

Milone & McBroom 2009. The Vermont Culvert Aquatic Organism Passage Screening Tool. Prepared for: Vermont Agency of Natural Resources Department Fish and Wildlife, Waterbury, VT. https://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/rv_VTAOPScreeningTool.pdf

NDMC 2021. United States Drought Monitor jointly produced by the National Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration. https://droughtmonitor.unl.edu/CurrentMap/StateDroughtMonitor.aspx?VT

NWS-Burlington 2013. NOAA's National Weather Service – Burlington, VT – Daily Climate Maps Archive (24-hr precipitation ending 7 a.m. Aug. 10, 2013). http://www.erh.noaa.gov/btv/html/climatemaps/

Olson, S.A., 2014. Estimation of flood discharges at selected annual exceedance probabilities for unregulated, rural streams in Vermont, with a section on Vermont regional skew regression, by Veilleux, A.G. U.S. Geological Survey Scientific Investigations Report 2014–5078, 27 p. plus appendixes. http://dx.doi.org/10.3133/sir20145078

OSU 2020. Streamflow Evaluations for Watershed Restoration Planning and Design: An Interactive Guide and Tutorial - Terminology. Oregon State University Civil, Construction, and Environmental Engineering Department. http://streamflow.engr.oregonstate.edu/terminology/index.htm

Randolph 2015. Hazard Mitigation Plan, Town of Randolph, VT. https://www.trorc.org/wp-content/uploads/2013/08/randolph_compiled_FINAL.pdf

Randolph 2019. Town Plan, Town of Randolph, VT. https://www.trorc.org/wp-content/uploads/2013/08/Randolph-Town-Plan-Approved-by-Selex-8-8-2019.pdf

Ries, H. and Merrill, F.J.H. 1895. "Clay Industries of New York". Bulletin of the New York State Museum, Vol. 3 No. 12, March 1895. https://nysl.ptfs.com/awweb/pdfopener?sid=08E01CEBE609999DE49A494067DD54B8&did=10579&fl=%2F99866.PDF

Rosgen, D.R. 1994. A classification of natural rivers. CATENA, Volume 22, Issue 3, 1994, pp. 169-199 https://doi.org/10.1016/0341-8162(94)90001-9. (https://www.sciencedirect.com/science/article/pii/0341816294900019 )

Schumm, S.A. The Fluvial System. New York, NY: Wiley. 1977.

Schumm, S.A., M.D. Harvey, C.C. Watson. 1984. Incised Channels: Morphology, Dynamics and Control. Water Resources Publications (ISBN-0918334-53-5), Littleton, CO.

Stocker, Matt & Penrose, Michael & Pachepsky, Yakov. (2018). Spatial Patterns of Concentrations in Sediment before and after High-Flow Events in a First-Order Creek. Journal of Environment Quality. 47, doi: 10.2134/jeq2017.11.0451.

Summersby, J. 2020. "Pandemic migration fuels Vermont real estate market". Middlebury Campus, September 17, 2020. https://middleburycampus.com/52106/local/pandemic-migration-fuels-vermont-real-estate-market/

Thompson, E. H. and Sorenson, E.R. (2000). *Wetland, woodland, wildland: A guide to the natural communities of Vermont*, 1st ed. Vermont Dept. of Fish and Wildlife and The Nature Conservancy. Hanover, NH: University Press of New England.

Thompson, E. H., E. R Sorenson, and R.J. Zaino (2019). *Wetland, woodland, wildland: A guide to the natural communities of Vermont*. 2nd ed. Montpelier: Vermont Dept. of Fish and Wildlife, The Nature Conservancy (U.S.) and Vermont Land Trust.

TRORC 2021. Planning documents from member towns in the Two Rivers-Ottauquechee Regional Commission region, Local Hazard Mitigation Plans in particular. https://www.trorc.org/member-towns/

USDA 2017. Census of Agriculture 2017. United States Department of Agriculture. https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/County_Profiles/Vermont/cp50017.pdf

USGS 2020. Historical Topographic Map Collection, Interactive Map. United States Geological Survey. https://www.usgs.gov/core-science-systems/ngp/topo-maps/historical-topographic-map-collection?qt-science_support_page_related_con=0#qt-science_support_page_related_con

UVM-SAL. 2002. Vermont Land cover/land use data developed by multiple partners including the University of Vermont Spatial Analysis Lab. Available from the Vermont Center for Geographic Information. https://maps.vcgi.vermont.gov/gisdata/metadata/LandLandcov_LCLU.htm

VCE 2020. Vermont Freshwater Mussel Atlas. Vermont Center for Ecostudies Vermont Atlas of Life. https://val.vtecostudies.org/projects/vermont-freshwater-mussel-atlas/elliptio-complanata/

VCGI Interactive 2020. Vermont Center for Geographic Information Interactive Map Viewer. https://maps.vermont.gov/vcgi/html5viewer/?viewer=vtmapviewer

VCGI Lidar 2020. Digital Surface Model – Hillshade (webservice). Composite hillshade of DSM from best available lidar-derived data statewide of the earth's surface including structures and vegetation. Sun angle is multidirectional. https://maps.vcgi.vermont.gov/arcgis/rest/services/EGC_services/IMG_VCGI_LIDARDSMHILLSHD_SP_CACHE_v1/ImageServer

Vermont Indicators Online 2020. Town Profiles, 2008-2012 American Community Survey (ACS). University of Vermont Center for Rural Studies and Vermont Center for Geographic Information. https://www.uvm.edu/crs/vermont-indicators-online

VSWI 2010. VSWI Wetland Class Layer. Vermont Significant Wetland Inventory (June 4, 2010), 2015A edition. Vermont Agency of Natural Resources, Vermont Open Geodata Portal. https://geodata.vermont.gov/datasets/VTANR::vswi-wetlands-class-layer; https://www.arcgis.com/sharing/rest/content/items/6e3e04c2346a4fd685c95fb988776ef9/info/metadata/metadata.xml?format=default&output=html

VT-ANR 2020. Vermont Agency of Natural Resources Atlas (interactive web mapping application). http://www.anr.state.vt.us/site/html/maps.htm

VT-AOT 2020. Vermont Agency of Transportation, Program Development, Better Roads Program. 1 National Life Drive, Montpelier, Vermont 05633.. https://vtrans.vermont.gov/highway/better-roads

VTCULVERTS. Online database, inventory and mapping tools. https://vtculverts.org/

VT DEC 2015. Vermont Dam Inventory. Vermont Department of Environmental Conservation Streamflow Protection Program. http://anrmaps.vermont.gov/websites/vgisdata/layers_anr/metadata/metadata.htm?xmlfile=http://anrmaps.vermont.gov/websites/vgisdata/layers_anr/metadata/WaterOther_DAMS.xml,xslfile=xsl/FGDC_Plus_body.xsl

VT DEC-MRP 2018. Summary Sheet: Developing the Municipal Roads General Permit. Vermont Department of Environmental Conservation Municipal Roads Program. Montpelier, VT. https://dec.vermont.gov/sites/dec/files/wsm/stormwater/docs/Permitinformation/MunicipalRoads/sw_MRGP_SummarySheet.pdf

VT DEC-WMD 2013. Stream Gravel Removal Policy. Vermont Department of Environmental Conservation Watershed Management Division. Montpelier, VT. https://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/rv_gravel_removal_policy.pdf

VT DEC-WMD 2018. White River Basin – Basin 9 2018 Tactical Basin Plan. Vermont Agency of Natural Resources Watershed Management Division. https://dec.vermont.gov/sites/dec/files/documents/2018%20White%20River%20Tactical%20Basin%20Plan.pdf

VT DEC Water Quality Division, 2018, State of Vermont 2018 303(d) List of Waters: Part A – Impaired Surface Waters in Need of TMDL. https://dec.vermont.gov/sites/dec/files/documents/mp_PriorityWatersList_PartA_303d_2018.pdf

VTrans 2019. The Orange Book 2019-2021: A Handbook for Local Officials. Vermont Agency of Transportation. https://vtrans.vermont.gov/sites/aot/files/documents/TheOrangeBook.pdf

VTFWD 2018. Press release, Vermont Department of Fish & Wildlife. https://vtfishandwildlife.com/newsroom/public-reminded-to-not-disturb-spawning-sea-lamprey-in-connecticut-river-drainage

VTFWD 2020. Vermont Trout Map – Rives and Streams. Vermont Department of Fish & Wildlife. https://vtfishandwildlife.com/fish/fishing-opportunities/vermont-trout-map-rivers-and-streams

VT-RMP 2009. Vermont Agency of Natural Resources Protocol Handbooks. Vermont Agency of Natural Resources River Management Program. https://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/rv_SGA_Phase2_Protocol.pdf

VT-RMP_ApxC 2007. Vermont Agency of Natural Resources Protocol Handbooks, Appendix C: Channel Evolution Models. Vermont Agency of Natural Resources River Management Program. https://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/assessment-protocol-appendices/C-Appendix-C-07-Channel-Evolution-Models.pdf

VT-RMP_ApxH 2009. Vermont Agency of Natural Resources Protocol Handbooks, Appendix H: Meander Geometry. Vermont Agency of Natural Resources River Management Program. https://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/assessment-protocol-appendices/H-Appendix-H-04-Meander-Geometry.pdf

VT-RMP_ApxI 2004. Vermont Agency of Natural Resources Protocol Handbooks, Appendix I: Stream Classification Systems. Vermont Agency of Natural Resources River Management Program. https://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/assessment-protocol-appendices/I-Appendix-I-04-Classification-Systems.pdf

VT-RMP FEH 2010. Municipal Guide to Fluvial Erosion Hazard Mitigation. Vermont Agency of Natural Resources River Management Program. https://anrweb.vt.gov/PubDocs/DEC/WSMD/rivers/docs/rv_municipalguide.pdf

VT-RMP NFIP-FEH 2010. NFIP & FEH Fact Sheet. Vermont Agency of Natural Resources River Management Program. https://anrweb.vt.gov/PubDocs/DEC/WSMD/rivers/docs/rv_NFIPFEHFactSheet.pdf

VT-RMP 2014. Stream Crossing Guiding Design Principles. Vermont Standard River Management Principles and Practice, May 2014. Vermont River Management Program, Department of Environmental Conservation Watershed Management Division. Montpelier, VT.

https://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/rv_Stream_Crossing_Guidance.pdf

VWRC 1921. Special Report of the Vermont Water Resource Commission to the Legislature of 1921 of the State of Vermont. Prepared in cooperation with United States Geological Survey. The Tuttle Company, pub.; Marble City Press, Rutland, VT. https://books.google.com/books?id=_lVGAAAAYAAJ

Walter, Robert & Merritts, Dorothy. (2008). Natural Streams and the Legacy of Water-Powered Mills. Science (New York, N.Y.). 319. 299-304. https://doi.org/10.1126/science.1151716

Walter, Robert, Dorothy Merritts, Karen Mertzman, Jordan Appleyard; Elvis Andino, Peter Rippberger, Ian Wachino, and Joseph Galella. A Controlled Freeze-Thaw Experiment to Model Sediment and Phosphorus Loads from Bank Erosion of Legacy Sediments. Poster Presentation, 2018 American Geophysical Union Annual Meeting, Washington, DC. http://www.bsr-project.org/uploads/2/6/5/2/26524868/walter_agu_2018_summary_freeze-thaw_needle_ice_experiment_for_bsr_website_smallfile.pdf

WRP 2020. River Corridor Planning reports from the White River Partnership website. https://whiteriverpartnership.org/reports/